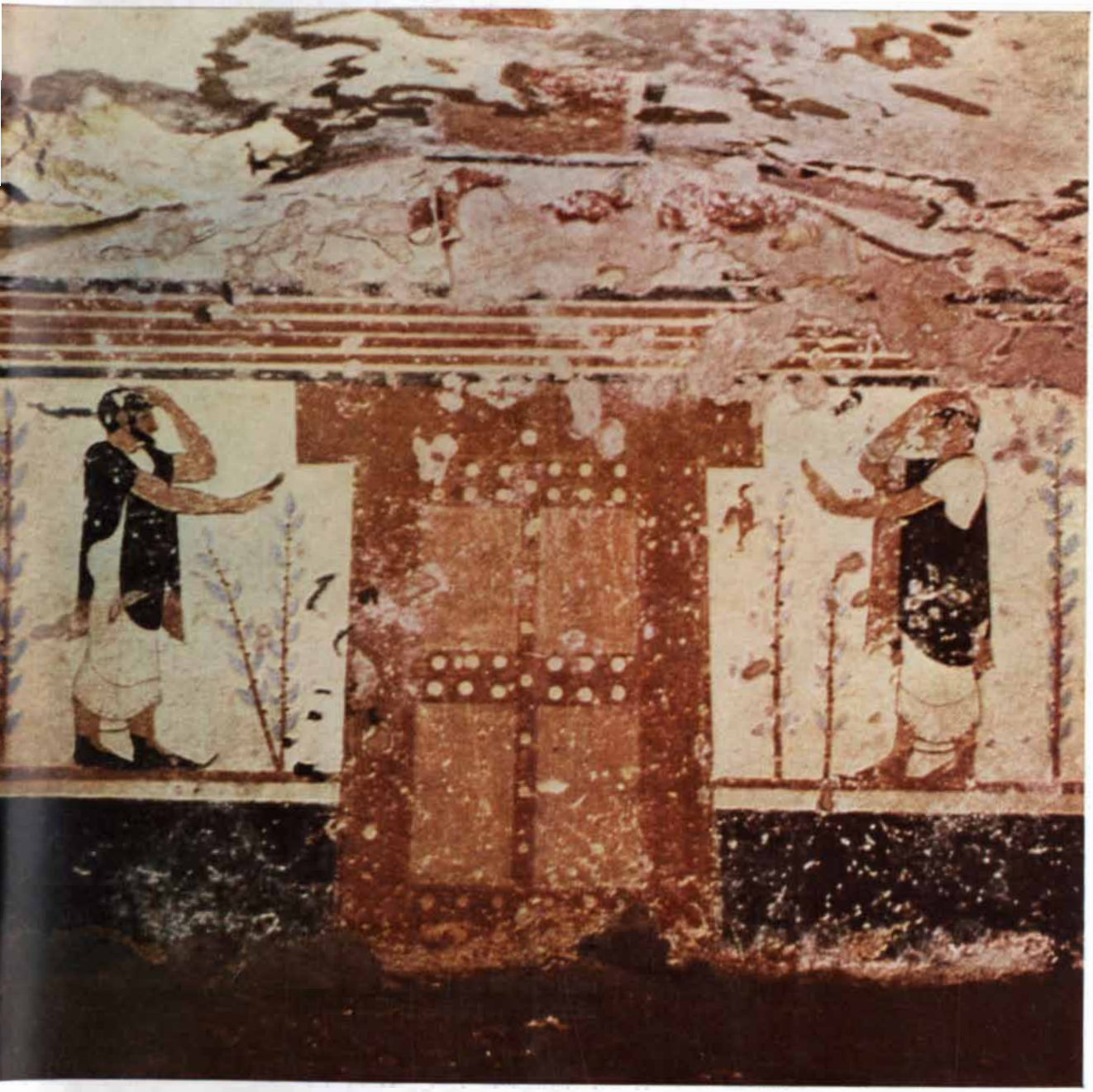
SCIENTIFIC AMERICAN



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February 1962

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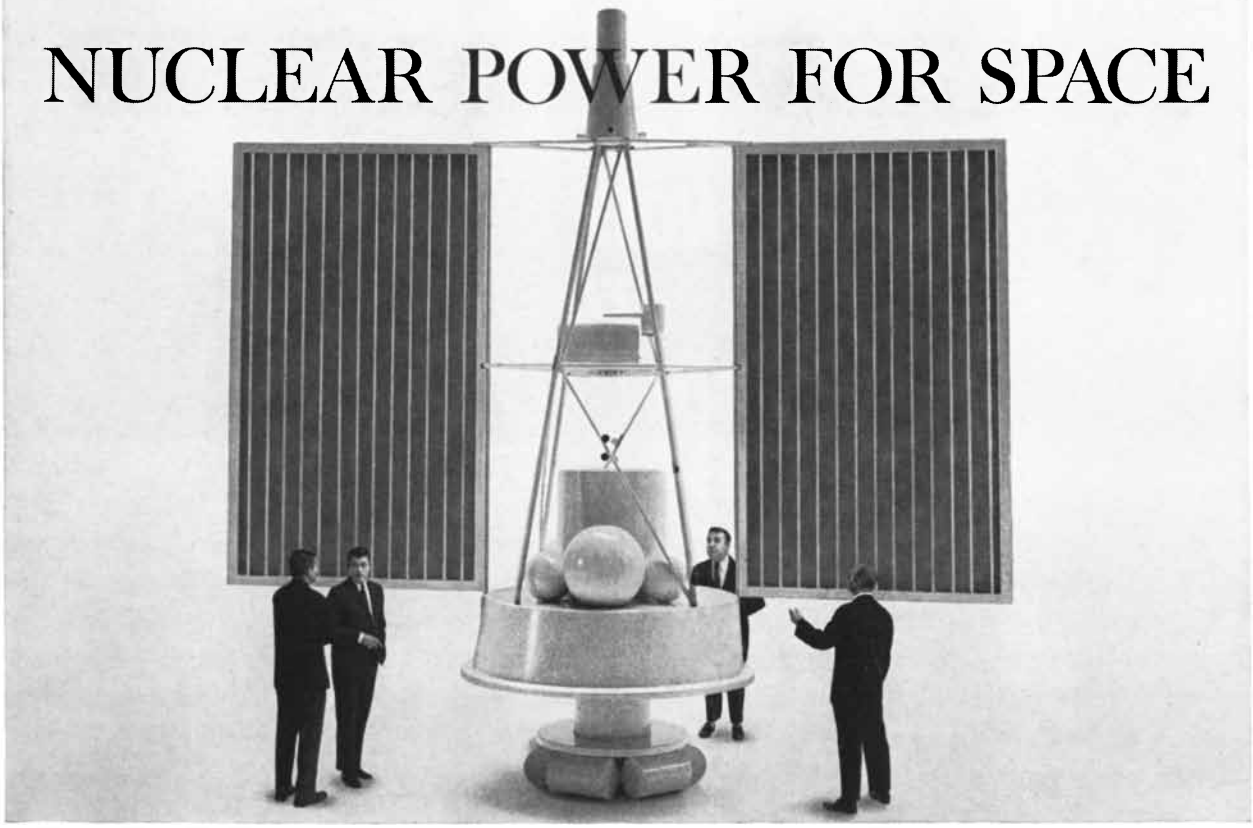

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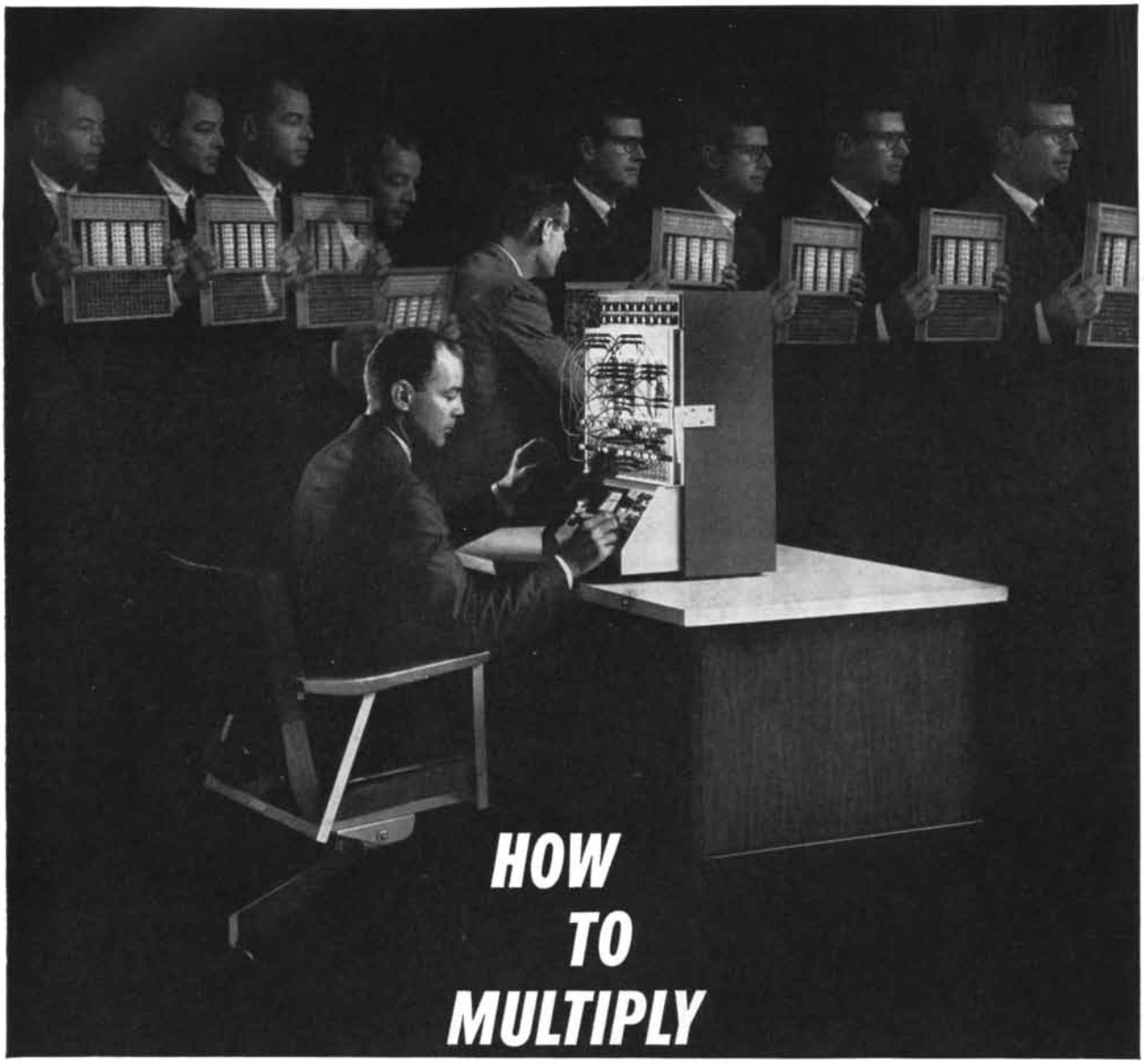

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Established 1845 **SCIENTIFIC AMERICAN** February 1962 Volume 206 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a wall painting in a tomb hollowed out of solid stone by the Etruscans. This remarkable people, who dominated Italy in the period immediately preceding the rise of Rome, built whole cities of tombs and decorated them as replicas of their homes and temples (*see page 82*). This fresco is in the Tomb of the Augurs at Tarquinia.

THE ILLUSTRATIONS

Cover photograph by Raymond Bloch, École Pratique des Hautes Etudes, Université de Paris à la Sorbonne

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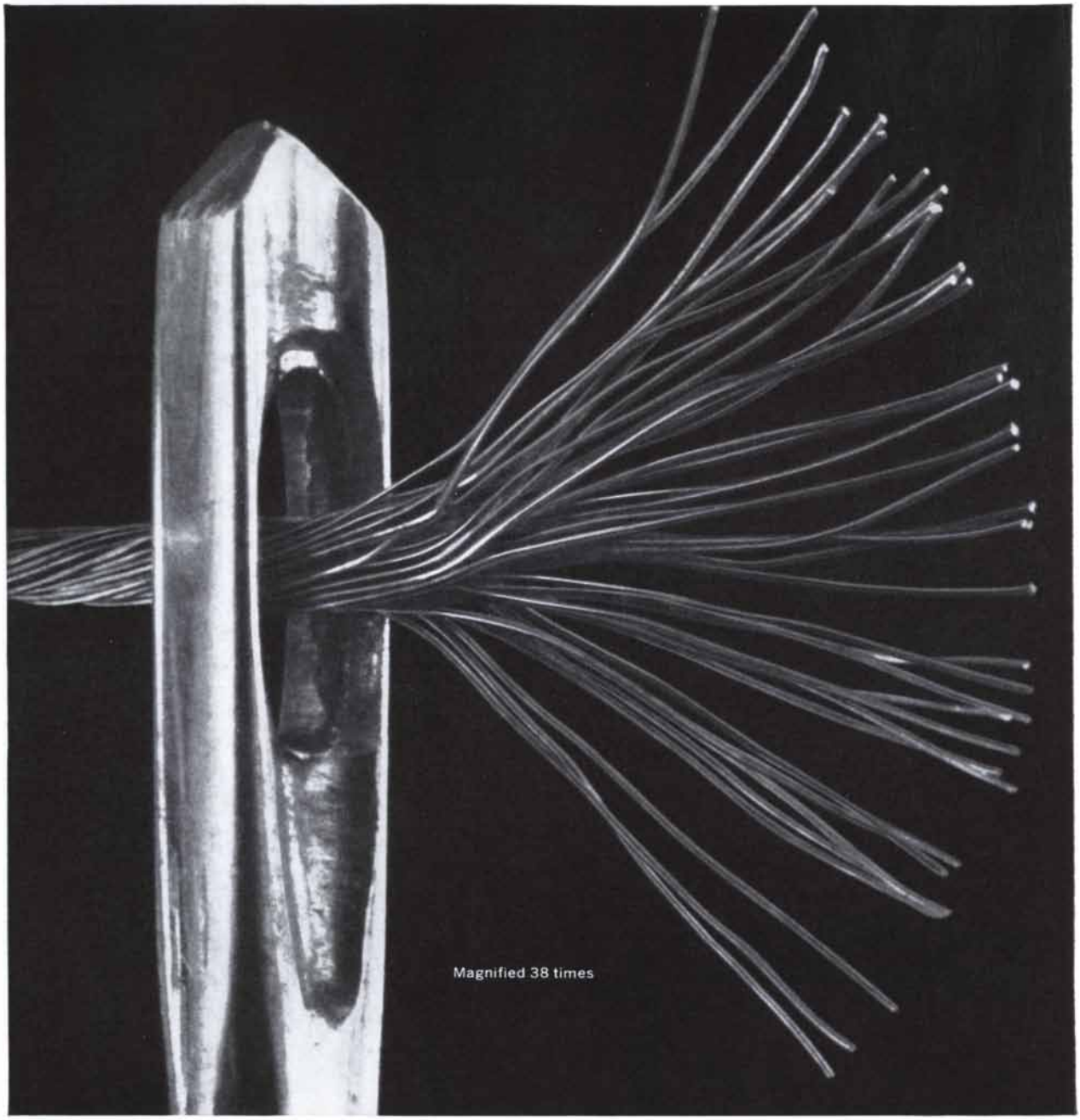

Wire: Seen through the eye of a needle

Imagine a wire drawn so fine that 40 strands of it, twisted together, would pass easily through the eye of a fine needle. The Electric Wire Company, one of Howe Sound's manufacturing subsidiaries, recently produced two miles of such a copper-stranded wire. This company expertly draws over 60 metals, bi-metals and alloys, including tinned, plated and clad metals, stainless steels, gold, silver and platinum. And it has the ability and enthusiasm to produce almost any kind and size of wire you may require. This is an example of the contributions to life and living made by Howe Sound companies—through generations of experience in metals.

HOWE SOUND

Howe Sound is a company you should know more about. Howe Sound Company, 500 Fifth Avenue, New York 36, N.Y.

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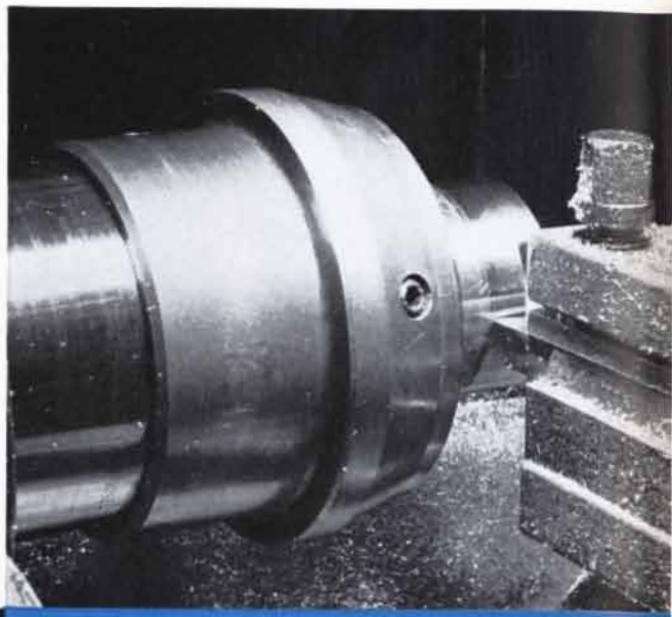
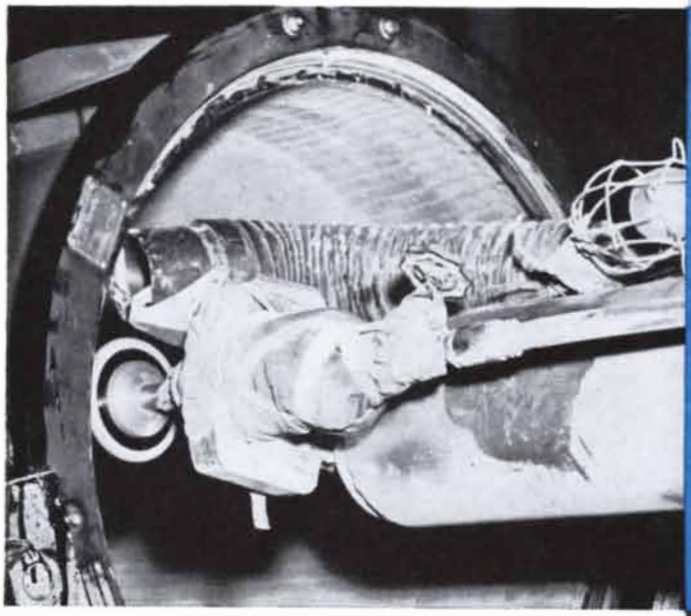
Right: Cylindrical aluminum mechanism for movie camera zoom lens is mirror-finished with natural-diamond lathe tool by Bell & Howell, Chicago. Two passes of the diamond tool remove .004 inch of stock, produce a surface finish of 16 micro-inch rms.



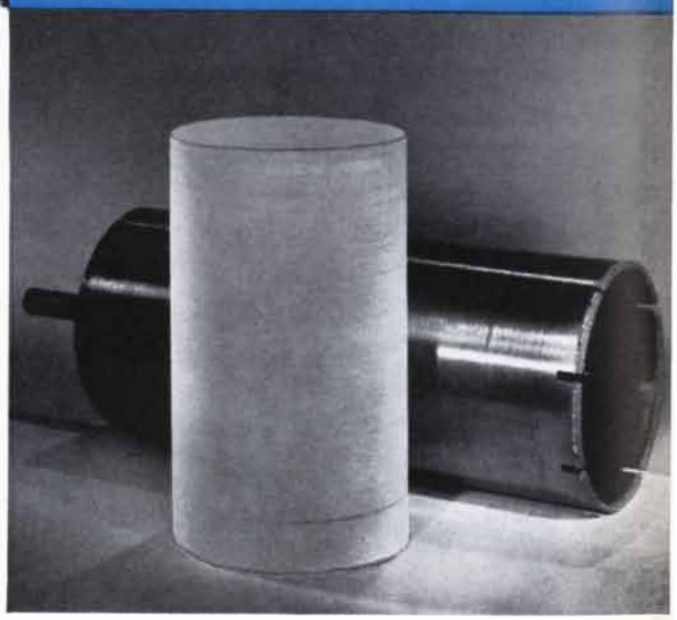
Below: H. I. Thompson Fiber Glass Co., Gardena, Calif., grinds the inside of a large-diameter tube for missile. Material is Refrasil ablation plastic, which is very hard and abrasive. Grinding head with natural diamonds turns at 17,000 rpm.

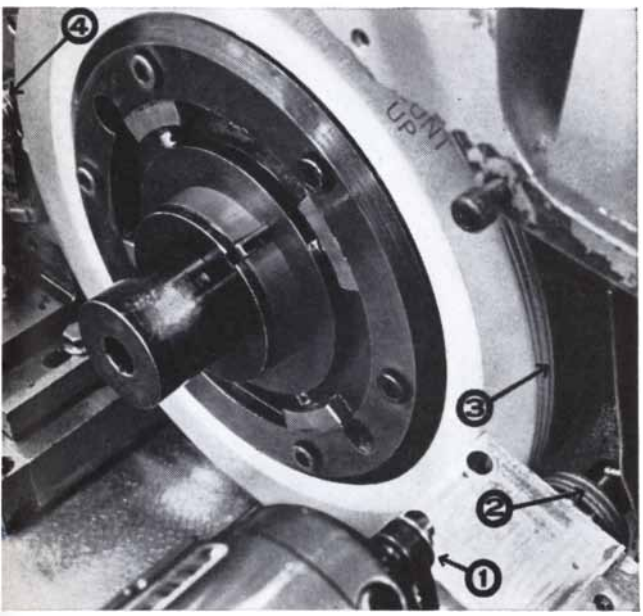


These manufacturers are using natural diamonds to advantage. You can, too.

Far Right: Split Ballbearing, Lebanon, N. H., makes specialized ball bearings. A perpetual form control uses metal-bond natural-diamond grinding wheel as dressing tool to maintain extremely close tolerances. Separate drive unit (1) powers circular diamond-impregnated cutter (2) as it dresses the formed face (3) of the abrasive wheel. Formed wheel increased speed of grinding four grooves in a ball-race bearing (4) by almost 500 per cent.

Right: This 4-inch-diameter, 8-inch-long PYREX® cylinder was cut in 45 minutes at Davidson Optronics, West Covina, Calif. Diamond-impregnated core drill was used with standard milling machine operated at an average speed of 300 rpm.





The grinding, drilling and surfacing jobs shown here are performed in completely different industries. But they have one important thing in common: in every case, natural diamonds are doing the job quickly—and economically.

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

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

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

Best grit for metal-bond wheels developed by the Diamond Research Laboratory in Johannesburg

A new impact crushing method for natural diamonds is now producing the strongest and most durable diamond grit ever obtained for metal-bond wheels. Your tool and wheel manufacturer is ready to help you select the diamond tool that's right for your job.

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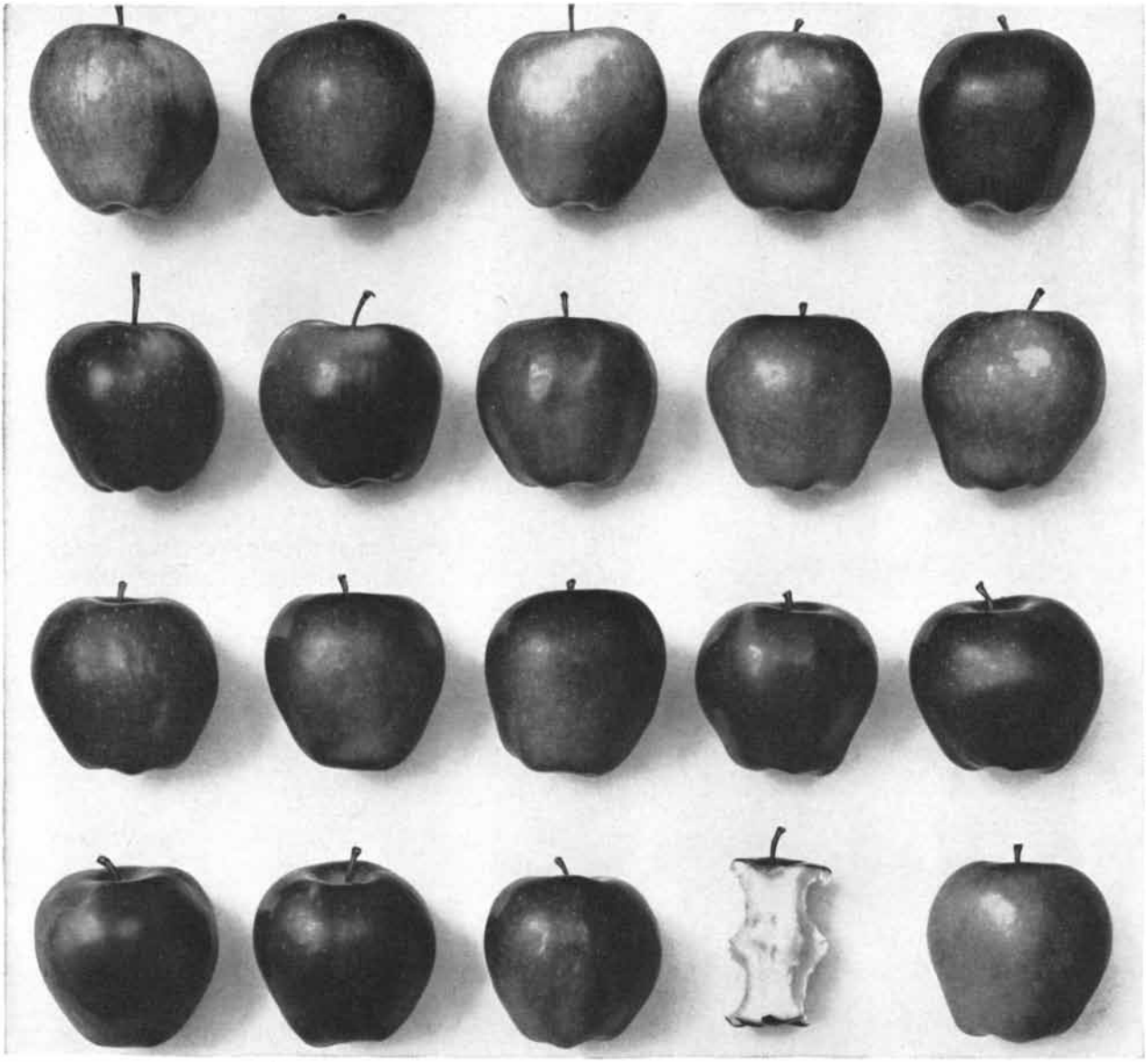

IN SAMPLE TESTING . . . X-ray gets to the core of the quality control problem

Where does quality start? For most industrial processes, the core of the quality problem can be found in the crystalline structure of the material being processed. And this is one area in which x-ray serves industry especially well.

General Electric, with a broad line of x-ray diffraction equipment, gives you the facility to perform such studies as qualitative and quantitative analysis, residual stress and orientation, to name a few. These and other complex physical investigations are performed routinely by one compact G-E instrument. Answers are delivered in *minutes* that might require *days* . . . or would be impossible to obtain with other analytical techniques.

