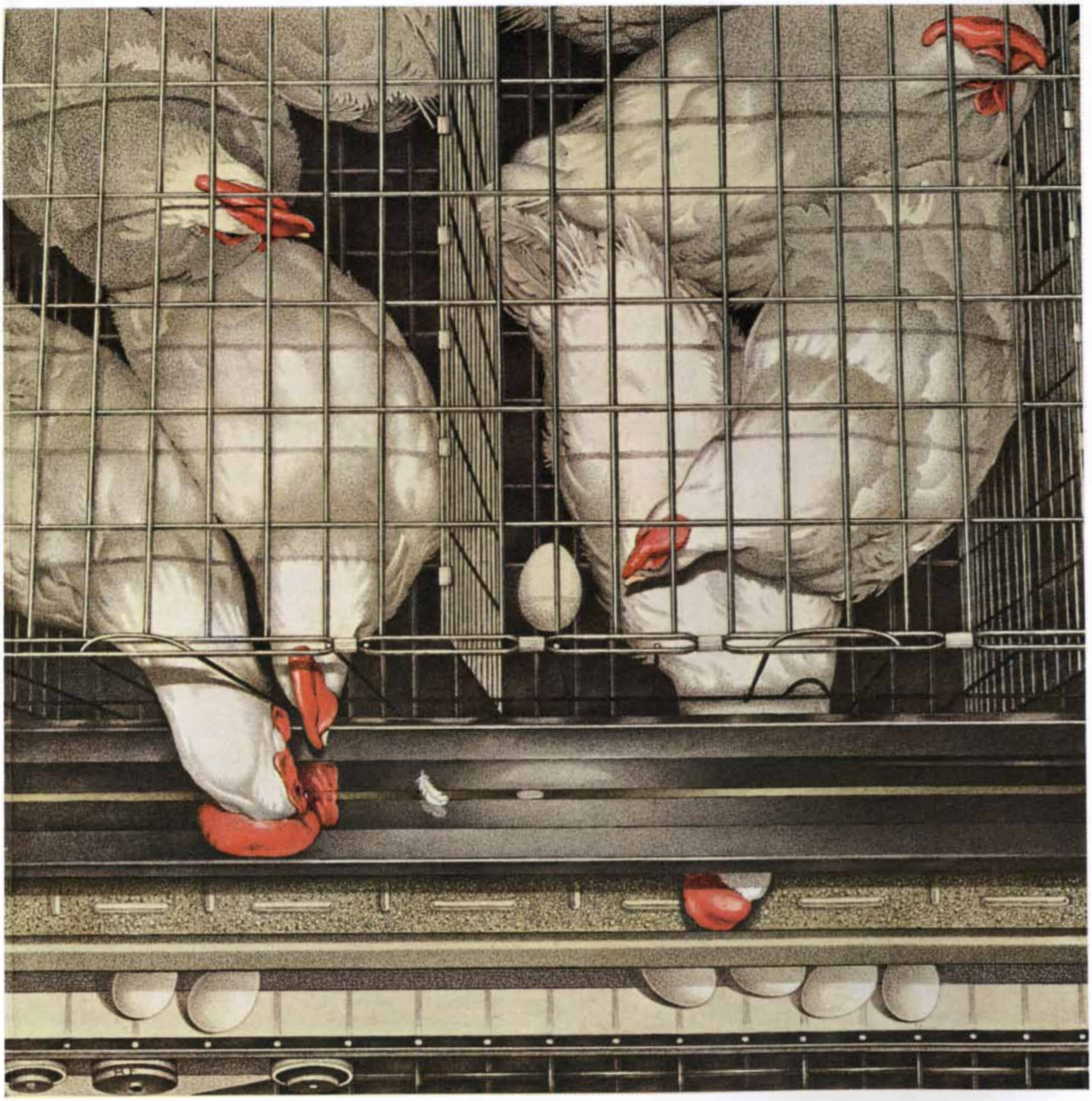
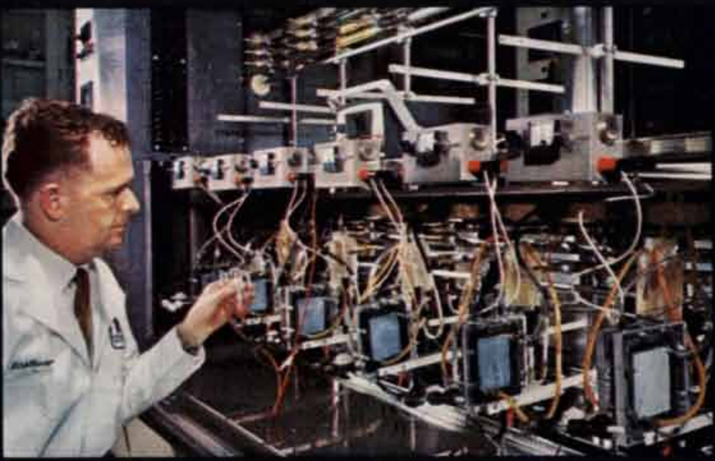
SCIENTIFIC AMERICAN

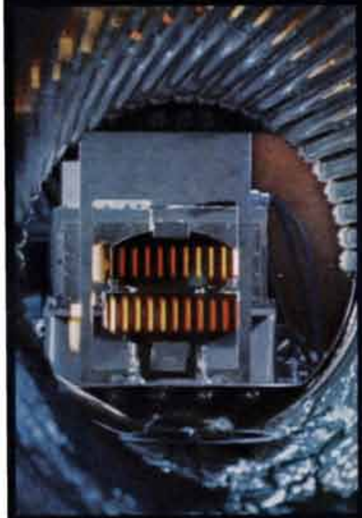


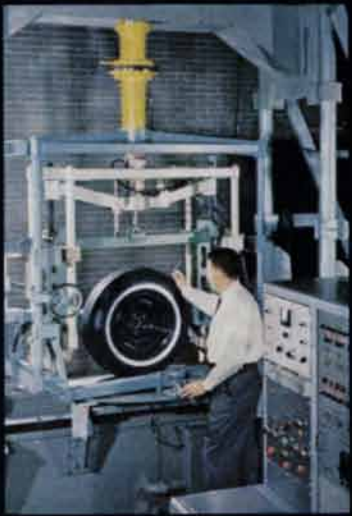
CHICKEN FACTORY

SIXTY CENTS

July 1966







Our anniversary pictures came out fine, but we're still not completely happy with them.

We're in a reminiscing mood.

Just ten years ago the General Motors Technical Center was formally dedicated, became our new home. It's an inspiring campus for contemplation . . . and accomplishment.

What have we been doing this past decade? Research ranging from adhesion to x-ray diffraction—covering crystals, corrosion, computers, energy conversion . . . magnetics, polymers, reliability, stress . . .

Some specific accomplishments in three broad areas:

- Research on combustion reactions, vehicle emissions, emission controls, and smog chemistry. We found that one-third of the automotive hydrocarbons in the atmosphere came from crankcase vents. So we shut them off. We've developed a system for effectively decreasing the exhaust hydrocarbons too. And we've discovered which hydrocarbons are the worst offenders in smog formation.
- Traffic dynamics, vehicle handling, and driver aids. We've developed mathematical descriptions of road traffic situations, pinned down many interrelationships between car, road, and driver. Our mathematical models also describe vehicle ride, vibration, and directional control. And we've explored automatic highways and car-road communications systems as new approaches to safe, efficient travel.
- Engines. Our gas turbines now have good fuel economy, excellent engine braking, and very low hydrocarbon emissions. The quiet GMR Stirling engine is extremely efficient, with a closed cycle taking heat from almost anywhere.

We like our anniversary pictures. But they tell such a small part of our whole story.

GM

General Motors Research Laboratories

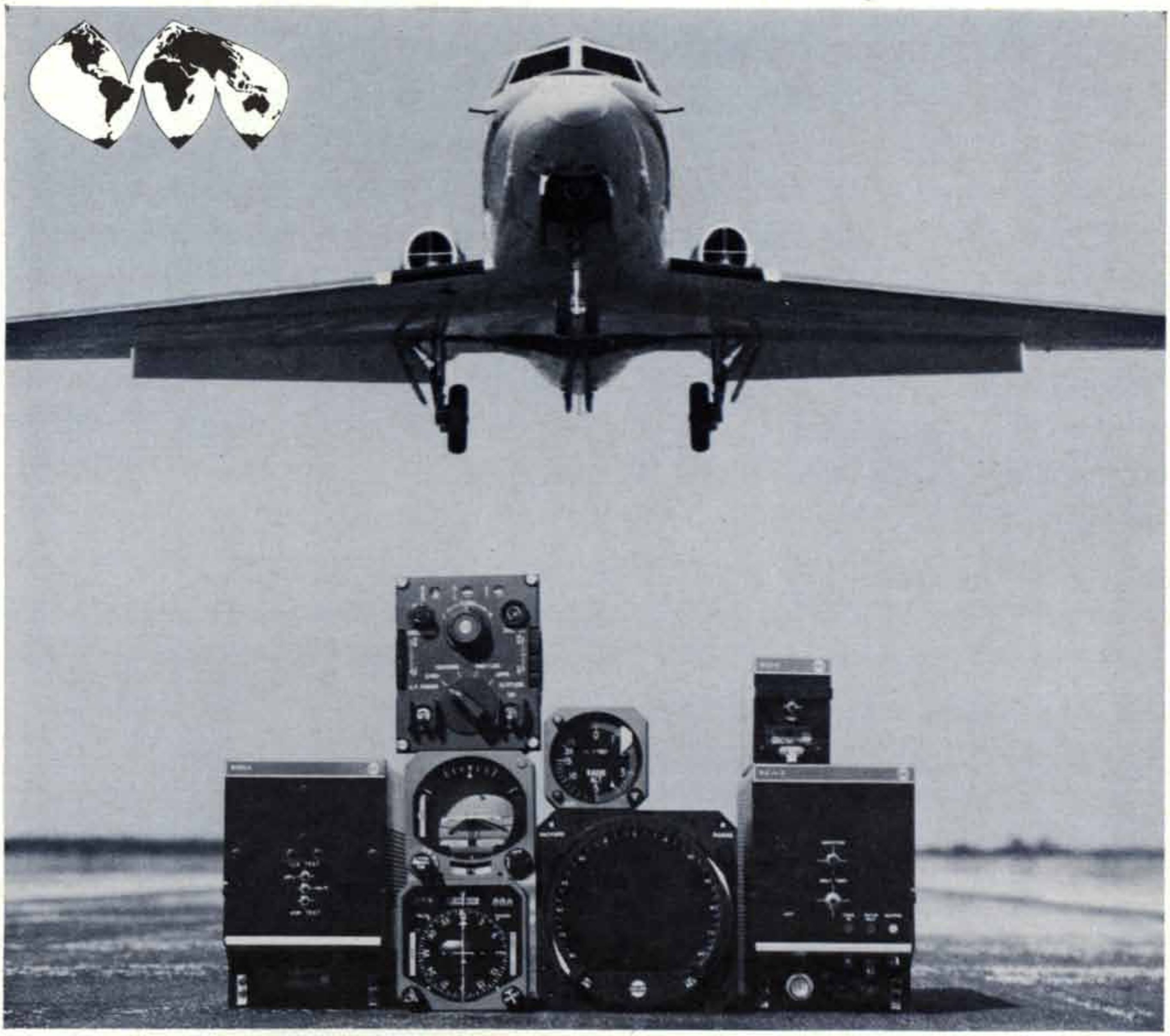
Warren, Michigan 48090

Research on fuel cell electrodes.

Long path infrared study of smog photochemistry; study of tire behavior.

Ferroelectric KNO_3 crystals; basic study of fluid mechanics.

Research on human injury tolerance.



Established 1845 **SCIENTIFIC AMERICAN** July 1966 Volume 215 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows two adjacent cages in one of the batteries of a modern egg ranch (see "Poultry Production," page 56). Four hens occupy each cage; a single battery may hold 3,000 fowl. The caged birds are virtually immobile; they drink water from a continuous trough and eat a feed mixture that is carried past the lower part of the cage on an endless belt. As an egg is laid it rolls down the slanting floor of the cage and is carried away by a second belt. The birds illustrated here are producers of eggs for the table; they are single-comb White Leghorns, one strain of a variety of Mediterranean fowl noted for combining a high annual output of white eggs with modest food requirements. The painting is based on equipment on the poultry ranch of Max M. Brender in Ferndale, N.Y.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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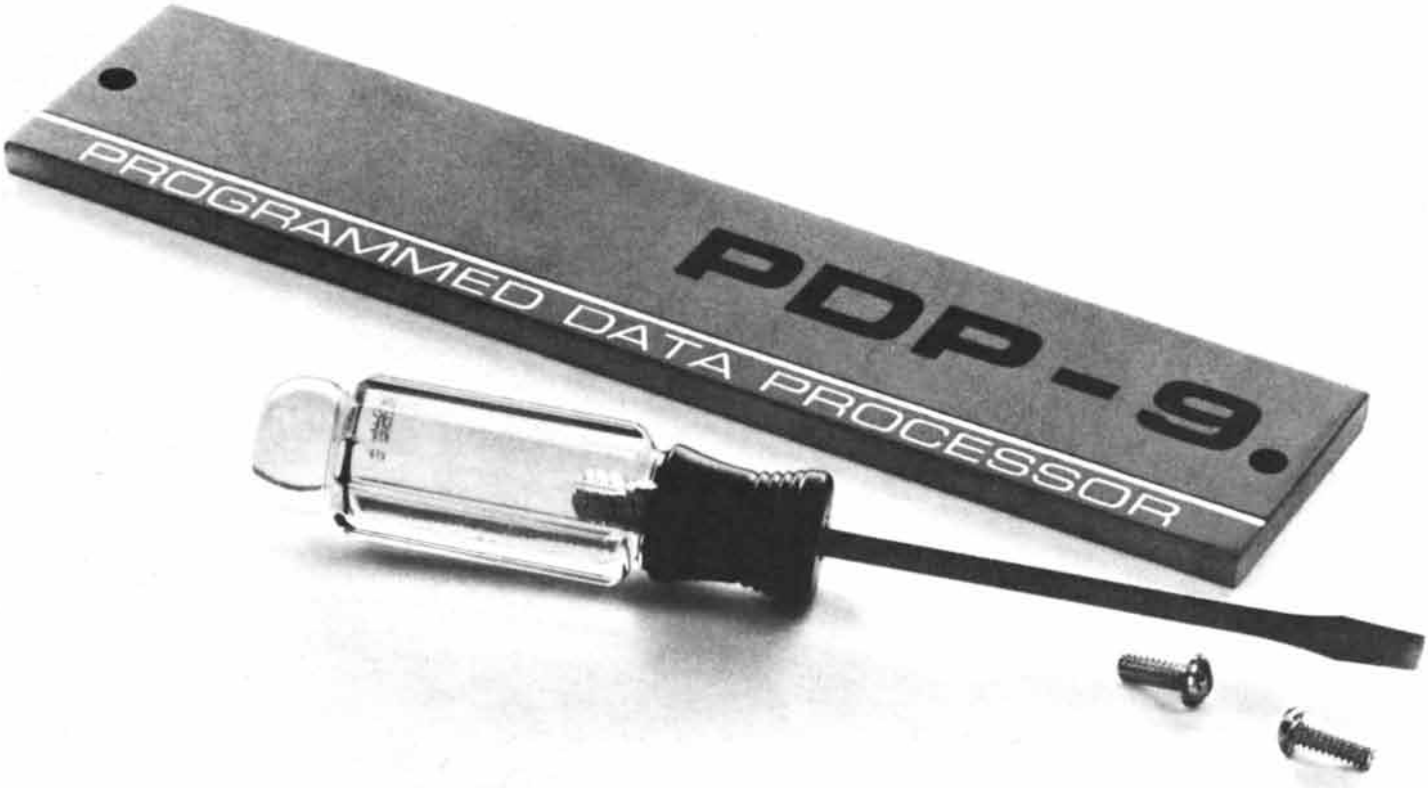

Los Angeles, August 23-26
New York, September 1-2
Boston, September 6-9

An operating PDP-9 will be at WESCON in L. A. on August 23, and New York and Boston immediately thereafter. The PDP-9 is a new, high speed, low cost, medium size general purpose computer.

If you're thinking of buying a CDC 1700, or an IBM 1800, or any other 16 to 24 bit computer, then wait.

Think on this. When the PDP-1 was introduced, it was the world's first computer for less than $100,000. When the PDP-8 was introduced, it was the world's first computer for less than $20,000.

The PDP-9 is bigger than the PDP-8. But price and performance are in our blood. The PDP-9 is worth its wait in gold.

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LETTERS

Sirs:

Shortly after World War II a small group of Cincinnatians, in which I was included, was invited to inspect a dredging operation on the Ohio River near Fernbank on the western outskirts of Cincinnati. We boarded the dredge and viewed the centrifugal pumps that drew up sand and gravel from the channel and discharged it through pipes onto a level fill between the railroad tracks and the river.

One of the men in the party picked up a large copper coin from the gravel. It was of an obsolete U.S. coinage. I have forgotten whether it was our guide or one of our group who told the following story explaining the presence of the coin in the effluent from the dredge pumps.

At about the time of the Civil War there had been a slaughterhouse for horses near this point on the bank of the river. At the time the slaughterhouse was operating it was common practice to make an incision in a horse's neck and push a copper coin into it so that the coin remained in place under the skin. When the horses were skinned for their hides, the coins dropped out, and many of them that did not find their way into the pocket of the skinner ended up in the river. After all these years they were being thrown back onto dry land by the dredge. The narrator went on to say that at the time the slaughtering was going on it was believed that a copper coin under the skin of a horse would prevent some disease.

When I read in the May issue of SCIENTIFIC AMERICAN the article "Chelation in Medicine," by Jack Schubert, particularly the part about the chelation of copper by aspirin and the possibility of chelating agents being naturally present in the human body, it reminded me of the story of the copper coins under the skins of horses' necks. At the time I heard about it I regarded the practice as based on ignorant superstition. Now I wonder if it may not have been the result of empirical observations we are now in the process of confirming.

I repeat this story for its interest for the history of science as well as for the local history of southwestern Ohio. I also do so as an illustration of the dictum among scientists that they should always be alert to new phenomena, however strange or contradictory to preconceived ideas they may be, and should never destroy the record of what appears to be valid observation of a phenomenon.

FREDERIC E. HOLMES

Falmouth, Mass.

Sirs:

I enjoyed reading the letter from Mr. Holmes, and his observation is most interesting. The implantation of a copper coin in a horse's neck could have been done for a good reason. It is known that sheep and cattle grazing in copper-deficient pastures in some areas develop deleterious bone changes, such as brittle bones and a condition similar to those that occur in scurvy. Such bone changes also occur in areas that have very high levels of molybdenum in the vegetation. The molybdenum can produce copper deficiency by causing high excretion of copper. As far as I have been able to ascertain, adult horses in these areas do not appear to be affected—the reason being that for one thing they require less copper and that they probably are given a supplementary feed of chaff and oats imported from other areas. Bone changes have been reported, however, in young horses in Australia grazing in copper-deficient pastures.

It is conceivable, therefore, that the horses mentioned by Mr. Holmes may have lived in an area in which the foals were adversely affected by a deficiency of copper. Since their copper requirement is very small, enough copper could be absorbed from the implanted copper coin to counteract a minor degree of copper deficiency and thus prevent lameness. I might add that the deficiency of iron and other metals in plants has often been treated by the use of a given metal or metal salts. Nowadays, however, metal deficiency in plants is more satisfactorily treated with metal chelates because they render the metal more readily available to the plant, as in the treatment of iron deficiency (chlorosis).

JACK SCHUBERT, PH.D.

Graduate School of Public Health
University of Pittsburgh
Pittsburgh, Pa.

Sirs:

D. D. Kosambi, the author of "Scientific Numismatics" [SCIENTIFIC AMERICAN, February], may be interested to know that at least one investigation has been made of the absorption rate for U.S. coins. Using the same assumption of exponential absorption, Dr. E. N. Gilbert of the Bell Telephone Laboratories found that the half-life of Lincoln pennies is about 12.1 years. For his analysis he used a sample of 2,041 Lincoln pennies minted in Philadelphia and collected in a UNICEF Halloween drive in Summit, N.J., in 1963. Since he had available U.S. Mint records giving the number of coins minted each year, Gilbert did not have to make Kosambi's tacit assumption that the number of coins minted a year was roughly constant. Gilbert found that one date appeared in his sample far more rarely than the theoretical absorption curve predicted—the 1943 penny. These were made of steel coated with zinc in order to conserve copper during World War II; they corroded badly and the Government has systematically removed them from circulation. If one is willing to assume that the price of a rare coin is proportional to the average length of time it would take to find one by sampling coins in circulation, Gilbert points out that the 12-year half-life is quite consistent with Lincoln penny prices as quoted by coin dealers in 1961.

A. ROSS ECKLER

Morristown, N.J.

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An Allen-Bradley announcement of importance to motor designers

The new MO6-C ferrite magnet having 30% higher intrinsic coercive force

■ The new Allen-Bradley MO6-C ceramic permanent magnets provide at least 30% increase in the highest previously available intrinsic coercive force—obtainable with A-B's MO5-C material. This advance is achieved with the same high residual flux density.

Designers of permanent magnet motors have a choice of these advantages—30% higher resistance to demagnetization, or 30% increase in motor output, or 30% increase in cold temperature protection. In fact, where the higher coercive force is not required, the designer can give himself a 30% reduction in magnet size.

This new Allen-Bradley MO6-C material opens the door to such motor designs where permanent magnets heretofore were not practical, namely for motors used in many portable tools and appliances. Like with the MO5-C material, these new MO6-C magnets are radially oriented, and are available in virtually all sizes and shapes currently being produced in segments for motors from ¾″ diameter to 10 hp. While MO5-C magnets will continue to satisfy most needs, MO6-C enables designers to satisfy more exacting motor design requirements because of its unusually high intrinsic coercive force.

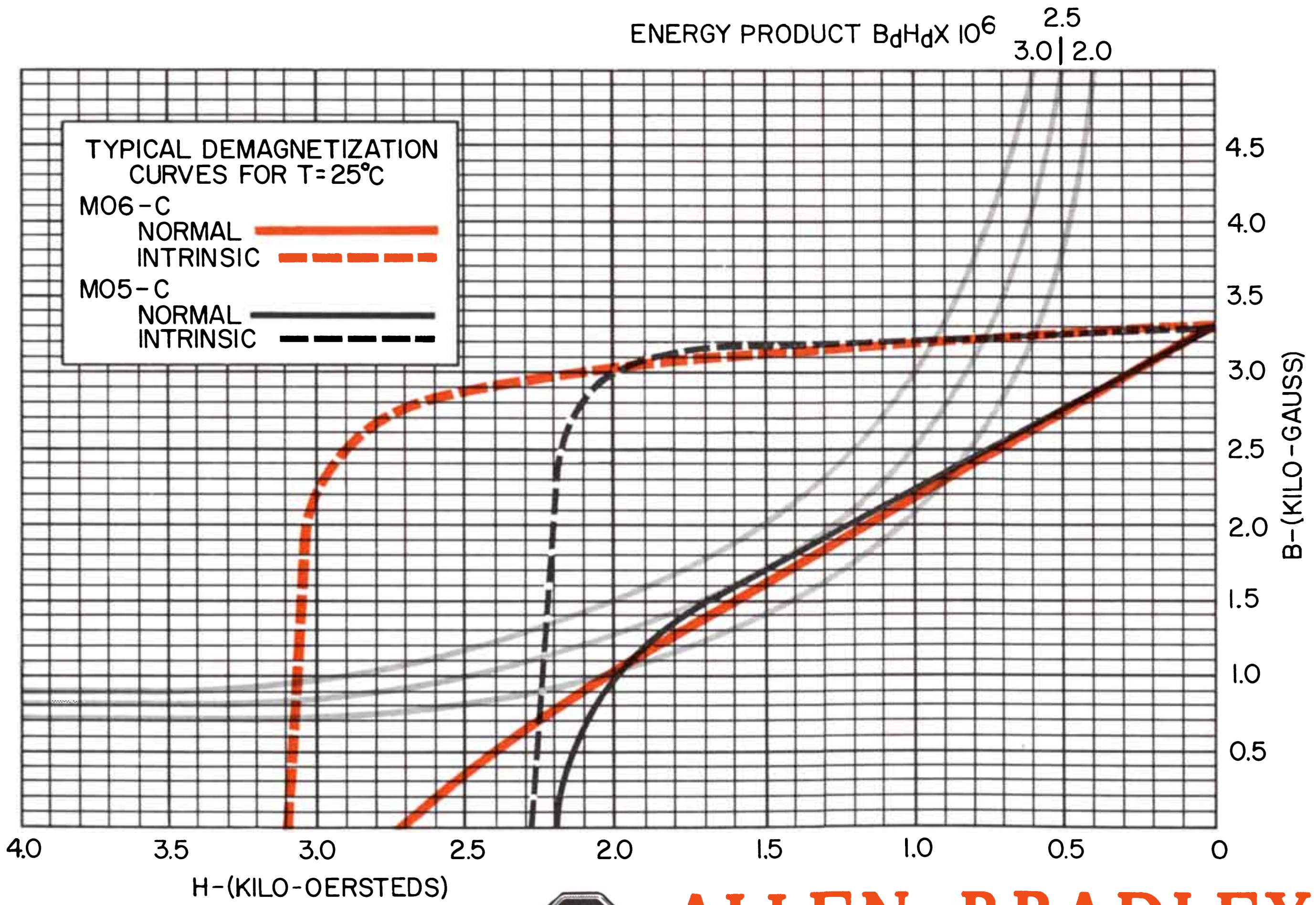
Allen-Bradley application engineers will be pleased to help you obtain maximum economy in your motor design through optimizing magnet performance. Please let us hear from you. Allen-Bradley Co., 1204 S. Third St., Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Limited. Export Office: 630 Third Ave., New York, N.Y., U.S.A. 10017.

TYPE MO6-C CERAMIC PERMANENT MAGNETS

Typical Characteristics

–stated values have been determined at 25°C.

Property	Unit	Nominal Value
Residual Induction (B_r)	Gauss	3300
Coercive Force (H_c)	Oersteds	2800
Intrinsic Coercive Force (H_{ci})	Oersteds	3100
Peak Energy Product (B_dH_d max)	Gauss-Oersteds	2.5×10^6
Reversible Permeability	—	1.09
Curie Temperature	+°C	450
Temperature Coefficient of Flux Density at B_r	%/°C	–0.20
Specific Gravity	—	4.9
Weight per Cu. In.	Lbs.	0.177



366-3B

ALLEN-BRADLEY

QUALITY MOTOR CONTROL
QUALITY ELECTRONIC COMPONENTS

The newest Burroughs 500 System

Announcing the Burroughs B 6500

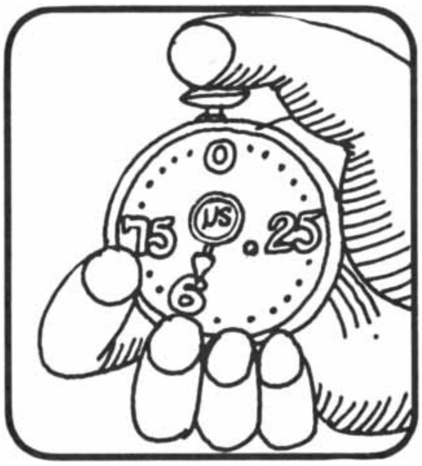
A new electronic data processing system with software that is ready right now

The B 6500 will have the kind of multiprocessing ability, dynamic modularity and high through-put per dollar proved in use by the B 5500.

In the B 6500, all these advantages are greatly enhanced by new hardware technology. The result: A system which is ideally suited to engineering/ scientific jobs or business applications or a combination of both. A highly advanced time-sharing system which completely obsoletes the rigid time allocations for on-site vs. remote-site work. With the B 6500, numerous jobs—all completely different—can be multiprocessed at the same time, regardless of origin. And all, of course, under full software control.

High speed monolithic integrated circuits

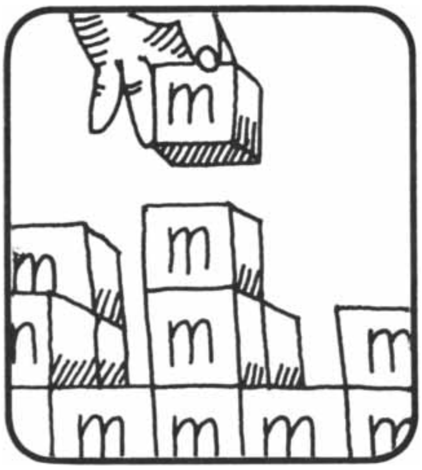
The clock rate of the B 6500 is 5 megacycles—an extremely fast speed made possible by the system's monolithic integrated circuitry.



Fast memory speed with thin film

The memory cycle time of the B 6500 is 600 billionths of a second—so fast that it cannot be equalled except by giant systems at a giant cost.

Consider our accelerating success with the unique B 5500 – or better still, see it demonstrated. Now, for requirements that extend beyond this already powerful computer, the new B 6500 implements that same proven software and internal organization by 5 times the processor speed, 7 times the memory speed, up to 3 times the memory capacity, and twice the I/O capability.



Large memory capacity

The B 6500 provides up to 106,496 words of thin film memory. This extensive capacity is available in functionally independent banks.

Input/Output Multiplexor

This is a device which provides up to eight high speed input/output operations simultaneous with each other and one or both processors.

We can't show you the hardware today. But we *can* demonstrate the internal organization and proven software: A comprehensive operating system that schedules and controls many jobs at once. Simultaneous COBOL, ALGOL and Fortran compilations. Even a mixture of batch and random access processing plus time-sharing.

Your local Burroughs representative will be glad to arrange such a demonstration or to discuss other Burroughs 500 Systems. Or write us at Detroit, Michigan 48232.

Burroughs Corporation

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1916: "Probably not until the official annals of the war are published years hence will the true secret of the Verdun operations be known. Despite the dispatch of at least two army corps from west to east, the threatening massing of British forces behind the lines and the incontrovertible tales of losses which have cut severely into the available reserves of Germany, the battalions of the Crown Prince continue their assaults at Verdun, seemingly with unabated fury and disregard for casualties. Whether these attacks are continued by the pure initiative of the Teutons or are necessitated by French vigor of operation one cannot definitely tell. It seems too late for even a German success at Verdun to be of material benefit; the time seems past when such a success would severely shake the morale of France, for with the passing months of the battle-siege and the tenacity with which General Pétain's troops have clung to the position of acknowledgedly little military value, all France is reported to have taken heart, even so far as to bear up should the so-long-defended position be evacuated."

"A proposed machine for computing perturbations of the planets is described in a recent memoir by the Finnish mathematician K. F. Sundmann, an extensive abstract of which has been published by Dr. Heber D. Curtis of the Lick Observatory. The machine which Sundmann hopes to construct will make the marvelous tide-predicting machines seem simple by contrast. Indeed, it is almost incredible that anyone should think of solving by mechanical means the question of the perturbations of a planet over long periods of time; but on the other hand, as Dr. Curtis points out, with the ever-increasing list of asteroids (the number of which will probably pass the 1,000 mark in a few years), 'if we are not to neglect any of these bodies, something in the nature of a "perturbation machine" would seem to be absolutely necessary.' Detailed plans of this 'perturbograph' have been drawn, and it is believed that perturbations can be secured with it with an error of less than 1 per cent of their magnitude. The machine would have a speed of movement such that one revolution of Jupiter would take about seven minutes, so that an interval of 10 days would correspond to one second. Two persons could set the instrument in about 25 minutes. With the aid of proper auxiliary tables it should be possible to determine the perturbations for all the oppositions during a revolution of Jupiter—i.e., for about 12 years—in one hour."

"Estimates of the age of the earth based on radioactive and ordinary geological phenomena differ greatly from each other. Professor Joly has suggested that the discrepancy between the radioactive and geological estimates would disappear in favor of the former if it could be shown that the rate of decay of uranium had decreased with the lapse of time. Readers of the novels of H. G. Wells, who is rapidly attaining the reputation of a Mother Shipton on the strength of the things in his stories which have later come to pass, will recall that in describing the death-dealing 'atomic bomb' he introduced a concept similar to this—that of a disintegrating element which in any period of a certain fixed length dissipates exactly half of its initial substance for that period. More rapid decay would, however, have been attended by a more rapid generation of heat of radioactive origin, and this would have prolonged or even reversed the secular cooling of the crust, again indicating an excessively great age for the earth. The escape from the dilemma would appear to be to deny that the earth's surface was formerly in a molten condition. The whole subject is, of course, largely speculative in the present state of science. It will, however, help greatly to elucidate the problem of the earth's age if it can be determined whether the rate of decay of uranium is dependent upon time, pressure and temperature."

Scientific American.

JULY, 1866: "Prof. Henry Draper writes in a new periodical called the *Galaxy:*—'The celebrated nebular hypothesis of Herschel and Laplace, which assumes that our solar system was at one time a gaseous mass, extending beyond the orbit of the farthest planet, Neptune, has been very freely discussed and has received much adverse criticism. Many strong objections have been urged against it, but the spectroscope confirms it. On applying the spectroscope to the investigation of the irresolvable nebulae, Huggins finds that some of them present the spectra characteristic of an ignited gas, that is, of a flame. The Fraunhofer lines in that case are bright instead of dark, as in the solar spectrum, and the evidence is of a very tangible and unmistakable kind. There are, then, in space masses of ignited gaseous matter of prodigious extent, shining by their own light, containing no star and resembling the nebulae, which the nebular hypothesis declares to have been the original state of the solar system.' "

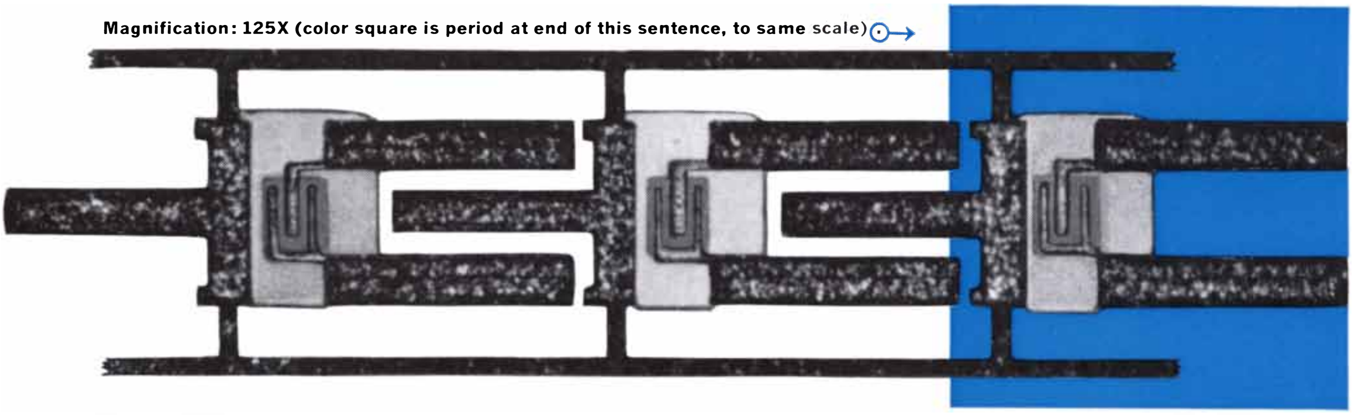
"The *Great Eastern,* with the Atlantic cable on board, will leave Shearness on the last day of June and commence laying operations about the 10th of July. She will be accompanied by the steamship *William Cary,* 1,500 tuns, the screw steamer *Medway,* 1,900 tuns, the screw steamer *Albany,* 1,500 tuns, and the man-of-war *Terrible.* The British government will lend only one ship this time. In the attempt to raise the old cable it is intended that three ships will grapple it at once, and the westernmost of them will put on the greatest lifting strain, so that should it break the cable the other two ships will have a comparatively easy task to raise it, the strain being taken off one end of the loop."

"The Great Northern Railway of England was the scene of an extraordinary casualty on June 14th, which was entirely unprecedented. It seems that a freight train broke down in a tunnel, and the precaution of flagging approaching trains having been neglected, one came along soon after and piled itself on the top of the freight train. Even this experience did not suffice, and a few minutes later another train came in from the other end and dashed on top of the rest. This jammed the tunnel full to the very crown, and one of the engines having turned over, the coals fell out and set fire to the combustibles. For two days this fire burned unhindered, for the simple reason that it was impossible to check it. The noise of the fire, caused by the heated air rushing out of the confined place, is said to have been fearful. The immense traffic of the road was entirely stopped for the period mentioned. All this was caused by the simple neglect in the first instance of not flagging the coming trains. Only two lives were lost."

Report from

BELL LABORATORIES

"Beam lead" technique for fabricating solid-state devices



Row or "ladder" of beam-lead transistors fabricated experimentally at Bell Laboratories has a transistor every 16 mils along its length. Each transistor (on light-gray areas) has three beam leads (dark-gray rectangular areas) for electrical and mechanical connection. The side rails at top and bottom of photo are used only for support and ease of handling.

To make tiny solid-state devices and circuits, groups of elements are generally formed on a single semiconductor slice or substrate. Then the slice is "diced" (physically separated) into pieces as either individual units or groups of units for integrated circuits. If used individually, they are connected to terminals or to other devices with short segments of extremely fine wire—a difficult and time-consuming operation. If used as groups of devices, they often need special processing to electrically isolate those making up each circuit.

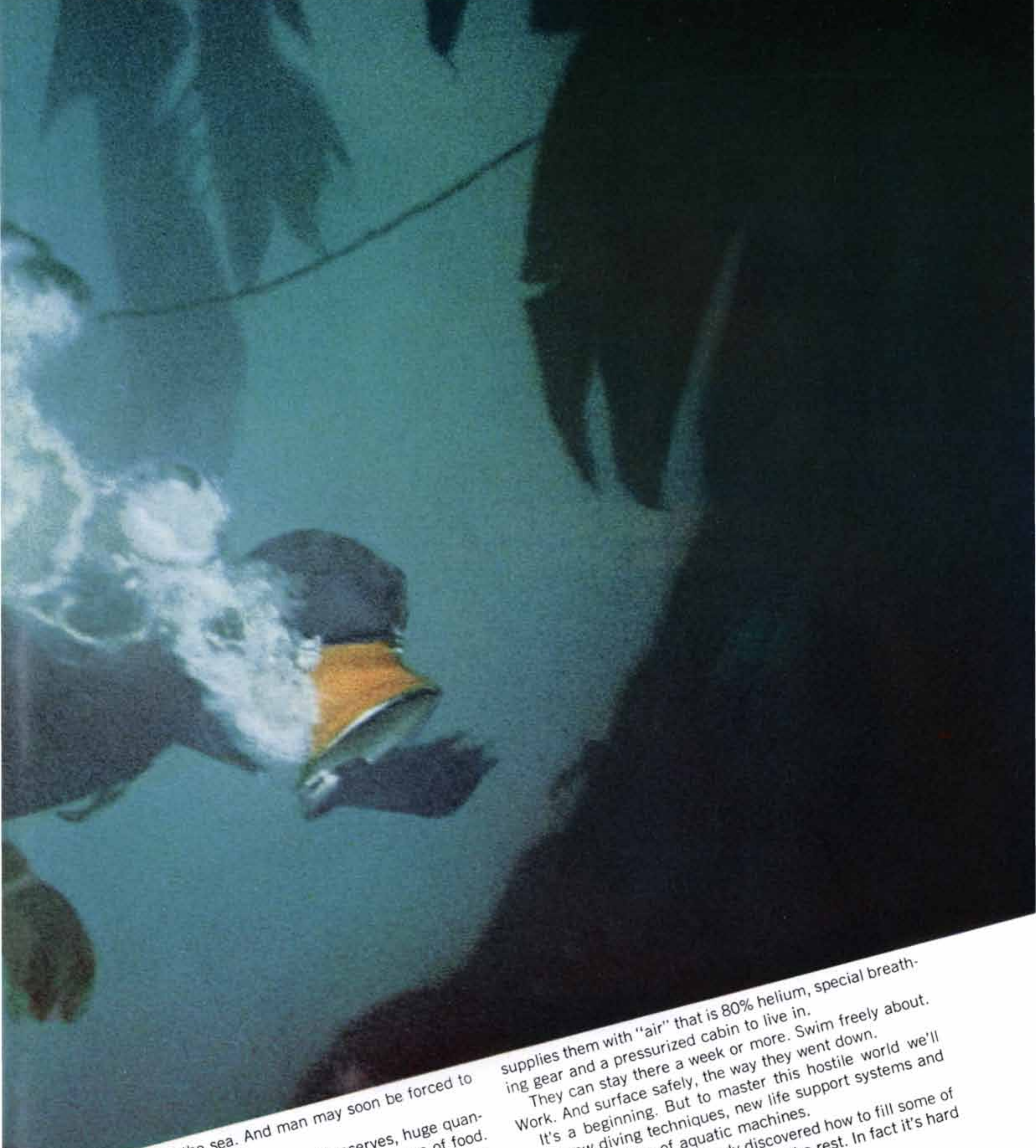
Bell Laboratories' M. P. Lepselter has developed a promising solution to both of these problems. After the device elements are formed, mechanically strong electrical leads are deposited onto them. These electrically and mechanically intraconnect the devices and circuits. Unwanted semiconductor material between the individual devices in a circuit is then removed . . . isolating them electrically, yet leaving them mechanically joined. This permits batch processing of electrical leads, eliminating many individual connections and requiring only connection to external terminals.

Thus, handling tiny devices and circuits is simplified. The leads, precisely positioned with respect to each other, are easily connected to a circuit board or other support, perhaps eventually by automated techniques. They are strong enough so that the semiconductor wafer or chip needs no further attachment to the substrate. Entire circuits joined by beam intraconnections can be handled as one unit.

M. P. Lepselter examines beam-lead model (enlarged about 300 times). Beams were thermally aged in 360° C steam for 1000 hours, centrifuged to 130,000 G, bent 90° twenty times without failure. Beams can be tapered for smooth impedance matching, widened to act as heat sinks.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

400 feet down on the farm.



Life began under the sea. And man may soon be forced to return there to support life.

There lie half the world's known oil reserves, huge quantities of other raw materials and a limitless source of food.

But at 400 feet, working creates enormous problems. Pressures are 13 times greater than at the surface. Normal air mixtures transform man into a senseless drunk. If he surfaces too quickly, he dies in agony.

Yet men are at work there now. Union Carbide's Ocean Systems Inc. brings them down in a new kind of diving bell; supplies them with "air" that is 80% helium, special breathing gear and a pressurized cabin to live in.

They can stay there a week or more. Swim freely about. Work. And surface safely, the way they went down.

It's a beginning. But to master this hostile world we'll need new diving techniques, new life support systems and a new generation of aquatic machines.

Union Carbide has already discovered how to fill some of these needs. And we're working on the rest. In fact it's hard to find anything we're not working on.

UNION CARBIDE

THE DISCOVERY COMPANY

THE AUTHORS

SIR EDWARD BULLARD ("The Detection of Underground Explosions") is professor of geophysics at the University of Cambridge. A Fellow of the Royal Society and a foreign associate of the U.S. National Academy of Sciences, Sir Edward has spent much of his career at Cambridge, of which he is a graduate. During interludes away from the university he has served as chairman of the physics department at the University of Toronto and director of the British National Physical Laboratory. He is interested in most aspects of the study of the solid earth, particularly in the geology of the oceans and in the earth's magnetic field. Sir Edward has attended many conferences on the banning of nuclear tests by treaty; the first was the meeting of scientific experts from several nations at Geneva in 1958.

LOUIS Z. COOPER ("German Measles") is assistant professor of pediatrics at the New York University School of Medicine. After graduation from Yale College in 1954 and the Yale University School of Medicine in 1957 he served an internship, a residency and a postdoctoral fellowship in various New England hospitals, with a two-year period of service as a medical officer with the Air Force. During his military tour he was chief of medical service at a 50-bed hospital serving an Air Force base in Labrador. Cooper spent a year as an instructor in medicine at the Tufts University School of Medicine before joining the medical faculty at N.Y.U. in 1964.

DAVID KAHN ("Modern Cryptology") is an amateur cryptologist who works in Paris as a news editor for the European edition of the *New York Herald Tribune.* Through his avocation he has become president of the American Cryptogram Association; he is also a past president of the New York Cipher Society. Kahn's extensive writings on cryptology include a book tentatively entitled *The Codebreakers;* it is a history of cryptology and is scheduled for publication this fall. Kahn maintains a large collection of books, articles, patents and miscellaneous material on cryptology.

WILBOR O. WILSON ("Poultry Production") is professor of poultry husbandry and chairman of the department of poultry husbandry at the University of California's Davis and Berkeley campuses. He joined the department in 1946, having previously been at South Dakota State University. Wilson did his undergraduate work at Oklahoma State University, being graduated in 1932, and received a master's degree from Kansas State University in 1933 and a doctorate in animal breeding from Iowa State University in 1947. He is the author of many papers on environmental physiology and biometeorology. Wilson writes that he is "truly a native American by birth" because both of his parents "were a fraction of Indian extraction, being members of two of the Five Civilized Tribes (Choctaw and Chickasaw) of Oklahoma."

GILBERT SHAPIRO ("Polarized Accelerator Targets") is a senior postdoctoral fellow at the Laboratory of High-Energy Particle Physics at Saclay in France. While holding the fellowship, which was granted by the National Science Foundation, he is on leave from the University of California at Berkeley, where he has been assistant professor of physics since 1963. Before that time he spent two years as a physicist at the Lawrence Radiation Laboratory (operated by the University of California for the Atomic Energy Commission) and six years at Columbia University, where he received a Ph.D. in 1959. Shapiro was graduated from the University of Pennsylvania in 1955.

BASTIAAN J. D. MEEUSE ("The Voodoo Lily") is professor of botany at the University of Washington. As a boy in the Dutch East Indies (now Indonesia) his interest in botany was aroused by the botanical garden in Buitenzorg (now Bogor). After his family returned to the Netherlands he studied biology at the University of Leiden, receiving a bachelor's degree in 1936 and a master's degree in 1939. Four years later he obtained a doctorate in plant physiology from the Technical University of Delft. After some years of teaching in Holland and an 18-month interlude at the University of Pennsylvania on a Rockefeller Foundation fellowship, he went to the University of Washington in 1952. Meeuse writes that his chief interests are in "plant physiology and plant biochemistry, algae, the chemistry of carbohydrates, animal behavior, entomology and pollination." Most of his current work is in the biochemistry of algae and the respiration of plants.

LLOYD R. PETERSON ("Short-Term Memory") is professor of psychology at Indiana University. He is a native of Minneapolis and was graduated from Gustavus Adolphus College in St. Peter, Minn., in 1944. He obtained master's and doctor's degrees from the University of Minnesota in 1951 and 1954 respectively. Peterson has been at Indiana University since 1954 except for the academic year 1964–1965, when he was visiting professor at the University of California at Berkeley and a research psychologist at the Institute of Human Learning there. His research interests include not only short-term memory but also the processes involved in learning and thinking. In some of his work Peterson has had the assistance of his wife, Margaret Jean Peterson, who received a Ph.D. in psychology at the University of Minnesota in 1955.

DON B. SULLENGER and C. H. L. KENNARD ("Boron Crystals") are respectively an investigator at the Mound Laboratory (which is in Miamisburg, Ohio, and is operated by the Monsanto Research Corporation for the Atomic Energy Commission) and a lecturer in inorganic chemistry at the University of Queensland in Australia. They met at Cornell University, where Sullenger was a candidate for a doctorate in physical chemistry and Kennard was a postdoctoral fellow. Sullenger previously had received a bachelor's degree at the University of Colorado, served in the U.S. Army during the Korean war and worked at the General Electric Research Laboratory. He has been at the Mound Laboratory since 1962, working on structural problems of plutonium and attempting to solve the structures of some newly obtained forms of boron and borides of very heavy metals. Kennard obtained a Ph.D. in crystallography at the University of New South Wales in 1961, spent two years at Cornell and then was a postdoctoral fellow at the University of Washington before taking his present position. Kennard's principal research interest is the crystal structure of metal complexes. Sullenger has two young sons and Kennard one; each father reports that the many models of crystal structure around the house are a source of great delight to his offspring.

ASA BRIGGS, who in this issue reviews *Selections from "London Labour and the London Poor,"* by Henry Mayhew, edited by John L. Bradley, is professor of history and dean of the School of Social Studies at the University of Sussex.

How to Build a Missile Submarine: A report from General Dynamics

REQUIREMENT: "Build a missile base that can be hidden under the ocean; that can keep moving so swiftly, so quietly, that it cannot be found. Although it will never be used unless the United States is first attacked, build it so that it and its crew can be kept so fit, so efficient, that it can respond instantly should the order come."

ANSWER: The SSBN—Submarine Ballistic Nuclear—more commonly known as the Polaris submarine.

The nuclear-powered submarine has revolutionized naval strategy. Freed from dependence upon the atmosphere or refueling, such a ship can remain submerged for months on end. The addition of a ballistic missile that can be fired from beneath the sea creates an invulnerable deterrent against attack.

General Dynamics delivered the United States Navy's first submarine, the Holland, in 1900. Since then we've built 250 undersea vessels for the Navy, including the first nuclear-powered submersible, the Nautilus.

But the Navy's Polaris submarine, the most complex ship yet devised, has also created a revolution in shipbuilding. Questions of seaworthiness and habitability that must be factored into any ship are multiplied a thousandfold.

Jigsaw puzzle:

The first essential in building a missile submarine is the integration of literally millions of parts, all of which must be designed to work together as a unity within the 425-foot length of the fish-shaped ship. Here are a few:

A nuclear reactor, turbines, gyroscopes, marine propulsion equipment, sixteen nuclear-tipped Polaris missiles, fire-control and navigation systems, water distillers, air purifying equipment,

A new Polaris submarine being launched by General Dynamics.

computers and defensive weaponry.

Navigation and weapons control alone involve six different sonar systems, fourteen different radio systems, two or three Ship Inertial Navigation Systems, a LORAN (Long Range Aid to Navigation) system, a TRANSIT system (for contact with satellites), star tracking facilities and almost forty computers. All these, scattered throughout the ship, must be tied together into one central control for instant reaction.

The ship must even carry its own spares, more than 30,000 different listings, each representing several sizes.

But creating a complete Polaris submarine system involves far more than a fitting job.

How do you join metals to withstand terrific pressures? How often does a man turn in his sleep? How do you keep a missile platform rock-steady in a rough sea? How do you muffle the noise of moving parts? How do you keep air fresh in a sealed environment?

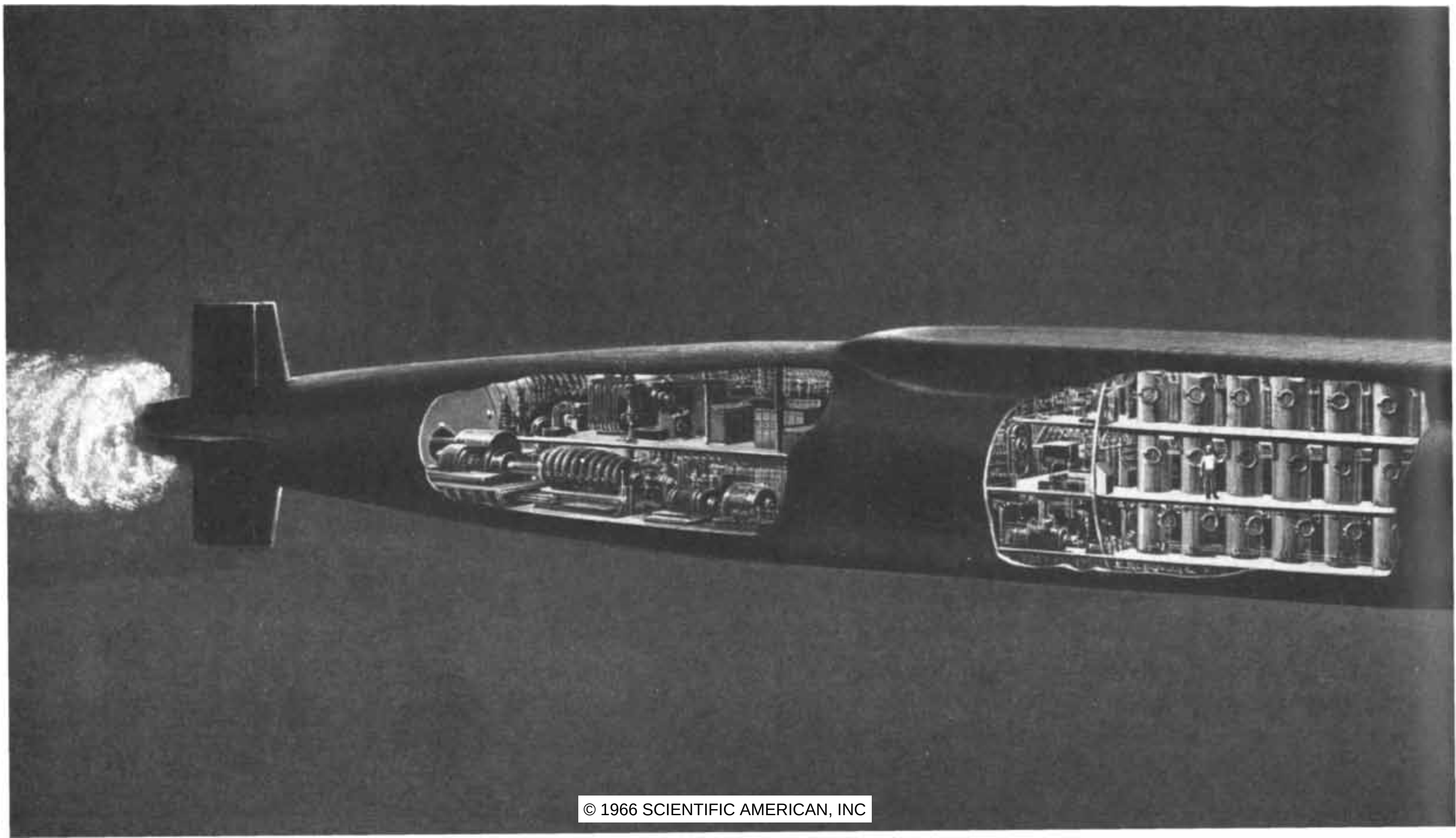
Steady and quiet:

SSBNs are built of HY-80 steel, an alloy that can withstand stresses of up to 80,000 pounds per square inch.

But when the first ship was being built of HY-80, the metal behaved differently on outdoor building ways than it had in prior laboratory tests. The answer turned out to be one of the simpler ones. Indoor metallurgical laboratories had been warm. Outdoors, the weather got cold. Now strip heaters warm steel hull sections to a constant 200 degrees, regardless of weather, throughout the joining process.

To launch a Polaris missile successfully, the ship must be as stable a platform as solid earth, maintaining precise depth no matter how rough the sea. Making this possible was one of the toughest single design problems.

A submarine is controlled through a combination of rudders, planes (somewhat like the wings of an aircraft), and



ballasting. To rise or descend, the ship must take on or force out ballast, in the form of tons of water. Ballast in various areas of a ship is continually being changed to maintain trim. An elaborate sensing and control system was developed to coordinate all parts of the complex in a perfect and delicate ballet.

In the depths, a nuclear submarine can be located mainly by sound. Anything that moves is soundproofed or cushioned. Shaft vibration of electric motors is reduced to less than ten-millionths of an inch. Hull openings, through which thousands of gallons of water must flow within seconds, are designed to minimize turbulence noise.

The millions of parts are supplied by some 11,000 industrial companies and Government agencies.

To insure total reliability, General Dynamics makes more than 50,000 tests –radiographic, ultrasonic, chemical and hydrostatic—on the ship's systems, not counting those on electronics and weaponry. Even nuts and bolts must be standardized and inspected.

Making it livable:

Extended submerged patrol also created new questions of habitability. More than 75 percent of the total space inside a missile submarine is taken up by equipment or stores. In the remaining area some 140 men must live and work, comfortably and efficiently, for 60 days.

The submarine's galleys, not much bigger than the average suburban kitchen, are organized to store, prepare and serve more than 800 full-course meals or snacks every day. Compact equipment distills 10,000 gallons of potable water daily. Laundries, pianos, ice-cream machines, are adapted to fit the available space.

Even sleep became a design problem. A seven-inch differential in the original space between multi-tiered bunks lets a crewman toss and turn normally to rest tired muscles.

On patrol the undersea sailor is rarely more than 150 feet from an operating nuclear reactor, yet shielding is made so effective that the submariner absorbs less total radiation than he would under normal surface conditions.

Crewmen on a Polaris submarine conduct a missile launch drill.

Breathing easy:

With nuclear propulsion, engines no longer need air, but men do.

The average young adult male breathes in about two pounds of oxygen each day; breathes out about two and one quarter pounds of carbon dioxide. In a sealed atmosphere the air could quickly become poisonous. The first nuclear submarines still surfaced periodically to refresh the air. When sustained submersion became the rule, air regeneration became necessary.

Oxygen is electrolytically processed from water. Banks of scrubbers, precipitators and catalytic burners remove the carbon dioxide and the 300 or so contaminants that can build up within a nuclear submarine.

Enough air conditioning to cool a small town dissipates the heat generated by machinery and human bodies. At the end of a long patrol, the air aboard a missile submarine is far cleaner than that of the average American city.

General Dynamics delivered the George Washington, the first Polaris submarine, in 1959. This month we launch the Will Rogers, the forty-first of these extraordinary ships that help the United States Navy guard the peace of the world.

Between the George Washington and the Will Rogers, a number of evolutions have taken place. New generations of submarine ships may be as much an advance over current models as the Polaris submarine is over the old Holland.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communication systems; machinery; building supplies; coal, gases.

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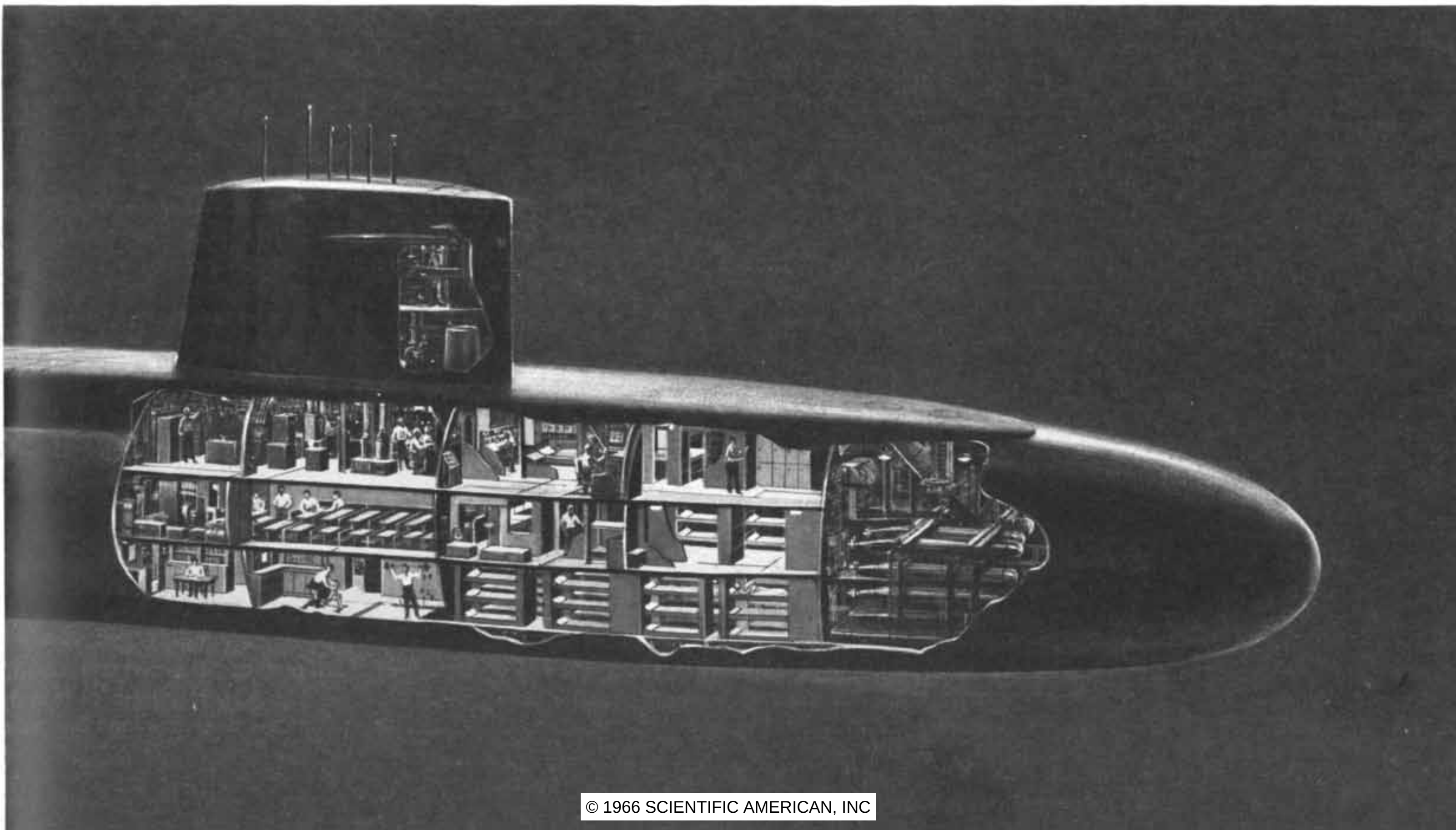

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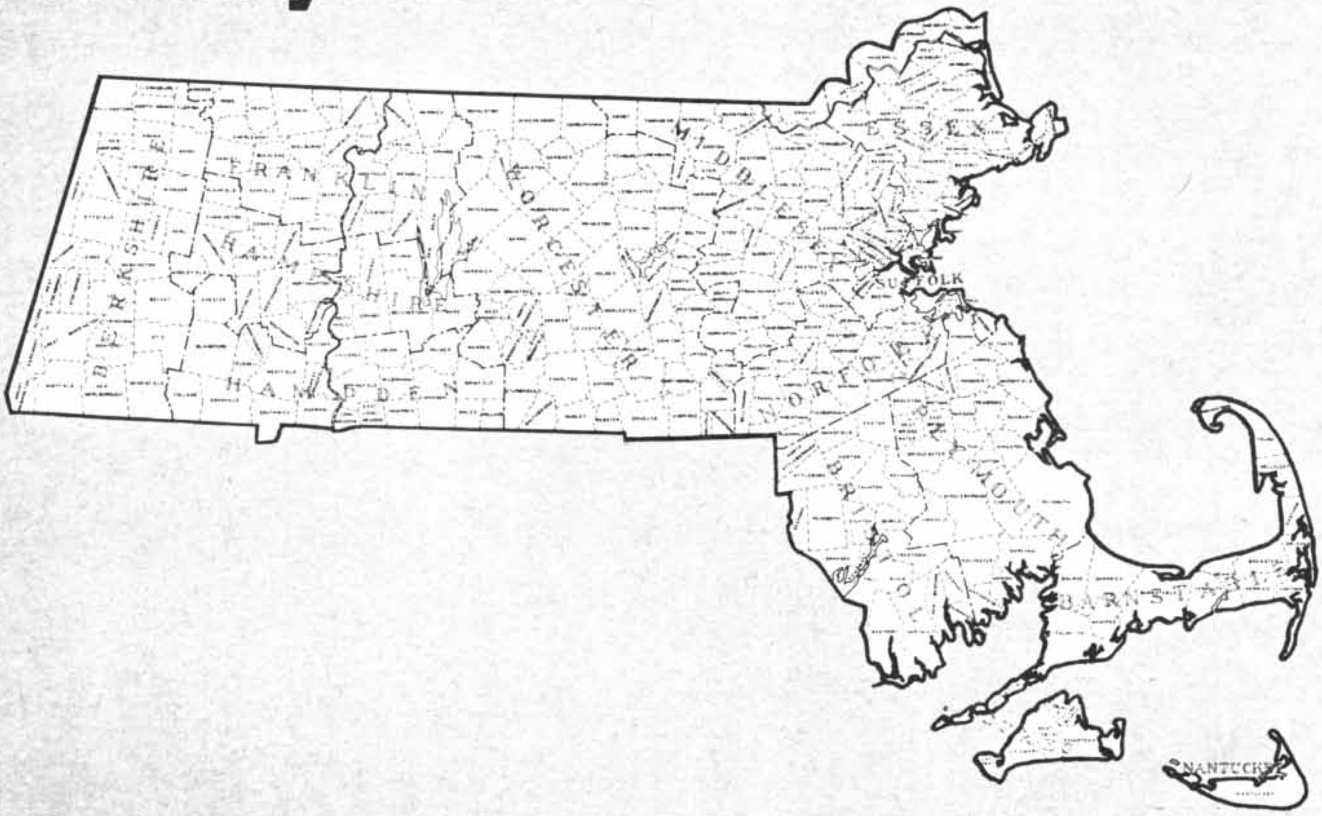

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The Detection of Underground Explosions

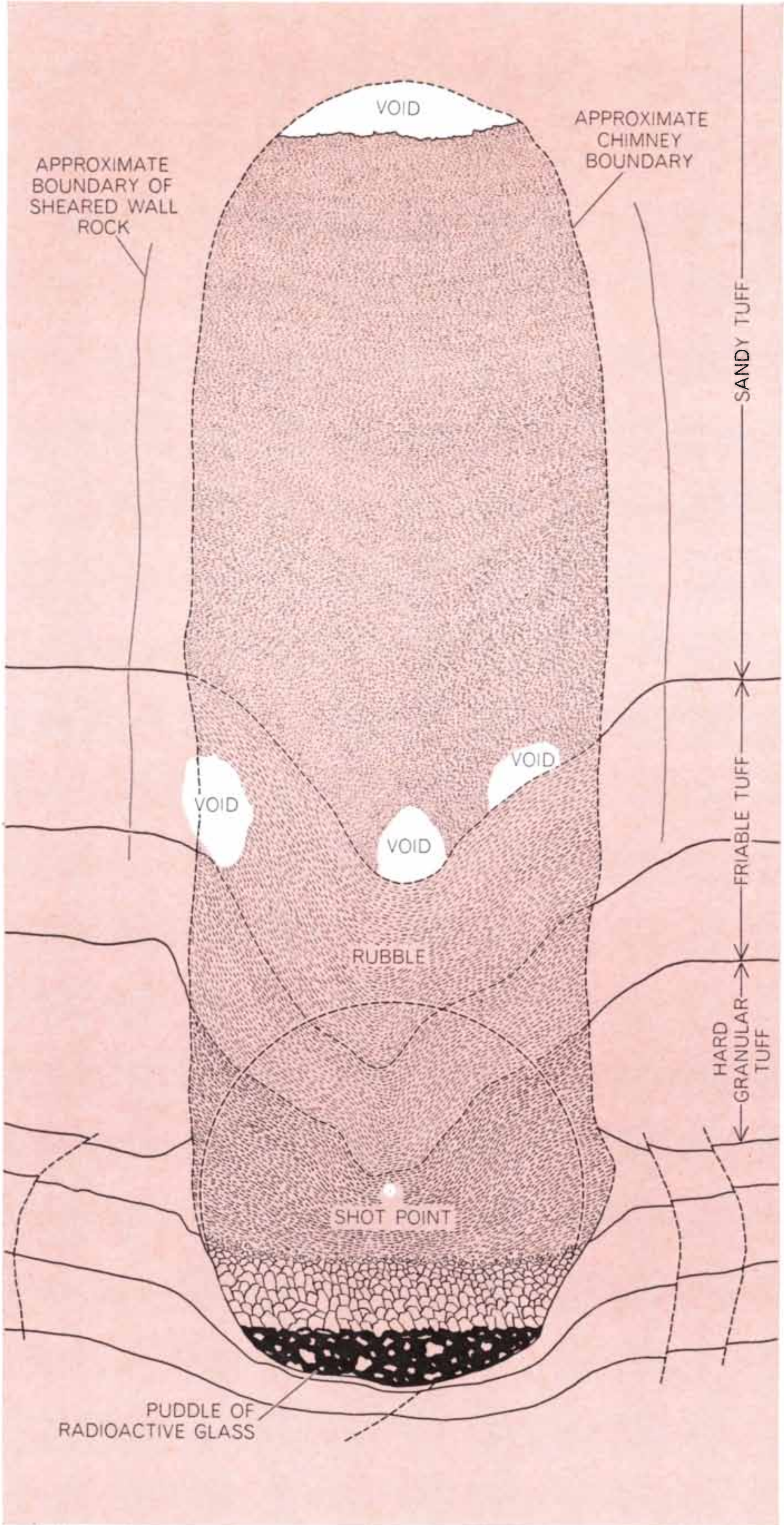
New methods make it possible to identify as such the great majority of earthquakes and explosions. Thus the technical basis for extending the ban on nuclear tests is established

by Sir Edward Bullard

Serious interest in the detection of underground explosions dates from 1958. In that year a conference of "experts" was held in Geneva to study methods of detecting violations of a possible agreement on the suspension of nuclear tests. At that time the interest in an agreement to stop testing came mostly from a wish to slow the arms race and to moderate the "cold war"; it was thought that it might be relatively easy to reach an agreement in this field and that it might then be possible to make progress in related fields of disarmament and arms control. The wish to halt the contamination of the atmosphere was also a powerful motive, but this is not relevant to underground testing. Since the conclusion of the treaty prohibiting atmospheric tests both France and China have exploded nuclear devices, thus increasing the membership of the "nuclear club" from three to five. The main reason today for wishing to stop underground testing is the desire to hinder additional nations from developing nuclear weapons by persuading them to join in a test-ban treaty.

The 1958 conference showed how

SUBSIDENCE CRATER was left by a nuclear explosion set off 1,620 feet belowground at the Nevada test site of the U.S. Atomic Energy Commission. The explosion, of "intermediate yield," took place in a formation of volcanic tuff. The "chimney" produced by the explosion, however, extended upward into alluvium, a loosely consolidated material, with the result that the chimney collapsed.



UNDERGROUND NUCLEAR EXPLOSION leaves a rubble-filled chimney above a puddle of radioactive glass. The explosion that produced this result at the Nevada test site was named "Rainier." The shot was fired at a depth of about 800 feet. Because the yield of the Rainier explosion was so low (1.7 kilotons) its effects did not extend upward into the alluvium above the chimney and thus the chimney did not collapse to produce a crater at the surface. The explosion created a temporary cavity (*white dot*) 19.8 meters in radius.

little anyone knew about underground explosions. To remedy this situation large programs of investigation were started in both the U.S. and Britain. My purpose is not to describe the renewal of the whole field of seismology that has followed from this work but to summarize the present state of affairs as it relates to the detection of clandestine tests of nuclear weapons below the surface of the earth. The detection of such tests has three aspects: detection, location and identification. Has anything happened? If it has, where did it happen? Was it a nuclear explosion?

When a nuclear explosion occurs in a cavity within the earth, the explosive device is converted to a very hot gas that reaches the wall of the cavity as a shock wave. The pressure exerted on the wall produces stress differences much exceeding the strength of the rock, and the temperature near the wall rises above the melting point. A "plastic" wave travels through the rock, leaving it permanently distorted. The wave spreads for a few hundred meters until it is so attenuated by spreading and absorption that it can no longer permanently distort the rock. Beyond this point the plastic wave becomes an elastic wave and is propagated much as if it had been produced by an earthquake. Some seconds or minutes after the explosion the roof of the cavity collapses, leaving a chimney-like hole filled with debris and with a puddle of molten rock at the bottom. Much work has been done on the processes occurring in the immediate neighborhood of the explosion, and the main features of these processes are understood.

From the point of view of detection the important result of an underground explosion is the motion of the ground produced by the seismic wave at distant points. It is customary to use the measured ground motions at such points to calculate a quantity known as the magnitude of the earthquake or explosion causing the seismic waves. The magnitude is intended to be a measure of the energy in these waves. Owing to the large range of energies to be covered the scale is a logarithmic one; each increase of one unit in the magnitude corresponds to an increase of 250-fold in the total seismic energy. The relation of magnitude to seismic energy is very uncertain, perhaps by as much as a factor of four. Our interest, however, is not in the seismic energy but in the ground motions. In spite of the uncertainty in the relation of the magnitude to energy, the magnitude does constitute a useful summary of the observed ground motions.

The energy in the seismic waves is of course only a part of all the energy released by an explosion; in smaller explosions it is commonly a few parts per thousand of the entire energy. The principal matter of practical significance is the energy of the explosion—the "yield"—needed to produce seismic signals of a given magnitude. This energy depends on the nature of the material in which the explosion occurs. The explosive energy needed to produce a given seismic effect in alluvium—unconsolidated material of the kind deposited by a river—is about 10 times the energy needed in granite. The volcanic tuff of the test site in Nevada requires twice the explosive energy that is needed in granite. It is unlikely that a clandestine explosion would be made in alluvium; the unconsolidated material above the cavity made by such an explosion usually collapses, leaving a crater at the surface that could be photographed by a reconnaissance satellite [*see illustration on page 19*].

There has been considerable difference of opinion as to the true relation between explosive energy and seismic magnitude. From the study of a large number of explosions it appears that the amplitude of the first few cycles of ground motion at distant stations is proportional to the energy released by the explosion. From this it may be deduced that the magnitude increases by one for a tenfold increase in the explosive energy [*see illustration at right*]. Most relations previously proposed gave a slower increase in magnitude with explosive energy. The revision is due to the results from the 80-kiloton explosion ("Longshot") recently set off in hard rock in the Aleutian Islands, which gave records of amplitude comparable to a magnitude-six earthquake.

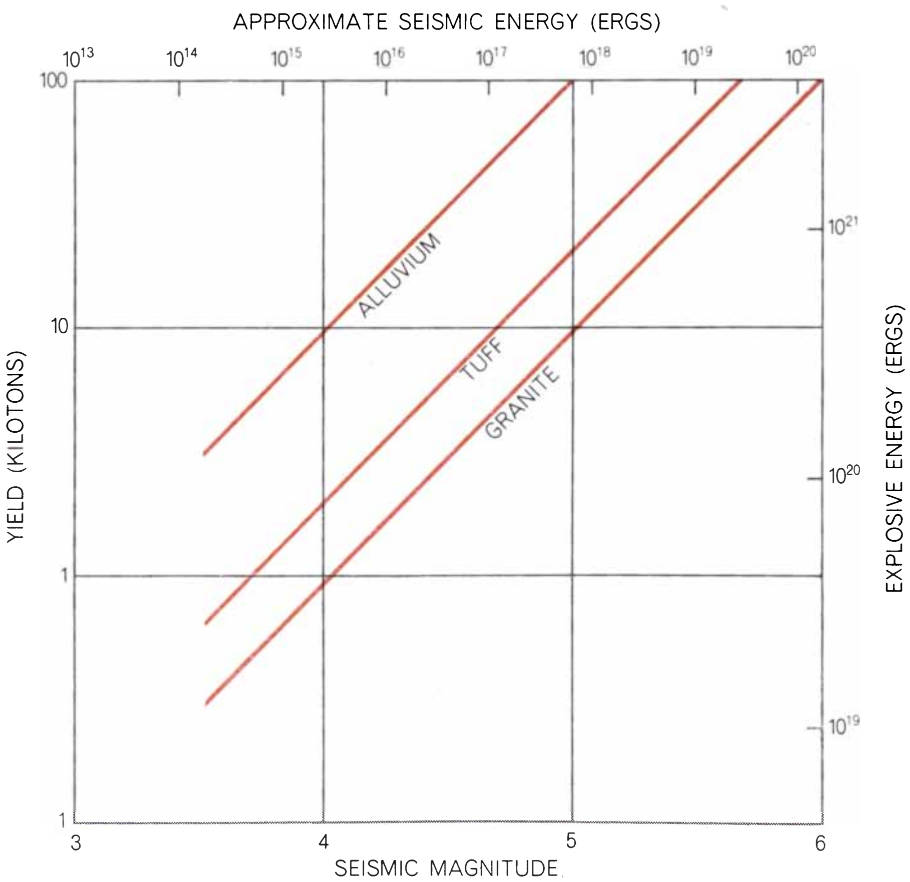
There is little room for difference of opinion concerning smaller magnitudes, for which data are available from numerous test explosions: an explosion of one kiloton in hard rock produces a magnitude-four seismic signal. The size of the smallest underground explosion that would be important in verifying a test-ban agreement is not well defined; in most discussions the lower limit has been considered to be a yield of a few kilotons, corresponding to a seismic signal of about magnitude four.