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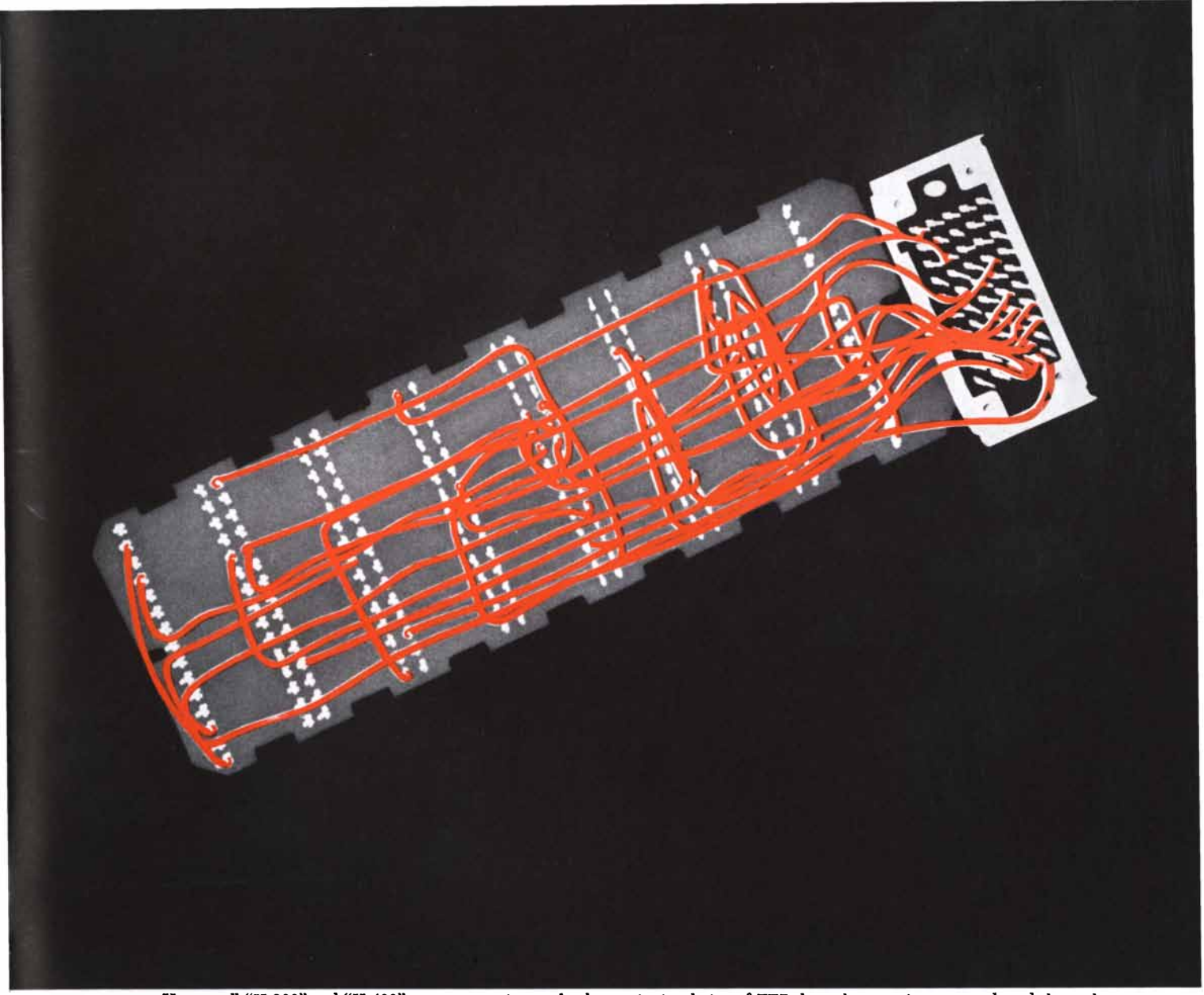

Honeywell "H 800" and "H 400" computer series use hook-up wire insulation of FEP throughout, as in program board shown here.

Computer logic: insulate hook-up wire with TEFLON® FEP

Modern high-speed circuits in data-processing equipment demand minimum capacitance, unvarying over a wide frequency range. This is provided by wire insulation of Du Pont TEFLON FEP-fluorocarbon resin, whose low dielectric constant is unaffected by variations in frequency and temperature. In addition, all wire-wrap techniques, including automatic high-speed wire wrapping, require high resistance to cut-through. The combination of primary insulation of TEFLON FEP with a jacket of a Du Pont ZYTEL® nylon resin has proved outstanding in this respect, and has handled well, particularly on the automatic wire-wrapping equipment.

Melt-processible TEFLON FEP now makes available the electronic, chemical and mechanical advantages of TEFLON in the forms of long, continuous extruded lengths of wire insulation and jacketing...easily molded electronic components. FEP resin is rated for continuous use to 400°F. In computers, in missiles, in automatic wire-wrapping applications – wherever utmost reliability and high production speeds are called for—this newest member of the family of TEFLON resins provides an economical solution to insulation problems. Find out more about it! Write: E. I. du Pont de Nemours & Co. (Inc.), Dept. S-2, Room 2526T Nemours Building, Wilmington 98, Delaware.

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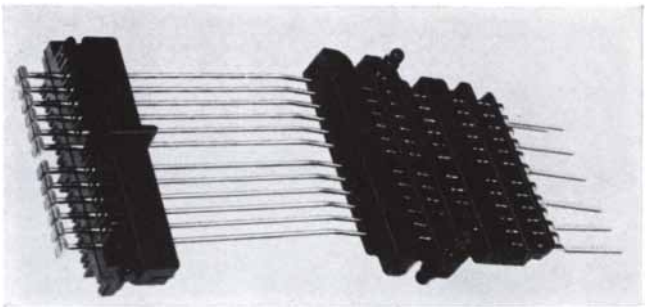
Where no metal but Palladium will do the job as well...

Relay contacts in the Bell Telephone System high-speed switching equipment, manufactured by Western Electric, are capped with Palladium



Single wire block—part of the relay—showing wire springs with palladium-capped contacts

Can you imagine handling more than 2000 calls a second... every second... of every day? The Bell System does.

Complex high-speed switching equipment spells simplicity for the user—and excellent service every time you pick up your phone.

Heart of the switching apparatus is millions of wire spring relays, manufactured by Western Electric... relays with palladium-capped contacts to provide low-noise high-fidelity transmission.

Here is yet another vital industrial application where precious palladium allows for minimum metal usage—maximum economical life.

It could pay you to use a Platinum Metal

Your problem might be readily and economically solved with Platinum Metals—where reliable make-and-break electrical contact is indicated, such as in low-noise high-fidelity transmission... where wear-resisting, non-tarnishing surfaces are required, such as for printed electrical circuits... where a combination of severe corrosion and erosion must be met, as in the case of spinnerettes for rayon production... where peak catalytic efficiency is required, as in the refining of high octane gasoline... or where product purity must be retained despite high temperatures, as in the case of lens glasses... the Platinum Metals have proved to be the most economical for certain critical equipment.

Industry is going to higher temperatures and higher pressures. Perhaps your own progress has been blocked by the limitations of materials to withstand such severe conditions. The Platinum Metals have removed many barriers. Have you considered them for your problems?

Platinum, palladium, rhodium, ruthenium and iridium have unique potentials, well worth your attention. Specialists are prepared to work closely with you in evaluating these metals for new commercial and scientific uses.

As a first step, write us for additional data on the outstanding characteristics and successful applications of the six Platinum Metals and their alloys—indicating your field of interest or how we might be of assistance.

CAN THESE PROPERTIES OF THE PLATINUM METALS HELP YOU?

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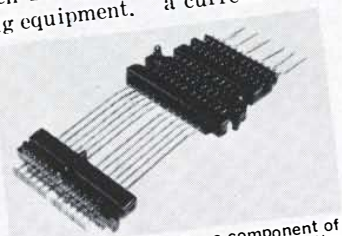
The International Nickel Company, Inc., 67 Wall Street, New York 5, N.Y.

As appeared in Scientific American, May, 1961

Hardly larger than cigarette packages, wire spring relays form the heart of switching apparatus for more than 200-million telephor calls a day. The pencil indicates the top row of tiny palladium-capped contacts which are vital to the relay's switching function

Probing for palladium via thermoelectricity

Wire spring relays are vital to the Bell Telephone System's reliable, high-speed switching equipment. Western Electric will manufacture more than 15 million relays in 1961. Palladium-capped contacts on these relays are necessary for their optimum performance—therefore, positive verification of the palladium is essential.



The single wire block — a component of the wire spring relay — showing the cupro-nickel contact points, some of which must be capped with palladium.

Verification by existing means has proved to be extremely difficult, however, because of the caps' size (only 0.01 x 0.073 x 0.042 inches) and the fact that the palladium and the cupro-nickel base blocks to which the caps are welded are similar in color, making visual checking highly unsatisfactory. Also, the characteristics of the metals involved make ordinary electrical and magnetic methods impractical.

Contact verification machine, developed and built by Western Electric, being programmed to check wire blocks for dielectric breakdown, physical configuration, and palladium contacts.

To overcome this problem, Western Electric engineers have developed and built an ingenious machine which utilizes the Seebeck thermoelectric effect, by which an electrical circuit made up of two different metals generates an electric current when the junction between the two metals is heated. In this case, nickel and palladium were the metals involved, but another feature of the Seebeck effect is that a circuit composed of nickel and cupro-nickel generates a current *which flows in the opposite direction.*

The engineers made use of this feature by using nickel probes — preheated to 300 degrees Fahrenheit — in the new machine. The probes touch all contacts on the relay's single wire block assembly, and the *direction* of the current produced indicates whether the probe has contacted palladium or the cupro-nickel base metal. Amplifier circuits enable the "indicator" currents to operate automatic controls and automatically reject defective assemblies.

Being able to intentionally leave caps off certain pre-selected contacts is also a prime advantage of this new verification process, since hundreds of thousands of relays use less than the maximum number of contacts. Savings in material costs, which are made possible by omitting precious palladium from unused contacts, are significant. But the most important advantage of the process is the proven ability to produce a product with verified quality — the kind of quality required by the Bell System's twenty-three local telephone companies to give highly dependable telephone service.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM

LETTERS

Sirs:

Comment is required regarding Virgil E. Barnes's article "Tektites" in your November 1961 issue.

First, the 1959–1960 U.S. Antarctic oversnow traverse in Victoria Land–Wilkes Land found no gravity or magnetic data supporting the meteoritic impact postulated to have occurred in that area on page 65 of the article. It is possible, of course, that the traverse did not cross the proper area. It might be noted, however, that the thick ice and snow cover of this part of Antarctica (8,000 to 9,000 feet) could have diminished, if not prevented, any large-scale tektite shower if the meteorite did fall in that area.

Second, the late E. C. Thiel and the writer discovered glassy spherules similar in appearance to tektites in ice layers of Antarctica developed less than 50 years ago. Even if the postulated meteorite impact 5,000 years ago formed the australites, and even if it ejected particulate matter into orbit around the earth, it seems unlikely that such particles would remain in orbit for over 5,000 years.

RICHARD A. SCHMIDT

University of Wisconsin
Madison, Wis.

Sirs:

As Richard A. Schmidt suggests, the thick ice cover in the Victoria Land–Wilkes Land region of Antarctica diminishes the possibility that the impact crater responsible for the australites could be there, the portion of Antarctica most distant from Africa and South America. In view of the rayed distribution of ejecta from impacts and the spotty distribution of australites in Australia, the impact site might be anywhere in Antarctica where the ice was thin or absent 5,000 years ago. In such a case it would be necessary to assume (1) that rays of ejected tektites missed southern Africa and South America or (2) that tektites are present in the southern part of these continents and have not been found. The author agrees with Dr. Schmidt that an impact crater could have been missed by the gravity and magnetic traverses referred to in his letter.

Dr. Schmidt's second contention is based on the supposed similarity of the minute glassy spherules to tektites. It seems apparent from Dr. Schmidt's description of these glassy spherules in a letter to the author (dated October 20, 1961) that they are not tektites, and if they are not tektites his argument is irrelevant.

VIRGIL E. BARNES

University of Texas
Austin, Tex.

Sirs:

I wish to contradict the view of Sid Deutsch ["Letters"; SCIENTIFIC AMERICAN, December, 1960] that "the probings of biophysicists and biochemists have shown that the living cell obeys causality, and that this is the answer to the questions [about the existence of a free will] posed by philosophy." The naïve concept of "free will" is not inadequate and not incompatible with scientific knowledge....

JOHAN H. GREIDANUS

Amsterdam, The Netherlands

Sirs:

The scientific and philosophical fallacies in Sid Deutsch's letter are almost so many and great as to defy analysis in short space, but the conclusions drawn from them are stated so confidently that the attempt must be made.

The sentence "Effect predictably follows cause—predictably in the sense that the present and future state of the uni-

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verse is completely determined by its past state . . ." is a concise statement of Laplacian determinism, which was based on the assumption that classical mechanics applied rigidly to every particle of the universe.

With the rise of quantum mechanics and the statement of the Heisenberg uncertainty principle it became apparent that events at the molecular and atomic level cannot be discussed in terms of causal chains. The physical properties of macroscopic bodies such as cylinders of gas or (in principle) human brains can be calculated by the methods of statistical mechanics from the properties of the microscopic entities (electrons, atoms, molecules) of which they are composed. The properties of macroscopic bodies that are assemblies of very large numbers of constituent microsystems assume "average" or "most probable" values that are sufficiently constant for them to be considered as in some general sense "determined" by the properties and numbers of the component particles. With assemblies of small numbers of particles, however, random variations from the mean of any property of the assembly become significant, and because of the inherent uncertainty at atomic level these fluctuations are not susceptible to a priori calculation.

Thus a supercomputer could not, even in principle, calculate the detailed configuration of the cerebral cortex of a single reader of the living-cell issue of *Scientific American*. Even if this configuration were known, it would not be possible to assert that he would be stimulated in the exercise of his particular scientific discipline since the correlation between mental states and the arrangements of electrons, atoms and molecules in the brain is not understood.

Whether or not human free will, or the illusion of possessing it, originates in uncertainty at the molecular level is debatable, but Mr. Deutsch's arguments are irrelevant to this question.

Finally, how could the recognition that living organisms "obey causality" give a chance of stopping man's race toward destruction? Would we not be tempted to throw up our hands in despair at the approach of our inescapable and causally predestined fate? On the contrary, "The fault, dear Brutus, is not in our stars, /But in ourselves, that we are underlings."

J. P. NICHOLSON

Faculty of Pure and Applied Science
University of Ottawa
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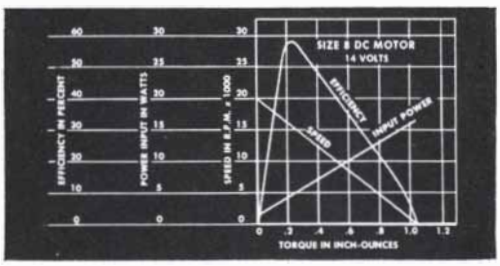

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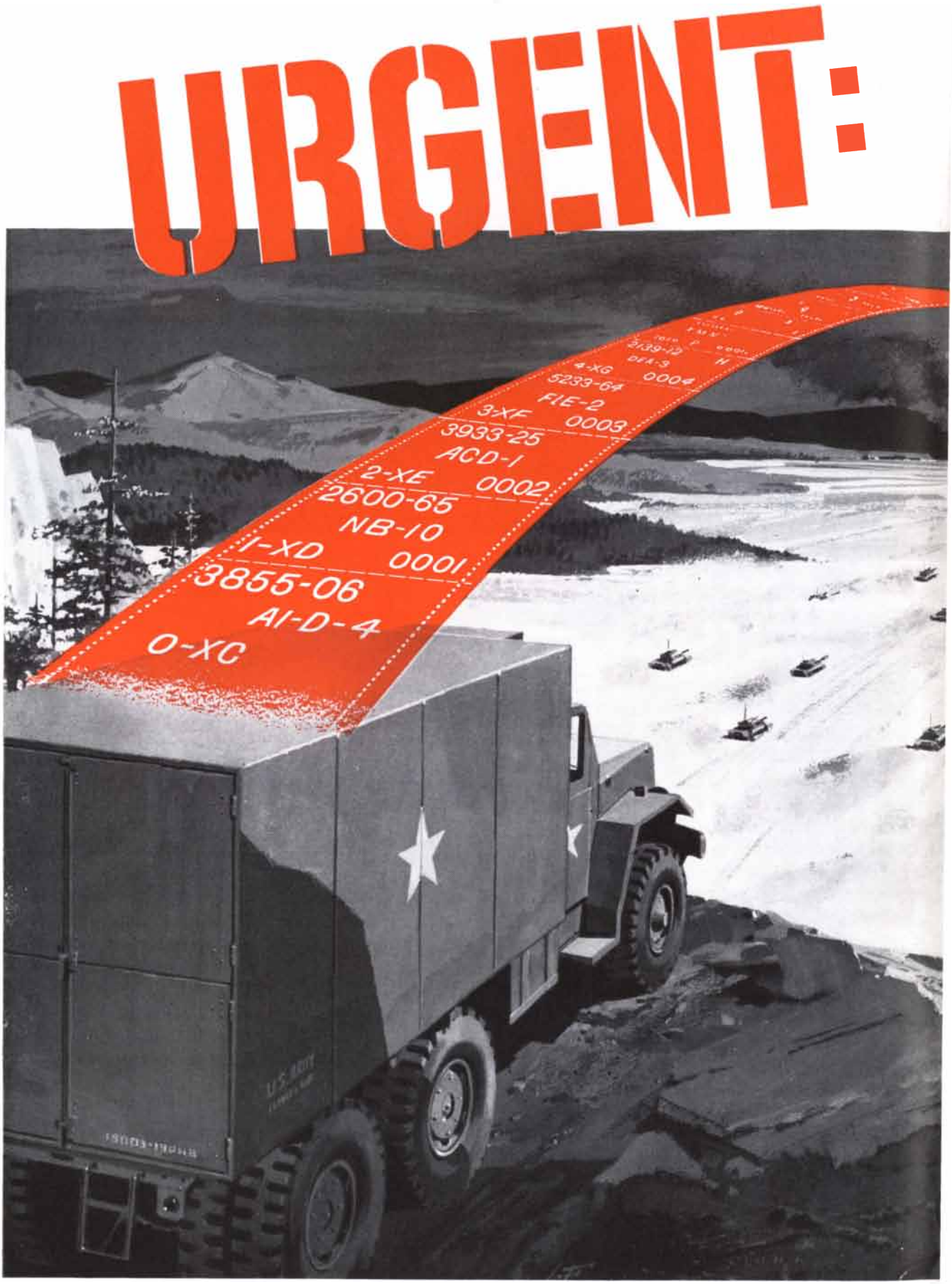
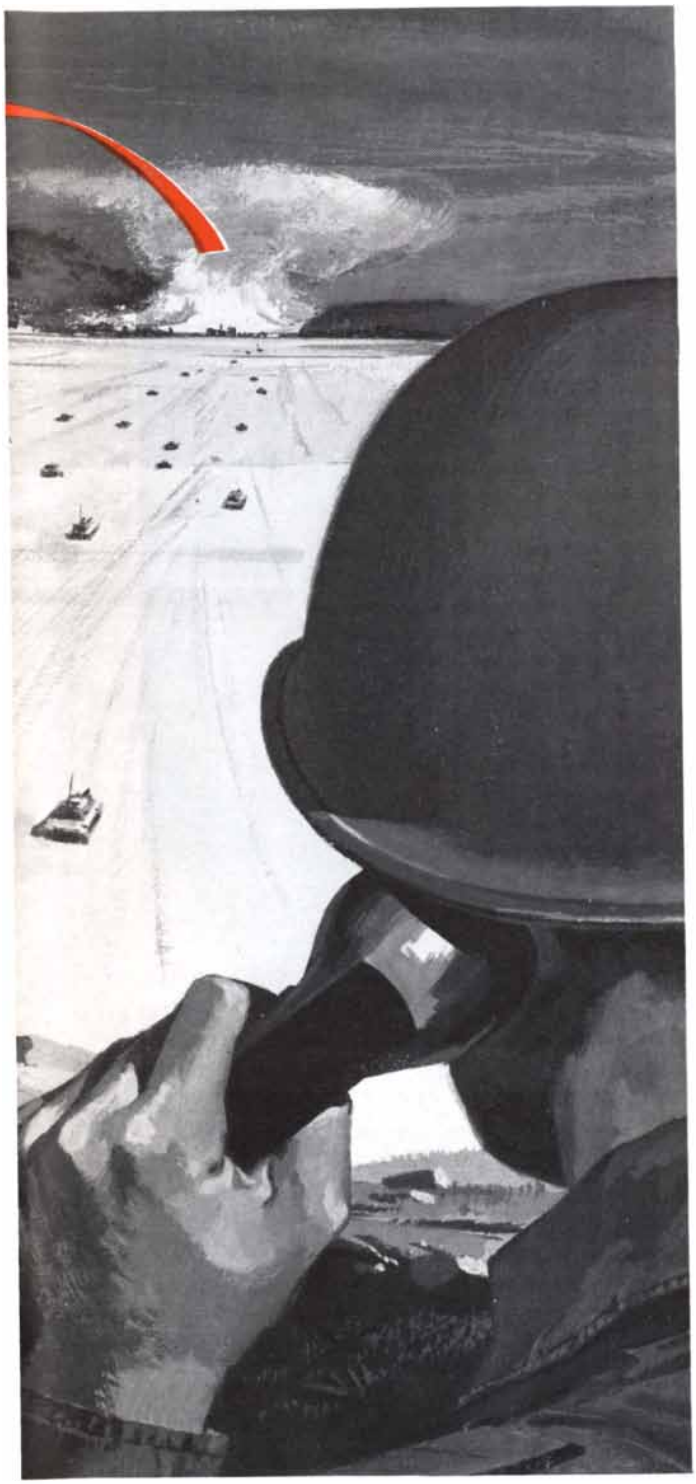


PROCESS VITAL DATA WHEN AND WHERE IT'S NEEDED!



Finding ways to process essential data in remote field armies the moment it's needed is a continual challenge we meet at Sylvania Electronic Systems.

For example, our development with the Signal Corps of the first large-scale, general purpose mobile digital computer (MOBIDIC) has created an important arm to military operations. No matter where the scene of action may be—in the desert, jungle, mountains or frozen North—a MOBIDIC can be on hand and working. It can process tactical and strategic data, logistical information—even command and control operations.

Further, a number of these systems are now in operation and are so rugged they can be moved over extremely difficult terrain without damage to the systems.

Putting new and better data systems on wheels to help field commanders is just one of the many ways the scientists and engineers of General Telephone & Electronics corporate family serve the nation. The vast communications and electronic capabilities of GT&E, directed through Sylvania Electronic Systems, can research, design, produce, install and service complete electronic systems. These systems include detection and tracking, electronic warfare, intelligence and reconnaissance, communications, data processing and display.

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

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Garrett-AiResearch Capability in Nuclear Engine Control Systems

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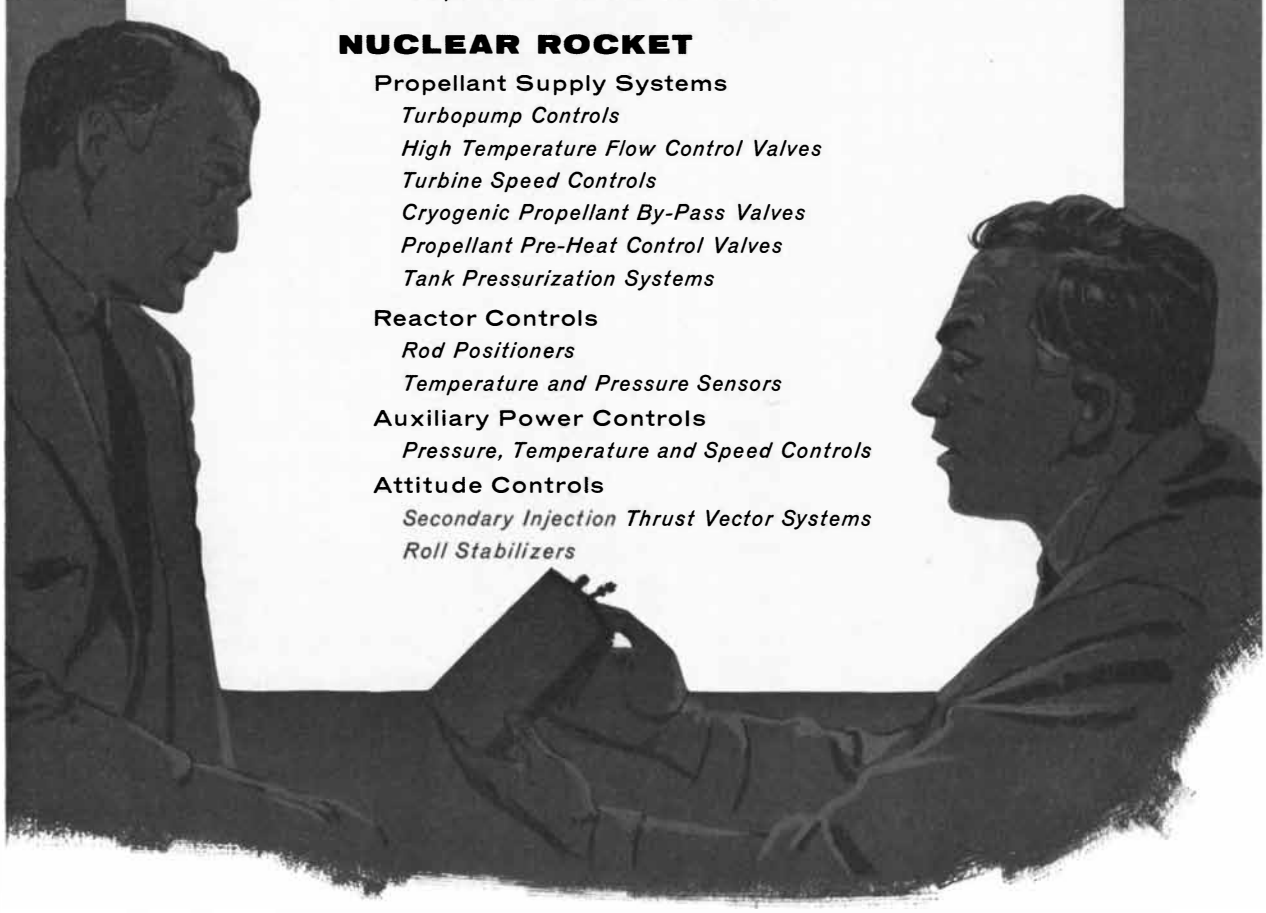

AiResearch experience in space nuclear power systems, and in hot gas and cryogenic control systems for aircraft and missiles, is directly applicable to the development of control systems for nuclear rocket and ramjet engines.

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AiResearch has more than six years of development work in nuclear power systems spread over a wide range of programs, including turbomachinery and heat transfer equipment. Please direct inquiries to Control Systems Sales, Phoenix Division.

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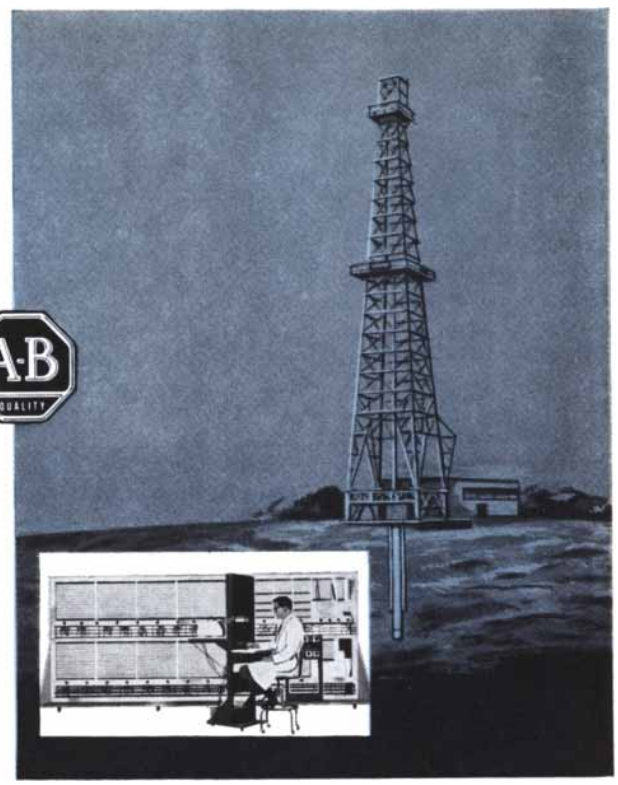
Electronic systems in Tiros Satellite, built by RCA for NASA, use A-B resistors.



Network of 150,000 A-B resistors at Schlumberger's Research Center helps locate oil wells.

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From meteorology to geology, from communications to commerce—wherever electronics is at work—Allen-Bradley resistors are helping to provide the necessary equipment reliability and performance. Allen-Bradley resistors, made by A-B's exclusive hot molding process, guarantee *complete freedom from catastrophic failures in service*. Always insist on Allen-Bradley resistors—there is no better molded composition resistor—either in this country or anywhere else in the whole world. For full details on the complete line of A-B quality electronic components, please send for Publication 6024. Write Allen-Bradley Co., 1204 S. Third St., Milwaukee 4, Wis. In Canada: Allen-Bradley Canada Ltd., Galt, Ont.

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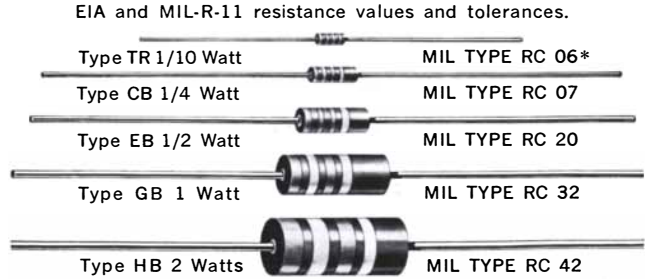

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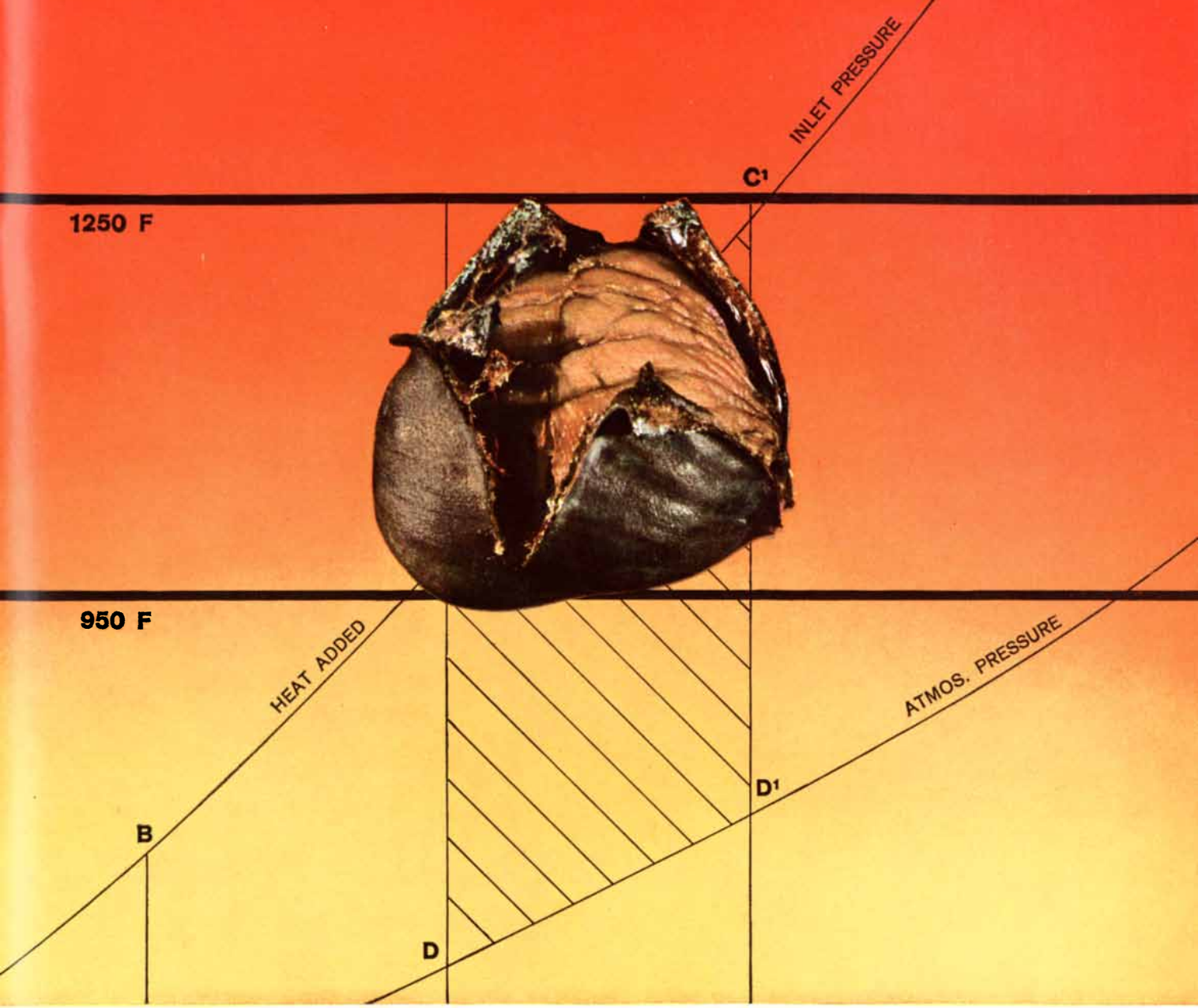
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1912: "There seems to be little doubt in the minds of aviation experts that the next great conquest of the aeroplanes will be the transit of the turbulent Atlantic. Plans are now far advanced toward securing a substantial prize for the undertaking and for encouraging builders to design aeroplanes for the ocean trip. To say that the trip is a hazardous one, that it presents difficulties both unique and severe, and that aeronautical science is as yet too crude to assist the designer greatly, is merely to confess that the problem of successfully crossing the Atlantic by aeroplane has few peers in difficult engineering. It would not be hard to picture the meaning of the transatlantic aeroplane trip to progress in general. The shortest time of transit would in all probability be cut in half, and the fact that only a few years' development of flying machines has produced a type capable of crossing the ocean should make the 'can't-be-done man' hesitate to include aeroplane transportation of light freight and passengers in his category of impossibles."

"A few thousand dollars donated by John D. Rockefeller will serve to maintain forever the little tanner's cottage at Dôle, in France, in which Louis Pasteur was born. This tribute from a wealthy American, although gratifying to French scientists, seems also to have aroused much comment. Why, it is asked, are Frenchmen of wealth so indifferent to the achievements of their own scientific men that they allow foreigners to preserve the houses in which they were born?"

"The announcement that the contract has been let for building the section of the New York Subway beneath Broadway from Park Place to Walker Street brings to mind the fact that the contractors will find that a certain amount of the work of excavation along this section has already been completed; for in the course of their work they will come upon an old construction in the shape of a brick-lined subway, which has been in



THE POWER RECOVERY "CHESTNUT"

or how to take power from 950F—1250F tail gas

A proven method for taking mechanical power from process tail gas below 950F is the turbine. Taking power from tail gas above this temperature has, in the past, been a power recovery "chestnut"—too hot to handle despite its desirability. But now, Worthington offers a Power Recovery turbine that can successfully pluck the meat from this very hot "chestnut."

The "meat" is extremely tasty. Frequently, if tail gas can be put to work at 1250F instead of 950F, as much as 12 to 15 per cent more power can be captured. In some installations, the heat exchangers that formerly handled the drop to 950F can be eliminated. In others, thermodynamic analysis will now show the feasibility of heating the gas to 1250F to get maximum mechanical power recovery.

In the past, use of Power Recovery turbines at the higher temperatures has been impractical. One major problem has been in mechanical design. Misalignment caused by excessive thermal expansion, higher temperature sealing, rotor construction, and forces imposed on the expander by inlet piping expansion and construction are all part of the problem. Today, Worthington has minimized them by creating a new design and using new materials.

A second major problem area that Worthington has overcome is analysis of the gas itself. Most tail gases are mixtures and their behavior is not fully plotted at the temperatures involved. But the behavior must be known before the turbine can be designed. Today, Worthington is ready to analyze the heat recovery potential of any gas or gas-steam mixture and to design a Power Recovery turbine to match.

Would you like to taste the meat of this power recovery chestnut above or below 950F? (Or do you need cryogenic turboexpanders?) Write or call Worthington Corporation. Turbine Division, Dept. 48-14, Wellsville, N. Y.

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Atomic Power... and the race to outer space

If man is to reach the other planets... and get back to Earth...he has three immediate choices: (1) A conventional rocket, many times the size of anything now existing. (2) A rendezvous in orbit, where the spaceship would be assembled. Or (3) an atomic-powered rocket ship. Because atomic power's efficiency is the highest, many experts believe the practical choice for space exploration is an atomic rocket engine.

Westinghouse and Aerojet General are now working with AEC's Los Alamos Scientific Laboratory to design such an engine. This industry-government team is working under the direction of the Joint Space Nuclear Propulsion Office of the AEC and NASA. You can be sure...if it's Westinghouse

existence between Warren and Murray streets for more than 40 years. What is more, they will find within this subway a complete car, which after carrying passengers on experimental trips has remained sealed up in its brick-lined vault beneath the streets of a busy city. The pioneer line built in the 1860's was planned and constructed by the late Mr. Alfred Ely Beach, who in partnership with the late Orson D. Munn founded SCIENTIFIC AMERICAN. The tunnel was built in 1869 under a franchise 'for the transmission of letters, packages and merchandise by means of pneumatic tubes to be constructed beneath the surface of the streets and public places.' In 1873 the charter was amended so as to permit the company to 'construct, maintain and operate an underground railway for the transportation of passengers and property.' "

"In a recent issue we published a description of an aviator's garment, so designed that it would belly out and constitute a parachute after a fall of a few feet. So convinced was the inventor, Franz Reichelt, an Austrian resident of Paris, of the merits of his garment that he determined to test it by jumping from the Eiffel Tower. On February 5 he donned his curious garment and proceeded to carry out his experiment, against the advice of M. Hervieu, an expert and the inventor of a similar device. He leaped from the first platform of the tower. The parachute failed to work and Reichelt was instantly killed by the fall of 180 feet. Reichelt's garment was provided with an enormous hood of silk gathered together on the back so that it resembled a knapsack. The hood was to be released by the wearer of the garment himself. Reichelt had made experiments with his garment in the courtyard of his house. A manikin had been used. The preliminary trials were for the most part unsatisfactory, according to accounts that we have received from Paris. It seems incredible that any man should venture on such a hazardous attempt and repeat it on so large a scale after failure."

Scientific American.

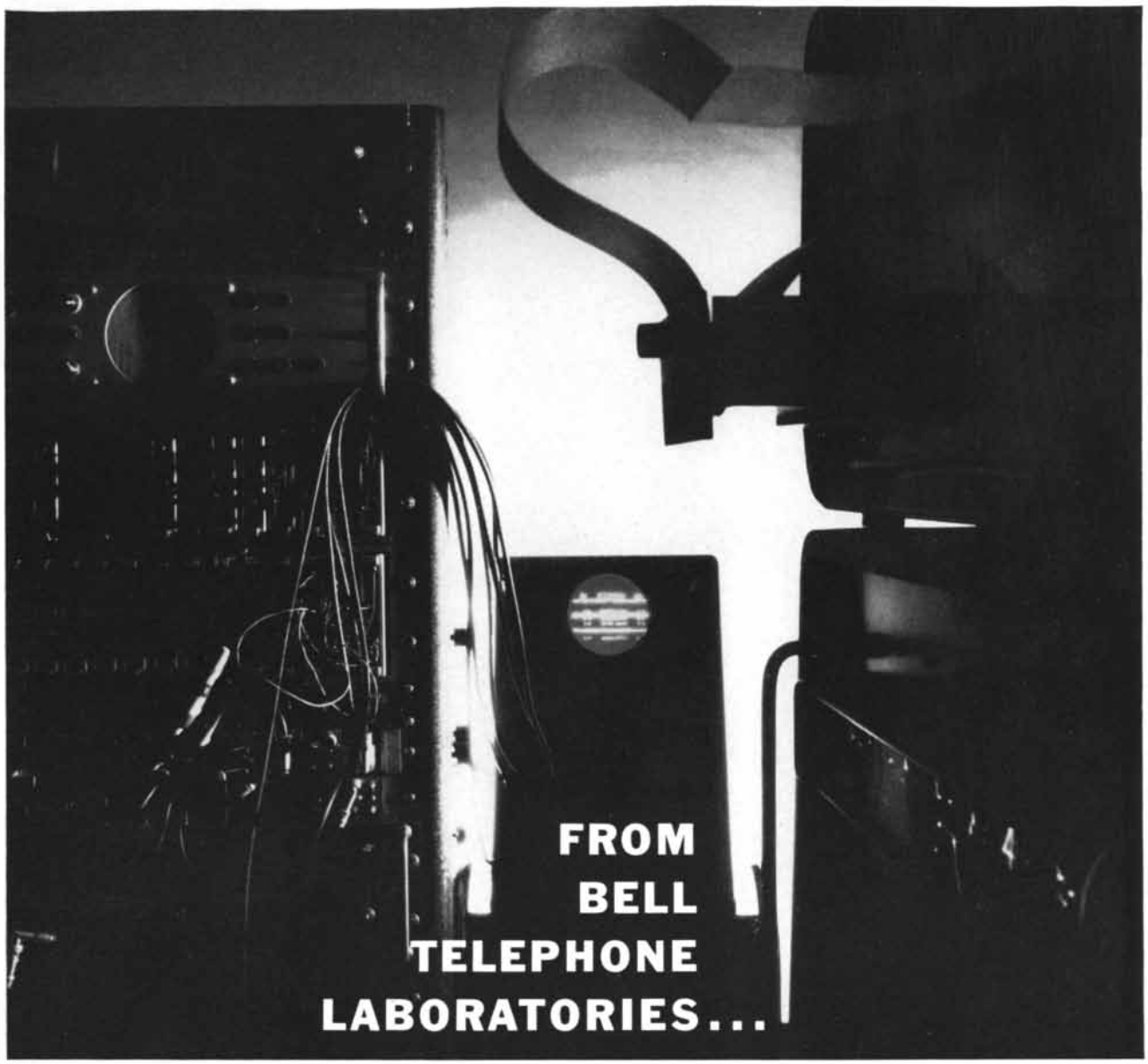
FEBRUARY, 1862: "Not many years since, the English were manufacturing muskets by hand labor, and knew of no other way. They learnt that we had invented machinery for manufacturing arms, and that we actually made them so that their parts would interchange. Com-

missioners were appointed who came to the Springfield Armory while Gen. Ripley was superintendent. With the consent of our government he allowed them to inspect all our machinery. They were then permitted to make contracts with the Ames Company at Chicopee, Mass., and other establishments for the manufacture of similar machinery, and to take drawings and models from the armory. Similar machinery did not exist elsewhere in the world, and without this kindness of our government they would to this day have been making muskets by hand. When the machinery was made, they were allowed to hire from the armory such men as they chose, to go to England and set up the machinery and superintend its operation. Some of these men are there now. At their new arsenal at Enfield Locks they are said to be making 200,000 muskets a year. For this they are indebted to our kindness. They now repay this kindness by forbidding the export of arms, saltpeter and lead to this country, and by seizing all they can find in the hands of our merchants, although it has been bought of their people and paid for."

"The Swedish government last year sent a scientific expedition to Spitzbergen. It has been ascertained that animal and vegetable life exists in the sea at a depth of 2,500 yards, and that the great current of the Atlantic Ocean, known by the name of the Gulf Stream, reaches as far as the coast of Spitzbergen, pieces of broken wood, bottles, &c., having been found there."

"A plan has long been under consideration to open up a steam and water communication between the West and East, by connecting the waters of the Mediterranean and Red seas. At present, it is said, there are 8,000 laborers employed in digging a canal across the Isthmus of Suez, in Egypt, for this purpose. If it should be completed and put into successful operation, it would be of vast influence upon the commercial and political world."

"Within the last three years there has sprung up in this country an important and extensive branch of industry—the refining of petroleum, or, as it is sometimes called, mineral oil. This is already a staple article, and its use as an illuminator is becoming every day more extended. When properly manufactured, it is not explosive, it affords a brilliant flame, it can be furnished at a moderate price, and, moreover, its sources of supply in this country are abundant."



The fundamental capabilities of pulse transmission are under study at Bell Laboratories. At a transmission rate of 200 million bits per second, for example, PCM could simultaneously transmit 3000 telephone conversations on a single circuit.

AN INTRIGUING DEVELOPMENT IN TELEPHONE TRANSMISSION

Bell Laboratories engineers have applied a method of transmitting telephone conversations which uses a series of ON-OFF pulses rather than the continuous electrical signals generally used since the time of Alexander Graham Bell's first famous message.

The method is called Pulse Code Modulation. With PCM the telephone caller's voice is sampled every 1/8000th second. Each sample is then encoded into a series of ON or OFF pulses, and these pulse groups are sent over the regular telephone line. Spaced periodically along the line are repeaters which clean up and amplify the pulses. At the receiving end the pulse groups are decoded and the caller's voice is reconstructed.

Since the pulses are of very short duration, it is possible to interlace many different voice messages and send them all over one line. For example, in a PCM system now operating between Newark and Passaic, N. J., a single pair of wires carries as many as 24 one-way voice signals.

Other systems for carrying more than one voice signal over a single telephone line have been developed and are in widespread use. PCM, however, provides special advantages, for example, in cable circuits connecting telephone offices in a congested metropolitan area.

PCM in its present practical form for cable circuits has been made feasible by Bell Laboratories' invention and development of the transistor, the key element necessary for a small economical system.

Currently, PCM systems carrying much larger bundles of communication channels are under study at Bell Laboratories. The goal as always is the improvement of Bell System communication services.

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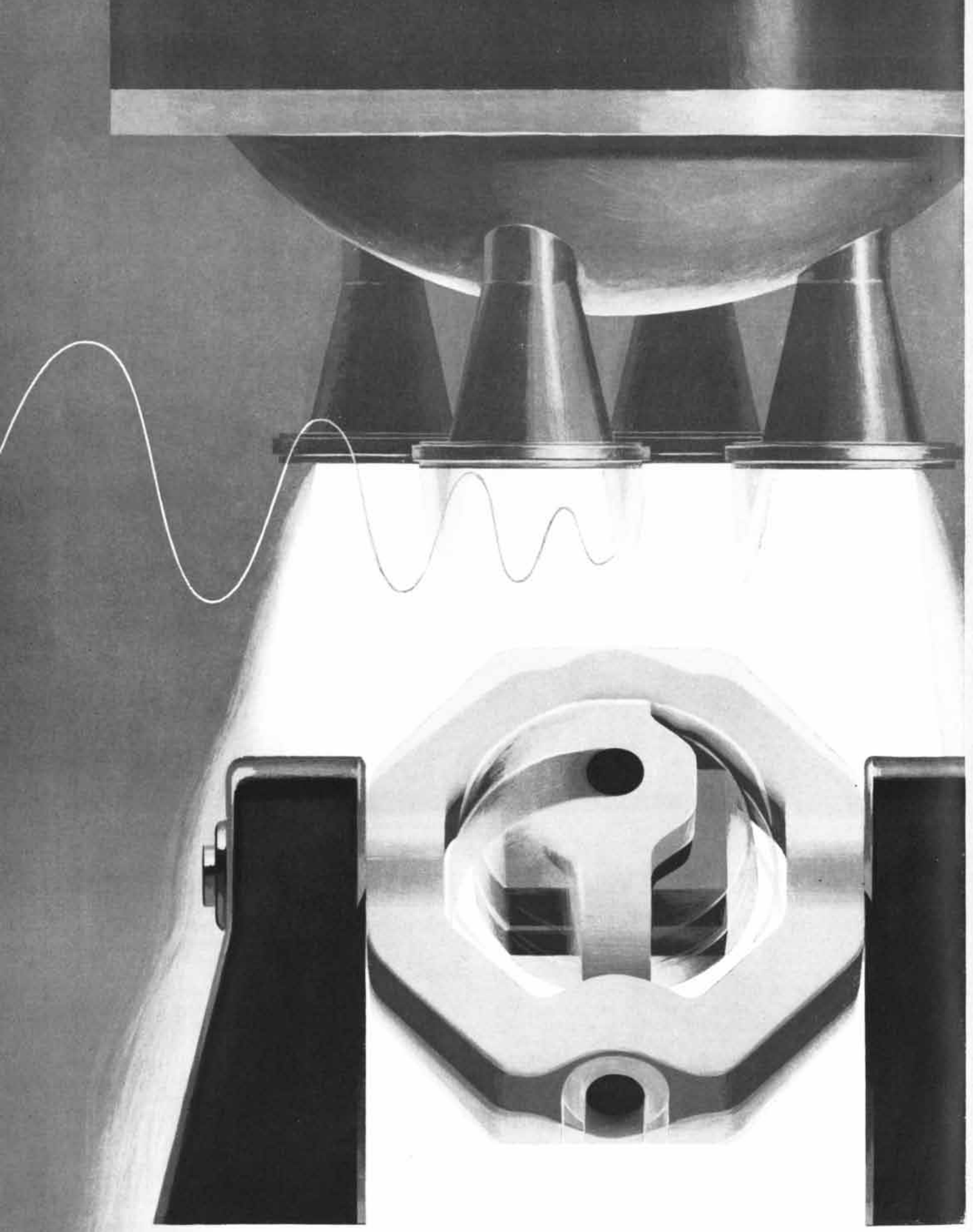

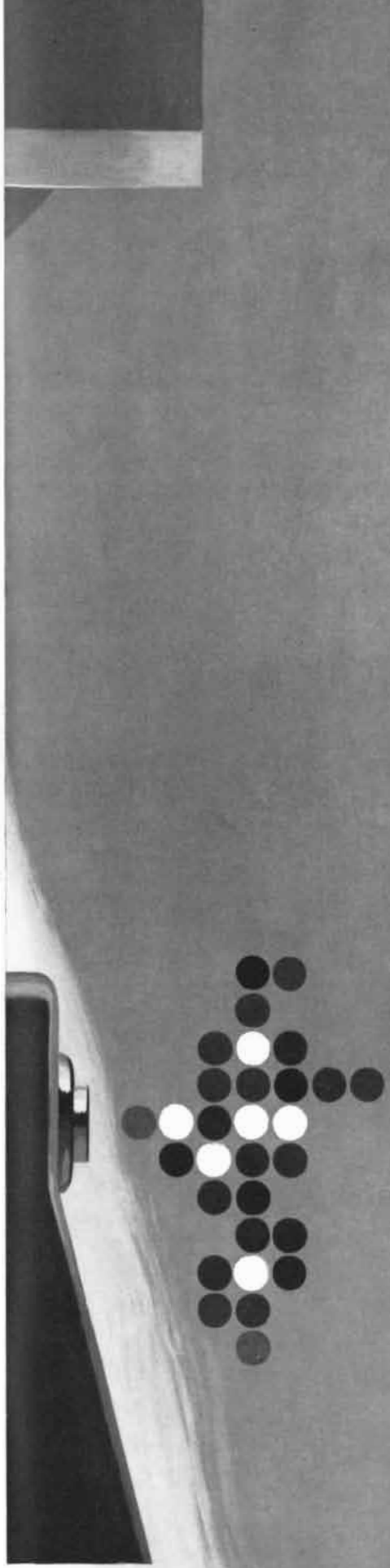

LABORATORY LAUNCH PAD

"In-house" missile flights are a daily occurrence at Lockheed Missiles & Space Company. The advantages of "flying" the POLARIS FBM inside the laboratory, on an amazing internally-developed simulator, are obvious.

The simulator performs many developmental and test functions. When the missile is first conceived, performance characteristics are cranked in; basic overall requirements are read out. Later, the simulator details the functional requirements of each subsystem and calculates specifications for hydraulic, electronic and pneumatic hardware. As each component is built, it replaces its computer counterpart.

Finally, the whole guidance and flight control package is put through simulated flights for final checkout. But that isn't all. The simulator also performs the role of post-flight evaluation detective when it is fed tapes of actual flights, and the effects are observed on earth-bound hardware.

It is with such elaborate equipment, guided by engineers and scientists of outstanding calibre, that Lockheed Missiles & Space Company has attained its place in the forefront of missile and space technology. And such progress is constantly creating key positions for other engineers and scientists of proved ability, so they may take up the exciting challenges offered by Lockheed and share in its rewards.

This unusual organization is located in Sunnyvale and Palo Alto, on the San Francisco Peninsula in California. For an informative brochure, "Your Place in Space," write to: Research and Development Staff, Department M-31C, 599 North Mathilda Avenue, Sunnyvale, California. An Equal Opportunity Employer.

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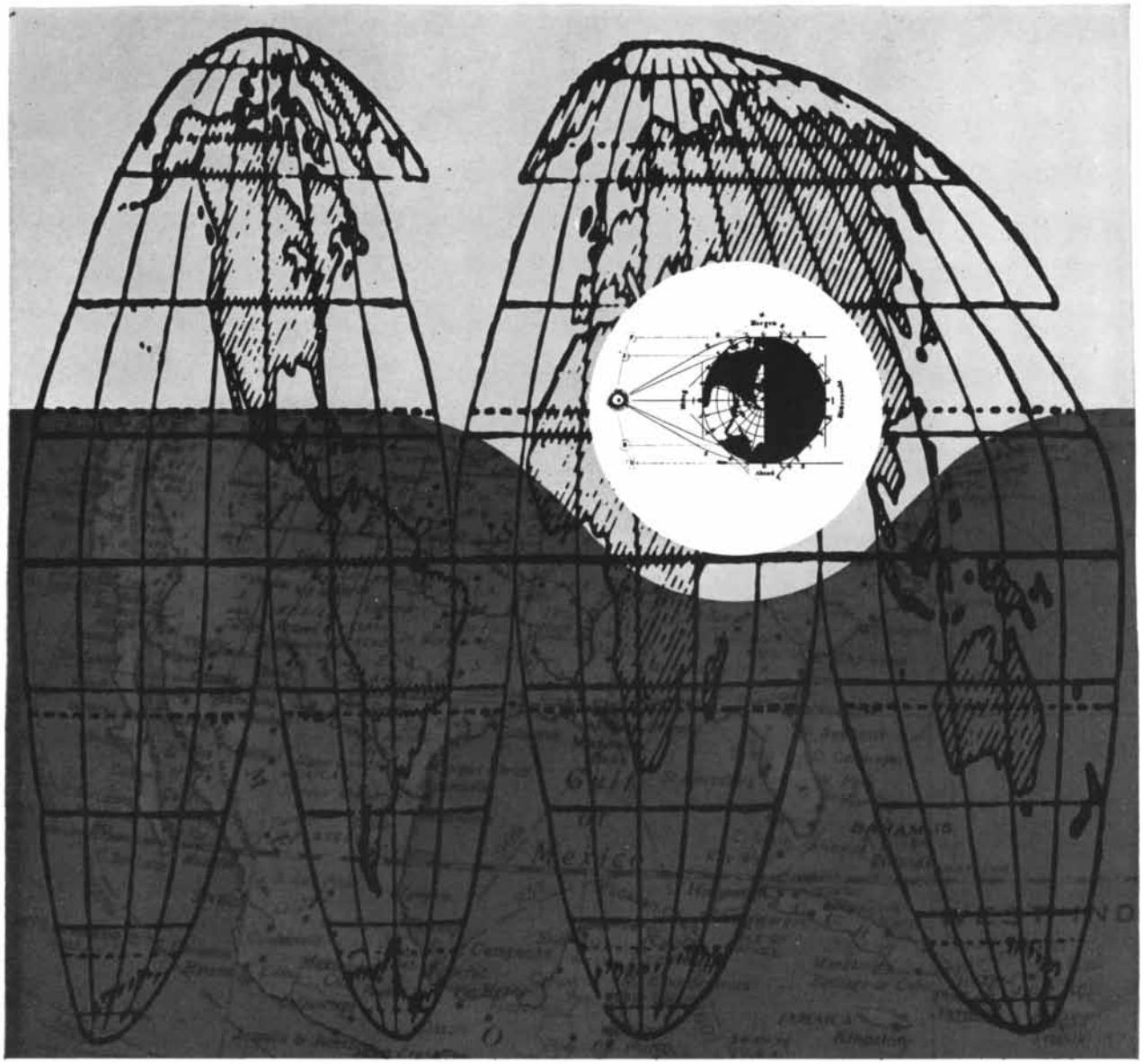

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EVERYWHERE ITT scientists and engineers talk mainly—and with great authority—about telecommunications. They talk about it in English, Spanish, German, French, Flemish, Italian, Turkish, Portuguese—indeed, in the languages and dialects of the 30 countries which are home to ITT divisions and subsidiaries. If a problem involving telecommunications/electronics arises in the Americas, in Europe or in the Far East, an ITT System man is on hand to hear, to understand—to solve! International Telephone and Telegraph Corporation, 320 Park Avenue, New York 22, N. Y.