Because the surface of the earth is in continuous motion all seismic signals have to be detected against a background of seismic noise. The main advances in recent years have resulted from improvements in the ratio of signal to noise. These improvements are of three kinds: the choice of quiet sites, the use of arrays of instruments and the processing of the recorded signals.

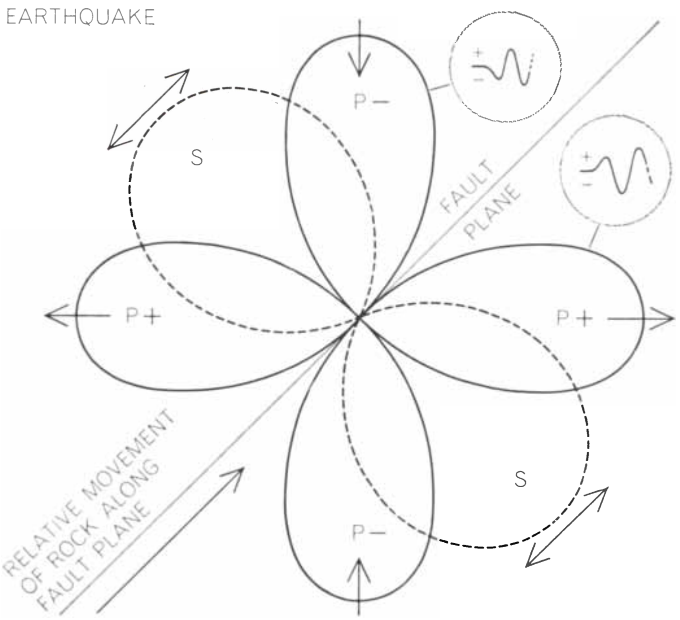
The background noise has many causes, among which are storms at sea, waves breaking on the shore, the rocking of trees and buildings by the wind, vibrations from traffic and machinery and the effects of innumerable earthquakes too small to be detected individually. The amount of disturbance varies greatly from place to place, and one of the most useful seismological discoveries of recent years is that there exist sites where the noise level is exceptionally low. As might be expected, such sites are on hard rock, in the interiors of continents and remote from industrial activity. Excellent sites have been found at Yellowknife in northwestern Canada, in the mountain states of the U.S., in the Sahara, in India and in Australia; doubtless others could be found in the U.S.S.R., Africa and South America.

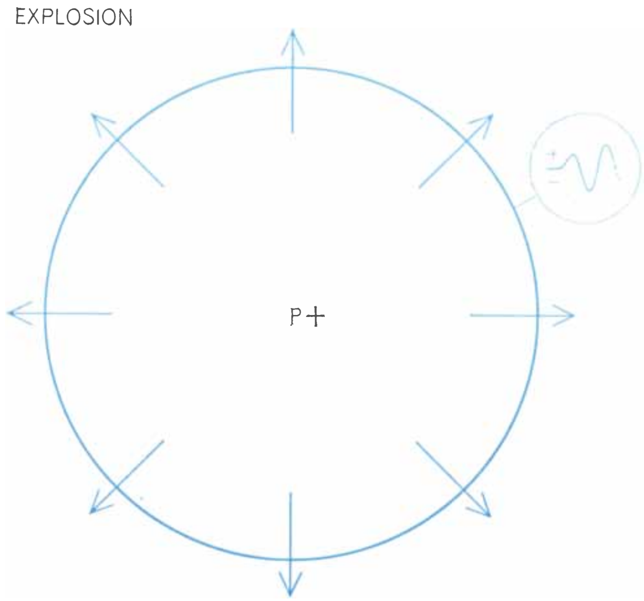
The background noise has a spectrum with a broad maximum at periods of oscillation between five and 10 seconds, whereas the bulk of the energy in the initial part of a seismic record (the *P* wave, or compressional wave) has periods between .5 and 1.5 seconds. A considerable improvement in the ratio of signal to noise can therefore be obtained by passing the signal through a filter that removes signals with periods greater than about one second. It is also desirable to remove signals whose frequencies are above 10 cycles per second; there is appreciable noise and almost no signal in this frequency range. When this filtering has been done, the ground motion at the best sites is less than 10^{-7} centimeter—only a few times the diameter of an atom—for a large part of the time. A poor site may give values 10 or 100 times greater.

Background noise is not the only impediment to obtaining a clear record of an explosion or earthquake. As a seismic wave travels through the earth it is reflected and scattered by discontinuities. Such reflected and scattered waves complicate the signal and increase the difficulty of extracting information about the source. A rather similar effect is produced by scattering



EXPLOSIVE ENERGY required to produce a seismic disturbance of a given magnitude is shown for three kinds of material. There is some evidence that the curves for alluvium and tuff should bend upward to give lower magnitudes for large explosions. A kiloton is the energy released by the explosion of 1,000 tons of TNT, equivalent to about 4.2×10^{19} ergs.

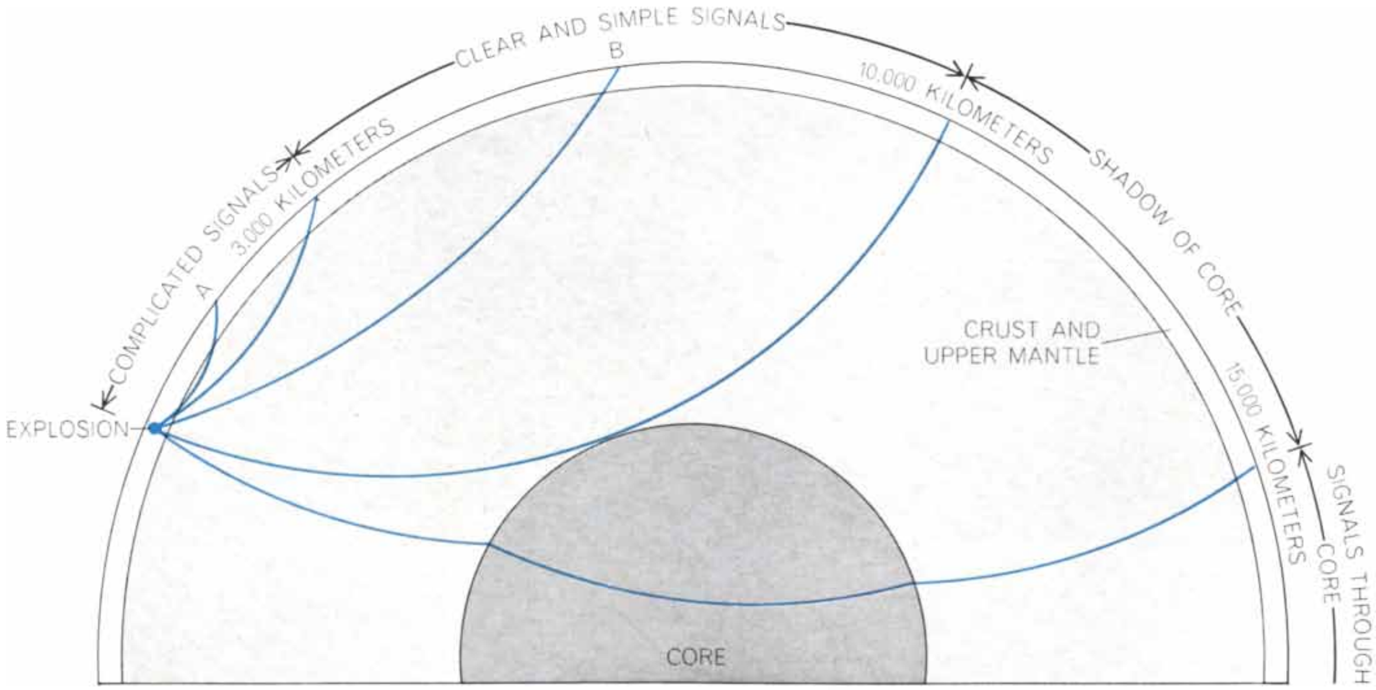




COMPARISON OF EXPLOSION WITH EARTHQUAKE shows that an earthquake (*left*) characteristically produces compressional *P* waves and distortional *S* waves, both of which vary with direction. In contrast, an explosion (*right*) produces an initial outward compressional motion in all directions. An earthquake normally originates in a fault where two bodies of rock slip past each other.

from topographic irregularities at the surface of the earth near the seismograph. This "signal-generated noise" is particularly troublesome when a large part of the path of the signal from source to seismograph runs through the outermost part of the earth. At greater distances the seismic ray goes steeply down from the source and steeply up to the seismograph [*see illustration below*]. There is then only a small part of its path over which it is affected by the complications of geology; the greater part is deep in the earth's mantle, where the material is more uniform than it is near the surface. Accordingly if one wishes to study the structure of the earth's crust, one should make measurements within, say, 1,000 kilometers of the seismic source, but if one wishes to study the nature of seismic sources or to detect clandestine explosions, one should observe at distances beyond 3,000 kilometers.

Between 3,000 and 10,000 kilometers the amplitudes of the first few cycles of the seismic signals are as great as or greater than they are between 1,000 and 2,000 kilometers. Beyond 10,000 kilometers the earth's core casts a shad-

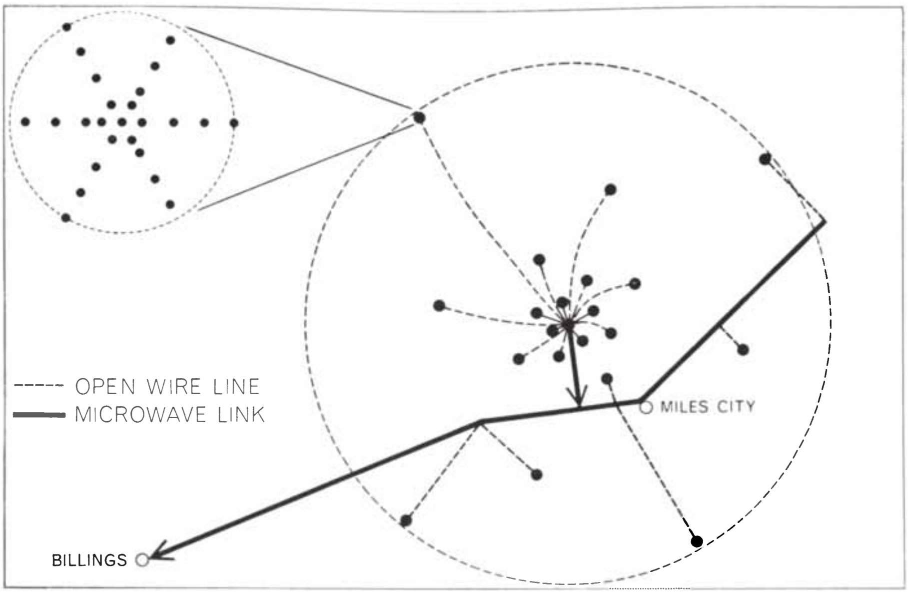


SEISMIC WAVES, whether produced by an earthquake or an explosion, can be recorded at great distances. In fact, the signals received at distances between 3,000 and 10,000 kilometers from an event are usually clearer than signals received within 3,000 kilometers. A ray received at *A* has its entire path in the crust and upper mantle of the earth, where irregularities in the rocks scatter the energy and complicate the record. The ray to *B* has most of its path deep in the earth, where the irregularities are few.

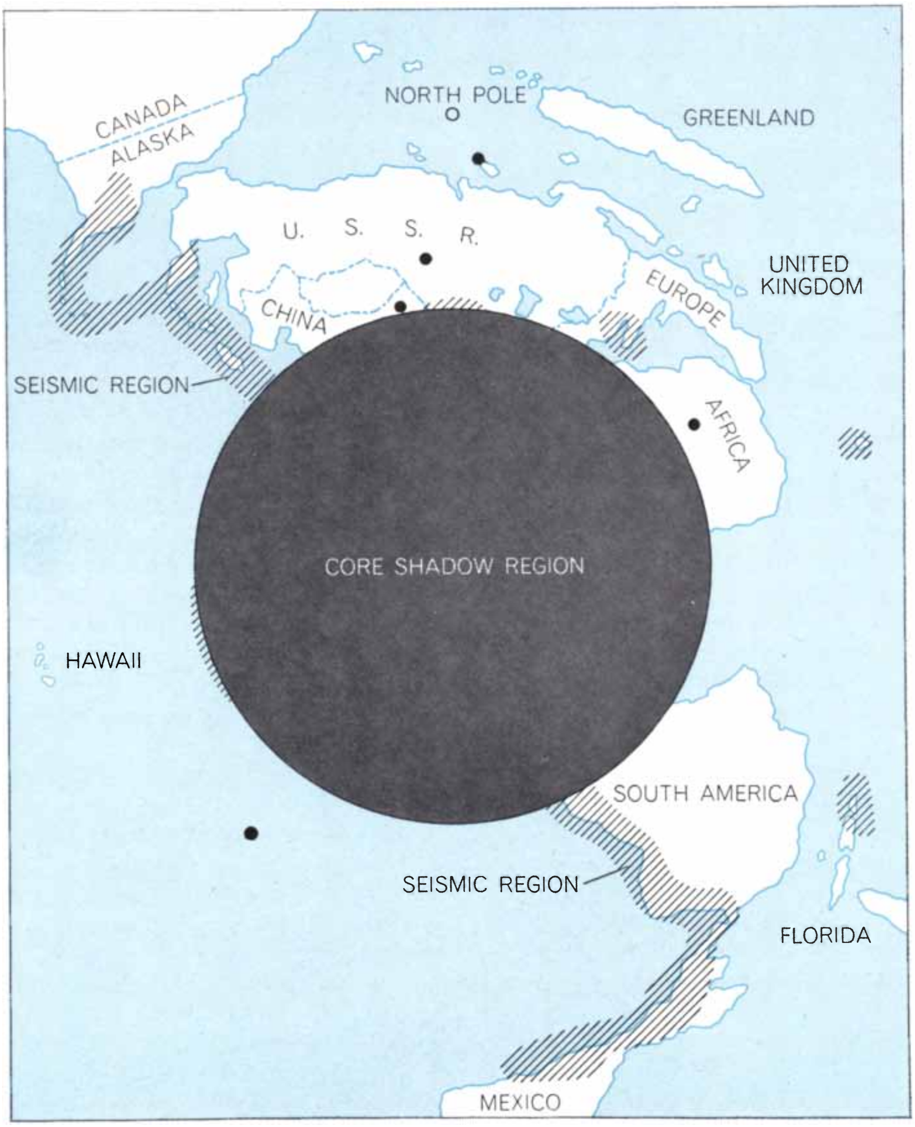
ow, making satisfactory observations of the earlier part of the seismogram impossible. Between 14,000 kilometers and the antipodes (20,000 kilometers) waves can be received through the core and could probably be used in the study of seismic sources, but this range of distances has been little studied for purposes of bomb-test detection. The range from 3,000 to 10,000 kilometers is convenient because the whole of the U.S.S.R. lies within this range from stations in the U.S.

A large improvement in the ratio of signal to noise can be obtained by the use of an array of seismographs instead of a single instrument. The idea of an array is not a new one; arrays have been employed for many years in the reception of short radio waves and in radio astronomy. If a row of n detectors receives a signal, and if the outputs from all the detectors are combined (after delaying the outputs to allow for different times of arrival at the different instruments), all the signals will add up to give a signal with an amplitude n times the amplitude of that from a single detector [*see illustration on next page*]. The array can be regarded as a telescope that selects signals coming from a given direction or, what is the same thing, as a device that selects signals arriving with a given apparent velocity of propagation over the ground. By adjusting the correction for the time lag it is possible to accentuate different parts of the seismogram, for example the compressional *P* waves or the distortional *S* waves. If the instruments of the array are not all on a single line but are spread out in two dimensions on the surface of the earth, the time lags can be adjusted so as to pick out signals coming from a given compass direction as well as those coming at a given angle to the vertical.

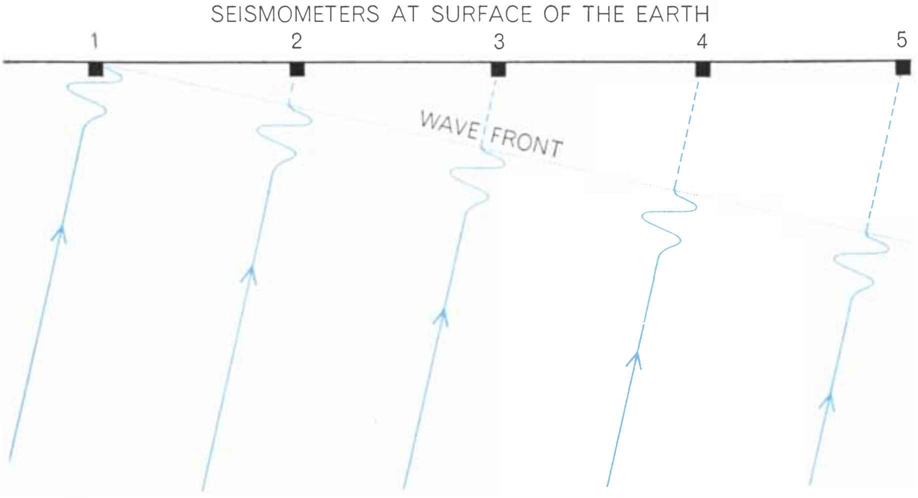
Obviously there would be no advantage in using an array if it enhanced the noise as much as it enhanced the signal. Provided that the noise at the different detectors is uncorrelated, an array of n detectors will yield a total value for noise that is roughly the square root of n times the noise received by a single detector. As a consequence the ratio of signal amplitude to noise amplitude will be increased in the ratio of n divided by the square root of n, that is, by a factor equal to the square root of n. For a real array the noise, particularly the signal-generated noise, will be partially correlated at the different detectors, and the improvement attainable may be greater or less than the



LARGE SEISMIC ARRAY recently installed by the AEC near Billings, Mont., consists of 21 clusters, each containing 25 seismometers. The clusters are seven kilometers in diameter. The entire seismic array is spread over a circular area 200 kilometers in diameter.



SEISMIC VIEW OF THE EARTH from the center of the Montana array shows the region in which seismic events can be detected and that in which they cannot be. Earthquake regions are hatched. Black dots indicate nuclear test sites in the U.S.S.R. and elsewhere.



FUNCTION OF SEISMIC ARRAY is to enhance the signal from a seismic event while suppressing noise. The diagram shows a seismic wave traveling upward to a line of five seismometers near the surface of the earth. The signal arrives first at the detector at the far left. To reach the next detector the wave must travel an extra distance. If the signals from the detectors are suitably delayed before they are added together, the combined output from the five detectors will have an amplitude five times that from a single detector.

square root of n. In practice it is usually possible to reach an improvement equal to the square root of n by using an array whose diameter is 20 kilometers or more. Since the number of detectors, n, in an array can exceed 100, the factor represented by the square root of n may represent a very large improvement.

An array can be organized in many ways to meet particular requirements, and much work has been done on the properties of different layouts. A common arrangement is to put two lines of instruments on the arms of a cross each about 20 kilometers in length. In the large-aperture seismic array recently installed in Montana the array consists of 21 clusters of seismometers spread over a circle 200 kilometers in diameter; each cluster contains 25 detectors spread over a circle seven kilometers in diameter. All 525 detectors are at the bottom of holes 200 feet deep to reduce noise generated at the surface by wind and other causes [*see top illustration on preceding page*].

Filtering and adding the outputs from a number of instruments is a linear process, and is especially suitable for improving the ratio of signal to noise when the signal is smaller than the noise, or not much larger. When the signal has been raised well above the noise level by these methods, it is advantageous to use nonlinear methods to "clean up" the record.

A particularly useful technique is to take the two records produced by summing all the instruments on each arm of a cross array, to accentuate the parts of these records that are similar and to reduce the parts that are dissimilar. This can be done by feeding the two records into a multiplier, multiplying them point by point and smoothing the product over time intervals of 1.5 or two seconds [*see illustration on opposite page*]. Such a record is called a correlogram.

With the aid of correlograms it has been possible to separate the signal of a small (400-pound) underground chemical explosion from the seismic disturbance produced by a small earthquake, both recorded by an array 2,400 kilometers distant [*see top illustration on page 28*]. If the array had been located several hundred kilometers farther away from the disturbances, the record of the explosion would probably have been even simpler. The detection of so small an explosion even though it was obscured by a preceding earthquake is remarkable. It shows that an explosion of the size of significance for bomb-test detection will usually be detected; the main difficulty is to identify it as an explosion.

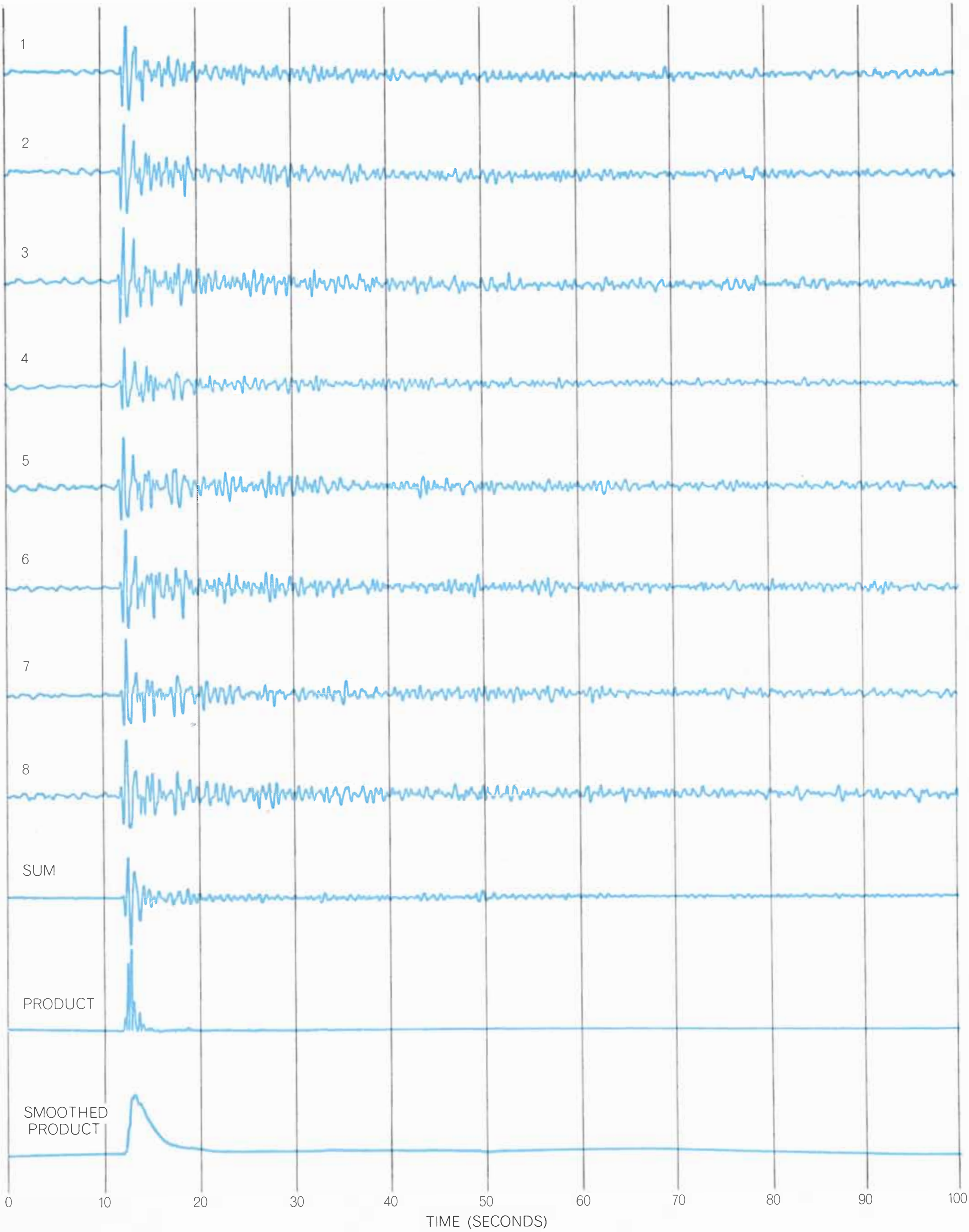
Information on the accuracy with which a seismic event can be located is not as complete as could be wished. The onset of the signals from an explosion can be determined to within a few tenths of a second. If a network of 10 or 20 stations could achieve this accuracy, the source would be located within a few kilometers. In practice the accuracy is degraded by local variations in the velocity of seismic waves, about which information is largely lacking. If data from stations distant from the event are used, it seems realistic to estimate that the site can be located within a circular area whose radius is about eight kilometers. Stations that are 500 to 2,000 kilometers from the event may give much larger errors, owing to irregularities in seismic velocities in the crust and upper mantle.

Since the great majority of events recorded at seismic stations are earthquakes, the critical problem in attempting to detect clandestine explosions is to distinguish a very few explosions among a great many earthquakes. Not surprisingly, small earthquakes are much more numerous than large ones. Roughly speaking, the number decreases by a factor of 10 for each increase of one unit in seismic magnitude. Throughout the world each year there are about 10,000 earthquakes of magnitude between four and five and only 10 or 20 of magnitude seven or greater [*see bottom illustration on page 28*].

About 1.5 percent of the world's earthquakes occur in the U.S.S.R. In an average year some 170 of these will be above magnitude four and only two or three will be above magnitude six. These numbers are only estimates of mean rates; the actual numbers fluctuate considerably from year to year. The fluctuations exceed the statistical expectancy for random events because in some years there may be 100 or more aftershocks following a single large earthquake. In a given year the total number of earthquakes above magnitude four in the U.S.S.R. might be as high as 300 or as low as 100.

The distribution of earthquakes over the world is extremely nonuniform; the great bulk of them occur along the Alpine-Himalayan chain, on the margins of the Pacific Ocean and along the mid-ocean ridges. In the U.S.S.R. earthquakes are practically confined to a belt along the southern border of the country and to the Kamchatka Peninsula, with a few on a north-south line to the east of the Lena River [*see illustration on pages 26 and 27*]. The areas of older rocks that constitute the greater part of the country appear to be completely free from earthquakes. The Russian testing ground near Semipalatinsk is just north of the earthquake belt and the testing ground in Novaya Zemlya is in an almost earthquake-free region.

Some earthquakes cause fractures at the surface of the earth; others cause fracturing entirely below the surface, commonly at depths of from 10 to 60 kilometers. The deepest earthquakes are about 750 kilometers below the surface.



EXPLOSION NEAR SEMIPALATINSK, a test site in the U.S.S.R., produced these records at a seismic array at Eskdalemuir in Scotland, 5,300 kilometers from the event. The first eight traces are from single instruments on one arm of the cross array. The next trace shows the sum of all instruments on both arms of the array. The next trace gives the product of the records from the two arms; the bottom trace shows the product after smoothing. The first wave to arrive is the compressional *P* wave of the explosion. The oscillations that are removed in the last two traces are noise generated by the signal itself. The explosion took place on May 16, 1964.

The deep earthquakes occur only in certain places, particularly on the inner side of the earthquake belt surrounding the Pacific. This can be seen in the map below: in the Kamchatka region the earthquakes just offshore are shallow and most of those inland are deep.

At first it seems that it should not be too difficult to distinguish an earthquake from an explosion. The mechanism at the source is quite different. An earthquake normally has its origin in a fault where two bodies of rock slip past each other, whereas an explosion produces a sudden and spherically symmetrical pressure pulse. The first motion from an explosion is always an outward-moving compressional pulse, which is similar in all directions. A fault, on the other hand, generates both compressional *P* waves and distortional *S* waves whose motion differs in different directions. The first motion is inward in some places and outward in others [*see top illustration on page* 22]. Moreover, the motion produced by an explosion is much simpler than that from an earthquake. This is not unexpected; an explosion is localized in both space and time, whereas a fault extends for some distance and may take some seconds to complete its movement.

These criteria have been considerably sharpened by the development of seismic arrays. The initial wave form can now be seen with great clarity, largely freed from the effects of the transmission path. For example, an underground explosion near Semipalatinsk on May 16, 1964, produced closely similar records at stations at Eskdalemuir in Scotland and Yellowknife in Canada [*see top illustration on page* 29]. The first few seconds of the records are almost

SEISMIC MAP OF U.S.S.R. shows earthquakes above magnitude 5¼ that occurred from 1911 to 1959. The shocks above magnitude 6½ are represented by larger circles, those of 5¼ to 6½ by smaller circles. Black circles indicate shallow earthquakes: depth less than 35 kilometers. Open colored circles indicate depths of between 35 and 300 kilometers; colored circles with dots indicate depths exceeding 300 kilometers. The map is based on one published by the Soviet Academy of Sciences. Novaya Zemlya and Semipalatinsk, identical at the two stations in spite of the widely separated paths followed by the seismic waves and the completely different geological setting of the two arrays. The wave form must therefore be determined largely by the events at the source of the energy.

Another striking example is given by comparing the records of the seismic waves from an explosion at the French testing ground in Algeria with those from an earthquake in Libya. The arrays at Eskdalemuir, Yellowknife and a station at Pole Mountain, Wyo., gave very similar records of the explosion and much more complicated and dissimilar records of the earthquake [*see bottom illustration on page 29*].

It has been suggested that the complexity in the wave form of earthquakes is due not to the source mechanism but to the tendency of earthquakes to occur in more complex geological settings than those in which explosions are fired. The recent Longshot explosion in the Aleutians has demonstrated that this is not so. This shot gave characteristic explosion records in spite of being fired in the circum-Pacific earthquake belt. The suggestion that it is only earthquakes of magnitude above 4.5 that have complicated records also appears to have no foundation.

The determination of depth is another criterion that enables a large number of earthquakes to be eliminated. An event occurring at a depth exceeding eight kilometers is certainly an earthquake. About 30 percent of all earthquakes occur at depths exceeding 50 kilometers. The number with depths between eight kilometers and 50 kilometers is not easy to determine because the complexity of the wave form makes it difficult to detect the wave reflected from the surface above the site of the fault. If an earthquake with a simple wave form occurred in this depth range, it should be possible to determine its depth and thus demonstrate that it is not an explosion. By a careful examination of records from arrays it is sometimes possible to estimate the depth of an explosion fired at a depth of as little as one kilometer below the surface of the earth. The determination of depth is of particular importance for detecting explosions in Kamchatka, where most of the shallow earthquakes occur in the sea just offshore and most of those on land are deep.

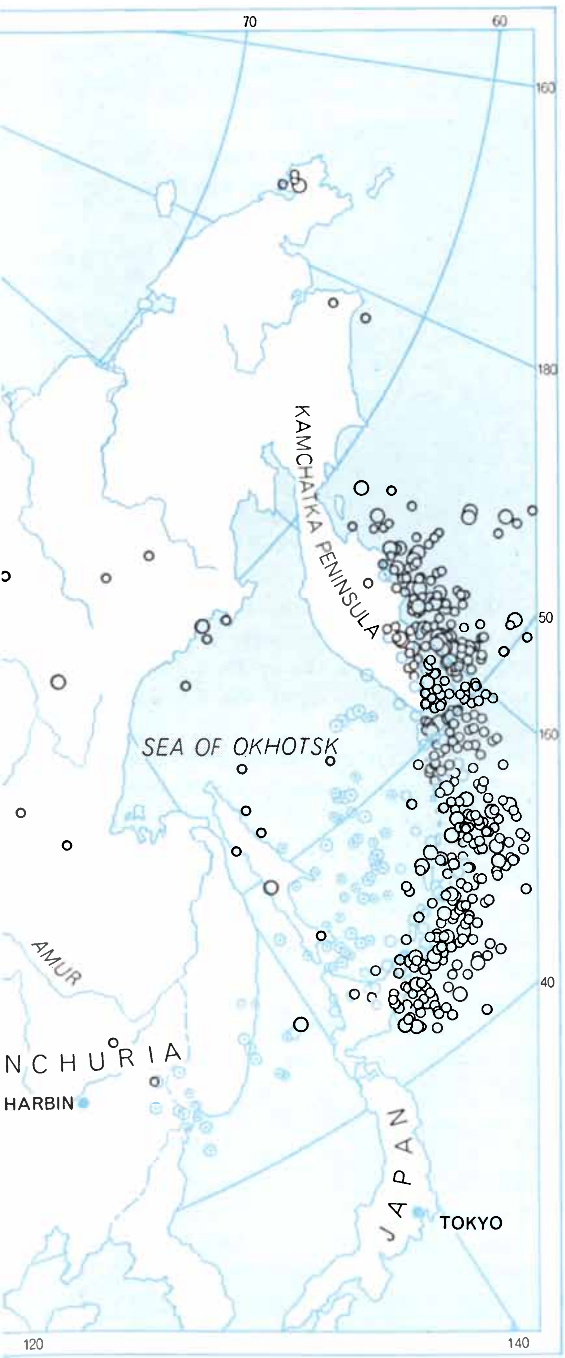
Attempts to use criteria depending on S waves and surface waves have not been very successful. The horizontally polarized S waves from an explosion are smaller than those from an earthquake, but there are many small earthquakes without detectable S waves or surface waves. The probable explanation is that the period of these waves falls near the peak in the frequency distribution of background noise. It is also true that less effort has been put into such methods than has been devoted to the study of P waves; moreover, the instruments used in the arrays are designed to respond to vertical motions and thus are unsuitable for detecting horizontally polarized waves. It may be that the matter deserves closer attention. It would be particularly interesting to see what results could be obtained from a cross array equipped with instruments capable of responding along three coordinate axes.

The critical question is whether, when all these criteria have been used, there is a residuum of earthquakes that are indistinguishable from explosions. The results of an examination of a worldwide sample of 161 earthquakes with depths of less than 50 kilometers have been published by the United Kingdom Atomic Energy Authority. There were seven earthquakes, or 4.5 percent, that could not be distinguished from explosions. This would give an average of eight "suspicious events" per year in the U.S.S.R. Estimates by some other authorities are about twice as high. The discrepancy is not surprising. "Suspicious" is not a precisely defined concept; how many events one regards as suspicious will depend to some extent on how suspicious one is.

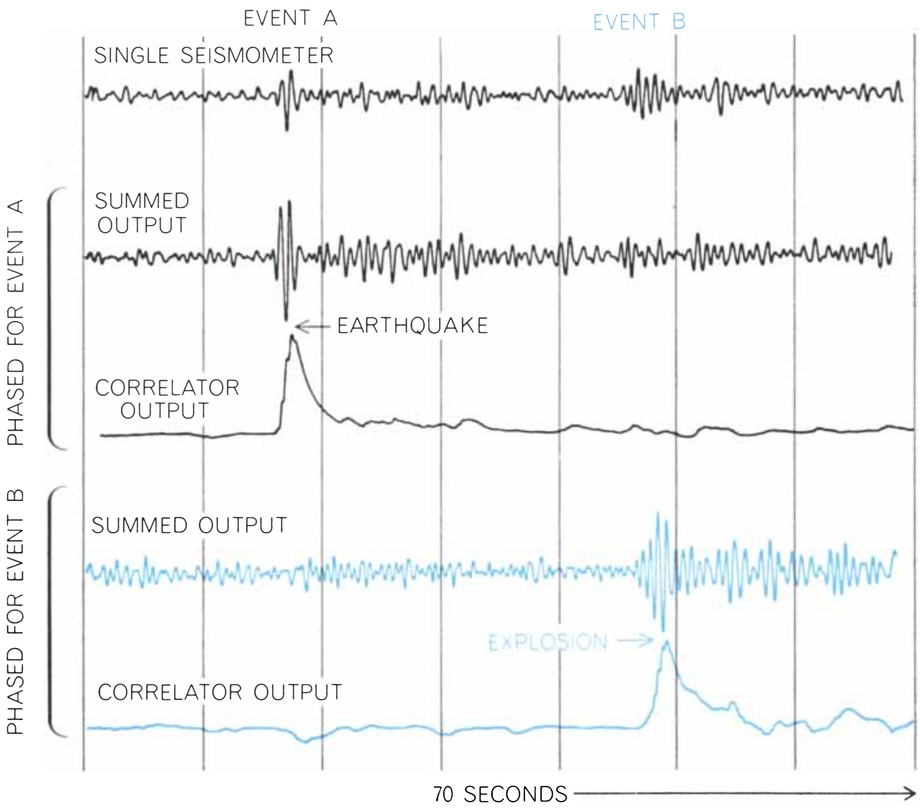
The number of arrays used in the Atomic Energy Authority's investigation was three, but for a large part of the time only one was in operation. Five of the seven explosion-like earthquakes were recorded while only one array was in operation. Some improvement is to be expected from the use of more arrays, particularly from those recently established in Australia and India, which receive signals from the U.S.S.R. in directions differing widely from the directions of signals received in Britain, Canada and the U.S. The arrays themselves are also susceptible to improvement; those employed in gathering the sample had only 20 detectors, compared with the total of 525 in the array in Montana. The use of more refined determinations of focal depth would also probably remove some ambiguous events.

It is clearly possible to chip away at the number of earthquakes within the U.S.S.R. that might be mistaken for explosions, but there is no reason to suppose that this number can be reduced to zero. Even if there are no earthquakes that virtually duplicate explosions, there may be earthquakes whose fault planes lie at such an angle that they give an initial outward motion at all distances beyond 3,000 kilometers. If one of these happened to give a simple wave form and to be shallow, it might not be distinguished from an explosion. With a system as complicated as the earth almost anything can happen occasionally. It seems prudent to assume that we shall not get a system that never mistakes an earthquake for an explosion.

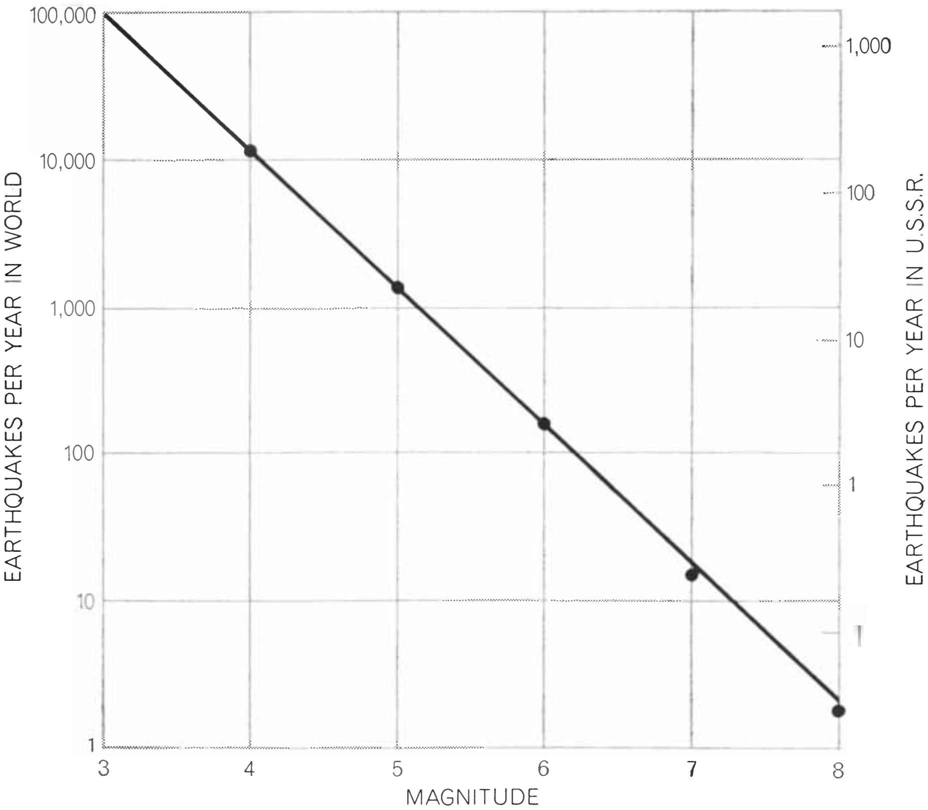
In a sample of 35 underground explo-



used as nuclear-test sites, are in regions that are free from earthquakes. In the Kamchatka area the earthquakes just offshore are shallow and most of those inland are deep.



EARTHQUAKE FOLLOWED BY SMALL EXPLOSION at a distance of some 2,400 kilometers were clearly distinguished by the seismic array at Yellowknife in Canada. The explosion was produced by .2 kiloton of chemical explosive set off belowground at Climax, Colo. The top trace shows the output of a single seismometer. The second trace shows the effect of adding the traces from 20 detectors with time lags chosen to emphasize the earthquake. In the fourth trace the lags emphasize the explosion. The remaining traces are "correlograms" obtained by multiplying and smoothing the summed output from the two arms of the array. Had the explosion been farther away the record probably would have been simpler.



ANNUAL NUMBER OF EARTHQUAKES above a given magnitude are shown for the entire world and for the U.S.S.R. It is assumed that 1.4 percent of all earthquakes occur inside Russian territory. There are sizable annual fluctuations around these mean rates.

sions studied by seismological means, one on Novaya Zemlya would have been regarded as an earthquake if it had occurred in a seismic region. Such misinterpretation is not, however, of much significance. In order to take advantage of it one would have to know beforehand that the conditions were such that an explosion would be misinterpreted as an earthquake.

Much attention has been given to the possibility that the seismic effects of an explosion could be reduced or modified so that it was undetectable or appeared to be an earthquake. The most promising method is to set off the explosion in a very large cavity. If this were done, theory suggests that the amplitude of the seismic signal would be reduced by a factor of 100.

The theory has been verified for chemical explosions of up to about one ton and there is no reason to suppose that it would not apply to nuclear explosions. In spite of the importance of the matter no experiments have been made with kiloton explosions. This is probably because of the great engineering difficulties involved in making cavities several hundred feet in diameter and also because of the possibility that such a cavity would collapse after an explosion and form a detectable crater at the surface. If the method were to be used for concealing a clandestine explosion, there would also be great difficulty in removing millions of cubic feet of material from the cavity without leaving conspicuous signs on the surface.

Other methods of concealment that have been proposed are to set off several explosions in a short interval or to set off an explosion just after an earthquake has occurred. Neither method is likely to be effective. The second entails a wait of years before a suitable earthquake occurs near the place where the test has been prepared.

It may be that it is possible to devise a method of concealing a nuclear explosion. As far as is known, however, this has not been done. To do it would itself involve an extensive series of tests. One of the reasons for wishing that a comprehensive test ban be not too long delayed is that the ban would prevent the development of methods of concealment that, if they were discovered before tests stop, would make agreement more difficult.

This article is not the place to discuss at length the influence that the facts presented here should have on international negotiations. The main political problem is to decide what means of verification, if any, are needed to ensure that a "suspicious event" is not a clandestine explosion. The only effective means of verification is to inspect the neighborhood of the event. The exact nature of the inspection is not of the first importance; a violator of a test ban would be unlikely to allow an inspection of a real explosion. Rather than be caught red-handed he would incur the odium of refusing access to the site or of abrogating the treaty. The object of having the right of inspection is to demonstrate to ourselves and to the world in general that suspicious events are not explosions, and to get a strong indication of a violation from the obstruction that would occur if a proposal were made to inspect the site of an actual explosion.

A formal theory can be set up: If there are N suspicious events in country A per year, and country B is allowed n inspections, what is the probability of A's conducting M tests in a year without B's asking to inspect one or more of them? A will require this probability to be quite high, say .95, since the consequences of being caught cheating on a matter concerned with nuclear weapons are serious. B, on the other hand, requires a high probability of detecting A's violation before too many tests have been carried out. In other words, B wants the probability formula to produce a low number. The following figures show for various numbers of inspections the probabilities that B will *not* ask to inspect one or more of the tests when there are five tests among 15 suspicious events:

Number of inspections	1	2	3	4
Probabilities	.67	.43	.26	.15

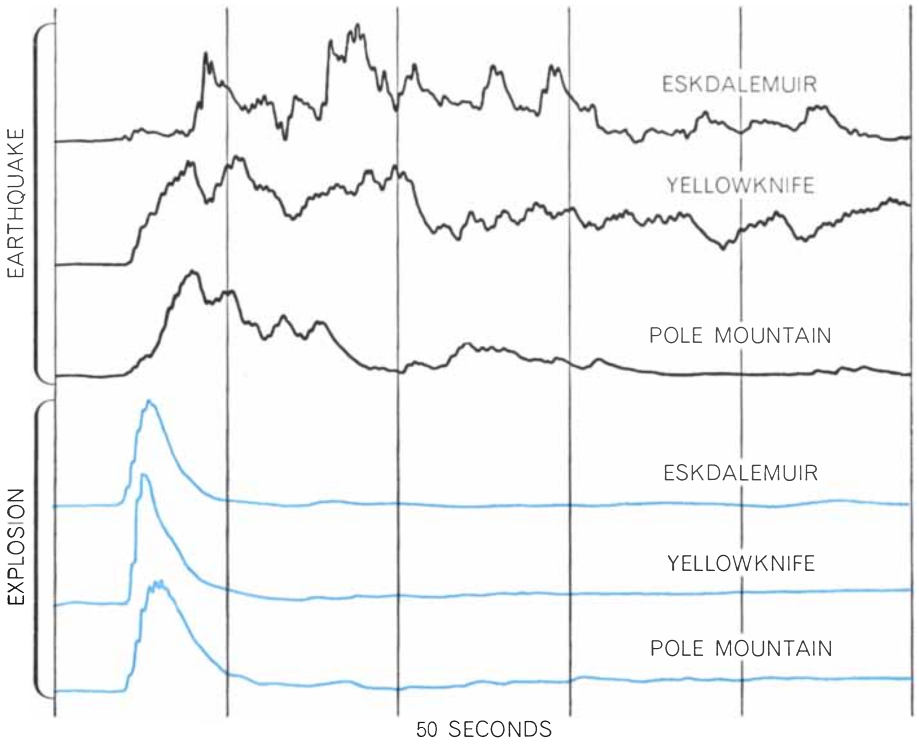
In summary, one can say that the technical facts are as clear as can be expected for a complicated subject and that there are now no very serious differences of opinion about them. Some further improvements in equipment are possible, particularly in the provision of more seismographic arrays. These, however, can hardly affect the political decisions, which must depend on a balance between the desirability of a test ban and the disadvantages of knowing that a few ambiguous events will occur in the U.S.S.R. each year, any of which could be an explosion but all or most of which are earthquakes. In practice the choice is among the following three courses:

First, to say that the real risks exceed the hypothetical gains and that we therefore do not want to seek a test ban.

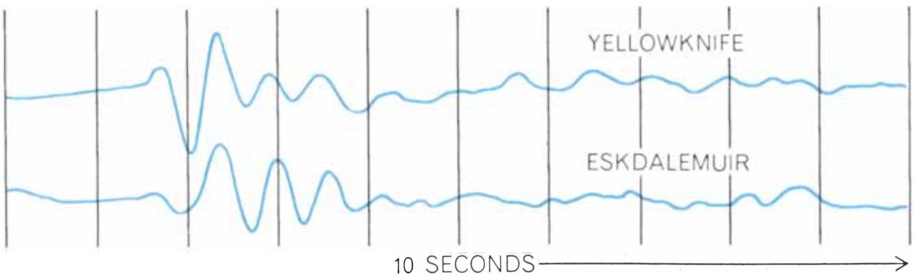
Second, to accept something like the Russian offer (since withdrawn) of "two or three" inspections a year.

Third, to say that no nation is likely to conduct clandestine tests in circumstances where there is an appreciable probability of their opponent's knowing that they are doing so, even if the violation cannot be proved in a court of law, and that a treaty without inspection is therefore acceptable.

Most informed opinion would accept the second course. The difficulty is that the Russians have stated categorically and recently that it is not acceptable to them. It is therefore not a possible choice for the U.S. The acceptance of the third course would be made easier if there were little chance of making important improvements in weapons by underground testing. In the absence of detailed knowledge one can only say that it is difficult to imagine what the improvements could be. It might be objected that acceptance of a test ban without inspection would leave us on a slippery slope where, if we were sufficiently lacking in judgment or firmness, we might find it hard to refuse unverified agreements about matters vital to our security.



EARTHQUAKE AND EXPLOSION are compared in the correlograms obtained from seismic arrays at Eskdalemuir, Yellowknife and Pole Mountain, Wyo. The earthquake (*top*), which occurred in Libya, gives a long-drawn-out, complicated record that is visibly different at different stations. The nuclear explosion (*bottom*), which was conducted by the French government at its test site in Algeria, gives simple and similar records at all stations.



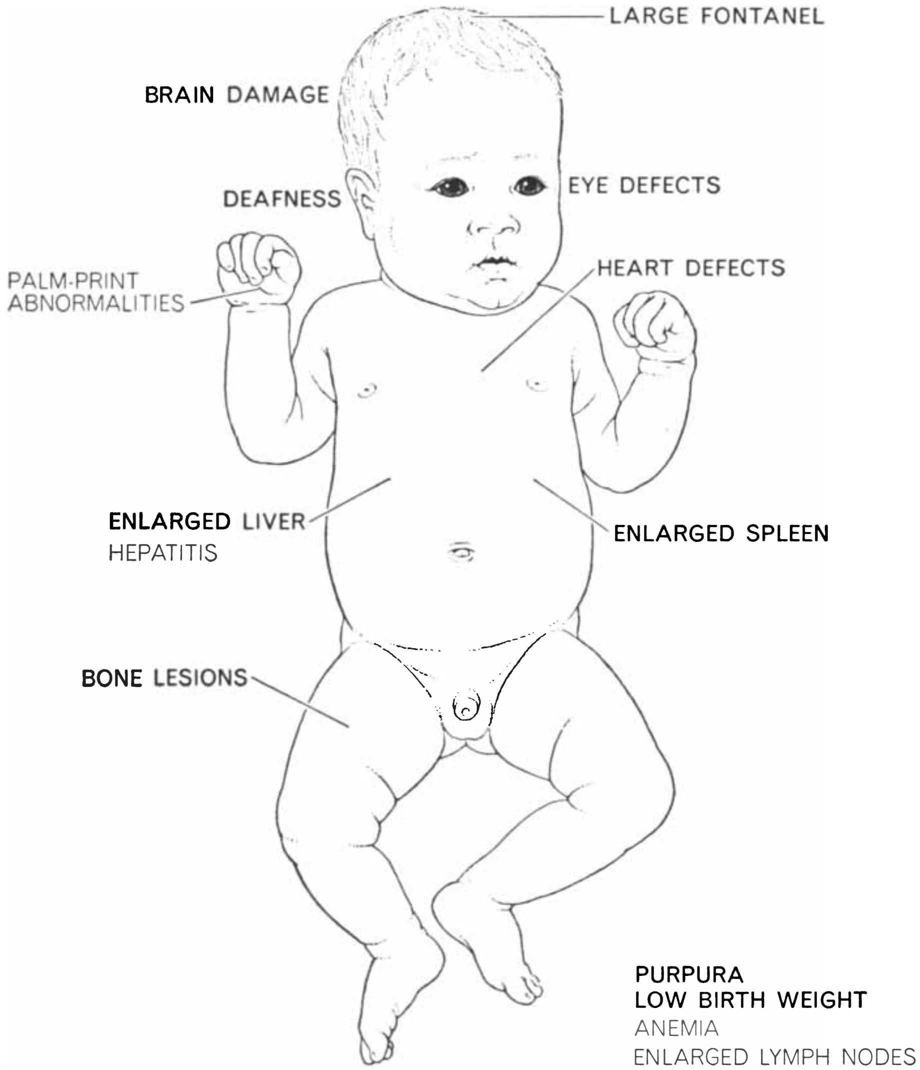
FRENCH UNDERGROUND EXPLOSION produced these records at Yellowknife and Eskdalemuir, respectively 9,000 and 3,500 kilometers from the event. The two traces are the summed output of all the instruments at each site. It can be seen that the initial wave form depends on the character of the original signal and is largely independent of the distance and the path from the source to the seismic arrays and of the geology near the arrays.

GERMAN MEASLES

This mild infection can have grave results during pregnancy. In 1964 an epidemic in the U.S. caused defects in 20,000 infants. Isolation of the virus has led to intensive efforts to develop a safe vaccine

by Louis Z. Cooper

Rubella, or German measles, is the least troublesome of the usual childhood diseases: some swollen glands, a little fever, a transient rash—and the child is well again and back at play or at school. In pregnant women German measles is something else again: during early pregnancy it can infect the developing fetus and harm the unborn child. The association of maternal rubella with the birth of infants that are blind, deaf, retarded or suffering from congenital heart disease has been recognized since 1941, but there has been no satisfactory way to cope with the tragedy of congenital rubella. The administration of gamma globulin and termination of pregnancies complicated by German measles during the first three months are both controversial and ineffective solutions for this serious problem. Not until 1961 was the rubella virus identified, opening the way for more intensive study of the disease and vigorous efforts to develop an effective and safe vaccine. Significant progress has been made, raising hopes that rubella can be brought under control.

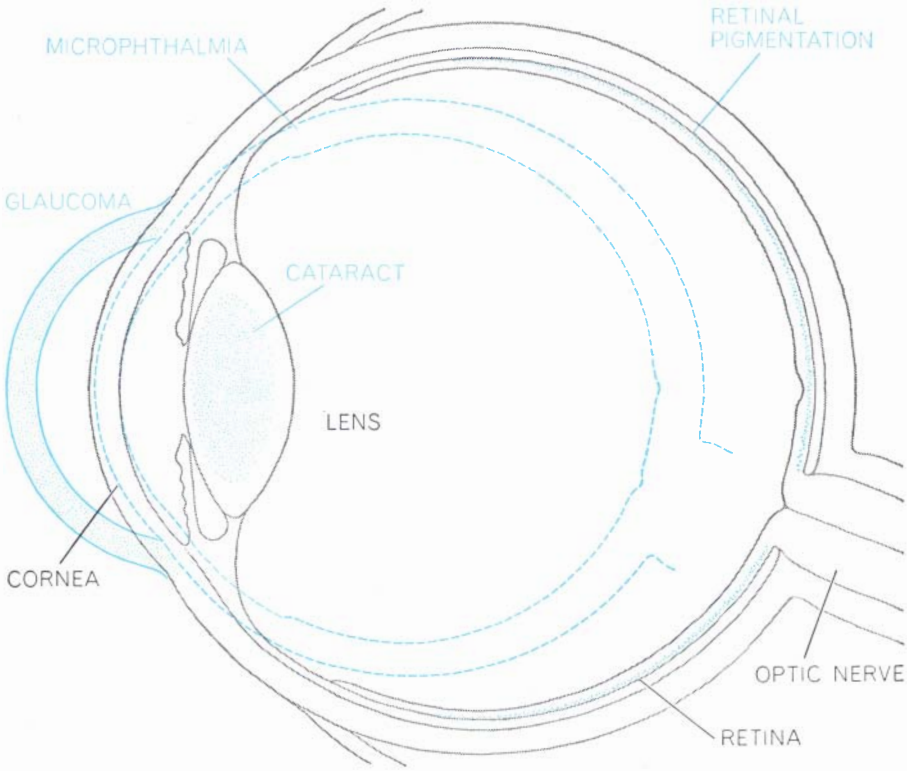


NEWBORN INFANT with congenital rubella may have any of the clinical manifestations of the disease indicated here; the most common are shown in boldface. The fontanel is an open area between bones of the skull, purpura a bleeding condition caused by a blood deficiency.

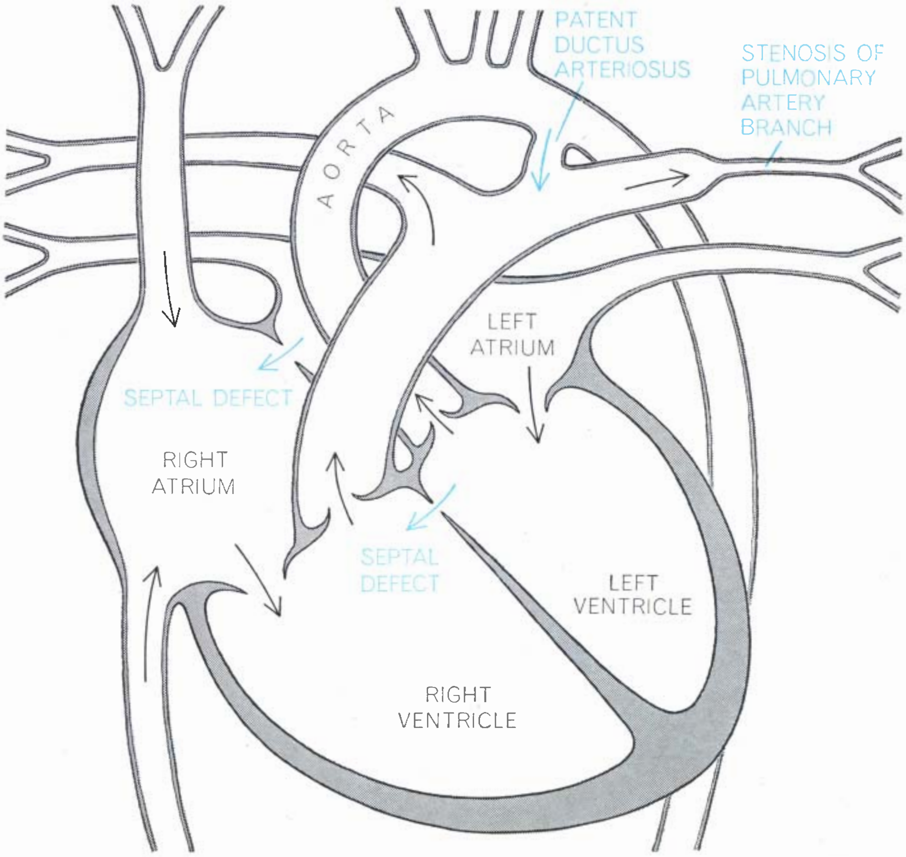
In 1815 an English physician described a disease that exhibited a rash like that of measles and scarlet fever but was much milder. Epidemics of the illness were noted in Germany during the first half of the century; there the disease was called *Rötheln,* from the word for redness. In 1866 an English physician practicing in India proposed the name "rubella"—perhaps for "red" and "pretty"—on the ground that *Rötheln* was "harsh and foreign to our ears." In 1874 J. Lewis Smith, the first professor of pediatrics at Bellevue Hospital in New York, describing an outbreak of rubella among children in an orphanage and among his private patients in the "suburbs of New York City on East 71st Street," called it *Rötheln* and also German measles. In time rubella became a widely recognized and distinct clinical entity, but it attracted little medical attention because of its mildness and brief duration.

In 1940 there was a widespread epidemic of rubella in Australia. The next year N. McAlister Gregg, an ophthalmologist, noted a sudden rise in the incidence of congenital cataract, a condition in which infants are born with, or soon develop, opaque areas in the lens of the eye. He startled the medical community with a paper that described 78 infants with congenital cataract and noted that the mothers of 68 of them remembered having had German measles during the first three months of pregnancy. Gregg's paper not only included a definitive description of the rubella cataract; it also noted the low birth weight and feeding difficulty, the high incidence of congenital heart defects and the high mortality that have since been confirmed as characteristic results of rubella acquired during intrauterine life. It is impossible to overemphasize the importance of Gregg's pioneering observations at a time when vague terms such as "faulty germ plasm" were still being applied to congenital defects. Rubella was the first clearly defined teratogen: an agent that causes developmental abnormalities. Ionizing radiation and the drug thalidomide have since been found to be teratogenic. There is some indication that infection with the influenza, mumps or Coxsackie viruses may have similar effects.

Gregg's conclusions were soon confirmed by extensive investigations in Europe, the U.S. and New Zealand as well as Australia. In numerous studies the birth of defective children was correlated with a history of rubella in their mothers. The effects of the virus were varied, but the most vulnerable targets were the eye, heart, ears and brain. None of those retrospective studies, in which the cases were accumulated after the fact, could shed much light on the crucial question of relative risk: What were the chances that a pregnant woman with German measles would bear a defective child? Prospective studies, which begin with a pregnancy, document maternal rubella and observe the outcome, were attempted during the 1950's. They established that rubella contracted during the first three months or so of pregnancy causes major congenital malformations in 15 to 20 percent of the infants. The earlier in pregnancy the infection occurs, the greater the risk. A prospective study in 1960 by Richard H. Michaels and Gilbert W. Mellin of the Columbia University College of Physicians and Surgeons reported a fetal hazard of 47 percent for rubella in the first month, 22 percent in the second and 7 percent in the third. (On the basis of such figures as these many U.S. hospitals will approve a request for therapeutic abortion when rubella occurs within the first 12 weeks of pregnancy, provided that the diagnosis of rubella is certified by two physicians.) There are indications that these



EYE ABNORMALITIES of congenital rubella are shown in color. Cataract (an opaque area in the lens), microphthalmia (underdevelopment of the eye) and patchy pigmentation of the retina are more common than glaucoma, in which the cornea is clouded and protrudes.



HEART ABNORMALITIES, named here in color, interfere with blood circulation. The ductus arteriosus is a vessel that should shut down at birth; if it does not, blood is misdirected. Septal defects are abnormal openings between chambers. Stenosis, or narrowing, of a branch of the pulmonary artery has been noted in some congenital rubella cases.

figures are on the conservative side—that the risk is somewhat greater and that it continues into the fourth month of pregnancy. Analyses in progress in several laboratories of recent rubella epidemics should provide more definitive risk statistics. The major source of error in such studies has been mistaken diagnosis, since other virus diseases can mimic rubella. The isolation of the rubella virus in 1961 has made it possible to eliminate such errors.

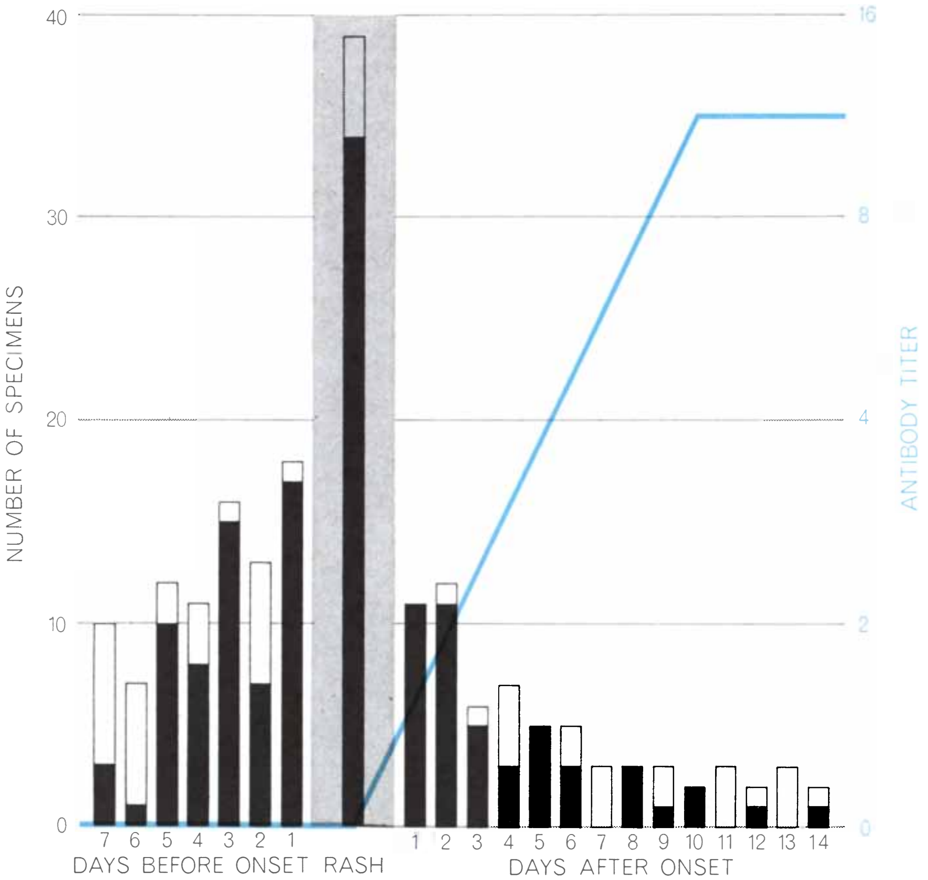
There had been general agreement that rubella was probably caused by a virus. Its incubation period, clinical course and lack of response to antibiotics were consistent with a viral origin; most important, it could be transmitted to volunteers by bacteria-free filtrates of blood serum or of throat washings from patients. All attempts to cultivate a specific infectious agent from such patients were unsuccessful, however, because of peculiarities of the rubella virus.

Viruses grow only in living cells, the machinery and substance of which they turn to their own ends. Most viruses can be propagated in tissue culture, and their presence is recognized by the changes they effect in the sheet of cells in which they grow; they first damage and then kill large numbers of cells [*see illustration on opposite page*]. Some viruses, however, can multiply in cells without killing them and therefore do not readily produce these cytopathic effects. In 1960 G. Hitchcock and D. A. G. Tyrrell of the Common Cold Research Unit in Britain discovered such an agent (a rhinovirus, one cause of the common cold) through an indirect technique based on the principle of viral interference. In their "interference technique" a substance containing a suspected virus is incubated in a tissue culture. If it contains a noncytopathic virus that infects the cells, the virus's effect will be invisible but it may stimulate the cells to produce interferon, an antiviral substance that prevents subsequent infection of the cells by another virus. If the second virus is one that is easily detectable because it can produce marked cytopathic effects, the absence of such effects indicates that the first substance contained a virus.

In 1960 Thomas H. Weller of the Harvard School of Public Health, concerned because his son's rubella-like illness was unusually severe, undertook laboratory tests of a urine specimen to make sure that some more threatening disease was not involved. He found no evidence of another disease but he did note "subtle and unique cytopathic activity" in a culture of cells from human amnion, the membrane that surrounds the embryo. With Franklin A. Neva, Weller went on to recover agents with similar effects from patients with more typical cases of rubella, thus establishing the presence of a specific rubella virus.

At about the same time physicians at the Walter Reed Army Medical Center isolated the virus with the interference technique. Paul D. Parkman, E. L. Buescher and Malcolm Artenstein of Walter Reed had inoculated several different kinds of tissue culture with throat washings taken from Army recruits with rubella. There were no detectable cytopathic effects or other typical signs of virus infection, but rather than discard the tissue cultures the investigators inoculated them with echovirus, an agent with distinct cytopathic effects. They found that the cultures previously inoculated with the rubella specimens were completely resistant to superinfection by echovirus. Laborious controlled experiments confirmed the presence of rubella virus in the specimens. Moreover, blood serum from the patients was shown to contain a specific antibody that neutralized the rubella virus. The Walter Reed and Harvard workers exchanged their specimens for testing by their respective techniques to satisfy themselves that the infective agents each group had isolated were identical, and arranged for simultaneous publication of their findings. Their example, incidentally, set a standard for the high degree of cooperation since maintained by investigators of rubella.

The discovery of techniques for isolating rubella virus and measuring antibody response has made possible more precise study of the clinical course of the mild postnatal disease as well as of the severe congenital disease. When susceptible children are exposed to the rubella virus either through contact or through administration of the virus in a nasal spray or by injection, they usually develop moderately tender swelling of the lymph nodes—usually those behind the ears or at the back of the head just above the hairline—after an incubation period of about two weeks. Within a

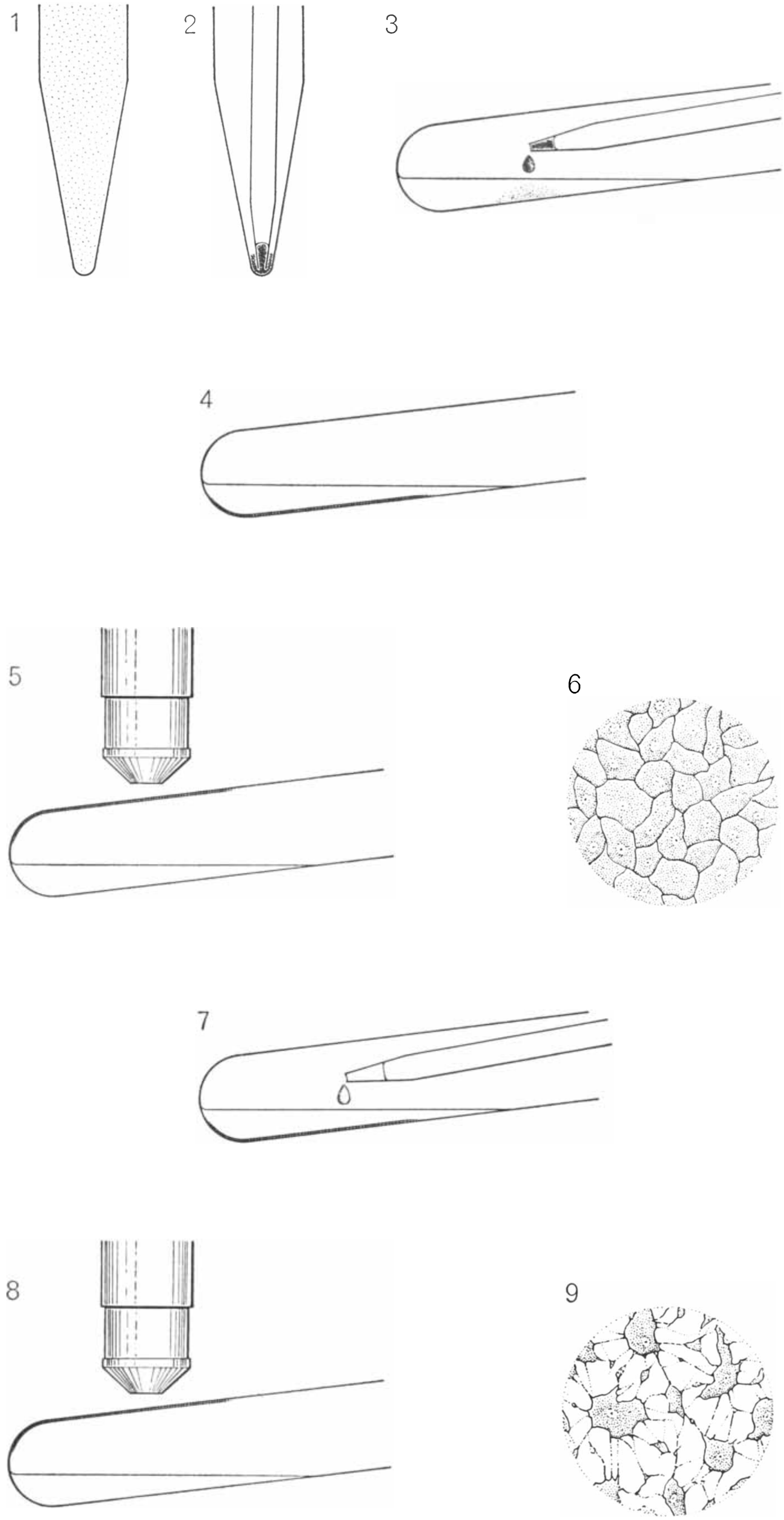


NORMAL COURSE of postnatal rubella was observed in 50 children by Robert H. Green and his colleagues at the New York University School of Medicine. The bars show results of tests for the presence of virus in the throat before onset of rash, on day of onset and after day of onset; black portions indicate the number of specimens with virus, white portions negative specimens. The colored curve shows changes in the rubella antibody level.

few more days a rash usually appears, first on the face and then over the trunk, arms and legs. The rash is quite changeable and difficult to distinguish from that of several other diseases; it usually lasts for only two or three days. There is a moderate decrease in the count of white blood cells and in the number of platelets—small bodies in the blood that promote clotting—but these changes usually produce no symptoms. In a few cases, however, the platelet count is low enough to give rise to purpura, a bleeding condition that produces numerous spots, like tiny bruises, in the skin and mucous membranes. An extremely rare complication is encephalitis; it has a high mortality rate but is perhaps 10 times less frequent than the encephalitis associated with measles.

The rubella virus is present in the throat and serum as early as a week before the appearance of the rash, Robert H. Green, Michael R. Balsamo, Joan P. Giles, Saul Krugman and George S. Mirick of the New York University School of Medicine have found [*see illustration on opposite page*]. It disappears from the serum within a day or so of the onset of the rash but persists in the throat for as much as two weeks more. (These observations emphasize the inadequacy of previous concepts of isolating the patient; indeed, they indicate that the disease cannot be controlled by isolation, since patients can be distributing the virus for days before anyone knows they are sick.) Antibody to the rubella virus appears within a day or so of the beginning of the rash, at about the same time as the virus largely disappears from the blood. It persists for years and seems to be completely protective against reinfection: Green and his associates were unable to produce infection in volunteers who had even minimal levels of rubella antibody. This finding is of great importance to a woman exposed to rubella during pregnancy, since it means that if she has demonstrable antibody at the time of exposure or soon thereafter there is no risk of maternal or fetal infection.

Rubella infection can, unfortunately, be present without any apparent symptoms at all, as Krugman showed with Robert Ward as long ago as 1953. Such inapparent infections present a difficult problem for the obstetrician. If his patient is exposed to rubella, she may develop a case that can be detected only by laboratory tests—which are not generally available and in any case take several weeks. The true incidence of inapparent cases is not known, but it is



TISSUE-CULTURE test for the presence of a virus begins with cells from the kidney of an African green monkey, prepared by digesting bits of kidney with an enzyme (*1*) and centrifuging the suspension (*2*). The cells are put in a test tube of nutrient medium (*3*), settle to the wall of the tube and grow together into a "lawn," or sheet of cells (*4*), with a characteristic pattern under the microscope (*5, 6*). If virus is added to the culture tube (*7*), in most cases it damages and then kills the cells and these cytopathic effects are obvious (*8, 9*).

probably increased by the practice of administering gamma globulin, the antibody-carrying blood fraction, to exposed women in the hope of protecting them against infection. The injection may provide just enough antibody to suppress symptoms without preventing infection. Gamma globulin may, on the other hand, somewhat decrease the risk of infection; data on this point are subject to contradictory interpretations. Certainly the number of infants born with congenital rubella in spite of the administration of gamma globulin to their mothers shows that globulin is not an adequate answer to the problem.

The most severe epidemic of German measles in 30 years swept across the U.S. in the late winter and early spring of 1964, producing congenital defects in perhaps 20,000 infants and causing fetal deaths in similar but unknown numbers. It happened that not long before the epidemic Stanley A. Plotkin of the Wistar Institute in Philadelphia, J. A. Dudgeon of the Hospital for Sick Children in London and Neva, Weller and Charles A. Alford, Jr., at Harvard had reported finding rubella antibody in serum taken from infants with typical signs of congenital rubella. The Harvard workers also found rubella virus itself still present in the throat secretions and the urine of several defective children. These findings made it possible to bring the tools of virology and immunology to bear in studies of fetal specimens and infants affected by the 1964 epidemic. Our group at the New York University School of Medicine asked physicians throughout the city to let us see newborn infants whose mothers had had rubella during pregnancy. During the fall and winter of 1964–1965 more than 200 infants were referred to us for physical examination, virus isolation and determination of antibody level.