ITT

THE AUTHORS

JERARD HURWITZ and J. J. FURTH ("Messenger RNA") are respectively associate professor and postdoctoral fellow in the department of microbiology at the New York University School of Medicine. Hurwitz took his B.A. at Indiana University in 1949, a Ph.D. in biochemistry at Western Reserve University in 1953, and for the next two years was research fellow at the National Institute for Medical Research in London. From 1956 to 1958, when he joined N.Y.U., Hurwitz taught at the Washington University School of Medicine in St. Louis. Furth acquired B.A. and M.D. degrees at Cornell and Duke universities respectively, the latter in 1958. He went to N.Y.U. after completing his internship at Bellevue Hospital in New York. This summer he will join the department of pathology at the University of Pennsylvania School of Medicine as associate professor.

R. GRANT ATHAY ("The Solar Chromosphere") is a member of the faculty in the department of astrogeophysics at the University of Colorado and a member of the Senior Research Staff at the university's High Altitude Observatory in Boulder, Colo. Born in Smithfield, Utah, in 1923, Athay was trained as a meteorologist during World War II and served for several years as a weather forecaster for the Army Air Force. Having studied physics and radio engineering at Utah State Agricultural College, where he acquired a B.S. in 1947, Athay saw in the field of astrophysics a chance to combine his different scientific interests in a single area of research. He joined the High Altitude Observatory in 1950, received a Ph.D. in astrophysics from the University of Utah in 1953 and became a member of the Senior Research Staff that same year. From 1955 to 1956 he was research associate at the Harvard College Observatory. Athay has worked at the University of Colorado since 1956.

TERENCE A. ROGERS ("The Physiological Effects of Acceleration") is assistant professor of physiology at the Stanford University School of Medicine. As a flight navigator of dive bombers in the Royal Navy during World War II, Rogers experienced firsthand some of the physiological stresses described in his article. After the war he took a degree in agriculture at the University of British Columbia and settled down with his wife on a Canadian dairy farm. Finding that he was more interested in animal physiology than in farming, Rogers moved to the Davis campus of the University of California, where he acquired a Ph.D. in 1955. He taught physiology at the University of Rochester School of Medicine from 1955 to 1959 and then joined the faculty of Stanford. In addition to teaching, Rogers is a member of a research team at the Ames Research Center of the National Aeronautics and Space Administration studying the various aspects of physiological stress under acceleration. He has also written a college text, *Elementary Human Physiology,* and was the author of the article "The Metabolism of Ruminants" in the February 1958 issue of SCIENTIFIC AMERICAN.

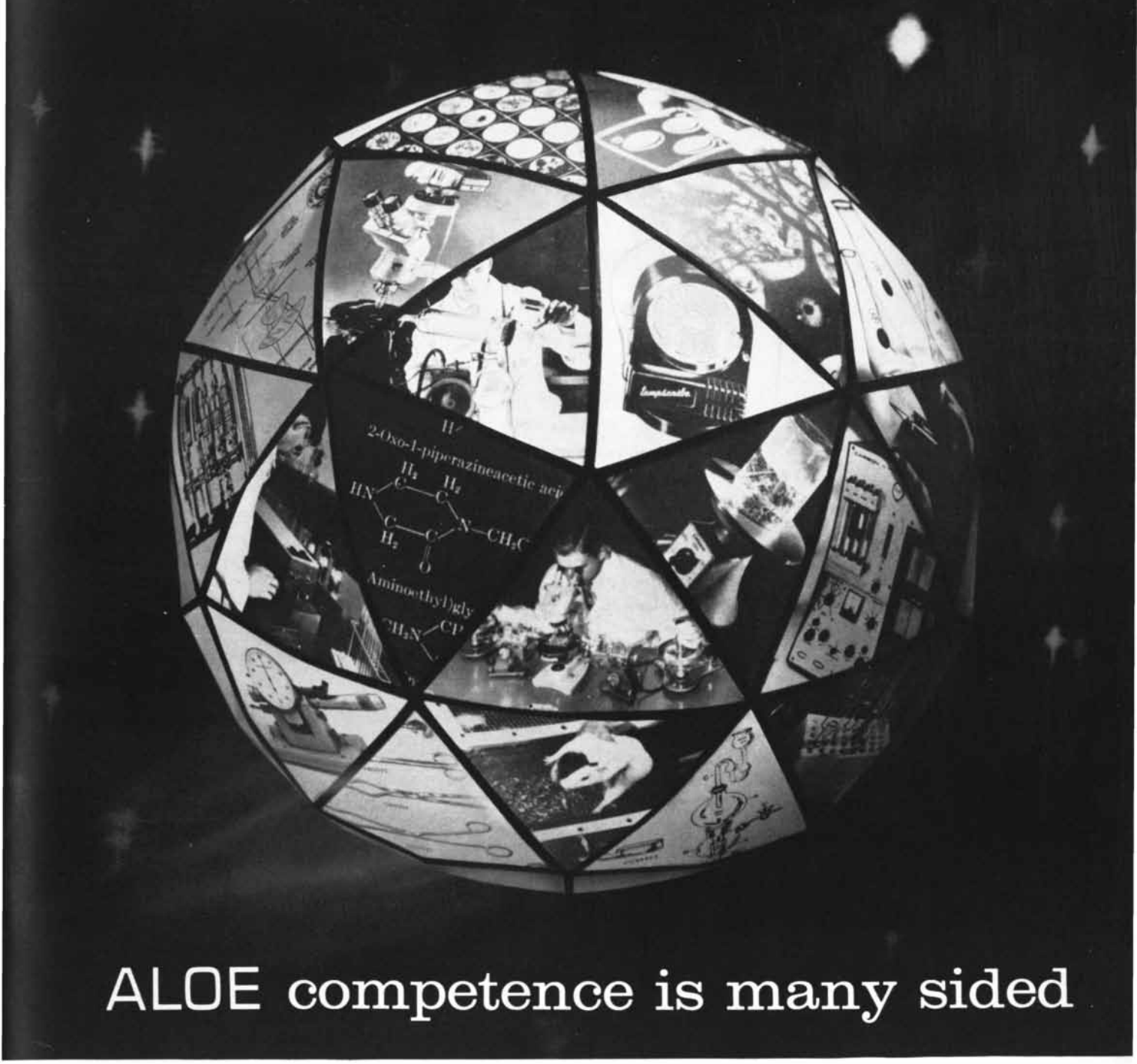
RAYMOND BLOCH ("The Etruscans") has since 1949 been director of studies in the École Pratique des Hautes Études of the Sorbonne, where he also holds the chair of Latin Epigraphy and Roman Antiquities. Bloch was graduated from the École Normale Supérieure in 1938 and taught at the École Française de Rome until the beginning of World War II. He spent the period from 1940 to 1945 as a German prisoner of war. Returning to the École Française in 1945, Bloch began in the following year to direct the archaeological excavations at Bolsena in Italy, and has continued to direct them since that time. Last year, also under the auspices of the École Française, he started excavations at Bologna.

W. WESLEY PETERSON ("Error-correcting Codes") is associate professor of electrical engineering at the University of Florida. He received an A.B. in mathematics from the University of Michigan in 1948, a master's degree in electrical engineering in 1950 and a Ph.D. in electrical engineering in 1954. Peterson began to study error-correcting codes in 1955, while working at the IBM Engineering Laboratories. He joined the faculty of the University of Florida in 1956 and in 1959 spent a year at the Massachusetts Institute of Technology, where he worked with Robert M. Fano and John McReynolds Wozencraft on error-correcting codes.

ROBERT D. ALLEN ("Amoeboid Movement") teaches cell physiology in the department of biology at Princeton University. He attended Brown University and the University of Pennsylvania, receiving a Ph.D. from the latter in 1953. While doing graduate work at Pennsylvania, Allen met John Runnström, a visiting professor of zoology from the University of Stockholm, who aroused his interest in the study of fertilization. A U.S. Public Health Service postdoctoral fellowship enabled him to continue his work with Runnström, first in Stockholm and Naples and then at Kristineberg on the west coast of Sweden. He described the results of these studies in an article called "The Moment of Fertilization," which appeared in the July 1959 issue of SCIENTIFIC AMERICAN. Since 1954 Allen has devoted an increasing amount of time to research on amoeboid movement and, more recently, other motility phenomena. This work included a seven-month visit to Japan last year to study marine amoebae, foraminifera and radiolaria.

ERNEST RABINOWICZ ("Wear") is associate professor of mechanical engineering at the Massachusetts Institute of Technology. A native of Germany, Rabinowicz moved to England at the age of 10, where he later did undergraduate and graduate work in physics at the University of Cambridge. He began studying friction and wear phenomena in the Research Laboratories of Rubbing Solids at Cambridge in 1947, using radioactive tracers that had just become available with the completion of England's first nuclear reactor. Rabinowicz went to M.I.T. in 1950 and is currently continuing his research on wear in the M.I.T. Surface Laboratory. The present article is the second that he has written for SCIENTIFIC AMERICAN. The first, which was entitled "Stick and Slip," appeared in May, 1956.

JOHN B. CALHOUN ("Population Density and Social Pathology") is research psychologist in the Laboratory of Psychology at the National Institute of Mental Health. Calhoun obtained his B.S. at the University of Virginia in 1939 and his M.S. and Ph.D. at Northwestern University in 1942 and 1943 respectively. After teaching at Emory and Ohio State universities Calhoun in 1946 joined a group at Johns Hopkins University that was studying the behavior of Norway rats. In 1949 he went to the Roscoe B. Jackson Memorial Laboratory in Bar Harbor, Me., to continue his research. From 1951 to 1955 he did research in the neuropsychiatry department of the Walter Reed Army Institute of Medical Research. He has held his present position since 1954, and he will spend this year at the Center for Advanced Study in Behavioral Sciences in Palo Alto, Calif.



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IF

- *you're weary of matching one assembler instruction per one machine language instruction*
- *you're spending half of your machine time translating compiler programs into machine language programs of questionable efficiency*
- *you're using up time and money with hunt-and-peck machine language debugging and reprogramming*
- *you're tired of seeking, teaching or even becoming a bilingual programmer—fluent in both problem and machine languages*
- *you're fed up with programming methods that are cumbersome, time-consuming and costly*

Then, you'll be interested in Burroughs B 5000, a new kind of information processing system which is the result of a total departure from traditional computer design concepts. A system in which *software* dictates equipment designs and specifications to bridge the communication gap between man and machine.

As a problem oriented system, its software capabilities accept ALGOL and COBOL statements directly because its logic matches the logic of problem-language programming. Instead of an instruction-address-instruction-address sequence, there's a continuous flow of instructions with table references when addresses are required. Addresses are independent of instructions.

The system language is designed to implement the problem language for extremely rapid translations allowing program translation each run. Object programs, as efficient as those written in machine language, can be created far faster than with the most advanced conventional computers.

The need for the programmer to know both problem and machine languages is eliminated. Now for the first time, the programmer is free to concentrate on the processing problem itself. Free of the gymnastics he used to employ to make his problem acceptable to the machine, he merely states the problem and the Burroughs B 5000 provides an efficient, rapid solution. Burroughs—TM

Burroughs Corporation, Detroit 32, Michigan

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THEY RELY ON RADIATION

for a unique low power PCM telemetry system in Nimbus

When *Nimbus*—the meteorological Satellite System being developed by the Goddard Space Flight Center of the National Aeronautics and Space Administration—begins sending its global weather reports to earthbound meteorologists, a Radiation PCM telemetry system will prepare data on the status and condition of the satellite for transmission. Other Radiation-produced systems in the *Nimbus* ground stations will process these data.

Innovations in the spaceborne system will slice power requirements to a fraction of that needed for current PCM equipment. In fact, data from 650 transducers will be digitized with only *1.0 watt* . . . compared to many times that required in present systems.

The idea is as simple as turning off the lights in an unused room: just switch off the power during the microsecond intervals between pulses. Its execution wasn't that simple, but Radiation engineers, working under the first contract ever awarded for a satellite PCM system, achieved the result—and a notable advance in the state-of-the-art.

The *Nimbus* system embodies PCM experience dating back to 1951, when Radiation contracted for the first airborne PCM system. This fast-growing company offers attractive career opportunities in a broad spectrum of scientific and engineering specialties. For details on Radiation write Dept. SA-22, Radiation Incorporated, Melbourne, Florida.

Radiation is an equal opportunity employer.

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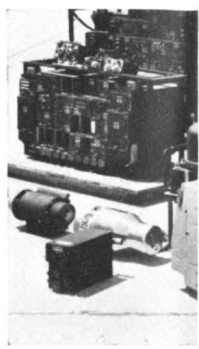
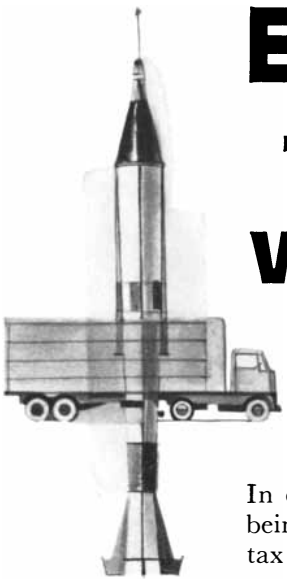




EXPECT MORE from your next weapons system

In our world, a defense system cannot be merely adequate. We cannot risk being second best. We cannot afford to demand less than full value for every tax dollar spent.

Industry's job is to grasp the full implication of the mission, to design and build the system to meet cost requirements and delivery schedules. And to *insure* that it will perform when the buttons are pressed.

The company which can do this job has a total capability. At Hughes, this capability has many parts—a record of 15 years of scientific achievement, a working force of over 28,000, facilities covering 5.3 million square feet, vigorously applied Value Engineering and Cost Improvement programs, a fund of over 100,000 *man-years* of systems experience.

These are impressive statistics even when taken piecemeal. But they are most meaningful when seen as parts of a functional unity. For Hughes can be likened to a dynamic, *creative system* which has proved its competence and spirit of purpose many times. Examples:— *The "Missile Monitor" truck-mounted mobile command and control air defense system — 16,000 airborne fire control systems — Surveyor soft lunar landing spacecraft — 33,000 Falcon air-to-air missiles.*

The broad capabilities reflected here fully equip Hughes to assume complete management responsibility for systems assembly, check-out and integration. This competence is backed by Hughes abilities in manufacturing, assembly, operator training, operational activation, field support and maintenance.

Expect more from Hughes. Hughes is ready to deliver.

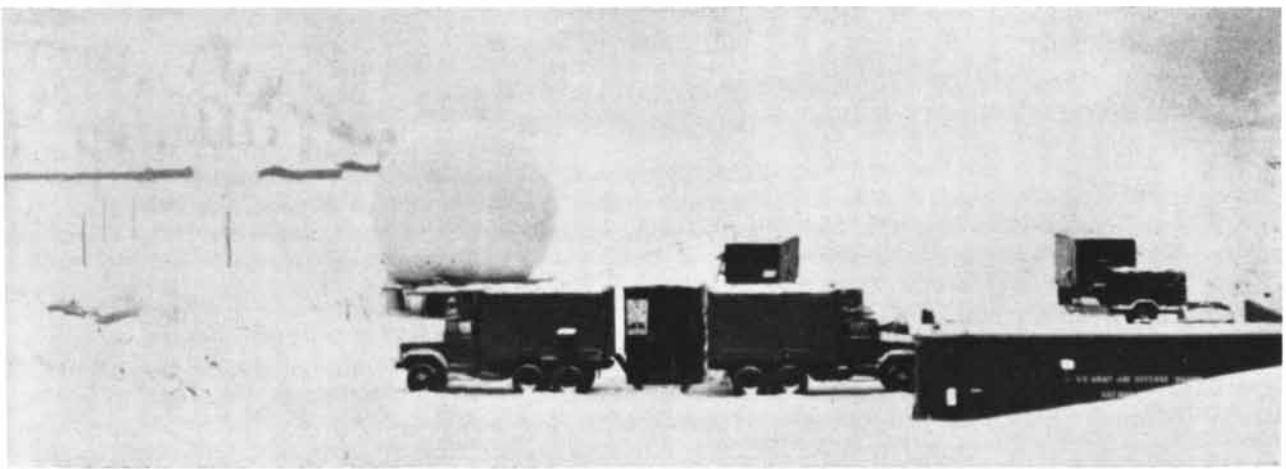
Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY

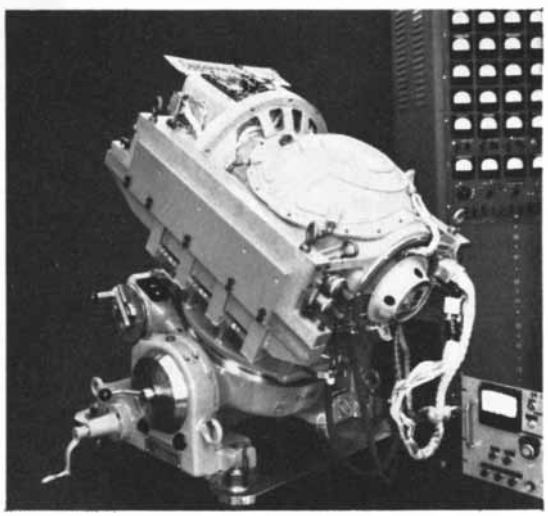
Systems integration, as well as design and development was Hughes responsibility in the MA-1/F-106 program. Nine similar Hughes systems have preceded and followed it—a total of 16,000 airborne systems having been produced. Hughes has been the sole supplier to the U.S. Air Force of all-weather interceptor fire control systems for 12 years.

Propulsion facilities—Hughes has tested over 1,500 missiles in every conceivable mode of operation. The Hughes Tucson plant has extensive facilities for solid propellant and explosives storage and final missile assembly. The company maintains special propellant and propulsion capabilities to support procurement of solid fuel engines.

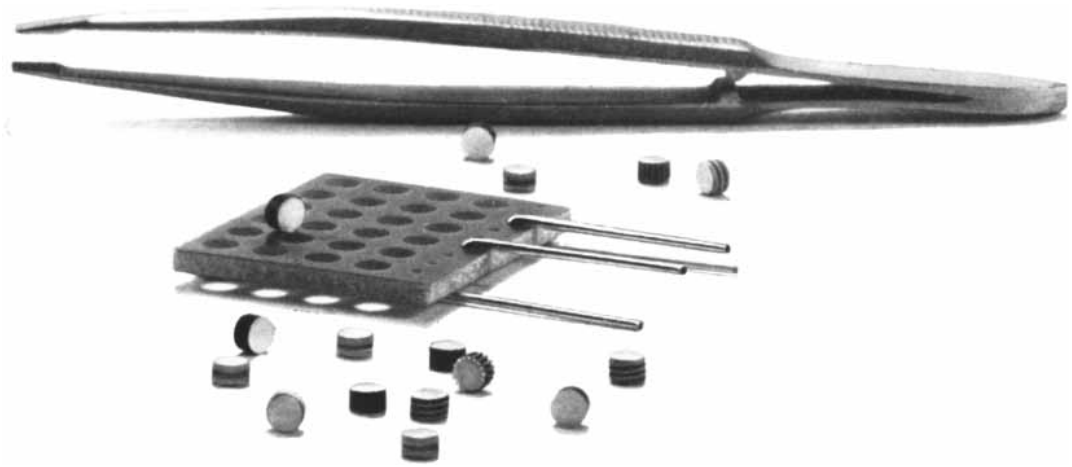


Command control experience—The "Missile Monitor" mobile electronic air defense system performs target acquisition and missile directing functions for Nike Ajax, Nike Hercules and Hawk batteries. At Hughes Fullerton, some 400 acres are devoted to special field test ranges for electronics systems and the Munsen course for full-scale testing of instrumented vehicles under the most rugged conditions. The Environmental Laboratory has one of the nation's largest low frequency and shock facilities.

Field service and support experience — Hughes large force of experts is permanently assigned in NATO, SEATO and the free countries of the world to insure that every Hughes missile and electronics system will deliver what it should. Hughes engineers work with the U. S. Air Force on the MA-1/Falcon system, with the U. S. Navy on the Polaris, with the U. S. Army on "Missile Monitor." A Hughes team is managing the Titan site activation (photo) at Mountain Home, Idaho.



Guidance experience—A Polaris missile guidance unit undergoing check-out. Other Hughes work in the area includes: Polaris Submarine Fire Control Systems, special ARPAT studies, airborne tactical attack systems, inertial platforms and components, stellar tracking systems and digital computers.



Electronic "reducing pills"

These tiny pellets are actually resistors and capacitors newly developed by Mallory to shrink drastically the size, complexity and power requirements of electronic circuits.

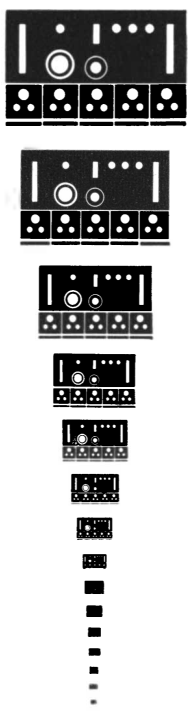
A half million of them will fit into a cubic foot of space.

These amazingly small components lead the way toward such marvels of miniaturization as vest-pocket electronic computers, complete TV circuits within the narrow frame of a picture tube, data transmission systems the size of an attache case.

You assemble these components into a complete micro-circuit by dropping them into place in a mounting plate no bigger than a match cover. For maintenance, you simply replace one entire circuit with another. This advanced Mallory concept of electronic design is called Unitized Component Assembly.

Mallory also automatically stacks tiny microcomponent wafers to form assembled circuits. They're already being used with notable success in the U.S. Army Signal Corps Micromodule Program.

We'll be glad to provide complete technical assistance in making these small wonders work to your best advantage. For engineering data, or to arrange a consultation, write P. R. Mallory & Co. Inc., Indianapolis 6, Indiana.

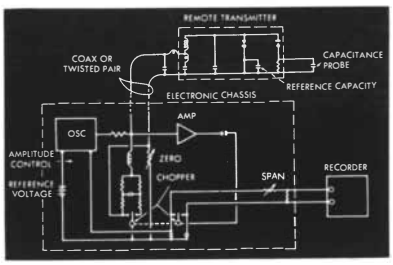


Imagination in electronics and metallurgy

P.R. MALLORY & CO. Inc.
MALLORY

Research and Engineering at Sun Oil Company

An Improved Capacitance Probe System



Circuit diagram of Sun's new capacitance probe measurement system.

Capacitance probe instrumentation is one of the most promising measurement and control techniques available to the process industries today.

In the past, this technique has enjoyed only limited use. One deterrent was the difficulty of placing capacitance probes, together with their complex instrumentation, in and around hazardous processing areas. Another was the fact that these instruments required alterations in their electrical circuitry for different applications and different transmitting cable characteristics.

In order to use the full potential of capacitance probes in difficult-to-control processing applications . . . applications involving high temperatures, corrosive fluids, explosive atmospheres, and erosive solids . . . Sun's engineers have developed a capacitance probe system that is not plagued by these restrictions.

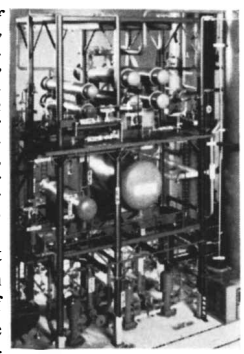
This new system consists of the following elements: a rugged, stationary probe having no moving parts that is permanently installed in the vessel or pipe line; a transmitter of passive elements in a totally-enclosed, explosion-proof housing that is mounted near the probe; and an electronic chassis that may be located in a control center up to 2000 feet away.

In operation, the probe acts as one plate of a condenser, the vessel or piping as the other, and the material under measurement as the dielectric. Changes in characteristics of the material alters the electrical capacity of this "condenser" and provides the basis for measurement.

For some years, Sun has used capacitance probes for such things as: liquid level measurement of hot sulfuric acid in pilot plant vessels; moisture determination down to parts per million in non-aqueous solutions and certain granular materials; continuous indication of aromatic content of hydrocarbon streams; interface measurement of different petroleum products passing through pipe lines; and measurement of catalyst levels in moving bed catalytic cracking units where catalyst pellets are extremely abrasive and temperatures reach 1000 F.

The U.S. Patent Office has issued a patent to Sun Oil Company on its new capacitance probe instrumentation system and the Company has concluded a license agreement with American Meter Company for the production and commercial sale of these units.

Designing High-Purity Propylene Plants



This scale model of the new high-purity propylene plant presently being built by Sun Oil shows precise locations of such equipment as super de-ethanizer, splitting towers, pumps, valves, piping, instruments and other essential components.

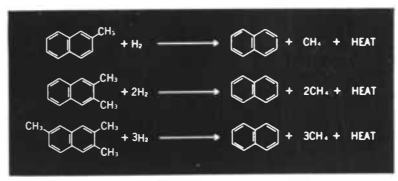
Propylene, a light hydrocarbon with a boiling point of minus 54 F, is the building block for polypropylene. It is also a raw material essential to the manufacturer of a host of other chemicals.

To makers of polypropylene who require high purity propylene Sun Oil consistently delivers 99.7 per cent propylene. This is not a simple task, since the utmost engineering sophistication is required to design a plant to meet these specifications.

Presently under construction at Sun's Marcus Hook Refinery is an additional 180 million lb/yr plant embodying features that will continue to deliver propylene of this purity. The design of this plant includes a super de-ethanizer, which precedes the "splitter" towers, to reduce the amount of hydrocarbons lighter than propylene in the feed from 2 per cent to less than 150 parts per million. Treating and drying facilities complete the purification process so that Sun is able to supply a product free of moisture, sulfur compounds, CO_2 and oxygen that is ready for use in any process.

When this new plant is completed in the second quarter of 1962, Sun Oil will have facilities to produce 300 million lb/yr of high-purity propylene and will be the largest producer in the country.

Producing Naphthalene From Furnace Oil Aromatics



Fuel Oil Aromatics + *Hydrogen* → *Naphthalene + Gas + Heat*

Several years ago it became apparent that there would be a naphthalene shortage in the United States because the principal source of naphthalene at that time was coal tar, a by-product of the steel industry. The supply of naphthalene was not keeping up with demand. Petroleum then became the best potential source for the required additional supply.

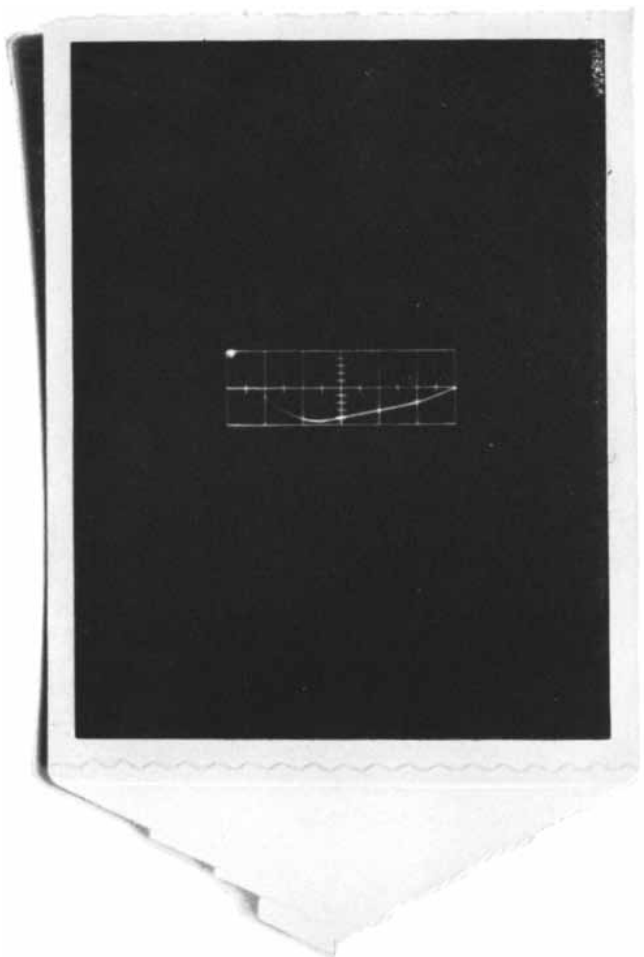
Fantastically large quantities of naphthalene formers are burned every day in furnace oil. For that reason Sun R&D engineers decided to capitalize on this source. It is essential that the aromatics so desirable for naphthalene production be separated from their source oil in better than 95 per cent purity, with a high recovery. Existing separation processes could be expected to produce aromatics at 90 per cent purity, with only fair recovery.

Faced with these rather unsatisfactory methods, Sun R&D developed a unique aromatic separation process that produces an aromatic concentrate of better than 99 per cent purity with over 85 per cent recovery of the critical naphthalene formers. And this process employs safe, readily-available chemicals to do the job. In addition to producing this highly desirable basic commodity, the process yields a higher quality furnace oil or a high cetane diesel fuel.

SUN OIL COMPANY
1608 Walnut Street **Philadelphia 3, Pa.**

SUNOCO

PROMOTING PROGRESS THROUGH RESEARCH



2 nanoseconds/cm: impossible to photograph until now

Polaroid has a new film that is so fast, it will reproduce scope traces that are almost invisible to the naked eye. The one above, a scintillation pulse, has never been photographed until now. Pulse duration was ten nanoseconds. Scope sweep speed was 2 nanoseconds/cm. *The new 10,000-speed Polaroid PolaScope Land film produced a finished usable print ten seconds after exposure.*

The maximum writing speed of the 10,000-speed film is about twice that of the Polaroid Land 3000-speed film, which is currently the standard for high speed photography. The new film not only gets "impossible" pictures, it also produces far better shots of slower pulses and steady state waveforms. Because of its high speed, less light is required; camera aperture and scope intensity can be reduced considerably, producing sharper pictures.

And besides oscillography, the PolaScope film opens up new possibilities in applications where light is at a premium, such as photomicrography and metallography. It is not suited, however, for pictorial work due to its high contrast and relatively coarse grain.

PolaScope film (designated Type 410) is packed twelve rolls to a carton. The price is actually lower than the 3000-speed film.

The film can be obtained through industrial photographic dealers. For the name of the dealer nearest you, write to Technical Sales Department, Polaroid Corporation, Cambridge 39, Massachusetts.

New Polaroid Land 10,000-speed film for oscillography.

Established 1845 SCIENTIFIC AMERICAN February 1962 Volume 206 Number 2

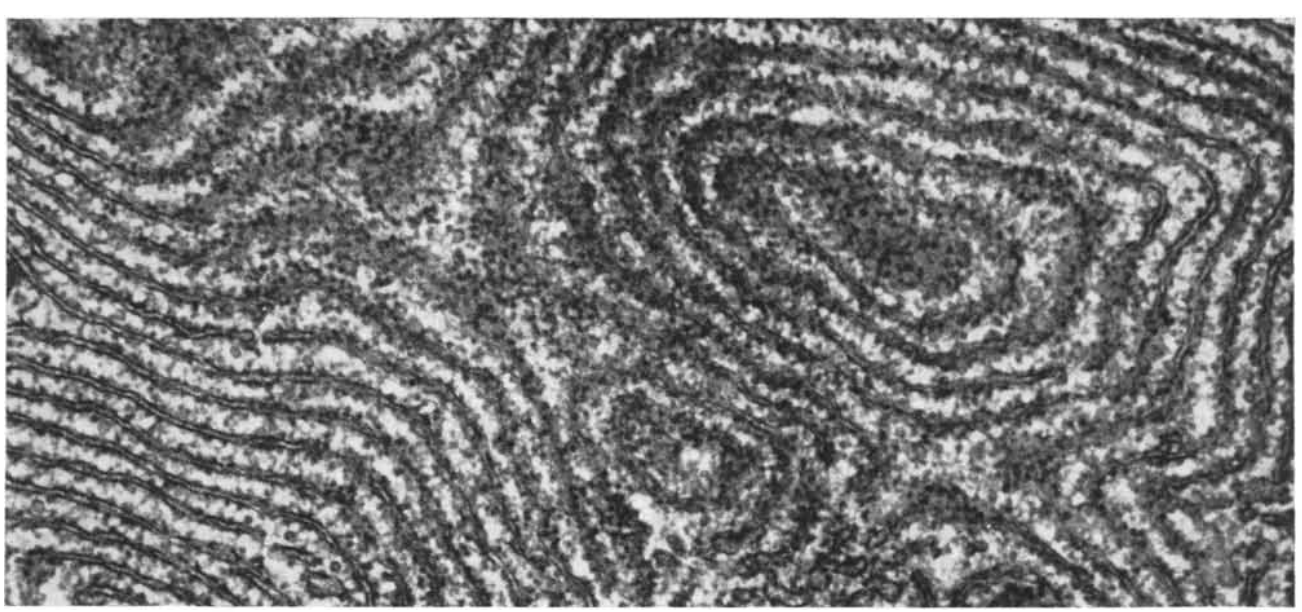
Messenger RNA

New experiments have found a kind of ribonucleic acid (RNA) that acts as a messenger to carry instructions from the genes to the particles in the cell where proteins are manufactured

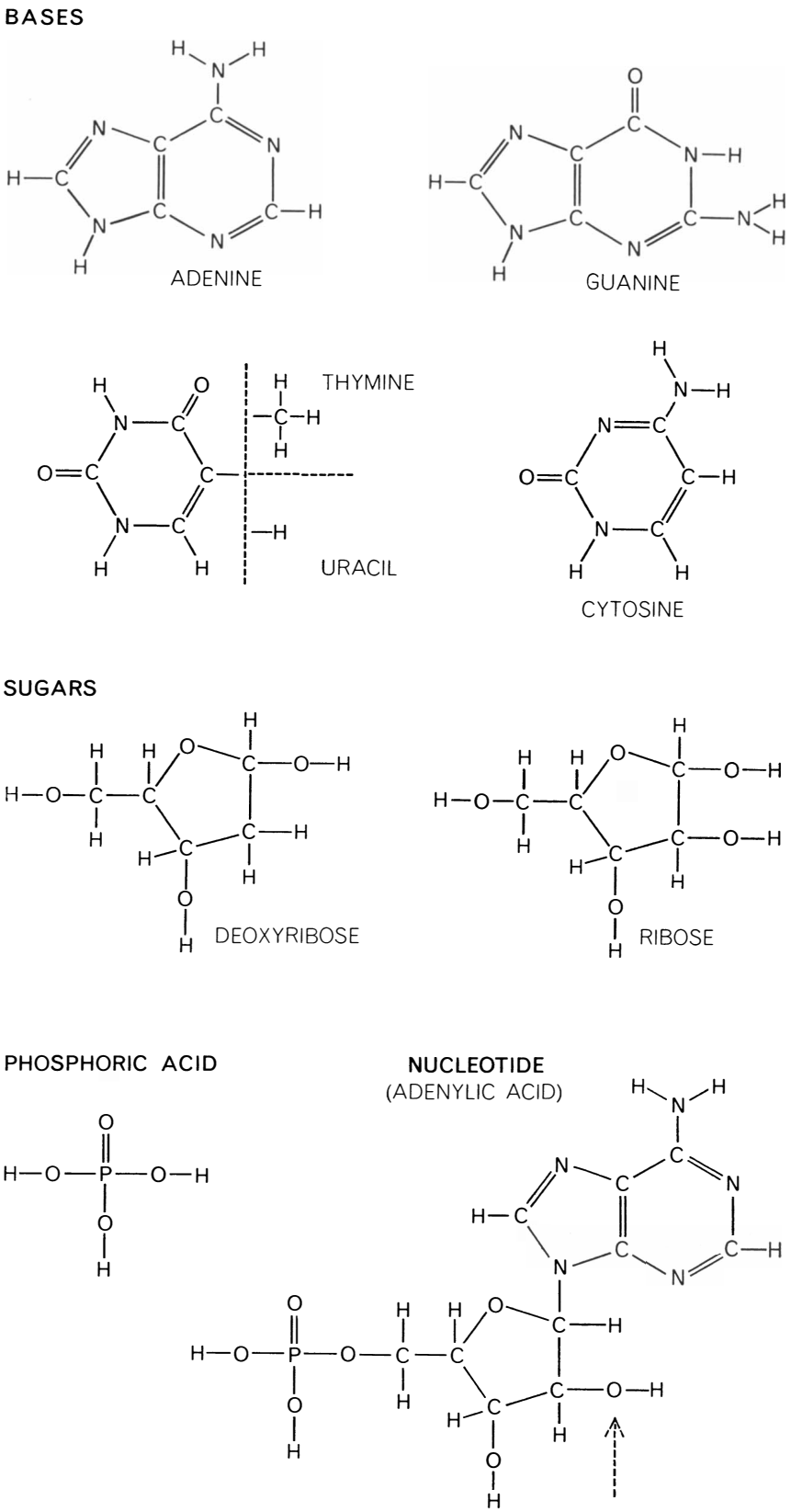
by Jerard Hurwitz and J. J. Furth

The gene theory of heredity implied from the outset that information coded in some fashion provides the specifications for each living organism. This information passes from the various genes and is embodied in the structure of some 1,000 to 2,000 of the protein catalysts called enzymes, which engineer all the rich chemical activity of living cells. Conceivably the genes could serve directly as templates for the synthesis of enzymes and other proteins, but this turns out not to be the case. The genes reside in the nucleus of the cell; the proteins, on the other hand, are produced chiefly outside the nucleus, in a multiplicity of small structures called ribosomes, which may be regarded as protein factories. This article will describe the recent work in a number of laboratories that has tentatively identified the "messengers" that carry instructions from the genes to the ribosomes, telling how each of the proteins is to be assembled.

As in so much of current biochemistry, the organisms that have proved most useful in unraveling the intricate relationship between genes and proteins are the common colon bacillus and the



SITES OF PROTEIN SYNTHESIS are the ribosomes, which appear as small, dark particles in this electron micrograph made by Bernard Tandler of the Sloan-Kettering Institute. It shows the cytoplasmic membrane of a human submaxillary gland cell enlarged 60,000 diameters. Evidently ribosomes can be "hired" by messenger RNA to make any protein for which RNA is coded.



MOLECULAR CONSTITUENTS of RNA and DNA (deoxyribonucleic acid) are five bases, two sugars and phosphoric acid. The union of a base, a sugar and phosphoric acid yields a nucleotide (*lower right*). RNA is a giant molecule built up of nucleotides containing ribose sugar and any one of four bases: adenine, uracil, guanine or cytosine. DNA consists of nucleotides containing deoxyribose and the same four bases except that thymine replaces uracil. Adenylic acid at lower right is an RNA nucleotide; if a particular oxygen atom is removed (*arrow*), it becomes deoxyadenylic acid and a building block for DNA.

viruses, notably those designated T2 and T4, that so readily multiply inside it. Within a few minutes after the genes of a virus have entered a bacillus they take over its entire metabolic machinery. The cell stops making its normal complement of enzymes and produces instead just those enzymes needed to make 100 or so copies of the attacking virus, each complete with a protein jacket. In a matter of minutes the new virus particles burst out of the cell.

Although the genes of the T2 or T4 virus contain much less information than do the genes of bacteria or men, they have the same chemical structure. This structure is a long-chain giant molecule of deoxyribonucleic acid, or DNA, in which the subunits—the genes—are strung together in a one-dimensional array [see "The Fine Structure of the Gene," by Seymour Benzer; SCIENTIFIC AMERICAN, January]. DNA normally occurs as a double-stranded molecule resembling a ladder that has been twisted into a helix. The sides of the ladder consist of alternating units of the sugar deoxyribose and a simple phosphate compound. The rungs of the ladder are attached to the sugar units. Each rung consists of a pair of complex organic bases, either adenine linked to thymine or guanine linked to cytosine [*see illustrations at left and on opposite page*]. This is the now familiar model proposed in 1953 by James D. Watson and F. H. C. Crick.

The Watson-Crick model was based in part on the careful chemical analysis of different DNA samples carried out by Erwin Chargaff and his associates at the Columbia University College of Physicians and Surgeons. They found that in all samples of double-stranded DNA the concentration of adenine always matches that of thymine and the concentration of guanine always matches that of cytosine. In DNA from different organisms, however, the ratio of adenine-plus-thymine to guanine-plus-cytosine can vary over a wide range. In some way the sequence of bases in DNA embodies the code for protein synthesis. The actual base sequence has not been established for any naturally occurring DNA.

The ribosomes, where most protein synthesis takes place, are discrete particles composed of protein and a close chemical relative of DNA: ribonucleic acid, or RNA. The molecule of RNA is generally a single-stranded structure that contains in its backbone the sugar ribose in place of the deoxyribose sugar found in DNA. The bases linked to the ribose units can be any of four different com-

pounds, of which three are identical with those in DNA. The fourth, which replaces the thymine found in DNA, is uracil, a close relative of thymine.

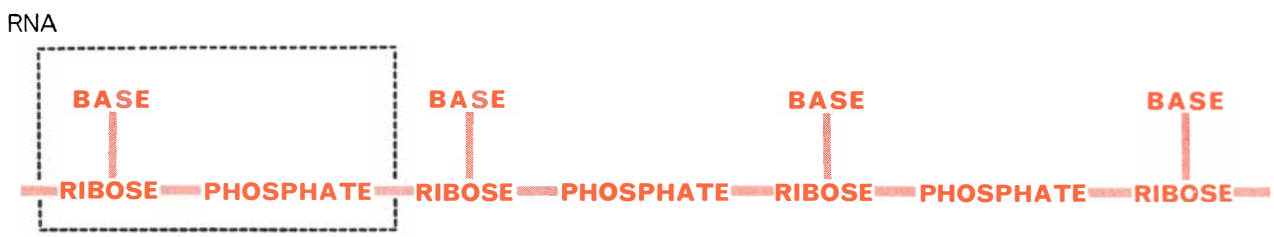
The proteins turned out by the ribosomes are giant molecules whose subunits are the 20 or so different amino acids. The sequence of events whereby these subunits are converted into proteins is known in part. An amino acid is first activated by being coupled with an energy-rich molecule characterized by three phosphate groups: adenosine triphosphate (ATP). The coupling is catalyzed by a specific enzyme, and this is accompanied by the release of two of the phosphate groups. The "activated" amino acid is then joined to a special form of RNA referred to either as soluble RNA or transfer RNA. Each amino acid is "recognized" by a different transfer RNA. The transfer RNA's carry the amino acids to the ribosome, where they are joined in proper order to form a protein. The transfer RNA's are released intact to pick up more amino acid molecules [*see illustrations on next page*].

The discovery of how the message from the genetic DNA is conveyed to the ribosomes with specific instructions as to what protein to make—and how much to make—is the work of many investigators who were examining two problems that at first appeared unrelated. One group of workers was trying to identify the enzymatic machinery used by the cell to synthesize RNA from adenine, uracil, guanine, cytosine and other building blocks. The second group was trying to learn how the DNA of a virus such as T2 pre-empts the metabolism of the host cell and converts it to the manufacture of virus.

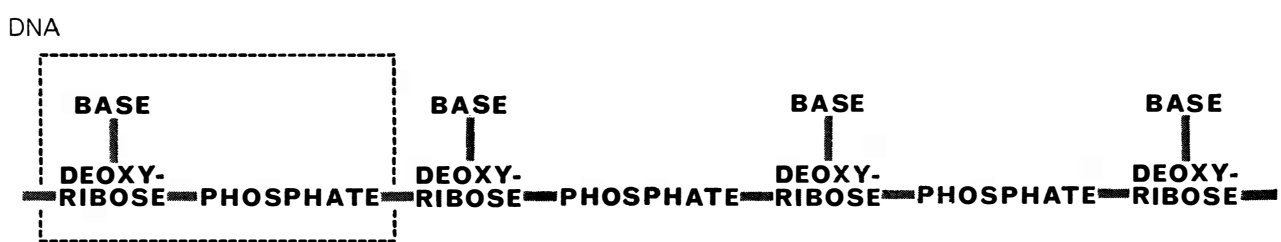
Our own work at the New York University School of Medicine began several years ago with the first of these problems, the synthesis of RNA from precursor molecules. The immediate building blocks of RNA are the ribonucleotides of the four bases. A ribonucleotide is a base linked to a ribose sugar, which is linked in turn to at least one phosphate group [*see illustration on opposite page*].

Within the cell the ribonucleotides can be linked to a second and even a third phosphate group. The bonds holding the second and third phosphate groups contain much more energy than the bond holding the first. This simply means that it is easier for the cell to synthesize RNA from nucleotides containing two or three phosphate groups than from those containing one phosphate group.

In 1955 Marianne Grunberg-Manago and Severo Ochoa of the N.Y.U. School of Medicine, using nucleotides of the diphosphate type, discovered the first enzyme capable of synthesizing RNA in a test tube. They called the enzyme, which they had obtained from a certain bacterium, polynucleotide phosphory-

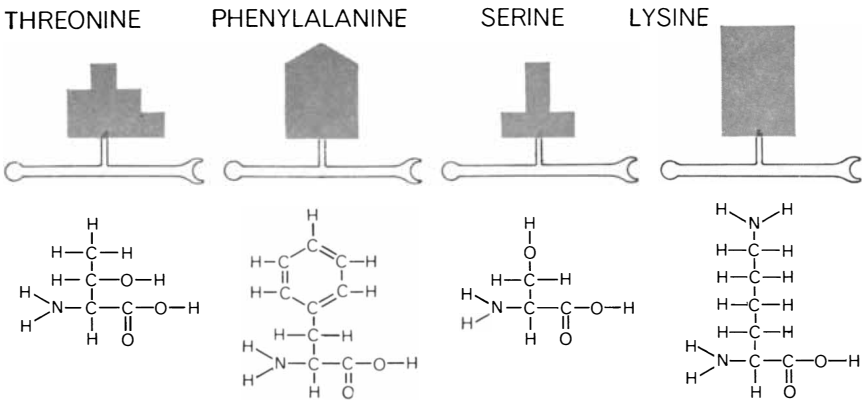


RNA MOLECULAR CHAIN directs the synthesis of enzymes and other proteins in the living cell. Its central structure consists of repeating units of ribose sugar and phosphate. Attached to each sugar is one of the four bases adenine, uracil, guanine or cytosine.

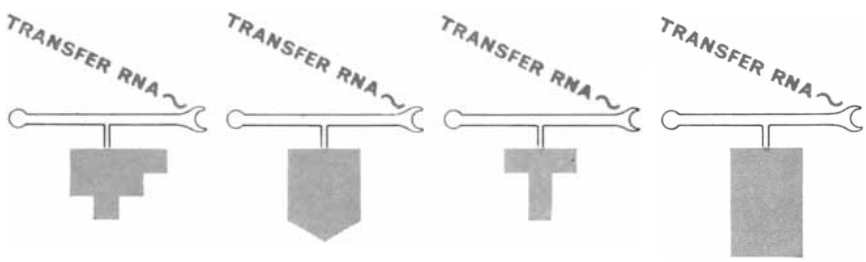


DNA MOLECULAR CHAIN comprises the genes of the cell and many viruses. The genetic code of each organism is determined by a specific sequence of hundreds of thousands of bases. Bases are the same as those in RNA except that thymine replaces uracil.

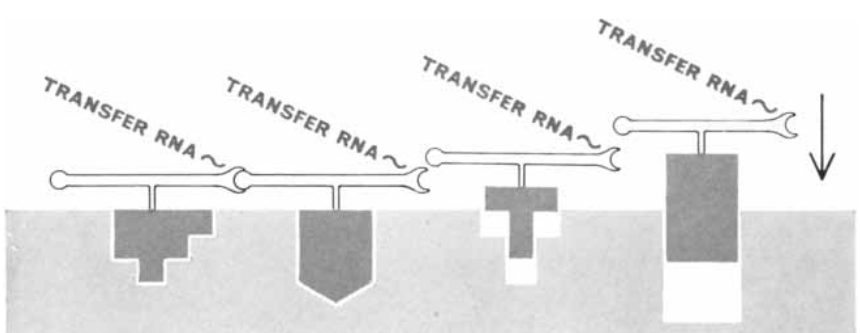
DNA HELIX is the normal configuration of the DNA molecule. Adenine (*A*) always pairs with thymine (*T*), and guanine (*G*) always pairs with cytosine (*C*). Thus when the molecule undergoes replication each strand of the helix forms a complementary strand. For clarity only one base pair is shown for each half-turn of the helix. The actual molecule contains five base pairs per half-turn.

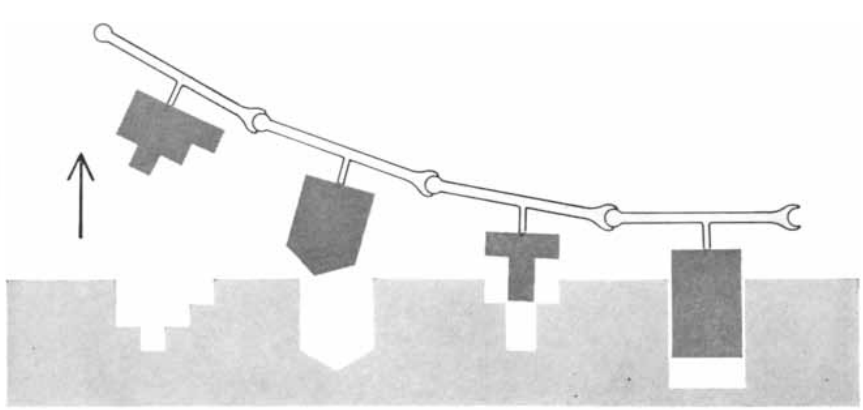


AMINO ACIDS are the building blocks of all protein molecules. Of 20-odd amino acids found in plant and animal proteins, four are symbolized here along with their chemical formulas. A typical cell can manufacture from 1,000 to 2,000 different kinds of protein.



TRANSFER RNA is the name given to a soluble form of RNA that comes in some 20 varieties, one for each of the amino acids. The role of transfer RNA is to "recognize" and transport specific amino acids to the ribosomes of the cell, where they are linked up into protein molecules. Each amino is activated and joined to transfer RNA by a different enzyme.





PROTEIN SYNTHESIS takes place on the surface of ribosomes, the tiny structures composed of protein and RNA. Amino acids, each carried by its own type of transfer RNA, find their proper sequence on the ribosome (*top*). The amino acids link up to form a protein chain, which then separates (*bottom*) from the ribosome (*see also illustration on page 49*).

lase. When this reaction was examined closely, however, it seemed doubtful that it was the reaction used by the living cell.

We suspected that the cell manufactured RNA from the more energetic nucleotides of the triphosphate type rather than from the diphosphates. In a search for enzymes that would catalyze this synthesis we examined extracts from a wide variety of bacteria and from cells of higher organisms.

There is a simple method for conducting such a search. The nucleotides are soluble in acid, but when they are assembled into RNA, they become acid-insoluble. We labeled nucleotides with the radioactive isotopes of phosphorus or carbon (phosphorus 32 or carbon 14) and added them to various cell-free extracts. If the extract formed an acid-insoluble precipitate, and if the precipitate was radioactive, this was evidence that an enzyme or enzymes in the extract had catalyzed the synthesis of RNA. We found by this method that crude extracts from a variety of sources produced low yields of RNA.

It occurred to us that the yields might be improved if RNA were added to the reaction to serve as a primer. This approach was suggested by the method previously found successful in synthesizing DNA with cell-free extracts. Arthur Kornberg and his associates at Washington University in St. Louis had shown that a primer of DNA was needed, in addition to an enzyme, to obtain good yields of synthetic DNA from triphosphates of its nucleotides. And just as the DNA primer was found to determine the sequence of bases in the synthetic DNA, it seemed reasonable that an RNA primer might determine the base sequence in synthetic RNA.

We therefore prepared RNA by a variety of procedures and, after many failures, isolated from colon bacilli a crude RNA preparation, together with a cell-free extract, that markedly stimulated the conversion of all four triphosphate nucleotides into synthetic RNA. We then set about the purification of both the RNA primer and the cell-free extract, which presumably contained the catalytic enzymes.

Purification revealed, first of all, that a single enzyme, which we have named RNA polymerase, was responsible for incorporating all four of the nucleotides into the RNA molecule. Second, the crude RNA was effective because it was contaminated with DNA. It was actually DNA that was stimulating the synthesis of RNA. In retrospect this seems entirely reasonable: it had generally been as-

sumed that RNA—if it is to carry information originally encoded in DNA—must somehow use DNA as a template.

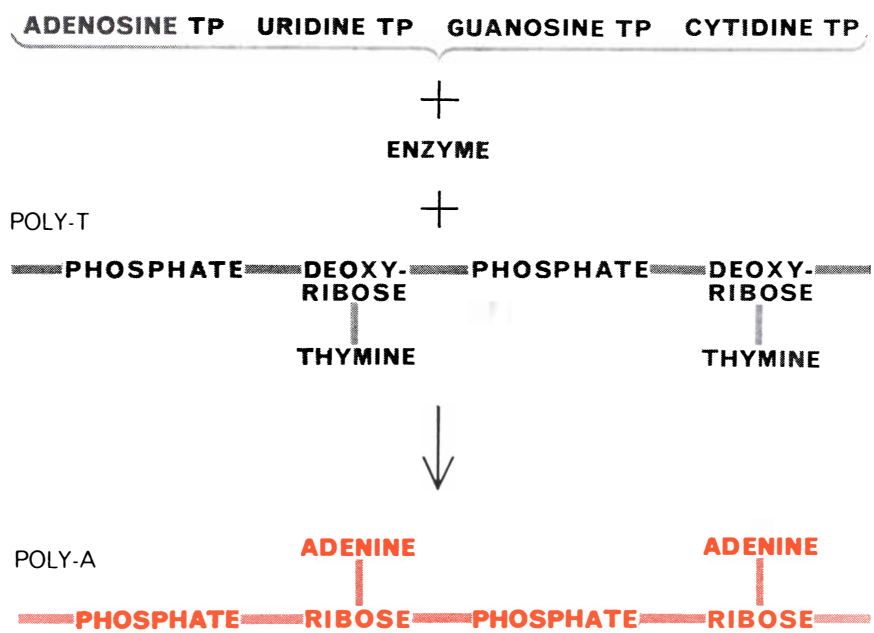
We next examined the relationship between the DNA used as a primer and the RNA created. As mentioned above, the amount of adenine in DNA is always matched by an equivalent amount of thymine, and similarly guanine is matched by cytosine. Moreover, for each type of organism the ratio of the paired bases, adenine-plus-thymine divided by guanine-plus-cytosine, has a specific value. For example, the ratio in the colon bacillus is 1, in *Micrococcus lysodockticus* it is .4 and in DNA extracted from the thymus gland of calves it is 1.3. It soon became apparent that the four bases appear in the synthetic RNA in the same proportions as they occur in the DNA used as primer, with uracil substituting for thymine. In other words, when the primer is DNA from colon bacillus, the ratio of adenine-plus-uracil to guanine-plus-cytosine in the RNA is 1. When DNA from calf thymus is used, the ratio is 1.3.

We obtained further evidence for the specificity of the reaction by using as primers two synthetic DNA polymers, one containing only thymine (referred to informally as poly-T) and one containing alternate units of adenine and thymine (called AT copolymer). With poly-T as the DNA primer, the resulting RNA contained only thymine's regular partner, adenine. With AT copolymer as the primer, the RNA consisted of a copolymer of uracil and adenine in perfectly alternating sequence. This specific incorporation of bases took place even though all four bases were present during the reaction.

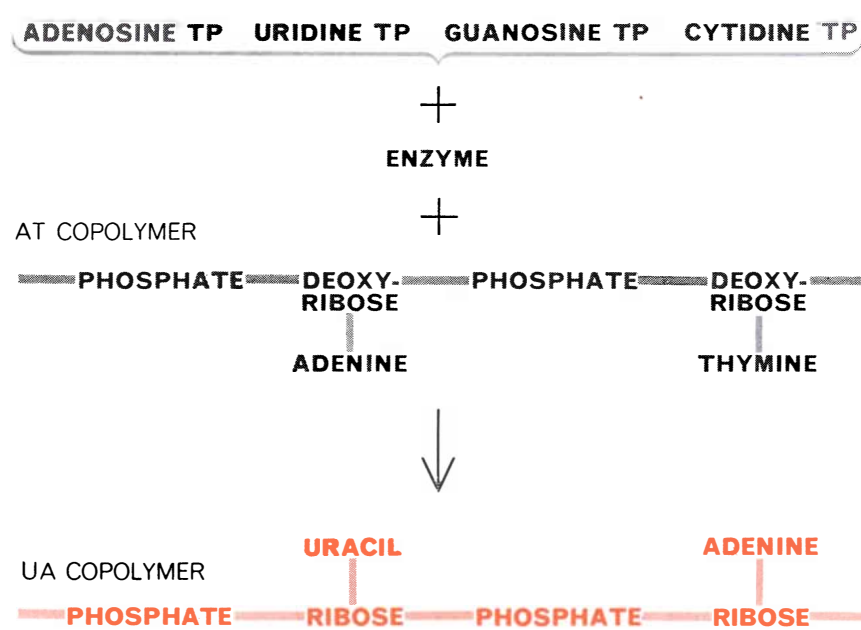
While we were making these studies similar observations were being made at the University of Chicago by Samuel B. Weiss and at St. Louis University by Audrey Stevens. Their experiments led to the same conclusion: The cell contains a mechanism for the DNA-directed synthesis of RNA, and in addition the sequence of bases in the primer DNA determines the sequence of bases in RNA.