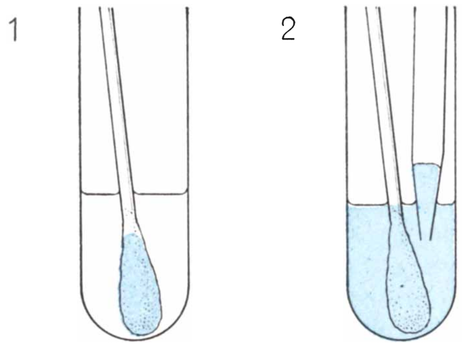
The children we saw had evidence of congenital disease involving a large number of different organ systems. The defects appeared singly and in all possible combinations. The infants with defects seemed to be generally debilitated: most of them weighed less than 5½ pounds and many weighed less than 4½ pounds. Congenital heart disease and cataracts, the abnormalities most frequently noted during the first month after birth, had in many cases not been recognized during the three to five days the newborn infants remained in the hospital nursery. The murmurs that lead one to suspect the most common cardiac abnormalities may not be present during the first days of life; the rubella cataract, which can be quite small at birth, was often first noticed by the mother after she brought the baby home from the hospital. Hearing loss is difficult to establish in infants and usually becomes apparent only after some months. The same is often true of brain damage involving even serious mental and physical retardation.

Certain defects were associated with rubella for the first time after the 1964 epidemic. One of the most striking is purpura caused by an extremely low platelet count, a condition that affected 70 of the first 200 babies we saw. These children as a group had a high incidence of other defects as well and have done poorly during the first year of life. Many of them had, in addition to the typical congenital symptoms, a number of conditions that had not been associated with rubella before, including hepatitis (inflammation of the liver), anemia and a bone disease. In the children that have survived, the purpura and lesser accompanying diseases seem to have cleared up spontaneously, suggesting that it may have been their transient nature that allowed them to remain undetected until this epidemic.

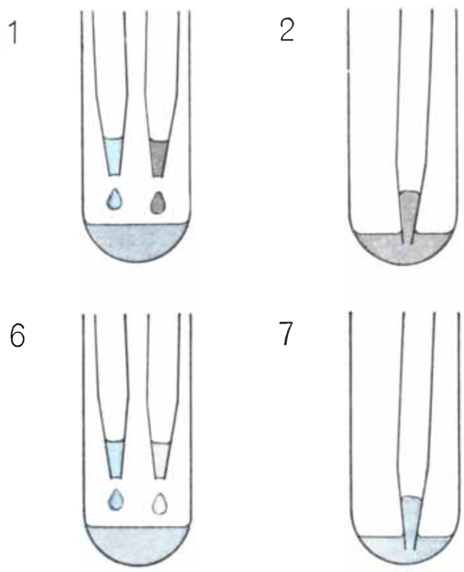
The most striking thing about congenital rubella is the chronic nature of the infection, in sharp contrast to the acute and self-limiting infection in the postnatal disease. The virus that infects the fetus is still present at birth and usually persists for some time after birth even though high levels of antibody are present in the infant's blood. The persistence of the virus in the presence of antibody that should neutralize it is surprising, but the fact is that processes involved in the maturation of immune mechanisms are poorly understood; study of this peculiar "experiment" of nature should yield new information on the immunological competence of the fetus and the newborn baby. Meanwhile the paradoxical persistence of rubella virus gives investigators a convenient and unusual diagnostic tool—a clear indication of the presence and location of rubella infection.

Many steps in the sequence of the infection have been documented. Virus present in the mother's bloodstream reaches the placenta (which provides blood to the developing embryo), infects it and then enters the fetal circulation. Timing is important. It is during the second through the sixth week of gestation that the embryonic organs are being formed; therefore infection is a major hazard to the heart and eyes at the time. By some time in the fourth month the fetus has acquired the ability to produce antibody and seems to be no longer susceptible to congenital rubella.

In a susceptible fetus the infection becomes widely disseminated and, as I have mentioned, it persists. Virus has been found in fetal tissue obtained by therapeutic abortions performed months after the mother had rubella. (Intrauterine tissue from the mother, interestingly enough, does not exhibit this chronic infection.) At birth most infants with congenital rubella still have detectable virus in their throat secretions, urine, cerebrospinal fluid and most tissues, and there is some indication that the most heavily infected organs show the most evidence of congenital damage.



INTERFERENCE TECHNIQUE is used to isolate a virus that has no marked cytopathic effects. A throat swab from a patient with suspected rubella, for example, is put in a

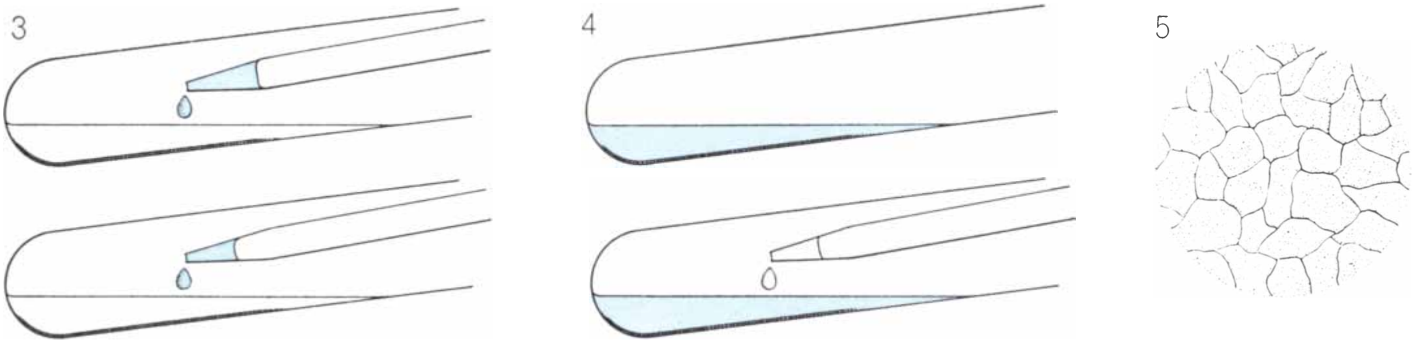


IDENTIFICATION OF VIRUS as rubella requires further testing. Some of the incubated virus reserved in the previous experiment (*4 in top drawing on these pages*) is

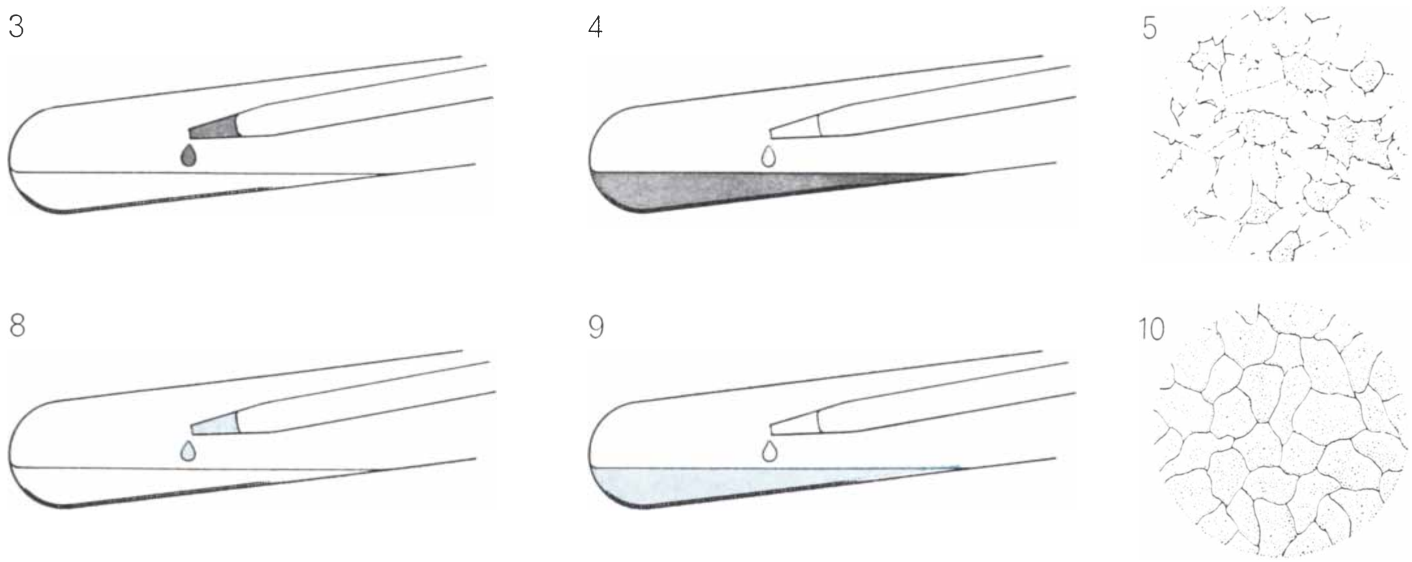
Rubella, in other words, is very different from such teratogens as thalidomide and radiation, which do their damage with one exposure in early pregnancy. The rubella virus probably does different things to the fetus at different times during gestation. It persists to cause an acute illness in the newborn involving such conditions as purpura and hepatitis. Thereafter the incidence of infection decreases slowly. Our preliminary data indicate that among infants with congenital rubella, virus was detected in 63 percent of one group tested during the first month of life, in 31 percent of a group aged five to seven months, in 7 percent of a group 10 to 13 months old and in none of a group of children three to 15 years old. The infants who carried the virus for the longest time seemed to be those with the most serious involvement. Their weight gain was poor and they showed evidence of increasing mental and physical retardation. It seems, in other words, that the virus may continue to do damage after birth. Throughout this period the children have antibody levels comparable to that of their mothers. Detectable antibody persists for several years and may continue to be present for life. Attempts are now being made to correlate the clinical history of these children with the trend of their virus level and antibody response.

Infants with virus in their throat secretions and urine can spread their infection, and susceptible doctors, nurses and members of the family have developed rubella after intimate exposure. Infants known to be infective can be isolated from direct contact with women who may be in the early stages of pregnancy, but some infected infants may be normal in appearance just after birth and may therefore not be recognized as sources of contagion. They are probably a hazard primarily to hospital personnel. An intriguing speculation that they may also represent a reservoir of infection between epidemics has not yet been confirmed; we have been able to record only 22 cases attributable to such infants.

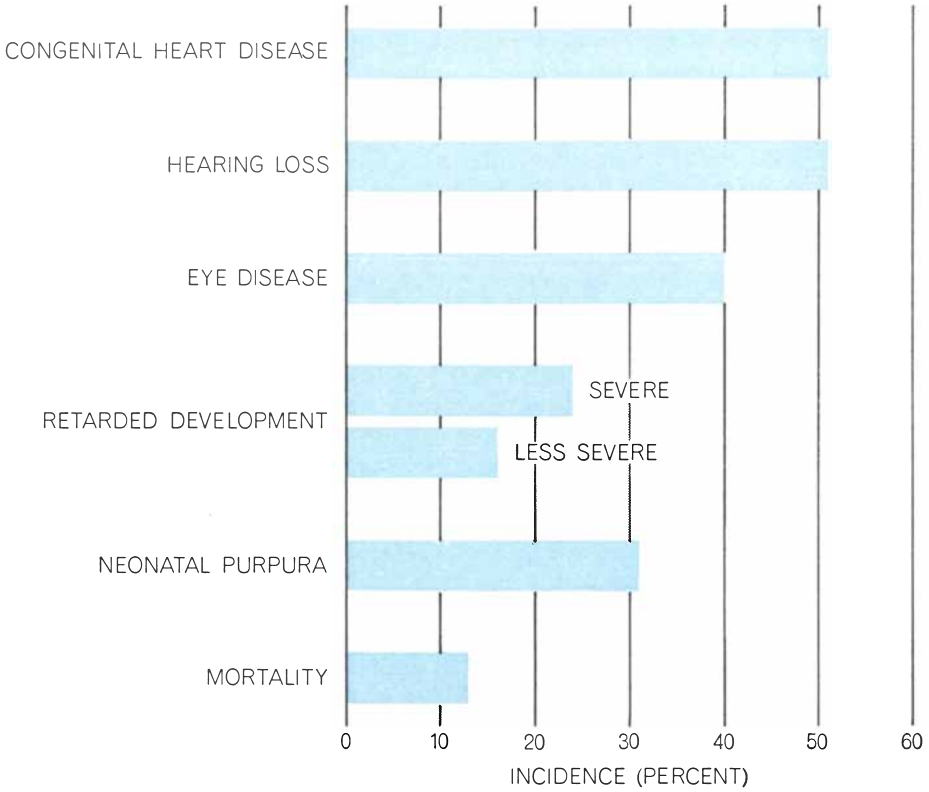
Investigations in Sweden and Britain indicate that infants with minor defects such as slight hearing loss have progressed well: their mortality rate in the first two years of life was not significantly greater than that of a control group. The outlook for more severely affected infants is different. The mortality rate for our group of infants with purpura exceeded 35 percent within the first year and the rate for all the chil-



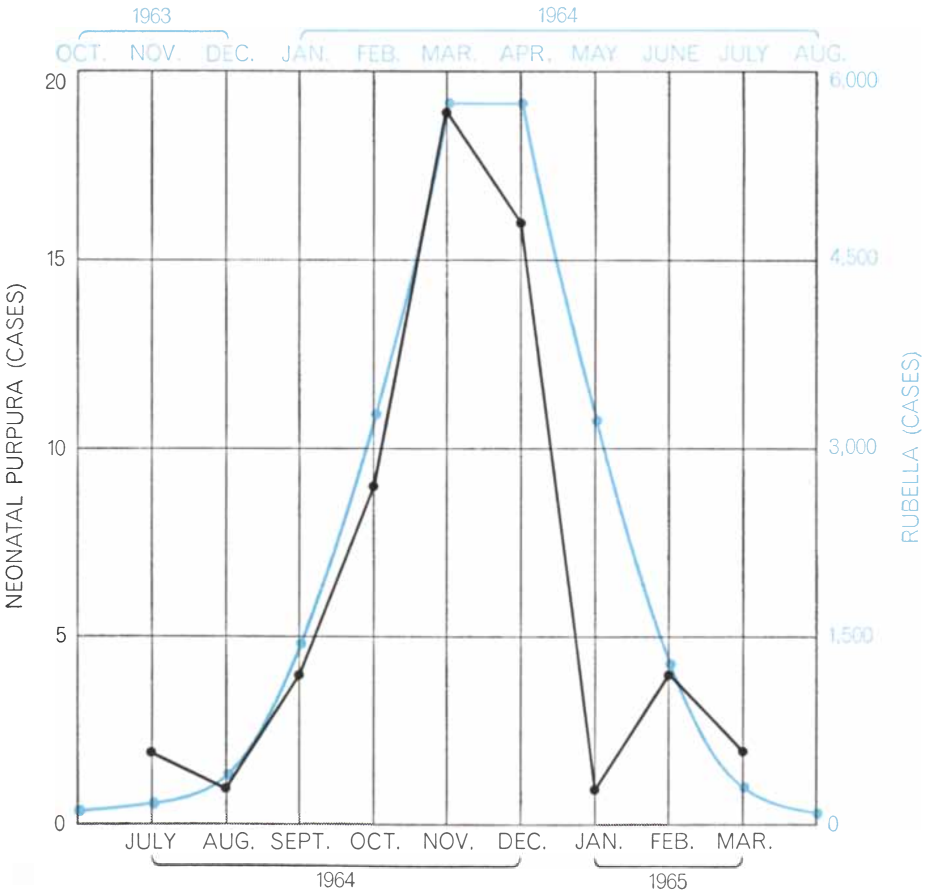
medium (*1*) and some of the suspension is withdrawn (*2*), inoculated into monkey-cell culture tubes (*3*) and incubated. After 10 days echovirus is inoculated into one tube and the other tube is reserved (*4*). If no cytopathic effects are observed (*5*), the echovirus has failed to infect the cells. It was "interfered with"—perhaps by interferon, a substance produced by cells when they are stimulated by a virus infection. The throat-swab specimen must therefore have contained a virus that infected the monkey cells.



mixed with serum containing known rubella antibody (*1*). A sample of the mixture is withdrawn (*2*) and inoculated into fresh monkey kidney cells (*3*). If the virus from the throat swab was indeed rubella virus, rubella antibody neutralizes it and interferon is not formed; now the echovirus that is added (*4*) can infect the cells, producing cytopathic effects (*5*). (If the virus had not been rubella, the antibody would have had no effect.) A parallel experiment with serum containing no rubella antibody serves as a control (*6–10*).



MAJOR MANIFESTATIONS of congenital rubella are shown as observed by the New York University School of Medicine rubella study group in 275 infants born with the disease after the 1964 epidemic. The manifestations were seen in different combinations.



PURPURA, a bleeding condition that produces spots in the skin, is a recently recognized symptom of congenital rubella. The association of neonatal purpura with the 1964 rubella epidemic is shown. The colored curve traces the incidence of rubella in New York City. The black curve gives the distribution of purpura cases seen eight months later at N.Y.U.

dren we saw was a little more than 10 percent. The infants whose mothers had rubella in early pregnancy but who have no detectable evidence of congenital rubella seem to fall into two groups. Some of them show persistently high levels of rubella antibody; they must therefore have been infected, but they were for some reason not harmed by the disease. Others were presumably never infected at all—why, we do not know.

The outlook for rubella-damaged infants varies with the specific defect. One heart defect, patent ductus arteriosus, can be repaired quite readily. Septal defects—openings between the left and right chambers of the heart—can be closed by more complicated open-heart surgery. The rubella cataract is more difficult to repair than adult cataracts, and children with cataracts in both eyes may have little vision. There is no specific treatment for the deafness caused by rubella, but the nerve damage is usually not complete, so that hearing aids and auditory training can be quite helpful. The outlook for infants with severe brain damage is very poor. Since brain damage seems to accompany prolonged persistence of the virus, it is these infants who provide the greatest stimulus to current efforts to find ways of combating the chronic postnatal infection.

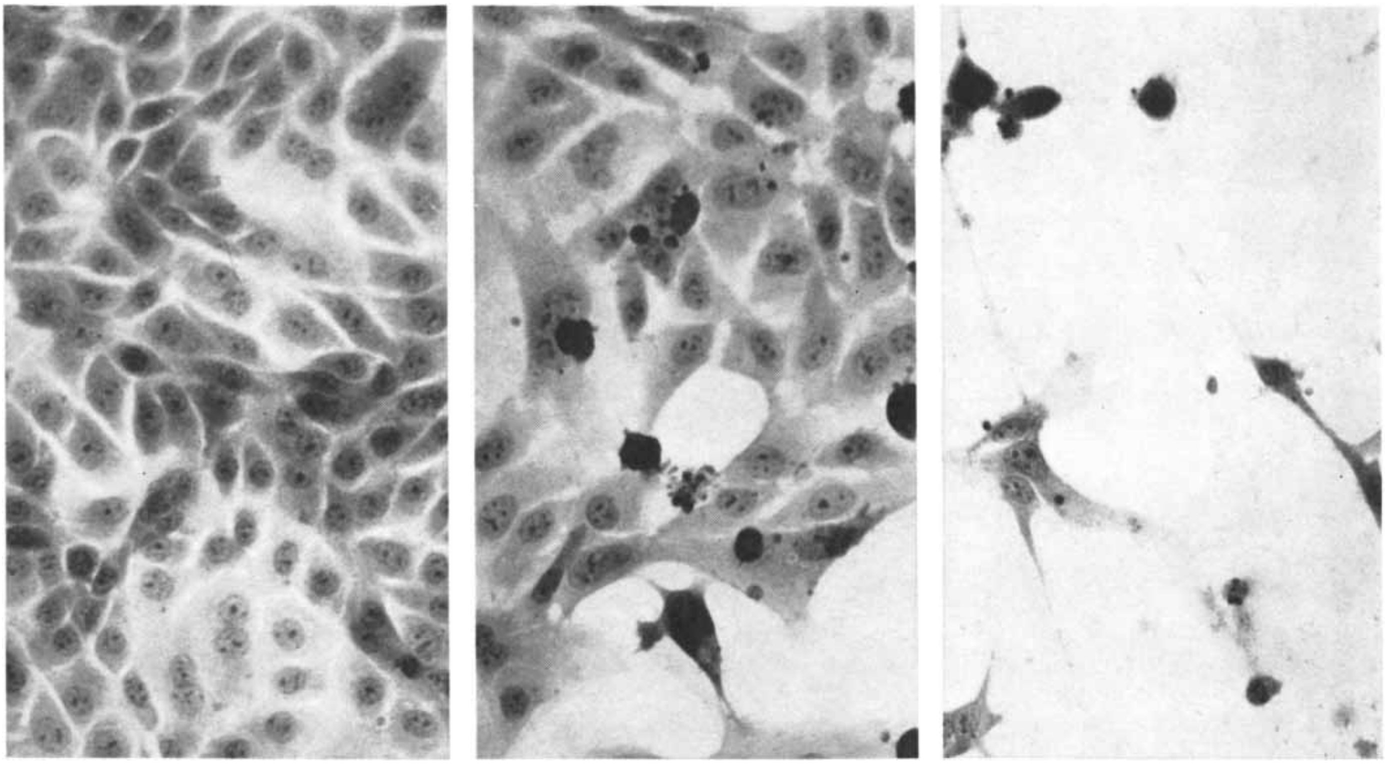
The varied and severe manifestations of congenital rubella observed after the 1964 epidemic suggested to some people that the epidemic was caused by a new and more virulent strain of virus. There is no evidence, however, that there are naturally occurring variations in rubella virus (as there are in influenza, for example). The postnatal illness observed in 1964 followed the usual pattern. The new reports of congenital defects probably reflected the magnitude of the epidemic, the availability of diagnostic tests and increased communication among investigators and physicians.

The actual mechanism whereby the rubella virus causes congenital abnormalities is not known, but two recent studies suggest a specific direction for research. At the Wistar Institute, Plotkin, André Boué and Joelle G. Boué found that infection with rubella virus inhibited the division of human embryonic cells grown in a tissue culture and increased the number of breaks in their chromosomes. Then Richard L. Naeye of the University of Vermont School of Medicine and William A. Blanc of the College of Physicians and Surgeons discovered that many of the organs of infants who died with congenital rubella were undergrown: they had fewer than the normal number of cells. These results suggest that the rubella virus may somehow inhibit the multiplication of certain kinds of human cells.

The obvious solution for the rubella problem was the development of a vaccine that would largely eliminate the disease from the entire population. On the face of it this should not have been difficult. In poliomyelitis and measles the naturally occurring virus had to be attenuated to produce an acceptably mild case while nevertheless stimulating the production of antibody. Rubella is a conveniently mild illness to begin with, however. The first experimental rubella vaccines produced good antibody responses and also mild cases of German measles that served as indicators of a successful vaccination. These vaccines were unacceptable, however, because the vaccinated person was infective: he could transmit his disease to susceptible contacts. This feature (which is desirable in live polio vaccine because it spreads the mild disease and therefore confers widespread immunity) could be disastrous in rubella, since even the mildest case is a severe threat to pregnant women. The problem was to attenuate the virus enough so that it would not produce an infectious case but not so much that it would fail to stimulate the production of antibody. A number of laboratories concentrated on this task.

Just this past April, Parkman and Harry M. Meyer, Jr., of the Division of Biologics Standards of the National Institutes of Health described a live, attenuated rubella vaccine that did not spread to susceptible contacts. This strain of virus had been cultured 77 times in succession in the kidney cells of the African green monkey and was clearly different from the unattenuated virus. It produced much more readily the cytopathic effects in rabbit kidney cells that had been observed in 1963 by Kevin McCarthy, C. H. Taylor-Robinson and Sally Pillinger of the University of Liverpool. And it evoked a two- to 16-fold increase in interferon production over the unmodified strain. When the attenuated virus was inoculated into monkeys, it was not transmitted to their cagemates. After extensive safety testing an initial vaccine trial was carried out with 16 rubella-susceptible girls who lived in a single cottage of an institution for the mentally retarded. Half were given vaccine and half remained unvaccinated to serve as controls. The vaccine produced no symptoms and was not transmitted to the girls who were not inoculated. Those who were vaccinated did develop antibody to rubella. On the basis of this trial more children were vaccinated in the same institution. When Parkman and Meyer reported their work, 32 out of 34 vaccinated children had demonstrated an antibody response and—most important—none of their 30 intimate contacts had become infected.

The Parkman-Meyer preparation represents a significant step toward the ultimate production of a safe, effective rubella vaccine because even their preliminary data shows that the rubella virus was markedly attenuated for humans by continued passage in tissue culture. The end is still not in sight, however. A small quantity of rubella virus was cultured from the throats of a few of the vaccinated children, and this may represent a source of potential contagion. Extensive testing may indicate that it is necessary to eliminate this possibility by further attenuation. The experience already gained in the development and administration of such live-virus vaccines as those for polio and measles will provide guidelines, however, for the production and distribution of an effective and safe rubella vaccine. It is not unreasonable to hope that a vaccine will be ready before the next major epidemic of rubella.



ATTENUATED VIRUS developed by Paul D. Parkman and Harry M. Meyer, Jr., of the National Institutes of Health can be recognized by its marked cytopathic effects in a culture of rabbit kidney cells. The effects of unattenuated virus are less striking. The photomicrograph at the left, made by Parkman and Meyer, is of an intact lawn of rabbit cells. The one in the middle shows cells after infection for five days with the attenuated rubella virus. After 10 days (*right*) the rabbit-cell lawn has been markedly disrupted.

Modern Cryptology

The making and breaking of ciphers and codes has always played a large role in the affairs of nations. Today cryptanalysts gather secret intelligence with the aid of electronics and mathematics

by David Kahn

In a world where nations have long made a practice of gathering information that other nations wish to conceal, the most effective means of obtaining such information has almost certainly become the breaking of codes. Today so much secret information is contained in coded radio messages that cryptanalysts can intercept more intelligence than secret agents can steal. And since this intelligence, cryptanalyzed under conditions of rigorous surveillance, consists of the sender's actual words, it is far more reliable than information received through intermediaries.

Obviously information about such activities is itself secret, but enough is known about them to indicate their scale. The U.S. Department of State sends and receives some 10 million enciphered words a month. The National Security Agency, which makes and breaks codes and ciphers for the U.S., is reported to have 12,000 employees and an annual budget twice as large as that of the Central Intelligence Agency.

Codebreaking has frequently influenced the course of history. In World War I the British solved German diplomatic codes and thus were able to read the notorious Zimmermann telegram, in which Germany offered to give Mexico three American states if she would enter the war on Germany's side. Most historians agree that this revelation gave the U.S. its final push into the war. On the eastern front repeated German successes in solving Russian ciphers accelerated the downfall of the Czarist armies. In World War II American cryptanalysts broke the principal Japanese naval code, which contributed greatly to the U.S. victory at the decisive Battle of Midway. The breaking of the Japanese merchant-marine code enabled U.S. submarines to take a high toll of Japanese shipping.

Secret messages that have resisted the efforts of cryptanalysts have also shaped events. In 1940 and 1941 the Russian intelligence network headed by Richard Sorge in Japan transmitted thousands of five-digit cipher groups that the Japanese intercepted but could not break. These messages told the Russians that Japan was not going to attack the U.S.S.R. but was going to move south. This information enabled the Russian commanders to withdraw army divisions from the East and use them to defend Moscow.

Secret communications are known from the beginnings of Western civilization. Learning that the Persian king Darius was about to attack Greece, a Greek living in Persia scratched a warning message on a wooden writing tablet, then covered the tablet with wax so that it looked like a fresh writing surface. He sent it to Sparta, where Gorgo, the wife of the Spartan king Leonidas, guessed that the blank wax writing surface covered something important, scraped it off and discovered the message that enabled the Greeks to prepare for Darius' attack—and to defeat him.

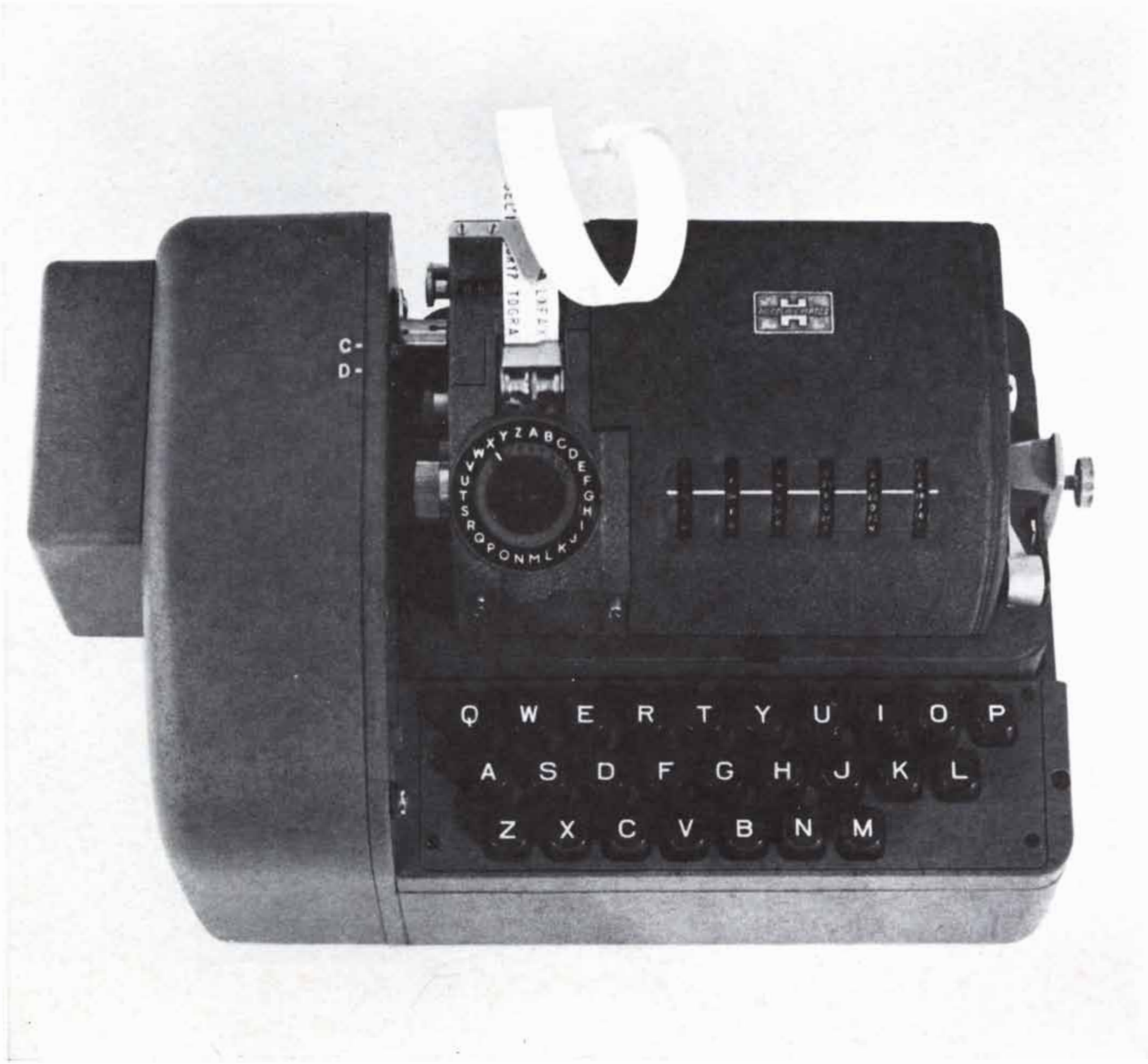
Techniques of this kind, which seek to hide the very existence of a secret message, are called steganography. Other forms of steganography are invisible inks, radio systems that emit long messages in a single short spurt, jargon code systems in which innocuous words have secret meanings, and systems in which only certain letters or words of a message signify anything, the others being mere padding to make the whole sound harmless. Steganography differs from cryptography, which makes no attempt to conceal the presence of a secret message. Cryptography aims at making the message unintelligible to outsiders by various transformations of the "plaintext," the cryptographer's term for the message to be transmitted.

Cryptography transforms the plaintext in two basic ways: transposition and substitution. In transposition the letters of the plaintext are jumbled, or rearranged. For example, the word *secret* might be transposed into ETCRSE. In substitution the letters of the plaintext are replaced by other letters, numbers or arbitrary symbols. *Secret* might be rendered as TFDSFU, or as 19 5 3 18 5 20. Transposition and substitution can be combined.

Substitution systems, which are much more diverse and more widely used than transposition systems, rest on the concept of the cipher alphabet. Such an alphabet provides a list of equivalents for converting letters into secret form [*see upper illustration on page 42*].

It is well known that this elementary system can be readily broken, provided that the message consists of more than just a few words. The reason, of course, is that the various letters of every written language have a remarkably constant frequency of occurrence. In any sufficiently large sample of English text about one out of eight letters will be an *e*, the most frequent letter in English, one out of 11 letters will be a *t*, the second most frequent, and so on [*see illustration on page 41*]. This makes it possible for the cryptanalyst to identify the plaintext letters under their ciphertext disguises. He can assume that the most frequent ciphertext letter probably stands for *e*, the second most frequent for *t*, and so on.

The phenomenon of frequency also holds for digraphs, or combinations of

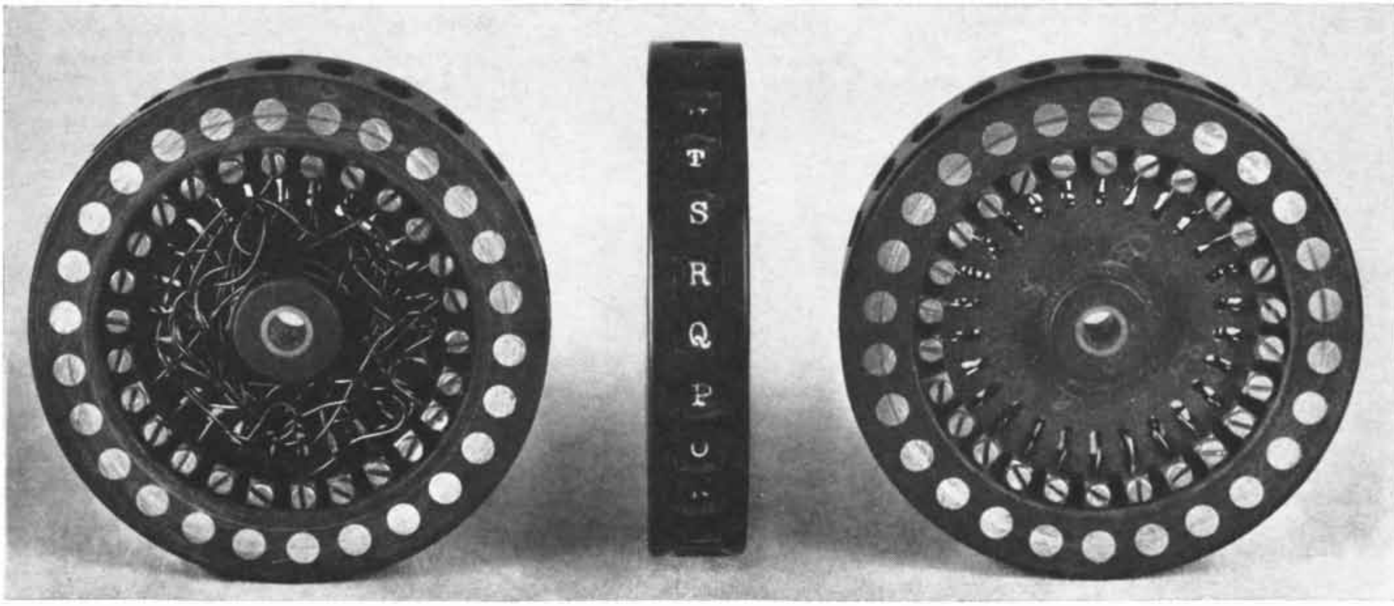


MODERN CRYPTOGRAPHIC MACHINE is a recent version of a device invented in 1934 by Boris C. W. Hagelin. Its innards consist of six wheels and a drum, which combine to generate the key. The key consists, in effect, of successive movements of the mechanism that slide the cipher alphabet through a variable number of positions after each letter is enciphered. The key is duplicated by an identical machine at the receiving end and is varied by changes in settings made by prearrangement or according to instructions sent as part of the message. To encipher, one types the message on the keyboard. Each enciphered letter is printed out, along with its "plaintext" equivalent, on a double tape (*top*). To decipher, one types the ciphertext and the plaintext is printed out. This machine can be teamed with another that automatically prepares or reads a punched tape that is compatible with a high-speed teletypewriter.

a

b

PRINTED TAPES show the output of the Hagelin cryptographic machine when it is enciphering and deciphering. The top line of the enciphering tape (*a*) shows what the cipher clerk is typing: the plaintext message (with *W* arbitrarily used to indicate breaks between words), automatically broken into five-letter groups. The next line shows the encipherment. The deciphering tape (*b*) shows the string of cipher letters and, below them, the deciphered message. (*W*, the word-break indicator, is omitted from the plaintext.)



ROTOR MACHINE (*top*), prototype of today's most advanced cryptographic machines, was invented in 1917 by Edward H. Hebern. This is a 1928 model. The 26 contacts on one side of a rotor (*bottom*) are wired in random fashion to contacts on the other side; the set of rotors provides an electrical path through what is in effect a series of cipher alphabets. A cipher clerk inserts the rotors in a prearranged order, sets them in prearranged positions and enciphers by pressing keys for a letter of the plaintext and noting the cipher letter illuminated on the panel. After a letter is enciphered, rotors turn to establish a new electrical path, changing the cipher alphabet. To decipher, a clerk at the receiving end presses keys for the cipher letters and reads off the plaintext.

two letters; in English the most frequent digraph is *th*. Starting with such assumptions, the cryptanalyst can form possible word skeletons such as *the-e*. These he can flesh out by guessing what the missing letters might be. With *the-e* he might try *r* or *s* as the missing letter, seeing which one makes sense elsewhere in the message.

Such is the basic form of substitution cryptanalysis. It has been known and practiced in the Western world for more than 500 years, and in a sense the entire history of cryptology may be viewed as the efforts of cryptographers to defeat it and of cryptanalysts to reduce each new system to terms in which this method can be applied.

One of the cryptographer's earliest and most obvious devices was to use more than one substitute for each letter. The cipherer might replace *e* by any of several homophones, or multiple substitutes, for example 16, 23, 98 or 55. *Enemy* might thus appear as 16 41 98 77 62 in one part of the message and as 23 41 16 77 62 in another. Cryptanalysts soon discovered that when the same word was enciphered two or three times, the homophones would differ while the other substitutes remained constant. This enabled them to reduce the homophones to equivalent terms and proceed with the basic method of solution.

About 1466, in a little treatise written after the pope's secretary asked him during a walk in the Vatican gardens to turn his mind to cryptology, the Italian architect Leo Battista Alberti devised a new cryptographic principle that lies at the basis of most modern ciphers. Called polyalphabeticity, it employs a number of cipher alphabets for a single message. Alberti generated his several alphabets from a single primary one by sliding them in relation to the conventional alphabet. This produces a table of as many alphabets as there are letters, each with a different keyletter [*see lower illustration on next page*]. A cryptogram produced by Alberti's method defeats the basic method of solution of monoalphabetic ciphers because the cipher equivalents for the plaintext letters vary.

The legitimate recipient of a polyalphabetic cryptogram would be as baffled as the cryptanalyst if he did not know which alphabet was used for each letter of the message. Alberti inserted keyletters at intervals in his cryptogram to indicate which alphabet would be used for the next few words. A Benedictine abbot, Johannes Trithemius, improved on this system by using a different alphabet for each letter and running through all the alphabets in order; this is called a progressive system. In 1553 Giovanni Battista Belasco devised a simple and secure way to indicate the alphabets in use. He used a keyword that could be easily remembered and as easily changed. To encipher a message he wrote this keyword repeatedly over the letters of the plaintext; each letter of the keyword then designated the cipher alphabet that was to encipher the letter of plaintext below it. To decipher the message the recipient would simply reverse the process.

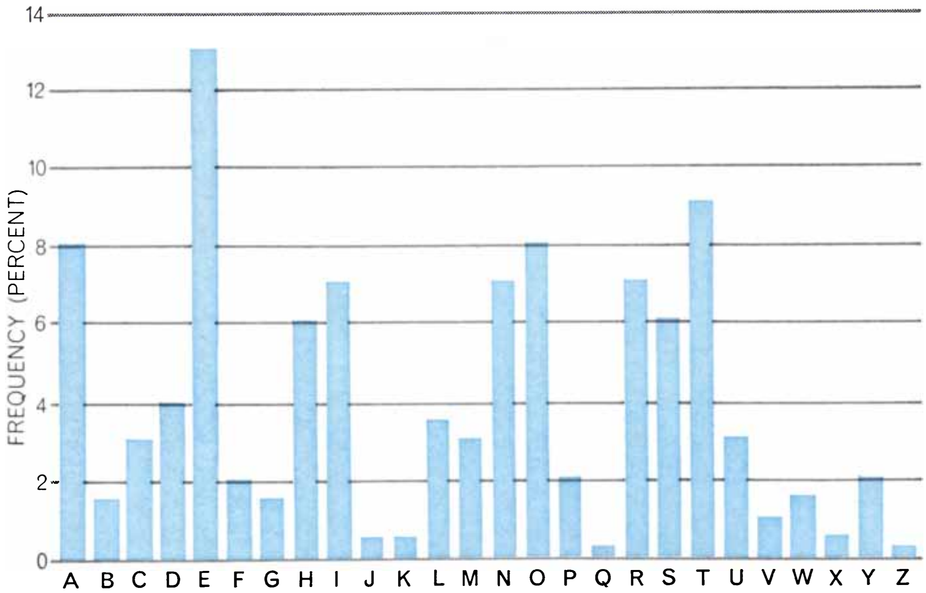
For some 300 years this cipher system remained essentially impregnable. Because it was tedious and subject to error, however, cryptographers clung to elaborate homophonic systems that employed substitutes for digraphs, syllables and common words and names. The invention of the electric telegraph made prompt corrections feasible and also created a demand for flexible ciphers, a demand that polyalphabetic systems fitted admirably. Probably as a result of this intensified interest Friedrich Kasiski, a retired German infantry major, discovered and in 1863 published the general method for the solution of polyalphabetic ciphers with repeating keys.

Kasiski's solution depends on the fact that like causes produce like effects. When the same portion of the repeating key is used to encipher a repeated bit of plaintext, the enciphered text will be the same in both cases. For example:

Key:	LABLABLABLAB
Text:	*attackatdawn*
Cipher:	LNYLSVLNCLPW

Here *at* occurs twice in the plaintext and happens to be enciphered both times by the cipher alphabets represented by the keyletters LA [*see lower illustration on next page*]. The L alphabet transforms *a* into L and the A alphabet transforms *t* into N. Because the key was repeated several times before it was used to encipher the second *at*, the distance between the repeated LN's will indicate both the number of times the key has been repeated and its length—the latter a datum of great value. If the cryptanalyst can find enough repetitions, he can determine what factor is common to the distances between them. For instance, if he finds repetitions that stand 18, 36, 42 and 60 letters apart, he can see that all these numbers are multiples of six and therefore that the keyword is six letters long. He can then sort the letters of the cryptogram into six groups, each of which has been enciphered by a single keyletter, that is, in a single cipher alphabet. The cryptanalyst can now analyze each group according to the principles of letter frequency, just as he would an ordinary monoalphabetic cipher.

Kasiski's technique for breaking a polyalphabetic cipher stimulated cryptographers to devise more ingenious enciphering schemes. They proposed



FREQUENCY CHART gives the relative usage of the letters of the alphabet. In a typical sample of English, for example, about 13 percent of the letters will be *e*'s, 7 percent *n*'s, 2 percent *p*'s. The frequency is remarkably constant and is the main tool of the cryptanalyst.

using keys that did not repeat ("running keys"), such as the text of a book. In 1883, however, a French language teacher named Auguste Kerckhoffs devised the general solution for polyalphabetic ciphers. His technique is called superimposition.

The cryptanalyst hunts among his intercepted messages for two or more identical ciphertext fragments. These would indicate that the same portion of running key has enciphered a repeated fragment of a plaintext. Another way to discover where the same portion of running key has been used to encipher two or more messages is by solving the system of indicators by which one cipher clerk tells another where in the keybook he is starting the running key.

The cryptanalyst then writes out the messages, lining them up so that parts that have been enciphered by the same portion of the running key stand one below the other [*see illustration on opposite page*]. This will assemble into columns the letters that have been enciphered by the same key letter; the result is columns of letters that have each been enciphered monoalphabetically. The cryptanalyst subjects each column to frequency analysis and thereby recovers the plaintext.

Given columns of sufficient length, Kerckhoffs' superimposition method can solve any polyalphabetic cipher—except one. And that is the one cipher that is theoretically unbreakable.

By 1914 several officers at the Army Signal School at Fort Leavenworth, Kan., primarily Captain Parker Hitt, had observed that a key that never repeated would not succumb to superimposition. Such a key would still be vulnerable, however, if it consisted of understandable language. This was shown in 1917 by William F. Friedman, who solved cryptograms produced with a nonrepeating but coherent running key. In effect he cross-solved for both the key and the plaintext, working one against the other. The Hitt and Friedman lines of work converged in the conclusion that the only unbreakable cipher is one with a key that never repeats and contains neither meaning nor pattern.

Lieutenant Joseph O. Mauborgne of the Army Signal Corps came to this conclusion when in 1918 he added the concept of a patternless, endless key to a cipher machine invented by Gilbert S. Vernam of the American Telephone and Telegraph Company. The resulting ma-

PLAINTEXT LETTERS	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
CIPHER LETTERS	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P

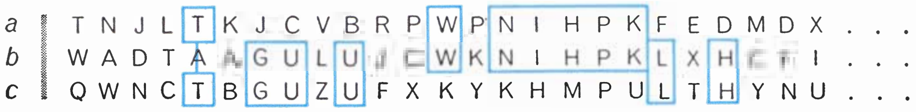
SUBSTITUTION, the basis of most ciphers, rests on a cipher alphabet that provides a list of letters, each equivalent to a different letter of the plaintext. With this alphabet, for example, *enemy* would be enciphered as CHCME; SWC would decipher as *foe*.

PLAINTEXT ALPHABET

KEYS		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
1	L	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P
2	B	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L
3	Q	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B
4	A	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q
5	C	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A
6	S	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C
7	R	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S
8	D	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R
9	T	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D
10	O	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T
11	F	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O
12	V	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F
13	M	M	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V
14	H	H	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M
15	W	W	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H
16	I	I	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W
17	J	J	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I
18	X	X	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J
19	G	G	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X
20	K	K	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G
21	Y	Y	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K
22	U	U	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y
23	N	N	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U
24	Z	Z	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N
25	E	E	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z
26	P	P	L	B	Q	A	C	S	R	D	T	O	F	V	M	H	W	I	J	X	G	K	Y	U	N	Z	E

CIPHER ALPHABETS

POLYALPHABETIC SYSTEMS provide a number of different sets of substitutes for letters of the plaintext alphabet (*top*). This alphabet table has 26 alternative cipher alphabets, each designated by a number or letter (*left*). A keyword can be used to indicate the alphabet that enciphers each successive letter. If the keyword is RUN, for example, the alphabets labeled *R*, *U* and *N* are used.



SUPERIMPOSITION of messages enciphered by a long key makes it possible to solve them all. Here messages *a* and *b* have been lined up by the repetition of NIHPK, messages *b* and *c* by statistical tests based on one-letter coincidences. This superimposes in columns the letters that have been enciphered by the same alphabet. Frequency analysis does the rest.

chine, based on the teletypewriter, carried its key in the form of a perforated teletypewriter tape; the pulses represented by the holes in this tape were automatically added to the teletypewriter pulses of the plaintext. At the receiving end a machine with an identical key tape subtracted the key pulses from the pulses of the enciphered message. Vernam's machine was the first that automatically enciphered and transmitted in a single operation. This automatic feature fitted it admirably for handling the interminable lengths of random key required to make the cipher unbreakable. An outsider could read the message only if the key tape itself fell into his hands.

Could not the cryptanalyst try every possible key until he obtained an understandable message? The answer is no. Suppose he were given a four-letter cryptogram and tried deciphering it with every four-letter key from AAAA to ZZZZ. He would find at the end that he had simply compiled a list of all the four-letter words in every language—together with much gibberish—and since he would have no reason to prefer any one of the keys to any other, he could no more pick out the correct plaintext from his list than he could from a dictionary.

Why, then, is this unbreakable cipher—the "one-time system"—not in universal use? Mainly because it would require too great a volume of key, equivalent in length to all the messages a nation might send during its existence. Secondarily because, in a fluid military situation, signal posts cannot cancel keys used by other posts in order to prevent the employment of a key twice. Some keys would inevitably be used two or more times, thereby leaving intercepted messages open to solution.

In diplomatic and secret-agent communications, however, one-time systems play an important role. Germany was the first nation to adopt such a system when early in the 1920's the Foreign Office began using "one-time pads." These were random numbers printed on sheets that were bound into pads; each sheet was torn off and discarded after a single use. The U.S.S.R. introduced one-time systems into its diplomatic correspondence and its secret-intelligence efforts in the 1930's. During World War II, Sorge obtained the keynumbers for his one-time system from a German book of trade statistics. Since the war Russian agents appear to have used the pure one-time system. Peter and Helen Kroger, arrested as Russian agents in Britain in 1961, had their key numbers listed on scrolls about the size of a cigarette butt, hidden inside a cigarette lighter. Rudolf Abel, the Russian agent captured in the U.S., used a postage-stamp-sized book of key numbers, printed partly in black and partly in red, presumably to distinguish enciphering keys from deciphering keys. Other users of one-time systems include the U.S. Department of State, the United Nations and the International Monetary Fund. The "hot line" between Washington and Moscow safeguards its messages with a mechanism of the Vernam type that uses a one-time tape.

Nevertheless, the practical difficulties of the one-time system have led cryptographers to employ other cipher systems. The best of the common modern systems is the rotor machine, invented first in 1917 by Edward H. Hebern of the U.S. and independently within the next few years by Hugo Koch of the Netherlands, Arvid G. Damm of Sweden and Arthur Scherbius of Germany.

The rotor of such a machine consists of a disk of hard rubber or plastic, usually about three inches in diameter, with 26 electrical contacts on one face that are wired in random fashion to 26 on the other face. Several rotors—up to eight in some models—turn on the same axis [*see illustration on page 40*]. When the cipher clerk presses a plaintext letter on the machine's typewriter keyboard, an electric current travels in a tortuous path through the series of rotors and emerges at the cipher letter. After each letter has been enciphered, one or more of the rotors turns one or more spaces, establishing a new network and therefore new cipher substitutes.

The effect of eight rotors is to pile eight polyalphabetic ciphers one on the other with the result that 26^8 letters—more than 200 billion—can be enciphered before the first cipher alphabet repeats. A cryptanalyst who wants to apply a solution of the Kasiski type to messages enciphered by an eight-rotor machine would need to have 40 or 50 times 26^8 letters in order to have enough letters enciphered by each alphabet to permit a frequency analysis. The volume requirement would be about the same for a solution by Kerckhoffs' method of superimposition.

Because such a general solution to a rotor cipher would require more text than would ever be available, the cryptanalyst must fall back on special solutions. He guesses at, or obtains in some fashion, part of the plaintext of a message. This is not too hard: The text of a diplomatic note handed to the Secretary of State can be compared with the enciphered version, and a military message to a forward headquarters that is followed by an attack may well have contained the order for the attack. Next the cryptanalyst converts the rotor wiring into algebraic terms, whose quantities are of course still unknown to him. This he does by enumerating the number of places between an input contact and an output one. For example, a wire from input contact No. 3 to output contact No. 10 would make a displacement of seven. Then, selecting two encipherments that result in the same cipher letter, he is able to set up a series of simultaneous equations in which the plaintext letter (in numerical form) plus the unknown quantities of the rotor displacements equal the cipher letter (also in numerical form). Given enough text to work with, these equations can be solved and the wiring of the rotors reconstructed. Friedman, in the 1920's, was the first to solve a rotor machine—Hebern's.

In the course of that work Friedman perfected a statistical test that revealed when two or more cryptograms were superimposed in such a way that the columns of letters were enciphered monoalphabetically, as would be required to apply Kerckhoffs' method. If they were not correctly superimposed, the cryptanalyst could shift one of the cryptograms one space and repeat the test. The test is of great practical importance, but more significantly it introduced the powerful arsenal of statistics and mathematics into cryptology,

	7	2	9	6	0	1	3	5	8	4
	o	r	i	e	n	t	a	l		
8	b	c	d	f	g	h	j	k	m	p
4	q	s	u	v	w	x	y	z	/	.

e	n	e	m	y	t	o	t	e	s	t	/	1	2	/	a	.	b	o	m	b	s	.
6	0	6	88	43	1	7	1	6	42	1	48	111	222	48	3	44	87	7	88	87	42	44
4	3	4	48	56	1	4	4	[illegible]	17	8	81	203	342	19	3	61	18	8	34	36	61	68
0	3	0	26	99	2	1	5	0	59	9	29	314	564	57	6	05	95	5	12	13	03	02

03026 99215 05992 93145 64576 05955 12130 302

ENDLESS KEY, whether in the form of pulses from a tape or a nonrepeating series of numbers, can make a cipher unbreakable. This cipher, of a type used by Russian secret agents, first transforms the plaintext into numbers according to a keysquare (*top*). This converts the eight letters of the keyword (ORIENTAL) into single digits and the 18 other letters of the alphabet, the period and the diagonal (which is used to indicate a switch from letters to numbers and back again) into pairs of digits like coordinates. Then the key, a nonrepeating series of digits (*color*), is added to the cipher numbers (using noncarrying addition) to make the final ciphertext, which is broken into five-digit groups for transmission.

opening the way to the many sophisticated analytical methods in use today.

This test helped Friedman and a team of Army cryptanalysts solve by August, 1940, the rotor-like Japanese diplomatic cipher machine called Purple, which yielded so much information about Japanese intentions before Pearl Harbor and afterward. During World War II the U.S.S.R. solved the German four-rotor machine Enigma (designed by Scherbius), probably using the basic method of rotor solution.

In the past 20 years rotor machines have become far more sophisticated than Purple and Enigma. The complexity of the simultaneous equations that must be handled to break the cryptograms produced by the new machines is so great that cryptanalysts must use electronic computers. In addition, the volume of cryptanalytical work has grown so large that the National Security Agency is believed to have more computers than any other organization in the world. It uses them not only to break ciphers but also to help develop them. To determine which of several cryptographic variations affords the greatest security, cryptographers can make mathematical models of them and use the computers to test them.

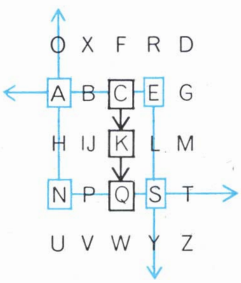
In addition to one-time systems and rotor systems, a third polyalphabetic system, simpler and cheaper but less secure than the other two, enjoys considerable popularity. Invented in 1934 by Boris C. W. Hagelin, a Swedish mechanical engineer, the system in effect is a gear with a variable number of teeth that drives a cipher alphabet through a variable number of places. Hagelin's device generates variations in such a way that it will encipher 2.8 billion letters before repeating. An earlier model of the Hagelin machine was used by the U.S. Army for middle-echelon communications during World War II. The Hagelin firm today sells its machines to some 60 nations.

All these systems encipher one letter at a time and are therefore called monographic. Polygraphic systems, which encipher two or more letters at a time, also exist. Probably the best-known digraphic system is the Playfair, devised by the 19th-century British physicist Sir Charles Wheatstone, probably to provide privacy for messages sent over the electric telegraph he had invented.

Named for Wheatstone's friend Lyon Playfair, the cipher utilizes a five-by-five array of letters to encipher two letters at a time [*see bottom illustration at left*]. Each two-letter cipher group depends on its plaintext pair as a whole and not on its individual members. Thus *th* might encipher to AB, whereas *ti* might become OK. The arrangement of letters within the array constitutes the key. The British used the Playfair as their field cipher during part of World War I.

Polygraphic systems can offer greater security than monographic ones because they can resist frequency analysis better. A digraphic cipher alphabet will contain 26^2, or 676, letter pairs. This means the cryptanalyst must distinguish among 676 elements instead of 26, and the characteristics of the elements are less pronounced. Whereas the difference in frequency between the most common single letter in English (*e*) and the next most common (*t*) is 3 percent, the difference between the most common digraph (*th*) and the second most common (*he*) is no more than .5 to .75 percent. The difference narrows progressively for the less frequent digraphs.

It follows that systems enciphering several letters at a time should offer even more security than a digraphic system. In 1929 the American mathematician Lester S. Hill invented an algebraic polygraphic system that can encipher any number of letters at a time. It transforms the letters into numbers and uses them as the variables in a set of simultaneous equations. The constants of these equations constitute the key of the cipher; the solutions of the equations constitute the text of the cipher. A difference of a single letter in the plaintext will affect all the equations of the set and so will alter a sizable section of the ciphertext. There is no theoretical limit to the number of letters that can be enciphered simultaneously, but even in polygrams of a few letters



en	em	ya	tx	ta	ck	in	ga	dj	ac	en	ts	qu	ad
AS	GL	UE	PD	NG	KQ	HP	AB	XM	BE	AS	NT	NW	GO

PLAYFAIR CIPHER converts two letters at a time. If they are in the same row, substitute for each the letter to its right; if they are in the same column (*ck*), substitute the letters below each. If in neither the same row nor column (*en*), trace their rows and columns and take the letters at the intersections as the cipher, with the row-letter of the first plaintext letter first. (Double letters are separated by a nonsignificant letter such as *X*).

the practical difficulties of encipherment are prohibitive. Even though the solution of the Hill system presents an extremely difficult problem, however, the cipher seems never to have been used by any government.

All the systems described thus far are ciphers. There is another general class in cryptography: code. A code consists of a list of from a few hundred to tens of thousands of plaintext elements—words, phrases, syllables, numbers—each of which is paired with its secret equivalent, usually a short group of letters or numbers.

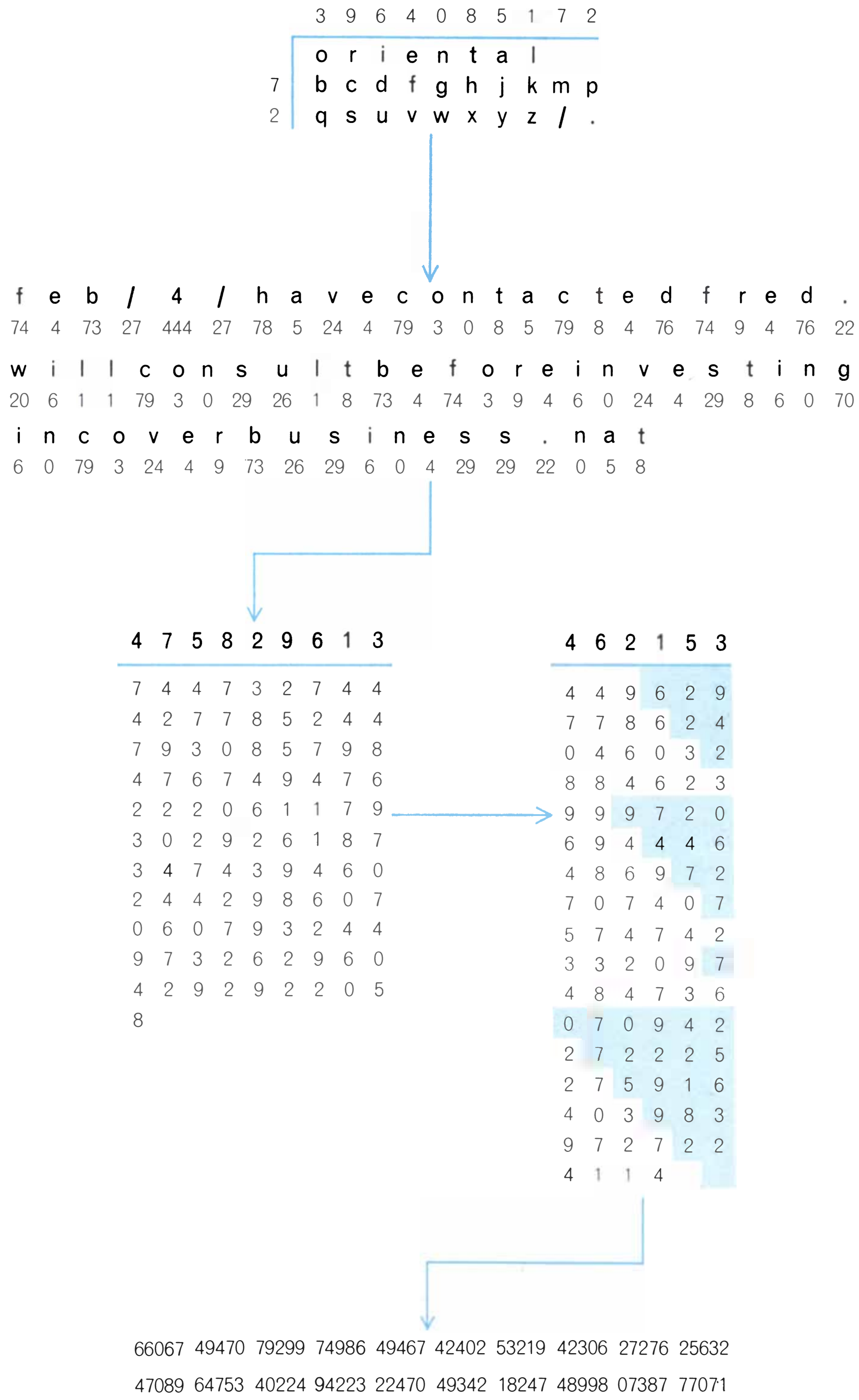
A code can be regarded as a gigantic monoalphabetic substitution in the sense that both employ a single list of equivalents. The distinction between code and cipher depends essentially on the length of the list; in theory no sharp dividing line can be drawn between them, but in practice they are quite distinct. Cryptologists sometimes say that a code deals with plaintext elements of variable length and a cipher with plaintext elements of constant length. A more penetrating and useful distinction, perhaps, is that codes operate on linguistic entities whereas ciphers do not—a cipher will split the *t* from the *h* in *the*, for example. Many cryptanalytic agencies have separate sections for solving codes and ciphers, the code section being staffed largely by linguists and the cipher section largely by mathematicians.

The solution of a code is mainly an extension into the domain of words of the techniques used in the domain of letters for monoalphabetic substitution. Repetitions and stereotyped expressions play a large part; often the first step is the identification of code groups that represent the stops, or periods, outlining the structure of the message.

To make this harder, codes are often superenciphered: the codewords or codenumbers are enciphered by some cipher system just as if they were ordinary plaintext. Yet cryptanalysts can strip off superencipherments; in effect they solve ciphers whose plaintext is itself code.

Feats such as this one may make it seem that, outside of the one-time tape, no unbreakable ciphers exist. In theory this is true; in practice it is not. Rotor systems can produce a cipher that no one will be able to break. They must, however, be used properly: key elements must be varied frequently, perhaps as often as once an hour. When the key elements are poorly chosen, or when a cipher clerk makes a mistake that necessitates a reencipherment of the same message, opportunities are presented for cryptanalysts to solve the system. Such human errors occur not infrequently in the message traffic of smaller countries, and they are mainly what keep the cryptanalysts of today in business. The major powers nearly always handle their cryptography correctly, and their messages remain largely inviolate.

Perhaps the outstanding example of a cipher that in theory can be broken but in practice cannot is a pencil-and-paper system used by the former Russian agent Reino Hayhanen, the man who betrayed Rudolf Abel. The system consisted essentially of a monoalpha-



HAYHANEN CIPHER begins with substitution according to a keysquare. The resulting string of digits is written into a transposition block (*left*). The digits are then taken out of the block by columns (in the order of the key numbers) and written into a second block (*right*). This one has steplike areas; the numbers fill first the space outside, and then inside, these areas. Finally the digits are transcribed by columns into groups of five.

–	52666	C	....Ship's papers
–	00547	C	....Ship ready for
–	07197	C	....Ship Rock
A	28810	A	Ship should
B	07827	A	Ship should
C	11096	A	Ship should
–	53316	B	....Ship should be
–	30764	A	....Ship's Steward-s—*from*—*of*
–	07488	A	....Ship still afloat
–	00982	C	....Ship to ship
A	35503	B	Ship was
B	27649	C	Ship was
C	11028	B	Ship was
–	51867	B	....Ship will
A	00296	B	Ship will be
B	28618	C	Ship will be
C	30799	A	Ship will be
–	35539	A	...**Shipment**—*of*
–	42581	C	....Shipment to
–	01683	A	...**Shipments**—*of*
–	50688	C	...**Shipowner**-s
A	11193	B	**Shipped**
B	28346	C	**Shipped**
C	31950	B	**Shipped**
–	03680	C	....Shipped at
–	36276	C	....Shipped by
–	50302	C	....Shipped from
A	28742	B	Shipped in
B	06863	B	Shipped in
C	27989	A	Shipped in
–	04130	B	....Shipped to
–	50817	A	...**Shipper**-s

–	07461	B	...My 749
–	07462	A	...Propert-y—*of*
–	07463	C	...Shall not
–	07465	B	...Simplicity—*of*
–	07466	C	...Unfit for
–	07467	A	...Swollen
–	07469	B	...This morning Thursday-'s
A	07470	C	...Nought six four five
B	07470	B	...Refit-s—*at*—*on*
C	07470	A	...25th November
–	07471	C	...Your 616
–	07472	C	...Thorn Rock
–	07474	B	...She will have
A	07475	C	...Hindustan, H.M.S.
B	07475	A	...25th June
C	07475	B	...19th March
–	07476	A	...Without waiting to
–	07477	C	...Wireless installation—*of*
–	07478	A	...Your 589
–	07479	C	...Unconnected
–	07480	B	...Undesirability—*of*
–	07482	C	...Pushed
–	07483	A	...Your 501
–	07484	B	...Tajura
–	07486	A	...Your 251
A	07487	B	...Rear Admiral, Egypt
B	07487	A	...Received—*at*—*on*
C	07487	C	...Lamlash
–	07488	A	...Ship still afloat
–	07489	B	...When ready to
–	07491	B	...*Spanish* Mac-Mahon
A	07492	A	...Submit I may be
B	07492	C	...These
C	07492	B	...She
–	07493	B	...Proceed-s in
–	07494	A	...Wired from

CODEBOOK of the British Navy in World War I listed numerical code groups opposite the words and phrases for which they substituted. Entries were arranged according to the alphabetical order of the plaintext word or phrase in the encoding section (*left*) and in numerical order in the decoding section (*right*). Common words and phrases had multiple substitutes for added security.

betic substitution followed by two transpositions [*see illustration on preceding page*].

Hayhanen had to remember four primary keys—a date, a word, a number and the first 20 letters of a Russian popular song—together with the complicated process by which they generated the keys for the substitution and the transpositions. The system also required a fifth key, a number that Hayhanen selected at random for each message and inserted in the final cryptogram at a predetermined point known to the decipherer. Since this randomly selected number affected the entire key-generation process from the outset, it completely changed the substitution and transposition keys from one message to another. This made each message essentially a unique problem for the cryptanalyst. Although cryptanalysts can envision ways of solving the Hayhanen system and might, given an indefinite amount of time, actually solve a message, the system is in practice impregnable.

Secrecy in communications is not limited to writing; it can be applied to speech and pictures as well. Telephone or radio signals can be distorted by scramblers that invert high sound frequencies to low, alter the normal amplitudes of speech, chop the stream of sounds into segments and transpose them, or combine several of these methods. Some of the more recent scramblers employ pulse-code modulation, which converts a voice signal into digital pulses; the pulses are then enciphered. Video-scramblers are used in subscription television to make the telecast unintelligible to viewers whose sets are not equipped with a descrambler.

What of the future? New systems of communication, such as might be provided by the laser, would at most impose a new level of technical complexity on top of the underlying linguistic problem. It would not reduce the need for secrecy. It seems likely that cryptology will continue to exist as long as knowledge in a nationalistic world remains power.

Kodak advertises: **a door in Chicago . . . a box in 5 visions . . . an interesting position for a supplier of light-sensitive materials . . . effective lantern slides, some a bit startling**

"This is photography

The Chicago Museum of Science and Industry has a new exhibit area that uses beauty and other wiles to plant an unconscious notion in the heads of youngsters, underprivileged and overprivileged, that photography is a *subject.* Please join us in hoping that for a few souls each day it will become a sort of door to a useful and interesting life.

Let's start thin-layer chromatography

The price of this EASTMAN CHROMAGRAM *Kit for thin-layer chromatography is $64 when ordered from Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company). We see:*

1. A busy industrial laboratory. Too many fires have to be put out before Friday afternoon to take time out for instructing the semi-professional personnel in new techniques like TLC. Along comes this kit. Its instruction manual demands few prerequisites. Under its guidance the learner takes out from the kit the pre-coated silica gel sheet, the developing apparatus, the handy little sample applicators, the eluant, the little bottle of test dye. By the time coffee break is over, the learner has resolved the test dye into its three components and feels a surge of incentive to plough on in the manual to find out about visualization of components that do not happen to come in three convenient colors, about other development techniques, about pre-treatment for certain separations, etc. By the time the learner's boss comes by to ask, "Any questions?" the foundations are in.

2. Headquarters for some sort of field force that has analytical chemical responsibilities: Decision is reached that times and techniques have changed and that here is a rare case where the trend is toward simplicity instead of complexity. Nice to have everything fit into one neat box. Modern separation technique breaks out of the central research lab and into the grass roots.

3. A collegiate institution proud to teach the skills that are marketable in this part of the century: Faculty decides that such an elementary technique should not have to be taught to graduates by their bosses. Kits ordered.

4. A collegiate institution that does not believe its function is to teach job skills: Faculty decides that plate-coating for thin-layer chromatography is not worth shoehorning into the curriculum but thin-layer chromatography itself is. Kits ordered.

5. High school desiring to elevate its standing just a touch: Chemistry teacher bases lecture demonstration on EASTMAN CHROMAGRAM Kit. Properly avoids reference to brand name. CHROMAGRAM® System ingratiates itself into the fabric of the age.

Price of the kit subject to change without notice. Laboratories that know all about TLC but have been waiting for alumina-coated sheet before adopting the System need wait no longer. We now have it.

Explain it to the fellows, Tom

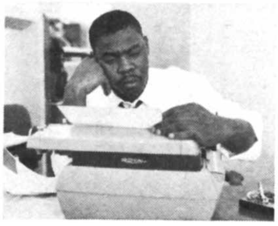
Ask a lawyer about holographs. He will tell you that in Scotland, Quebec, Louisiana, and in most of continental Europe a holograph is valid without being attested by witnesses, being a document wholly in the handwriting of the maker. If he is a patent lawyer, however, he may only groan and launch into bitter complaint about overwork and a hopelessly lengthening backlog. This indicates that he understands all too well the new meaning of holography because he is working for one of the hundreds of organizations where implausible but nonetheless feasible ideas are popping fast on how to use the new lensless photography, or laser photography, or wavefront reconstruction, or whatever it's called in the latest article where some reporter strives valiantly to explain holograms.

(Yes, holography does permit making perfectly respectable photographs through ground glass. Yes, stereoscopic photographs. Stereoscopic singles, unpaired. Why not?)

As one might guess, we are finding the mail and the switchboard loaded with oh-by-the-way-type questions about materials on which to make holograms. Nobody can be blamed for wanting to sound casual about the subject. Maybe it *will* all blow over. Maybe nothing will come of it. Too bad so to conclude and then turn out to have been wrong.

Which leaves us, as a leading supplier of light-sensitive materials, in an interesting position. To advertise that we offer the perfect material for holography would seem timely but unfortunately would be sheer nonsense. Holography represents such an entirely different viewpoint on the nature of photography—such an entirely different collection of viewpoints, in fact—that even defining what you want the photographic material to do may be half or three-quarters of the battle. And useless to the next holographer on the phone.

If it would help to try talking it out with someone who understands photographic materials, try 716-325-2000, extension 2720, which connects you with Eastman Kodak Company, Special Applications, Rochester, N.Y. 14650. We begin each conversation with a clean sheet of the note pad and a certain type of carefully cultivated memory loss. Meanwhile, pity poor Tom Freeman. He has a tough assignment. Here he is trying to write an article for our men on the road that will tell them what to reply when a customer asks about holography.



Dangers in the dark

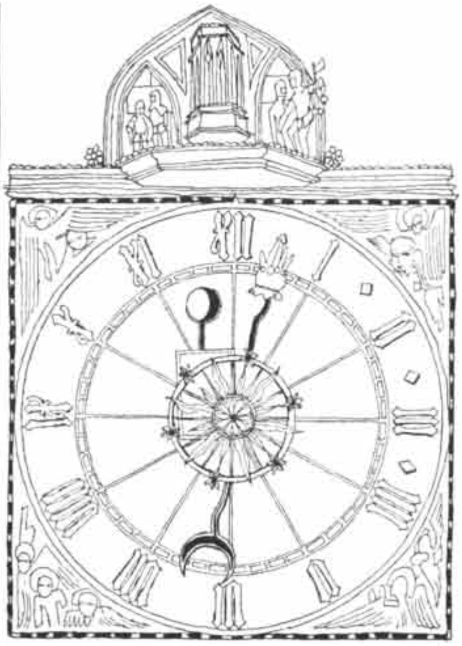
Once upon a time there were two imaginary and imaginative brothers named Ike and Mike who did not imagine alike. Ike was quite a showman. He reeked pizazz. He could think of a million little tricks to make people sit up and take notice. The sad part about Ike was that after the people did sit up and take notice, they felt cheated when they discovered how little he had that was worth taking notice of.

This taught a valuable lesson to Mike, who was younger. Mike devoted his share of the family brilliance to soundness. He shunned pizazz like the plague. And he turned out sadly, too. He made his stuff sound and look so dull that the people couldn't bear to give it any attention. Far too late to do him any good, his brilliant imagination was recognized one cold night in a library by a scholar searching for something of an entirely different category.

A middle course is not only possible but desirable. A lecture to a class or a paper to a colloquium can be vivid without going quite as far in its graphics as the average television commercial. For an occasional "spectacular," where some representation of motion such as flow of different rates and directions, reciprocation, rotation, vibration, etc. will help get a complicated idea across at an important presentation, we now even offer a rotating polarizing device called the KODAK Motion Adapter that fits over the KODAK CAROUSEL Slide Projector. We shall be glad to tell you how to come by a new kind of slide that provides such apparent cyclic motion. Inquire of Eastman Kodak Company, Motion Picture and Education Markets Division, Rochester, N.Y. 14650.

The same address can also provide a short pamphlet entitled "Effective Lantern Slides," which deals with less startling slides. Nevertheless, reading it and heeding it will keep you from doing unto others what has all too often been done unto you in the dark. Single copies free; $6 per thousand to program committees and others concerned about unnecessary punishment of technical audiences.

SCIENCE AND



Another Step toward Doomsday

China's third nuclear test, a sizable explosion involving a thermonuclear reaction, moved the Chinese a step closer to the hydrogen bomb and the human species another step along the road to nuclear instability. The Department of State at first minimized both the magnitude and the importance of the explosion; later the estimate of the yield was increased and the possibility was raised that the U.S. might agree to a "no-first-use" pledge in return for Chinese adherence to the limited test-ban treaty.

The Chinese reported the test, which took place on May 9 in the province of Sinkiang, as "a nuclear explosion that contained thermonuclear material." The State Department first announced that the explosion was of about the same magnitude as the first two Chinese tests, or about 20 kilotons. It was assumed that no significant thermonuclear, or fusion, reaction had taken place. A few days later the estimate of the yield was raised to 130 kilotons. On May 20 the Atomic Energy Commission reported that the yield was at the "lower end of the intermediate range," which runs from 200 kilotons to a megaton. A yield of even 200 kilotons would be very large for a device utilizing the fission process alone and would involve an uneconomic expenditure of enriched uranium. Apparently, then, at least part of the explosion's force came from a thermonuclear reaction. Analysis of debris in the atmosphere showed, moreover, that the thermonuclear material lithium 6 had been present in the device, confirming the impression that China would soon be testing a full-scale thermonuclear bomb.

The Chinese have declined to sign the U.S.-Britain-U.S.S.R. treaty of 1963 that banned nuclear tests in the atmosphere, under water and in space. China has not accepted UN invitations to join nuclear-arms talks in Geneva or the world disarmament conference scheduled for next year. In May, Premier Chou En-lai said China was obliged to continue testing because the U.S. would not agree that neither country would be the first to use nuclear weapons against the other. The U.S. was reported thereupon to have inquired (through its ambassador in Poland, who maintains contact with the Chinese ambassador there) if such a pledge might be the condition of China's assent to the test-ban treaty. The exploratory move was regarded as a significant U.S. diplomatic initiative, but it seemed unlikely that the Chinese would discontinue their tests until they had developed a hydrogen bomb.

No Mohole?

Rising costs and competition from other quarters have put the continuation of the Mohole project in doubt. In spite of considerable scientific support for this first effort to investigate the earth's mantle by drilling into it, the House of Representatives has followed its appropriations committee in cutting the project out of the budget for the fiscal year 1967. The committee said it acted "in view of the current world situation and the need to continually review priorities." It has been noted that the project has lost its principal champion in Congress, the late Representative Albert Thomas of Texas. Until his death early this year Thomas had been chairman of the subcommittee that deals directly with the appropriation for the National Science Foundation, which is in charge of the Mohole project.

When the project was inaugurated in 1960, its cost was estimated at $47 million. Now, according to the National Science Foundation, it will cost $79.6 million to bring the work to the stage where drilling can begin and $11 million annually for about three years of drilling. The plan is to drill from a seaborne platform near Hawaii; the estimated depth from sea level through the earth's crust and the Mohorovičić discontinuity to the mantle at that point is between 28,000 and 31,000 feet. Supporters of the project have argued that direct investigation of the mantle would provide much important information about the history of the earth and the nature of its solid interior. Such arguments may yet save the project, but in the circumstances the prospect seems doubtful.

Migrant Scientists

The "brain drain" has become a bit of 20th-century folklore, but the exact extent of migration by scientists and engineers has been somewhat obscure. Now a survey by the Organisation for Economic Co-operation and Development (OECD) has provided much relevant information. According to the survey, nearly 5,000 highly trained scientists and engineers migrate to the U.S. each year. About 42 percent of them come from Europe and 25 percent from Canada. A separate survey made for the United Nations Special Fund calls attention to an ironic element in the situation: Since Europe's outflow of scientists and engineers is roughly equal to the inflow from former colonies, the net effect of the migration is to benefit the developed nations and nullify any efforts they may be making to advance the training of scientists and engineers in the underdeveloped nations.

The first survey, published in a special issue of *The OECD Observer* devoted to science, covers the period from 1952 to 1963. Expressing the migration as a percentage of each nation's output of science and engineering graduates in 1959, the survey found that the figures range from .9 percent for France to 32.3 percent for Canada. "Moreover, there is evidence that the loss thus sustained is much more serious in terms of quality than of mere numbers. Probably no more than 5 percent of American scientists were trained abroad, but of the 631 members of the U.S. National Academy of Sciences no less than 18 percent were trained abroad."

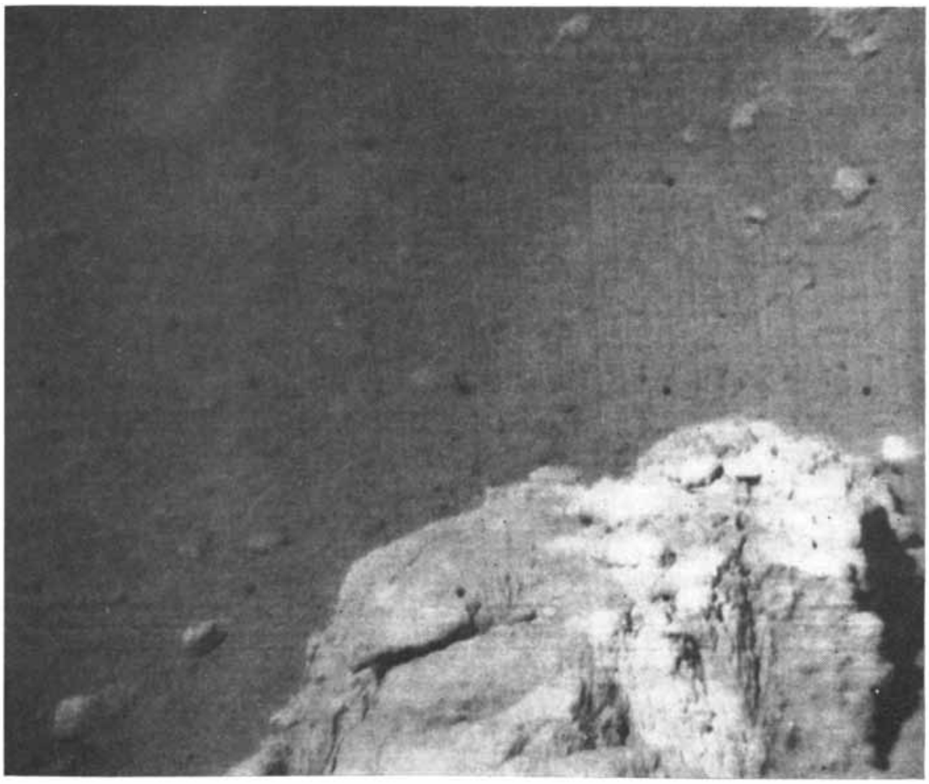
The second survey was made for the UN Special Fund by Ehsan Naraghi, an

Iranian sociologist. He predicted that the trend of migration to the U.S. would increase because American universities are not producing enough highly trained graduates to meet the demand. Naraghi suggested an international effort to regulate supply and demand, at least to the extent that some kind of compensation—perhaps in the form of scholarships—would be provided by the nations receiving scientists and engineers to the nations losing these specialists.

Soft Touch

Six hundred miles from the site where the Russian spacecraft *Luna 9* made the first controlled landing on the moon in February the U.S. spacecraft *Surveyor 1* touched down in the Sea of Storms and began sending back thousands of pictures. In spite of the proximity of the two landing sites, they present a markedly different appearance. The pictures from *Luna 9* show a porous surface strewn with rubble and pocked with small craters. The pictures from *Surveyor 1* show an area having the appearance of a "freshly turned field" with rocks and pebbles protruding through a thin layer of dust. The landing pads of the spacecraft made circular footprints about an inch deep and threw out miniature "rays" resembling those that might have been produced by a small meteorite. All the evidence indicated that the surface can easily support astronauts as well as spacecraft.

The odds against *Surveyor 1*'s landing safely on the moon and sending back pictures had seemed extremely high. It was anticipated that there would be several failures. The Surveyor program had fallen three years behind schedule and had cost $800 million, 10 times more than the original estimate. Never before, however, had so many untried techniques and mechanisms worked so well the first time. The hydrogen-fueled Centaur rocket engine that had powered the second stage of the launching vehicle had not previously been used in an operational mission. The mid-course correction system employed not one but three small rockets, which had to fire in unison and shut down at the same instant. Finally, the entire technique of achieving a "soft" landing on the moon (with three small vernier engines controlled by radar and a computer aboard the spacecraft) was untried. The 620-pound craft had been built by the Hughes Aircraft Company, which had also designed its 22-pound television-camera unit. The Surveyor program was directed by the Jet Propulsion Laboratory, which is operated for the National Aeronautics and Space Agency by the California Institute of Technology.



MOON ROCK, photographed from *Surveyor 1*, is about six inches high. This view was made by the spacecraft's narrow-angle camera, which is about 12 feet away from the rock.

A few weeks before *Surveyor 1*'s successful flight President Johnson had proposed that the United Nations adopt a treaty banning the use of the moon and neighboring planets for military purposes. While the spacecraft was in flight the U.S.S.R. asked the UN to sponsor a similar treaty. The two proposals would extend to outer space the neutralization agreement signed by the U.S. and the U.S.S.R. in 1959, which forbids the use of Antarctica for military purposes.

Reading the Genetic Map

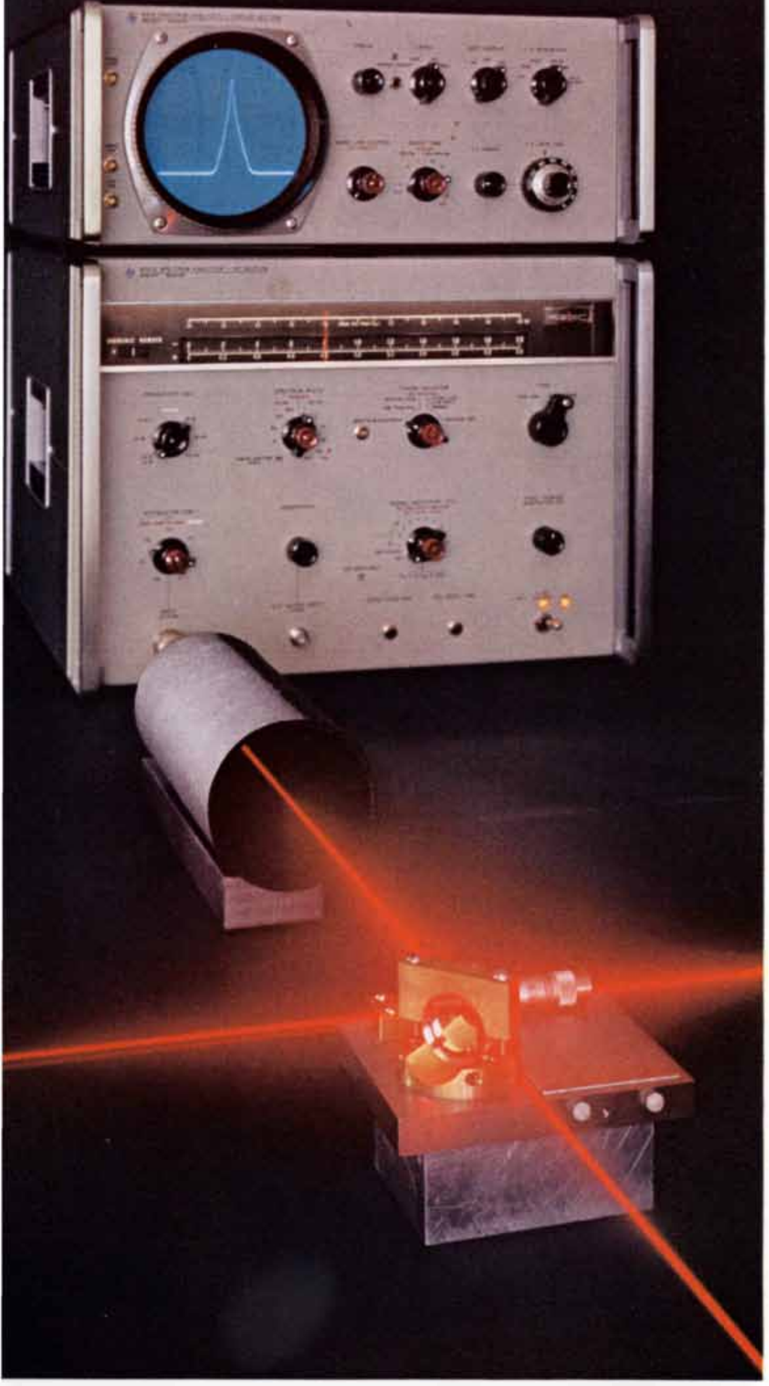
The goal of relating specific mutations in a gene to specific changes in the protein controlled by that gene has been attained. The work has also established how the "reading direction" of coding units in the gene is related to the direction of synthesis of the protein molecule. This dual achievement is reported in *Nature* by J. R. Guest of the University of Sheffield and Charles Yanofsky of Stanford University.

The two workers studied how mutations in a particular gene of the bacterium *Escherichia coli*—the "*A* gene"—gave rise to changes in the related "*A* protein": the enzyme tryptophan synthetase. The changes in the gene were identified by methods so sensitive that they could tell when a "recombination" had occurred between a single codon, or coding unit, in a gene of one bacterium and a codon in a gene of another bacterium with which it was crossed. A codon consists of a sequence of three nucleotides in the genetic material deoxyribonucleic acid (DNA), each molecule of which consists of hundreds of thousands of nucleotides and embraces many genes. The nucleotides are designated A, C, G and T for adenine, cytosine, guanine and thymine, the substances that give each nucleotide its distinctive character.

In one of the recombinations studied a bacterium that had a GAA codon at one site was crossed with a bacterium that had an AGA codon at the same site. One result of such a cross was a bacterium with a GGA codon, the first G being supplied by the donor and the GA by the recipient. Such recombinations take place only once in 250,000 to a million crosses.

The codon sequences were not actually identified but were inferred from the changes in the amino acid composition of the *A* protein controlled by the *A* gene. In manufacturing protein molecules the cell has a choice of 20 different amino acids, each of which is

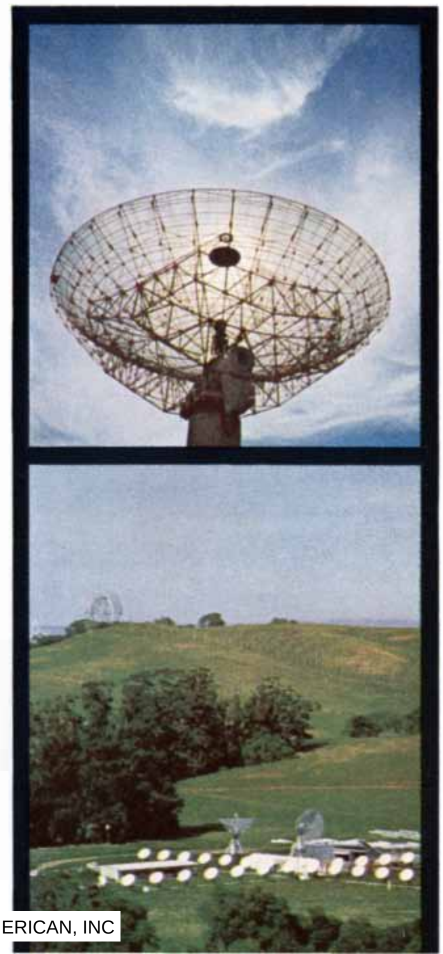

Mom, what's a UniRoyal?
Ask your father.
W. Thomas



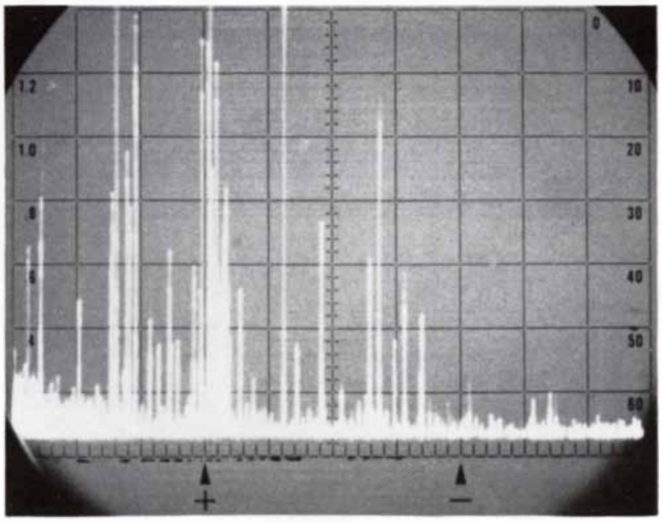
At the left, the hp spectrum analyzer is being used to look at the 800 MHz difference frequency between two coherent laser beams. The wide 2 GHz spectrum width and large 60 dB dynamic range of the analyzer make it easy for the scientist to see the results of any adjustments in the system.

New tool for quantitative

Radiation patterns of antennas and antenna systems, below, are pinpointed accurately with a simple set-up using the spectrum analyzer. Such identification is particularly important in communications in outer space, though it also has broad military, public safety and private communications application.



The oscillogram below shows the total TV and FM broadcast spectrum of the San Francisco Bay Area, demonstrating the radiation "traffic" density of one frequency range — and the convenience and precision offered by the spectrum analyzer.



analysis of the crowded frequency spectrum

As the electromagnetic spectrum becomes more crowded with man's communications, the need for identifying and analyzing components of the spectrum becomes ever more urgent. Terrestrial use of the spectrum for public safety, commercial and private communications is continually expanding. Military and scientific activities make further demands on high frequencies for communication in outer space.

The spectrum analyzer is a tool which provides precise information about a spectrum by measuring signal amplitude in relation to frequency. And the hp spectrum analyzer represents the first major advance in the technique in the past 15 years.

By adding quantitative measurement capabilities and wide sweep capabilities, the Hewlett-Packard spectrum analyzer helps make possible more communications in the limited frequency spectrum without mutual interference. It further implements new advances in circuit and component design through instantaneous and accurate analysis of radiation.

Because it provides accurate quantitative information, the hp analyzer is a basic measuring tool. It is both versatile and easy to use, and offers unparalleled performance at a reasonable cost.

The instrument's new capabilities were made possible by hp-developed solid-state components, hp cathode-ray tube technology, advanced circuitry techniques, human-engineered design and precision manufacturing methods. These new capabilities include wide frequency sweep, high frequency stability for narrow-band analysis, wide dynamic range, high sensitivity, extraordinary resolution, accurate measurement display and extreme simplicity of operation. A wide choice of accessories increases the versatility of the analyzer.

The fully calibrated Hewlett-Packard 851B/8551B Spectrum Analyzer responds to signals from 10 MHz to 40 GHz, thus covering virtually all the electromagnetic spectrum now used. It is capable of sweeping over frequency ranges as wide as 2000 MHz, so signals in a wide range can be viewed at one time. Conversely, it will sweep bands as narrow as 100 kHz (narrower, using vernier) for detailed examination. Display circuits permit simultaneous display of signals having a wide 60 dB amplitude range. Precision is enhanced by the analyzer's substantial freedom from spurious and residual responses.

Compatibility among increasing numbers of communications channels, making them free from interference, is broadly aided by this instrument. The analyzer has opened whole new areas of technological advances through new applications, as described in a series of Hewlett-Packard publications. It is another reason for looking to Hewlett-Packard for today's most advanced, yet practical measuring instrumentation. Further information on the instrument and on spectrum analyzer techniques may be obtained by writing Hewlett-Packard, Palo Alto, California 94304, Tel. (415) 326-7000; Europe: 54 Route des Acacias, Geneva.

The spectrum analyzer is the product of a continuing program of research and development at Hewlett-Packard, aimed at making true contributions to the science of measurement. To assist in this work, hp is continually interested in ambitious scientists and engineers who desire a stable future and a stimulating opportunity for creative endeavor.

HEWLETT hp PACKARD

An extra measure of quality

specified by a particular codon. The *A* protein consists of 280 amino acid units. Guest and Yanofsky found that the amino acid glycine occurs at two nearby sites in the protein chain, and that these sites could be related to mutations in the cell's DNA. On the basis of recombination experiments they concluded that the first glycine was specified by GGA and the second by GGT (or GGC). A single mutation could evidently change GGA to AGA, with the result that glycine was replaced by arginine in the *A* protein. If GGA mutated to GAA, the glycine was replaced by glutamic acid. Similarly, GGT (or GGC), the codon for the second glycine, could mutate to GAT (or GAC), yielding aspartic acid, or to TGT (or TGC), yielding cysteine.

Since the two glycine units could be related to the genetic map according to how they had mutated, Guest and Yanofsky were able to clarify a fundamental and much-disputed question concerning the way in which genetic information is transmitted: How are the codons oriented with respect to the direction in which protein chains are synthesized? They established that in terms of the conventional genetic map the codons for glycine appear left to right as GGA and GGT (or GGC). In terms of chemical structure the G is nearer the end of the DNA molecule in which a terminal phosphate unit is attached to the "5-prime" carbon of the sugar deoxyribose, and the third letter of the codon (A, T or C) is nearer the end in which a hydroxyl (OH) unit is attached to the "3-prime" carbon of the sugar. In the "messenger" ribonucleic acid (mRNA) that transcribes the genetic information from DNA and carries it to the site of protein synthesis, the codon lies in the same 5-prime-to-3-prime orientation. Finally, the 5-prime-to-3-prime orientation establishes the "reading direction" of the genetic map: the sequence in which amino acids are incorporated into a protein chain.

Quasar Clues

The discovery of absorption lines in the spectra of several quasi-stellar radio sources (quasars) may provide valuable clues to the internal structure of these mysterious celestial bodies. Until recently only emission lines had been detected in spectrograms of quasars. The absorption-line data obtained so far suggest that at least some quasars have extended atmospheres somewhat similar to the atmospheres of stars.

In a recent letter to *The Astrophysical Journal* E. Margaret Burbidge and Geoffrey R. Burbidge of the University of California at San Diego and C. R. Lynds of the Kitt Peak National Observatory report the results of their analysis of spectrograms of the quasar 3*C* 191. The spectrograms were obtained with the 84-inch telescope at Kitt Peak and the 120-inch telescope at the Lick Observatory. A very strong absorption line was identified at a wavelength of 4,566 angstrom units superposed on a very broad emission line slightly to the short-wavelength, or blue, side of the center of the emission line. Three other absorption lines were observed on the short-wavelength side of a very strong emission line at 3,597 angstroms, and several other absorption lines with no associated emission lines were also observed.

The strong emission lines at 4,577 and 3,597 angstroms were identified, on the basis of the ratio of their wavelengths, as resulting respectively from radiation from quadruply ionized carbon atoms and Lyman-alpha radiation from hydrogen atoms. The absorption line at 4,566 angstroms and one of three absorption lines near 3,597 angstroms appear to be associated with the same elements. From an analysis of the Doppler shifts of these absorption lines with respect to the corresponding emission lines Lynds and the Burbidges estimate that the absorbing material must be moving toward the observer at 600 kilometers per second with respect to the emitting material. This comparatively small relative velocity is taken as conclusive evidence that the absorption lines are produced in a region associated with the quasar and not in intergalactic material between the quasar and the solar system.

Lynds and the Burbidges point out that the appearance of fairly narrow absorption lines in some cases superposed on broad emission lines and in other cases occurring by themselves is reminiscent of the spectra of B-emission stars and shell stars, both of which are characterized by extended atmospheres.

Two other letters in the same issue of *The Astrophysical Journal* report similar absorption features in the spectra of other quasars. In one letter Maarten Schmidt of the Mount Wilson and Palomar Observatories and the California Institute of Technology reports the observation of a strong absorption line on the short-wavelength side of a quadruply ionized carbon emission line at 3,870 angstroms in a spectrogram of the quasar 3*C* 270.1. Schmidt has also observed a strong absorption line, about 30 angstroms wide, in the spectrum of the quasar 1116+12. A different absorption line in the spectrum of 1116+12 is reported in another letter by Lynds and A. N. Stockton of the University of Arizona. Analyses of these and possible other absorption lines are under way.

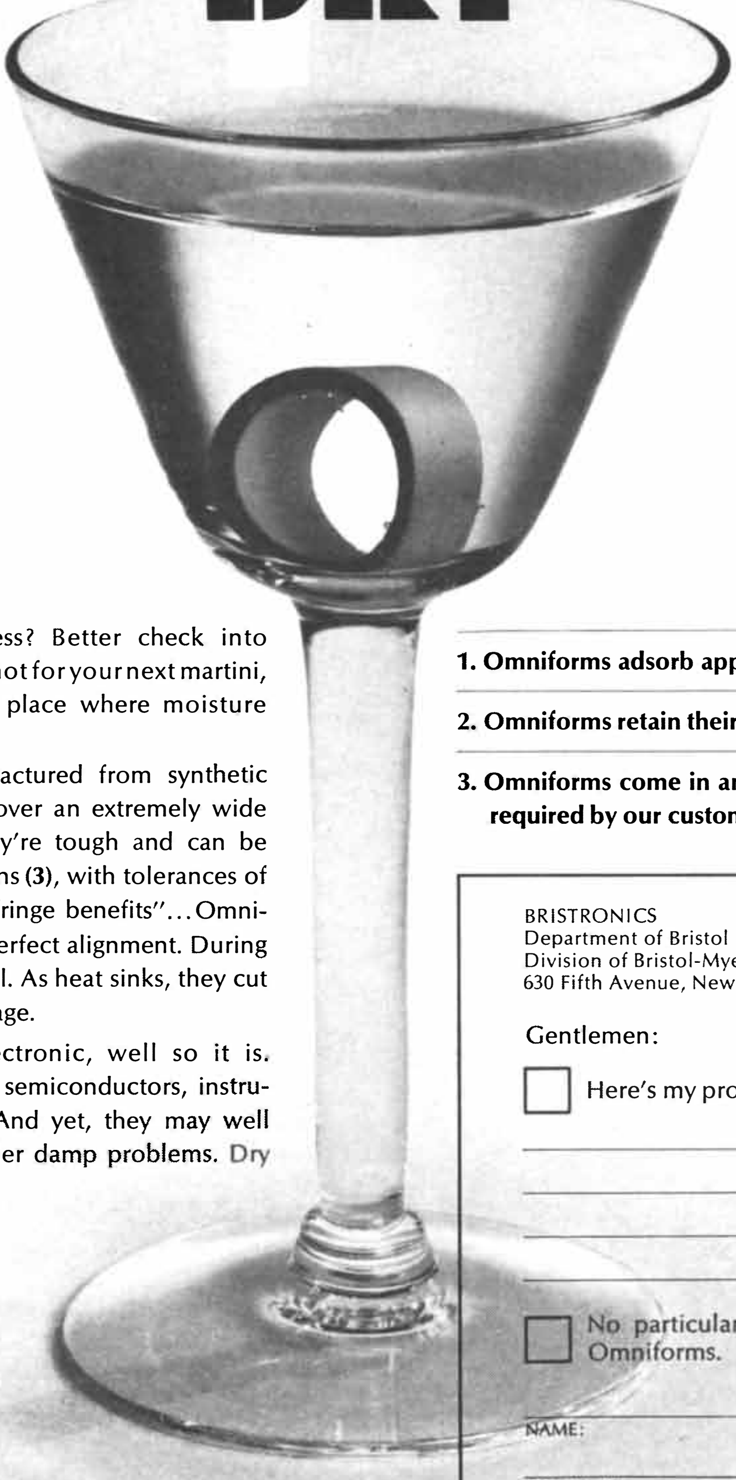
Bacterial Signatures

A technique for identifying bacteria through gas chromatography has been developed by workers at the General Electric Electronics Laboratory and at Cornell University. They have found that the pattern of metabolic products of different bacteria is distinctive enough to serve as an identifying signature of each organism. So far they have obtained such signatures for 32 different species and strains of bacteria.

In gas chromatography a small sample of the substance to be analyzed is driven by an inert gas through a column that allows different molecules to pass at different speeds. The arrival of each component at the end of the column is sensed by a detector and registers as a peak on a chromatogram. Calibration with known materials makes it possible to identify each component on the basis of its time of passage, and the height of each peak indicates the relative quantity of a component in the substance being tested. Martin Alexander of the Cornell College of Agriculture and John R. Gould of General Electric suggested that bacterial metabolic products might be subject to analysis in this manner. Together with Robert T. O'Brien of General Electric and Yigal Henis of Hebrew University in Israel, they centrifuged bacterial cultures and extracted the volatile metabolic products for passage through a chromatograph.

The distinctive signature of each bacterium consists simply of a list of up to 13 metabolic products—acetic acid and lactic acid, for example—in order of decreasing quantity; the distinctiveness is based on the presence or absence of the various products and on variations in their relative quantity. The method is extremely sensitive, according to Gould, detecting smaller quantities of organisms than conventional procedures can and distinguishing among closely related types. So far the system has been applied only to pure strains; it will next be tested on mixed cultures. The hope is eventually to make chromatography a tool for detecting specific bacteria or for identifying a number of bacteria—in a clinical situation, perhaps, or in space research. That will presumably require advanced methods of pattern analysis.

KEEP IT DRY



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BRISTRONICS

POULTRY PRODUCTION

The per capita consumption of poultry in the U.S. has more than doubled during the past 30 years. To meet the demand, automatic factories today convert tons of feed into tons of meat and eggs

by Wilbor O. Wilson

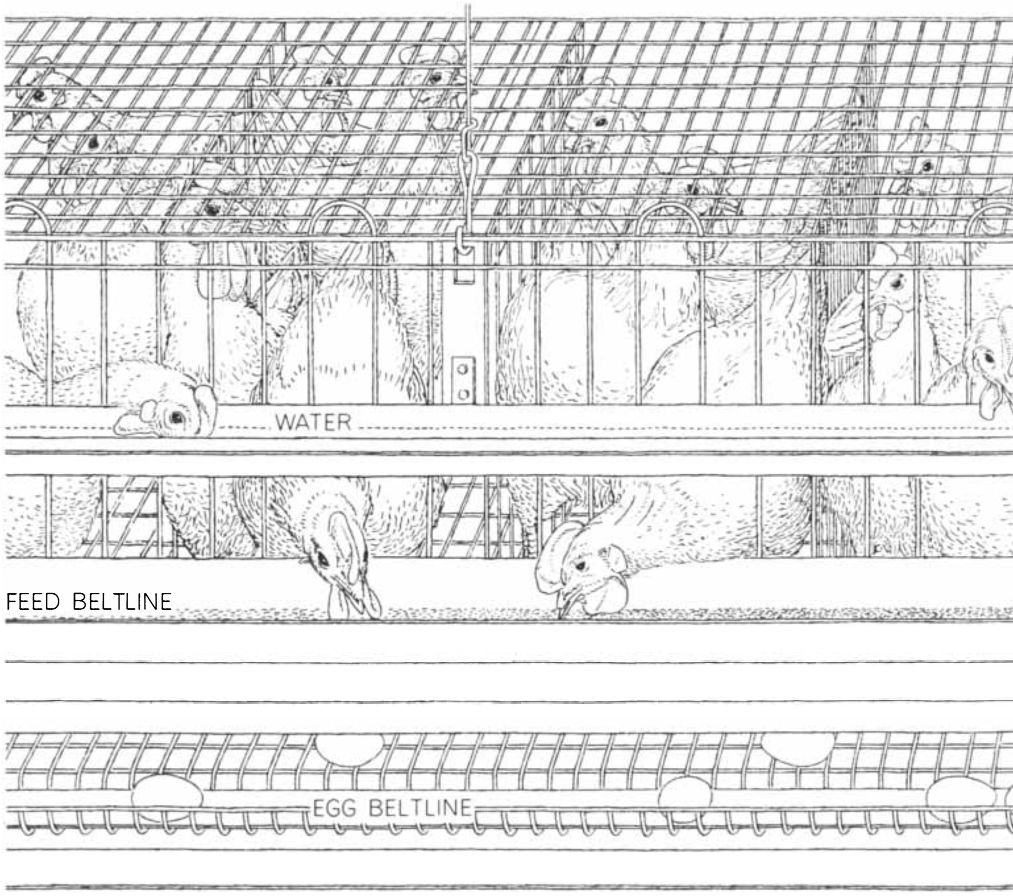
The term "chicken feed" used to be a synonym for insignificance. Biologically and agriculturally the domestic fowl were not a major factor in American life. Over the past 30 years, however, their status has changed remarkably. Today the production of poultry is no longer a trivial or small-scale business. A few figures will illustrate the dimensions of the change. In 1935 the annual consumption of poultry in the U.S. amounted to 13.1 pounds of chicken and 1.5 pounds of turkey per capita; in 1965 the consumption per person had risen to 33.3 pounds of chicken and 7.4 pounds of turkey. Thirty years ago comparatively few commercial egg farmers kept more than 2,500 hens; nowadays ranches consisting of 30,000 laying hens are not uncommon, and the average annual production of eggs has been increased from 121 per hen in 1930 to 217 per hen today.

Paradoxically, although the poultry industry has grown greatly in size, it has almost disappeared from sight on the American scene. A generation ago nine out of 10 farms in the U.S. kept chickens or other poultry; today in much of the countryside the chicken yard is becoming a rarity. Poultry production is now conducted mainly in establishments that are best described as factories. A technological revolution has transformed this field of agriculture, and in so doing it has raised poultry to a position of new importance in man's economy.

Origins of Poultry Production

The cultivation of poultry as a food source is actually a rather recent development. Chickens were domesticated early in man's history (witness the cock's crow mentioned in the Bible and the painting of a cock on a potsherd found in the Egyptian tomb of Tutankhamen), but it appears that these animals at first were used primarily for the sport of cockfighting. Until the 20th century the chicken was prized more as a showpiece than as an item for the table. Beautiful breeds of chickens were raised for exhibition, and more than 200 varieties of them, bearing names such as the Golden Laced Wyandotte and the Speckled Sussex, were measured by a "Standard of Perfection" in appearance that was established by the American Poultry Association in 1874. It was not until about 1910 that the raising of hens for egg-laying became a more important enterprise in the U.S. than the breeding of fancy poultry for exhibition.

Nonetheless, the domestic fowl have historically contributed to man's material welfare and his culture in a multitude of ways. The Declaration of Independence was written with a quill pen made from a goose feather. Painters



MODERN EGG FACTORY automatically handles the nutrient demands and the egg output of large numbers of virtually immobilized laying hens. Feed reaches the birds on a moving since early times have used egg yolk as a durable vehicle for pigments. In California today geese are employed to weed the cotton fields: they eat the grassy weeds and leave the cotton plants alone. Another useful fowl, developed in our laboratory at the University of California at Davis, is the Japanese quail: requiring very little cage space and laying more than 300 eggs a year, this bird has proved to be an excellent subject for the testing of antifertility drugs.

Our debt to the chicken in science and medicine is profound. It was the ill effects of a diet of polished rice on a flock of chickens, first investigated by the Dutch physician Christiaan Eijkman in 1896, that led to the discovery of vitamins and their dietary importance. The chicken was one of the chief early instruments for studies of the sex hormones, because of its conspicuous manifestations of their effects, particularly on the cock's comb. Louis Pasteur's development of the first vaccine for a bacterial disease (anthrax of cattle) originated from his investigation of fowl cholera. Later the chick embryo—that is, the fertilized chick egg—was found to be an ideal medium for culturing microorganisms, including viruses, and this led to the conquest of many infectious diseases. Today a stubborn disease of poultry—fowl leukosis—serves as one of the most useful experimental tools in the investigation of cancer.

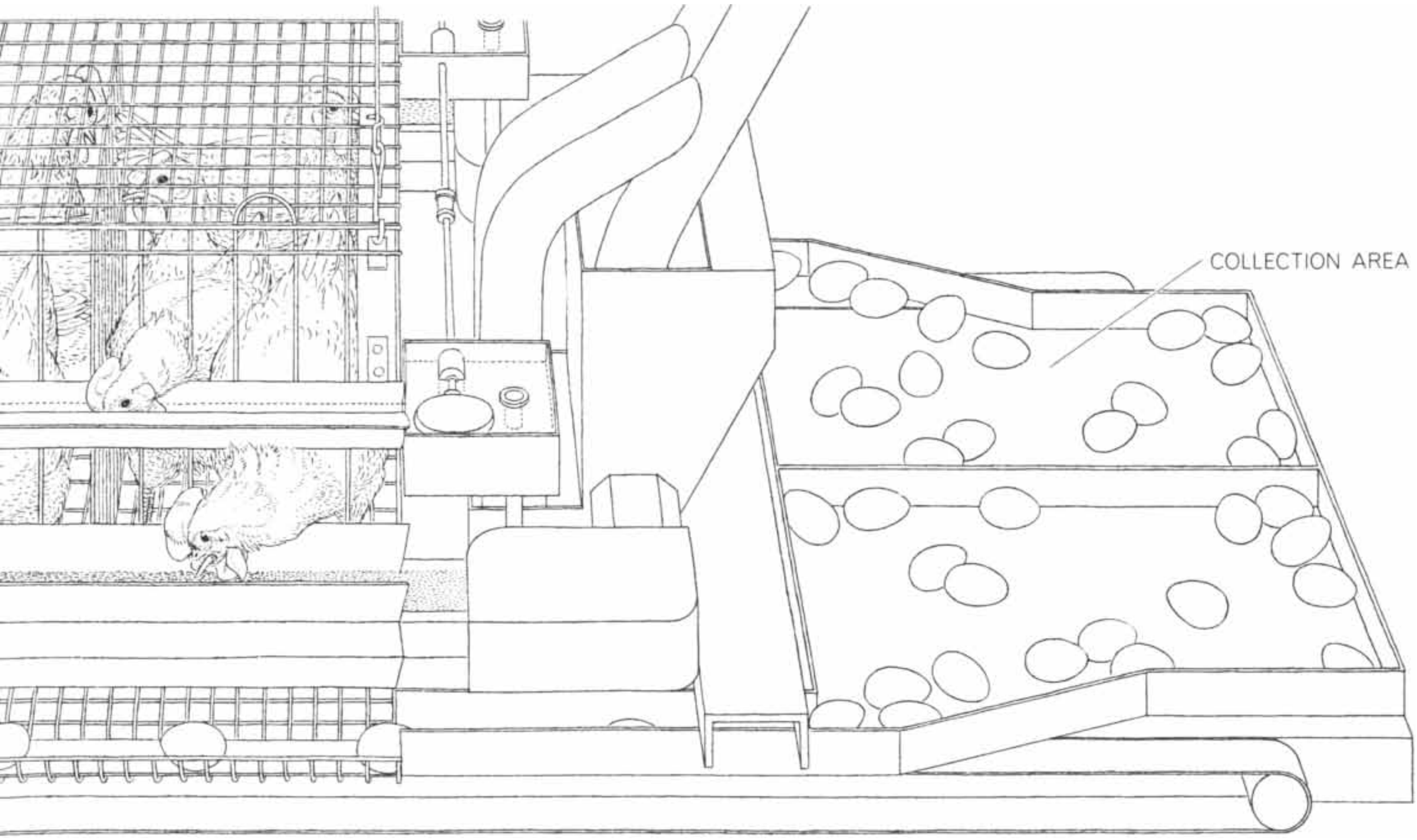
Modern Poultry Production

This article is concerned with the production of poultry as food. In the U.S. this essentially means the production of chickens and turkeys. Other birds—guinea fowl, ducks, geese, swans, pigeons, peafowl and quail—are important contributors to the food supply elsewhere in the world and may become so in the U.S. in the future, but they are not a large factor here at the present time. The chicken, of course, is universal. The turkey is indigenous to America and was raised by the Indians long before the Europeans arrived; according to the archaeological evidence, Indians in New Mexico domesticated the bird thousands of years ago.

Until recent years the practicable size of poultry flocks was rigorously limited by technical difficulties. Diseases and other factors that attacked the birds under crowded conditions made it impossible to handle and sustain large flocks economically. Elaborate forms of management were tried but all failed. In the 1930's, however, intensive research promoted by the Poultry Science Association and carried out by investigators at agricultural experiment stations in the U.S. began to yield solutions to the problems. The advances fall under four headings: improved breeding, improved feeding, control of disease and improved management, including mechanization.

The breeding of chickens has gone through an evolution of drastic change in objectives. Originally and up to fairly recent times the breeders selected chickens primarily for their fighting ability. Then, in the exhibition era, the animals were bred for fancy feathers, combs, colors and shapes. Today the breeders' objectives are utilitarian and twofold: maximum meat production and maximum egg production.

As it happens, these goals are difficult to attain in one bird. Large birds tend to have low egg production, and good egg-layers tend to be small—about half the size of the meat breeds. Chickens such as the Plymouth Rock, the Wyandotte and the Rhode Island Red were developed in the latter half of the 19th century as a compromise. Produced by crossbreeding between the two types,



belt and water in a trough. The cage bottoms slope so that, as soon as a hen lays an egg, it rolls away to a moving belt and is carried to a collection area. A single factory building may house more than 50,000 hens, which produce an average 3,000 dozen eggs a day.

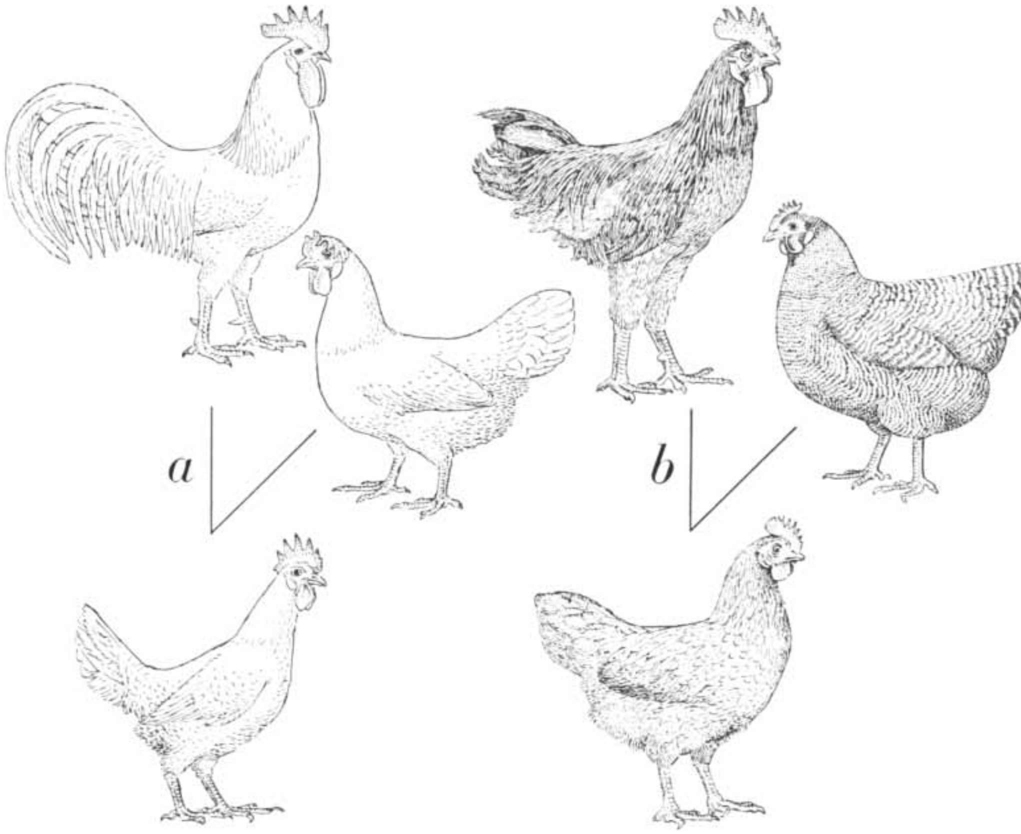
they are of fairly good size and give fairly good egg production. In the present system of poultry production, however, specialization is the rule. Poultry farmers raise their birds either for meat or for egg production, and they select their breeds for high performance in one or the other.

The pioneer of modern fowl breeding was the British biologist William Bateson, who even before Gregor Mendel's genetic experiments with plants were generally known had discovered the same basic principles of inheritance in experiments with chickens. These principles, involving the action of single genes, apply with particular fidelity to feather color and comb type. Rate of growth—the ability to gain weight rapidly in the first few weeks of life—is under the control of a number of genes that act additively. This too is a highly heritable characteristic.

One instance of selection concerns the work of British breeders. They developed a tightly feathered, well-muscled chicken called the Cornish. It laid few eggs and had low fertility, and for many years it was used only for exhibition. The Cornish, however, eventually was found to be an excellent stock for meat birds, and most of the modern strains of fryers or broilers are descended from that stock on one side of the family tree.

Breeding for egg production turned out to be more difficult. This capacity seems to be less accurately controlled by a bird's genes than body weight or feather color is. Moreover, egg production is greatly influenced by diet and by environmental circumstances, making it difficult to assess the fowl's inherent laying capacity. Finally, an egg farmer is interested not only in the number of eggs a hen produces but also in the size, color and quality of the eggs, and these properties are not under a single genetic control. Scientific testing in recent years has shown, however, that heredity is an important factor in the improvement of laying breeds. Different strains of hens, reared under basically the same conditions, have been found to vary in production by as many as 45 eggs a year.

A bird, unlike a plant, is not altogether at the mercy of its environment. It maintains its own internal stability (homeostasis) and thus can tolerate considerable variation in the weather. Furthermore, in poultry husbandry today conditions such as temperature and light are carefully controlled; diet can be accurately suited to the bird; resistance to disease can be supplied by vaccination. All of this helps to simplify the breeding of chickens and turkeys for productive capacity; the breeder does not need to be so concerned, as in plant-crop breeding, with genetic adaptation to local climates or specific diseases. Indeed, today's breeders have developed birds that are raised the world around.



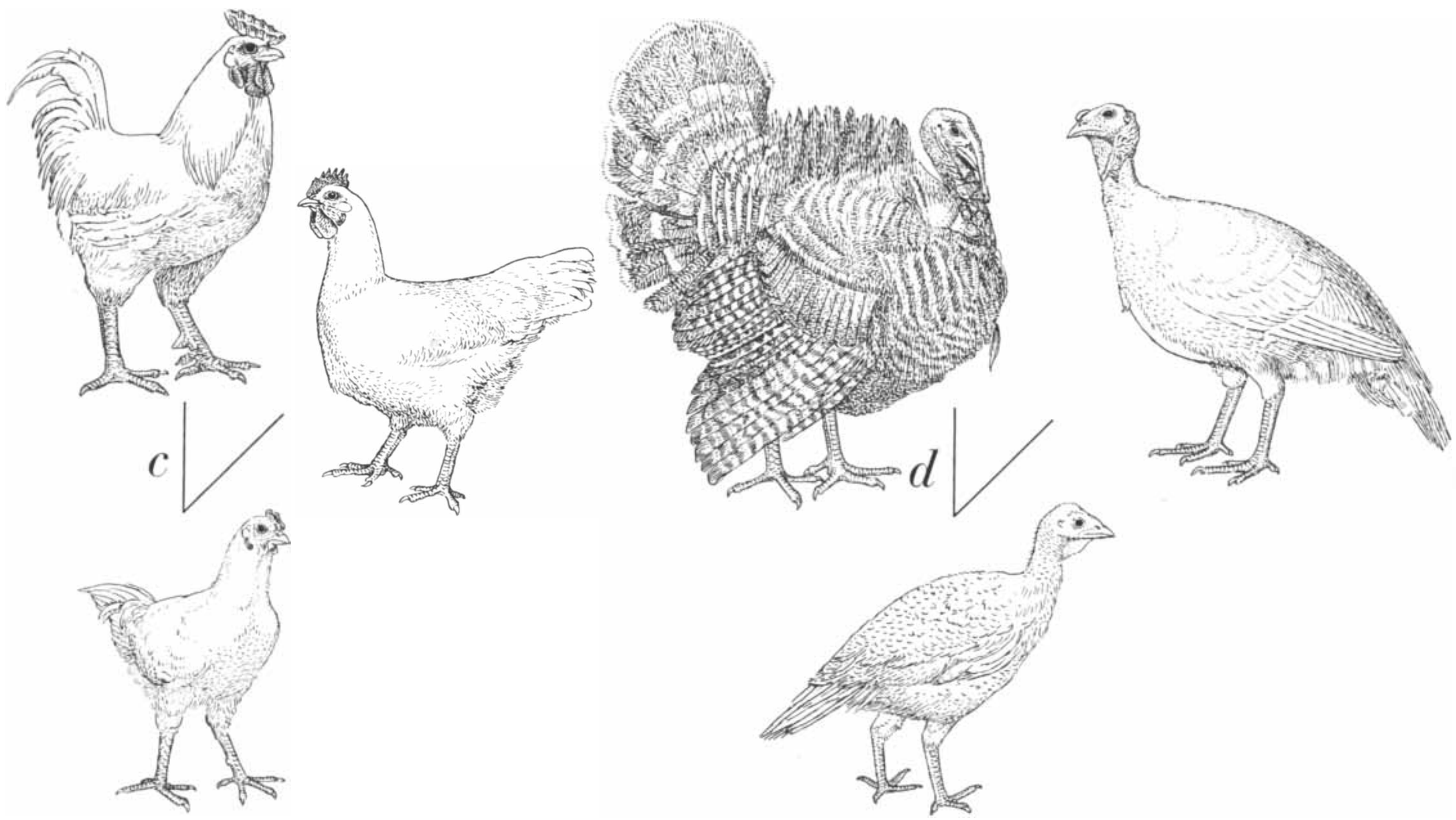
POULTRY STRAINS that lead in popularity today often have some distant European and Asiatic ancestors in common, but they are fundamentally the product of selective breeding programs in which many new varieties and strains have been developed during the past 20 years. A strain-cross involving two strains of the single-comb White Leghorn variety (*a*) yields a superior producer of white eggs. A variety-cross of the Rhode Island Red with the

Since 1932 the Poultry Husbandry Department of the University of California at Berkeley has been breeding a population of hens for improvement in egg production. The feeding, housing and management of the birds have been kept more or less uniform; no outside genetic material has been introduced since 1941, and the only important variable has been the progressive selection of the best layers in the flock for reproduction. The experiment has produced a steady rise in the annual production of eggs per hen [*see bottom illustration on page 64*], even though inbreeding, such as this flock has experienced, usually reduces egg-laying capacity. Hybridization by the crossing of inbred strains could have increased the gain, and the use of hybrid chickens is now common practice in commercial husbandry.

Of the nearly 200 varieties of chickens that used to be raised in the U.S., only four or five are commercially important today. The meat breeds, as I have mentioned, can all trace their ancestry in part to the Cornish breed. Practically all the important egg-laying strains are derived from the Leghorn breed. The popular present strains of turkeys (featuring white feathers and a plump breast) can also be traced back to a single superior stock: a breed called the Broad-Breasted Bronze that was developed in England and introduced in the U.S. in the 1930's.

Chicken Feed

Turning now to the feeding of poultry, we must observe that the modern fowl thrives on a diet almost totally foreign to any food it ever found in nature. Its feed is a product of the laboratory. The nutrition of the chicken has been investigated more thoroughly than that of most other animals, including man. It was by experiments on chickens that investigators determined the needs of animals for vitamin D (the sunshine, or cod-liver-oil, vitamin), the antihemorrhagic vitamin K, the vitamin-B complex, vitamin G (riboflavin) and



Barred Plymouth Rock (*b*) yields chicks with a sex-linked gene affecting feather color. The cockerels are readily culled 24 hours after hatching; the hens are superior producers of brown eggs. The meat fowl are larger than egg fowl and often have Cornish blood in their ancestry. One such rooster (*c*) and a White Plymouth Rock hen, when crossed, yield a hen whose offspring are prime broiler fowl. Because dark pinfeathers are objectionable, the Broad-Breasted Bronze turkey (*d*) is not often raised for market. Instead the Bronzes have been bred with white-feathered turkeys, such as the White Holland, to produce birds with the best features of both.

various essential minerals. Fowl are primarily grain eaters, but research has established that they cannot live by grain alone. Their requirements of protein, minerals, vitamins and energy-suppliers have been established in much detail, and ways have been found to enhance the efficiency of their diet by artificial supplements such as antibiotics. Since cost is a prime factor in successful poultry husbandry, the computer has been enlisted to calculate the correct proportions of various available ingredients that differ in price in order to achieve a ration of fixed dietary value at minimum expense.

The barnyard fowl used to live on scraps from the farmer's table and what insects and grain it could find in the field. Later it was promoted to a standard feed consisting of a mixture of four grains and meat and bone scraps, supplemented with milk and greens. In the present poultry factories the ration is one omnibus mixture containing all the necessary ingredients, presented in the form of a mash or in pellets. The ration varies, of course, with the bird: a growing pullet, for example, needs more vitamins and protein than a mature, laying hen does.

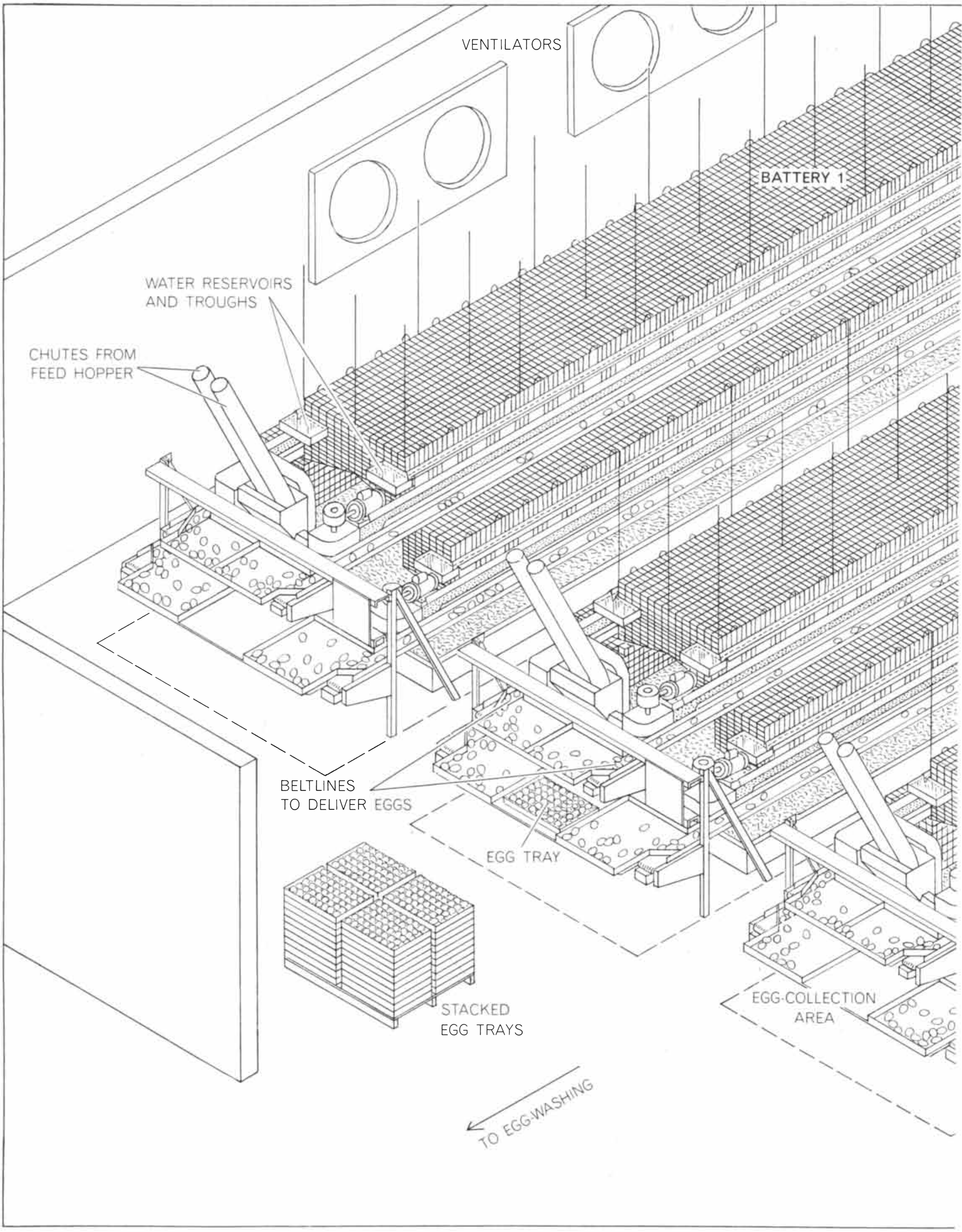
The efficiency of a fowl's conversion of feed into meat or eggs, under favorable conditions, is impressive. In a 1964 egg-laying test in California the average production of the hens entered was better than a pound of eggs for each three pounds of feed consumed by the bird. Young fryers marketed at the age of eight weeks weigh about four pounds and generally yield about a pound of body weight for each two pounds of feed they have eaten. The turkey does even better: up to the age of six weeks it converts each pound of food into nearly a pound of tissue. From the sixth to the 26th week turkeys gain weight at the rate of more than a pound a week. As chickens and turkeys grow larger and older, the efficiency of their conversion of feed into meat declines.

Along with the advances in nutrition, considerable progress has been made in the control of poultry diseases. By improved sanitary practices, the use of medicated feeds and vaccination poultrymen in the U.S. have eradicated fowl plague and greatly reduced the toll from formerly catastrophic diseases such as coccidiosis, pullorum disease, bronchitis, laryngotracheitis, Newcastle disease (a viral invasion of the nervous system), fowl pox, fowl cholera and fowl typhoid. In spite of these gains, however, the overall disease mortality among chickens has been reduced only moderately: from about 20 percent 25 years ago to 15 percent today. The chief reason for the persisting high rate is leukosis, the cancer-like disease of the blood. In chickens and turkeys, as in man, this leukemic disorder still frustrates the search for prevention or cure.

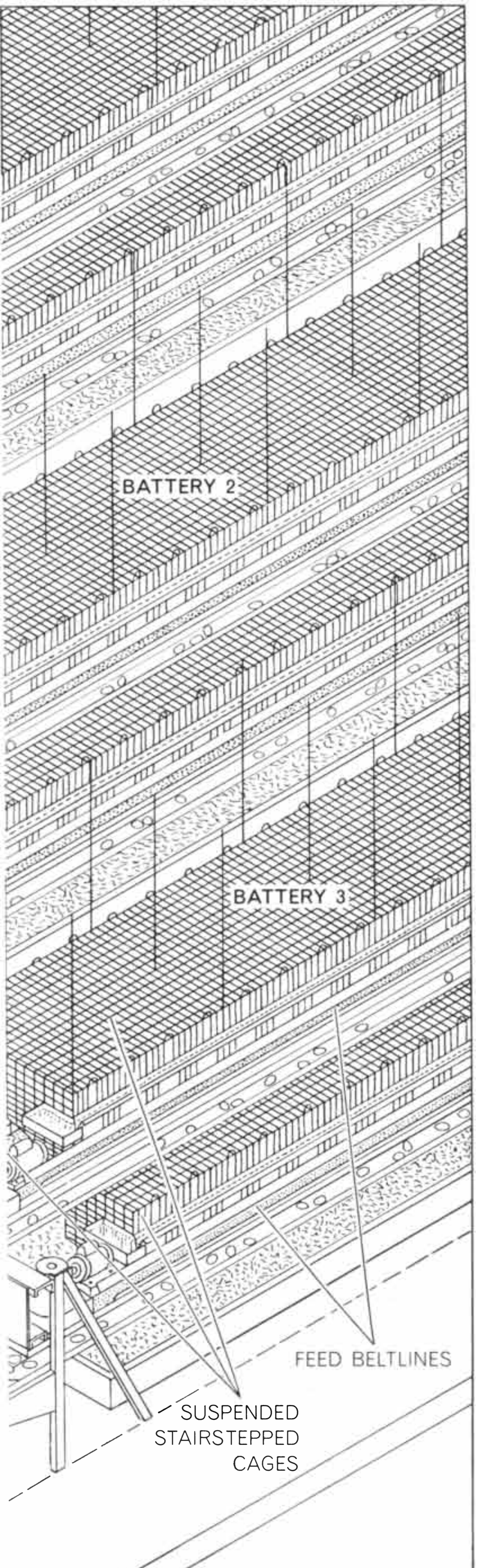
Mechanization

Undoubtedly the most striking change that has taken place in the poultry industry is in the scale of its operations and the standardization, or mechanization, of nearly all its processes. Once the hen has delivered its offspring in the form of eggs, the hatching and rearing of the young can be taken over entirely by artificial devices. In present practice the procedure is so highly mechanized that from the hatching of the egg to the delivery of the final product in the supermarket (a dozen boxed eggs or a neatly packaged fryer) almost no human handling is involved.

There are highly efficient poultry fac-



TWO-TIERED BATTERIES are suspended from the roof of the egg-production unit illustrated. In cross section the four rows of cages in each battery form two "stairsteps" back to back. Each cage contains two or three hens. Suspension from above facilitates me-



chanical cleaning; a 20,000-bird flock produces more than a ton of droppings a day.

tories today that integrate all the operations under one management: hatching, production of feed, rearing both egg-layers and meat chickens and marketing the products. For the most part, however, poultrymen still obtain their raw materials from special processors: chicks from hatcheries and feed from dealers in that commodity. The feed is delivered not in the cotton sacks that once provided material for the farmer's wife's dresses but by the ton in bulk. In the egg-producing branch of the industry there are specialists who rear the chicks through the pullet stage and then deliver them to the egg rancher. The pullet rancher receives only female chicks; the crowing of the chanticleer is never heard on his ranch. The supplying hatchery determines the sex of its chicks when they are a day old. The supplier then kills the males and ships the females.

The term "ranch" in this industry is now in a sense a misnomer, as the "ranches" consist of roofed buildings. In the comparatively mild climate of California these are generally open to the air. Many modern poultry houses, however, are entirely enclosed (some even have no windows) so that the light, temperature, humidity and ventilation can be controlled with precision. It has been found that the control of light during the rearing of pullets can increase their later egg production as laying hens and even influence the size of their eggs; it can also improve the growth of meat chickens and turkeys and reduce cannibalism and other vices of poultry. Control of temperature and humidity is also important, particularly during the early weeks of growth. After the first few weeks of brooding, during which the young fowl must be kept warm, the control is designed to maintain a cool, even temperature: poultry produce best at a temperature between 50 and 70 degrees Fahrenheit.

The chicken's or turkey's home today is generally a small cage, whose dimensions have been reduced as mechanization has proceeded. The laying hen used to be allowed an individual cage about 16 inches high, 12 inches wide and 18 inches deep—affording a total floor space of 1.5 square feet. Many poultrymen now keep three hens in a cage of this size, and it has been found feasible to maintain two hens in a cage only eight inches wide. The feeding of caged poultry has been thoroughly mechanized. Commonly the feed is sluiced mechanically into a trough outside the wire front of the cage, and the food delivery is regulated by a time clock. Other systems employ an electrically driven feed hopper or a large hopper in which the birds receive bulk rations that last for several days. "Chicken feed" today is measured in tons: for a flock of 60,000 hens, although each bird eats only about a quarter of a pound a day, the daily ration amounts to seven and a half tons.

The cleaning of the poultry house, the most unpleasant chore of the old-fashioned chicken farm, is now handled by skip-loading tractors or small powered cleaners of various types. The gathering of eggs, formerly the most pleasant aspect of keeping chickens, also is now fully mechanized. The hen's cage or nest is usually designed with a sloping floor so that the egg rolls gently out of the cage as soon as it is laid. (As far as can be determined, the disappearance of the egg does not make the hen neurotic.) A moving belt catches and carries off the eggs to a collection area, where they are picked up and packed by pneumatic "fingers." Before they are packed they are washed, dried and sometimes sprayed lightly with oil to protect them against evaporation and loss in quality on the way to the consumer.

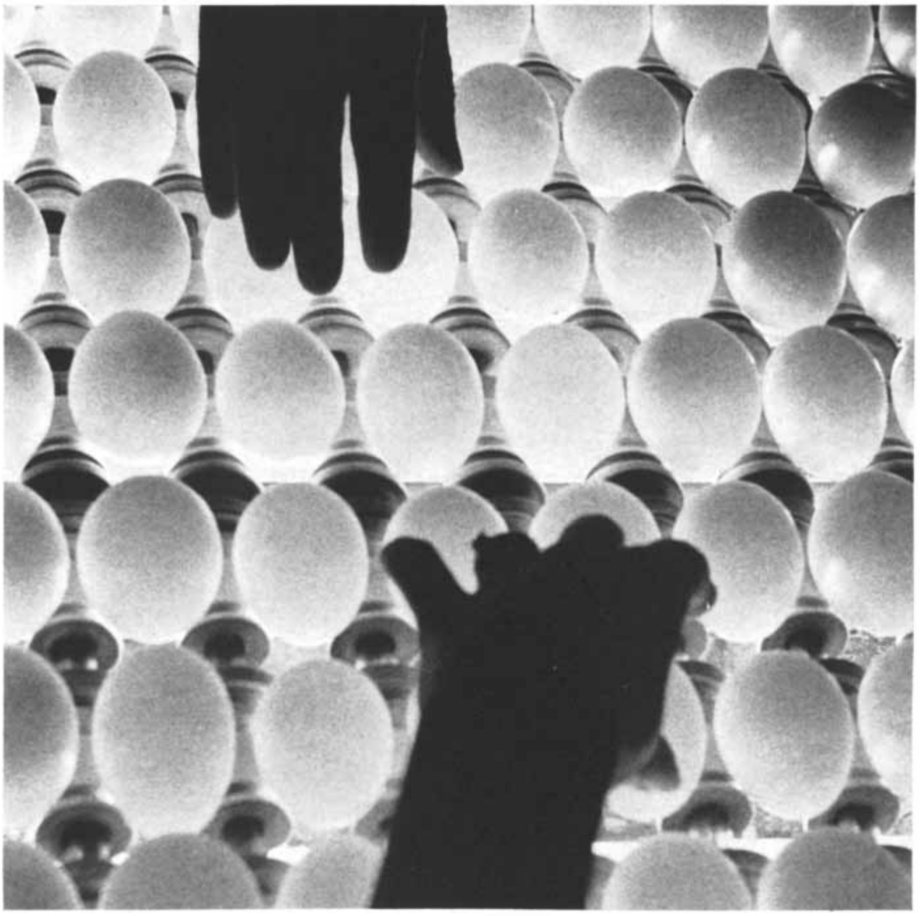
The Turkey

Turkeys are raised by mass-production methods similar to those used for chickens destined for the meat market. In the turkey's case, however, the breeding of the birds for large size has markedly reduced their fertility. Consequently a large proportion of the turkeys produced today (about 90 percent of those in California) are bred by artificial insemination.

The composite result of the improvements in poultry-raising technology is a spectacular increase in the birds' health and productivity. Turkeys are marketed at 18 weeks (for females) or 22 weeks (for males) instead of at 30 to 35 weeks, and the amount of feed required to raise them to market weight has been nearly halved.

Similar improvements have been achieved with chickens. Twenty years ago it took 14 weeks and 12 pounds of feed to produce a three-pound fryer chicken; today it takes only six to seven weeks and five or six pounds of feed. Hens in well-run egg factories now produce considerably more than 240 eggs a year (the minimum required for commercial success in a modern establishment).

WASHING EGGS is one of the final steps en route to market. After leaving the washing machine eggs often receive light coating of oil to reduce evaporation before consumption.



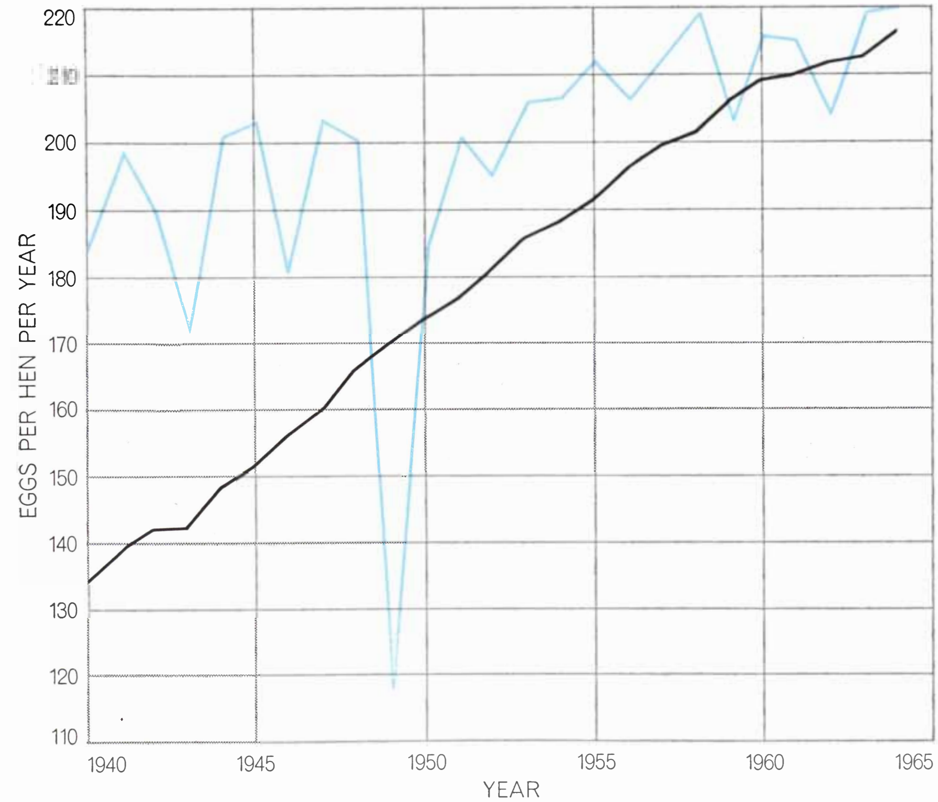
CANDLING MACHINE moves 30 dozen eggs a minute past two inspectors who keep watch not only for eggs that are not clean or have cracked shells but also for any internal defects.

The mechanization of the industry naturally has reduced drastically the amount of human labor required. Studies by the University of California Agricultural Extension Service over the years show that, whereas in 1935 the labor requirement on a commercial egg farm averaged two man-hours per hen per year, in 1964 it averaged only three-tenths of a man-hour per year. The present price of eggs (and of chicken and turkey) of course reflects the improvements in production and the savings in labor. The real price of eggs, allowing for the depreciated dollar, is lower today than it was before World War II, and the price of poultry meat is considerably lower. The year-round availability of eggs and poultry has also been improved. The laying season, formerly concentrated in the months of February, March, April and May, has been extended over the entire year, and it is now uncommon to find cold-storage eggs in the market. Freshly killed turkeys, once marketed only at Thanksgiving and Christmas, are now available throughout the year. The same is true of fryer chickens, which used to be known as "spring" chickens.

Economics

The new poultry technology has radically altered both the economics of the industry and the position its products occupy in the American diet. It has made poultry production a large-scale business and yet in a sense a shrinking enterprise from the standpoint of the number of people engaged in it. As in other branches of agriculture, the pressures of price competition and advancing technology in the poultry industry compel an ever increasing enlargement of the unit of production. The small poultry farm cannot compete in efficiency with a modern mechanized ranch. Moreover, this field of agriculture receives no governmental protection in the form of price supports or production quotas. The result has been a rapid decimation of the number of poultry farmers. Even the specialized units, while growing in size, have been reduced in number. The number of chick hatcheries in California, for example, decreased from 371 in 1947 to 81 in 1964, and the number of hatcheries for turkeys from 142 to 74—this in spite of the great increase in consumption of poultry during that period. Of course, the shrinkage in the number of producing units has been more than made up for by the expansion of the size

AUTOMATIC FEEDING of turkeys is accomplished by a weekly filling of hoppers that hold 500 pounds of feed at the Ephrata Turkey Farm in Ephrata, Pa. Up to the age of six weeks turkeys eat only a little more than a pound of feed for each pound that they gain.



NUMBER OF EGGS produced in a year by the average hen in the U.S. has risen more than 40 percent in the past 25 years (*black curve*). Although part of the gain is due to improved feeding and shelter, selective breeding has been the predominant factor. One example is the 15 percent increase within a genetically closed flock at the University of California at Berkeley (*colored curve*); each generation's best layers mothered the next generation. The large production dip in 1949 reflects an outbreak of Newcastle disease during that year. The chart is based on the work of Hans Abplanalp and I. M. Lerner of the University of California.

of the surviving establishments. The poultry industry today requires large capital, high technical skill, business acumen and fewer and fewer workers.

The new role of poultry in the U.S. diet represents no less pronounced a change than the position of poultry in agriculture. Turkey or chicken was once a special item reserved for Sunday dinner or holiday feasts; today it is an everyday staple. Poultry has become competitive in price with red meat and fish and is offered in inviting new forms. The aged, noble hen that used to require several hours of boiling to be made edible has been relegated to canned dog food and is replaced in the market by young fryers or broilers or by the chicken "TV dinner" and turkey roll that need only warming up. Chickens and turkeys now come with a stamp of guaranteed quality; about 85 percent of the dressed poultry sold in the U.S. is Government-inspected.

As we have noted, the annual consumption of poultry meat in the U.S. has more than doubled in the past 30 years—from 14.6 pounds per capita to 40.7 pounds. This is still considerably less than the 167 pounds of red meat the average American ate in 1965, but it seems likely that poultry will continue to gain a larger share of the meat diet.

Eggs too have been gaining steadily in favor. An egg contains only about 70 to 75 calories (thereby qualifying as a friend of the dieter), yet it is a rich source of vitamins, unsaturated fats, protein and other essential nutrients. Indeed, it would be a completely balanced food if one ate the shell! The shell's contribution (calcium) can easily be obtained from a supplement such as milk or a vegetable. Other aspects that promise a bright future for the egg as food are the extreme simplicity with which it can be prepared (notably as the boiled breakfast food) and its versatility. The egg's culinary possibilities, still only partly explored, cover a wide range, from the conversion of egg white into meringue and candies to the use of the yolk's emulsifying property to make mayonnaise or its yellow color to lend attractiveness to other dishes.

Research, particularly in the land-grant colleges and universities of the U.S., has been primarily responsible for the extraordinary development of the efficient new poultry technology and its products as a growing contribution to the U.S. food supply. It seems fair to say that continuation of the research will yield increasing benefits as time goes on.

The boy has a visual neuromuscular instability. Prescription: a big dose of television.

Steven's eye muscles are not balanced. So he has trouble using both eyes to see a single image. Because it is confusing for him to use both eyes, he uses one and suppresses the image from the other.

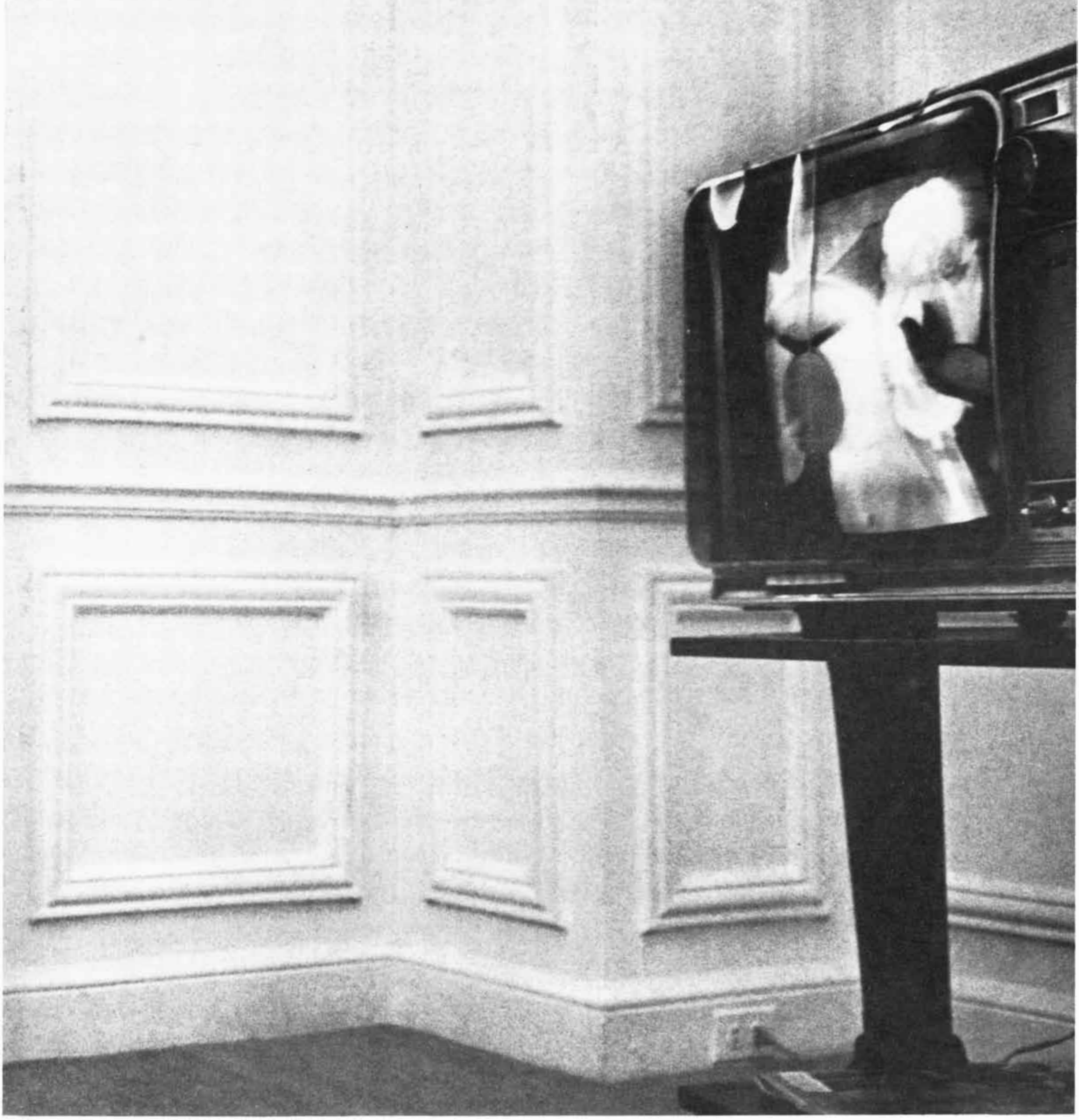
He must be taught to use binocular vision. And to help him learn, the ophthalmologist may prescribe an unusual therapy: watching television with the Polaroid/American Optical TV Trainer.