One can conjecture that the double helix of the DNA molecule partially unwinds in the course of the reaction so that ribonucleotides (in triphosphate form and with the aid of the enzyme RNA polymerase) can pair off against the nucleotides in one strand of the DNA [*see illustration on next two pages*]. After the complementary pairing has taken place two of the phosphate groups depart, allowing the ribonucleotides to link up into an RNA polymer. The RNA then pulls away from the DNA matrix, and the DNA reverts to its previous double-stranded form.

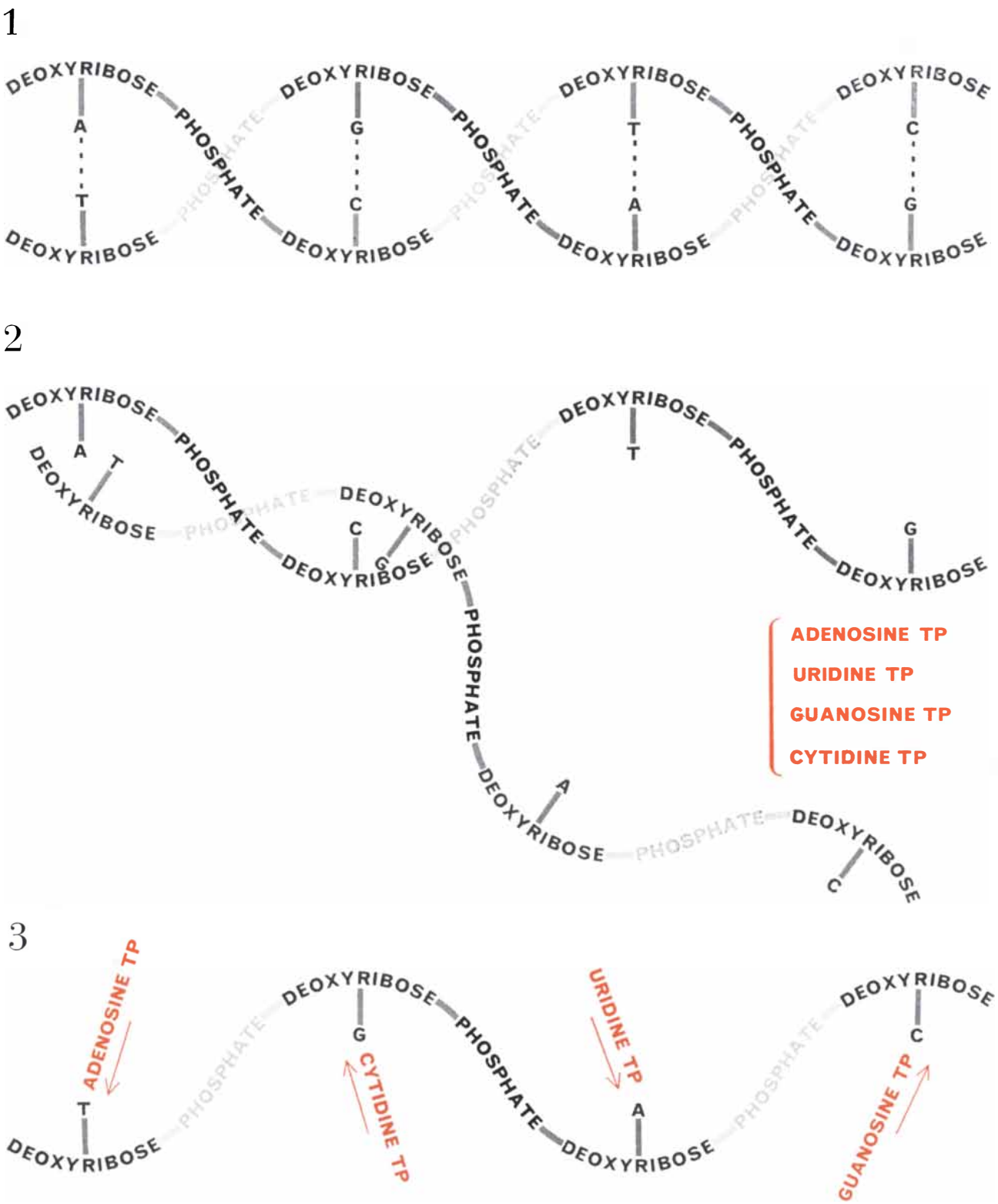
But what is the biological role of this RNA? The answer has come from the workers who were studying how the T2 and T4 viruses commandeer the metabolism of the colon bacilli they infect. It has been known for a decade that only the DNA of the virus enters the bacterium; the protein jacket that surrounds the DNA in the complete virus particle remains outside the cell. In some fashion the virus DNA must "instruct" the cell



DIRECTED SYNTHESIS OF RNA is achieved by exposing RNA nucleotides in their triphosphate form (*designated "Adenosine TP" and so on*) to the action of a special enzyme—RNA polymerase—in the presence of a synthetic form of DNA in which the only base present is thymine (*"Poly-T"*). The resulting RNA polymer contains only adenine (*hence called "Poly-A"*). Adenine is specifically incorporated, although all four bases are present.



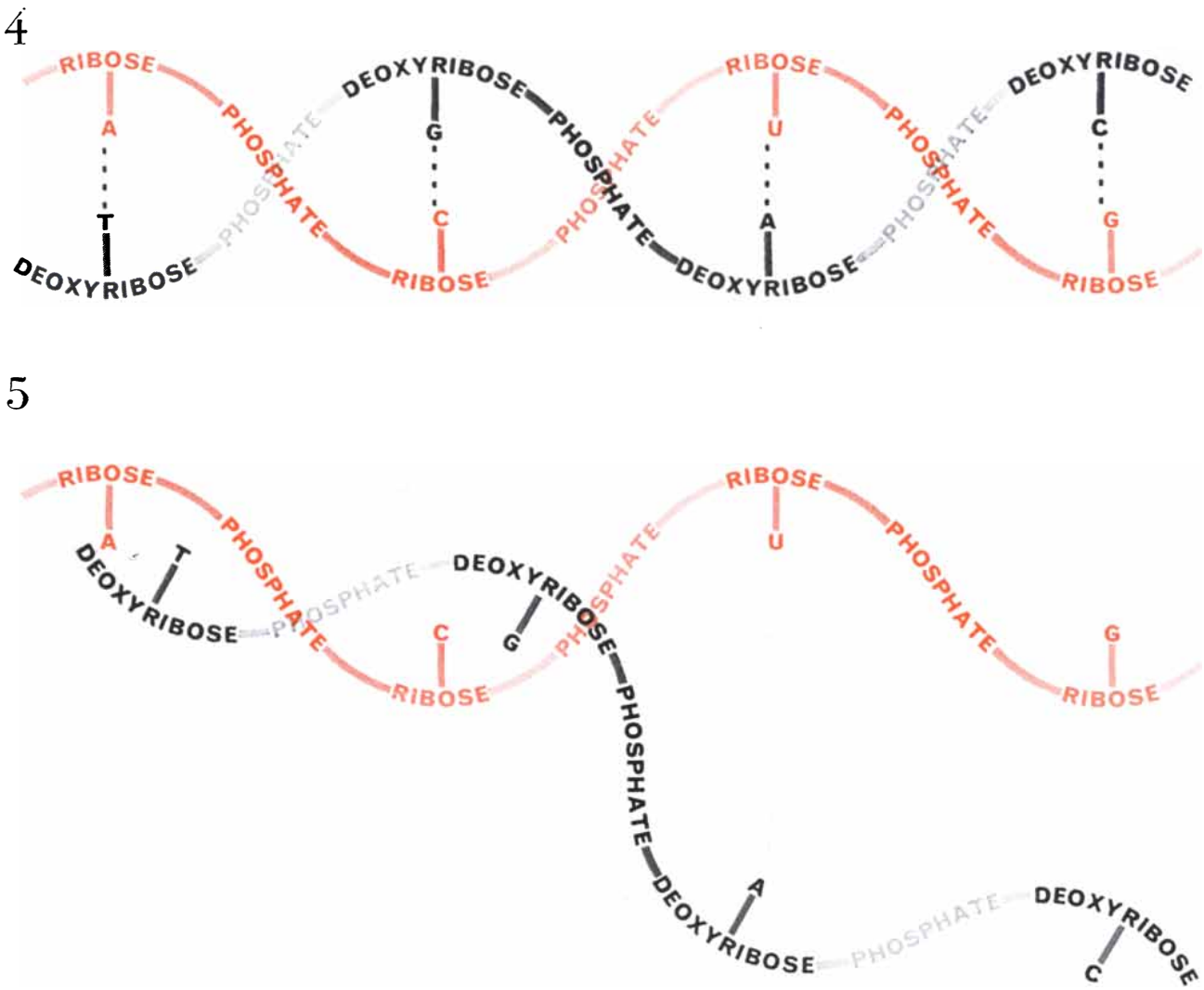
ANOTHER DIRECTED SYNTHESIS takes place when the nucleotides are mixed with RNA polymerase and DNA containing adenine and thymine in alternating sequence (*"AT copolymer"*). The resulting RNA contains alternate units of uracil and adenine (*"UA copolymer"*).



how to make a variety of special virus components not found in normal cells. The most intensively studied of these substances is the base hydroxymethylcytosine. This base, not normally present in the colon bacillus, replaces cytosine in virus DNA.

The appearance of a new substance such as hydroxymethylcytosine in a bacterial cell suggests that one or more special enzymes has to be created to produce it and to utilize it. Enzyme synthesis, in turn, implies a mechanism involving RNA and almost certainly the ribosomes of the cell. Since the virus injects only DNA into the cell, the virus DNA must be responsible for creating the RNA needed for enzyme synthesis.

When this hypothesis was examined, however, the results were puzzling. It was found that immediately after virus infection there was a net synthesis of DNA and protein inside the cell but no net synthesis of RNA. The puzzle was finally explained by Elliot Volkin and Lazarus Astrachan, working at the Oak Ridge National Laboratory, who showed that immediately after a cell is infected by the T2 virus an RNA appears that is rapidly synthesized and just as rapidly



SYNTHESIS OF MESSENGER RNA is evidently directed by specific regions of the DNA molecule that constitute the genes (*1, opposite page*). Presumably the process requires the DNA helix to unwind, at least partially and briefly (*2*). The nucleotides that will form the RNA molecule are present as their triphosphates. Also present, but not shown, is the enzyme needed for RNA polymerization. In step *3* the nucleotides pair up with the bases in the DNA chain: adenosine TP with thymine (*T*), cytidine TP with guanine (*G*), uridine TP with adenine (*A*) and guanosine TP with cytosine (*C*). In step *4* the nucleotides, in ordinary monophosphate form, link up to create messenger RNA. In the last step the RNA chain pulls away from the DNA template, leaving the DNA free to rewind.

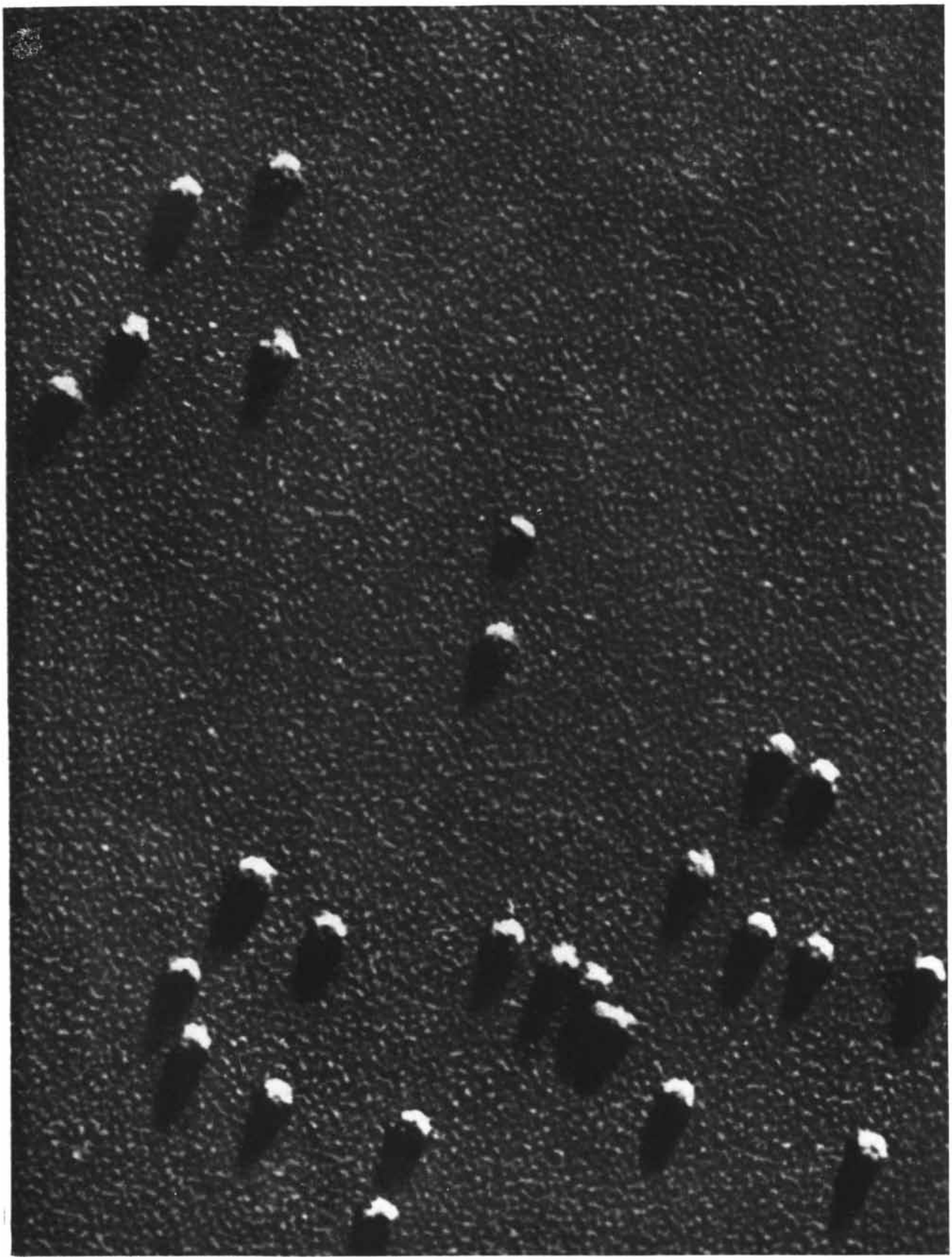
destroyed. They found, moreover, that this RNA was virus-specific, having a base ratio reflecting that of the T2 DNA. Recently other workers have confirmed the existence of a similar type of short-lived RNA in normal bacterial cells. That is, bacterial cells contain a species of RNA having a base composition resembling that of the DNA constituting the bacterial genes.

An RNA of just this sort had been predicted by Jacques Monod and François Jacob of the Pasteur Institute in Paris. They called it messenger RNA. They proposed that its role was to transmit information contained in the DNA code to the ribosomes—the protein factories of the cell. According to this view the DNA of a virus reorganizes the protein-synthesizing machinery of a cell by producing a variety of messenger RNA's that pre-empt the services of the cell's own ribosomes. This general picture has now been confirmed by studies of colon bacillus infected with T4 virus and by studies of protein synthesis in cell-free extracts.

The studies with the T4 virus were made less than a year ago at the California Institute of Technology by Sydney Brenner, François Jacob and Matthew S. Meselson. Using an ingenious combination of radioactive and nonradioactive isotopes, they were able to make the following observations. First, they could distinguish between ribosomes existing in the cell before virus infection and any that might be created after infection. Second, they could observe if virus-specific RNA formed *after* infection became associated with ribosomes present *before* infection.

To carry out the experiment they grew colon bacilli on substances containing isotopes of nitrogen and carbon that are heavier than the most abundant isotopes of these elements, thereby producing cells with "heavy" ribosomes. The cells were then infected with T4 virus and simultaneously transferred to a medium containing ordinary nitrogen and carbon. Therefore any new ribosomes created after infection would be lighter than those present at the time of infection. Immediately after infection the cells were exposed briefly to radioactive phosphorus to label the messenger RNA produced by the virus DNA.

A technique known as density-gradient centrifugation was used to separate the heavy ribosomes from the light ones. To provide enough light ribosomes to make the separation work successfully,



RIBOSOME PARTICLES, isolated from colon bacilli and enlarged about 300,000 diameters, appear in this electron micrograph made by Cecil E. Hall and H. S. Slayter of the Massachusetts Institute of Technology. Slightly smaller than the smallest viruses, ribosomes contain about 50 per cent protein and 50 per cent RNA. It is not known how much of the RNA in a ribosome is messenger RNA.

such ribosomes were added from normal cells that had not been infected. When the two ribosome fractions were examined for radioactive messenger RNA, it was found that only the heavy ribosomes —those present in the cells before infection—were radioactive. Since no radioactivity was found in the lighter fraction, it could be assumed that no new ribosomes were synthesized after infection.

In a parallel experiment the protein formed after infection was radioactively labeled rather than the messenger RNA. This was done by exposing the infected cells to radioactive sulfur, which is incorporated in protein but not in RNA. The experiment showed that the newly formed protein was associated with the old ribosomes before it appeared in the soluble protein fraction of the cell.

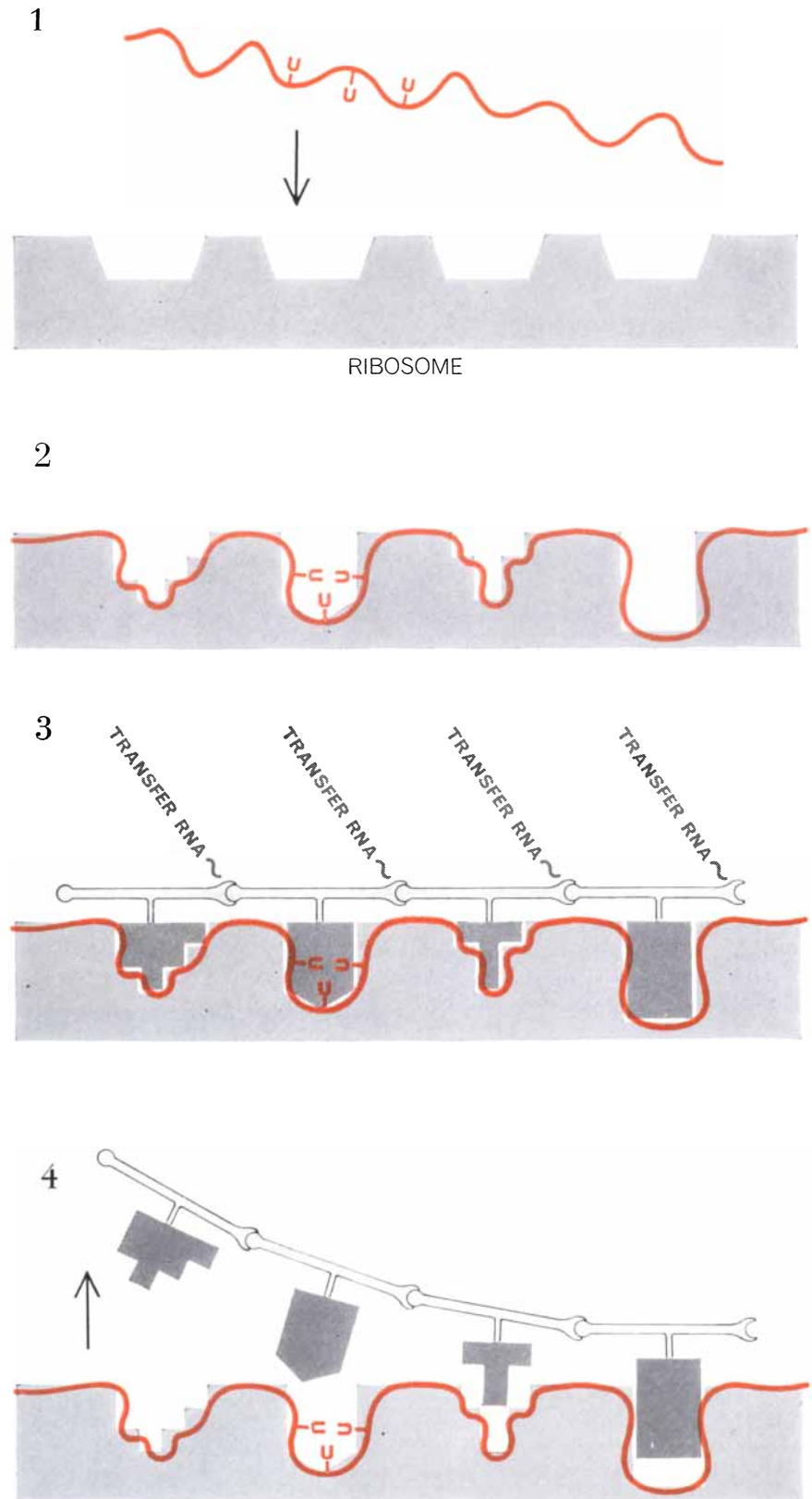
The conclusion to be drawn from these experiments is clear. Ribosomes are "for hire." A ribosome is only a machine responsible for synthesizing protein. Not until the machine has been supplied with the proper instructions, derived from the primary code residing in the genes, can a given protein be synthesized.

But what is the code, built on only four bases, that enables messenger RNA to select any one of 20-odd amino acids and specify the order in which each is to be linked into a protein?

Within the past year the first clear insight into the nature of the code was obtained by Marshall W. Nirenberg and J. Heinrich Matthaei of the National Institutes of Health. To a cell-free extract containing the protein-synthesizing machinery of the colon bacillus they added a synthetic RNA molecule consisting of repeating units of uridine. When they examined the small protein-like molecule that resulted, they found that it was made up solely of repeating units of the amino acid phenylalanine.

It is generally believed, although yet to be proved, that it takes a sequence of three bases to specify one amino acid. Thus in the Nirenberg-Matthaei experiment the sequence uridine-uridine-uridine in messenger RNA is transcribed into phenylalanine on the ribosome [*see illustration at right*]. And, as we have seen, the uridine-uridine-uridine sequence of the RNA is itself a transcription of the adenine-adenine-adenine sequence in the DNA.

The code in the DNA is transcribed into messenger RNA. This RNA transmits the information to the ribosome and the ribosome synthesizes the protein. The dream of the gene has become the reality of the protein.



SYNTHESIS OF A PROTEIN, as now visualized, is directed by messenger RNA, shown as a wavy colored line in step *1*. Succeeding steps show how the ribosome is evidently "hired" by the messenger RNA to turn out a particular protein whose structure is dictated by the sequence of bases in the RNA. It has recently been found by Marshall W. Nirenberg and J. Heinrich Matthaei of the National Institutes of Health that the sequence uracil-uracil-uracil (*U-U-U*) is the RNA code for phenylalanine (*second amino acid from the left, 4*).

THE SOLAR CHROMOSPHERE

It is a narrow region lying between the visible disk of the sun and the corona. Within it are found many clues to phenomena in the sun, in interplanetary space and in the earth's atmosphere

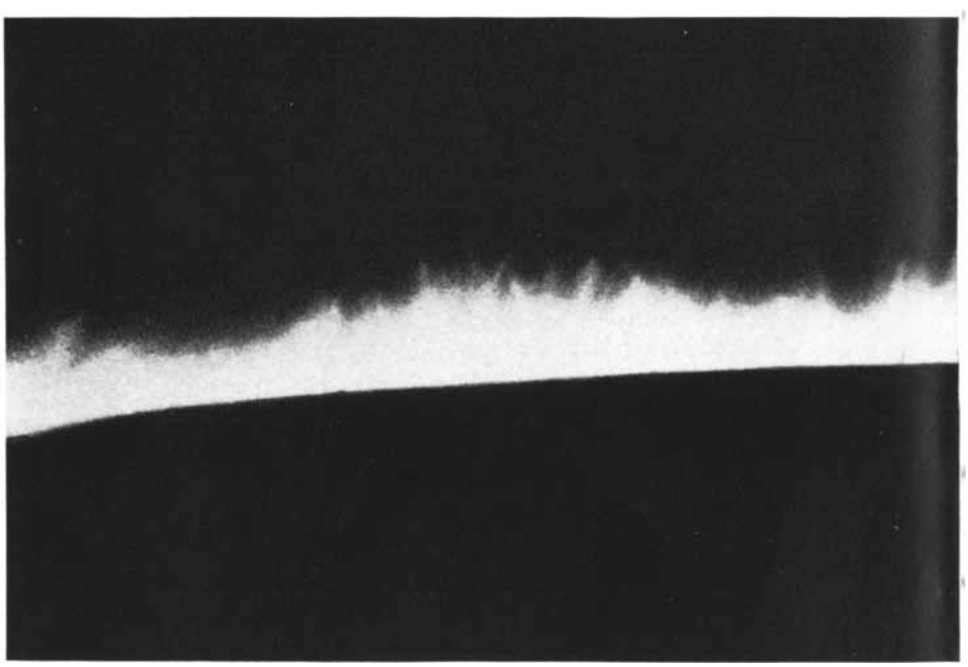
by R. Grant Athay

On October 2, 1959, I stood on a barren hilltop at the southern tip of Fuerteventura, one of the Canary Islands off the west coast of Africa, viewing the image of the eclipsing sun in a small telescope. My task was to cry "Now!" at the instant when the moon covered the last visible portion of the brilliant disk of the sun's photosphere. That instant would bring into view the rosy-red annulus of the chromosphere and the pearly-white corona extending into space beyond it. The signal from me would set in motion a battery of six cameras and expose more than 1,000 square feet of film in the next 2½ minutes in order to record the spectra of these two elusive features of the sun. My colleagues and I, from the High Altitude Observatory of the University of Colorado and the Sacramento Peak Observatory in Sunspot, N.M., were particularly concerned to capture good images of the chromosphere. Two years of costly engineering and shop time spent in perfecting the apparatus, months devoted to preparations for transporting the delicate instruments, electric-power sources, machine tools, a 10-man crew and the necessities of life 6,000 miles from Boulder, Colo., to the remote island, and over a month of instrument-checking, rehearsing and waiting—were to yield their harvest in those 150 seconds.

Seconds before totality, however, the sun disappeared behind high, broken clouds, and I had to give my command at the computed time of totality rather than by observation. The cameras whirred, and the clouds did thin for a precious few seconds, giving us a faint view of the corona and some bright prominences. Five minutes after the eclipse the clouds moved away from the sun. We had not observed the chromosphere at any time.

Our failure was made the more bitter by the still vivid memory of a similar fiasco the year before at Danger Island in the South Pacific and by the knowledge that seven other expeditions in the Canaries had failed along with us. Yet when this issue of SCIENTIFIC AMERICAN comes from the press, we shall be off again, this time to Lae in New Guinea. In July, 1963, we shall send another eclipse expedition into northern Canada, beyond the Arctic Circle. Whether it is cloudy or fair at these eclipses, we shall make still more journeys to other remote sites (eclipses are seldom so accommodating as to pass over established observatories). A sane person may reasonably wonder why we continue such costly and difficult expeditions in the face of a high probability of failure.

The answer is this: The chromosphere, which can be viewed in the required detail only during a total eclipse, holds clues to many physical processes in the sun itself, in interplanetary space and in the upper atmosphere of the earth. Of greatest interest is the nature and the source of the nonradiative energy that wells up out of the sun and creates the chromosphere and the corona in the first place. This energy is absorbed primarily in the chromosphere and is there transformed into visible light and other forms of electromagnetic radiation. Without the nonradiative energy and its mysterious transformation in the chromo-



MIDDLE AND UPPER CHROMOSPHERE appear in this photograph, made by R. B. Dunn with the 16-inch coronagraph at the Sacramento Peak Observatory in Sunspot, N.M. The coronagraph is a telescope that artificially eclipses the bright disk of the sun. A highly

sphere the solar atmosphere would simply grow cooler and thinner in direct proportion to the distance from the sun. Instead, the temperature rises from 4,300 degrees Kelvin (degrees centigrade above absolute zero) at the surface of the photosphere to more than 6,000 degrees in the lower chromosphere. It climbs to approximately 50,000 degrees in the middle chromosphere and then takes a huge leap to nearly a million degrees in the corona.