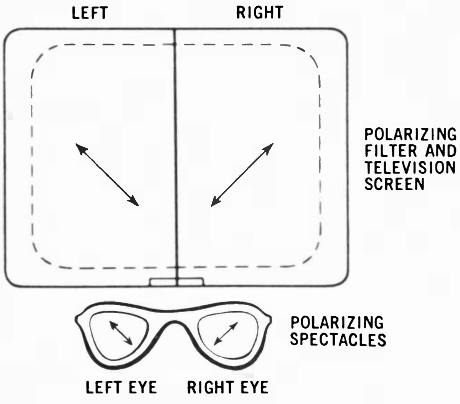
The TV Trainer is simple. It consists of a pair of Polaroid polarizing spectacles and a special polarizing filter which attaches to an ordinary TV screen. (Since 1937 Polaroid polarizing filters have been put to many uses. From polariscopes to sunglasses. From analyzing the atmospheres of planets to helping kids like Steven.)

The TV Trainer principle is this. The filter is divided down the center into two linear polarizing sections (a linear polarizer channels helter-skelter light waves into waves that go in one direction along a certain axis). These two sections polarize the light from the TV screen in two different directions.

The lenses in the spectacles are also linear polarizers. The left lens has the same polarizing axis as the left half of the filter. The right lens has the same as the right half. (We've diagrammed it here.)

Now, when light goes through two polarizers with identical axes, the polarizers remain transparent. But when it goes through two polarizers with axes that cross, the polarizers are opaque.





(The arrows indicate the polarizing axes.)

So when a child watches television with the TV Trainer he can see the whole picture only if he looks at the left side with his left eye (through the two left polarizers) and at the right side with his right eye (through the two right polarizers). In other words, he must use binocular vision. If he suppresses the image from one eye, that half of the picture will appear black. The polarizers won't let one eye work for him here.

A child learning binocular skills must do a great deal of work for himself. The advantage of the TV Trainer is that it makes it about as easy as possible. It makes it easy for him to recognize suppression, to know if he is using binocular vision and how well he is maintaining it. And it makes even a long training session a painless affair. No little boy is going to mind doing his homework if the homework is watching Captain Kangaroo.

POLAROID CORPORATION
Cambridge, Mass.

Polaroid ®

Polarized Accelerator Targets

Crystals in which the nuclear particles are all spinning in the same direction are bombarded with high-energy particles to measure how much the nuclear forces depend on the spin of the nuclear particles

by Gilbert Shapiro

Physicists have known for nearly 40 years that many elementary particles of matter are in a state of constant rotation, or spin. For most of this period it has been recognized that the forces that hold the atomic nucleus together depend in large part on the direction of spin of the particles that compose the nucleus (protons and neutrons). The spin-dependence of the nuclear forces has until recently been inferred from indirect measurements, because under the usual experimental conditions the axes of spin of the nuclear particles are oriented at random. In such circumstances one measures the "spin-averaged" nuclear interaction, that is, the nuclear forces averaged over all possible orientations of the particles' spin. Within the past few years workers at a number of laboratories around the world have succeeded in producing large samples of nuclear particles that are polarized (all spinning in the same direction). By using such polarized samples as targets in high-energy particle accelerators it has become possible to measure directly the extent to which the nuclear forces depend on the spin of the nuclear particles.

It does not mean quite the same thing to say that an elementary particle (for example a proton) is spinning as it does to say that a large object (for example a top) is spinning. When a top spins, its parts rotate in circles about an axis; one can put marks on the top and observe their motion. Subatomic particles cannot be treated so simply. It would be very difficult, for instance, to ascertain how fast a proton rotates, or how many revolutions per second it makes. The property a proton does possess in common with all other spinning objects is angular momentum. (For a large rotating object angular momentum is equal to the product of the object's mass times its velocity times its radius of rotation.) Like energy and linear momentum, angular momentum is believed to be conserved; the total amount of it in the universe stays the same forever. Any change in the angular momentum of any object must always be accompanied by a corresponding opposite change in some other object. It is only by studying such transfers that one is able to measure the angular momentum of an elementary particle.

The amount of angular momentum a proton possesses is the same as that of an electron, a neutron and several other particles. This fundamental unit of spin is equal to Planck's constant divided by 4π, a very small quantity by most standards. (If a pellet a millimeter in diameter and a milligram in weight had only this much spin, it would take 300 million years for the pellet to rotate through an angle of one second of arc!) A proton can never lose this small amount of angular momentum. Spin is one of its basic properties, and it would not be the same particle any more if it could stop spinning. The proton can, however, have its axis of rotation changed. Since angular momentum is a vector, or directed, quantity, its direction is just as important as its magnitude. When a proton that is spinning in a clockwise direction about some axis changes to spinning counterclockwise about the same axis, two basic units of angular momentum are transferred to the "outside world." This is the maximum amount of spin that can be extracted from the internal motion of a single proton.

It should be evident from the foregoing account that if a particle had spin but for some reason its direction of spin could never be changed, there would be no way to detect the spin, and it would be meaningless to talk about it. The fact that a particle possesses intrinsic angular momentum can only be established by observing its spin-dependent interactions with other particles. The discovery of the spin of the electron, first proposed by George H. Uhlenbeck and Samuel A. Goudsmit of the Netherlands in 1925, was based on the spin-dependence of the electron's electromagnetic interactions. The spin of the proton has been verified by studies of the spin-dependence of the nuclear forces as well as the electromagnetic forces.

There is a simple model that accounts for the spin-dependent forces that act on the electron. The electron possesses an electric charge. If the electron is spinning, this charge is in continual motion. An electric charge in motion constitutes a current. An electric current gives rise to a magnetic field. It follows that a spinning charged particle such as the electron will have electromagnetic properties much like those of a tiny bar magnet [*see top illustration on page 70*].

The strength of such a magnet is known as its magnetic dipole moment. A convenient unit for measuring magnetic moments is called the Bohr magneton; the electron's moment is slightly more than one of these units. Since many of the elementary particles have the same amount of angular momentum, the ones with more mass must be rotating slower and therefore must generate weaker electric currents. In general the greater the mass of a particle, the weaker its magnetic properties. The electron, being the lightest of all the particles that have an electric charge, has by far the strongest magnetic moment.

The magnetic interactions of the electron provide good examples of spin-dependent forces. One such example is the "spin-spin" type of interaction. Two electrons in close proximity exert the same kind of magnetic forces on each other as two bar magnets do. If the electrons happen to be parts of two different neutral atoms, these magnetic forces may be the dominant interaction between the two atoms. Spin-spin forces are characterized by a tendency to realign the two spin axes in such a way as to make them parallel to each other and by a capacity for producing motion at right angles to the line from one particle to the other. Spin-spin forces can be either attractive or repulsive; they are often both attractive and repulsive at the same time, depending on the relative orientations of the two spins involved.

Another type of spin-dependent electromagnetic force, called the "spin orbit," or velocity-dependent, force, is exemplified by a close encounter between a moving electron and a charged nucleus, in which the nucleus has either a very small magnetic moment or none at all [*see bottom illustration on next page*]. From the electron's point of view the nucleus is moving. The motion of a charged particle sets up a magnetic field in which the lines of force are circles centered on the line of motion of the particle. The strength of the magnetic field is, of course, greater the closer the electron comes to the nucleus.

First consider an electron about to pass by the nucleus on the left side. Suppose it is spinning about a vertical axis so that its magnetic dipole moment is pointing upward. The effect of the magnetic field is to tend to reorient the direction of the magnetic moment, just as the earth's magnetic field can reorient a compass needle. The preferred orientation is one in which the magnetic moment is parallel to (in the same direction as) the direction of the magnetic field. The particular electron we are considering is in the opposite orientation; its magnetic moment is said to be antiparallel to the magnetic field. It can accommodate itself to the magnetic field either by reversing its direction of spin so that the magnetic moment points down instead of up or by moving farther away from the nucleus, where the field is weaker—in other words, by moving farther to the left.

Now consider another electron, also with its magnetic moment pointing upward, but passing by the nucleus on the right side. The direction of its magnetic moment is parallel to the direction of the field, and as a result the electron tends to move closer to the nucleus, where the field is stronger. It is evident that an electron with its magnetic moment pointing upward will be deflected to the left by the magnetic field, no matter what side of the nucleus it passes.

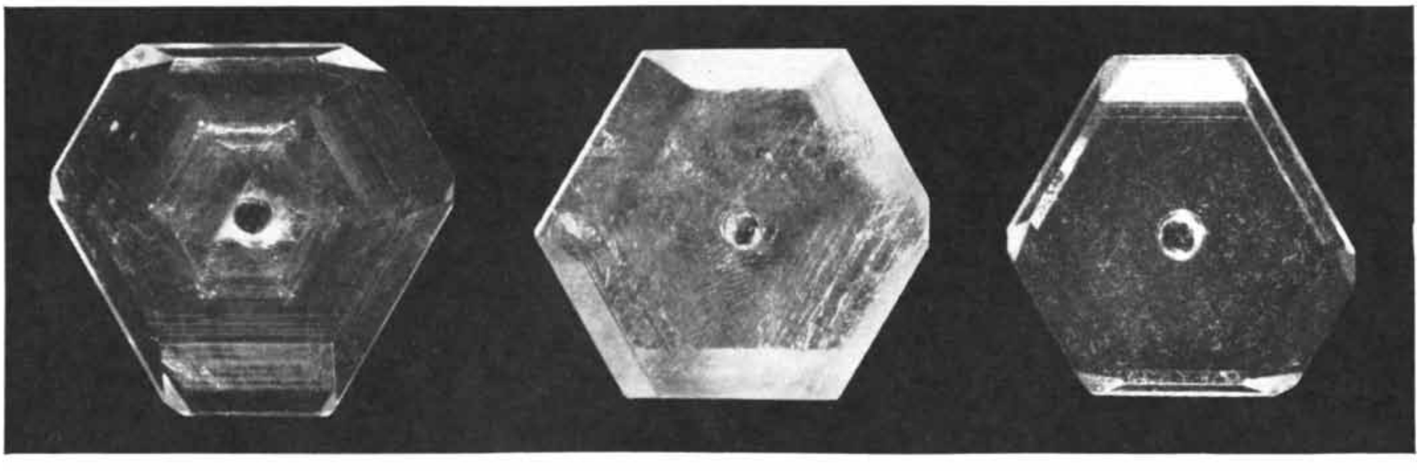
One can repeat the same argument to show that electrons with their magnetic moments pointing downward will be magnetically deflected to the right. It is much more appealing, however, to use a symmetry argument here. Having convinced oneself that "spin up" electrons are deflected to the left, simply turn the bottom illustration on the next page upside down to verify that the very same forces act to deflect "spin down" electrons to the right.

There are two features of such scattering by spin-orbit forces that should be remembered. The first is that if the incident beam is partially polarized—that is, if there is an excess of spin-up particles over spin-down particles (or vice versa)—there will be an asymmetry in the number of particles scattered by these forces: more particles will be scattered to the left than to the right (or vice versa). The second point is that even with equal numbers of spin-up and spin-down incident particles the scattered beam may be partially polarized. The beam scattered to the left may include more spin-up than spin-down particles, whereas the beam scattered to the right may have the opposite polarization.

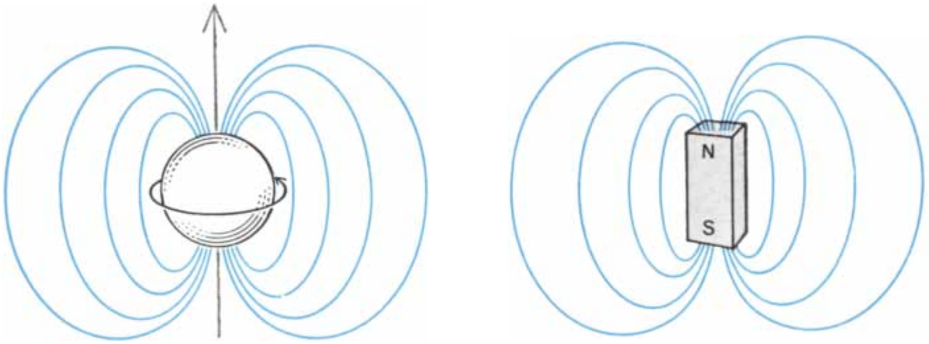
The model I have just used to describe the spin-dependent scattering of an electron by the magnetic field of a nucleus is a rather crude one. A correct treatment of the subject requires the use of quantum mechanics. This problem was first considered by the British theoretical physicist N. F. Mott in 1929, and the process has come to be known as Mott scattering. So much for the electron.

Indirect evidence has been accumulating since the 1930's that the forces between the nuclear particles are also spin-dependent and that the strength of these interactions is far too great to be accounted for by electromagnetic effects. This evidence comes from four principal sources:

First, the magnetic moment of the proton was found in 1932 to be, not 1,836 times smaller than that of the electron, as one might expect from the ratio of their masses, but 1/658 Bohr magneton—nearly three times too large. This discrepancy can be attributed to a difference in the internal structures of the proton and the electron, a difference that must arise from the nuclear nature of the proton. No theory can yet account



TARGETS used by the author and his colleagues in their polarized-proton experiments at the Lawrence Radiation Laboratory of the University of California at Berkeley are large single crystals of lanthanum-magnesium double nitrate [$La_2Mg_2(NO_3)_{12} \cdot 2H_2O$], in which 1 percent of the rare-earth element lanthanum is replaced by another rare-earth element, neodymium. The hole in the center of each crystal is not caused by the accelerator beam; it is an imprint of the small pedestal on which the crystals were grown.



BAR-MAGNET ANALOGY is helpful in visualizing the electromagnetic properties of a spinning charged particle. The angular momentum of the particle, which is a vector, or directed, quantity, is indicated by the large gray arrow. The strength of the field set up by the particle is known as its magnetic dipole moment. Since many of the elementary particles have the same amount of angular momentum, the ones with more mass must be rotating slower and therefore must generate weaker electric currents. The electron, being the lightest of all the particles that have an electric charge, has by far the strongest magnetic moment.

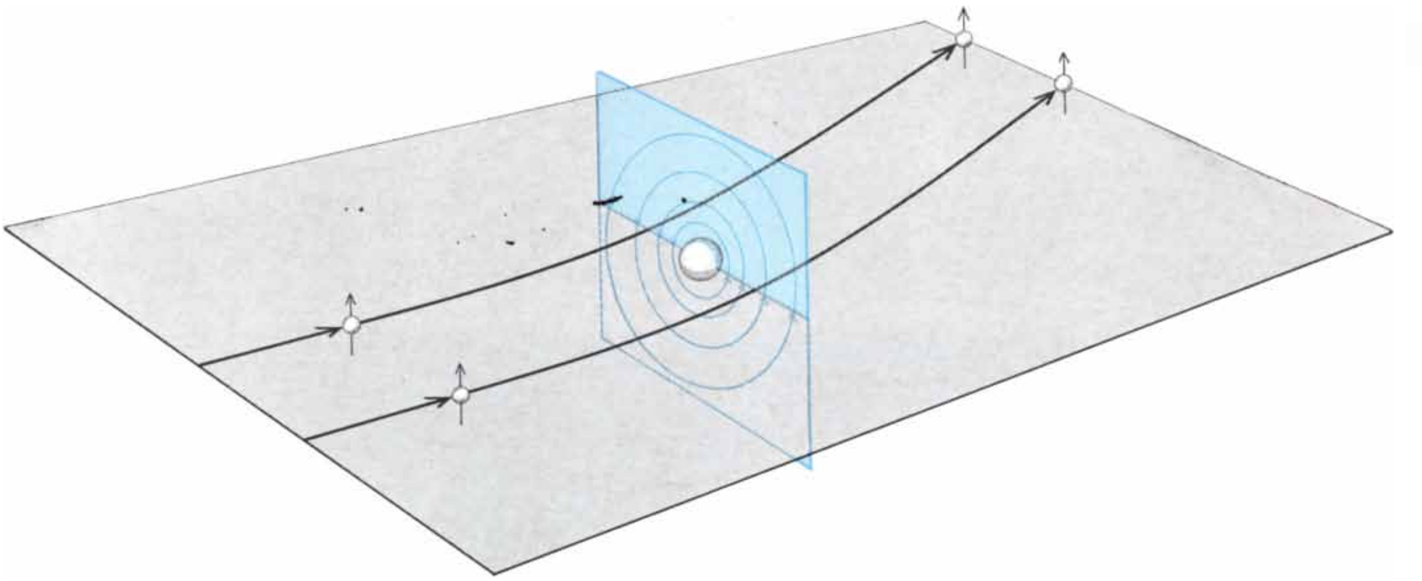
for the magnetic moment of the proton, although the magnetic moments of nonnuclear particles, such as the electron and the muon, can be calculated correctly to five or six decimal places.

Second, the neutron, which has no electric charge, has a magnetic moment comparable to that of the proton. This puzzling fact can be accounted for in a general way by imagining that there is a distribution of electric charge inside the neutron such that the negative charge rotates at a greater distance from the center than the positive charge does, while the net charge remains zero. Again there is no comprehensive theory that satisfactorily accounts for the neutron's magnetic moment.

Third, the simplest atomic nucleus—the binding of a proton and a neutron to form a deuteron—exists only when the proton spin and the neutron spin are aligned parallel to each other. There is no bound state when the spins are antiparallel. This suggests the existence of nuclear spin-spin forces far too strong to be simply magnetic.

Fourth, in the shell model of nuclear structure, proposed in the late 1940's by Maria Goeppert Mayer of the University of Chicago and J. H. D. Jensen of the University of Heidelberg, a strong spin-orbit force had to be assumed in order to obtain the proper spacing for the shells. Again the strength of the assumed force ruled out any purely magnetic explanation.

Then in the early 1950's a series of experiments performed at the University of Rochester and the Lawrence Radiation Laboratory of the University of California at Berkeley demonstrated the existence of spin-orbit forces in the interactions of protons with various nuclei. Similar work was reported soon after at Harvard University and at the British Atomic Energy Establishment in Harwell. In a typical experiment a beam of protons with a kinetic energy of some 300 million electron volts (mev) is extracted from an accelerator [*see illustration on opposite page*]. The beam is allowed to strike a target made of some substance such as graphite (chosen, among other reasons, because carbon nuclei have no spin). Some of the protons are scattered by colliding with the target nuclei. Particular attention is paid to the protons that are scattered at a certain angle, designated ϕ, which is chosen arbitrarily. The protons scattered at the angle ϕ to the left are called the *L* beam; those scattered to the right at the same angle are called the *R* beam. Particle detectors are placed in the paths of the *L* and *R* beams to verify



SPIN-DEPENDENT ELECTROMAGNETIC FORCE (in this case a "spin orbit," or velocity-dependent, force) is exemplified by a close encounter between a moving electron and an electrically charged nucleus. From the electron's point of view the nucleus is moving and therefore sets up a magnetic field in which the lines of force are circles centered on the apparent line of motion of the nucleus; the field is stronger closer to the nucleus. When the electron passes by the nucleus on the left side, its magnetic dipole moment (which is pointing upward) is antiparallel to, or in the opposite direction from, the magnetic field, and the electron responds by moving farther away from the nucleus, where the strength of the field is less. When the electron passes by the nucleus on the right side, its magnetic moment (again pointing upward) is parallel to, or in the same direction as, the field, and as a result the electron tends to move closer to the nucleus, where the field is stronger. Thus an electron with its magnetic moment pointing upward (a "spin up" electron) will be deflected to the left by the magnetic field no matter on which side of the nucleus it passes. By simply turning the illustration upside down it is possible to verify that the very same forces act to deflect "spin down" electrons to the right.

that there are an equal number of particles in both beams. This equality demonstrates that either the accelerator beam is unpolarized or there are no spin-dependent forces operating in the scattering. I shall now explain why the second hypothesis must be dropped.

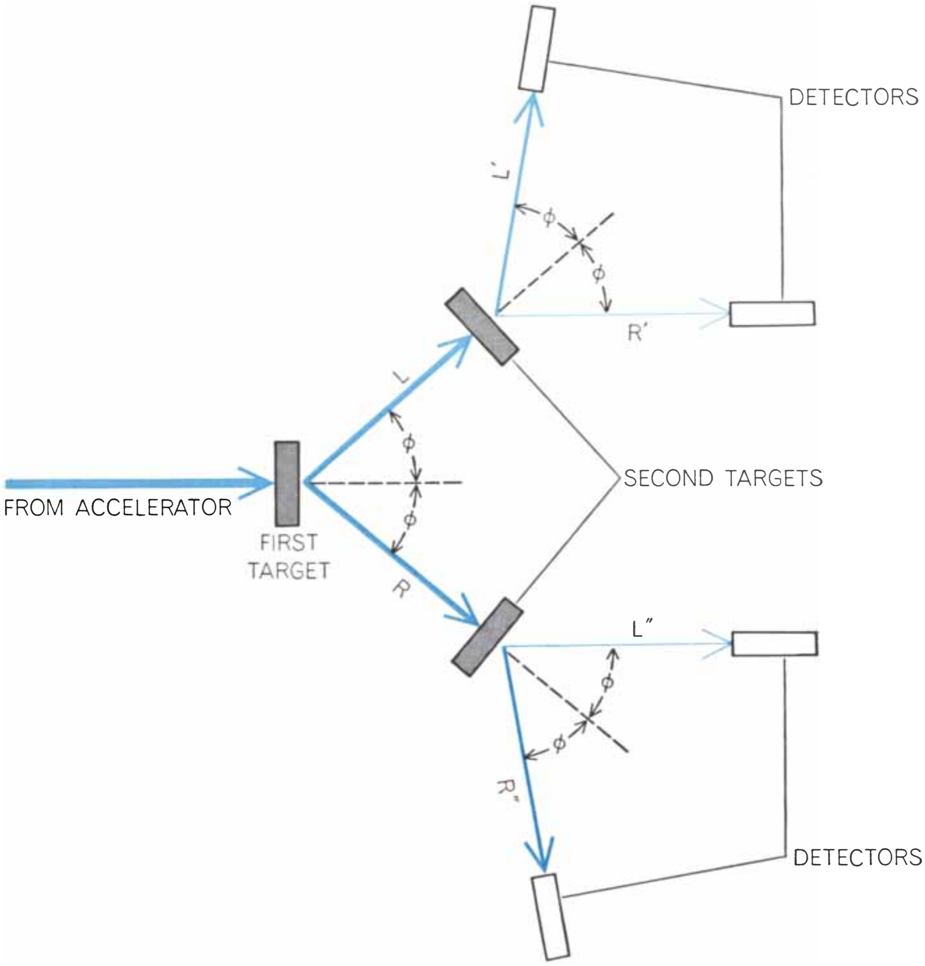
The *L* beam is conducted many feet across the experimental area, through slits, focusing devices, steering magnets and other equipment (not shown in the illustration), to a second scattering target, identical with the first. Once again the protons scattered at the same angle ϕ are observed to the left (L') and the right (R'). This time, however, there is a definite asymmetry. The number of protons in the L' beam consistently exceeds that in the R' beam. As a check the *R* beam is allowed to strike another identical target, and again an asymmetry is detected in the second-scattered beams. This time it is the R'' beam that exceeds the L'' beam in the number of particles detected.

The logic of analyzing this experiment is straightforward. The second scattering of the *L* and *R* beams is as identical with the first scattering as it is possible to achieve: same target, same angle, same energy beam. Something has happened to the protons as a result of the first scattering that makes them behave differently at the second scattering. Moreover, the protons carry information with them; somehow they "remember" at the time of the second scattering whether they were left-scattered or right-scattered the first time. The few feet the protons travel between scatterings is an enormous distance on the nuclear scale. Given the short range of nuclear forces, it is inconceivable that the protons can still be feeling the influence of the first target at the time of the second collision. It is clear that the direction of the first scattering was recorded on some internal coordinate of the protons. The only internal coordinate a proton has, as far as is known, is the direction of its spin axis. Hence the proton beam must become polarized in the course of the first scattering. The asymmetry exhibited in the second scattering is conclusive evidence for the existence of spin-orbit forces in nuclear scattering.

The double-scattering experiment I have just described is typical of many that have been performed over the past decade in order to examine the spin-dependence of the nuclear forces. A further refinement is the triple-scattering experiment. The first scattering serves to produce a beam of polarized particles. The second scattering is the nuclear reaction whose spin-dependence is being measured. The third scattering analyzes the polarization of the particles after the reaction. Related to triple-scattering experiments are "spin correlation" measurements, in which an unpolarized beam strikes an unpolarized target in the reaction under study. The polarization of both the scattered particle and the recoiling target nucleus is then analyzed by two simultaneous second scatterings.

A partial theoretical success has been achieved in analyzing the scattering of protons by protons and of neutrons by protons by taking the spin-dependence of these reactions into consideration. All the data concerning these reactions at energies of up to 400 mev can be accounted for if, and only if, one assumes that the force between the two particles is a strong spin-orbit force that is otherwise dominated (when the particles are fairly far apart) by the effects of exchanging a single "mediating" particle—a meson.

The success is only partial because such a theory is "phenomenological." One guesses at the form of the forces and then adjusts several "free" quantities to obtain the best fit. Very little information is gained about what one is to expect in other reactions, or in the same reactions at higher energies. In a complete theory one expects to be able to derive all these results starting from first principles. Nobody yet claims to have developed a full theory of nuclear scattering. The phenomenological theory continues to be used, because it is the best theory available. It is by no means trivial to be able to account for so many



DOUBLE-SCATTERING EXPERIMENT depicted here is typical of many that have been performed over the past decade to examine the spin-dependence of the nuclear forces. A beam of protons from an accelerator is allowed to strike a target, and some of the protons are scattered by colliding with the target nuclei. The protons that are scattered at an arbitrarily chosen angle ϕ to the left are called the *L* beam; those scattered to the right at the same angle are called the *R* beam. At this stage there are an equal number of particles in both beams. The *L* and *R* beams are then conducted many feet across the experimental area to two second-scattering targets, both identical with the first. Again the protons scattered at the same angle ϕ are observed to the left and to the right. This time, however, the number of protons in the L' beam consistently exceeds that in the R' beam, while the number in the R'' beam exceeds that in the L'' beam. The asymmetry exhibited in the second scattering is taken as conclusive evidence of the existence of spin-orbit forces in the first scattering.

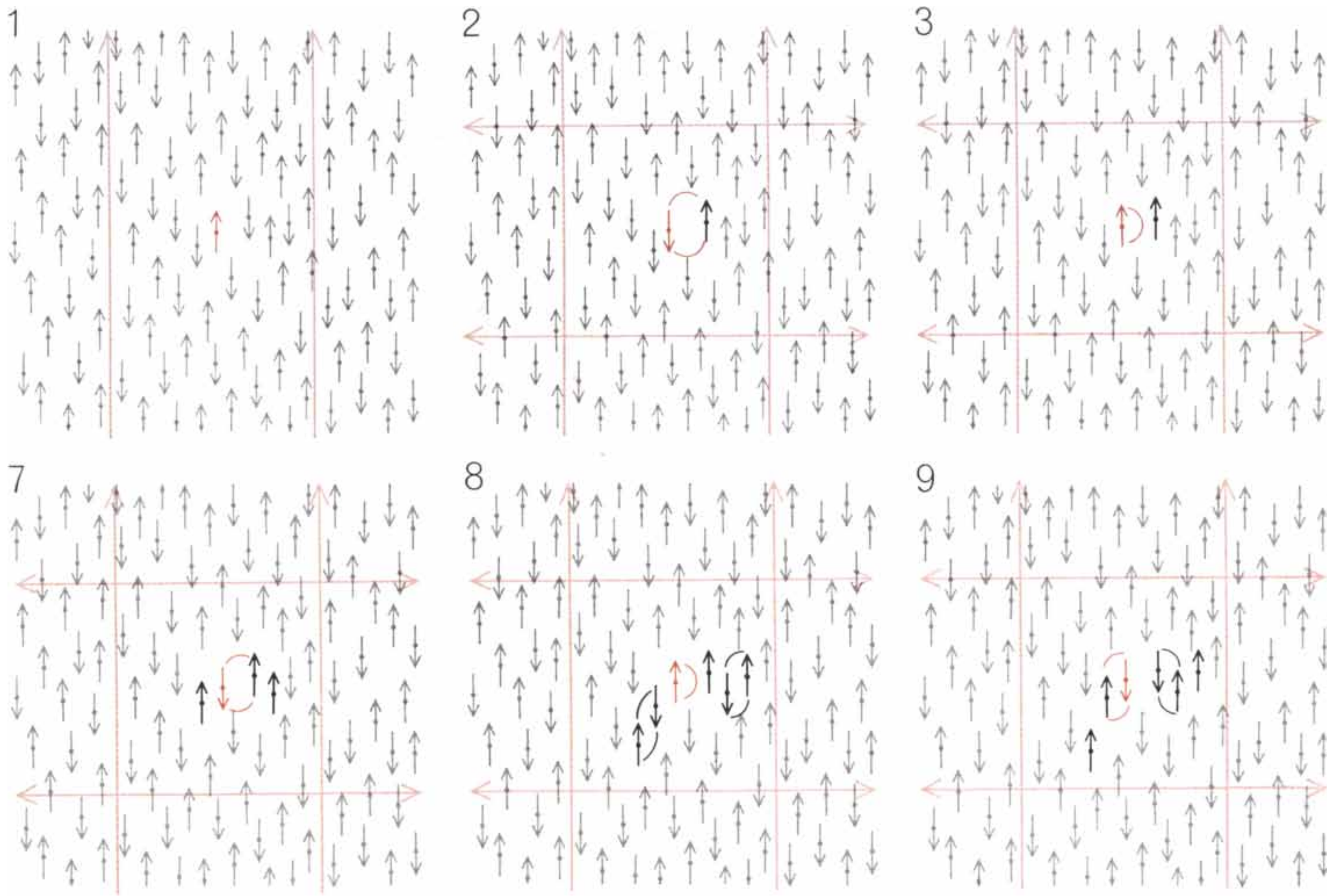
experimental results with so few assumptions.

Although double- and triple-scattering experiments yield extremely valuable information, they are beset with several rather severe difficulties. The experimenter must deal with very low counting rates, since only a small fraction of the particles are actually scattered at the desired angle by each target. Moreover, the effects one hopes to observe are small, not only because the spin-dependent part of the scattering may sometimes be only a small fraction of the total scattering but also because the beam is rarely 100 percent polarized by the first scattering, nor is the final scattering a perfect analyzer. Precise geometric alignment of all the pieces of equipment is essential, because reaction rates sometimes depend strongly on the scattering angle, and a small misalignment can result in a false left-right asymmetry. Errors are introduced because the polarizing and analyzing powers of the scatterers are not accurately known. These powers depend on the energy of the particle being scattered. At some energies there is very little spin-dependence, making it hard to polarize the particles or to analyze their polarization after scattering.

In recent years two techniques have been developed to circumvent some of these difficulties; one involves the use of polarized accelerator beams and the other the use of polarized nuclear targets. A polarized accelerator beam is made by polarizing the particles *before* they are accelerated by the machine. It is not at all certain that the process of acceleration will not destroy the polarization; this is a factor that depends critically on the design of the particular accelerator. Success has been achieved, mainly at "low" energies (less than 100 mev), in accelerating polarized beams of protons and deuterons.

A polarized target is simply a sample of some solid material containing nuclei whose spins are polarized. Before considering how such polarizations are obtained, a numerical definition of the term "percentage of polarization" appears to be in order. If all the particles in a sample are spinning in the same direction about parallel axes, they are said to be 100 percent polarized. If they are all spinning at random, they are 0 percent polarized. Usually one encounters situations somewhere between these two extremes. A partially polarized sample is described as though a certain fraction of the particles (say 60 percent) were completely polarized and the remainder completely unpolarized; such a sample would be called 60 percent polarized. In actuality, of course, one can never distinguish which protons are in the polarized fraction and which are in the unpolarized fraction.

An alternative interpretation is ob-

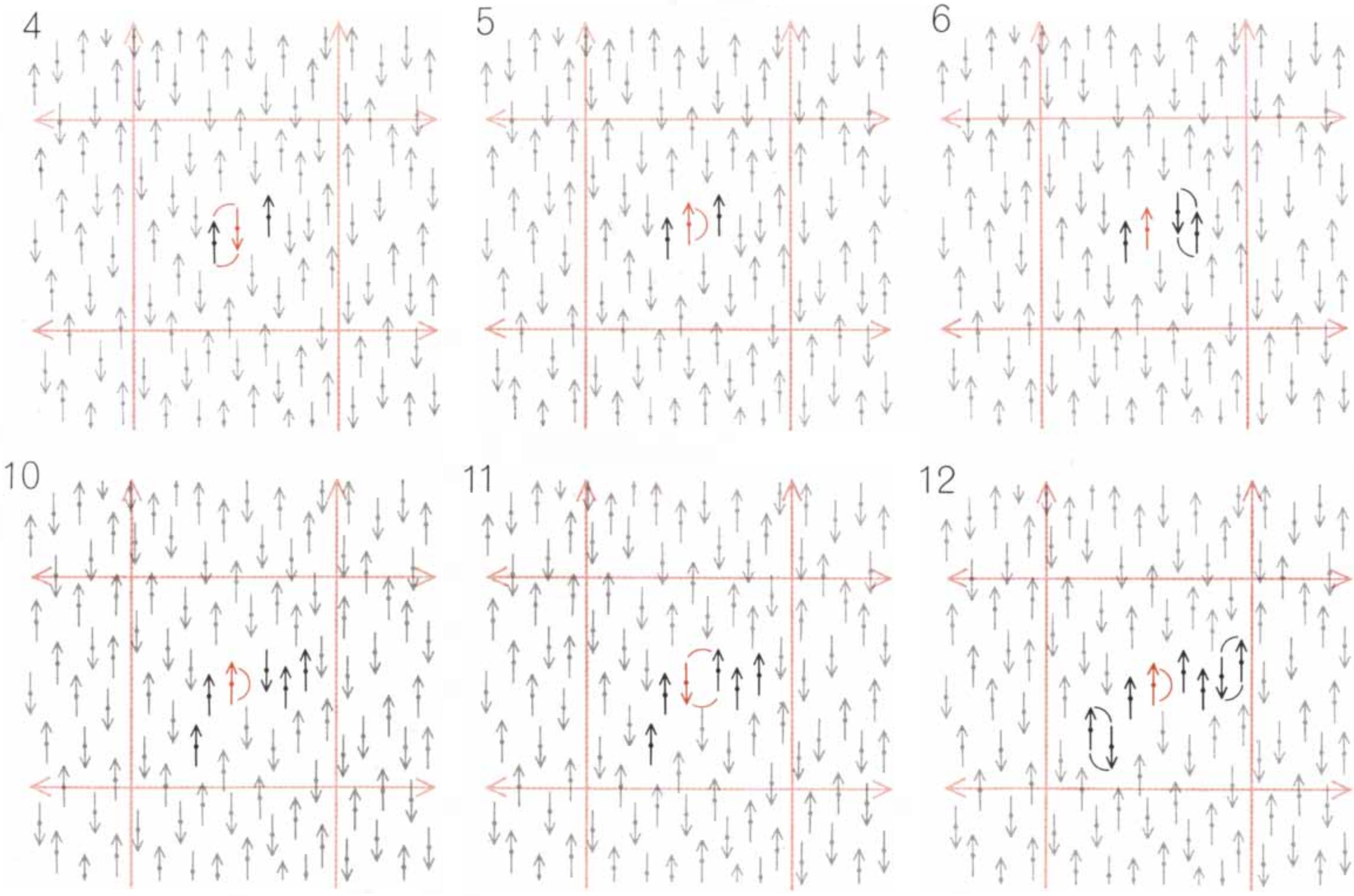


"DYNAMIC NUCLEAR POLARIZATION" is a general term used to describe several techniques for transferring the high polarization achieved in certain solids at very low temperatures in the presence of a strong magnetic field to some of the nuclei in the solid. The particular technique shown here, known as the solid-state effect, was discovered in the late 1950's mainly by C. D. Jeffries of the University of California at Berkeley and by A. Abragam of the Center for Nuclear Studies at Saclay in France. The solid-state effect requires a medium in which the unpaired electrons cannot be effectively depolarized, that is, a medium in which they undergo such frequent collisions with neighboring atoms that, no matter what process takes place to change their polarization temporarily, it returns immediately to its thermal-equilibrium percentage. On the other hand, the spins of the protons are so "slippery" that, once polarized, they may take many minutes or hours to return to equilibrium. As in other dynamic-polarization techniques, the number of protons being polarized may be much greater than the number of electrons acting as polarizing agents, since one electron can polar-

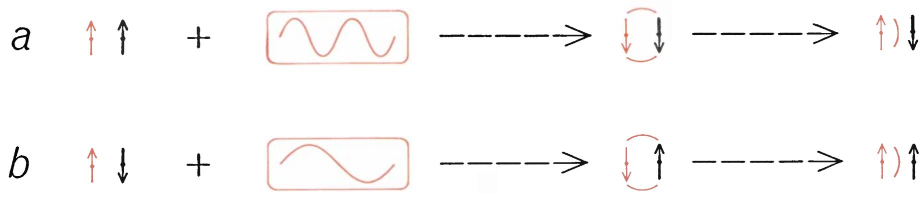
tained by considering rotation about a particular axis and noting the number of particles that are spinning in a right-handed sense about this axis (spin up) compared with the number rotating in a left-handed sense (spin down). In the 60 percent polarized sample just described all the polarized sample plus half of the remaining 40 percent are spin-up, for a total of 80 percent, while the rest are spin-down. Using either interpretation, it is easy to show that the "percentage of asymmetry" in the scattering is proportional to the percentage of polarization of the beam or the target. The constant of proportionality is the measure of the spin-dependence of the reaction under study.

The most obvious way to polarize a large sample of particles—by subjecting them to a very strong magnetic field—has come to be known among high-energy physicists as the "brute force" method. I mentioned earlier that a spinning particle with a magnetic moment has properties similar to those of a bar magnet. The analogy can be carried a step further to point out that in the presence of the earth's magnetic field all compass needles point north. In the terminology of this article the needles would be called 100 percent polarized.

Under ideal conditions the spins of any sample of particles would be similarly polarized in the presence of a magnetic field. As the reader may surmise, however, the conditions are seldom ideal. In any real solid at temperatures other than absolute zero the atoms and nuclei are constantly buffeted by collisions with the lattice of neighboring atoms. These collisions have the same effect on spinning nuclei that violent shaking has on a compass needle: the magnetic-moment direction (which is the same as the spin axis) keeps getting reoriented away from the magnetic-field direction, so that the percentage of polarization is much reduced. The actual amount of polarization that is obtained when a system of particles is in thermal equilibrium with its environment at some low temperature and in the presence of some magnetic field can be calculated. This brute-force polarization is given roughly by the ratio of the magnetic energy (the product of the magnetic moment of the particle times the strength of the magnetic field) to the average thermal energy of the surrounding atoms (proportional to the absolute temperature). For example, taking the magnetic moment of the proton (1/658 Bohr magneton), the field of a strong laboratory electromagnet (20,000 gauss) and a temperature conveniently reached by cooling with liquid helium (1 degree above absolute zero), one finds that the thermal-equilibrium polarization of protons under these con-



ize many protons. In step *1* a single electron (*color*) is shown with its angular-momentum vector pointing in the same direction as the static magnetic field (*large vertical colored arrows*). The angular-momentum vectors of the protons (*gray*) are oriented at random (in quantum mechanics they can be regarded as being simply half spin-up and half spin-down). In step *2* radio power (*large horizontal colored arrows*) is applied at right angles to the static magnetic field at a frequency corresponding to the simultaneous "spin flip" of an electron and a proton. In step *3* the electron snaps back immediately, ready to work on a new proton (step *4*); the protons that are transferred to "up" stay that way. In subsequent steps the polarization "diffuses" outward to more remote protons by the spontaneous transfer of polarization from one proton to another. The electron continues to flip the protons that are adjacent to it. If the electrons are more efficient at polarizing the protons than various other processes are at depolarizing them, most of the protons will soon be polarized. Several groups have achieved polarizations of better than 70 percent using this particular dynamic polarization technique.



FREQUENCY OF RADIO POWER (represented here by discrete quanta, or energy parcels) can be changed slightly to achieve either direction of proton polarization without changing the static magnetic field or otherwise affecting the experimental conditions. In *a* the frequency is just right for the transition "electron up, proton up" to "electron down, proton down." In *b* the frequency corresponds to the transition "electron up, proton down" to "electron down, proton up" (this is the transition shown in the illustration on the preceding two pages). In both cases the transitions can go either way, but since most of the electrons are "up" to begin with the transitions go predominantly to the right. The electrons snap back to equilibrium immediately, but the protons, once polarized, stay that way.

ditions is .2 percent. This means that in a sample of 1,000 protons 501 will be spin-up and 499 spin-down. To obtain higher polarizations in this manner one must build expensive high-strength magnets and use special techniques to reach very low temperatures. Hence the term "brute force."

If one considers the effect of the same magnetic field and temperature on the polarization of the electron, one finds quite a different situation. Because the electron's magnetic moment is so large, its magnetic energy is comparable to the thermal energy at 1 degree above absolute zero in a field of 20,000 gauss. The thermal-equilibrium polarization of electrons is well over 50 percent in such a situation. Unfortunately, in a solid (everything but helium is solid at these temperatures) electrons are strongly constrained to team up in pairs with equal and opposite spins, resulting in zero polarization. The thermal-equilibrium polarization percentage quoted above applies only to the unpaired electrons, which may be only a small fraction of the total number of electrons present. The same pairing constraint does not usually apply to the nuclei in these solids, one important exception being the protons in solid pure hydrogen at thermal equilibrium. Again unfortunately, this is one of the substances physicists would be most interested in polarizing.

There are several clever tricks one can play to transfer the high polarization of the unpaired electrons to some of the nuclei in a solid. The oldest method for effecting this transfer is the "static" method proposed independently by M. E. Rose, then at the Oak Ridge National Laboratory, and C. J. Gorter at the Kamerlingh Onnes Laboratory in the Netherlands in the late 1940's. They noted that in many substances there is an unpaired electron close to each nucleus. These electrons interact with the nuclei by means of magnetic spin-spin forces. In effect they set up extremely strong local fields. At the site of the nucleus these local fields may be millions of gauss, or 100 times stronger than the external field. The local fields vary in direction from place to place in the crystal, averaging to nearly zero over any sizable volume. But if the electrons are highly polarized and the solid has the right crystal structure, the local fields *at each nuclear site* will all be in the same direction. Therefore the nuclei become polarized as if they were in that same strong external field.

The most famous use of the Rose-Gorter technique was in the 1956 experiment by C. S. Wu of Columbia University and a group at the National Bureau of Standards that demonstrated that the beta decay of polarized cobalt-60 nuclei can be used to make an absolute distinction between right and left [see "The Overthrow of Parity," by Philip Morrison; SCIENTIFIC AMERICAN, April, 1957]. Experiments employing polarized heavy nuclei as targets in nuclear reactions have also been carried out by groups at the Bureau of Standards, Oak Ridge and the Brookhaven National Laboratory.

Most physicists would prefer to have polarized targets of protons or of some light nucleus such as that of deuterium or helium 3 (a rare isotope of helium with nuclei consisting of two protons and one neutron). The interpretation of such experiments is not unduly complicated by problems of nuclear structure, and one expects to be dealing with more fundamental interactions. The static methods of obtaining polarization do not seem to be applicable to hydrogen and helium. For these nuclei we must appeal to "dynamic" nuclear polarization methods.

In 1953 Albert W. Overhauser, then at the University of Illinois, proposed a novel method for obtaining nuclear polarization in alkali metals (for example lithium and sodium). The conduction electrons (which are unpaired in alkali metals) are highly polarized in thermal equilibrium at suitable temperatures and field strengths. If one deliberately depolarizes the electrons and then permits them to return to equilibrium, they will do so mainly through the mechanism of spin-dependent collisions with nuclei. Overhauser postulated that the nuclei have no fast way to get rid of the excess angular momentum transferred to them by such collisions. Therefore if one repeatedly depolarizes the electrons (by applying radio power at just the proper frequency), the nuclear polarization will build up until it is equal and opposite to that of the electrons. To the surprise of many physicists, T. R. Carver and Charles P. Slichter at Illinois demonstrated in 1955 that this effect works exactly as Overhauser had predicted.

Almost immediately it was recognized that the principle of dynamic nuclear polarization applied to much more general situations than the one treated by Overhauser. Many different variations in the method have been used to obtain polarization in many different nuclei. These variations have several features in common with the Overhauser effect. For one thing, the number of nuclei being polarized may be much greater than the number of electrons acting as polarizing agents, since one electron can polarize many nuclei. In all cases external power is applied to selectively flip the spins of certain parts of the system. Finally, the polarization obtained is many times higher than would occur at thermal equilibrium.

The particular method that has been of most use in polarizing protons was discovered in the late 1950's mainly by C. D. Jeffries of the University of California at Berkeley and by A. Abragam of the Center for Nuclear Studies at Saclay in France. The latter has called this method the "solid-state effect." The development of the method has been carried out principally by these two workers and notably by M. Borghini, who worked first at Saclay and then at the European Organization for Nuclear Research (CERN) in Geneva. Important contributions have also been made by groups at the University of Oxford, the University of Besançon, the University of Minnesota, Yale University, Harvard University and the Joint Institute for Nuclear Research at Dubna in the U.S.S.R.

The solid-state effect requires a medium in which the unpaired electrons cannot be effectively depolarized, that is, a medium in which they undergo such frequent collisions with neighboring atoms that no matter what process takes place to change their polarization temporarily it returns immediately to its thermal-equilibrium percentage. On the other hand, the spins of the nuclei that are being polarized (which we shall hereafter take to be protons) are so "slippery" that, once polarized, they may take many minutes or hours to return to equilibrium. It is possible, however, to transfer polarization from one proton to another, so that if the protons closest to the unpaired electron get polarized first, this polarization can "diffuse" out to more remote protons [*see illustration on pages 72 and 73*].

Radio power is applied at right angles to the static magnetic field at a frequency corresponding to the simultaneous "spin flip" of an electron and a proton. For example, the frequency may be just right for the transition "electron up, proton up" to "electron down, proton down" [*see illustration on opposite page*]. The transition can go either way, but since most of the electrons are "up" to begin with the transition goes predominantly to the right. The "down" electron snaps back up immediately, according to the solid-state hypothesis, ready to work on a new proton. The protons that get transferred to "down" stay that way. The reaction proceeds until there are very few "up" protons left, or until most of the protons become polarized "down."

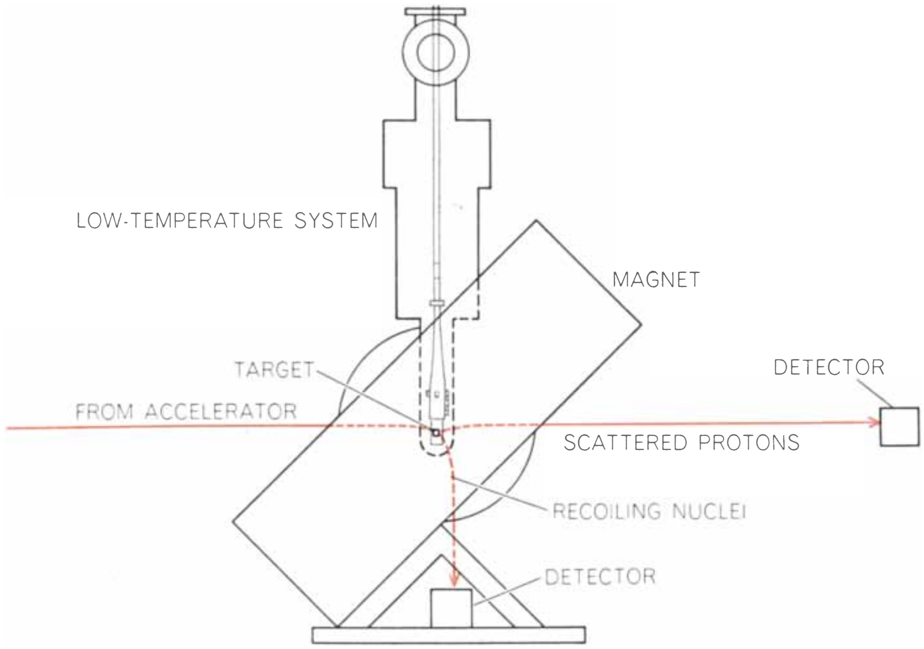
In a similar way, one can also obtain protons polarized "up" by changing the radio frequency to correspond to the transition "electron up, proton down" to "electron down, proton up." As before, the transition proceeds mainly to the right, until there are very few "down" protons left. Thus one can achieve either direction of proton polarization without changing the magnetic field or otherwise affecting the experimental conditions.

The substance that has been found most suitable for obtaining high proton polarization is lanthanum-magnesium double nitrate, whose chemical formula is $La_2Mg_3(NO_3)_{12} \cdot 24H_2O$, in which 1 percent of the rare-earth element lanthanum is replaced by another rare-earth element, neodymium, which provides the unpaired electrons. This compound was chosen because it contains both rare earths and an appreciable content of hydrogen, in addition to having the properties required to make the solid-state effect work. Several groups have reported proton polarization higher than 70 percent in this crystal. It would be desirable to polarize materials richer in hydrogen, and the search for such possibilities is continuing.

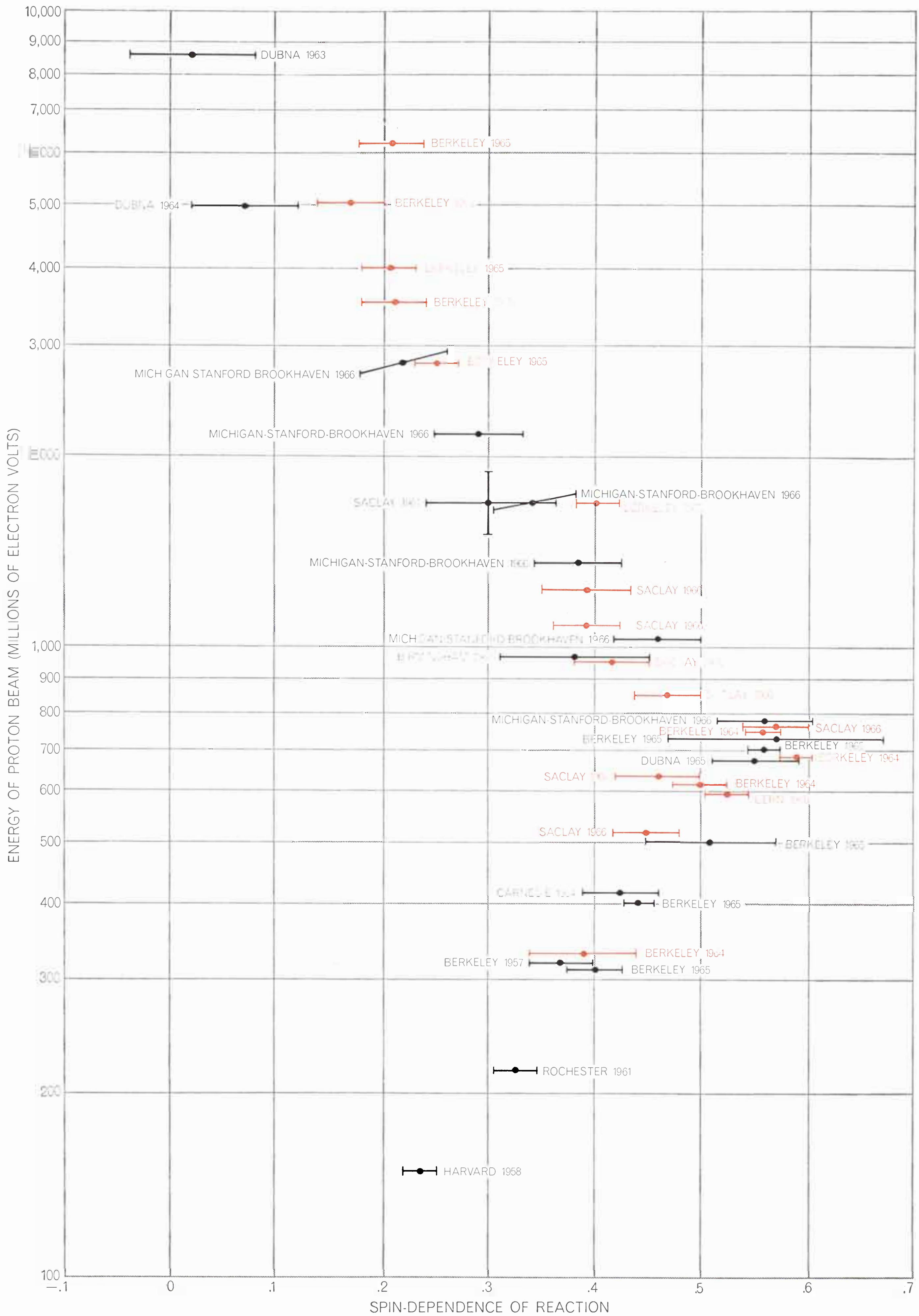
At least one other method of obtaining nuclear polarization has been used to polarize the nuclei of helium 3. Groups working at Texas Instruments, Inc., and at Rice University use the technique of "optical pumping" for this purpose [see "Optical Pumping," by Arnold L. Bloom; SCIENTIFIC AMERICAN, October, 1960]. Light of the proper wavelength and polarization is used to excite the helium-3 atoms in such a way that when they return to the "ground" state they always wind up in one orientation of the nuclear spin (say spin up) rather than the other. This technique, unlike all the others mentioned so far, works at room temperature, which is a great advantage. In order to avoid the collisions that would quickly restore thermal equilibrium, however, it is necessary to work with a low-density gas. The technique works best at a pressure of only one millimeter of mercury. Such low densities are inconvenient for studying nuclear reactions; the walls of the container are likely to do more scattering than the gas itself. Nevertheless, these workers have shown that it is possible to do certain experiments—for example the scattering of alpha particles by helium-3 nuclei—using such a target.

The relation between multiple-scattering experiments and experiments with polarized targets can be deduced from considerations of symmetry. One such consideration, applicable to proton-proton scattering, is the indistinguishability of identical particles. After a collision between two protons it is impossible in principle to tell which of the final particles was originally the target and which the projectile. Therefore it makes no difference whether the beam or the target is polarized; one obtains the same asymmetry in scattering.

Another symmetry consideration is that of "time reversal." This notion says in effect that a motion-picture film of any process should show the system appearing to obey the same laws of physics whether the film is run forward or backward. Until 1964 no experiment had ever contradicted this idea of time-reversal invariance, but it has recently been called into question by certain experiments in the decay of neutral *K* mesons [see "Violations of Symmetry in Physics," by Eugene P. Wigner; SCIENTIFIC AMERICAN, December, 1965]. In the case of an elastic collision, not necessarily between identical particles, one can think of two processes that are time-reversed images of each other. In the first process two unpolarized parti-



EXPERIMENTAL SETUP used in the polarized-proton tests at Berkeley is shown here. The low-temperature system keeps the target crystals at 1.15 degrees above absolute zero by bathing them in liquid helium at low pressure. The magnet generates a field of 18,750 gauss, uniform to within one gauss over the volume of the sample. The microwave-frequency power used to maintain the dynamic polarization is about one watt at 70,000 megacycles per second. Detectors are placed to intercept both the scattered protons from the incident beam and the recoiling nuclei from the target (which in this case are also protons).



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SPIN-DEPENDENCE OF REACTION

cles collide and one of them becomes polarized by the collision. In the backward-image process one of the initial particles is polarized and the final polarizations are not measured. The principle of time-reversal invariance states that there will be an asymmetry in the second process that is numerically equal to the percentage of polarization induced in the first process.

The implication of this statement is that a single scattering from a polarized target can yield the same information as double scattering from unpolarized targets. Not only that, but most of the disadvantages of double scattering mentioned earlier are overcome. For example, the problem of precise geometric alignment of the detectors is avoided. One observes the change in counting rates when the directions of spin of the target protons are reversed. This is equivalent to turning the apparatus upside down, thus changing "left" to "right" without moving any detectors at all. In addition, measurements can be made at several angles simultaneously. Counting rates are high, because only one scattering process is involved. With a polarized target it is possible to measure this kind of spin-dependence over a wide range of energies in many different reactions, and to do it fairly quickly.

By the same token, triple scattering can be simulated with only two actual scatterings when a polarized target is available. Sometimes use of a polarized target is the only way to make such a measurement, as when the incident particle is a meson. Some mesons have no spin and hence cannot be polarized themselves; they are also unstable and hence cannot be made into targets for a polarized-proton beam to strike. In order to simulate triple scattering of mesons by protons there is no alternative but to do a double scattering with a polarized target.

RESULTS of experiments in elastic proton-proton scattering using the double-scattering technique (*black*) and the polarized-target technique (*color*) are compared. The experiments were performed in the years indicated at university laboratories in several countries and at the Center for Nuclear Studies (Saclay), the European Organization for Nuclear Research (CERN) in Geneva, the Joint Institute for Nuclear Research (Dubna) in the U.S.S.R. and the Brookhaven National Laboratory. The spin-dependence, or polarization parameter, of each reaction is equal to the percentage of asymmetry of the scattered protons divided by the percentage of polarization of the target protons. Bars indicate experimental error.

With both a polarized beam and a polarized target one can perform the time-reversed process of a spin-correlation experiment. This is an extremely economical use of the accelerator beam, since one accomplishes in a single scattering what formerly required three separate scatterings to measure. The first experiment actually to use a polarized target, conducted by a group at Saclay, made just this kind of measurement in proton-proton scattering at 20 mev.

In an inelastic collision in which the final particles are not the same as the initial ones the time-reversal argument used above does not apply directly. One can still derive the same conclusions, however, provided that the final particles have the same amount of spin as the initial particles and that the "relative intrinsic parity" of the final particles is the same as that of the initial particles. (Intrinsic parity is a property, like spin, that is often ascribed to particles. Parity can take only two values: +1 or −1. Since parity, unlike angular momentum, is not always conserved, it is only meaningful to talk of the relative parity of pairs of particles.) It is thus possible to determine the spin and parity of certain new particles by comparing the results of two experiments. In the first experiment one produces the particles under study by means of a certain reaction, using an unpolarized target, and observes to what extent these particles emerge polarized. In the second experiment one conducts the same reaction, using a polarized target, and observes the spin-dependence of the reaction rate. The results of the two experiments are numerically equal if, and only if, both the spin and the relative parity of the final particles are the same as those of the initial particles. If the relative parity has changed, the two experiments should give equal but opposite results.

Two experiments of this nature have already been performed, although the analysis of them is not complete at this writing. At Berkeley we have measured the relative parity of the sigma and K particles. At CERN an experiment has been performed to test the parity of the xi hyperon with respect to the proton. The results of these experiments will be of some importance, since nearly every theory currently being advanced predicts negative relative parity in the former case and positive relative parity in the latter.

Our group at Berkeley, headed by Owen Chamberlain, became interested in building a polarized-proton target for studying high-energy nuclear reactions in 1960. Some of the members of the group had formerly been involved in the double- and triple-scattering experiments mentioned earlier in this article. Working closely with Jeffries, we decided to use the solid-state effect to obtain proton polarization. Until that time only small samples, crystals weighing at most 200 milligrams, had been polarized. In order to intercept a reasonable fraction of the high-energy beams available at the Berkeley accelerators we needed a target 100 times larger. This presented a formidable engineering task. Everything had to be scaled up by a factor of 100: the capacity of the liquid-helium cooling system, the amount of high-frequency power needed to maintain the polarization, the extent of the highly uniform magnetic field. Large single crystals had to be grown, a painstaking and often frustrating process [*see illustration on page* 69]. In 1962 Claude Schultz and I succeeded in obtaining about 20 percent polarization in the protons contained in a 26-gram sample.

Many improvements have been made since our first success. The polarized-proton system as it now stands consists of the following ingredients: the target itself, a stack of crystals of lanthanum-magnesium double nitrate with a 1 percent neodymium impurity; a low-temperature system, which keeps the target at 1.15 degrees above absolute zero by bathing it in liquid helium at low pressure; a magnetic field of 18,750 gauss, uniform to within one gauss over the volume of the sample, and microwave-frequency power to maintain the dynamic polarization, in this case about one watt at 70,000 megacycles per second [*see illustration on page* 75]. Under usual running conditions the proton polarization varies between 45 percent and 65 percent. On isolated occasions all the groups have measured even higher proton polarizations.

Two important problems had to be solved in connection with the use of this target. One was the question of knowing exactly how much polarization we had at any time. The other was the problem of how to distinguish the effect caused by the free protons (which constitute only 3 percent of the total weight of the crystals) from the contributions of the oxygen, lanthanum and other nuclei in the compound. The amount of polarization is measured by the technique of nuclear magnetic resonance. A small amount of power is applied at a frequency of about 80 megacycles and the amount of power absorbed by the crystals is measured. This amount is roughly proportional to the amount of polarization, but several complicated corrections must be made in order to obtain a precise result. As for distinguishing the effect of the free protons, we noted that any change in a reaction rate that takes place when the target polarization is reversed must be due to the protons, since most of the other nuclei have no spin, or if they do, they have negligible polarization. In addition, we made use of the law of conservation of energy and momentum to show that there is a relation between the energy and the angle of the outgoing particles when the scattering is by a free proton that is not satisfied when the scattering is by a heavy nucleus. In the experiments we have done so far it has often turned out that at the proper scattering angles the free-proton events outnumber the background by a factor of five or more.

With such a wide and largely unexplored field now made accessible to experiment, it is no surprise that so many laboratories have constructed their own polarized-proton targets. In addition to Berkeley, Saclay and CERN, the Rutherford Laboratory near Oxford in England and the Argonne National Laboratory have already had polarized-target experiments performed at their accelerators. At CERN it is not uncommon to have two polarized targets operating simultaneously. Lower-energy installations have also gone into the business.

It is only a slight exaggeration to remark that every reaction ever studied with an unpolarized proton target can profitably be repeated with a polarized target, in order to learn the spin-dependence of the reaction. This is in fact the program on which all these laboratories seem to have embarked. One takes all possible beams of particles—protons and pi mesons first, perhaps *K* mesons and antiprotons next—at all energies available and measures the polarization dependence of elastic scattering at all angles. To be sure, techniques of particle detection and data handling have improved since the unpolarized experiments were first done, and the efficiency of gathering data is much greater. Within the past few years elastic scattering at a wide range of energies has been performed with polarized targets.

The maximum value attained in proton-proton scattering by the polarization parameter (the ratio of the percentage of asymmetry of the scattered beams to the percentage of polarization of the target) at each energy is shown in the illustration on page 76. There are four remarks to be made about these results. First, the agreement among the various laboratories at points where the data overlap is heartening, showing that target polarizations are correctly calibrated. Second, the agreement between the polarized-target data and the (generally less accurate) double-scattering data at various energies indicates that there is as yet no evidence of a violation of the principle of time-reversal invariance in this reaction. Third, the large polarizations observed near 700 mev, when correlated with other data in the same vicinity, may be evidence for a new "resonance," or unstable particle, perhaps a highly excited unbound "helium 2" nucleus. Fourth, there is still considerable spin-dependence at the maximum energy available at Berkeley. There is a theoretical prediction, based on rather general considerations, that at sufficiently high energies the spin-dependence of all nuclear reactions disappears. No estimate is given of how high an energy is "sufficiently high"; from our data it appears that it must be considerably more than 6,200 mev.

As for the pion-proton scattering, data gathered below 1,700 mev at the Rutherford Laboratory enabled its theoreticians to distinguish several resonant particles that overlapped one another in mass. At least two previously unsuspected resonances were identified by this method and their properties determined. The Argonne group has made a similar analysis at a slightly higher energy, and the Berkeley group is now analyzing pion-proton data in a still higher energy range. There will also be interest, at the highest energies now being studied at CERN and Brookhaven, in the rate at which spin-dependence disappears (if it does) with increasing energy.

For the future there are many possible paths to follow with the technique of dynamic nuclear polarization. There will certainly be multiple-scattering experiments using polarized targets before very long. One may also consider inelastic scattering from these targets. Specific proposals may be advanced, such as the recent one made by T. D. Lee of Columbia, to search for time-reversal violation in electromagnetic interactions by studying inelastic electron-proton scattering from polarized targets. There are surely enough experiments to be done to keep many groups at many laboratories busy for many years.

THE VOODOO LILY

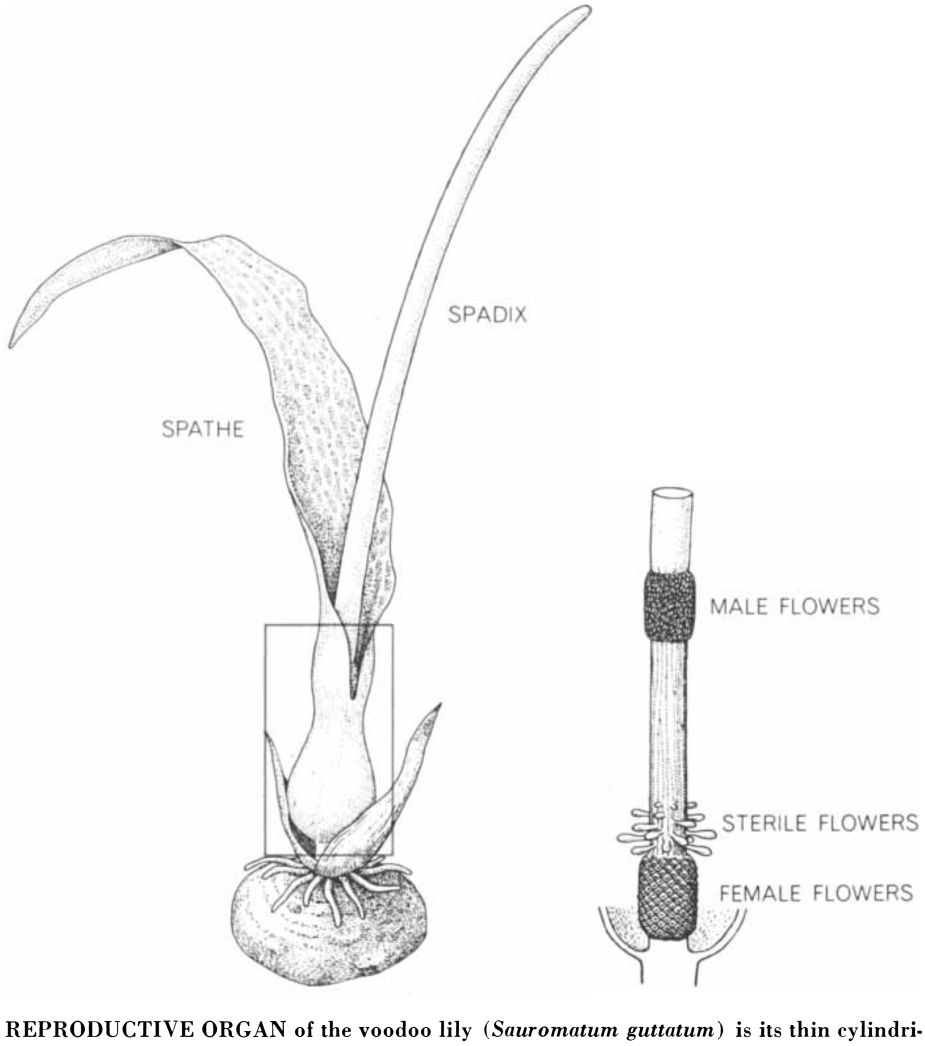
This tropical plant and its relatives emit a highly unpleasant odor that attracts insect pollinators. To broadcast its scent the plant resorts to unusual metabolic pathways that make part of it quite hot

by Bastiaan J. D. Meeuse

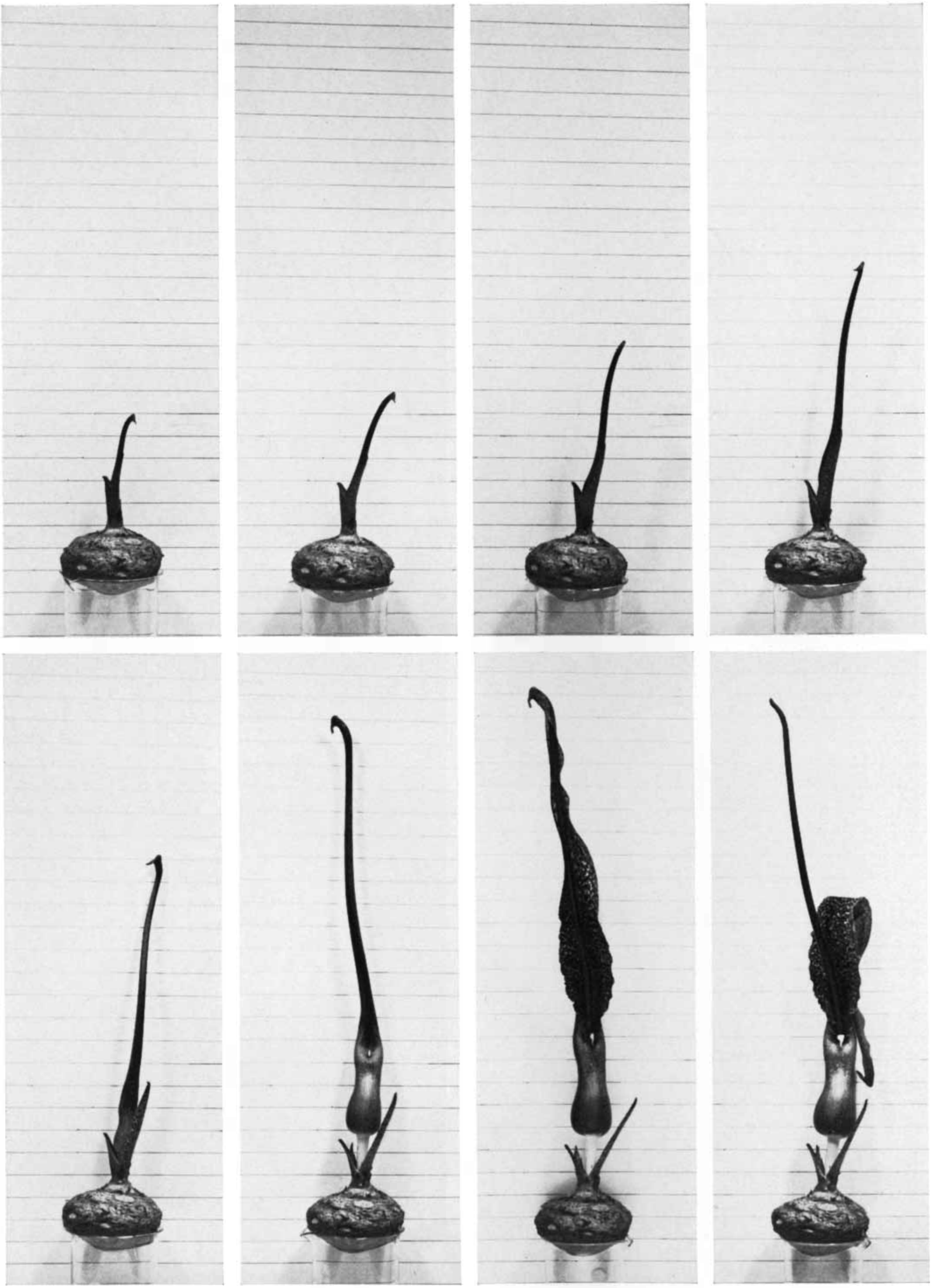
Animals differ considerably in their rates of metabolism; a shrew, for example, has a far higher metabolic rate than a sloth. One does not usually think of such differences in plants, but they do exist. The highest rate of metabolism among the higher plants is found in the tissues of certain members of the arum family, which includes such familiar plants as the calla lily, caladium and philodendron. One of the arums—the voodoo lily (*Sauromatum guttatum*)—has such a high rate of metabolism that on the first day of its flowering the temperature of part of it exceeds the temperature of the air by 10 to 15 degrees centigrade (18 to 27 degrees Fahrenheit). The heat volatilizes some of the plant's content of amines and ammonia so that it emits a characteristic unpleasant odor, reminiscent of dung, urine, carrion or decaying blood.

The smell of the voodoo lily and other malodorous members of the arum family serves a useful purpose: it attracts flies and some kinds of scavenger beetles that pollinate the plants. The source of the heat is respiration, which in plants as in animals is the process by which such foodstuffs as carbohydrates are oxidized in a series of steps catalyzed by enzymes to provide energy for the organism's life processes. A number of plant physiologists have investigated the intense respiration of the arums, and we are extending these investigations in our laboratory at the University of Washington.

The arum family (formally known as the Araceae) is one of the largest among the monocotyledonous plants; it consists of some 2,000 species in more than 100 genera. Arums live not only on land but also in the water; some are epiphytic, that is, they live on other plants without being parasitic. One of the aquatic arums—water lettuce (*Pistia stratiotes*)—is a rootless plant that spends its life afloat, supported by spongy, air-filled tissue on the bottom surface of its leaves. Another, *Cryptocoryne ciliata,* takes root in the bottom of streams and ponds and in flowering exposes a "flag" on the surface that lures insect pollinators into a foot-long underwater floral chamber. Both philodendron and the less familiar *Monstera deliciosa* (whose flowers develop into a prized tropical fruit) are epiphytes that climb like vines on the trees of their tropical forest habitat. Of the terrestrial arums perhaps



REPRODUCTIVE ORGAN of the voodoo lily (*Sauromatum guttatum*) is its thin cylindrical spadix (*left*). The plant's leaflike spathe surrounds the base of the spadix; the enclosed area is the floral chamber. The lily's multiple male and female flowers grow on the spadix inside the chamber, separated by a set of sterile flowers (*detail at right*). When the female flowers mature, the upper part of the spadix, called the appendix, becomes hot and malodorous. The odor attracts insects to one voodoo lily after another; cross-pollination results.



SUDDEN GROWTH of the voodoo lily's spadix and spathe during the days before the flowers mature is recorded in a series of photographs (*left to right, top to bottom*). An elongation of as much as 500 millimeters has been recorded in the course of nine days' growth.

ARUM ITALICUM, an Old World species akin to the jack-in-the-pulpit, was raised in the author's laboratory at the University of Washington. The photograph at the left shows the plant shortly after the process of appendix-heating and odor-broadcasting has occurred. At right the wall of the floral chamber has been cut away to reveal the many insects that were drawn to the plant by the odor.

the best-known are the wild forms of the Northern Hemisphere: the skunk cabbages (*Symplocarpus* in eastern Asia and eastern North America and *Lysichitum* in Asia and the American West); jack-in-the-pulpit (*Arisaema*), found in Asia and eastern North America; lords-and-ladies (*Arum maculatum*), its European relative, and another European species known as Italian lords-and-ladies (*Arum italicum*). Some terrestrial species are of considerable economic importance; among them are the sweet flag (*Acorus calamus*) and Indian ipecacuanha (*Cryptocoryne spiralis*), both of which have roots that are used as medicines, and taro (*Colocasia antiquorum*), which is cultivated as a foodstuff throughout the South Pacific.

It is evident from their numbers and diversity that the arums have been highly successful in the evolutionary struggle for survival. One of the reasons for their success is the ingenuity displayed by the ways in which they are pollinated. Cross-pollination, as opposed to self-pollination, confers an evolutionary advantage on a plant species, and even among the most primitive arums, such as the skunk cabbages, self-pollination is unusual. Although the hundreds of tiny flowers that develop on each skunk cabbage's fleshy central spadix are bisexual, their pollen-receiving female organs mature sooner than their pollen-shedding male stamens. Moreover, the stamens tend to mature from the base of the spadix upward, thereby minimizing the likelihood of pollination by gravity. Instead the plants are cross-pollinated by beetles that move from one skunk cabbage to another, attracted by the pungent odor the plants emit when they flower.

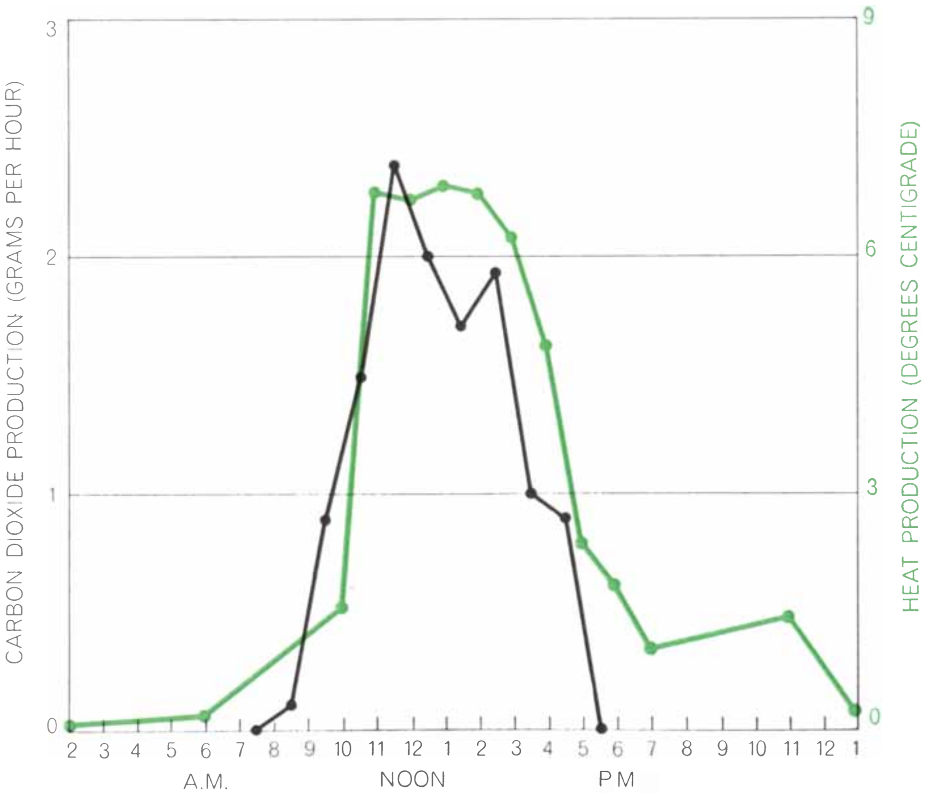
The pollination of the Italian lords-and-ladies, one of the more highly evolved arums, is perhaps more typical of the family as a whole. It was the great Jean Baptiste de Lamarck who in 1778 first recorded the fact that the flowering spadix of *A. italicum* is hot and has an unpleasant smell. The flower-bearing part of the plant's spadix is divided into four zones. At the base of the structure is a cluster of female flowers; above this zone is a bristly growth consisting of sterile flowers. Above the bristles is a cluster of male flowers, and above them is a second zone of bristles. All four zones are surrounded by the plant's leaflike spathe, which forms an enclosed floral chamber. The rest of the spadix protrudes from the floral chamber like a poker; this upper part is called the appendix [*see illustration on page 80*].

The odor wafting from the appendix on the plant's first day of flowering is a highly effective insect attractant. In 1926 Fritz Knoll, then at the University of Prague, made models of the flowering parts of three European arums and scented the models either with decaying blood or with the appendixes of live arums. He found that his scented models attracted many midges. In nature both the arum's appendix and the inside of the floral chamber are coated with tiny droplets of oil that deny a foothold to the insects that are lured to the plant. The visitors literally fall through the bristles at the top and middle of the chamber. They settle among the female flowers at the bottom of the chamber, where they feed on the sweet fluid exuded by the flowers' stigmas. In the process they also become coated with the fluid.

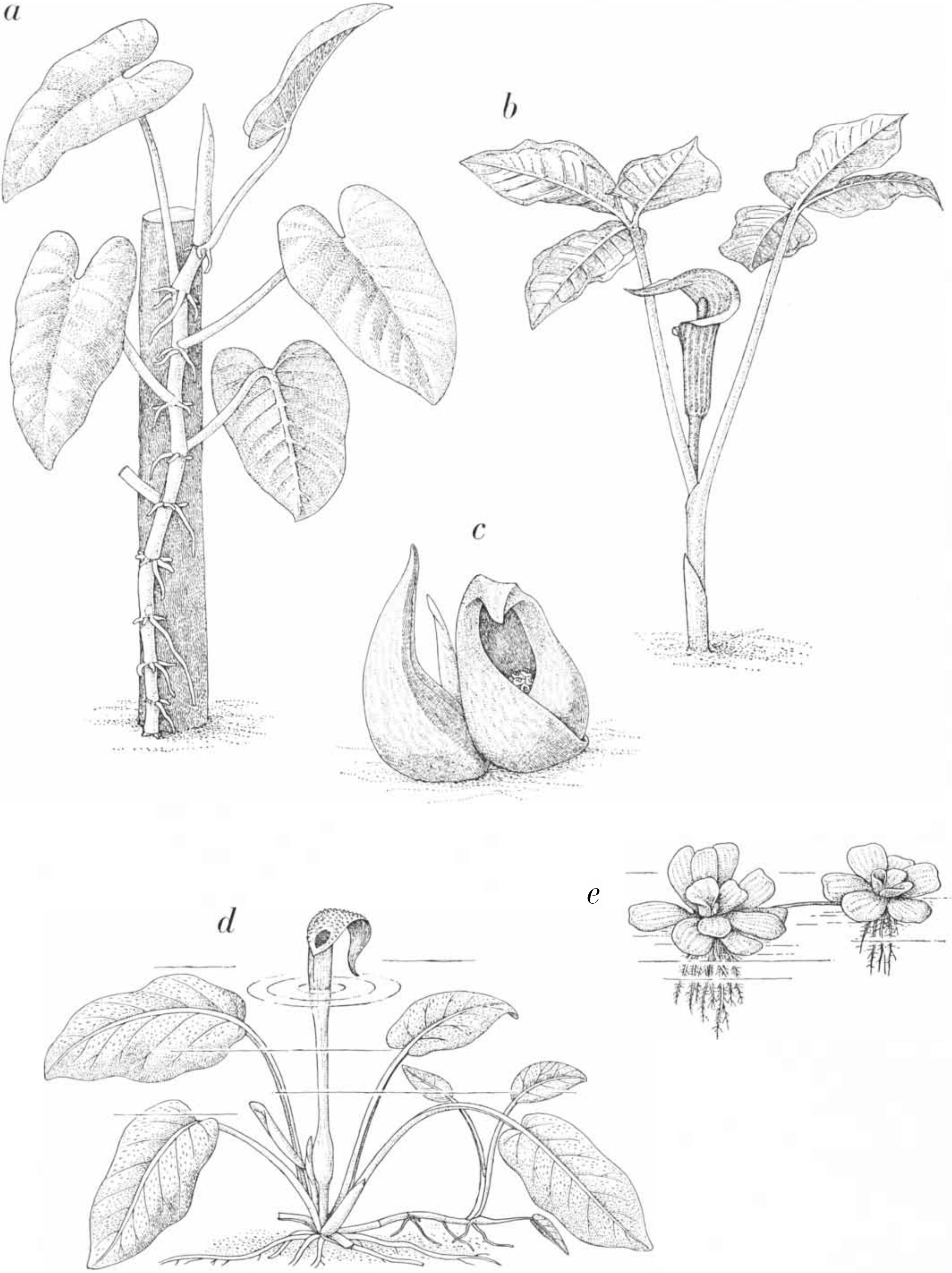
Overnight the male flowers in the upper part of the floral chamber ripen and shower the insects with golden pollen. Soon the insects, already covered with sticky fluid, are coated with the pollen. When they resume their attempts to escape the next day, they find that the bristles have wilted somewhat and now provide a better foothold. They emerge from the floral chamber and take flight—only to be attracted by the scent of another flowering arum. Then they are captured again and deliver their freight of pollen to the female flowers.

In examining these events from the physiological point of view, one may first ask what purpose is served by the intense metabolism that heats the arum's appendix. Opinion on the matter has been divided. To test whether or not the heat alone is attractive to the pollinating insects, Knoll placed inside his models light bulbs that made them warmer than the surrounding air. The heated but odorless models failed to draw any insects. Knoll concluded that the sole function of the heating of the appendix was to increase the rate at which the scent compounds were volatilized. On the other hand, Stefan Vogel of the University of Mainz proposed that the appendix heating served no function in itself and was only a by-product of the plant's metabolic activity as it synthesized the scent compounds.

To make a choice between these two hypotheses it is necessary to come to some conclusions about the exact nature of the arums' scent-producing process. Bruce Smith of our laboratory has made chromatographic analyses of the scent compounds produced by the voodoo



RUNAWAY RESPIRATION that heats the voodoo lily's appendix at maturity is marked by a rise in the tissue's hourly rate of carbon dioxide production between early morning and noon. During this time temperature of the appendix rises seven degrees centigrade.

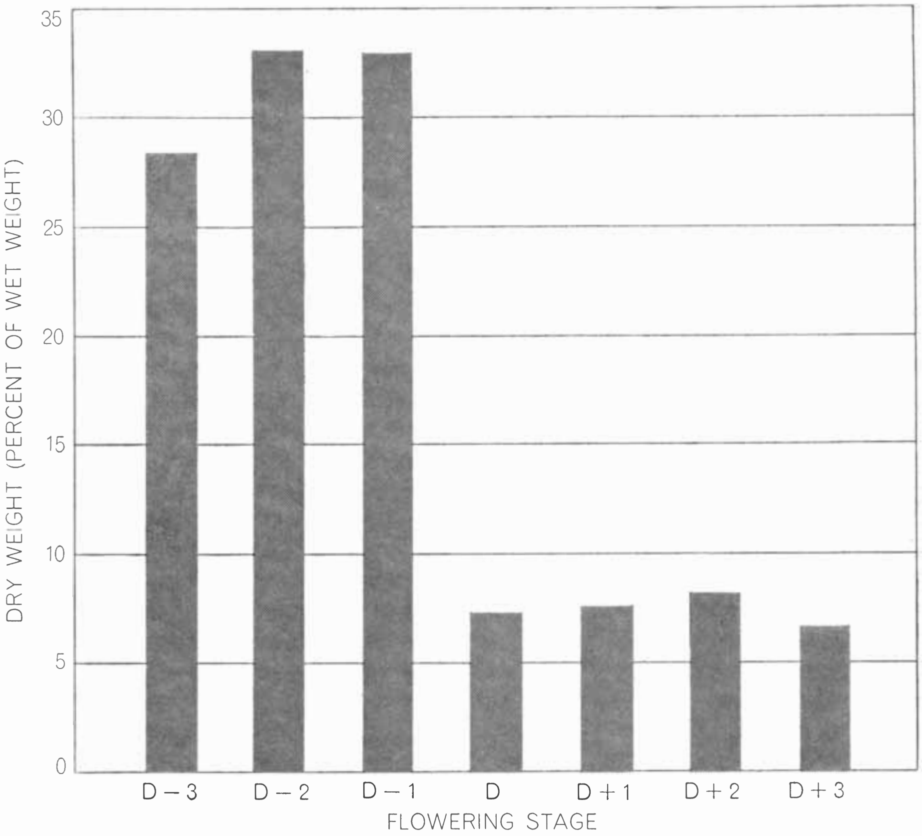


ARUM FAMILY MEMBERS are adapted to three kinds of habitat. The philodendron (*a*), native to the Tropics of the New World, is an epiphyte: it lives on other plants without being a parasite. The jack-in-the-pulpit (*b*) and Eastern skunk cabbage (*c*) are terrestrial plants of the Temperate Zone; each emits an odor that attracts insects. So does the aquatic arum of the Far Eastern Tropics, *Cryptocoryne ciliata* (*d*). Another aquatic arum, water lettuce (*e*), spends all its life afloat, buoyed by the air in its leaf tissues.

lily, by lords-and-ladies and by three other odoriferous arums: *Arum dioscoridis, Dracunculus vulgaris* and *Hydrosme rivieri.* He has identified a variety of amines: chemical relatives of ammonia (NH_3) in which a hydrogen atom is replaced by any one of a number of groups of atoms. It was discovered, however, that the major scent component is ammonia itself. The ammonia is probably derived from the plants' copious supply of the amino acid glutamic acid in a process catalyzed by glutamic acid oxidase, an enzyme that is present in nearly all higher plants.

We have shown that, in the case of the voodoo lily and lords-and-ladies, the activity of glutamic acid oxidase in the appendix during the plants' flowering roughly parallels their overall rate of respiration. Moreover, three of the amines Smith has identified can be derived from common amino acids present in the plants with little expenditure of energy. In the case of the voodoo lily we have found that, although the appendix's total output of scent substances is no more than a few milligrams, during its period of intense activity the appendix itself may lose as much as eight grams of carbohydrate in 12 hours. It seems doubtful that so much fuel is needed to produce so small a quantity of scent compounds, the more so when they are not particularly difficult to synthesize. A further consideration is the fact that a rise in temperature from 25 to 40 degrees C.—a range nearly equal to the maximum range that an arum appendix can accomplish—suffices at least in the case of one arum amine to increase its rate of evaporation by 100 percent.

In the light of these facts it is evident that the heating of the arum's appendix during flowering constitutes a particularly elegant demonstration of what has been called "the principle of biological parsimony." Heat production and scent production are two aspects of a single respiratory process; both events are simultaneous and inextricably linked. As Knoll suggested, the larger part of the energy serves to volatilize the malodorous compounds, which are made at the expense of very little energy or none at all.



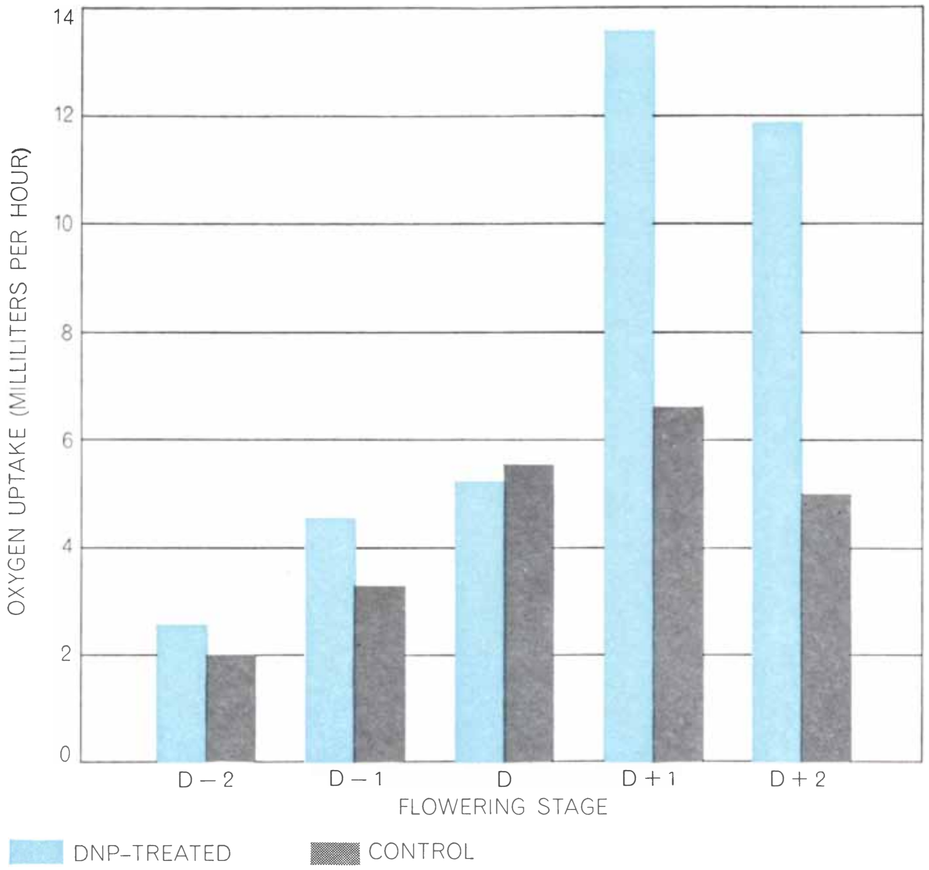
FUEL COMBUSTION at the time of maturity was assessed for *Arum maculatum* by recording the wet-to-dry-weight ratio of appendixes passing through the flowering stage ("D day"). The ratio after flowering was less than 25 percent of the preflowering average; most of the starch reserve stored in the appendix was consumed in a few hours' respiration.

In plants any energy that appears in the form of heat during respiration is normally considered wasted, and in order to avoid such waste the respiratory process depends on the chemical process known as "coupling." Coupling provides that, in several of the enzyme-catalyzed steps involved in respiration, surplus energy is not dissipated as heat but is trapped in the form of the high-energy compound adenosine triphosphate (ATP) or of comparable substances. This coupling between a specific respiratory step and the creation of a high-energy phosphate is usually obligatory. In the laboratory, however, coupling can be abolished by the addition of small amounts of such "uncouplers" as azide, pentachlorophenol or 2,4-dinitrophenol (DNP).

The arums' period of intense respiration is quite brief. The voodoo lily heats up in a few morning hours and lords-and-ladies in the course of an afternoon. Both the intensity and the brevity of the process suggest that it is an example of the uncoupled kind of respiration. One way to test this assumption is to add an uncoupling agent such as DNP to slices of appendix tissue taken from arum plants at various stages of development. If respiration in the appendix is indeed uncoupled at the time of the plant's flowering (which we shall call D day), then the administration of an artificial uncoupler to a bit of naturally uncoupled D-day tissue should not give rise to a respiration rate significantly different from that of an untreated bit of D-day tissue. In tissue samples taken at other stages in the plant's development, however, the administration of an uncoupling agent should enhance respiration in a clear-cut manner.

An experiment conducted in our laboratory by Conrad Hess proved this to be true for appendix tissue from voodoo lilies. In samples of tissue taken at D day both untreated tissue and tissue treated with DNP exhibited about the same respiration rate [*see illustration on next page*]. When DNP was added to samples taken on the two days following D day, however, the treated tissue showed a respiration rate at least double that of the untreated tissue.

Nonetheless, the Hess experiment offered us only indirect evidence that D-day respiration in the appendix of the voodoo lily is uncoupled. We wondered how more direct evidence might be obtained. Would it be possible to detect either the D-day synthesis of ATP, signifying a coupled respiratory process, or the absence of such synthesis, signifying an uncoupled process? One possible way to answer such questions would be to examine the appendix cells' mitochondria, the intracellular particles known to be the site of important respiratory processes. Unfortunately it



ABSENCE OF COUPLING, which traps the surplus energy of the respiratory process in the form of adenosine triphosphate (ATP), is indirectly indicated by this experiment. The compound 2,4-dinitrophenol (DNP), which can uncouple respiration either by breaking down ATP or by preventing its formation, is added to appendix tissues of plants passing through the stage of flowering (D day). Control and test tissues that day show about the same metabolic rate, suggesting that control-tissue respiration was already uncoupled naturally. In the next two days, however, the DNP-treated test tissue shows a rate more than twice the control tissue's, suggesting that latter's respiratory process is back to normal.

is extremely difficult to obtain reliable measurements of the production of ATP in plant mitochondria. In the voodoo lily and kindred arums this difficulty is compounded by the presence in the appendix of a high concentration of adenosine triphosphatase (ATP-ase), an enzyme that decomposes ATP with a vigorous action that is very hard to suppress.

We thought for a time that the presence of ATP-ase in the arum mitochondria might hold a clue—even *the* clue—to the uncoupling process. Our reasoning was as follows. In many plant tissues, including arum appendixes, the ATP-ase of the mitochondria can be activated by DNP. If it could be shown that the activation increased dramatically from D day to D day plus one, an explanation for the behavior of the slices of tissue in DNP solutions would be available. Addition of the DNP after D day would give rise to higher ATP-ase activity, resulting in a higher level of inorganic phosphates and more intense respiration. On D day itself, however, no such effect would obtain. Such is the result one would expect if on D day the ATP-ase in the mitochondria were already activated maximally by some intracellular agent, that is, if respiration were already uncoupled. So far, however, we have been unable to detect any change in the activation of the ATP-ase by the addition of DNP during the flowering sequence.

Another way to account for the voodoo lily's brief period of runaway activity is to assume that the plant does not depend on conventional uncoupling to achieve intense respiration. In ordinary respiration the last step of the process is catalyzed by cytochrome oxidase, an enzyme that can be inactivated by cyanide. In 1938 A. W. H. van Herk of the University of Amsterdam noted that the administration of cyanide to arum appendix tissue had no effect on its respiration rate. Van Herk took this to mean that the plants had a respiratory system that eliminated some of the usual steps in the respiratory process. Later studies, however, presented a striking paradox. In spite of the fact that the respiration rate of arum appendix tissue slices is not affected by cyanide, other tests clearly show that the tissue does contain cytochrome oxidase. Thus it would seem that the respiratory steps leading to cytochrome oxidase cannot be absent from the tissue's respiratory process.

Is there any way to resolve the paradox? Britton Chance and his associates at the University of Pennsylvania School of Medicine have proposed one way. If the amount of cytochrome oxidase in the appendix tissue is large enough at the start, they suggest, then even when the bulk of the enzyme has been inactivated by cyanide, enough of it will remain unaltered to be able to participate in normal respiration. To account for certain experimental findings on this basis, however, requires the assumption that the appendix tissue contains 60 times the expected amount of cytochrome oxidase. This is not easy to accept.

An alternate resolution of the paradox assumes the existence of a "bypass" system. On this hypothesis most of the respiration in the appendix tissue goes through the usual steps leading to cytochrome oxidase, but these steps can be bypassed under special circumstances, among which is an encounter with cyanide in the laboratory. When this hypothesis is taken out of the laboratory and examined in the voodoo lily's natural environment, a potential evolutionary factor becomes apparent. Any plant equipped with two respiratory pathways would probably not continue to inherit the extra pathway through thousands of generations unless possession of the two pathways had some significant survival value. When one looks in this light at the peculiar life cycle of the voodoo lily and its relatives—in which the runaway respiration that heats the appendix is the key to the plant's pollination and thus to the survival of the species—the bypass hypothesis becomes increasingly attractive. Nonetheless, it should be obvious that much remains to be learned about the matter.

Putting aside the question of the voodoo lily's precise mode of respiration, an equally intriguing topic for investigation is the means by which the plant's dramatic D-day activity is triggered. With the aid of electron microscopy E. W. Simon of the University of Manchester has detected structural changes in the mitochondria that evidently reflect increased activity as the appendix develops in the period before D day. In our laboratory we have detected a gradual buildup of flavine compounds and certain biochemical cofactors in appendix tissue in the same period. Neither the structural nor the biochemical changes, however, are sufficient to account for the explosiveness of the D-day flare-up.

In 1939 van Herk made a breakthrough in research on the mechanism of triggering. He cut the male flowers away from the spadix of a voodoo lily more than 18 hours before the plant was due to blossom. The appendix failed to heat up or to produce the characteristic odor. When he delayed the excision of the male flowers until from six to 18 hours before blossoming, the appendix became hot and malodorous on schedule. On the basis of these experiments van Herk proposed that the male flower buds secrete a triggering hormone, to which he gave the name "calorigen." Later he obtained an extract of the male buds and used it to treat pieces of appendix tissue from voodoo lilies he had rendered inactive by early excision of the male flowers. After a lag of from 19 to 22 hours the treated tissues became hot.

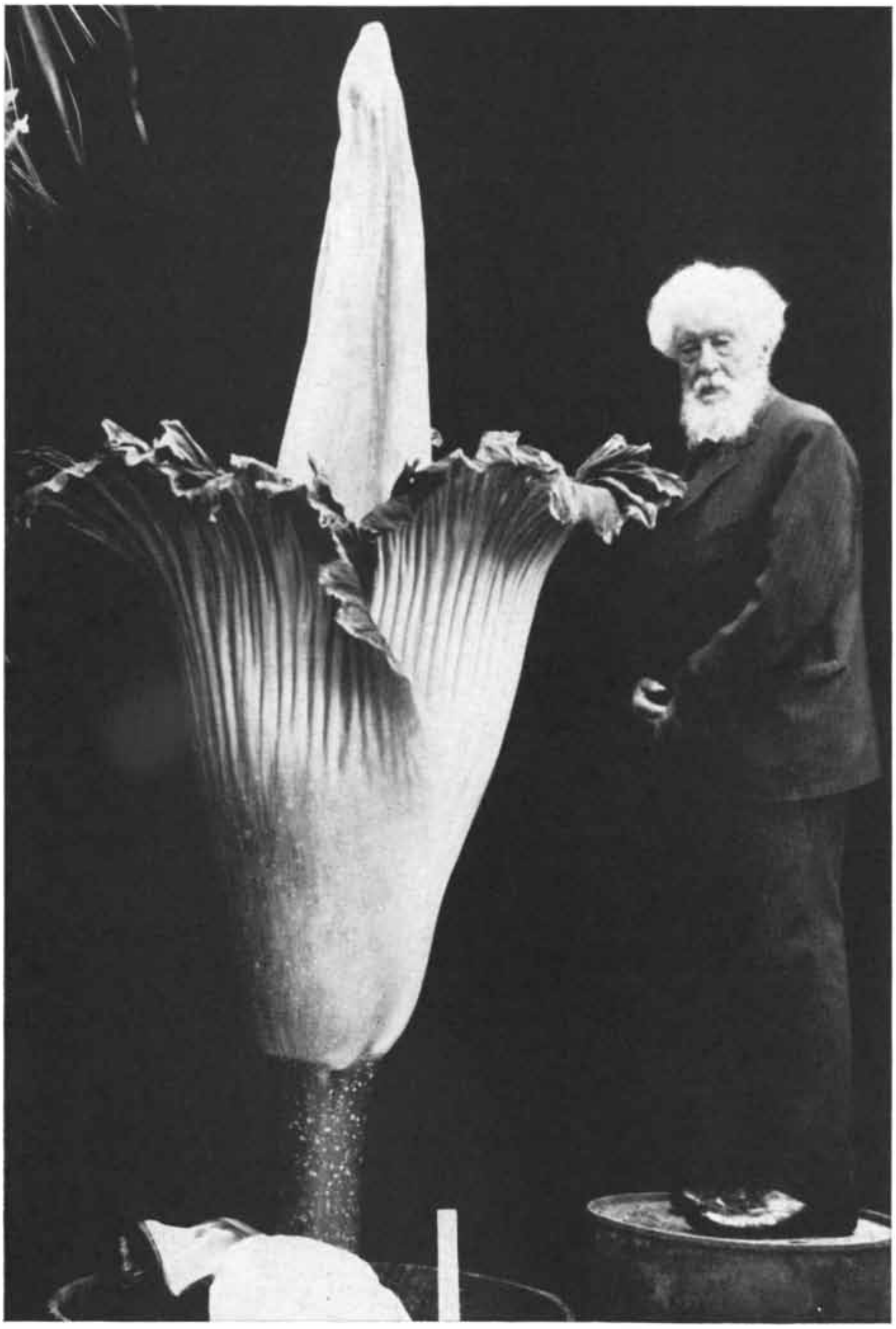
Van Herk's experiments clearly showed that the voodoo lily does secrete some substance that triggers the appendix-heating process. The chemical nature of the substance remains unknown, and the treatment of appendix tissue with inorganic phosphate, various sugar phosphates, sugars, vitamins, amino acids and cofactors has failed to produce a similar response. But even though the chemical nature of calorigen is unknown, one may still seek to discover whether something in the external environment triggers the production of the trigger hormone. Looking through the relevant literature, we found that some investigators had speculated on this point with reference to lords-and-ladies, to its relative *A. italicum* and to the large tropical arum *Amorphophallus variabilis*. Inspired by these scattered hints, we recently began to use the voodoo lily in a detailed study of the question.

Thus far we have conclusively proved that, as the earlier investigators had suggested, it is a factor in the external environment that triggers the trigger. This factor is light or, more properly, variations in light. We turned night into day and day into night in our laboratory. Instead of maintaining their usual metabolic rhythm, the voodoo lilies adjusted to this reversal of the diurnal cycle; the peak of appendix-heating and scent production took place at midnight instead of noon. We kept some plants in constant darkness during the days preceding D day and even afterward; they failed to flower at all. We kept others constantly illuminated and found that their response was more complex. When the lighting was intense, normal flowering was delayed and in some cases completely suppressed. When the lighting was more moderate, the plants flowered normally but did so at random times rather than reaching their normal noontime peak. Finally, by exposing still other plants to varying periods of alternate darkness and moderately intense light, we were able to determine the minimum daily light requirement for normal flowering. The requirement proved to be about three hours of light per day; this sufficed to trigger appendix-warming, but the performance could only be described as halfhearted.

At the same time that we demonstrated the role of illumination in the voodoo lily's respiratory climax we also encountered some new puzzles. Consider, for example, the question of which wavelengths of light have the strongest effect in stimulating flowering. One would expect that red light would produce results distinctly different from light of other wavelengths. It is known, for example, that when phytochrome, a substance that plays a role in many flowering events, is exposed to far-red light with a peak wavelength of 7,300 angstrom units, the treatment can abolish the effects of previous exposure to ordinary red light with a peak wavelength of 6,600 angstroms, and vice versa. We have exposed our voodoo lilies to various wavelengths and gauged the effect of each wavelength by measuring the amount of carbon dioxide produced by the appendix. So far no clear-cut difference has been detected between the action of one part of the spectrum and that of another.

An experiment based on van Herk's discovery that the male flowers of the voodoo lily are the apparent source of calorigen also produced puzzling results. We rigged one plant so that all the spadix except the area bearing the male flowers was kept in darkness; the male flowers were exposed to a normal alternation of light and darkness. As we anticipated, the appendix heated up on schedule. To provide a control for this experiment, however, we had kept the male flowers of other voodoo lilies in continuous darkness and had exposed the rest of each spadix to the normal diurnal alternation of light and darkness. We expected that in the control plants heating of the appendix would be suppressed, much as it had been when van Herk cut off the plants' male flowers early enough. In some cases this was the outcome but in a number of others the appendix became hot anyway. We can no more explain this result than we can the apparent sameness of the voodoo lily's response to various wavelengths of light.

As often happens in studies of this kind, our experiments have both left a number of old questions about the physiology of the arums unanswered and added new questions to the list. Nevertheless, one thing is certain: The plant physiologist and the biochemist have in the appendix tissue of the voodoo lily and comparable members of the arum family an invaluable experimental material. Not only does the appendix display the most intense respiration known among plants; it unleashes this burst of energy only when it has received the appropriate light stimulus. In all probability the voodoo lily is the best subject in the entire plant kingdom with which to study the physiology and biochemistry of light responses.



GIGANTIC ARUM *Amorphophallus titanum* is native to the tropical highlands of Sumatra. This specimen was raised to maturity in a Netherlands greenhouse in the early 1930's; standing beside it is the Dutch botanist Hugo de Vries, a pioneer student of plant mutations.

SHORT-TERM MEMORY

Tests of how long information is retained and the circumstances in which it is forgotten suggest that short-term and long-term memory are closely related but involve some separate mechanisms

by Lloyd R. Peterson

It is easy to forget information that has recently been acquired, as anyone knows who has failed to remember a name heard only a few minutes earlier at a social gathering. Such forgetfulness can be annoying, but it appears to have its uses. It might be distracting, for example, if one remembered every telephone number one had ever looked up. Considering all the information the memory does retain, it is probably just as well that something like an unfamiliar telephone number is remembered long enough for a single call and then forgotten. Besides, new information can usually be stored in the memory without undue effort if one has reason to think the material may be needed again.

The common experience of forgetfulness on the one hand and retentiveness on the other suggests that memory functions in two distinct ways—on a short-term basis and on a long-term one. For purposes of discussion it is often convenient to speak of a short-term memory and a long-term memory, although actually the two seem to be so closely related that they are described by some investigators as two aspects of the same phenomenon. Short-term storage serves well for many occasions in daily life. Long-term storage is, in fact, learning: the process by which information that may be needed again is stored for recall on demand.

A number of psychologists and physiologists who have investigated memory have suggested that two mechanisms are involved in it. One can be called an activity mechanism: a single experience gives rise to activity among neurons, or nerve cells. The activity soon dies out if the experience is not repeated. Here, then, is the basis for short-term storage. The second mechanism is structural change: with repetitions of an experience some kind of relatively permanent alteration occurs among neurons. This is the basis of long-term storage. The two mechanisms may be related in that the activity mechanism presumably assists in the production of the structural change.

Psychologists have traditionally studied short-term storage by presenting a sequence of digits to a subject and having him attempt immediately to recall them in the same order. The longest sequence of digits he can repeat correctly measures his span of immediate memory. Long-term storage has typically been studied by having a subject go over a list of words or other material repeatedly until he can recall the items without error. Hours or days after he has learned the list he is tested for recollection of it. The percentage of recall measures his long-term memory. Tests of these two kinds have resulted in considerable understanding of memory and have led to the design of further experiments intended to explore the re-

EXPERIMENTAL APPARATUS in the author's laboratory at Indiana University enabled the experimenter, who is at left in the photograph above, to show the subject various words lation between short-term and long-term storage. Although these experiments have provided some answers, they have also raised some intriguing questions that remain to be answered.

One type of experiment used to explore the relation between short-term and long-term retention involves a variation in the routine of the immediate recall of digits. The experimental subject is presented with a sequence of digits that is longer than he can be expected to recall after a single presentation. In a long series of these "superspan" tests one sequence of digits is repeated from time to time. Between repetitions several other sequences are presented and tested. For example, the first sequence might be 978263147; after hearing it the subject attempts to repeat it and then is given one or more different sequences, each of which he attempts to repeat immediately after presentation. Now and then the first sequence is repeated.

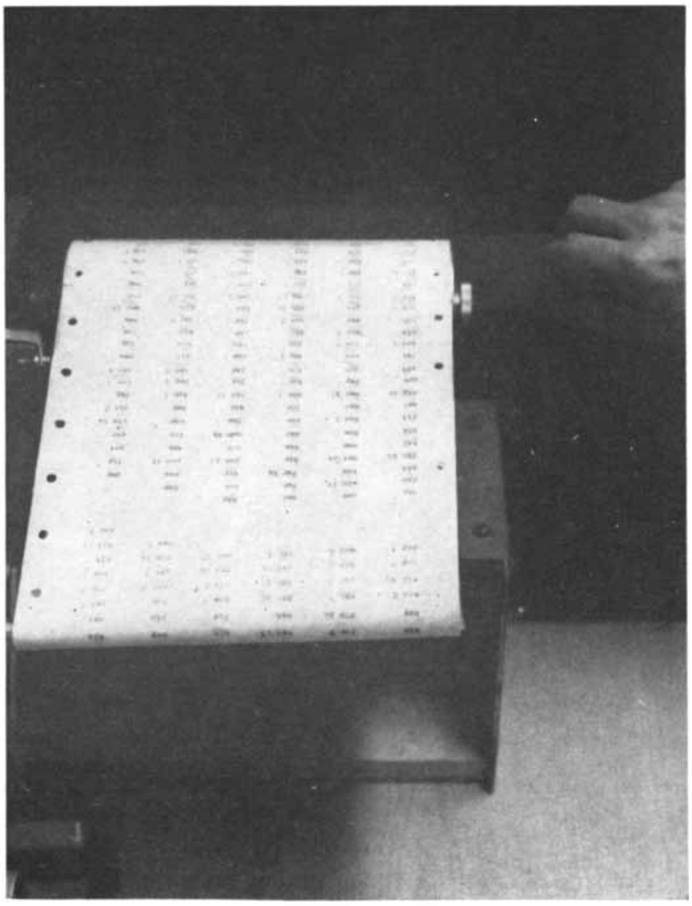
D. O. Hebb of McGill University designed this experiment, which was later elaborated by Arthur W. Melton of the University of Michigan. Their objective was to see if a single presentation leaves any lasting trace. They reasoned that if a single presentation caused nothing but transient neural activity, succeeding sequences would obliterate the activity. If, however, the occasional repetition of a given sequence amid several others produced improvement in the recall of that sequence, then even a single presentation must have caused some structural change.

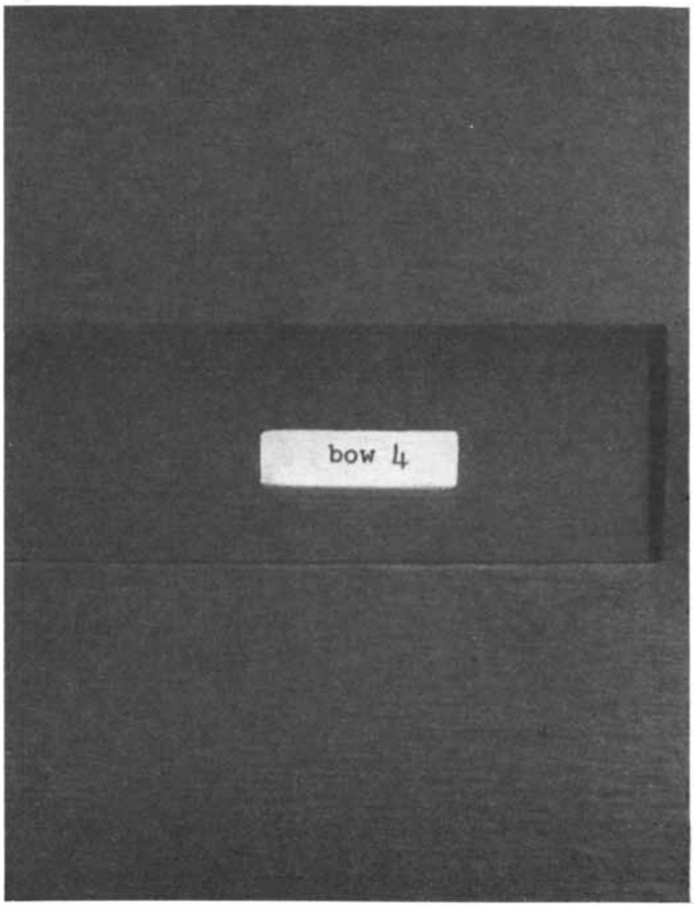
Hebb, Melton and others who have conducted this experiment have found that the sequence was indeed recalled with increasing accuracy the more it was repeated. Improvement occurred even when as many as five tests of new sequences were given between two successive repetitions. Beyond five there was little evidence of improvement, and up to five the rate of improvement tended to decline as the number of intervening sequences increased. Nevertheless, the finding of any improvement at all when other sequences intervened indicated that something more than transient neural activity results from a single presentation and test.

This experiment does not provide a way to measure changes in memory with time. Varying intervals of time separate the presentation of an individual digit from the recall of that digit. Undoubtedly the digit could have been recalled immediately after it was presented. In a long sequence, however, the digit might be forgotten before testing. How long was it retained?

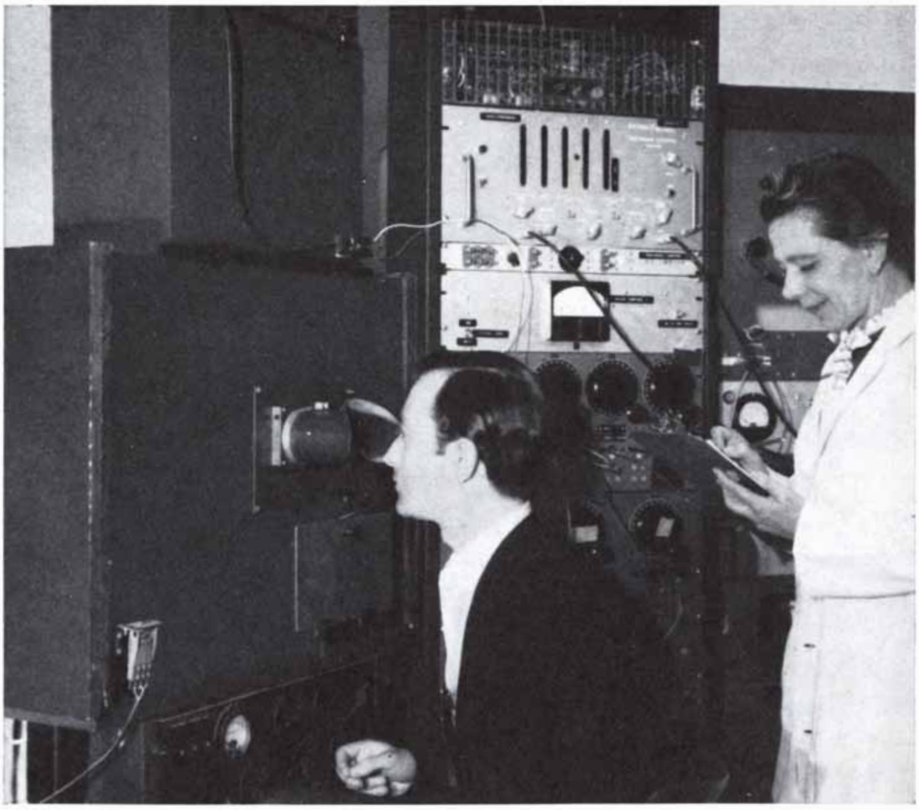
To examine this question we devised in our laboratory at Indiana University an experiment in which we presented a message of subspan length—a message that could be recalled immediately with complete accuracy—and introduced delays between presentation and recall. We chose the events of the delay interval carefully to fit two specifications. On the one hand we wanted to keep the subject talking so that he would have little or no opportunity to rehearse the message. On the other hand we wanted his activity during the delay to be as different as possible from the message in order to minimize confusion between the two. In this way we could plot a curve of forgetting for a single short message over a period of time.

A typical experiment proceeded as follows. The experimenter spoke a combination of three letters that did not constitute a word. Without any break he spoke a three-digit number, and the subject then counted backward rapidly from that number. On a signal from the experimenter the subject stopped counting and tried to recall the three-letter





paired with digits or with other words and to test his ability to recall the associations over varying periods of time. The middle photograph shows the apparatus as seen from the experimenter's side; the photograph at right, a typical exposure seen by the subject.



TACHISTOSCOPE was used by George Sperling of the Bell Telephone Laboratories to investigate short-term forgetting. For .05 second it showed arrays of letters such as those in the illustration below. A musical tone then told the subject which four-letter row to report.

ARRAYS OF LETTERS shown in the tachistoscope included these. A tone of high pitch told the subject to report the top row, of medium pitch, the middle row, and of low pitch, the bottom row. The tone was helpful only if given within a second. The results suggested that a factor in short-term forgetting is decay in the retention of newly acquired information.

message. We found that recall dropped quite rapidly over an 18-second interval. When subjects were told to say the message aloud once or twice before counting, their retention curves were higher [*see upper illustration at left on opposite page*].

Bennet B. Murdock, Jr., of the University of Toronto and Melton have conducted similar experiments in which they found that the number of chunks in a message is a significant variable. A one-letter message is recalled very well over fairly long intervals of counting. The recall of a two-letter message is poorer and of a three-letter message poorer still. With each added letter the retention curve (based on fully correct recall) is lower. As might be expected, this finding holds true only for unrelated letters. If the letters form a familiar word, retention of the word is as good as that of a single letter. The reason is that words have become units through use.

Our experiments established that rapid forgetting occurs after a single presentation of three unrelated letters. What causes the forgetting? One factor is undoubtedly competition from previous messages. A case can also be made for a second factor that can be termed spontaneous decay.

A contrast that appeared between the results of delayed-recall tests using visual presentation and the results of similar tests using auditory presentation will illustrate the point. In each case, as it was found in experiments conducted by Geoffrey Keppel of the University of California at Berkeley and Benton J. Underwood of Northwestern University, delayed recall on the first test of a session was much better than that on succeeding tests. With visual presentation, however, the entire curve was higher than that resulting from auditory presentation. In other words, a visual presentation produced almost no forgetting over an 18-second interval on the first test and more forgetting on subsequent tests, whereas an auditory presentation produced significant forgetting even on the first test. The contrast suggests that in the visual presentation interference from previous tests was the only source of forgetting but that in the auditory presentation another factor was at work to produce the relatively poor showing on the first test. Presumably the auditory presentation makes less of an impression on the memory, so that spontaneous forgetting occurs more readily.

Further evidence for the conclusion that earlier tests interfere with later tests comes from the errors made in delayed recall. A frequent error is the intrusion of a single letter from one message into the same position in the recall of a succeeding message. On one test, for example, the message might be *KQF;* on the next test the message is *MHZ* but the subject recalls *MQZ.* Evidently a letter from the first message has won out in competition with a letter from the second, and this is indicative of interference. A problem still unsolved is why the intruding letter tends to reappear in its original position. Apparently the memory somehow codes the letter for position, and this characteristic is retained in spite of failure to remember other aspects of the context in which the letter originally appeared.

The effect of competition from previous tests can be minimized in certain ways, with results that throw light on the process of retrieving a message from storage. Consider a delayed-recall experiment by Delos D. Wickens of Ohio State University in which the naming of colors was used as the intervening activity to curb rehearsal. The first few tests had digits for messages and resulted in the typical decrease in ability to recall as the tests progressed. Wickens then switched to a test in which the message consisted of three letters. On the first test the recall was virtually as good as it had been on the first test of the digit message. Evidently the subjects rejected intrusions from previous messages—those with the digits—as being of the wrong class, and so these messages did not interfere with recall of the message containing letters. The subject during retrieval remembers not just digits and letters; he remembers also that digits were not presented in the current trial. This kind of information is evidently useful in the organization of memory.

In this connection it seems reasonable to expect that the longer it has been since a subject heard or saw messages of one class, the less they will compete with another message of the same class. Previous messages should not interfere if they have been forgotten. This supposition is borne out in delayed-recall tests; the longer the rest interval between the end of one test and the beginning of the next, the better the retention has been. Moreover, a long rest interval results in fewer intrusions, such as that in the example of the letter *Q* from one message that appeared in the effort to recall a later message.

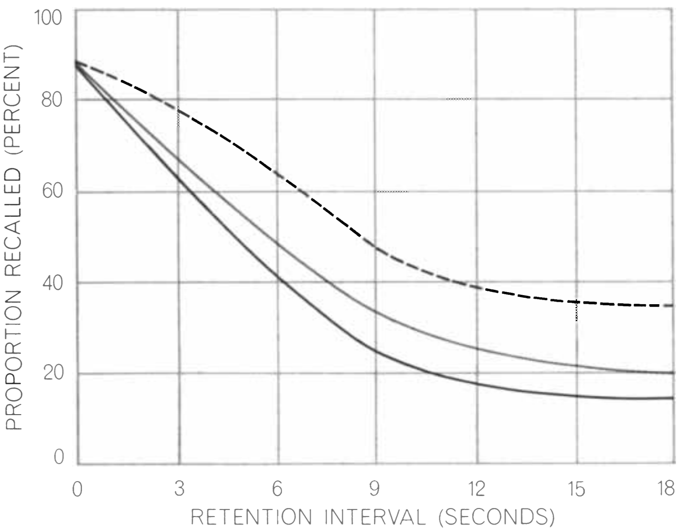
This finding raises the question of why the previous message weakens over a rest interval. The answer appears to involve the spontaneous decay that I believe to be a factor in short-term memory. To the extent that short-term memory is based on activity of the neurons initiated by events in the outside world, it seems plausible that after the events have changed or disappeared the activity should diminish and eventually cease.

George Sperling of the Bell Telephone Laboratories has investigated a type of decay that is associated with visual presentation. He tested recall of messages presented by a tachistoscope, a device that enabled him to limit the duration of a visual message to .05 second. Subjects were required to give only a partial report of a superspan message. The experiment showed that there is more information available to a subject for a brief moment after presentation than he can report later.

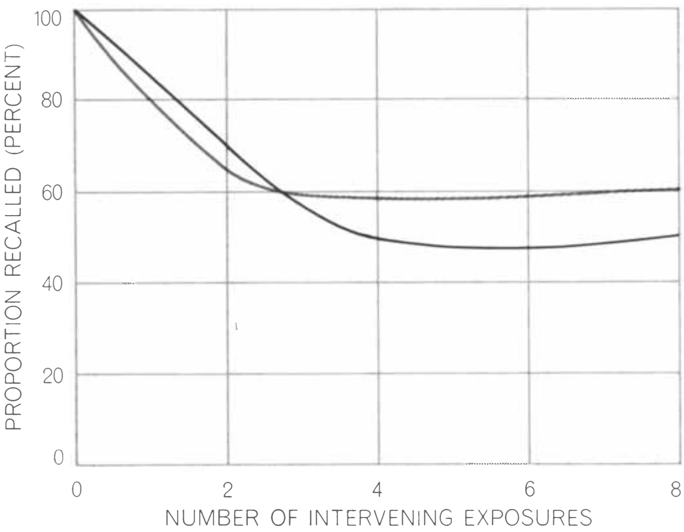
Sperling's apparatus presented letters in an array four columns wide and three rows deep. A tone of high, medium or low pitch signaled to the subject which four-letter row he was to report. When this signal was given immediately after the presentation, the row it identified was reported with a high degree of accuracy. When the signal was delayed by a quarter of a second, the report was less accurate. A delay of as much as a second made the signal valueless in aiding accuracy; the subject could not report the signaled row with any more accuracy than he showed in reporting the three rows.

This rapid decrease in the availability of the message strongly suggests a decay factor in short-term storage. The decrease occurred even though no interfering events could be identified; the subject just sat, waiting for a chance to report. Probably this type of decay is characteristic of storage near the sensory organ. Perhaps the decay should be considered a perceptual phenomenon rather than an element in what is traditionally called memory; it occurs before the subject has had time to process the message. Nonetheless, it is interesting to have clear evidence of spontaneous decay in neural systems. It may well be that decay is also characteristic of neural systems more closely related to memory.

Other experiments that indicate a decay factor in short-term memory have varied the rate of presentation and recall. In such experiments R. Conrad of the British Medical Research Council has found that in some circumstances fast rates will produce better recall than slow rates. It is difficult to interpret these



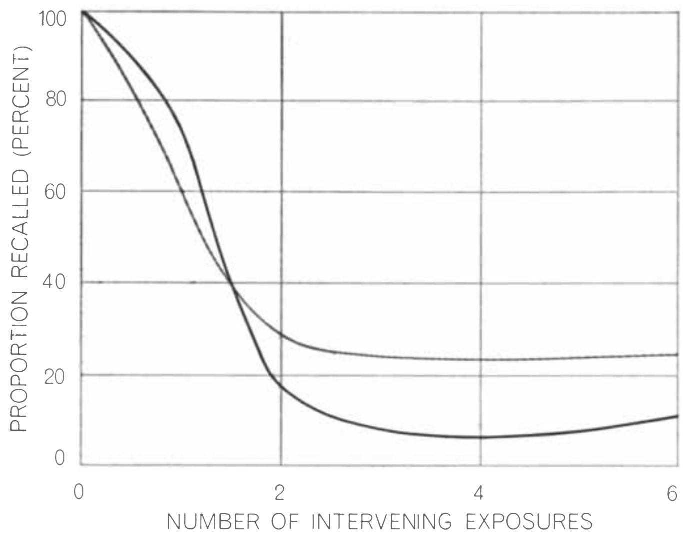
IMPROVED RECALL occurred when subjects repeated aloud a message of three unrelated letters before an interval of counting backward followed by a test for recall of the message. The curves, beginning at the bottom, represent zero, one and three repetitions.



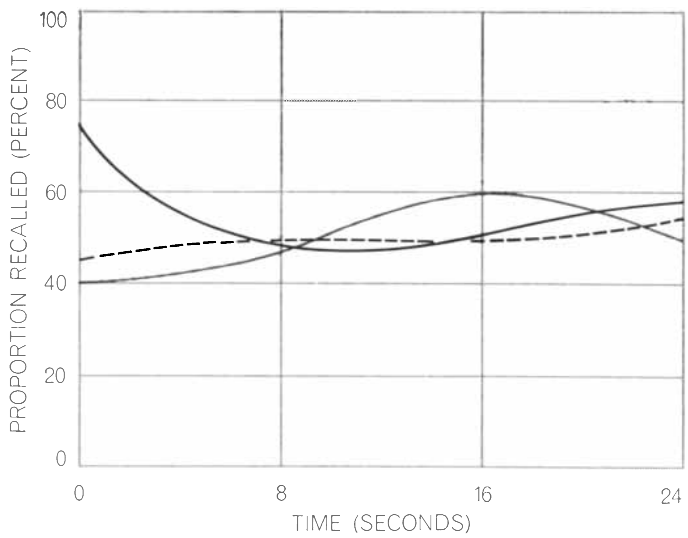
SPACING between two presentations of the same pair of words affected short-term retention. Presentations were either successive (*dark curve*) or separated by eight seconds (*light curve*). Other pairs filled the interval between second presentation and test.

EDGE	8	HOSE		COOK		APE	6	BOAT	1	MAD	3
COOK	5	EDGE	8	NOTE	2	LAW	9	APE		BOAT	
HOSE	4	COOK	5	NOTE		MAD	3	LAW	9	JOKE	10
SAW	7	JOKE	10	BOAT	1	SAW	7	LAW		SAW	7

WORD-DIGIT PAIRS were used in lists such as this to test short-term memory. The subject saw the pairs one at a time, beginning with EDGE 8 and reading down. In a test a word was shown alone and the subject attempted to recall the number associated with it.



TIME FACTOR in short-term retention appeared when rate of presentation was varied. Paired words were shown every two seconds (*dark curve*) or four seconds (*light curve*), with other pairs filling the interval before test. Fast rate produced better recall with one intervening event; slow rate, with from two to six events.



RISING CURVES appeared when subjects tried to recall pairs of words after presentation of a list followed by varying intervals of digit-reading. The entire curve (*dark curve*) is shown for the fifth and last pair; for the first (*broken curve*) and third (*light*) pairs the drop is assumed to have occurred before the digit-reading began.

findings except in terms of decay. In the learning of lists a slow rate of presentation results in better learning than a fast rate, given an equal number of presentations. Furthermore, a longer time for recall should increase the chance of a correct response. Both considerations favor slow rates over fast ones. The fact that the faster rate produces better short-term recall indicates that at the slow rate the factor of decay with time has overridden the advantages of slow presentation and recall.

To sum up, short-term forgetting seems to be caused by two factors: interference from similar messages and decay. In most situations the effect of competing messages is so strong that it obscures any evidence of decay. An analogy can be drawn with the disappearance of an ice-cream cone in the hands of a small boy on a warm day. Undoubtedly the temperature contributes to the disappearance by causing some melting, but this effect is insignificant compared with that of the boy's appetite and enthusiasm. In short-term memory interference from other messages is the prime source of forgetting. It requires a special situation for the decay factor to be clearly observed.

The experiments described thus far provide good evidence that interference plays a strong role in short-term forgetting and that repetition improves short-term retention. Because the same factors produce similar effects in the learning of lists—that is, in long-term retention—Melton has suggested that short-term and long-term retention are regions on a continuum. In this view there is a single underlying mechanism for both kinds of retention, and hence the effect of a single presentation can be described as the simplest kind of learning.

Several other investigators believe the situation is somewhat more complex than the single-mechanism argument suggests. They do not deny that learning occurs with a single presentation, but they suspect that a short-term storage mechanism operates in addition to a learning mechanism. The presence of a decay factor in short-term forgetting is considered to be one type of evidence for the existence of a short-term storage mechanism. This conclusion follows from the consideration that learned messages—those that are in long-term storage—do not appear to decay with time.

Another indication that memory is more complex than the single-factor interpretation suggests can be found in a variation of the usual type of cued-recall experiment. Normally in such an experiment the subject is repeatedly shown a list of pairs of words. Suppose one of the pairs is HANDLE–TREE. On a given test of learning HANDLE appears first—as a cue—and the subject is given a moment to see if he can recall TREE. He makes his response and then is shown HANDLE–TREE together again. The proportion of correct responses on successive trials provides an index of the subject's progress in learning.

Such an experiment is usually thought of as a measure of learning, but it can also be regarded as a measure of retention. The interval of retention is the time since the word being tested (TREE) was shown on the preceding trial; typically the interval will range from 15 seconds to several minutes. Experiments in short-term retention include tests at intervals within this range and also tests at much shorter intervals. Such experiments can be considered as testing both short-term memory and learning, or long-term memory. In this light the experiments in short-term retention of paired words might be expected to provide information not only on learning but also on the relation between learning and short-term memory. If variables such as rate of presentation and spacing of tests have an effect on the early portion of the retention curve that is different from that on the later portion, then one can infer differences between short-term memory and learning.

It was against this background that several investigators undertook to modify the standard type of cued-recall experiments by making them miniature paired-associate tests. Murdock tried varying the number of pairs of words. He presented a list once and tested for some member of the list by showing one member of a pair as a cue. In general, the more pairs in the list, the lower the asymptote, or leveling-off point, of the retention curve. Interestingly enough, however, the initial slopes of the curves were similar regardless of how many pairs Murdock showed. In other words, the variable—the number of pairs—affected the later part of the curve but not the earlier part. It seemed to affect learning rather than short-term memory.

In a similar experiment repetitions of pairs were found to raise the asymptote of the retention curve, but again the initial slope was not significantly affected. Then the duration of presentations was varied, and this variation too exerted its most pronounced effect on the final portion of the curve. The effect of all these experiments was to provide more evidence that the single-mechanism explanation of short-term and long-term memory does not go far enough.

We have found an even more striking discrepancy between the effect of a variable on the early part of a retention curve and its effect on the later part. In this case the variable was the spacing interval between two presentations of the same pair. Sometimes we gave the second presentation immediately after the first; sometimes we put several other pairs or tests between the two presentations. In both cases the retention interval from second presentation to test was filled with verbal material of the same class.

Forgetting occurs rapidly in this situation because of the large amount of interference from other pairs. For this reason it might be predicted that the effect of the first presentation would be strongest when it was immediately followed by the second presentation. In the case where other pairs separate the two presentations it would seem that forgetting between the first and the second presentation should reduce the cumulative effect of the two presentations. Such forgetting is invariably shown if a test is given instead of a second presentation after a spacing interval.

These commonsense predictions turn out to be true only for the early part of the curve that measures retention after the second presentation. Spaced presentations do produce poorer recall if only one or two events fill the retention interval, but with more events the curves cross [*see upper illustration at right on page 93*]. Thereafter the spaced presentations are recalled better than those that were not spaced.

The significance of these spacing studies is twofold. First, the fact that the curves cross suggests that there is something different about recall when one or two events have intervened between second presentation and test and recall when more events filled that interval. One storage system would seem to dominate recall in the first case and another in the second. Although a learning mechanism is evidently assisting in both early and late retrieval, the early retrieval appears to have in addition the assistance of a short-term storage process.

The second point concerns the higher effectiveness of spaced presentations rather than of successive presentations at the longer retention intervals. The explanation of this phenomenon may be that the second presentation has a different effect in a successive situation than it does in a spaced situation. The subject may pay less attention to a pair he has just seen than to one that occurred earlier. Another possibility is that the long-term effect of the first presentation has time to consolidate during the spacing interval. This is one of the questions that goes unanswered. It remains a paradox that in order to remember something better you should allow some forgetting to occur.

A crossing of curves also appeared in some experiments we conducted involving changes in the rate of presentation and test. In these experiments pairs of words were presented at either a two-second rate or a four-second rate; various pairs in each block were tested after from zero to six intervening exposures of other pairs. A sample block of exposures appears in the illustration below. In that sample the third pair presented is FACE–ARMY. After one intervening pair (CAR–APPLE) the word FACE is shown to the subject again to see if he remembers its associate, ARMY.

In these experiments the fast rate was found to produce better recall with one intervening exposure, whereas the slow rate produced better recall when from two to six events intervened [*see illustration at left on opposite page*]. Evidently, then, time is a factor in the relation between short-term and long-term memory and must be regarded as a significant variable along with the number of intervening events. Thus these experiments provide another bit of evidence that there is a decay factor in short-term memory.

An intriguing question that so far can be answered only speculatively involves retention curves that rise. In one of our experiments we presented a list of pairs once and tested for recall at periods ranging from zero to 24 seconds. If the test did not follow the presentation immediately, the subject filled the interval by reading digits aloud as rapidly as possible. On these cued-recall tests pairs from the first part of the list were recalled better after 24 seconds of digit-reading than they were immediately after presentation of the list. Pairs from the last part of the list showed first a decreasing retention curve and then a slight increase [*see illustration at right on opposite page*].

Undoubtedly each pair at the beginning of the list could have been recalled with complete accuracy if the subject had been tested on it right after it was presented. It is also clear that the availability of these pairs must have declined during presentation of the succeeding pairs. This picture of declining recall followed by increasing recall suggests several factors interacting in short-term and long-term retention.

The surprising fact is not that forgetting occurs soon after presentation but that the retention curve subsequently rises. The rapid forgetting could be ascribed to the short-term memory and the rise to the long-term memory. Even so, a question remains. Why should there be any rise?

Perhaps there is a characteristic of the retrieval process that enables it to work more efficiently after an interval of irrelevant activity. A related possibility is that recall itself is a disrupting process, tending to interfere with storage activities. If so, then the passage of time may allow some consolidation of information to take place so that the memory is less easily disrupted. We hope that further experimentation will clarify situations such as this one and lead to an improved understanding of human thought processes.

HOUSE–ITEM	FACE	CLUB–BARN	SIGN–HAIR
BROOK–TOOTH	ARM–BOOK	ARM	CHECK–DOOR
FACE–ARMY	TABLE–EYE	EGG–BOTTLE	CLUB
CAR–APPLE	HORSE–MOON	EGG	WORM–TREE

PAIRED WORDS in blocks such as this were used in the tests involving changes in the rate of presentation. Pairs were shown to the subject one at a time at either a two-second or a four-second rate. The first two pairs were dummies. Tests for recall, such as that involving the associate of FACE, were given either immediately or after the presentation of from one to six other associated pairs.

BORON CRYSTALS

X-ray analysis of the crystals formed by boron and its compounds has turned out to be fruitful beyond expectations and has led to a considerable extension of the concepts of structural chemistry

by Don B. Sullenger and C. H. L. Kennard

Boron is an old chemical acquaintance that in recent years has become something of a prodigy. In the forms of borax and boric acid it has long been known for its household and industrial uses. A new appreciation of the element began to develop early in this century when the German chemist Alfred Stock and others found that it could form unusual compounds. In the past 25 years boron has aroused increasing interest among investigators in chemistry and physics. It has lent itself to an entire constellation of important new substances, and the element itself has become a prominent factor in new technologies. Within the past decade boron has also emerged in a more basic role: the elucidation of the three-dimensional spatial arrangements of the atoms in its compounds has led to a considerable extension of the concepts of structural chemistry.

This article is an account of the results of some of these structural studies. An earlier article in *Scientific American* has described boron's chemical history and uses [see "Boron," by A. G. Massey; January, 1964]. We shall merely review a few salient facts that are pertinent to our account. Boron, the fifth element in the periodic table (occupying the position between beryllium and carbon), is a nonmetal that is low in chemical reactivity at ordinary temperatures (if it is not too finely divided). In its crystalline state, although it is less dense than aluminum, it is stronger than steel and as hard as Carborundum. It is opaque to visible light but transparent to infrared radiation. It has a high melting point (2,100 degrees centigrade) and remains a liquid only within a narrow temperature range, vaporizing at 2,400 degrees. It is a poor conductor of electricity at normal room temperatures, but the conductivity increases remarkably with increasing temperature.

Boron reacts readily with oxygen at higher temperatures, and it is found in nature only in oxygen-containing compounds. About 100 of these are known; they are chiefly borates (salts) and boric acid. In overall abundance boron is not a common element (it constitutes only one atom in every 2,000 in the earth's crust), but this scarcity is mitigated by its concentration in the salts of ocean waters and the dry beds of ancient inland seas. Deposits of borax, the hydrated sodium salt of boron ($Na_2B_4O_7 \cdot 10H_2O$), occur in many places, notably in the Middle East, and boric acid has been found in high concentration in volcanic vapors of the Tuscan region of Italy. During the 19th century the Stassfurt deposits in Germany provided the world's major source of boron in the form of boracite, a compound of boron, magnesium, chlorine and oxygen. Today more than half of the world's supply of boron comes from the Mojave Desert of California, where the element is mined in the form of the mineral kernite ($Na_2B_4O_7 \cdot 4H_2O$).

Borax and its derivatives have a wide variety of uses: as a water-softener, a welding flux, a rust-inhibitor, a household bleach, a chemical agent serving various purposes in textile dyeing, printing, leather processing and other industries, and as the basis for manufacturing the tough and durable Pyrex glass. The last is boron's principal present use. Borax is also useful in the laboratory as an analytical reagent for the identification and measurement of various substances.

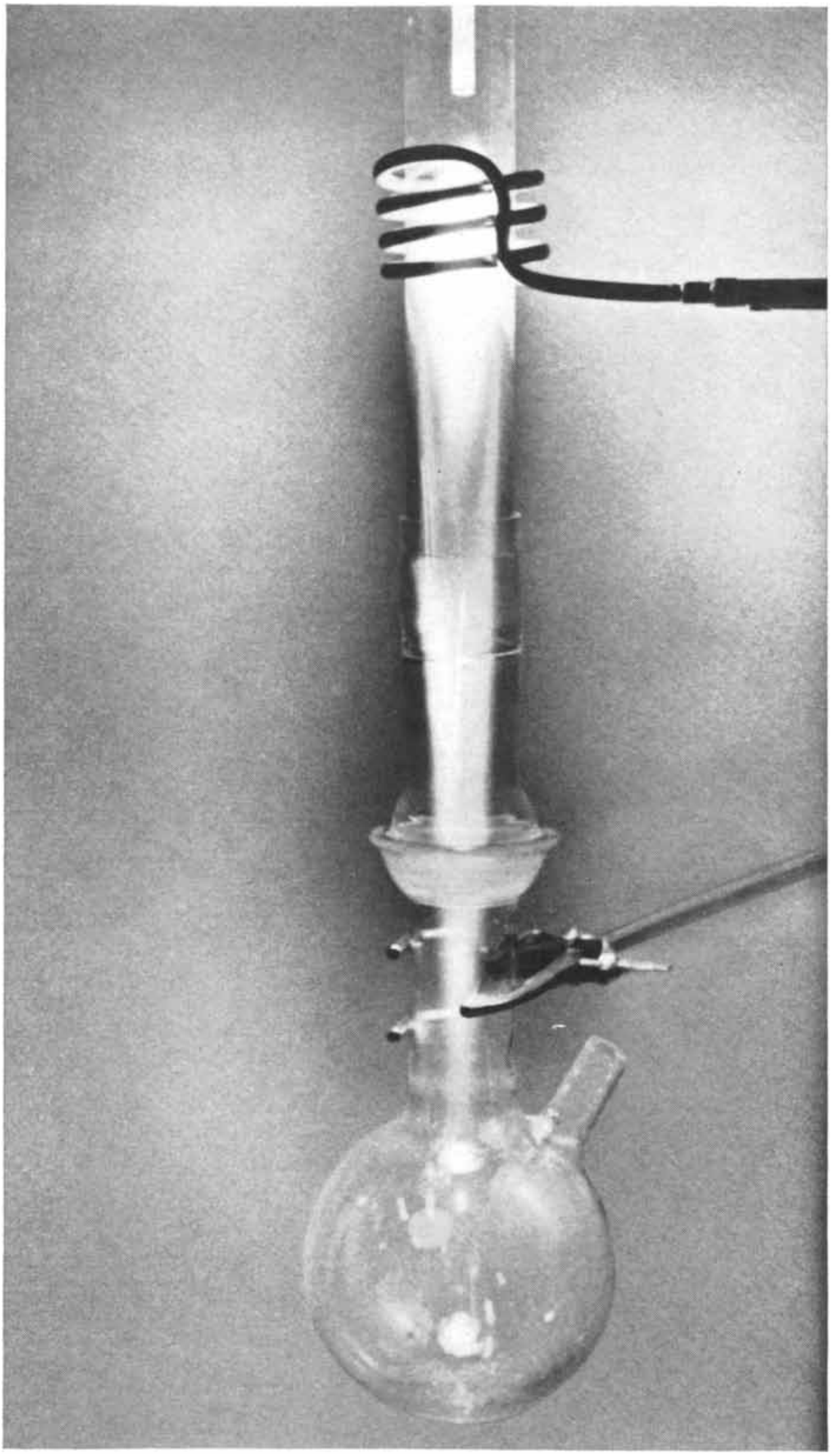
When nuclear technology developed, boron quickly achieved prominence because its stable isotope boron 10 (which constitutes approximately 20 percent of the natural boron) was found to be an excellent absorber of thermal, or slow, neutrons. Thus it was put to use in control rods and shielding for reactors. In rocketry boron has attracted much interest because its compounds combine low mass with a high energy yield as fuels. So far high cost and certain technical difficulties have restricted the utilization of boron in fuels, but perhaps these drawbacks will ultimately be removed. Other possibilities seem more immediately hopeful. They include the use of boron or boron compounds as materials for windows transparent to infrared radiation, for semiconductors that will operate reliably at high temperatures and for electrical generators of the thermoelectric type.

Let us now examine the basic structural nature of boron and its compounds. In modern chemistry no solid—whether it be an element, a compound or a complex organic substance such as a protein—is considered to be genuinely known until it has been crystallized and its structure determined, usually by means of X-ray diffraction [see "The Three-dimensional Structure of a Protein Molecule," by John C. Kendrew; SCIENTIFIC AMERICAN, December, 1961]. The X-ray analysis of boron and its compounds has turned out to be fruitful beyond expectations. In general it began with studies of compounds containing a relatively small proportion of boron and went on to those in which boron was more and more dominant. This sequence of studies showed that boron imposes peculiar and complex effects on the structures in which it is present. With increasing boron content the crystal structures become increasingly intricate, culminating in an extraordinarily complex symmetry when the crystals consist of the element alone.

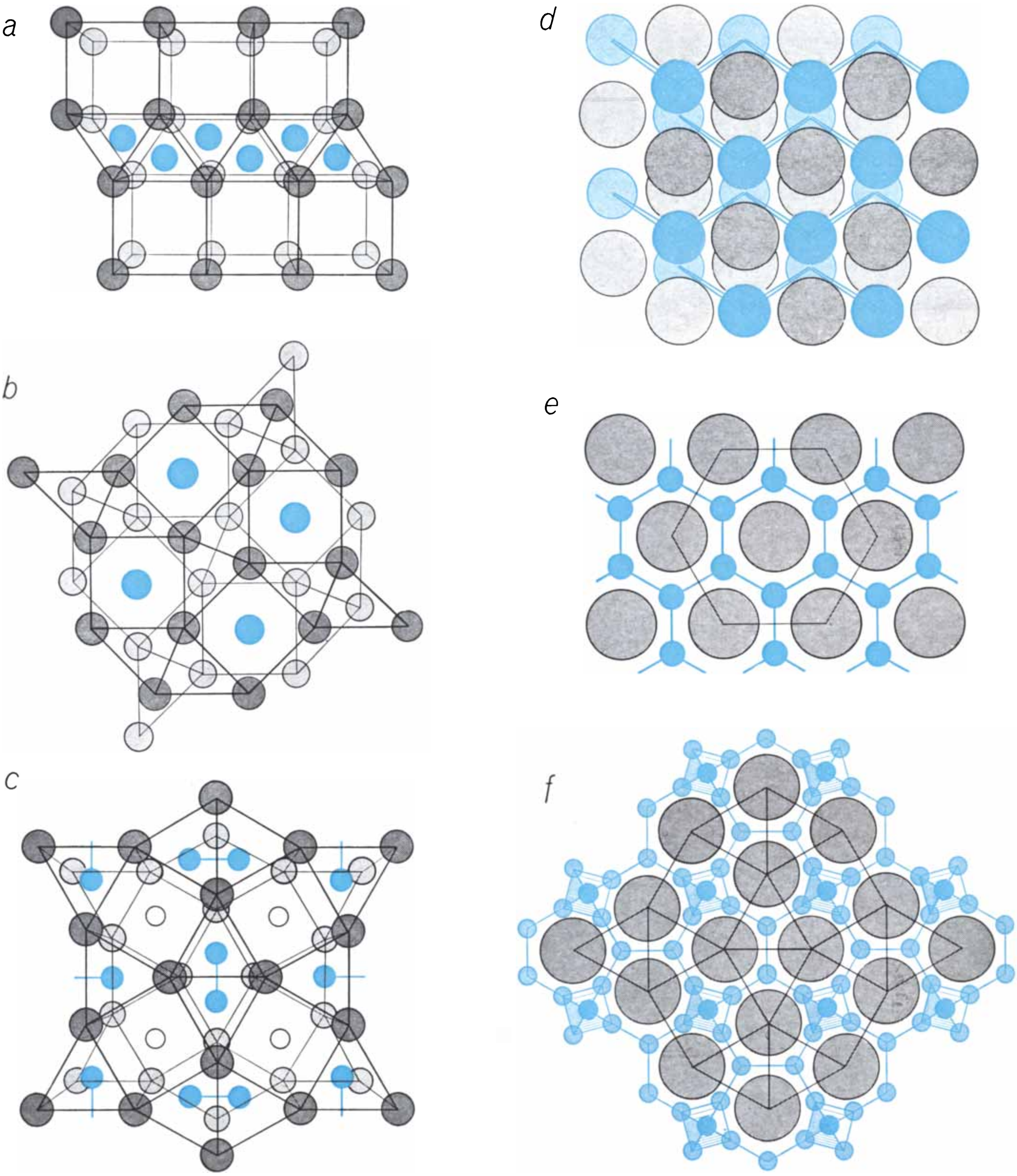
For the analysis of crystal structure by X-ray diffraction one needs well-formed single crystals of considerable size—at least a tenth of a millimeter in diameter. Such crystals were not easily obtained in the case of boron. The early methods used to purify boron and its compounds did not yield specimens of sufficient size or purity. The first crystals to fulfill the requirements were produced in the 1940's by A. W. Laubengayer and his students at Cornell University. They passed a mixture of a vaporized boron compound and hydrogen over a hot metal filament (the metal being tungsten, tantalum or niobium). The hydrogen reduced the compound, and crystalline elemental boron was deposited on the filament. Since then other methods for preparing good small crystals have been developed. For example, by dissolving boron to saturation in molten platinum and then cooling the melt, another form of boron is precipitated in a pure, crystalline state. A third crystalline form of boron can be obtained by melting the powdered element in a vacuum and then cooling it under carefully controlled conditions.