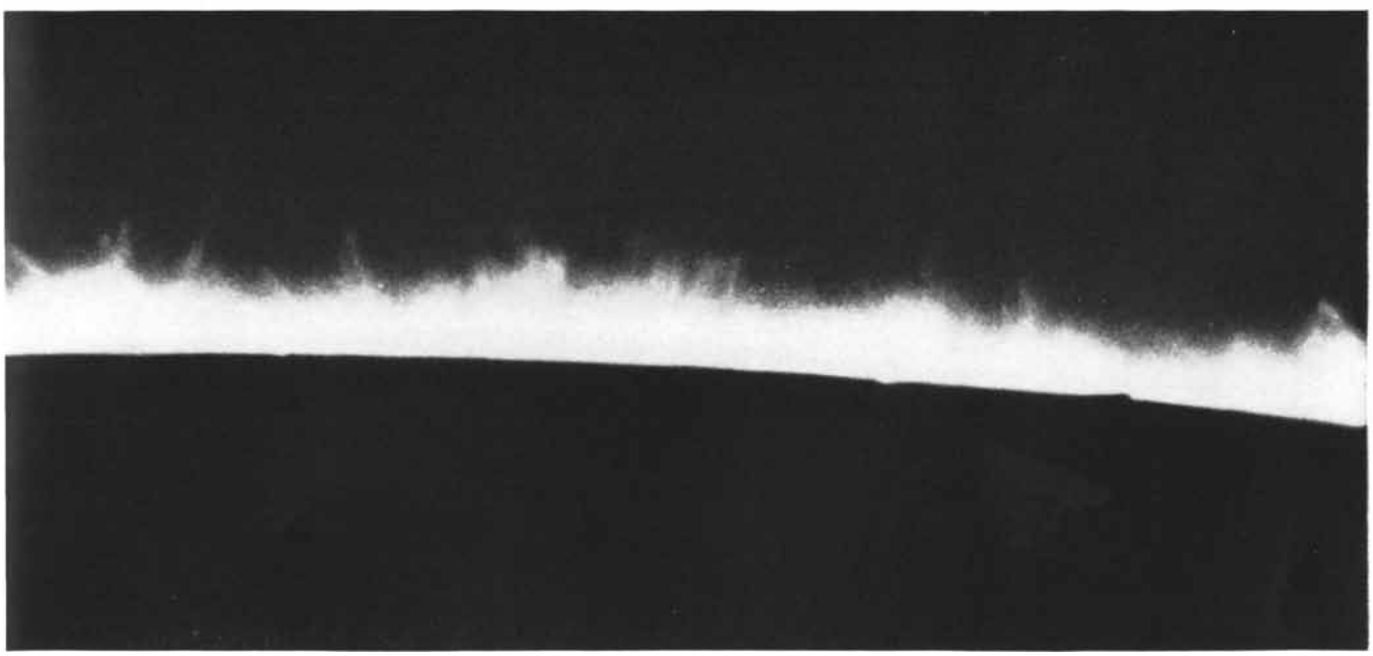
The chromosphere, under excitation by the nonradiative energy, emits intense ultraviolet radiation. In the upper atmosphere of the earth this radiation sets up the electrically charged layer known as the ionosphere, which reflects radio waves and makes possible long-distance radio communication. The chromosphere is also the birthplace of the great solar flares. Energetic particles reaching the earth from these flares generate auroras and, on occasion, disrupt the ionosphere and the radio communications that depend on it. The geyser-like projections called spicules spring up continuously from the chromosphere, feeding into the corona the protons that eventually escape into interplanetary space to make up the "solar wind." Finally, certain atoms in the chromosphere absorb specific wavelengths of radiation from the photosphere, producing the strongest of the many absorption (dark) lines that cross the otherwise continuous spectrum of the photosphere.

So little is known about the chromosphere that one incomplete set of observations of its spectrum made by our first expedition, to the Sudan in 1952, lays much of the basis for the present conception of its physics. In contrast to the spectrum of the photosphere, the spectrum of the chromosphere consists of bright, narrow emission lines separated by broad, dark regions. The light at each wavelength represents the radiative output of excited atoms or of ionized atoms (that is, atoms with one or more electrons stripped from them) of one or another element in the chromosphere, such as hydrogen, helium, oxygen, calcium, iron and titanium. The chromosphere gets its name from the red color of one of the stronger emission lines of hydrogen. At the top of the chromosphere the spectrum changes abruptly into the continuum of colors, punctuated by a few faint emission (bright) lines, that characterizes the corona.

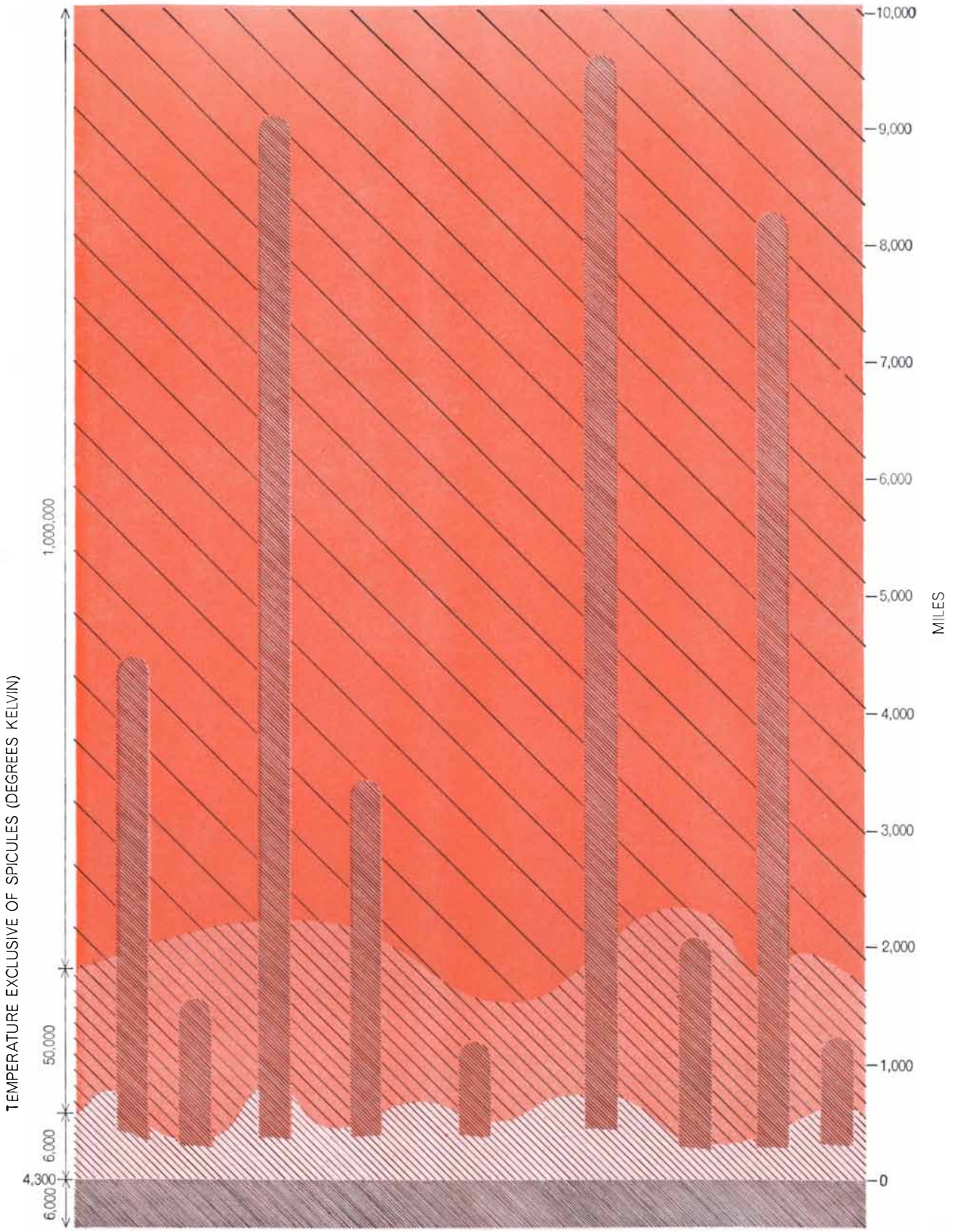
During an eclipse the moon moves across the face of the sun at some 200 miles per second; this means that the most interesting portion of the chromosphere, its lower 600 miles, shows for only three or four seconds. The upper chromosphere, which can extend for as little as 1,000 miles to as much as 10,000 miles above the photosphere, is seen for less than a minute. In the span of a century the lower chromosphere is visible for a total of less than 10 minutes. An astronomer who observes 10 eclipses—far more than the average—may expect to observe this region of the chromosphere for no more than a minute in his lifetime, and that only if he is luckier than any other astronomer ever born.

Apart from total eclipses, it is possible to make a few, somewhat compromised observations of parts of the chromosphere. The entire disk of the sun may be photographed, for example, in the monochromatic light that comes from the center of one of the chromospheric absorption lines (since the light is less intense than that of the surrounding portions of the spectrum, the line still appears to be dark). Such pictures contain a wealth of detail, but there is as yet no way to extract very much useful information about the chromosphere from them. They are made today in order to detect solar flares and other events on the sun. The study of the chromosphere would be a by-product of this effort, but one that could well prove to be more useful in the long run than the detection of unusual solar activity.

The highly active upper part of the chromosphere shows up to advantage in the coronagraph, a telescope that produces artificial eclipses, primarily for studies of the corona. The lower chromosphere lies too close to the photosphere to be visible in the coronagraph, but the middle region, which extends from 600 miles to about 2,000 miles,



monochromatic filter excluded almost all light except the red color emitted by excited atoms of hydrogen at a wavelength of 6,563 angstrom units. Top of chromosphere consists of spicules, geyser-like columns each 500 miles wide, that shoot up at 20 miles per second from lower chromosphere. Spicules inject protons into the corona, from which they move outward as the "solar wind."



SOLAR CHROMOSPHERE, seen here in a highly schematic diagram, consists of three layers, decreasing in density (*hatching*) and increasing in temperature by sudden jumps (*color*). Upper photosphere is at bottom. Lower chromosphere averages 6,000 degrees Kelvin, middle chromosphere 50,000 degrees and corona, between spicules, nearly a million degrees. The spicules show evidence of two temperature ranges throughout their length, about 10,000 degrees and near 50,000 degrees, possibly because a hot envelope encases a cooler core. This complex temperature structure is not shown. Spicules make up third, or top, layer of the chromosphere.

can be seen. Above this height the chromosphere assumes an extremely rough appearance: it bristles with spicules that well up from the lower chromosphere and fall back or disappear into the corona at a height of about 10,000 miles. An early observer, seeing the spicules, likened the glowing chromosphere to "a burning prairie."

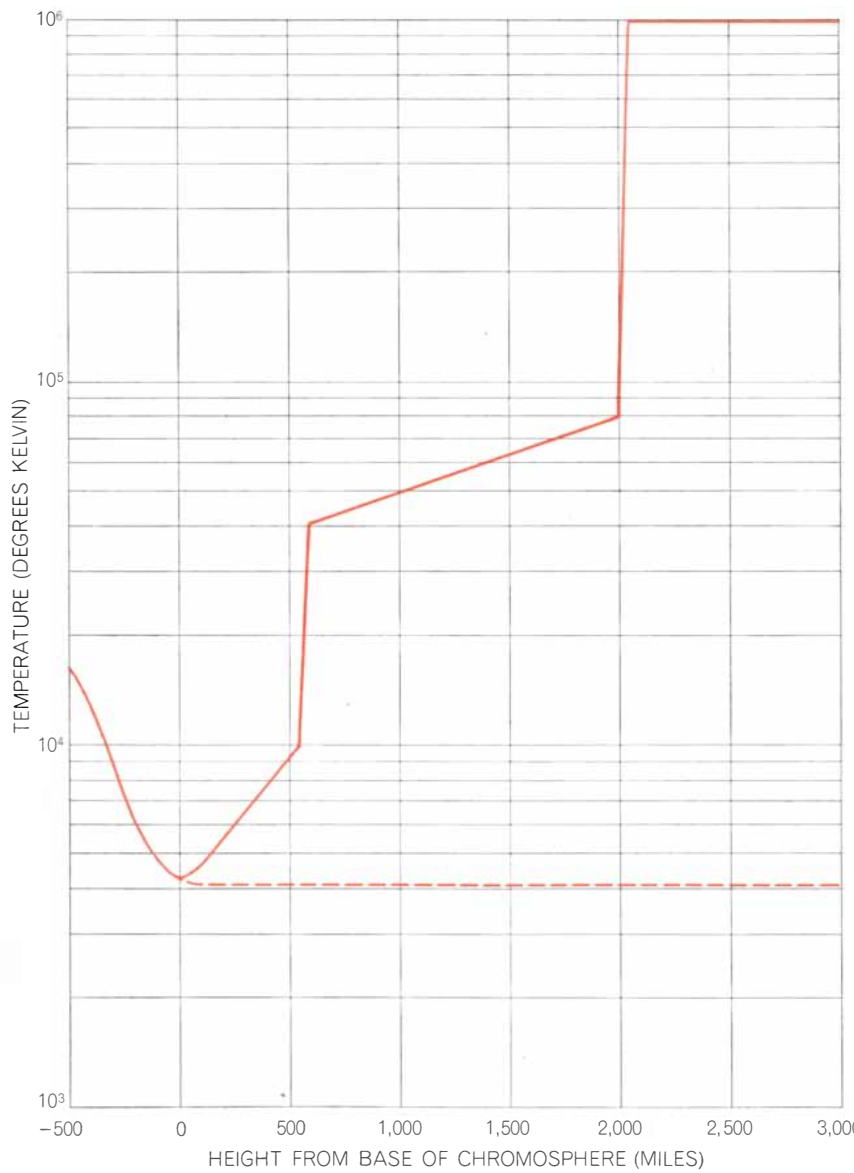
Radio astronomy provides a fourth way to observe the chromosphere: radio noise of wavelengths shorter than 10 centimeters originates in the region. As yet radio telescopes cannot resolve the disk of the sun in sufficient detail to provide the kind of data needed. Eclipses improve the radio definition but so far few radio observations have been made during eclipses.

For the present most of what is known or postulated about the chromosphere comes from analysis of its optical spectrum. As in all spectroscopy, the wavelength of an emission line provides reliable identification of the atoms that are the source of the radiant energy of that point in the spectrum. The absolute intensity of the spectral line can be taken, although with much less reliability, as an index to the number of atoms present; in other words, to the density of the chromosphere in the region observed. This deduction is heavily qualified, as will be seen, by other variables. With corresponding qualifications and uncertainty, both the width and the relative intensity of an emission line can be taken as indicators of the temperature.

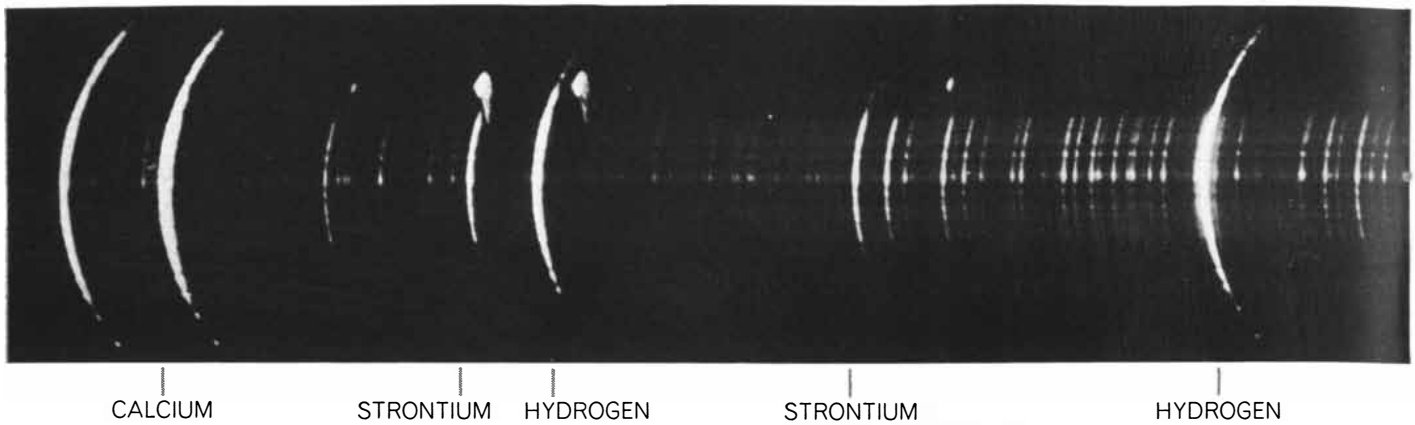
The scantiness and uncertainty of the data can be judged by the wide swings in interpretation that have engaged students of the chromosphere in recurrent controversy over the past half-century. Early observers were impressed by what they found to be, from measurement of the intensity of the spectral lines, the unexpectedly high density of the chromosphere. The density of any atmosphere tends to decrease exponentially with altitude. In the upper photosphere, which like the rest of the sun is gaseous, the density falls off by a factor of 2.7 (the base for natural logarithms) for each 60-mile increase in altitude; the 60-mile unit is called the scale height. Measurement of the intensity of the hydrogen lines in the spectrum of the chromosphere gave the startling scale-height value of 600 miles; that is, the 2.7 decline in density in the chromosphere was found to occur over a depth of 600 miles, compared with 60 miles in the photosphere immediately below.

Astronomers had to postulate some "support mechanism" capable of holding up the chromosphere. In 1929 W. H. McCrea of the University of London suggested that the chromosphere was in violent, turbulent motion, which produced enough pressure to force the atmosphere outward. Observations made during a total eclipse in 1941, however, led R. O. Redman of the University of Cambridge to propose another mechanism. After measuring the width of many chromospheric spectral lines he concluded that the temperature in the lower chromosphere was 35,000 degrees Kelvin. Since the scale height of a quiescent atmosphere is directly proportional to its temperature, 35,000 degrees K. was clearly enough to produce a large scale height in the chromosphere without the help of turbulence or any other support mechanism. Now the question was: What produces the high temperature?

The most effective challenge to Redman's results came in 1954, when Redman himself and Z. Suemoto of the Tokyo Astronomical Observatory showed that the 1941 work had failed to take into account factors other than temperature that may broaden spectral lines. As a result they concluded that the temperature of the lower chromosphere is only 5,000 to 10,000 degrees K. The support problem was now to the fore again,



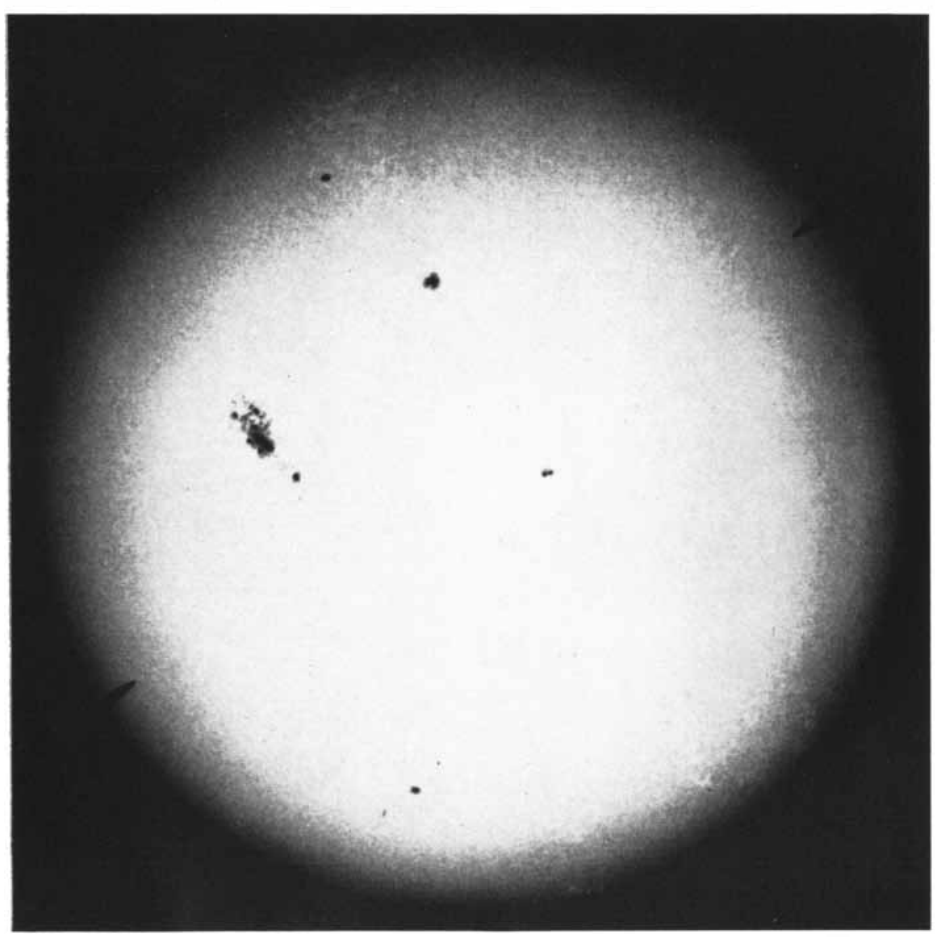
TEMPERATURE STRUCTURE of chromosphere is represented by solid line. The jumps are caused by chromospheric response to nonradiative energy emitted by the sun. If energy flowed out of the sun by radiation alone, the temperature would decline with distance but so slowly that, in the distance shown, the drop would not be apparent (*broken line*).



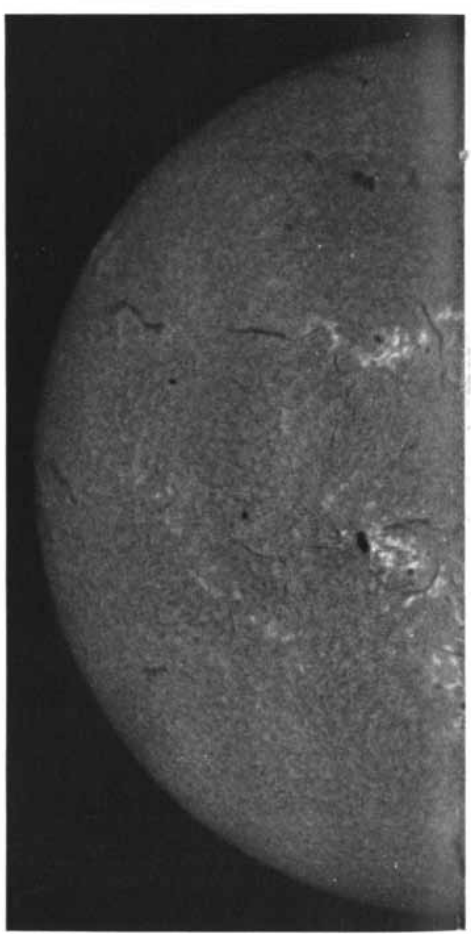
SPECTRUM OF CHROMOSPHERE consists of many bright emission lines separated by dark areas. This is the violet-to-blue portion of the spectrum, photographed at Khartoum in the Sudan by the 1952 eclipse expedition of the High Altitude Observatory of the

but Redman's suggestion of a high temperature was nevertheless to lead eventually to new concepts in chromospheric physics.

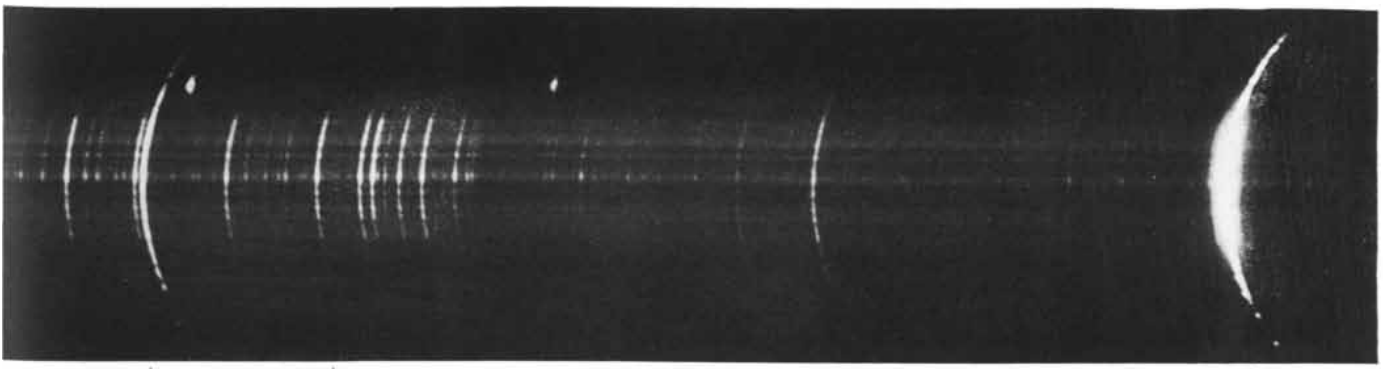
Shortly after this a largely empirical analysis of our data from the 1952 eclipse unexpectedly revealed a serious flaw in the simple reasoning that for so long had assigned a scale height of 600 miles to the lower chromosphere. Our analysis included an allowance for the changes in the intensity of the hydrogen lines that would result from ionization. Since it is the excited electron that emits radiation as it gives up surplus energy, hydrogen ceases to radiate when it has been ionized, that is, stripped of its single electron. Accordingly we derived a new density scale height of only about 100 miles. The same calculations gave a sharp rise in temperature from about 5,000 degrees at the base of the chromosphere to about 6,000 degrees at a height of 600 miles, which would ac-



DISK OF SUN photographed in white light is the visible sun. It shows sunspots and other structures. The chromosphere and the corona are both invisible on such white-light photographs.



CHROMOSPHERIC DISK shows plainly in photograph made by red

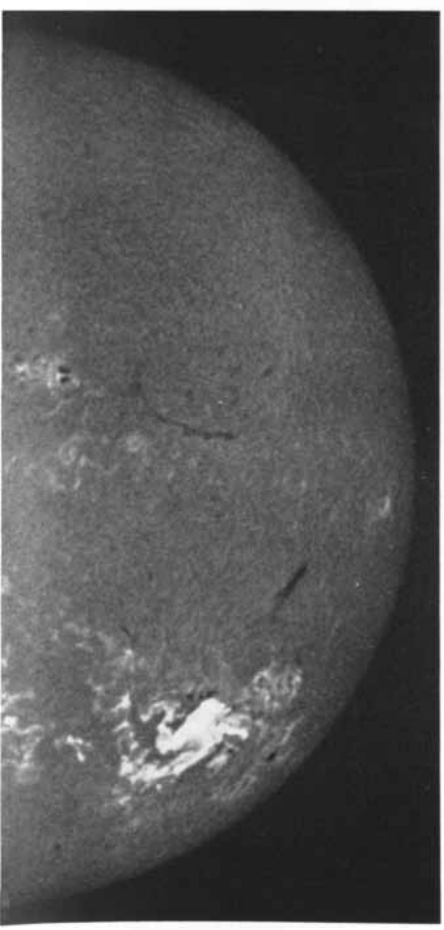


University of Colorado. The two strong calcium lines at far left appear on the spectrum of the photosphere as the heaviest of many absorption (*dark*) lines. Spectra such as this, available only at total eclipse, are the major source of data on the chromosphere.