Not until about 1950 were materials and techniques available for systematic investigation of the structure of boron-containing crystals. Indeed, boron was the last common solid element to resist having any of its forms structurally elucidated. One of the first to publish significant findings in this regard was Roland Kiessling of Sweden. He studied borides of various metals, and he found that when the ratio of metal atoms to boron atoms in the crystal is three or more to one (as in the nickel boride Ni_3B), the boron atoms are distributed essentially as isolated atoms between layers of the metal atoms. The general structure, with the metal atoms of each layer arranged in alternating squares and isosceles triangles, is of a classic type exemplified by the iron carbide (Fe_3C) called cementite [*see "a" in illustration on next page*]. As the illustration shows, the boron atoms lie in prismatic pockets between the superposed triangles. In some cases (including the nickel and cobalt borides) the array of metal atoms is distorted from the perfectly regular rows of squares and triangles.

When the ratio of metal atoms to boron atoms is reduced to two to one, as in the iron boride Fe_2B, the picture changes. In most of these borides the metal atoms of each layer are still ar-



PLASMA TORCH at the Mound Laboratory, which is operated by the Monsanto Chemical Company for the Atomic Energy Commission, is used by one of the authors (Sullenger) and his colleagues to prepare microcrystals of pure boron for X-ray analysis. Pulverized boron is dropped into the apparatus through the small tube at top; as the boron passes through the region inside the induction coil, where an argon plasma with a gas temperature as high as 20,000 degrees Kelvin (degrees centigrade above absolute zero) is maintained, the boron particles are heated by energy absorbed from the excited argon atoms. Most of the powdered boron melts at the temperature it attains, and some even vaporizes, producing a glowing green tail to the flame. As the microcrystals that have resolidified from the melted droplets or condensed from the vapor fall through the lower, cooler part of the flame, they form bright red and yellow streaks, several of which are visible in the photograph. The microcrystals then fall into the spherical flask at the bottom, where they are collected.



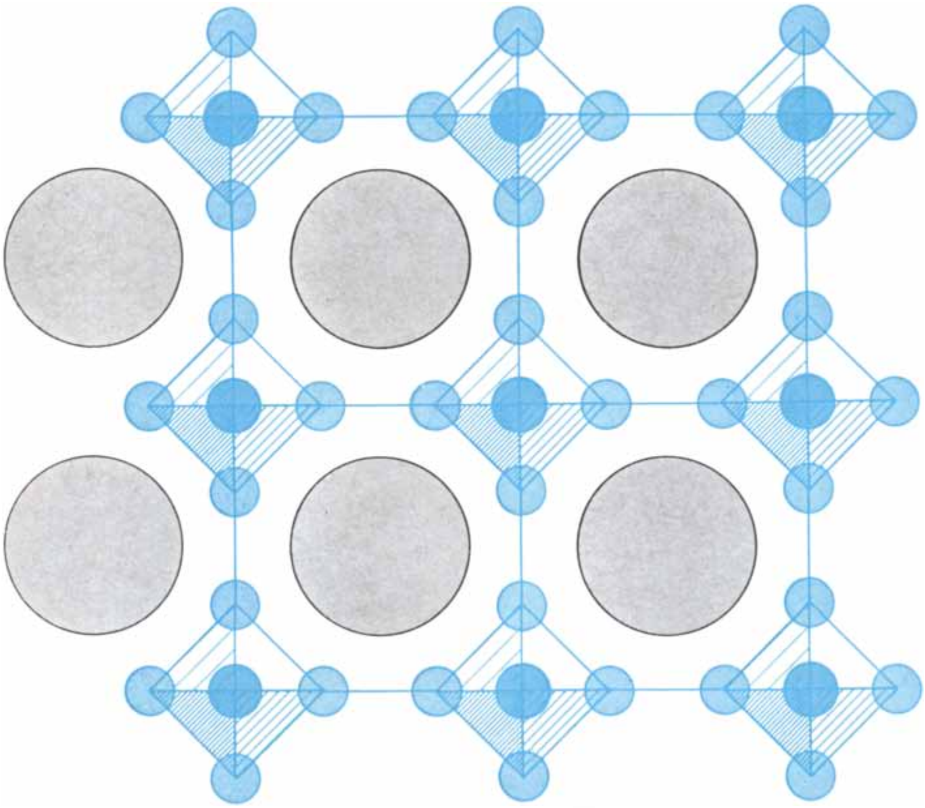
SIX BORIDES, compounds containing boron atoms (*color*) and metal atoms (*gray*), are represented here in order of increasing boron content. When the ratio of metal atoms to boron atoms is three or more to one (*a*), the boron atoms are distributed essentially as isolated atoms between layers of the metal atoms. The metal atoms in each layer are arranged in alternating squares and isosceles triangles, with the boron atoms lying in prismatic pockets between the superposed triangles. When the ratio of metal atoms to boron atoms is reduced to two to one (*b*), the metal atoms of each layer are still arranged in alternating squares and triangles, but each layer is rotated by 45 degrees with respect to the next one; the boron atoms are centered between the squares. In compounds with a three-to-two ratio of metal atoms to boron atoms (*c*) the boron atoms become paired at closer distances. In the case shown here, where the metal atoms are of two different sizes, the large metal atoms form layers with the triangle-square arrangement; the small metal atoms (*white*) lie between the superposed squares of the layers, and the boron atoms are positioned between the superposed triangles. In borides in which the ratio of boron atoms to metal atoms is one to one (*d*) the boron atoms are arrayed in zigzag chains between the layers of metal atoms. When the boron atoms outnumber the metal atoms two to one (*e*), the boron atoms form layers between the metal atoms; they are arrayed in a hexagonal pattern in their layer, whereas the atoms in the metal layer form a close-packed hexagonal network. When the ratio of boron atoms to metal atoms is four or more to one (*f*), the boron atoms are no longer arrayed simply in flat layers between metal layers but are linked up in three-dimensional structures in spaces between metal atoms.

ranged in alternating squares and triangles, but each layer is rotated by 45 degrees with respect to the next one, so that the squares of the successive layers are not eclipsed. The boron atoms are centered between the squares [*see "b" in illustration on opposite page*]. In these compounds the boron atoms are still not directly linked by chemical bonds in the usual sense; they are nearly as far from one another as they are from the metal atoms that surround them.

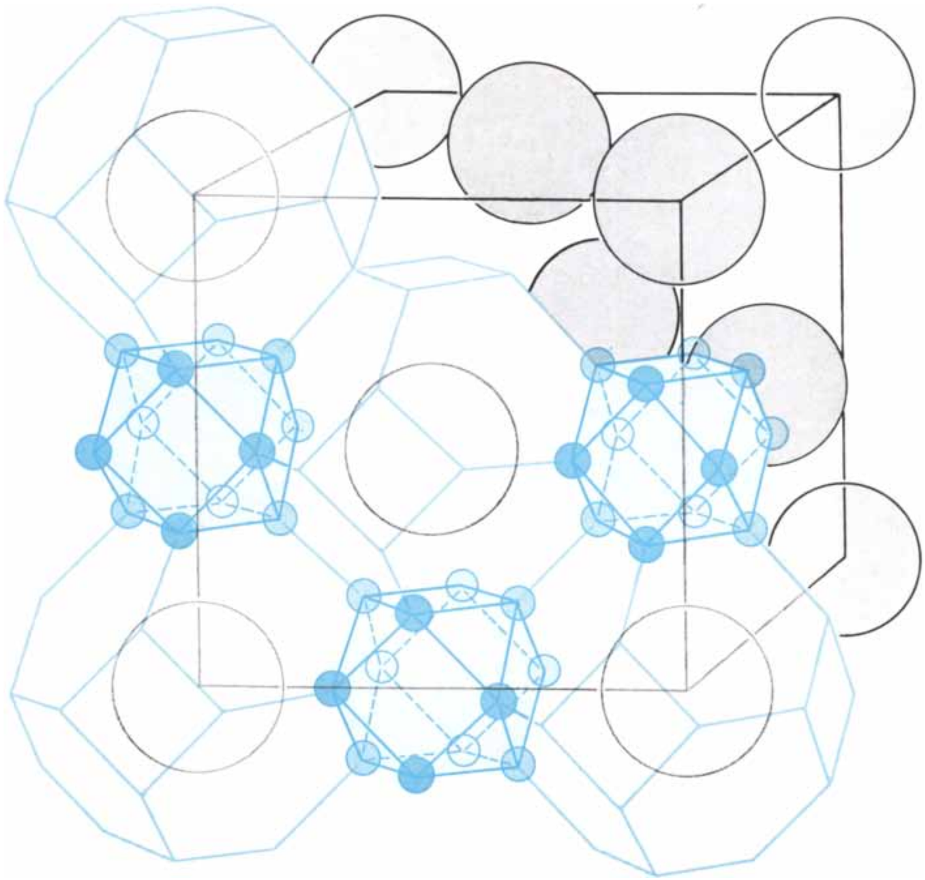
At the next level, in compounds with a three-to-two ratio of metal atoms to boron, the boron atoms are paired at closer distances. In the case where the metal atoms are of different sizes (different in atomic radius), two of them being larger than the third, the large metal atoms form layers with the triangle-square arrangement. The small metal atoms lie between the superposed squares of the layers and the boron atoms are between the superposed triangles, thus lying closer together [*see "c" in illustration on opposite page*].

In borides in which the ratio of metal to boron atoms is one to one (for example the iron boride FeB) the structure is still fairly simple, with the boron atoms arrayed in zigzag chains between the layers of metal atoms [*see "d" in illustration on opposite page*]. Thereafter a new complexity begins to develop. In compounds in which the boron atoms outnumber the metal atoms two to one the boron atoms form layers between the metal layers; they are arrayed in a hexagonal pattern in their layer, whereas the atoms in the metal layer form a close-packed hexagonal network [*see "e" in illustration on opposite page*]. The hexagonal boron pattern in these compounds is like that of the layers of carbon in graphite. The structure of the diborides is typified by the compound with aluminum (AlB_2); boron forms similar compounds with titanium, zirconium, niobium, tantalum, vanadium, chromium, molybdenum, uranium, magnesium and many other metals.

In any democratic society, when the minority becomes the majority it begins to impose its own character or predilections on the society. So it is with boron: as its atoms gain greater numerical superiority in its compounds, boron exercises increasing dominance over the structure. When the ratio of boron to metal atoms is four or more to one, the boron atoms are no longer arrayed simply in flat layers between the metal layers but are linked up in three-dimensional structures in the spaces between the metal atoms [*see "f" in illustration on opposite page*]. In the



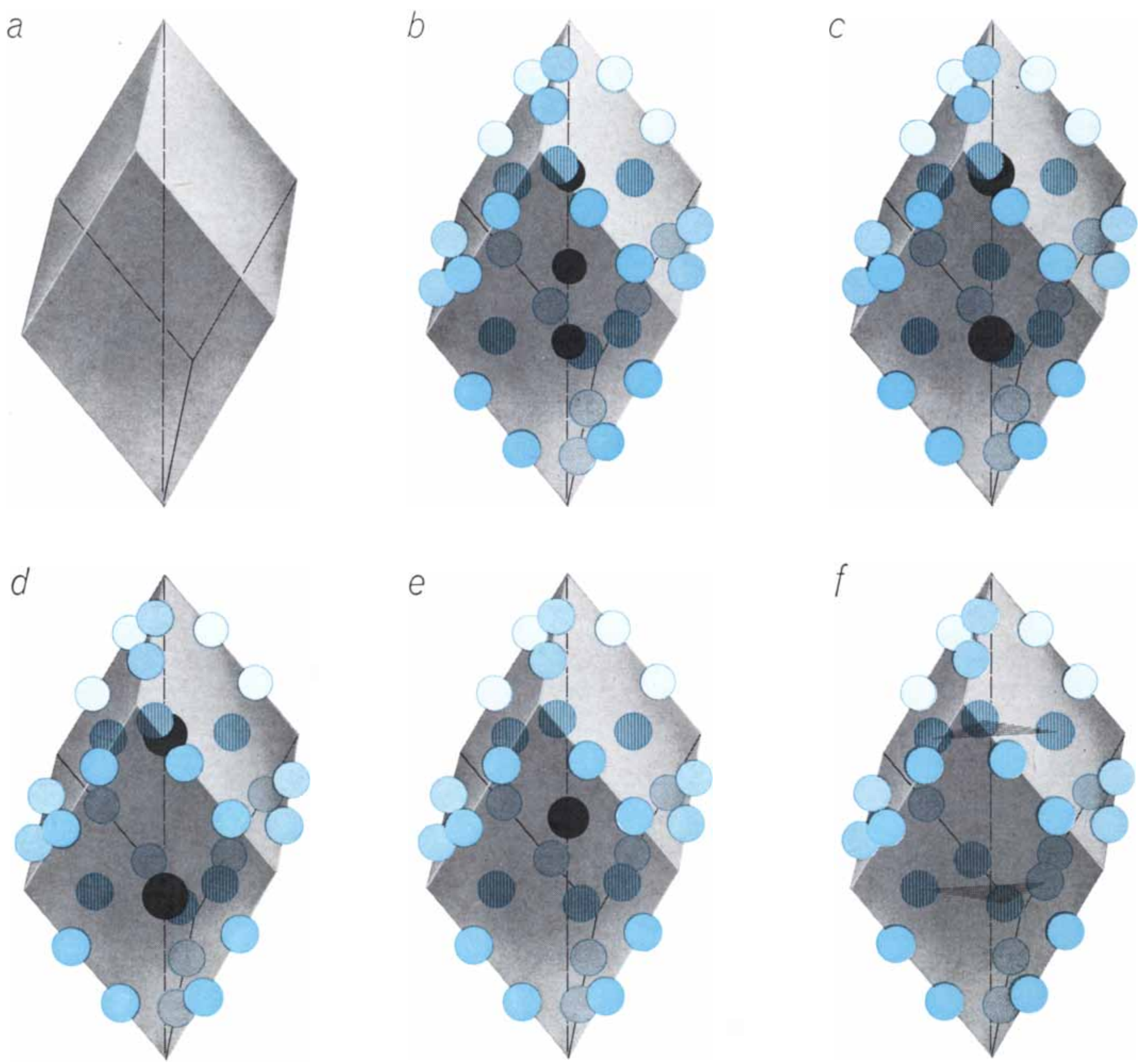
SIX-TO-ONE RATIO of boron atoms to metal atoms results in a boride structure in which the boron atoms form aggregates, or units, in the shape of a regular octahedron; these units are positioned at the corners of successive cubes with a metal atom at the center of each cube.



TWELVE-TO-ONE RATIO of boron atoms to metal atoms results in a boride structure in which the boron groups take a many-sided shape called the semiregular cube-octahedron, which roughly resembles a sphere. The boron aggregates pack together with metal atoms in much the same way that sodium and chlorine atoms are packed in crystals of common salt.

case where the ratio is six boron atoms to one metal atom, the boron atoms form aggregates, or units, in the shape of a regular octahedron, and these units are located at the corners of a cube with a metal atom at the center [*see top illustration on preceding page*].

In metal borides composed of 12 boron atoms for every metal atom, the boron groups take a many-sided shape called the semiregular cube-octahedron, which roughly approaches a sphere. In these crystals the approximately spherical boron aggregates pack together with the spherical metal atoms in much the same way that sodium and chlorine ions are packed in the crystals of common salt [*see bottom illustration on preceding page*]. Finally, in other compounds containing a high proportion of boron the aggregates of boron atoms are commonly observed to organize themselves in an even more symmetrical three-dimensional form: the regular

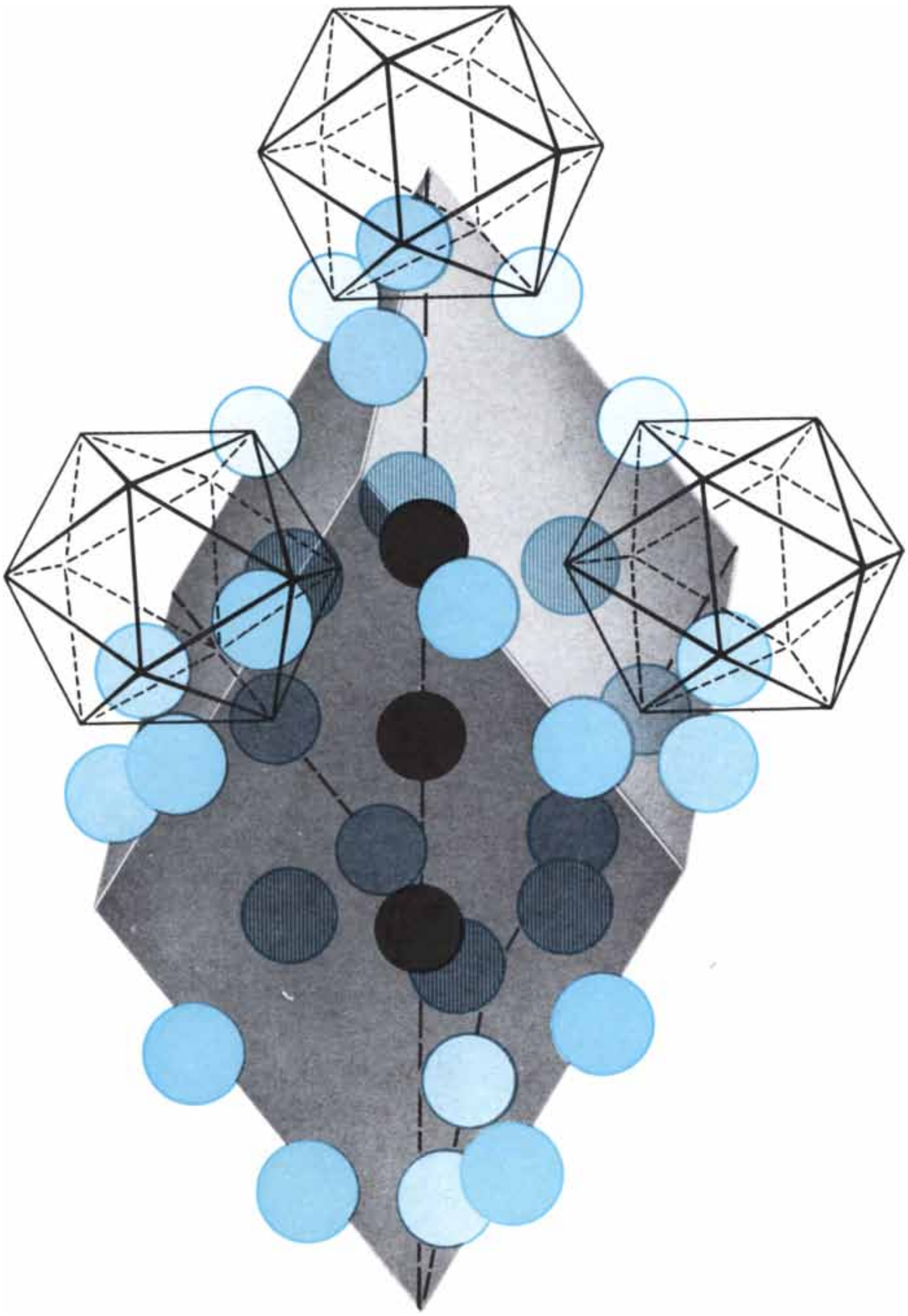


RHOMBOHEDRAL UNIT CELLS are characteristic of several boron compounds. In *a* the bare outline of one of these cells is shown. In the rest of the cells the chemical bonds between atoms have been omitted for clarity. In *b*, a unit cell of boron carbide ($B_{12}C_3$), the carbon atoms (*black*) are located along the major cell diagonal, one at the center and the other two equidistant from it in opposite directions. Twelve boron atoms can be regarded as belonging to the cell; six are wholly within it (*vertical colored hatching*), and 24 others (*color*) are placed along the 12 cell edges so as to divide each edge into thirds. Each of these 24 atoms is shared by four rhombohedral cells, in effect contributing six more boron atoms to each cell (*see illustration on opposite page*). The structure in *c* is typical of a group of compounds in which the boron atoms outnumber the other atoms 13 to two. (Such compounds can be formed with phosphorus, arsenic, silicon or oxygen.) A single boron atom is at the center of the cell, with two of the other atoms (*black*) flanking it along the cell diagonal. In *d* boron atoms and silicon atoms (*black*) combine in the ratio of 2.89 to one. Only two silicon atoms are along the diagonal; other silicon atoms are substituted at random in the boron positions inside the cell. In *e*, a boron-sulfur compound with the chemical formula $B_{12}S$, a single sulfur atom (*black*) is at the center of the cell, and the boron atoms are arranged as in *b* and *c*. The pure-boron structure in *f* is called the alpha-rhombohedral form (*also see top illustration on page 105*). There are no atoms along diagonal, but connections are made across diagonal by means of "delta" bonds (*horizontal hatched triangles*).

icosahedron, a figure with 20 equilateral triangular faces, 12 vertexes and 30 edges. This array is closely related topologically to the cube-octahedron, and perhaps one structure is changed to the other by the influence of other atoms present in the crystal.

Surveying the effects of increasing boron content, we can see the boron atoms progressively organized in more and more complex arrangements, from isolated atoms to two-dimensional networks to three-dimensional, many-sided forms contained in closely connected three-dimensional networks. Boron's propensity for forming remarkable structures is typical not only of its combinations with metals but also of its compounds with other elements. With nitrogen, for example, boron has been found to combine in three different BN structures, one layered in a hexagonal pattern similar to that of graphite and the other two three-dimensional [*see illustration on next page*]. In both three-dimensional forms each boron atom and each nitrogen atom is tetrahedrally surrounded by atoms of the other species, but the two forms are connected together differently to give in one case a cubic cell and in the other a hexagonal cell. In a compound with carbon containing four boron atoms to each carbon ($B_{12}C_3$) the boron aggregates, in the form of icosahedrons, make up unit cells in the shape of a rhombohedron, with the boron icosahedrons connected to three-atom carbon chains [*see illustration at right*]. This rhombohedral lattice turns out to be used in various compounds, with other atoms substituted for carbon. Among these crystals are a boron phosphide ($B_{13}P_2$), boron silicide ($B_{31}Si_{11}$), boron sulfide ($B_{12}S$) and even a form of boron alone, with the positions of the other atoms simply left vacant [*see bottom illustration on opposite page*].

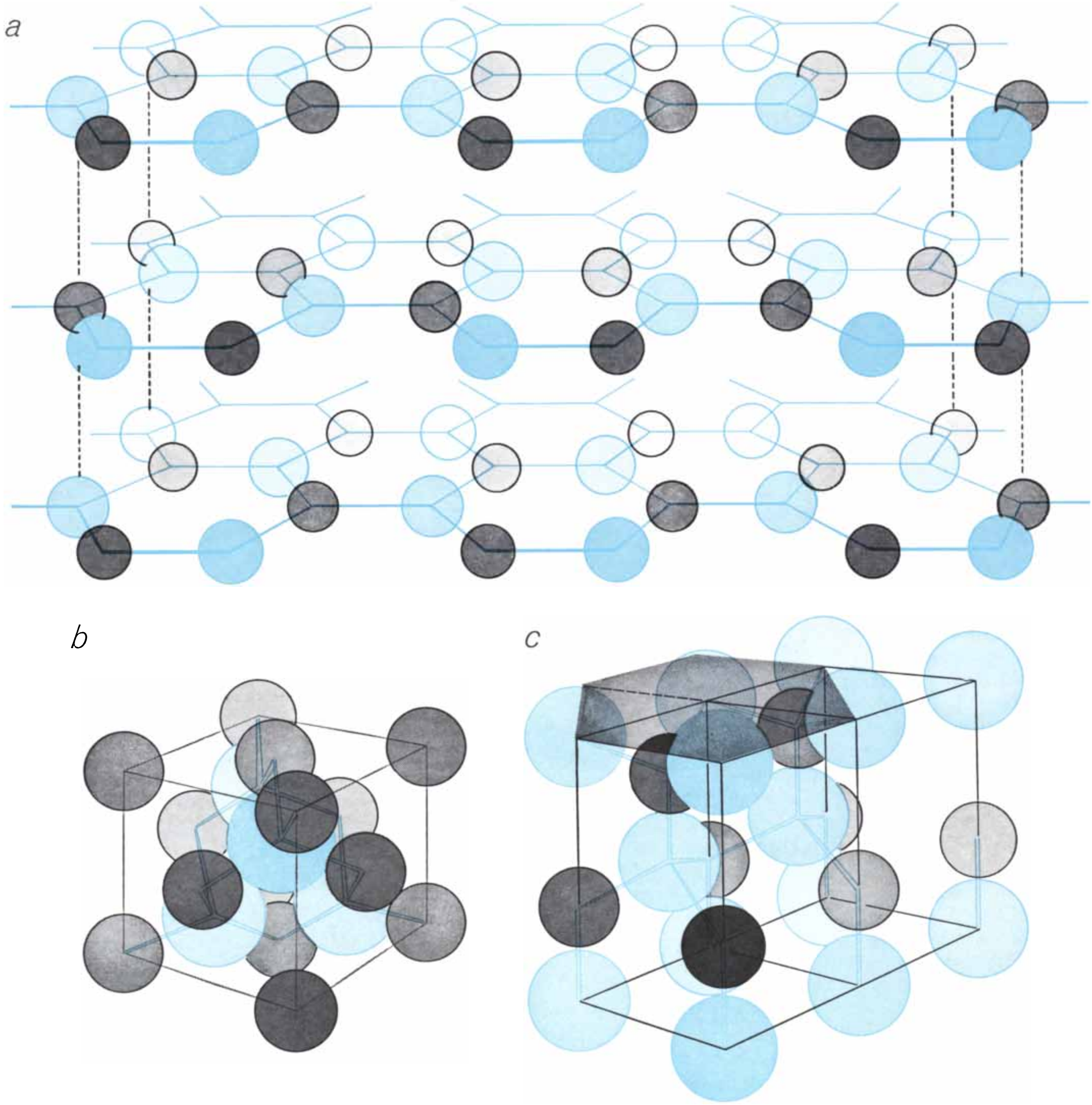
In recent years investigators have worked out the structures of some of the boron-hydrogen compounds—the boranes, or boron hydrides—that the pioneer Alfred Stock first produced decades ago. In these compounds a hydrogen atom, which normally can attach itself to only one other atom, is sometimes linked to two boron atoms by sharing their electrons. Using revolutionary ideas in X-ray diffraction analysis to overturn erroneous notions from chemical evidence about the spatial arrangement of atoms in the molecule of decaborane ($B_{10}H_{14}$), J. S. Kasper, C. M. Lucht and David Harker at the General Electric Research Laboratory found that this molecule has the form of a regular icosahedron that is not quite complete. Two positions are unfilled because there are only 10 boron atoms in the molecule instead of 12.



ANOTHER VIEW of a rhombohedral unit cell of boron carbide ($B_{12}C_3$) illustrates how the boron atoms are shared with adjacent cells. The boron groups are in the shape of icosahedrons, three of which are shown here in typical positions. Other bonds have been omitted.

By this time a reader may well be wondering about all this emphasis on the details of structure. Apart from the intrinsic interest of the subject, these details have basic significance with respect to the properties of any material. Even more than is the case with most other elements, the physicochemical characteristics of boron and its compounds are strongly dependent on structure. This is dramatically illustrated by boron nitride (BN). In its usual form, composed of alternating layers of boron and nitrogen atoms in hexagonal arrays, the compound is a soft white substance with a high melting point and great chemical stability. Under high pressure (45,000 atmospheres) and high temperature (15,000 degrees C.), however, the atoms can be restructured into three-dimensional cells, and in that form the compound is converted to a very hard material (nearly as hard as diamond and able to withstand high temperatures even better than diamond) that is a transparent white when free of crystal defects and sometimes yellow when impure. The transformation is almost as striking as the conversion of carbon from the graphite to the diamond form.

Thus far we have been considering boron in its combinations with other elements. Let us now focus on boron itself in its pure forms. Of the several different crystal types that have been discovered the structures of three have been analyzed. All of them are composed largely of icosahedral units (or aggregates closely related to the icosahedron), but they differ in the arrangement of the icosahedrons. One form, first prepared by Laubengayer and his group at Cornell by reducing boron tribromide with hydrogen and depositing the boron on a metal filament at 1,200 degrees C., is a black crystal composed of cells consisting of four boron icosahedrons plus two single boron atoms per cell in a tetragonal arrangement [*see bottom illustration on opposite page*]. Its structure was determined by J. L. Hoard and his students, also at Cornell. The second form, prepared at the General Electric Research Laboratory by two methods (depositing the boron on a hot filament at a somewhat lower temperature or crystallizing it from solution in molten platinum), consists of similarly oriented regular



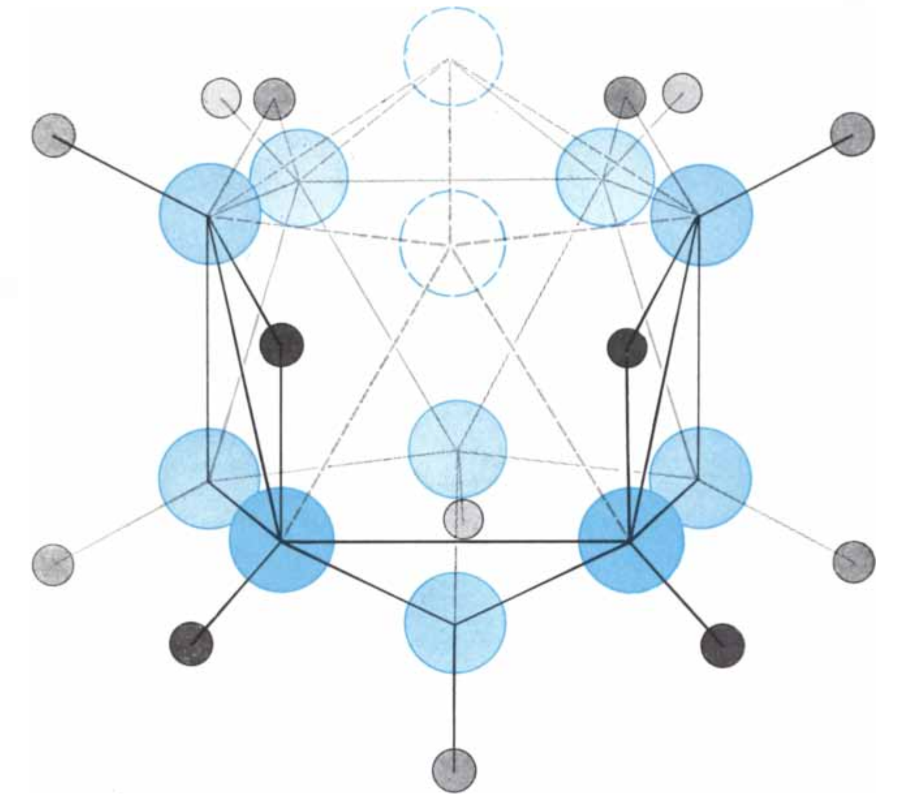
BORON AND NITROGEN combine to form three different boron-nitride (BN) structures, one layered in a hexagonal pattern similar to that of graphite (*a*) and the other two three-dimensional. In *b* the boron and nitrogen atoms are arranged in unit cells called face-centered cubes; in *c* the unit cells are hexagonal. Both *b* and *c* are produced under conditions of high pressure and temperature. The structure in *a* is a soft white substance with a high melting point and great chemical stability. Structures *b* and *c* are very hard materials (harder even than diamond) that are a transparent white when free of defects. Boron atoms are in color, nitrogen atoms in gray.

icosahedrons organized in rhombohedral cells [*see top illustration on page 105*]. The crystals are red. This type has been named the alpha-rhombohedral form, because a second version that has cells in the rhombohedral shape (named beta-rhombohedral) has also been produced. Recently the beta-rhombohedral form was analyzed at Cornell. After an extensive investigation under the guidance of Hoard, its structure was determined by a team consisting at various times of the authors of this article, R. E. Hughes, D. E. Sands and H. A. Weakliem. The crystal cell in this case is a complicated structure containing a total of 105 atoms, variously organized in simple icosahedrons and icosahedrons fused into 28-atom groups surrounding a lone atom in the center [*see bottom illustration on page 105*]. Fairly large "holes" exist in this structure, and there is evidence that some of them are filled, the degree of filling probably varying from specimen to specimen. This form of boron can be prepared reliably in various ways and perhaps will become the most important one for technological use. It offers the possibility that it may be thermodynamically stable at all temperatures.

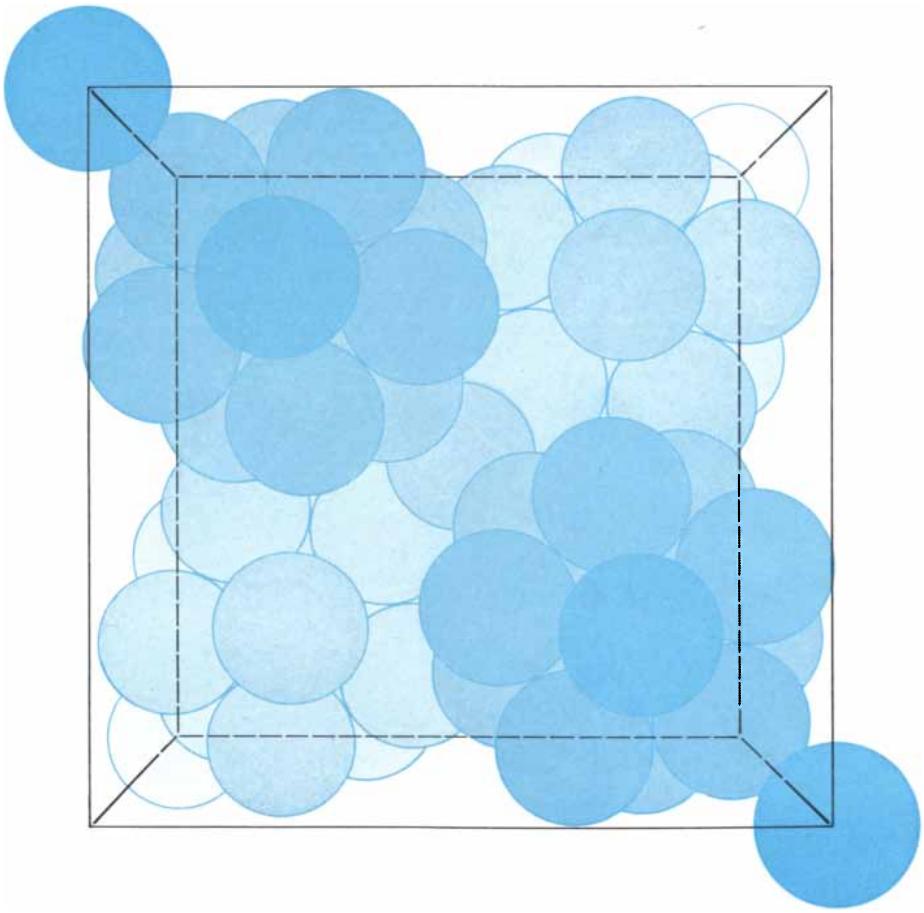
We have seen that the icosahedron (or a closely related structure) dominates most of the crystal structures dictated by boron, including the structures of metal borides, boron hydrides and boron itself. Why does this geometric form play so central a part? For a partial answer we must look more closely into the details of its geometry.

The icosahedron has a strange kind of beauty arising from its perfect but complex symmetry. Let us digress for a moment to consider the meaning of symmetry. Basically it embodies two qualities: balance and efficiency. Aesthetically we find pleasure in the balance of a well-composed painting, the rotationally related facets of a gemstone, the repeating pattern of a wallpaper, the symmetrical shape of a flower. Living organisms exhibit the efficiency of symmetry in almost innumerable examples, from the hexagonal cells of the honeycomb built by a bee to the bilateral structure of the human body, one half of which is essentially a mirror image of the other. The farmer makes maximum use of his land by planting his corn in square arrays; the orchardist, by laying out his trees in parallel rows.

The symmetry of the icosahedron can be understood at a first approximation by considering the globe of the earth.



DECABORANE MOLECULE ($B_{10}H_{14}$) has the form of a regular icosahedron that is not quite complete, two positions (*broken circles*) being unfilled (since there are only 10 boron atoms in the molecule instead of 12). Boron atoms are in color, hydrogen atoms in black.



TETRAGONAL BORON, one of the three well-known crystal forms of pure boron, is produced at about 1,200 degrees Kelvin. Its cells, each consisting of four 12-atom icosahedrons and a single atom at the center, have a tetragonal form like a somewhat flattened cube.

On this sphere the city of New York is located at 41 degrees north latitude and 74 degrees west longitude; at the same position in the Southern Hemisphere, 41 degrees south and 74 degrees west, is the city of Castro in Chile. At the Equator each city is a mirror reflection, geometrically speaking, of the other. To change the perspective, if we could look along the axis from New York through the center of the earth, we would find the Australian city of Perth at the other end of the axis; thus the two cities are opposite vertexes of a symmetrical figure. From another point of view, suppose we fly around the globe in the east-west direction in five equidistant hops beginning and ending at New York. The stopping places in such an event are said to be related to New York by fivefold symmetry.

An icosahedron has three kinds of rotational symmetry. It is a figure of 20 equilateral triangular faces with a total of 12 vertexes. Each vertex is related through a center of inversion to another vertex. If we stand the icosahedron on one vertex and look down through the figure from the opposite vertex, we see that this is an axis of fivefold rotational symmetry; if we stand the figure on an edge, we look along an axis of twofold symmetry; standing the figure on one of its faces, we see a threefold symmetry [*see top illustration on page 106*]. In any of these views one can see that a hypothetical mirror rising vertically out of the page toward the observer in any of several orientations would in principle reflect half of the figure into the other. In other words, we are dealing with a figure that permits various symmetrical arrangements. If we numbered the 12 vertexes, we would find that 120 distinct orientations are possible.

We are now in a position to understand how geometrical factors help to shape the three well-known forms of boron crystals: alpha-rhombohedral, beta-rhombohedral and tetragonal. As a basic premise we can assume that under the given conditions in each situation the crystal will take the form that maximizes symmetry and compactness and still maintains certain bonding arrangements. How, then, will groups of boron atoms bonded in the icosahedral arrangement, each containing 12 atoms, pack together to fulfill these criteria?

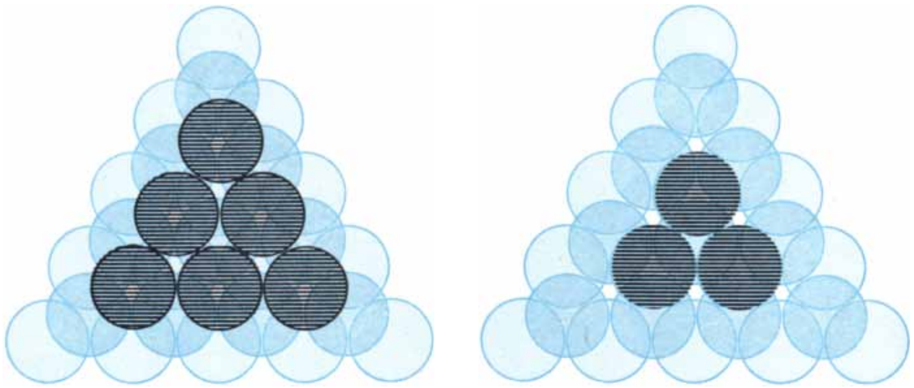
Since the icosahedron closely approximates a sphere, we can begin by considering the ways in which identical spheres can be packed most densely. In a single layer the densest arrangement is the one in which they nestle together with each sphere touching six others. There are then two ways the layers can be packed on one another. One is called cubic close-packing, the other hexagonal close-packing [*see illustration below*].

When icosahedrons are packed in the cubic close-packing array, the unit cells they form have the rhombohedral shape, because the successive layers are slightly shifted with respect to each other. This is the packing that characterizes the alpha-rhombohedral type of boron crystal. The cell has a threefold symmetry along the long diagonal of the rhombohedron, but it lacks most of the other symmetries that belong to a cube. To date no boron structure based on hexagonal close-packing has been found, although such a structure was postulated and some implications of its arrangement were investigated some years ago by W. N. Lipscomb, Jr., of Harvard University.

In the beta-rhombohedral form of boron, 12 icosahedrons are packed icosahedrally around a 13th icosahedron, so that the overall assembly has the same symmetry and orientation as the core icosahedron. These "supersets" of 156 boron atoms are in turn tied together in a complicated fashion that merges three of the peripheral icosahedrons (one from each of three large units) by means of a sharing of faces. The overall structure is such that only one of the 105 atoms thereby allotted to the unit cell is not included in these agglomerates. The analogy with the alpha-rhombohedral form can be preserved by considering the packing of 84-atom subunits obtained in the following way. Around a single regular icosahedron arrange 12 half-icosahedrons (that is, six-atom pentagonal pyramids each formed by cutting an icosahedron in half at right angles to one of its fivefold axes), each rotated so that its axis of fivefold symmetry coincides with that of the central icosahedron and with its apex pointing inward toward the center of the surrounded icosahedron. The enclosing figure will then be a 60-vertex (or 60-atom) semiregular figure having regular hexagonal faces alternating with regular pentagonal faces so as to preserve the icosahedral symmetry [*see bottom illustration on page 106*]. These large units, which resemble spheres even more closely than icosahedrons do, pack together again in near-cubic close-packing array with a few "chinking" atoms filled in along the rhombohedral cell diagonal.

The tetragonal form of boron, which is probably thermodynamically metastable, or temporarily stable, is much less densely packed. Its cells, each consisting of four 12-atom icosahedrons and a single atom at the center, have a tetragonal form that approaches a cube but is somewhat flattened. Although the structure is rather open, the adjacent icosahedrons are nevertheless closely linked: the distance between the neighboring atoms of one icosahedron and the next (1.68 angstrom units) is less than that between atoms within the icosahedron itself (about 1.80 angstroms).

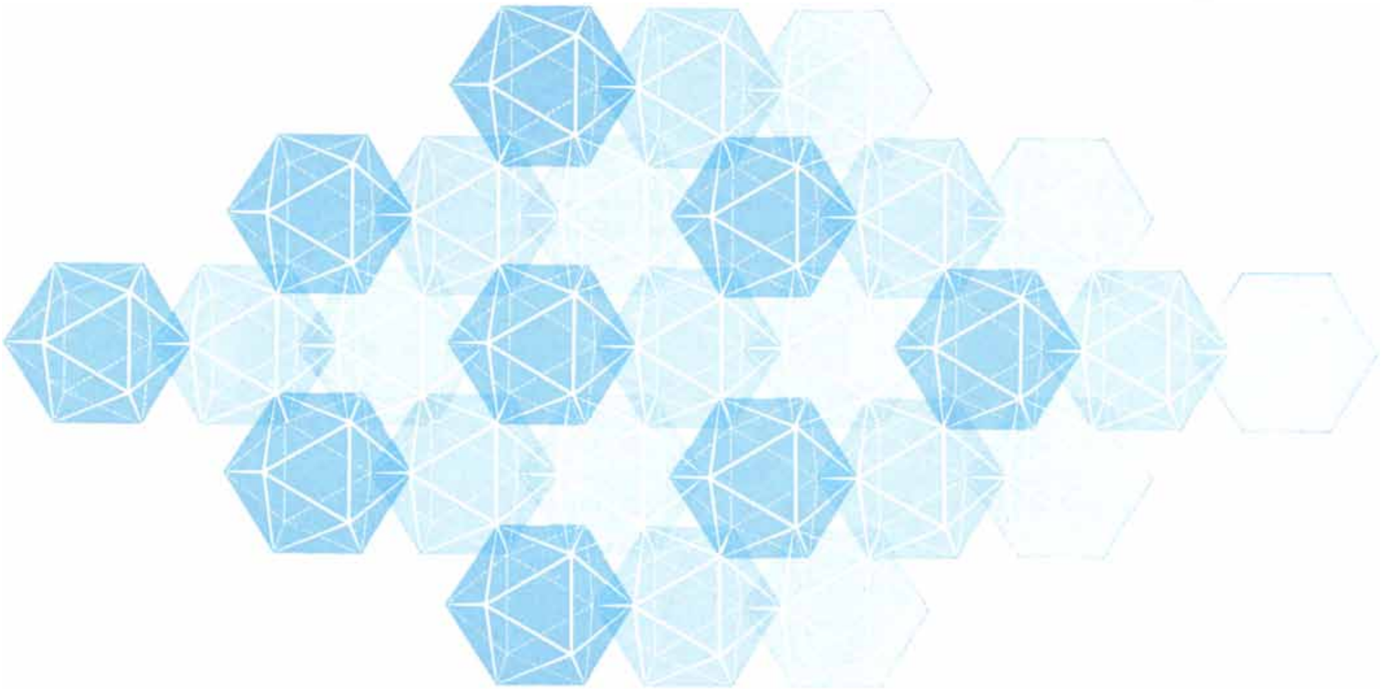
What has been learned so far concerning the stereochemistry, or structural chemistry, of boron is obviously only part of the story. Boron is a remarkably versatile builder of matter: the crystals it constructs range from



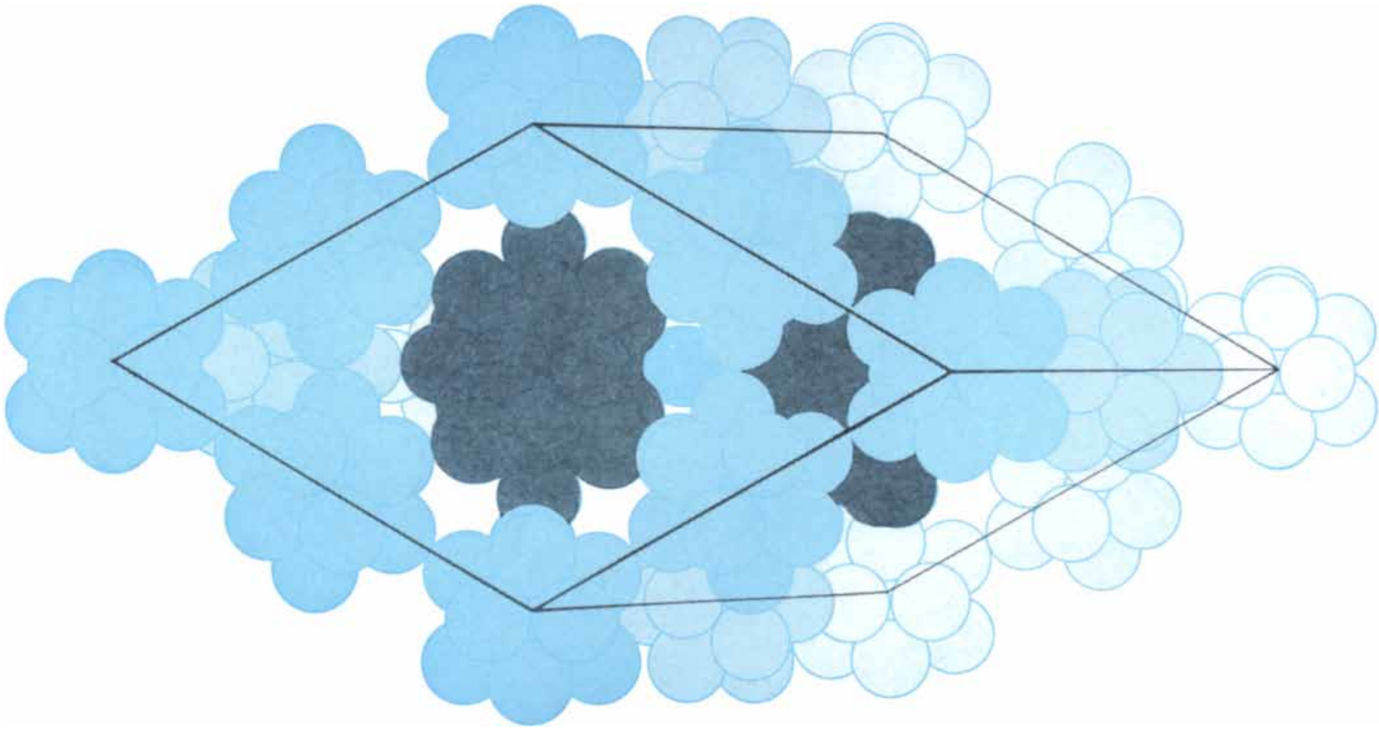
CLOSE-PACKING of identical hard spheres can be achieved in the two ways shown here. In cubic close-packing (*left*) every fourth close-packed layer is superposed directly over the bottom layer. In hexagonal close-packing (*right*) every third layer is directly over the bottom layer. In this vertical overhead view the two kinds of close-packing can be imagined as two different methods of piling cannonballs on the courthouse lawn; on the same triangular base the three-layered pile at left contains 31 balls, whereas the three-layered pile at right contains only 28 balls. The two kinds of packing have the same density of balls but different arrangements. The black cross-hatched balls are in the uppermost layerin each pile.

very simple ones in which single atoms constitute the units to those in which the typical unit is a highly involved affair made up of 12 atoms. What are the factors responsible for boron's formation of these complex structures? For a full answer we must look beyond considerations of geometrical packing into the nature of the linkages between boron atoms and the relative energies involved in various arrangements of atoms.

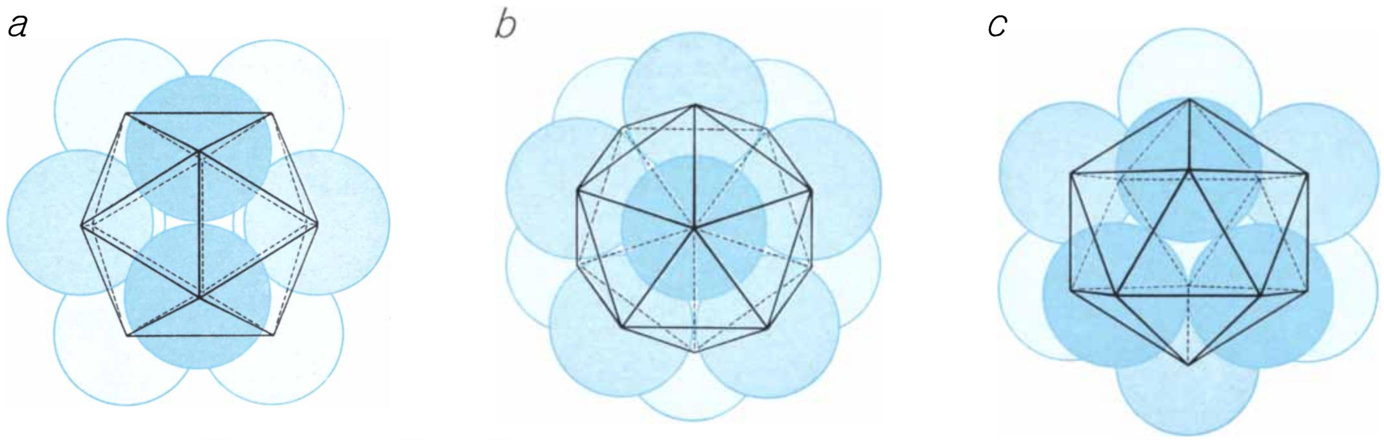
Boron is not a metal; therefore its atoms cannot be considered to be held together by the kind of bonding (involving the freeing of electrons from tightly bound positive atomic nuclei and the overall arrangement of the charges to minimize the free energy of the system) that joins the metal atoms in a crystal. Nor can the boron aggregates (the icosahedrons and other forms) be re-



ALPHA-RHOMBOHEDRAL BORON is characterized by approximate cubic close-packing of the 12-atom icosahedral boron groups, which are shown here as geometric figures. The darkest-colored layer is closest to the viewer. The unit cells formed by the icosahedrons have the rhombohedral shape, because the successive layers are shifted apart slightly with respect to each other. The cell has a threefold symmetry along the major diagonal of the rhombohedron but it lacks most other symmetries that belong to a cube.



BETA-RHOMBOHEDRAL BORON is characterized by a highly complex packing with a lesser density of atoms than in the alpha-rhombohedral form. Greater stability of beta-rhombohedral form may be a result of the icosahedral packing of 12 half-icosahedrons about a central icosahedron to form an 84-atom unit enclosed by a truncated icosahedral array (*see bottom illustration on next page*). There are 105 atoms in the cell. Completely inside are two 28-atom aggregates (*dark color*), merged from three icosahedrons by a sharing of faces, and a single atom at the center. Icosahedrons at corners are the same as in the alpha-rhombohedral form.

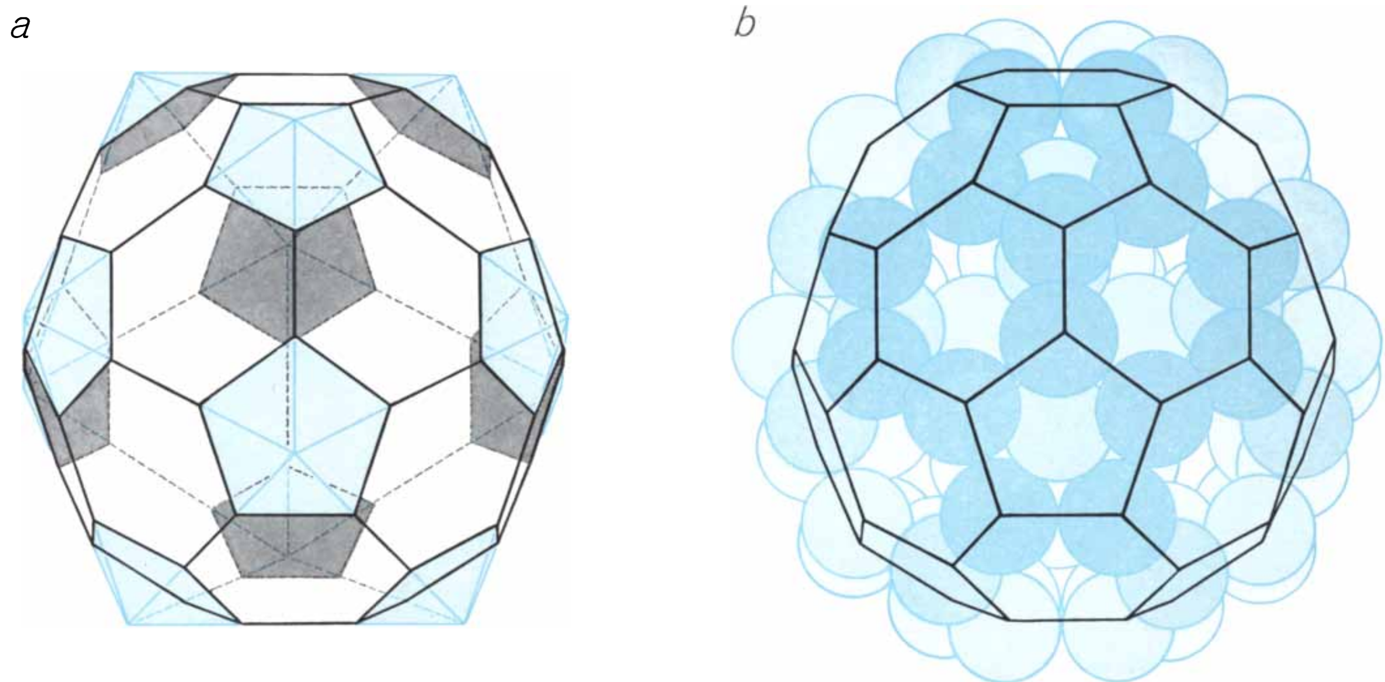


REGULAR ICOSAHEDRON, a three-dimensional figure with 20 equilateral triangular faces and 12 vertexes, is formed by the boron aggregates in compounds containing a high proportion of boron. The icosahedron has three kinds of rotational symmetry. In these three views one is looking along the twofold axis of symmetry (*a*), the fivefold axis of symmetry (*b*) and the threefold axis of symmetry (*c*). In addition to these rotational symmetries, the icosahedron has a "center of inversion" in many planes of symmetry.

garded as molecules (except in the case of the boron hydrides); molecularity is ruled out by the extreme hardness and thermal stability of these structures and particularly by the fact that the atoms within such an aggregate are less closely linked together than one aggregate is to another.

We must therefore consider the possibility of some kind of linkage that is not molecular but that is still based on an exchange, or sharing, of electrons between the atoms. Boron has three electrons available for combining purposes (the three in its only partly filled outer shell) and four orbitals. There are two extreme ways in which such linkages with neighboring atoms might be achieved: the ideal ionic type of bond, involving the complete transfer of an electron from one atom to another, or the ideal covalent bond, involving the mutual sharing of a pair of electrons by two atoms. It seems unlikely that the bonding of the boron aggregates is extensively ionic, because little evidence has been found of any large transfer of charge between aggregates in the crystals. The evidence suggests rather that the linkage is more covalent.

There is a peculiar anomaly about this bond, however. In most of the substances with a high boron content there are not enough valence electrons to provide two for every pair of atoms. Linus Pauling, building on the previous ideas of Robert E. Rundle, has pointed out that not only the number of pairs of electrons but also the number of available electrons is insufficient to account in a traditional manner for the number of actual atomic linkages in these crystals. W. H. Eberhardt, Bryce Crawford and Lipscomb, then at the University of Minnesota, came forth with a plausible



TRUNCATED ICOSAHEDRON is formed by removing the pentagonal pyramidal caps from the vertexes of a regular icosahedron (*left*). When atoms are placed at all the new vertexes (*right*) and at the center of the figure in the form of a regular icosahedron (not visible here), the rhombohedral cell made with such figures at the corners (and with the addition of 21 "chinking" atoms along the cell diagonal) is equivalent to the model of beta-rhombohedral boron shown on the preceding page. The resulting model is analogous to that of alpha-rhombohedral boron, with truncated icosahedrons replacing the regular icosahedrons of the latter.

explanation of this anomaly. They suggest that three boron atoms, rather than two, may share a pair of electrons in a linkage that they have named the "delta bond." The structural arrangement of the boron atoms in the boron hydrides, in some of the higher borides and in some crystalline forms of boron itself allows for such three-way sharing. Their idea is supported by the chemical behavior of various boranes and recent measurements of the electrical properties of some of the borides.

Technologically boron is playing a key role in the revived interest in two-phase composite materials. Its outstanding lightness, stiffness, resistance to stretching, chemical inertness and especially thermal stability make boron a leading candidate as a reinforcing substance for matrices of soft metals (for example aluminum, silver or copper) or plastics (for example the epoxy resins or various ceramics). The promise of such materials for lighter, stronger airframes and trains, higher buildings, longer bridges and more efficient turbines is exciting indeed. The preliminary results of tests of boron-reinforced materials have been very encouraging, and the familiar process of boron deposition on tungsten filaments has been adapted to pilot-plant scale in several places in order to provide the required continuous-fiber material. In spite of some problems, boron seems to have a bright future in this area of technology.

Three recent fundamental advances in the structural chemistry of boron are particularly noteworthy. One is the substitution of two carbon atoms for two boron atoms in an icosahedral framework to produce carborane molecules, which are amazingly resistant to attack by heat and a wide range of chemicals. First prepared in 1956 by workers at Reaction Motors, Inc., but kept under security wraps until late 1963, these molecules have now been extensively developed, and the variety of polyhedral aggregation they portend is staggering.

A second achievement of note is the connecting of complete icosahedrons or fragments of icosahedrons to form more extended but stable molecular species, perhaps leading toward a linkup in the three-dimensional arrays characteristic of elemental boron. Examples of such molecules are those of the two $B_{18}H_{22}$ borane forms discovered in 1962 by A. R. Pitochelli of the Rohm and Haas Company and M. F. Hawthorne of the University of California at Riverside [*see illustration at right*]. The structures of both these forms were worked out by Lipscomb and his students at Harvard. Other examples are the $B_{20}H_{16}$ molecules prepared by W. E. Miller and E. L. Muetterties at E. I. du Pont de Nemours & Co. (whose structure was again solved by Lipscomb and his students) and the $C_4B_{20}H_{22}$ molecules (whose structure was solved in 1965 by L. N. Hall, A. Perloff, F. A. Miner and S. Block at the National Bureau of Standards from samples supplied by the Rohm and Haas Company and the Thiokol Chemical Corporation).

In the past year Stephanie Richards and J. S. Kasper at the General Electric Research Laboratory have completed the first successful determination of the structure of a "hectoboride" (one of a group of recently discovered boron-rich heavy metal compounds with compositions approaching a boron-to-metal ratio of 100 to one). Their specimen, yttrium hectoboride (YB_{70}), was characterized by a huge cubic cell (23.5 angstroms on an edge) that contained some 1,700 atoms. A striking feature of its structure was the existence in it of eight aggregates, each consisting of 156 boron atoms arranged in the form of 12 icosahedrons icosahedrally arrayed about a 13th icosahedron in a fashion identical with that found in beta-rhombohedral boron. In the hectoboride, however, the units were disparate instead of merged as in the case of the elemental boron form.

In sum, these developments indicate a strong tendency for the formation of icosahedral bonds among assemblies of boron atoms, a tendency that extends out even beyond neighboring atoms. They also give some inkling of the great diversity and complex connectivity that is afforded by boron-dominated frameworks. The properties of these types of substances will undoubtedly be so different from materials already at hand that they will eventually find unique and varied applications. In principle the complexity of these substances also suggests the possibility of "tailoring" them for special tasks.

The investigation of boron is proceeding with increasing ardor and almost daily reports of new developments. New forms of pure boron are being produced —as powders, thin films, extremely tiny crystals and in other manifestations. The history reviewed in this article is probably a preface to a still more eventful boron chemistry to unfold in the next decade. Boron has already given theoretical chemists an entire new area to think about. The findings not only apply to boron but also promise to help in the understanding of various intermetallic compounds (compounds of two or more metals). Indeed, boron has given us beautiful new views of order in complexity. We can say of boron, as Alexander Pope wrote of Windsor Forest:

Not chaos-like together crush'd
and brus'd,
But, as the world, harmoniously
confus'd:
Where order in variety we see,
And where, though all things differ,
all agree.

FRAGMENTS OF TWO ICOSAHEDRONS are joined together to form this borane isomer designated $B_{18}H_{22}$, one of two such molecules discovered in 1962 by A. R. Pitochelli of the Rohm and Haas Company and M. F. Hawthorne of the University of California at Riverside. Structure of this molecule was worked out by W. N. Lipscomb, Jr., and his students at Harvard University. In the authors' words, these new molecular types of boron compounds "serve to emphasize the already impressive icosahedralism of things boronic."

MATHEMATICAL GAMES

Freud's friend Wilhelm Fliess and his theory of male and female life cycles

by Martin Gardner

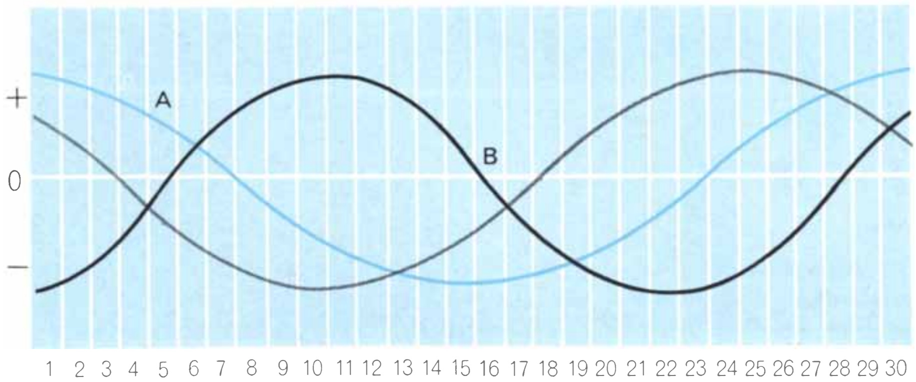
One of the most extraordinary and funniest episodes in the history of numerological pseudo-science concerns the work of a Berlin surgeon named Wilhelm Fliess. Fliess was obsessed by the numbers 23 and 28. He convinced himself and others that behind all living phenomena and perhaps inorganic nature as well there are two fundamental cycles: a male cycle of 23 days and a female cycle of 28 days. By working with multiples of those two numbers—sometimes adding, sometimes subtracting—he was able to impose his number patterns on virtually everything. The work made a considerable stir in Germany during the early years of this century. Several disciples took up the system, elaborating and modifying it in books, pamphlets and articles. In recent years the movement has taken root in the U.S.

Although Fliess's numerology is of interest to recreational mathematicians and students of pathological science, it would probably be unremembered today were it not for one almost unbelievable fact: For a decade Fliess was Sigmund Freud's best friend and confidant. Roughly from 1890 to 1900, in the period of Freud's greatest creativity, which culminated with the publication of *The Interpretation of Dreams* in 1900, he and Fliess were linked in a strange, neurotic relationship that had—as Freud himself was well aware—strong homosexual undercurrents. The story was known, of course, to the early leaders of psychoanalysis, but few laymen had even heard of it until the publication in 1950 of a selection of 168 letters from Freud to Fliess, out of a total of 284 that Fliess had carefully preserved. (The letters were first published in German. An English translation entitled *The Origins of Psycho-Analysis* was issued by Basic Books in 1954.) Freud would have destroyed these letters if they had come into his possession. He was staggered by the news that they had been preserved, and he begged the owner (the analyst Marie Bonaparte) not to permit their publication. In reply to her question about Fliess's side of the correspondence Freud said: "Whether I destroyed them [Fliess's letters] or cleverly hid them away I still do not know." It is assumed that he destroyed them. The full story of the Fliess-Freud friendship has been told by Ernest Jones in his biography of Freud.

When the two men first met in Vienna in 1887, Freud was a relatively unknown Viennese psychiatrist aged 31, happily married and with a modest practice. Fliess had a much more successful practice as a nose and throat surgeon in Berlin. He was two years younger than Freud, a bachelor, brilliant, witty and well informed on medical and scientific topics. (Later he married a wealthy Vienna woman.) Freud opened their correspondence with a flattering letter. Fliess responded with a gift, then Freud sent a photograph of himself that Fliess had requested. By 1892 they had dropped the formal *sie* (you) for the intimate *du* (thou). Freud wrote more often than Fliess and was in torment when Fliess was slow in answering. When his wife was expecting their fifth child, Freud declared it would be named Wilhelm. Indeed, he would have named either of his two youngest children Wilhelm but, as Jones puts it, "fortunately they were both girls."

The foundations of Fliess's numerology were first revealed to the world in 1897 when he published his monograph *Die Beziehungen zwischen Nase und weibliche Geschlechtsorganen in ihrer biologischen Bedeutungen dargestellt* (*The Relations between the Nose and the Female Sex Organs from the Biological Aspect*). Every person, Fliess maintained, is really bisexual. The male component is keyed to the rhythmic cycle of 23 days, the female to a cycle of 28 days. (The female cycle must not be confused with the menstrual cycle, although the two are related in evolutionary origin.) In normal males the male cycle is dominant, the female cycle repressed. In normal females it is the other way around. The two cycles are present in every living cell and consequently play their dialectic roles in all living things. Among animals and humans both cycles start at birth, the sex of the child being determined by the cycle that is transmitted first. The periods continue throughout life, manifesting themselves in the ups and downs of one's physical and mental vitality, and eventually determine the day of one's death. Moreover, both cycles are intimately connected with the mucous lining of the nose. Fliess thought he had found a relation between nasal irritations and all kinds of neurotic symptoms and sexual irregularities. He diagnosed these ills by inspecting the nose and treated them by applying cocaine to "genital spots" on the nose's interior. He reported cases in which miscarriages were produced by anesthetizing the nose, and he said that he could control painful menstruation by treating the nose. On two occasions he operated on Freud's nose. In a later book he argued that all left-handed people are dominated by the cycle of the opposite sex, and when Freud expressed doubts, he accused Freud of being left-handed without knowing it.

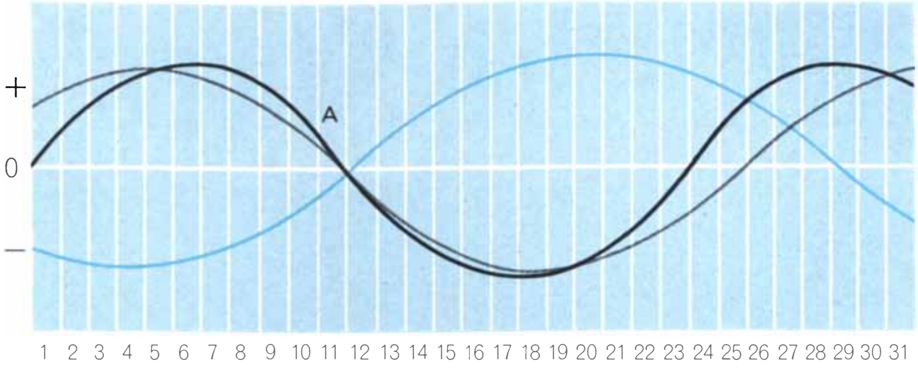
Most of this was hailed by Freud as



Clark Gable's two heart attacks (A, B) came on November 5 and 16, 1960 a major breakthrough in biology. He sent Fliess information on 23- and 28-day periods in his own life and the lives of those in his family, and he viewed the ups and downs of his health as fluctuations of the two periods. He believed a distinction he had found between neurasthenia and anxiety neurosis could be explained by the two cycles. In 1898 he severed editorial connections with a journal because it refused to retract a harsh review of one of Fliess's books. There was a time when Freud suspected that sexual pleasure was a release of 23-cycle energy and sexual unpleasure a release of 28-cycle energy. For years he expected to die at the age of 51 because it was the sum of 23 and 28, and Fliess had told him this would be his most critical year. "Fifty-one is the age which seems to be a particularly dangerous one to men," Freud wrote in his book on dreams. "I have known colleagues who have died suddenly at that age, and amongst them one who, after long delays, had been appointed to a professorship only a few days before his death."

Freud's acceptance of Fliess's cycle theory was not enthusiastic enough, however. Fliess, who was abnormally sensitive to even the slightest criticism, thought he detected in one of Freud's 1896 letters some faint suspicions about his system. This marked the beginning of the slow emergence of latent hostility on both sides. Freud's earlier attitude toward Fliess had been one of almost adolescent dependence on a mentor and father figure. Now he was developing theories of his own about the origins of neuroses and methods of treating them. Fliess would have little of this. He argued that Freud's imagined cures were no more than the fluctuations of mental illness, in obedience to the male and female rhythms. The two men were on an obvious collision course.

As one could have predicted from the earlier letters, it was Fliess who first began to pull away. The growing rift plunged Freud into a severe neurosis, from which he emerged only after painful years of self-analysis. The two men had been in the habit of meeting frequently in Vienna, Berlin, Rome and elsewhere, for what Freud playfully called their "congresses." As late as 1900, when the rift was beyond repair, we find Freud writing: "There has never been a six months' period where I have longed more to be united with you and your family.... Your suggestion of a meeting at Easter greatly stirred me.... It is not merely my almost child-like yearning for the spring and for more beautiful scenery; that I would willingly sacrifice for the satisfaction of having you near me for three days.... We should talk reasonably and scientifically, and your beautiful and sure biological discoveries would awaken my deepest—though impersonal—envy."

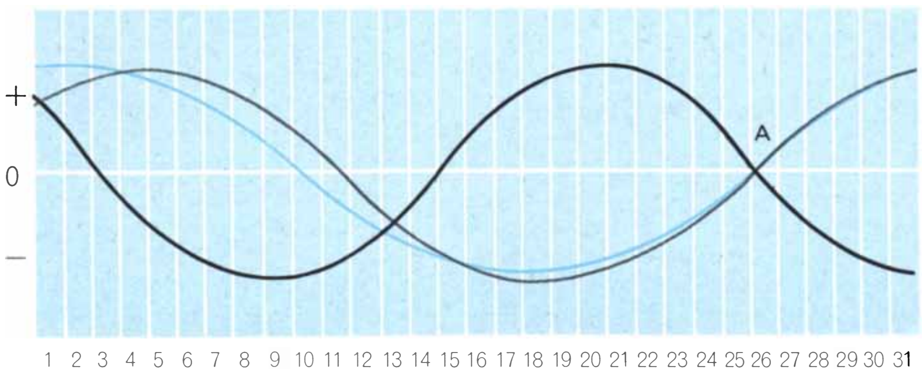


The day of the Aga Khan's death* (A) *in July, 1957, was near a triple switch point

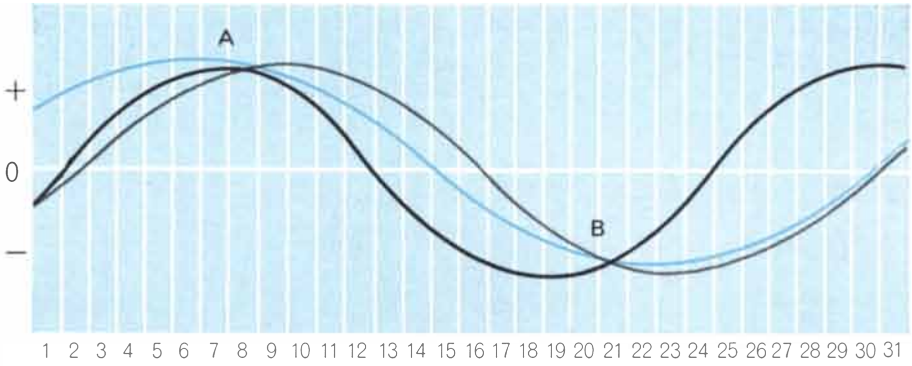
Freud nevertheless turned down the invitation, and the two men did not meet until later that summer. It was their final meeting. Fliess later wrote that Freud had made a violent and unprovoked verbal attack on him. For the next two years Freud tried to heal the breach. He proposed that they collaborate on a book on bisexuality. He suggested that they meet again in 1902. Fliess turned down both suggestions. In 1904 Fliess published angry accusations that Freud had leaked some of his ideas to Hermann Swoboda, one of Freud's young patients, who in turn had published them as his own.

The final quarrel seems to have taken place in a certain dining room of the Park Hotel in Munich. On two later occasions, when Freud was in this room in connection with meetings of the analytical movement, he experienced a severe attack of anxiety. Jones recalls an occasion in 1912, when he and a group that included Freud and Jung were lunching in this same room. A break between Freud and Jung was brewing. When the two men got into a mild argument, Freud suddenly fainted. Jung carried him to a sofa. "How sweet it must be to die," Freud said as he was coming to. Later he confided to Jones the reason for his attack.

Fliess wrote many books and articles about his cycle theory, but his magnum opus was a 584-page volume, *Der Ablauf des Lebens: Grundlegung zur Exakten Biologie* (*The Rhythm of Life: Foundations of an Exact Biology*), published in Leipzig in 1906 (second edition, Vienna, 1923). The book is a masterpiece of Teutonic crackpottery. Fliess's basic formula can be written $23x + 28y$, where x and y are positive or negative integers. On almost every page Fliess fits this formula to natural phenomena, ranging from the cell to the solar system. The moon, for example, goes around the earth in about 28 days; a complete sunspot cycle is almost 23 years. The book's appendix is filled with such tables as multiples of 365 (days in the year), multiples of 23, multiples of 28, multiples of 23^2, multiples of 28^2, multiples of 644 (which is 23×28). In boldface are certain important constants such as 12,167 [23×23^2], 24,334 [$2 \times 23 \times 23^2$], 36,501 [$3 \times 23 \times 23^2$], 21,952 [28×28^2], 43,904 [$2 \times 28 \times 28^2$] and so on. A table lists the numbers 1 through 28, each expressed as a differ-



***Arlene Francis' accident in May, 1963, was on a triply critical day* (A)**



Periods during which Arnold Palmer won (A) *and lost* (B) *tournaments in July, 1962*

ence between multiples of 28 and 23 [for example, $13 = (21 \times 28) - (25 \times 23)$]. Another table expresses numbers 1 through 51 [$23 + 28$] as sums and differences of multiples of 23 and 28 [for example, $1 = (\frac{1}{2} \times 28) + (2 \times 28) - (3 \times 28)$].

Freud admitted on many occasions that he was hopelessly deficient in all mathematical abilities. Fliess understood elementary arithmetic, but little more. He did not realize that if any two positive integers that have no common divisor are substituted for 23 and 28 in his basic formula, it is possible to express *any positive integer whatever.* Little wonder that the formula could be so readily fitted to natural phenomena! This is easily seen by working with 23 and 28 as an example. First determine what values of x and y can give the formula a value of 1. They are $x = 11$, $y = -9$:

$$(23 \times 11) + (28 \times -9) = 1 .$$

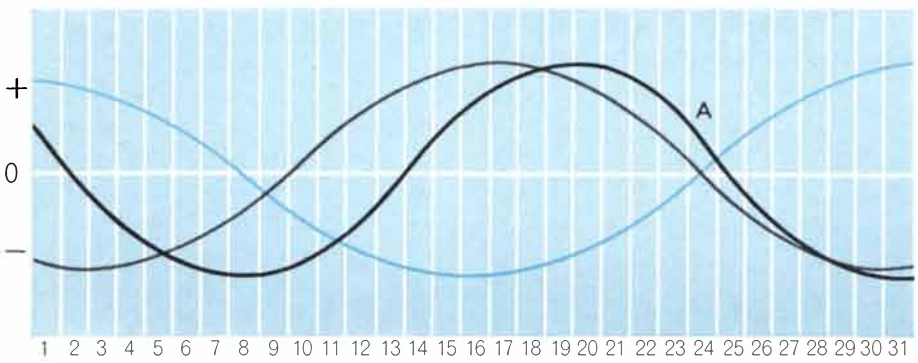
It is now a simple matter to produce any desired positive integer by the following method:

$$[23 \times (11 \times 2)] + [28 \times (-9 \times 2)] = 2$$
$$[23 \times (11 \times 3)] + [28 \times (-9 \times 3)] = 3$$
$$[23 \times (11 \times 4)] + [28 \times (-9 \times 4)] = 4$$
$$\ldots$$

As Roland Sprague recently pointed out in a German puzzle book, even if x and y are limited to positive integers, it is still possible to express all positive integers greater than a certain integer. In the finite set of positive integers that *cannot* be expressed by this formula, asks Sprague, what is the largest number? In other words, what is the largest number that cannot be expressed by substituting positive integers for x and y in the formula $23x + 28y$? Readers may enjoy working this out before Sprague's answer is given next month.

Freud eventually realized that Fliess's superficially surprising results were no more than numerological juggling. After Fliess's death in 1928 (note the obliging 28), a German physician, J. Aelby, published a book that constituted a thorough refutation of Fliess's absurdities. By then, however, the 23–28 cult was firmly established in Germany. Swoboda, who lived until 1963, was the cult's second most important figure. As a psychologist at the University of Vienna he devoted much time to investigating, defending and writing about Fliess's cycle theory. In his own rival masterwork, the 576-page *Das Siebenjahr* (*The Year of Seven*), he reported on his studies of hundreds of family trees to prove that such events as heart attacks, deaths and the onset of major ills tend to fall on certain critical days that can be computed on the basis of one's male and female cycles. He applied the cycle theory to dream analysis, an application that Freud criticizes in a 1911 footnote to his book on dreams. Swoboda also designed the first slide rule for determining critical days. Without the aid of such a device or the assistance of elaborate charts, calculations of critical days are tedious and tricky.

Incredible though it may seem, the Fliess system still has a small but devoted band of disciples in Germany and Switzerland. There are doctors in several Swiss hospitals who continue to determine propitious days for surgery on the basis of Fliess's cycles. (This practice goes back to Fliess. In 1925, when Karl Abraham, one of the pioneers of analysis, had a gallbladder operation, he insisted that it take place on the favorable day calculated by Fliess.) To the male and female cycles modern Fliessians have added a third cycle called the intellectual cycle, which has a length of 33 days. Two books on the Swiss system have been published here by Crown: *Biorhythm,* 1961, by Hans J. Wernli, and *Is This Your Day?,* 1964, by George Thommen. Thommen is the



Benny (Kid) Paret took fatal punch on March 24, 1962 (A)

president of a firm that supplies calculators and charting kits with which to plot one's own cycles.

The three cycles start at birth and continue with absolute regularity throughout life, although their amplitudes decrease with old age. The male cycle (*black curves in illustrations*) governs such masculine traits as physical strength, confidence, aggressiveness and endurance. The female cycle (*gray curves*) controls such feminine traits as feelings, intuition, creativity, love, cooperation, cheerfulness. The newly discovered intellectual cycle (*colored curves*) governs mental powers common to both sexes: intelligence, memory, concentration, quickness of mind.

On days when a cycle is above the horizontal zero line of the chart, the energy controlled by that cycle is being discharged. These are the days of highest vitality and efficiency. On days when the cycle is below the line, energy is being recharged. These are the days of reduced vitality. When your male cycle is high and your other cycles are low, you can perform physical tasks admirably but are low in sensitivity and mental alertness. If your female cycle is high and your male cycle low, it is a fine day, say, to visit an art museum but a day on which you are likely to tire quickly. The reader can easily guess the applications of other cycle patterns to other common events of life. I omit details about methods of predicting the sex of unborn children or computing the rhythmic "compatibility" between two individuals.

The most dangerous days are those on which a cycle, particularly the 23- or 28-day cycle, crosses the horizontal line. Those days when a cycle is making a transition from one phase to another are called "switch-point days." It is a pleasant fact that switch points for the 28-cycle always occur on the same day of the week for any given individual, since this cycle is exactly four weeks long. If your switch point for the 28-cycle is on Tuesday, for instance, every other Tuesday will be your critical day for female energy throughout your entire life.

As one might expect, if the switch points of two cycles coincide, the day is "doubly critical," and it is "triply critical" if all three coincide. The Thommen and Wernli books contain many rhythmograms showing that the days on which various famous people died were days on which two or more cycles were at switch points [*see illustrations*]. On two days on which Clark Gable had heart attacks, the second fatal, two cycles were at switch points. The Aga Khan died on a triply critical day. Arlene Francis had a triple switch point on May 26, 1963, when she lost control of her car on a throughway and collided with another. Arnold Palmer won the British Open Golf Tournament during a high period in July, 1962, and lost the Professional Golf Association Tourney during a triple low two weeks later. The boxer Benny (Kid) Paret died after a knockout in a match on a triply critical day. Clearly it behooves the Fliessian to prepare a chart of his future cycle patterns so that he can exercise especial care on critical days; since other factors come into play, however, no ironclad predictions can be made.

Because each cycle has an integral length in days, it follows that every person's rhythmogram will repeat its pattern after a certain interval of n days. This interval will be the same for everybody. For example, n days after every person's birth all three of his cycles will cross the zero line simultaneously on their upswing and his entire pattern will start over again. Two people whose ages are exactly n days apart will be running on perfectly synchronized cycle patterns. The reader should have no difficulty computing the value of n. It is an important constant in the Swiss Fliessian system, but I withhold its value until next month.

John Muschinske has an M.S.E.E. and a job at Fairchild R&D. He works long hours, but when he creates something, he gets to follow it out the door. He helps cost it, change it, and sometimes, sell it. For the last year, he's been working on power device development. Right now, he's following his latest device through Volume Manufacturing — and he's late for dinner.

We need three more like him. All three of you, contact Jack Sheets at Fairchild Semiconductor, 313 Fairchild Drive, Mountain View, California.

We need an M.S. in Physics or E.E., with experience in semiconductor design, to fill the chair next to Bob in Device Development. He'll design and develop advanced SCR's and related devices.

We're also looking for an M.S. in Chemistry, with two years experience in metallurgy or ceramic technology. He'll direct research in materials and develop new concepts in sealing and encapsulation of advanced integrated circuits.

And we need a B.S. or M.S. in Chemistry with applicable experience, to develop and direct wafer fabrication processes in the development of high performance linear integrated circuits.

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THE AMATEUR SCIENTIST

An inexpensive machine to record observational data automatically

Conducted by C. L. Stong

The results of many experiments can be expressed in the form of a graph produced by a mechanized pen that writes on a moving sheet of paper. Such a recorder has many advantages. At the very least it relieves the drudgery of making prolonged observations. In addition it will function indefinitely and will maintain accuracy under circumstances that would affect a human observer adversely. If such a recorder is suitably designed, it will register data too subtle or fleeting to be detected by human senses.

Commercial recorders have fairly complex parts and require considerable precision in manufacture. Hence they cost more than most amateurs are willing to pay. Thomas W. Maskell of Baltimore has developed a somewhat unconventional recorder that can be built inexpensively by an amateur. The instrument can not only make graphs but also record a series of events and measure the interval of time in which an event occurs. In addition it can feed information back to the source, thus functioning as a servomechanism. In its present form the instrument is best suited for the observation of events that extend over periods of minutes or longer rather than fractions of a second. Maskell hopes that other amateurs will improve the device.

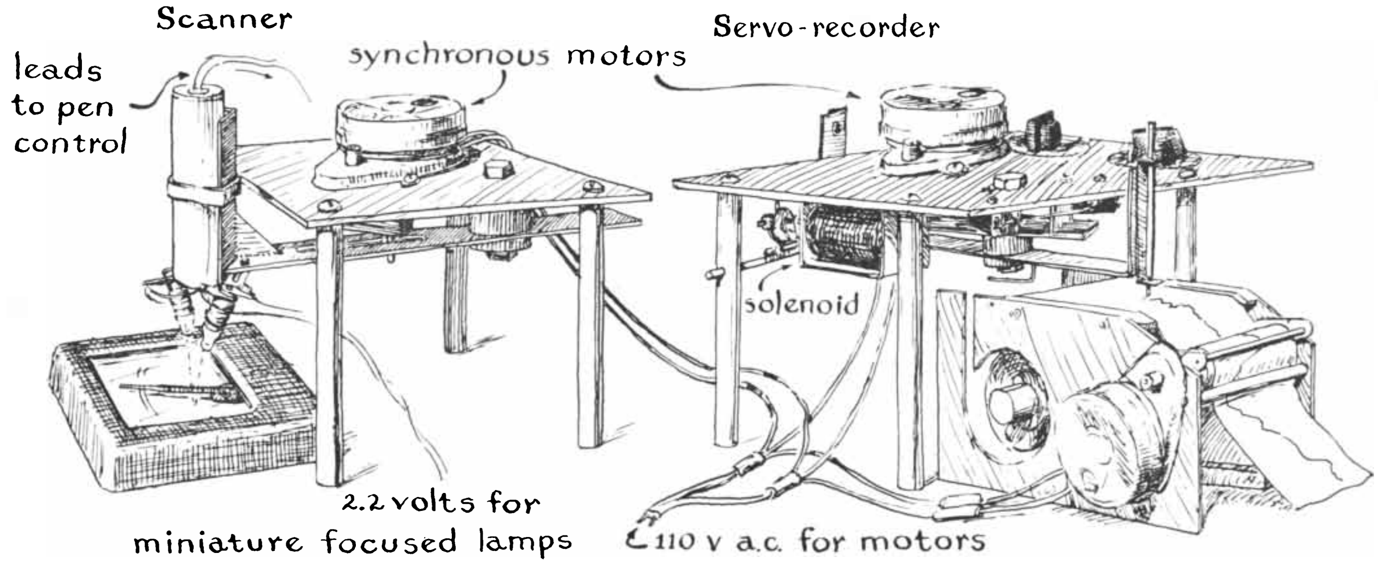
Maskell writes that a graphic recorder must perform three functions. "The phenomenon to be recorded must be sensed, the information must be changed into a form acceptable to the recorder and the record must be written. Systems for performing these functions vary in complexity and capability.

"One of the simplest is the water-stage recorder, in which a pen linked indirectly to a float writes on a drum rotated by a clockwork. As the float rises and falls with the water level the pen moves across the rotating chart. In the resulting graph the water level is plotted against time. The float acts as the sensing element. The linkage—a rope and a system of pulleys—acts as the signal-conditioner, reducing the distance traveled by the float to a proportional motion of the pen that is appropriate to the width of the paper-covered drum.

"In more complex systems the sensing devices are strain gauges, microphones, photocells, thermocouples, scintillation counters and a host of other devices. The majority of modern signal-conditioners are electronic. Most pen motors have as their key element a rugged ammeter to measure an electric current that varies in proportion to the phenomenon under observation.

"Largely for diversion, I undertook about five years ago a review of available instrumentation to discover a combination of electromechanical elements that would yield the most recorder-controller system per dollar of investment. The results are embodied in the device I shall describe here. I call it a 'scanner–servo-recorder' to suggest its several functions.

"As a scanner it can make direct observations. As a servo its pen arm can be 'slaved,' or linked, to the phenomenon under observation; it thus closes a feedback loop so that the phenomenon becomes self-controlling. As a recorder it can write a record in any of several ways. I built the instrument for $18.20,



A general view of the "scanner–servo-recorder" excluding the cost of scrap materials.

"The device has three major units: the scanner, the servo-recorder and the paper transport. The scanner consists essentially of a motor-driven lever that moves back and forth horizontally through an arc of about 45 degrees. At its outer end is a simple optical system consisting of a lens and a photocell. The arrangement is shown schematically in the accompanying illustration [*right*]. In a typical application the photocell 'watches' a miniature lamp bulb attached to the pointer of a dial. The photocell functions as an on-off device.

"A similar lever that also oscillates continuously in the horizontal plane forms one element of the separate servo-recorder unit. The oscillating levers of both the scanner and the servo-recorder units are driven through cranks by synchronous motors. When the levers are started together in phase, they continue to oscillate in phase.

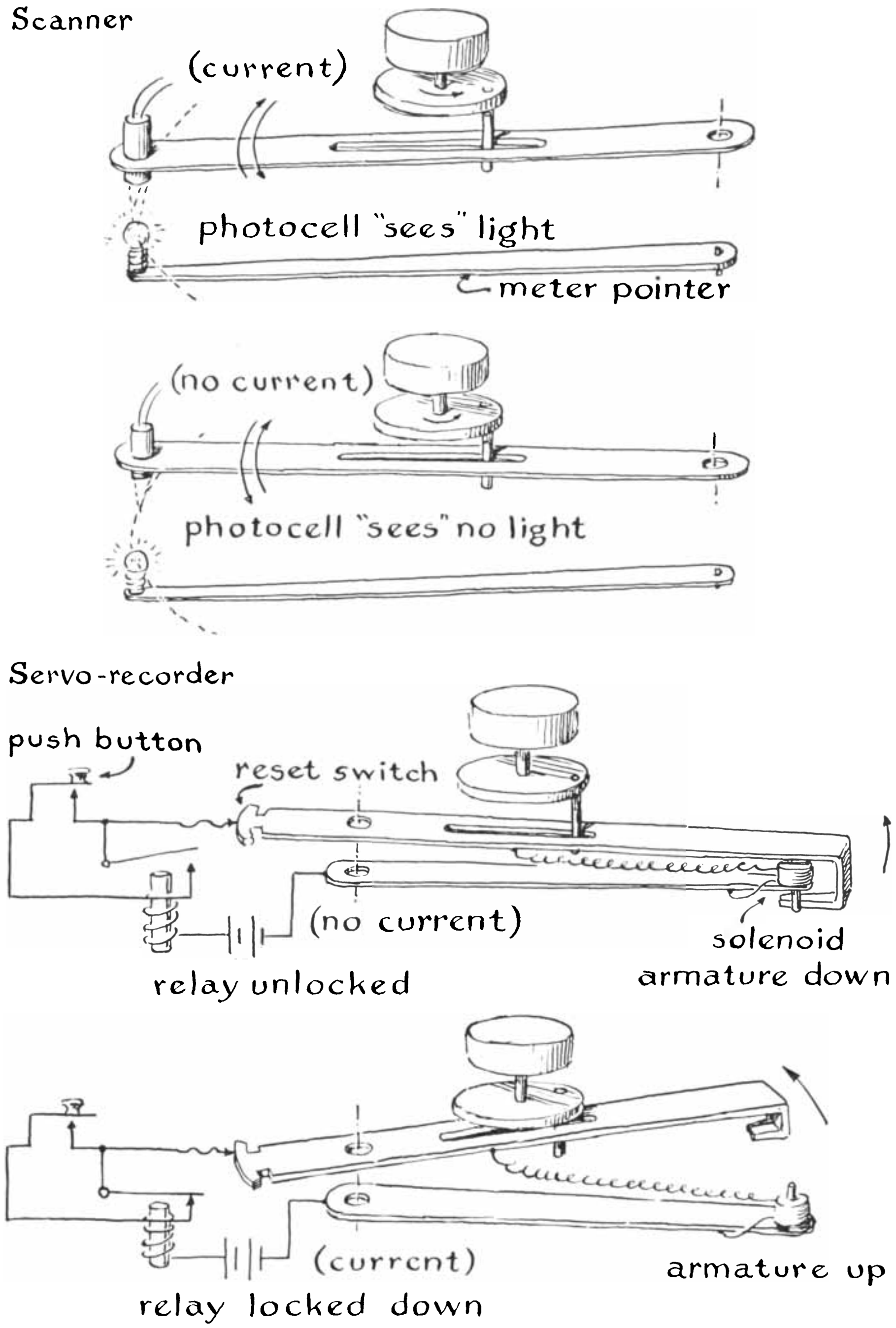
"The servo-recorder contains a second lever mounted below the oscillating lever. Both levers turn freely on the same fixed shaft. The second lever can be equipped with a pen. I call it the pen arm. These two levers can be coupled and uncoupled by means of an electromechanical latch operated by a solenoid. When they are latched, the oscillating lever drives the pen arm. In the schematic illustration the latching mechanism is represented by a finger that extends from the end of the oscillating lever; the finger engages the armature of the solenoid when the solenoid is not energized. The latch can be disengaged by energizing the solenoid.

"The electrical circuit includes a relay wired to remain locked down after it has been energized by a pulse of current. The pulse can be generated by a push button (as is shown schematically in the illustration) or by a photocell (as is actually the case). A reset switch associated with the oscillating lever breaks the circuit and unlocks the relay at each extreme of the lever's travel. When it is appropriately directed by the push button, the oscillating lever will push the pen arm in either direction from any point to any point within the limits of its excursion. In effect the push button issues either of two orders to the oscillating arm: 'Move the pen arm' or 'Drop the pen arm.'

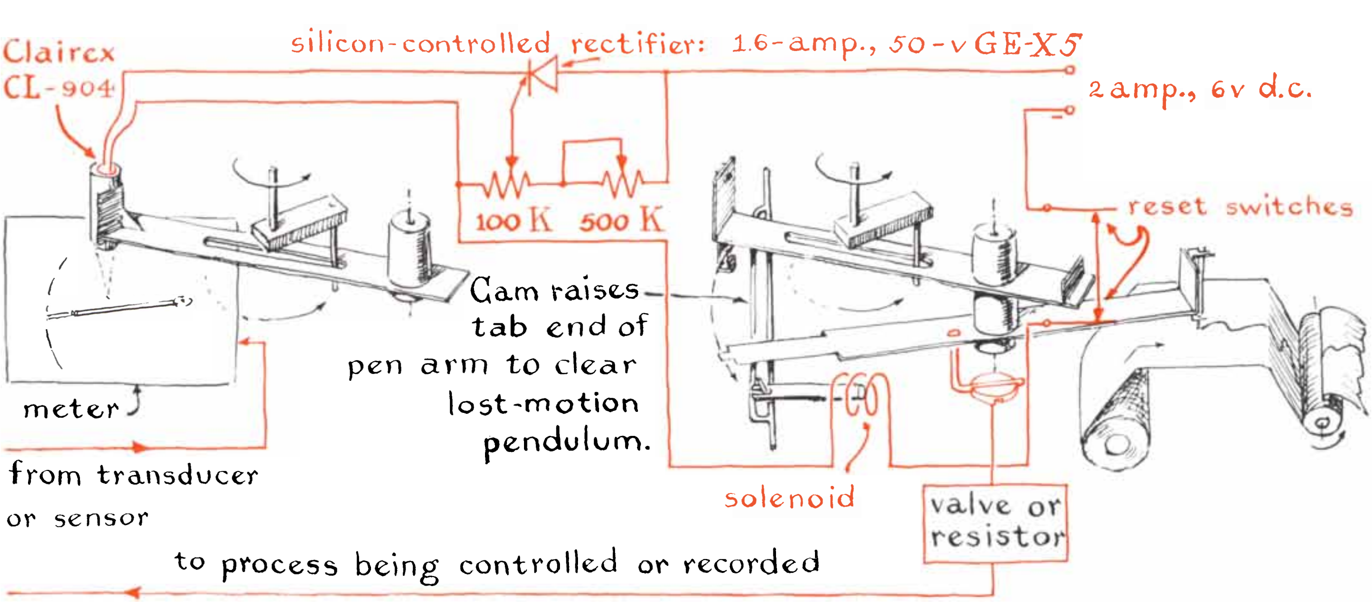
"The two units are combined into a scanner–servo-recorder system by replacing the push button portion of the schematic circuit with the photocell. The system is put in operation by applying power to all circuits and starting the oscillating levers in phase. Assume that the system has been started and that the miniature lamp being watched by the photocell is midway between the limits of its excursion. The solenoid is not energized because the reset switch has broken the circuit. The armature has therefore dropped to its lowered position for engagement with the finger of the oscillating lever.

"The pen arm is pushed along as the oscillating lever moves toward its distant limit. When the photocell encounters the miniature lamp, light initiates a signal that actuates the relay. The solenoid operates and unlatches the pen arm. The pen arm now occupies the same relative position as the miniature lamp. The oscillating levers continue to the distant limit of their excursion, where the reset switch unlocks the relay and drops the solenoid to the latching position. The oscillating levers now return. During the transit, if the position of the lamp has not changed, the photocell again issues an unlatching command on reaching the light; the pen arm then remains undisturbed.

"Now assume that the position of the lamp has shifted somewhat toward the distant limit. (Remember that the oscillating lever is moving toward the near limit.) In this case the solenoid will op-



Principles on which recorder is based



Electrical controls of the instrument

erate when the photocell reaches the miniature lamp and the oscillating lever of the servo-recorder will ignore the pen arm. On reaching the near end of its excursion the lever will operate the reset switch and release the solenoid for engagement with the pen arm during the next outward transit. On that transit, therefore, the pen arm will be pushed to the position of the lamp and then dropped.

"Similar analysis will demonstrate that the pen arm is slaved to the movement of the light under all conditions. A periodic record of the position of the lamp can be written by attaching a pen to an extension of the pen arm and placing it in contact with a moving sheet of paper. A feedback loop can be closed by linking the pen arm to the input of the system, in this case by appropriately coupling the pen arm to the driving mechanism that alters the position of the lamp.

"The actual construction includes a number of refinements that add to the accuracy and dependability of the instrument. For example, the relay is replaced by a silicon-controlled rectifier that in effect can be locked down by either a pulse of current or the momentary interruption of an established current. Such a response occurs when the photocell encounters either a bright object against a dark background or a dark object against a light background, such as the pointer of a meter.

"The arrangement of the latching mechanism also differs from that depicted in the simplified schematic illustration. The outer half of the pen arm actually consists of a leaf spring that terminates in a rectangular finger about an eighth of an inch wide. When the leaf spring is straight, this finger engages a projection of the oscillating lever and is thereby pushed in one direction or the other.

"If both engaging projections were rigidly attached to their respective levers, the pen arm would be moved too far by an amount equal to half of the combined widths of the fingers each time the direction of the movement was reversed. The required compensation can be achieved by what is called a lost-motion pendulum. It is made by attaching one of the fingers to a pendulum lever free to swing through a distance equal to the width of the two fingers [*see illustration on opposite page*]. The pendulum is attached to the end of the oscillating lever and its excursion is restricted to the distance between a pair of eccentric washers that act as adjustable stops. The edges of the movable finger, which serves as the lost-motion mechanism, are cut at an angle so that the faces of the two fingers make flat contact; in this way they disengage readily.

"The leaf spring of the pen arm can be bent upward by a long cam that extends completely across the traversed path. When the pen arm is thus bent, it is not engaged by the finger of the lost-motion mechanism. The cam, which is rotated by a solenoid, consists of a slender shaft fitted with a stiff wire in the form of an elongated *C*. The cam turns in bearings supported by a pair of posts. In addition to bending the leaf spring and thus unlatching the mechanism, the cam serves as a friction brake for locking the pen arm in the position to which it has been moved.

"The oscillating lever of the servo-recorder makes mechanical contact with a limit switch at each end of its traverse. The switch opens the solenoid circuit and 'unlocks' the silicon-controlled rectifier. The leaf spring then assumes its straight position for engagement with the lost-motion pendulum.

"The pen arm is actually pivoted in the middle, the leaf spring being carried by one end and the pen by the other. In the middle is a 'torque takeoff' fitting for coupling feedback devices to the instrument. Both the scanner and the recorder are supported by four mounting posts at the corners of a base plate of sheet metal. The length of the mounting posts was chosen to place the lens of the scanner at optimum height above the object to be scanned and to place the pen in light contact with the writing platform of the paper transport. I have used both a weighted ball-point pen and an unweighted Esterbrook Feltwriter.

"For economy of operation I designed the paper transport to accept adding-machine paper 3½ inches wide. The writing table, made of 24-gauge brass, is four inches long, including a sloping apron one inch long. The supply roll is carried by a fixed shaft. I did not equip the device with a take-up; the paper collects in a basket.

"The paper is pulled through the transport by a rubber roller. The roller is a heavy-walled length of rubber tubing slipped over a quarter-inch shaft that is supported at each end by a synchronous motor. Since the output shafts of the motors face in opposite directions, one shaft must turn clockwise and the other counterclockwise so that the rubber roller will turn in the same direction regardless of which motor is energized. One motor turns at 10 times the speed of the other and thus the arrangement provides a choice of two paper speeds. When one motor is energized, the other idles. The disadvantage of using unruled adding-machine paper for the graphs can be overcome by scoring the calibration of the instrument on a sheet of thin, clear plastic and filling the grooves with color from a wax pencil. By this means the dimensions of the graph can be read directly by placing the scored sheet over the paper.

"I used synchronous-timing motors in all positions. They are available in speeds ranging from one revolution per second to one revolution per hour. Such motors can be obtained on the surplus market for about $1.50 each. Aluminum plate 1/8 inch thick was used for the base, and the sides were made of 1/16-inch brass sheet. The reciprocating levers and the pen arm were made of one-inch by 1/16-inch extruded half-hard brass to avoid the labor of shearing and sawing. Steel or aluminum could be used in cases requiring greater strength or where weight must be minimized. Brass is a good compromise, since it is dependable bearing material that is easy to solder. The reciprocating levers might well be made of aluminum or magnesium in instruments designed to operate at speeds in excess of one sweep per second. The crank assemblies were made of steel.

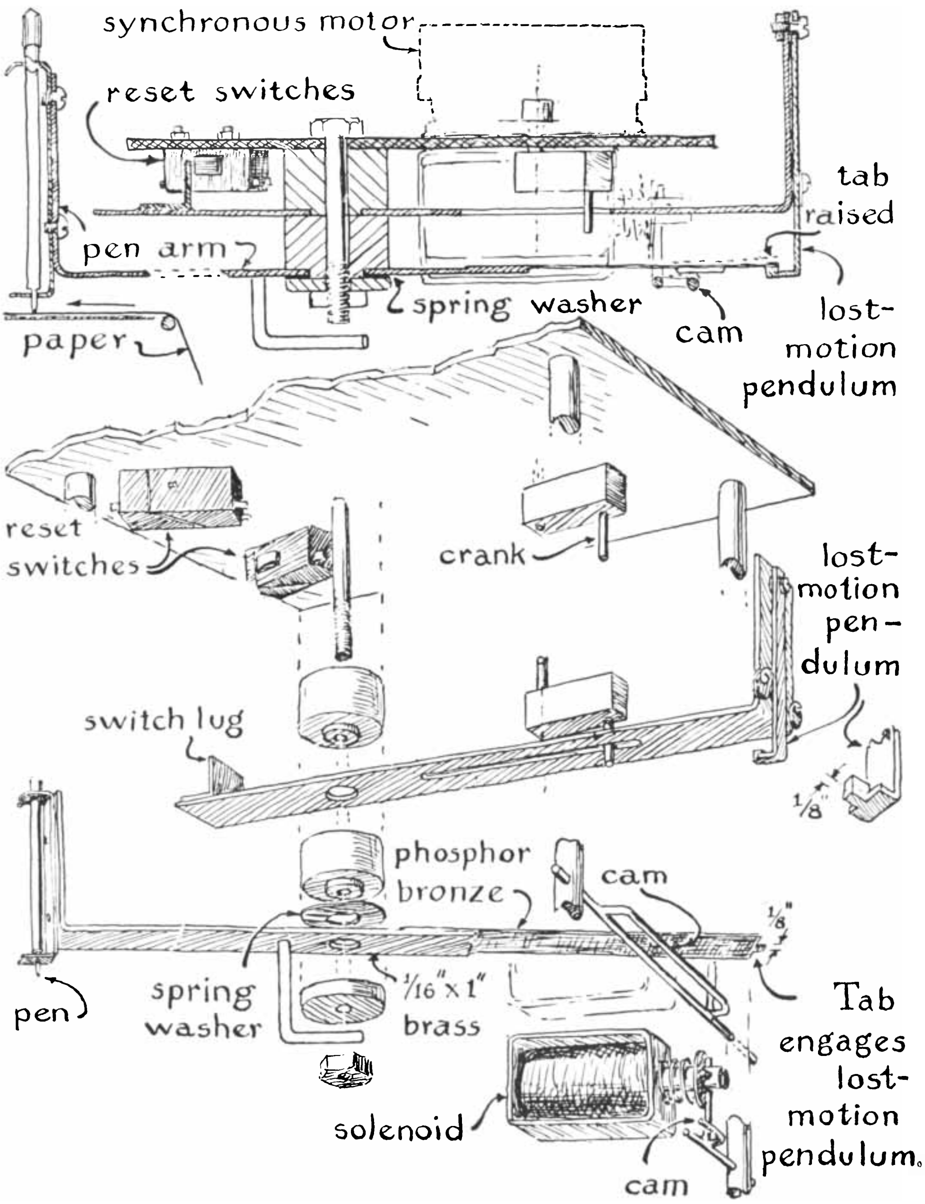
"The photoelectric scanning head is only one of several available sensors. It is the most versatile, responding to the position of anything that can be seen—from bands of adhesive tape on the stalk of a growing plant to the hairline pointer of a galvanometer. Normally my scanner is used to follow the pointer of a direct-current meter that has a sensitivity of 10 millionths of an ampere at full-scale deflection.

"I use a Clairex CL-904 photocell, the active area of which is confined to a thin line. The cell is rotated so that this line is parallel to the pointer of the meter. An image of the pointer is focused on the cell by a lens of approximately 2¾ inches focal length. I bought the lens at a novelty store. A friendly optician ground the edge of the lens for a sliding fit with an aluminum tube about 3/4 inch in diameter. A preground lens of the same size is available from the Edmund Scientific Co. of Barrington, N.J.

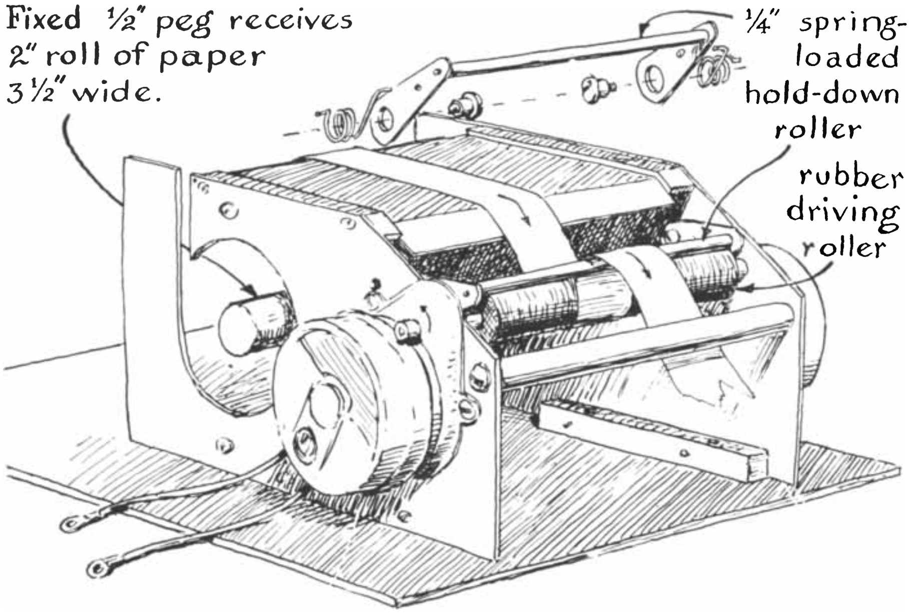
"The lens is supported at one end of the tube by a split retaining ring. The photocell at the other end is mounted in a wooden dowel. I determined the focal length of the lens by clamping the glass in a wire fixture that made a sliding fit with a wooden yardstick. A similarly supported cardboard screen was clamped behind the lens. A light baffle placed around the lens prevented scattered light from reaching the image plane. The focal length was then measured by adjusting the separation of the screen and lens until a distant source (the sun) came to sharp focus. When the cell is placed at twice this separation from the lens, an object also placed at twice the separation on the other side of the lens will be in sharp focus on the active area of the cell.

"Photocells of designs that differ from the Clairex 900 series can be used. I selected this type solely because the active area is confined to a thin rectangle, a configuration that develops a maximum signal in response to the image of a slender dark object such as the pointer of a meter. Cells of other configurations would be more appropriate for images of other shapes.

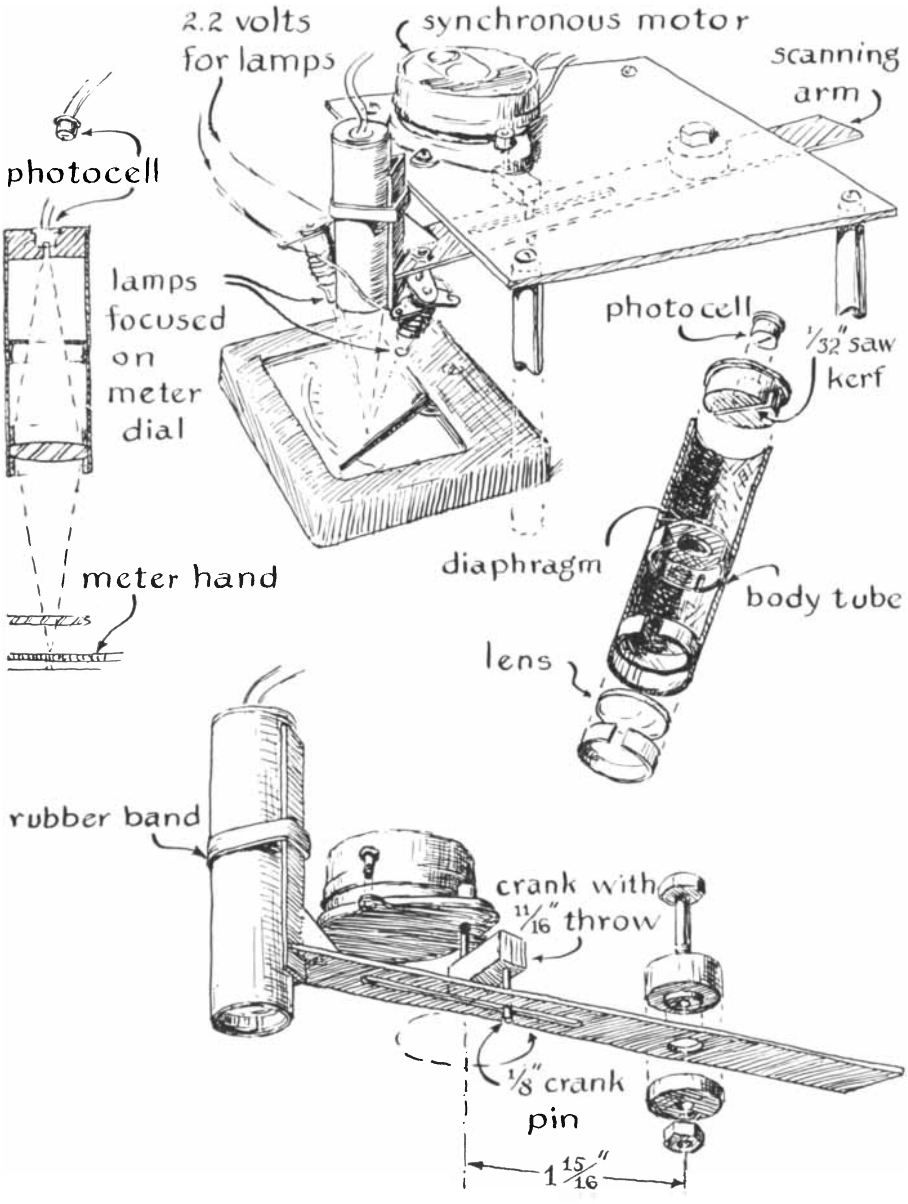
"When the image of a white surface lighted by a pair of self-focusing miniature bulbs falls on the photocell, the resistance of the active material is lowered to about 20,000 ohms. At this resistance the voltage applied to the gate terminal of the silicon-controlled rectifier is more nearly equal to that of the cathode than that of the anode. At the gate potential the rectifier acts as an open switch and no current flows through the solenoid. When the light is reduced, as by the image of the black pointer, the resistance of the cell increases to many hundreds of thousands of ohms. This change has the effect of



Details of the latching mechanism



Arrangement of the paper transport



Optical system of the scanner

making the potential of the gate more nearly equal to that of the anode.

"When the change in the gate potential reaches a critical value, the rectifier conducts; it continues to conduct until the circuit is broken, even though the intensity of the light is restored. By interchanging the positions occupied by the photocell and the 500,000-ohm potentiometer in the circuit the same action can be triggered by a comparable increase in light. In each of these modes of operation the 100,000-ohm potentiometer is adjusted to select the critical intensity of light at which the rectifier conducts.

"Writing devices other than pens can be mounted on the pen arm. For example, it is possible to couple to the armature of the solenoid an inking device that would make a dot on the graph when energized by a pulse of current. The range of applications can be increased by making other obvious modifications. The scanning lever, for instance, can be equipped with an insulated electrode for making sliding contact with a resistor or a commutated surface. The relative opaqueness of translucent solids or solutions can be plotted by interposing an optical gray scale between the photoelectric scanning head and the light source to be measured. Such a determination can be made either by scanning the fixed gray scale or by replacing the photocell scanning head by the gray scale and sweeping the scale past the photocell.

"The magnetic state of a scanned surface can be evaluated by equipping the scanning lever with a reed switch positioned at selected distances above the surface. When it is equipped with the photoelectric head, the scanner can also replace stepping switches for periodically monitoring a variety of events. In this application each event to be charted could cause a miniature lamp to light. The lamps would be arranged in an arc below the scanning head. With this arrangement an impulse pen could then print out the sequence of events against time.

"Numerous comparable applications as well as refinements in construction will suggest themselves to experimenters who enjoy innovation. The present design is submitted in the belief that amateurs would find it useful to have not only an instrument that illustrates where a recording system begins and ends but also a design that accommodates the craftsman who, like myself, is endowed with an abnormal quota of thumbs."

RECENT
findings

RESEARCH LABORATORIES

SELECTIVE FORMATION OF RADICALS

Hydrogen atom bombardment technique developed by Ford scientists points to better understanding of organic free radical reactions.

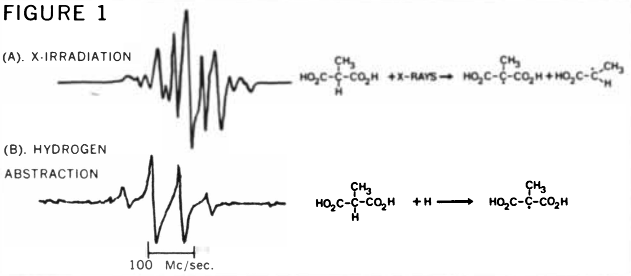
A new, different and advantageous technique for the formation of radicals from organic and biological molecules has been developed at Ford Motor Company Research Laboratories.

Other techniques such as high-energy radiation, ultraviolet radiation, and heating have in general the disadvantage of being non-selective. In many organic and biological molecules x-irradiation results in the concurrent breakdown of carbon-hydrogen, carbon-carbon, and carbon-oxygen bonds. This indiscriminate bond breakage results in various types of free radicals and greatly complicates the study of their structure and the control of their reactions.

In contrast, hydrogen atom bombardment results in the *selective* formation of such radicals. In this technique hydrogen molecules are passed through a microwave discharge chamber in which they are dissociated into hydrogen atoms. These atoms, which are quite reactive, are then allowed to strike a powdered sample of an organic compound. It has been found that this technique results in the selective formation of radicals via two paths:

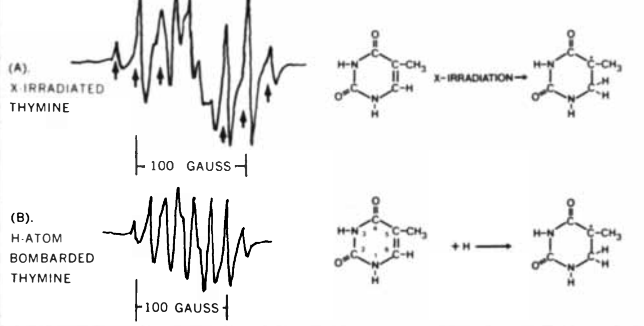
1) Radical Formation by Hydrogen Atom Abstraction. The impinging hydrogen atoms abstract a hydrogen atom from a C-H bond. (A specific case is the compound methyl malonic acid (Figure 1) formula.) Figure 1-A shows the electron spin resonance (ESR spectroscopy is uniquely suited to the identification of free radicals) spectrum of methyl malonic acid damaged by x-rays. The ESR pattern demonstrates that two types of radicals (their formulae are shown in Figure 1-A) were formed by the irradiation, i.e., one by the breakage of the central C-H bond of the parent molecule and the other by the breakage of the C-C bond. On the other hand, hydrogen atom bombardment of the methyl malonic acid results in the formation of *only one of these radical species*, i.e., that due to a C-H bond breakage (Figure 1-B).

FIGURE 1



2) Radical Formation by Hydrogen Atom Addition. An example of hydrogen atom addition is the compound thymine (one of the four basic components of DNA). The ESR spectrum of x-irradiated thymine is shown in Figure 2-A. The six outside signals (labeled by arrows) of this pattern plus some of the central lines are due to the thymyl radical (see formula in Figure 2) which was formed by the addition of a hydrogen atom to one of the carbon atoms with a double bond. This hydrogen atom had been dissociated from a neighboring molecule during the primary effects of the radiation. However, the remaining signals in the central portion of the pattern are due to other radical species which were also formed during the irradiation. In contrast, hydrogen atom bombardment results in the formation of the *thymyl radical alone*, as is shown by the "cleaner" and simpler ESR pattern of Figure 2-B. The striking hydrogen atom attacks the double bond region between C5 and C6 breaking one of the bonds and reforming a C-H bond with carbon atom (6) and leaving carbon atom (5) with an unpaired electron.

FIGURE 2



This technique of selectively forming radicals is expected to contribute substantially to a better understanding of the structure of these species, as well as the nature of reactions which these species undergo. Among other things, it is expected to be useful in the study of the reaction of molecules of biological interest, as evidenced by the results on the thymine molecule.

In addition, many useful and interesting chemical reactions, e.g., polymerization reactions, are known to be initiated by a primary step which involves a hydrogen atom addition. The present technique has the potential of accomplishing the same reactions, possibly in a more controlled manner.

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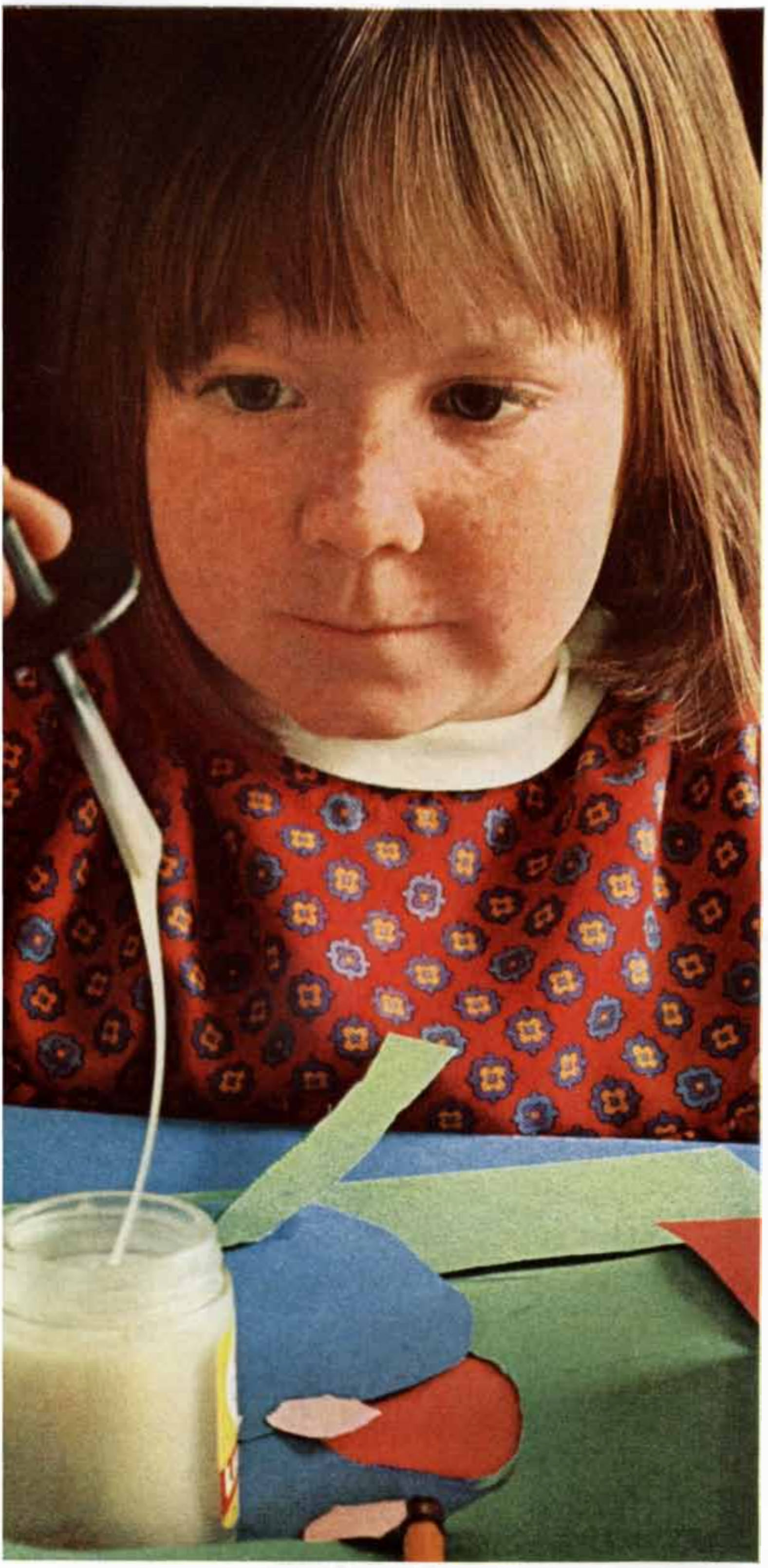

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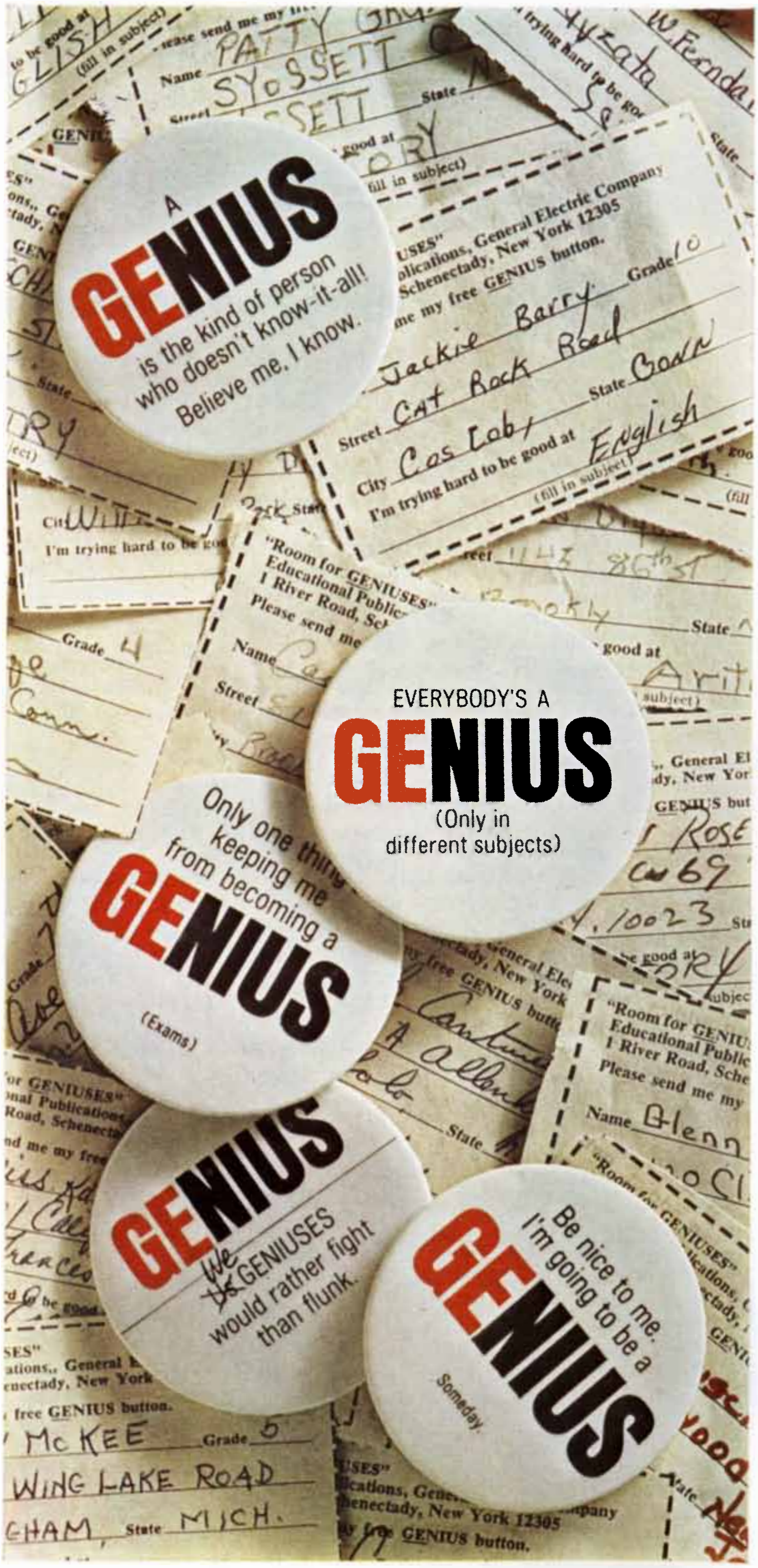

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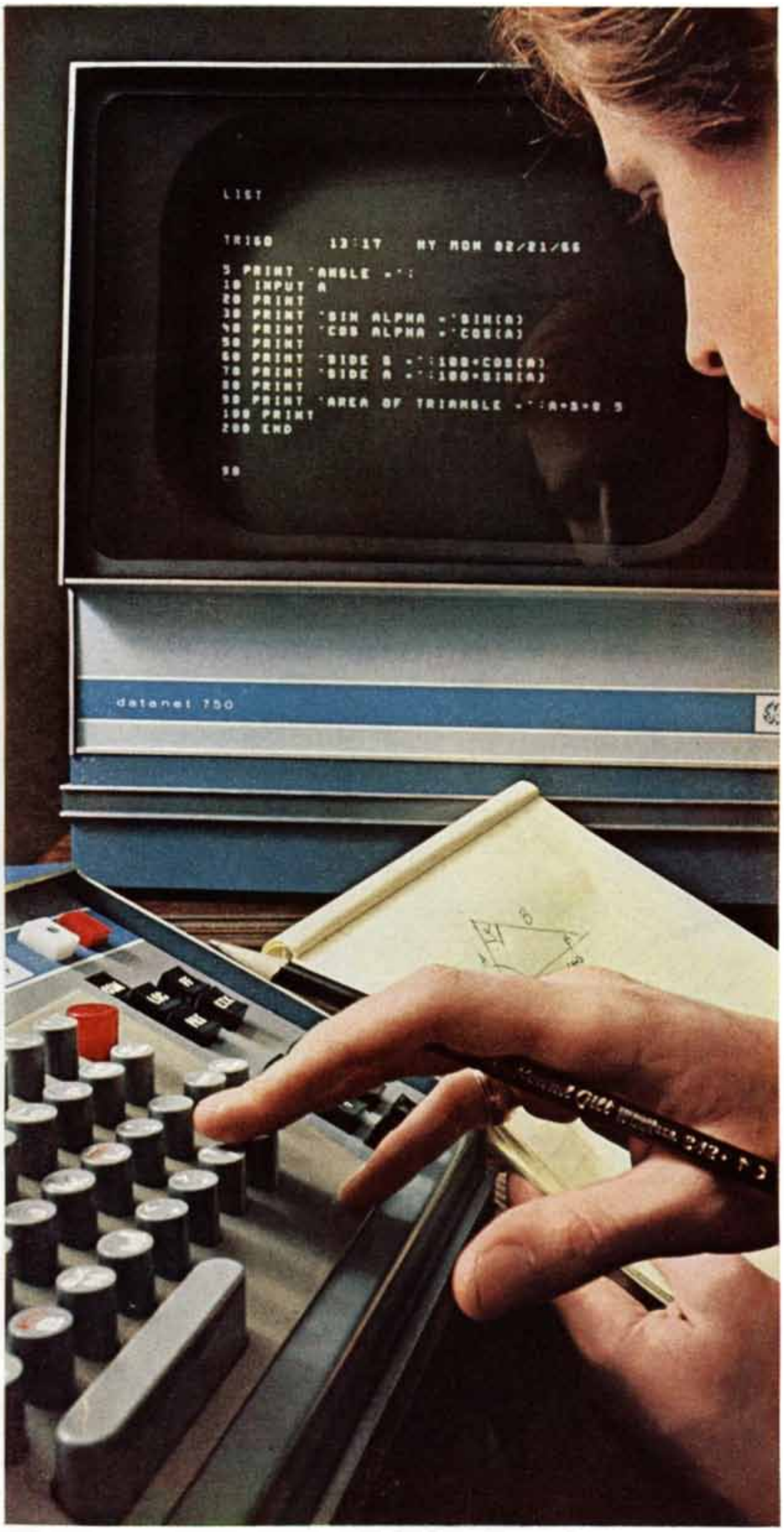

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BOOKS

The culture of poverty in 19th-century London

by Asa Briggs

SELECTIONS FROM "LONDON LABOUR AND THE LONDON POOR," by Henry Mayhew. Edited by John L. Bradley. Oxford University Press ($2.75).

There is a rich literature about the turbulent, gaslit cities of the 19th century, much of it shot through with fear, some of it bursting with pride. Cities were growing, and as they grew they posed problems, urgent problems of health and order, communications and government. The great metropolises, many of them ancient cities such as London and Paris, presented at least as many problems as the new industrial cities, which seemed to represent a new way of life. It was, after all, in the great metropolises that there were the sharpest contrasts between riches and poverty and also the most serious threat to the social fabric from what were called in London, Paris and New York alike "the dangerous classes." It was there, too, that there was the greatest hope of cities becoming genuine centers of "civilization."

Henry Mayhew's *London Labour and the London Poor* is a classic document of this period in city history, and it has deservedly become, albeit in severely abbreviated form, the latest in the "World's Classics" series of the Oxford University Press. Published originally in the form of letters to the London *Morning Chronicle* in 1849 and 1850, it grew almost like London itself, until it became four solid Victorian volumes, the last of which appeared in 1862. Its writing therefore straddled the period of Victorian "prosperity" that followed the stormy conflicts of the 1840's. These were years when the Victorians were most proud of being Victorian, when they believed, indeed, that they had created one of the world's great civilizations. They were not alone in this. As Massimo Taparelli d'Azeglio, a distinguished Italian visitor to Britain, put it, this was "the highest level of civilization the world had ever known." Paris—the brilliant Paris of Napoleon III—might dispute the claim, but then Parisians usually found London "too large, too overwhelming." More sensitive than most Englishmen, they dwelt, in the words of Francis Wey, a visitor of 1856, on "the mortification of feeling oneself a mere grain of sand in the desert, and the knowledge of how small a part the feeling of human interdependence plays in this immense city." The remarkable exile from Russia, Alexander Herzen, wrote also of the loneliness felt in London by "nervous and romantic temperaments," yet with an eye for the squalor as well as the splendor he added generously, "I came to love this dreadful ant-heap, where every night a hundred thousand men know not where they will lay their heads, and the police often find women and children dead of hunger beside hotels where one cannot dine for less than two pounds."

It was the darker side of London that interested Mayhew and his readers. He was contemptuous of proud catchphrases such as "this vast capital—this marvellous center of the commerce of the world" and dismissed them as "stereotype phrases of civic elegance." Like Herzen, he turned to themes such as hunger and disease and crime. Yet far from treating these themes mysteriously

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JAMES R. NEWMAN

James R. Newman, who had conducted the book department of SCIENTIFIC AMERICAN for the past 18 years, died of a heart attack on May 28. His age was 58.

Newman's work on this magazine was only one aspect of an unusual career. He was educated as a lawyer, practiced law for 12 years and entered Government service at the beginning of World War II. During the war he was, among other things, a senior intelligence officer for the Board of Economic Warfare in London; at the end of the war he was special assistant to Undersecretary of War Robert P. Patterson. Thereafter he became counsel to the Senate Committee on Atomic Energy, and he played a central role in drafting the present atomic-energy law.

Even as he practiced law, however, Newman had embarked on a separate career. He had taken graduate courses at Columbia University in philosophy and mathematics; one result was a collaboration with Professor Edward Kasner on the highly successful book *Mathematics and the Imagination*. After he had joined SCIENTIFIC AMERICAN in 1948 he completed his four-volume anthology *The World of Mathematics*. More than 150,000 sets were sold. He also wrote (or collaborated in the writing of) 10 other works, ranging from the foundations of mathematics to the folly of the nuclear-arms race.

This last topic was Newman's passion. Although he had been an important figure in the successful struggle for civilian control of atomic energy, after the battle was over he was an outsider. He nonetheless continued to give counsel and comfort to many, both outsiders and insiders, during the troubled years that followed. He had a huge circle of friends, and he gave himself freely to them. He was a man of expansive humor, rich language and forthright opinions. His death leaves a large vacancy in the ranks of the living.

in the lurid style of Eugène Sue's *Mystères de Paris* or George W. M. Reynolds' *Mysteries of London* (there was also a *Mysteries of New York*), he set out to talk to people "naturally" and to report directly on his conversations, to discover the relevant statistics, to explain, when he came in his fourth volume to prostitution and crime, what he called "the physics and economy of vice and crime generally." He had a strong moral purpose, very Victorian in flavor: the attempt to "induce us, or at least the more earnest amongst us, to apply ourselves steadfastly to the removal or alleviation of those social evils that appear to create so large a proportion of the vice and crime that we seek by punishment to prevent." It is often forgotten that in addition to writing *London Labour and the London Poor* Mayhew also wrote success stories about historic figures who had triumphed by virtuous conduct and unflagging determination. Apparently indolent himself, he extolled effort. In some respects a failure (he went bankrupt in 1847 and in spite of his achievements as a writer died in oblivion), he had no illusions about the consequences of failure. When he moved among "outcasts," he was very much of a Victorian Englishman, not a Herzen—or a Baudelaire.

The strength of *London Labour and the London Poor* can be fully appreciated only in this context. There had been many official "blue books" on the seamier side of London. Some of them, like Edwin Chadwick's great reports on public health, had been best sellers and had stirred consciences. Mayhew ruffled the complacency of the more comfortable mid-Victorians by writing not as a royal commission but as a person. Much of his work was published in the form of "twopenny numbers." It provoked readers in all parts of the country to send letters and ask questions, and Mayhew, learning all the time, replied on the wrappers of the individual publications. As John L. Bradley says in his introduction to the *Selections,* "his individuality of method, compounded of journalistic inquiry, literary presentation, and sociological investigation, stands forth in singular relief when placed beside similar endeavours of the time." There were many similar endeavors, some of them fascinating books such as George Godwin's *Town Swamps and Social Bridges* (1859) and John Hollingshead's *Ragged London in 1861* (neither of which is mentioned by Professor Bradley), yet it is Mayhew whose work has rightly been remembered. "Wherever you sink a shaft in London —whether in the center or the outskirts," Hollingshead wrote, "and penetrate with a good guide, perseverance and fair local knowledge, you will find endless veins of social degradation,... a dead level of misery, crime, vice, dirt and rags." Mayhew knew best how to sink the shafts. He himself became the good guide. Unlike Hollingshead, he discovered not a dead level but a living panorama. Beginning with the facts of London life in the middle of the 19th century ("the savagery of civilization," he called it), he ended with a superb and still supremely readable drama of the human condition.

He had three immense assets: the gift of being able to communicate with people quite different from himself (a rare capacity in class-conscious Victorian England); an artist's sensitivity to color, smell, sound and atmosphere, and a bountiful sense of humor. The first of these assets is amply demonstrated in the accounts he gives of conversations with costermongers, flower girls, lodging-house keepers and street entertainers, not to speak of more esoteric individuals such as "sheep's trotter women," "bird-duffers," "pure-finders" ("pure" was dog's dung, which commanded a good price at London tanneries) and "mud-larks." Consider this account of a conversation with coster-lads, which incidentally shows that the habits of London youth in the 20th century mark no strange mutation in human behavior:

"A lad about fourteen informed me that 'brass buttons, like a huntsman's, with foxes' heads on 'em looked stunning flash, and the gals liked 'em.' As for the hair, they say it ought to be long in front, and done in 'figure-six' curls, or twisted back to the ear 'Newgate-knocker style.' 'But the worst of hair is,' they add, 'that it is always getting cut off in quod, all along of muzzling the bobbies.' "

Not all Mayhew's conversations are as difficult to understand. A fascinating account of a conversation with a dredger (a man who earned his living dredging the bed of the Thames for anything he could find—from cargo to bodies) begins with the dredger's words: "Father was a dredger, and grandfather afore him; grandfather was a dredger and a fisherman too. A'most as soon as I was able to crawl, father took me with him in the boat to help him to pick the coals, and bones, and other things out of the net, and to use me to the water."

It is not difficult to reconstruct from conversations of this kind and Mayhew's comments on them a sociology of London labor in the mid-Victorian period. The dredgers passed their occupation on to their children. Many other jobs were casual, and people fell in or out of them according to the vicissitudes of age, health and fortune. The mud larks, for example, were obviously at a lower level than the dredgers: they searched the riverbank for what they could find, wading "sometimes up to their middle through the mud left on the shore by the retiring tide." They were often old women who had lost all other means of livelihood. "They notice no one; they never speak, but with a stolid look of wretchedness they plash their way through the mire, their bodies bent down while they peer anxiously about, and occasionally stoop to pick up some paltry treasure that falls in their way." Their plight may be compared with the affluence of the "cads" (omnibus conductors), who earned four shillings a day, and it is not surprising that Mayhew found that "nearly all classes" had contributed to the ranks of conductors: "Among them are grocers, drapers, shopmen, barmen, printers, tailors, shoe-makers, clerks, joiners, saddlers, coach-builders, porters, town-travellers, carriers, and fishmongers." Like all sociologists, Mayhew liked an occasional catalogue of this kind. He also liked an occasional quantitative calculation. After describing sheep's-trotter women (sheep's trotters were sheep's feet—tasty but not very meaty delicacies) he concluded:

"The returns I collected show that there is expended yearly in London streets on trotters, calculating their sale, retail, at ½d. each, 6,500l., but though the regular price is ½d., some trotters are sold at four for 1½d., very few higher than ½d., and some are kept until they are unsaleable, so that the amount may be estimated at 6,000l., a receipt of 7s. 6d. weekly, per individual seller, rather more than one-half of which sum is profit."

Mayhew's sensitivity to atmosphere makes him something far more than a sociologist. He is particularly good on the effects of gaslight, on the smell of crowds ("Forward they came, bringing an overpowering stench with them, laughing and yelling as they pushed their way through the waiting-room") and on the sound of "running patterers," bawling out the names of cheap publications on accidents or assassinations, rapes or murders ("All these men state that the greater the noise they make, the better is the chance of sale, and better still when the noise is on each side of the street"). There is no better introduction to Mayhew than to read his frightening account of a night at a rat-killing, too long to quote but brilliantly sustained, a journalistic feat that transcends journalism. The account begins in the tavern where the rat-killing session was held—a tavern where "drinking seems to have been a secondary notion in its formation, for it is a low-roofed room without any of those adornments which are now generally considered so necessary to render a public-house attractive. The tubs where the spirits are kept are blistered with the heat of the gas, and so dirty that the once brilliant gilt hoops are now quite black." The brutality Mayhew goes on to describe horrifies the modern reader far more than it must have horrified many of his Victorian readers. Most other writers would have hidden away some of the facts and impressions; Mayhew exposes all.

There is even a touch of somewhat sardonic humor at the end of the rat-killing narrative. In other parts of the book the humor is an integral part of the story. When one of the running patterers is describing the market for his murder broadsheets, he complains: "Greenacre didn't sell so well as might have been expected, for such a diabolical out-and-out crime as he committed; but you see he came close after Pegsworth, and that took the beauty off him. Two murderers together is never no good to nobody." A bookseller is explaining which secondhand books sell and which do not: "The *Sentimental Journey,* no, sir, *Tristram Shandy,* rather hangs on hand, the *Pilgrim's Progress* (but it must be sold *very* low).... No, I can't say I could sell Milton as quickly as any of those mentioned." Mayhew often jolts his religious readers with accounts of the garbled religious views of the men and women he is describing, men and women who have never been brought into contact with either church or school. "What was St. Paul's...? A church, sir; so I've heard. I never was in a church.... Jesus Christ? Yes. I've heard of him. Our Redeemer? Well, I only wish I could redeem my Sunday togs from my uncle's." It comes as a surprise to encounter a passage where Mayhew sets out his own views on religion, describing "the great munificent Creator of the sea, the mountains, and the flowers—the stars, the sunshine, and the rainbow—the fancy, the reason, the love and the heroism of man and womankind—the instincts of the beasts—the glory of the angels—and the mercy of Christ."

This passage comes at the end of an account of a peculiarly sordid public entertainment in London's East End. Mayhew demanded more wholesome entertainment for the people he had been describing, along with proper education. "It is idle and unfeeling to believe that the great majority of a people whose days are passed in excessive toil, and whose homes are mostly of an uninviting character, will forego *all* amusements, and consent to pass their evenings by their *no* firesides, reading tracts or singing hymns." One wonders if Mayhew, having communicated successfully with costermongers and running patterers, was equally successful in communicating this message to his middle-class readers. Professor Bradley, in his necessarily brief introduction, has no room to help with speculations of this kind, nor does he date his selections or relate them to their context in Mayhew's own volumes. Perhaps the reception of Mayhew in his own time—and later—deserves a full study in itself.

For modern readers Mayhew opens up Victorian London, even gives the feeling of getting inside it. On one occasion, in a different book, he described getting above it—in a balloon. Then the detail was lost and only speculation was left. "It was a most wonderful sight to behold that vast bricken mass...all blent into one immense black spot—to look down upon the whole as the birds of the air look down upon it, and see it dwindled into a mere rubbish heap—to contemplate from afar that strange conglomeration of vice, and avarice, and low cunning, of noble aspirations and human heroism, and to grasp it in the eye, in all its incongruous integrity, at one single glance—to take, as it were, an angel's view of that huge town where, perhaps, there is more virtue and more iniquity, more wealth and more want, brought together into one dense focus than in any other part of the earth."

Short Reviews

PRELUDES IN THEORETICAL PHYSICS, IN HONOR OF V. F. WEISSKOPF, edited by A. De-Shalit, H. Feshbach and L. Van Hove. North-Holland Publishing Company ($12.75). When Victor Weisskopf, a well-liked and respected physicist, announced that he was resigning his post as director general of the European Organization for Nuclear Research (CERN) after a five-year term and returning to his professorship at the Massachusetts Institute of Technology, a number of theoretical physicists who had spent time at CERN during his tenure were invited to contribute to a volume honoring him. The papers, as in any comparable *Festschrift,* are a mixed bag, but the contributors include some of the foremost investigators in the field. A few have let themselves go and produced *jeux d'esprit,* which are more or less designed to emulate and to appeal to Weisskopf's broad outlook, his "intuitive" way of looking at the problems and dilemmas of contemporary physics, his constant attempt "to reduce to bare minimum formal derivations." Among the stimulating items are R. Hagedorn's "Causality and Dispersion Relations," an imaginary dialogue between "Inventor" and "Physicist" about a pair of sunglasses conceived by "Inventor" that let through only one frequency and absorb the rest ("Physicist" proves to "Inventor" that the glasses will not work and along the way teaches him a bit about causality); J. Robert Oppenheimer's discourse ("The Symmetries of Forces and States") on the wholly unsolved mysteries ("beyond or against quantum theory and relativity") of the hierarchies of interactions and symmetries that continue to challenge and leave a "great work for physicists"; Philip Morrison's essay "Time's Arrow and External Perturbations"; Leslie T. Foldy's design for a "neutron bottle," which he asserts is theoretically feasible (he leaves the means of filling it as a "nontrivial exercise for the interested reader"); J. S. Bell and M. Nauenberg's "The Moral Aspect of Quantum Mechanics" (a notion apparently introduced by Eugene P. Wigner), which firmly charges that quantum mechanics, for all its successes, is tainted by self-deceptive epistemological hanky-panky, is "at the best, incomplete," "carries in itself—because of defects in its internal structure—the seeds of its own destruction" and will be superseded in time by an "imaginative leap that will astonish us."

A SOURCEBOOK IN THE HISTORY OF PSYCHOLOGY, edited by Richard J. Herrnstein and Edwin G. Boring. Harvard University Press ($12.50). A collection of 166 excerpts of writings on different topics in the history of experimental and quantitative psychology from Aristotle to William McDougall, Karl Lashley, Max Wertheimer and other investigators of the present century. The material is divided into some 15 chapters dealing with such topics as sensory specification, psychophysics, theories of space perception, objective reference, cerebral localization, the reflex, association, learning and the nature of psychology. Useful and ably written introductions are provided for each chapter and excerpt. More than a quarter of the articles are translated into English for the first time. A fine, well-balanced contribution to the history of psychology; one would like to see a comparable work on social and clinical psychology.

Birds of the Atlantic Islands: Volume II, by David Armitage Bannerman and W. Mary Bannerman. Oliver & Boyd Ltd (84 shillings). The second volume of this study treats of the birds of Madeira and its neighboring islands. In collaboration with his wife, who shared the fieldwork with him, Bannerman describes, among others, the grebe, petrel, buzzard, spectacled warbler, gray wagtail, goldfinch, bee-eater, shrike, stilt vulture, osprey, hoopoe and jackdaw—all in his characteristic fashion, which combines scientific accuracy and engaging discursiveness. Included are eight color plates by D. M. Reid-Henry. Two further volumes are planned on the Azores and the Cape Verde Islands.

Practical Applications of Dynamic Symmetry, by Jay Hambidge. The Devin-Adair Company ($4.95). A reprint of a well-known book that contains lectures Hambidge delivered in New York during the winter of 1921, largely concerned with the application of his principles of dynamic symmetry to problems of architectural decoration, furniture design, type display and the like. One of the leading characteristics of dynamic, as distinguished from static, symmetry is that the lines bounding areas embodying it are nearly always incommensurable, a feature the Greeks frequently employed in the design of buildings, vases and other things.

All about Ants, by Peggy Pickering Larson and Mervin W. Larson. The World Publishing Company ($5.95). About 6,000 different kinds of ants are known today, with several hundred new kinds being discovered each year—all together forming a kingdom of these tiny, complex creatures that girdles the earth and reaches from below sea level to the highest mountaintops. There are also many hundreds of books and perhaps thousands of papers on the subject from the most technical to the simplest primers. The Larson book fits about midway in the scale of difficulty and high on the scale of merit. It is a clear, compact popularization that anyone from a teen-ager to a grown-up can thoroughly enjoy. It is rich in information about life cycles, ant homes, primitive forms, about such types as huntresses, gardeners, dairymaids, hitchhikers, builders and warriors, about instincts and intelligence, tastes and smells and social organization. Ants, it appears, have everything but labor unions. A superior book for anyone seeking information about these remarkable animals. Photographs.

The Works of William Harvey, M.D. Johnson Reprint Corporation ($25). A reprint in this publisher's "Sources of Science" series of Robert Willis' well-known 19th-century translation of Harvey's three great books: *De motu cordis, De circulationa sanguinis* and *De generatione animalium.* Also included are a biography of Harvey, translations of several of his letters and his last will and testament.

The Crabs of Sagami Bay, by Tune Sakai. East-West Center Press ($25). Descriptions of or brief notes on 350 species of crabs selected from the Emperor of Japan's collection assembled over a period of more than 35 years. The striking feature of the book is the delicate watercolors of each species.

Anglo-Saxon Architecture, by H. M. Taylor and Joan Taylor. Cambridge University Press ($35). This imposing two-volume work, to which the Taylors devoted "the leisure of thirty years," is a survey and a complete catalogue of the churches of England that contain well-authenticated examples of the Anglo-Saxon style of architecture. Anglo-Saxon in this context means the kind that prevailed before the Norman Conquest (although some of the churches covered are known to have been built after the Conquest). Following a short introduction the authors provide a meticulous, detailed description of each structure. There are 362 plans and diagrams and 280 photographs to illuminate the inventory. A superb undertaking.

Everest: The West Ridge, by Thomas F. Hornbein. Sierra Club ($25). The foreword to this volume, which gives the story of the American Mount Everest expedition of 1963, says that the author does not like to write but brought himself to do the book because he wanted to tell about the climb. His reluctance to write is quite understandable: the text is a rather sad example of high-altitude prose. Leaving aside this by-product of mountain sickness, the volume affords a collection of magnificent color photographs of Everest and the surrounding countryside, of snow, ice, trees, lakes and flowers, of the people who inhabit this part of the world. These are without question the most stunningly beautiful pictures of the Everest region that have yet appeared.

Notes

The Pursuit of Certainty, by Shirley Robin Letwin. Cambridge University Press ($9.50). A study of the work of four British writers: David Hume, Jeremy Bentham, John Stuart Mill and Beatrice Webb, the focus of attention being the relation between their political, philosophical and social thinking.

Human Nature in Geography, by John Kirtland and John Wright. Harvard University Press ($10). A collection of papers, written during the period 1925–1965 by the former director of the American Geographical Society, on a variety of topics such as the style of map makers, the measurements of mountain heights and aspects of early American geography.

Ideas in Modern Biology, edited by John A. Moore. The Natural History Press ($8). An examination by 19 biologists of salient ideas in modern animal biology, based on papers delivered at the Sixteenth International Congress of Zoology, held in Washington in 1963.

Physics. D. C. Heath and Company ($6.12). The second edition of this cooperative text prepared by the Physical Science Study Committee of Educational Services, Inc., contains a number of changes and revisions, of which the most extensive is the rewriting of the material on electromagnetic induction and electromagnetic waves.

Primate Behavior, edited by Irven DeVore. Holt, Rinehart and Winston, Inc. ($10). A collection of papers summarizing present knowledge about monkeys and apes in their natural environment, based on field studies by a number of specialists in fields from anthropology to linguistics.

A History of British Philosophy to 1900, by W. R. Sorley. Cambridge University Press ($2.45). A soft-cover reissue (first edition 1920) of a history of philosophy in Britain until the end of the Victorian era.

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