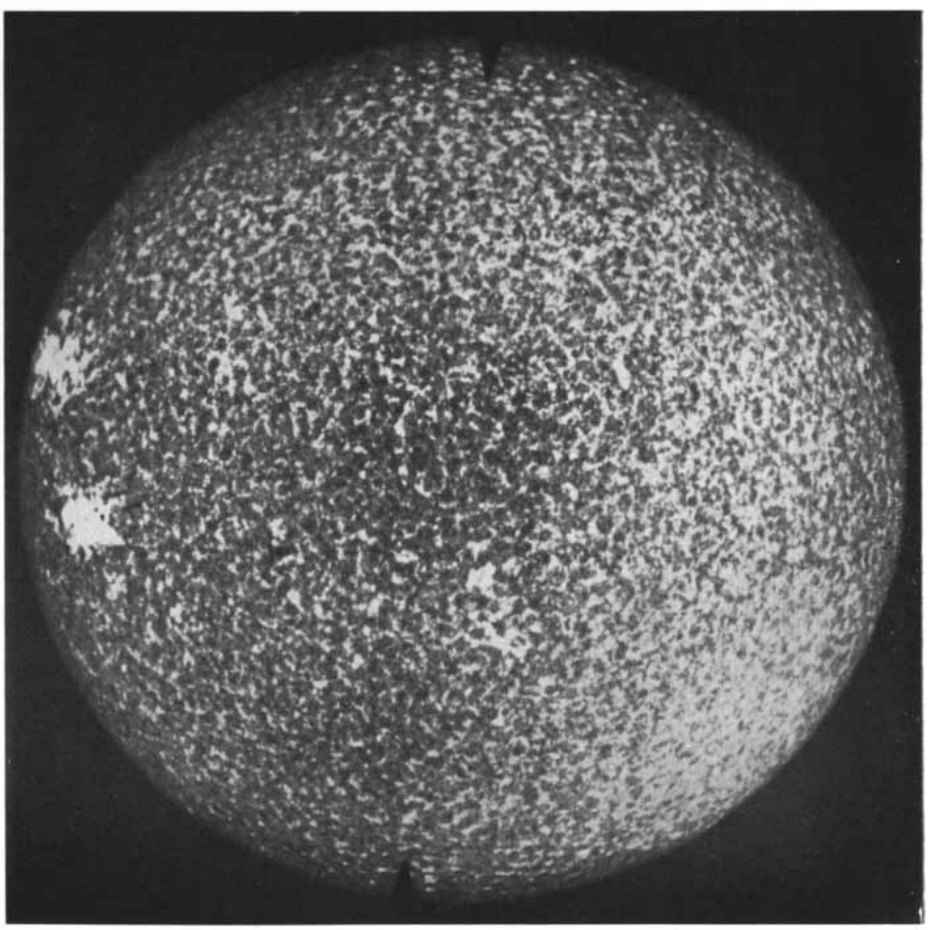
count adequately for the new scale height without any other support mechanism.

Thus the question of support vanished once again, this time, we feel, permanently. Another question was raised, however, by the rise in temperature. Our initial results were later refined by Stuart R. Pottasch of the Institute for Advanced Study in Princeton, N.J., and Richard N. Thomas of the National Bureau of Standards, who deduced a temperature at the bottom of 4,500 degrees, which rose to 7,500 degrees at 600 miles. This sharp rise poses the main problem of the lower chromosphere. The temperature change, incidentally, is matched by a constant increase in the density scale height.

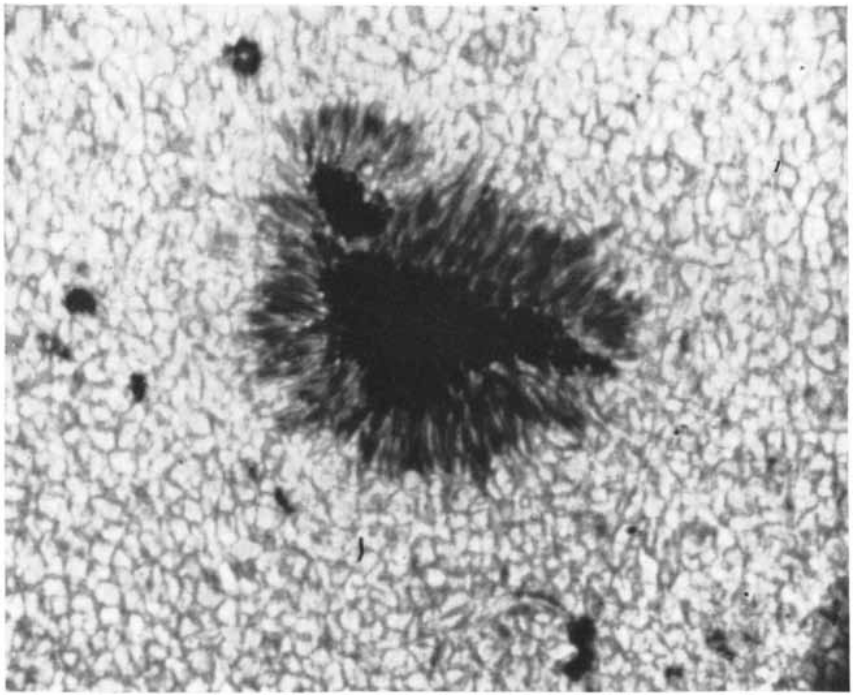
Above the 600-mile level, in the middle and upper chromosphere, two other factors enter the problem: the structure and movement of the spicules, and the state of the gas within and between the



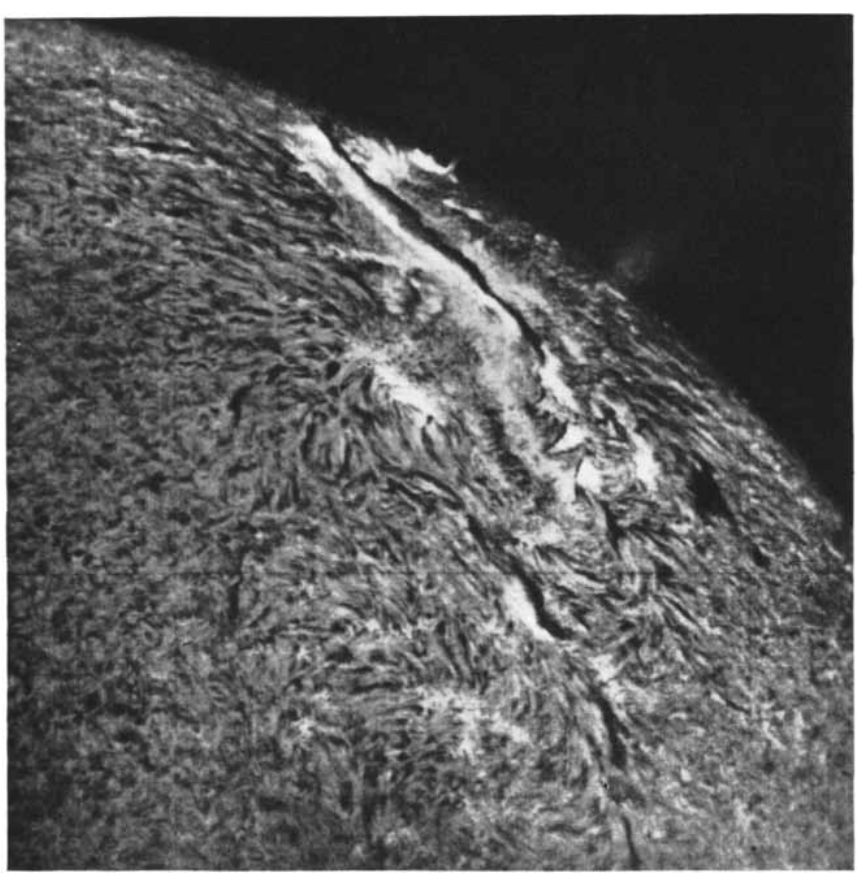
light emitted by atomic hydrogen. Bright spot is a large solar flare.



CALCIUM EMISSION along violet line at far left in spectrum at top of these two pages produces another detailed view of chromosphere. The bright patches at left surround regions of sunspots.



SURFACE OF PHOTOSPHERE is highly granulated. One sunspot appears in this photograph, made with a 12-inch telescope carried to 80,000 feet by an unmanned balloon. Unusual detail appears because balloon was outside most of earth's atmosphere. Photograph is from Project Stratoscope I of Princeton University, sponsored by Office of Naval Research, National Science Foundation and National Aeronautics and Space Administration.



GRANULAR STRUCTURE characterizes chromosphere in this photograph made by the red light of atomic hydrogen. Large features are over sunspot. This photograph, from Mount Wilson Observatory, shows a far larger portion of solar disk than photograph at top of page.

spicules. It is here that the geometry of the chromosphere becomes extremely important.

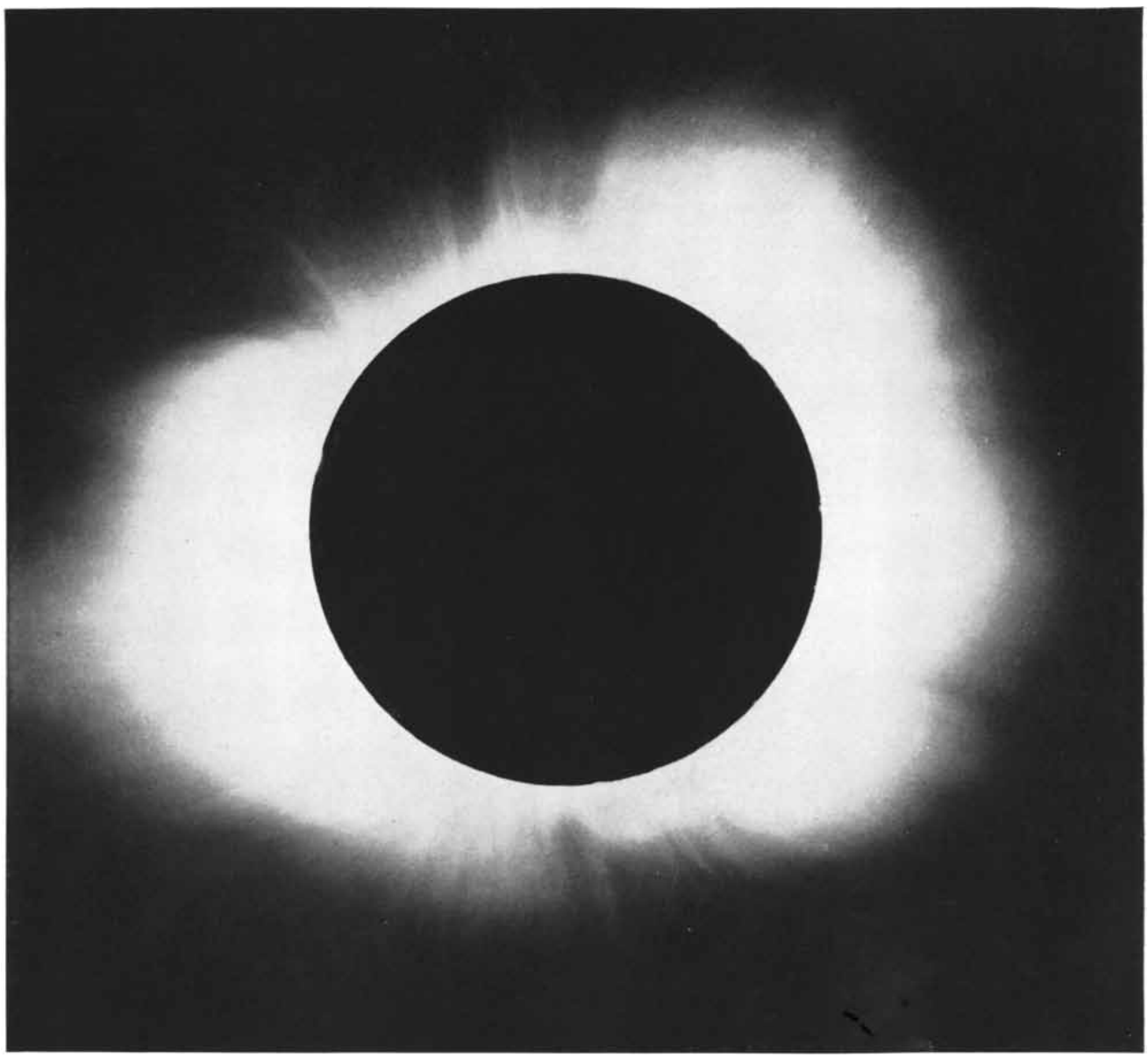
Oddly enough, Redman's mistaken announcement of a 35,000-degree temperature in the lower chromosphere led the way to present understanding of the chromosphere. Thomas and R. G. Giovanelli of the Commonwealth Scientific and Industrial Research Organization in Australia, seeking to reconcile the high temperature with seemingly contradictory data, were led to suggest the abandonment of the whole theoretical basis of chromospheric studies—the idea that the chromosphere is in a state of thermodynamic equilibrium. This ideal state normally prevails in the laboratory, where the temperature of a gas can be determined by measuring the intensity of radiation at one or two points of the spectrum. On the basis of such laboratory studies, the German physicist G. R. Kirchhoff and others as long ago as 1860 deduced very simple concepts for explaining the properties of spectra produced by atoms in a gas. Under equilibrium conditions each microscopic process in the gas is exactly balanced by its inverse process: for every atom that absorbs a photon of light, another atom of the same kind radiates an identical photon; for each atom that gains energy in a collision, another loses exactly as much energy in an identical collision. So long as thermodynamic equilibrium prevails—or is assumed—all processes balance, and there is no need to know such details as how often one or another event takes place or which processes are the most important.

The solar physicist quite naturally applied this simplifying assumption to the sun. In the case of the photosphere it has given many valuable and undoubtedly correct results. In the early 1940's, however, it became apparent that the extremely hot, tenuous gas of the solar corona could not exist in the state of thermodynamic equilibrium. More recently investigators have found themselves compelled to set the concept aside in coping with the problems of the chromosphere. In fact, the idea of equilibrium has been shown to be invalid for the formation of some of the spectral absorption lines produced by atoms within the photosphere. Still other absorption lines that were attributed to the photosphere are now known to originate in the chromosphere without the blessings of thermodynamic equilibrium.

The abandonment of this concept is not a trivial matter for the theoretician

or for the observer. According to Kirchhoff's law, one could assume that a darker region of the sun is at a lower temperature than a brighter region. Studies have now shown that a cloud of hydrogen at a temperature of, say, 50,000 degrees K. can show up as a dark feature when viewed in the line spectrum against a brighter background arising from hydrogen at 10,000 degrees. On the other hand, a dark cloud can also be cooler than the brighter background. Similarly, a bright cloud may be hotter or cooler than its darker background. Only detailed scrutiny of the spectrum can reveal the true situation. By allowing for departures from thermodynamic equilibrium, however, one can begin to form some idea of events on the microscopic scale and can determine which processes dominate the scene.

From such analysis of the spectra recorded in 1952 we have been able to piece together otherwise contradictory data into a consistent description of the chromosphere that is completely different from earlier ideas. It is at greater altitudes in the chromosphere that these departures become more significant. Beginning at about 600 miles the chromosphere separates into relatively cool, high-density columns, which are the spicules, and hot, low-density regions between them. As the coronagraph so clearly reveals, spicules shoot out at about 20 miles per second, attaining a height of 8,000 to 10,000 miles before they fade from view or fall back to the sun. Each spicule is about 500 miles in diameter (the width of the state of Colorado) and endures only five or 10 minutes. A given point on the solar surface undergoes spicule upheaval about once in 24 hours, and at any one time 100,000 spicules are passing through some stage of their evolution over the surface of the sun. It is true, as McCrea suggested, that the middle and upper chromosphere is in a continuous state of agitation. But the motions bear little resemblance to the usual concept of



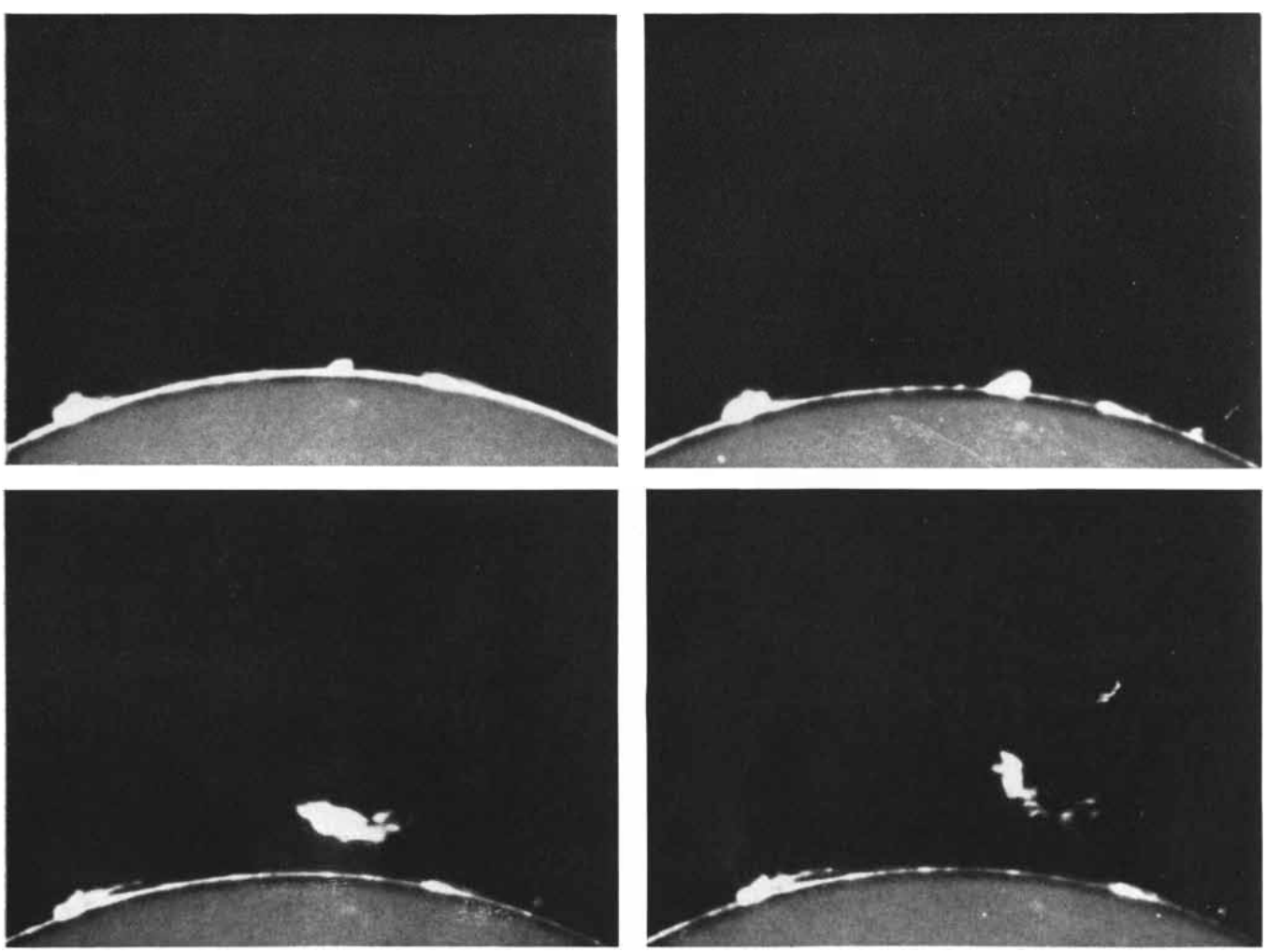
SOLAR CORONA, the tenuous outer atmosphere that lies beyond the chromosphere, is pearly-white. Although some of its features can be viewed with a coronagraph, it is best seen, as here, during the natural total eclipse of the sun that occurs about once a year.

turbulence; they are essentially well ordered. My colleagues and I feel intuitively that the spicules must somehow result from convection starting in the hydrogen convection zone that lies beneath the photosphere. They may, however, arise from some basic instability in the lower chromosphere that we do not yet understand.

Without doubt spicules occupy an important place in the over-all economy of the sun. Enough protons move outward across the 3,000-mile level of the chromosphere, for example, to replace the entire corona in less than three hours. This is more than a thousand times the observed flow of protons out of the sun into interplanetary space in the solar wind. If even a small fraction of the spicule flux continues to move upward, the spicules play a decisive role in the chromosphere-corona complex. Actually, so far as we can tell from observations, about half of the spicules move upward with no evident return flow. The flux of energy due to the spicules exceeds the energy radiated by the corona in the ultraviolet and X-ray regions of the spectrum, and it just about equals the flux of ultraviolet radiation from the chromosphere that is represented by the strong Lyman-alpha lines of hydrogen and ionized helium. This amounts to about a ten-thousandth of the sun's total energy output—a small fraction but a far from negligible quantity in absolute terms.

Apparently the spicules have an exceedingly complicated temperature structure. There is strong evidence for two discrete ranges of temperature—either near 10,000 degrees or near 50,000 degrees—rather than for a continuous variation. The two temperature ranges appear to occur at every height in a spicule, as if the spicule had a cool core encased in a hot envelope, or vice versa. It is no exaggeration to say that the explanation of the origin and subsequent history of spicules is one of the most challenging problems of solar physics.

The relatively quiescent regions between the spicules, which make up most of the upper and middle chromosphere, present still other problems. The low density and high temperature of the interspicular spaces with respect to the spicules make them difficult to observe. From a height of 600 miles up to about 2,000 miles much of the radiation from un-ionized helium atoms and from ionized helium atoms seems to originate in the region between the spicules, where the temperature is about 50,000 degrees. At 2,000 miles the spectrum of the interspicular spaces throughout the visual and photographic regions suddenly takes on all the characteristics of the corona at a temperature of a million degrees. At such heights the ultraviolet portion of the spectrum displays strong lines of oxygen, nitrogen and carbon atoms that have been stripped of several of their outer electrons. These lines probably originate within the interspicular spaces, but little more can be said about them at present. In any case, it seems ap-



EXPLOSIVE FLARE, which erupted on November 20, 1960, in the chromosphere on the limb of the sun, ejected a huge mass of incandescent gas into space. Sequence was recorded in red light by a High Altitude Observatory coronagraph at Climax, Colo. Second

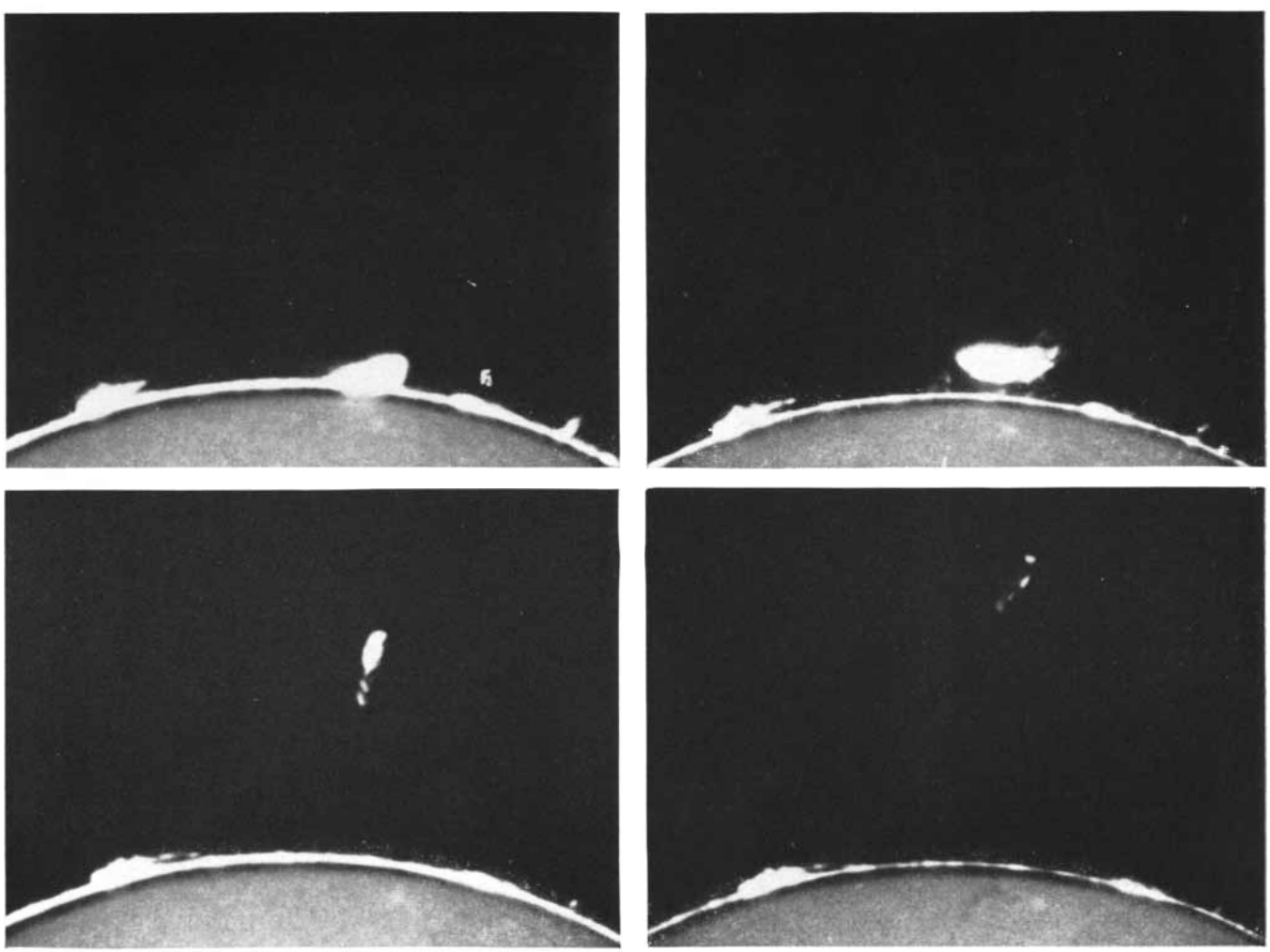
parent that the helium emission from between the spicules disappears at the 2,000-mile level.

The curious steplike temperature gradient of the chromosphere and the lower corona, with sudden increases from about 10,000 degrees to 50,000 degrees and then to a million degrees, demands an explanation. Thomas and I have proposed a theory that relates the temperature plateaus to the chemical composition of the solar atmosphere as observed in the spectra.

We assume that the initial rise in temperature in the chromosphere requires a nonradiative source of energy, perhaps sound waves originating in the hydrogen convection zone below the photosphere. Such a source of energy would square the account left unbalanced in the energy-conservation ledger by the strong outflow of radiant energy. We also assume that the chromosphere and the corona absorb the nonradiative energy and re-emit it in the form of radiation. These conditions permit only certain ranges of temperature in the solar atmosphere. For each small increase in temperature up to 10,000 degrees, it can be shown that un-ionized hydrogen will radiate proportionately more of the inflowing nonradiative energy and so keep the inflow and outflow of energy about equal. Above 10,000 degrees, however, any increase in temperature makes the hydrogen radiate less energy. The temperature must therefore rise until some other element in the solar gases is able to dispose of the energy. The next possibility is ionized helium at temperatures above about 40,000 degrees. Helium will continue to radiate more and more energy until the temperature reaches about 80,000 degrees. This is the temperature approximately 2,000 miles above the photosphere. There a new regime must take over.

The next possible absorber and radiator of energy appears to be heavy elements that have lost about 10 electrons. The observed temperature of a million degrees in the corona will strip that many electrons from an atom. According to theoretical calculations, the amount of energy an atom radiates increases as the fourth power of the electric charge on its nucleus. A loss of 10 electrons thus increases the ability of an atom to radiate by a factor of 10^4. Such a high degree of ionization is required because the corona possesses only a few atoms of the heavy elements; the deficiency in numbers must be made up by an ability to radiate more intensely. It can be seen that the relative numbers of atoms of various elements, as shown by the spectrograph, becomes a crucial factor in explaining the temperature structure also indicated by the spectrograph.

If our interpretation of the chromospheric structure holds up, then the major unsolved problems are the source and nature of the nonradiative energy that creates and powers the chromosphere, and the cause of spicule upheaval. The two problems are probably closely related.



photograph was made 10 minutes after the first. Remainder were made 20, 25, 27, 28, 30 and 32 minutes respectively after start. The region of the sun shown is more than 340,000 miles across. Particles from such solar flares can disrupt communications on the earth.

GONDOLA of the human centrifuge of the Naval Air Development Center in Johnsville, Pa., is large enough to hold a test subject and a considerable amount of equipment. The gear teeth along the rim are part of the gimbaling system used to orient the gondola.

The Physiological Effects of Acceleration

Accustomed to the gravitational acceleration that gives him his sensation of weight, man is now faced with the problems of greatly increased weight and of weightlessness in manned rocket flights

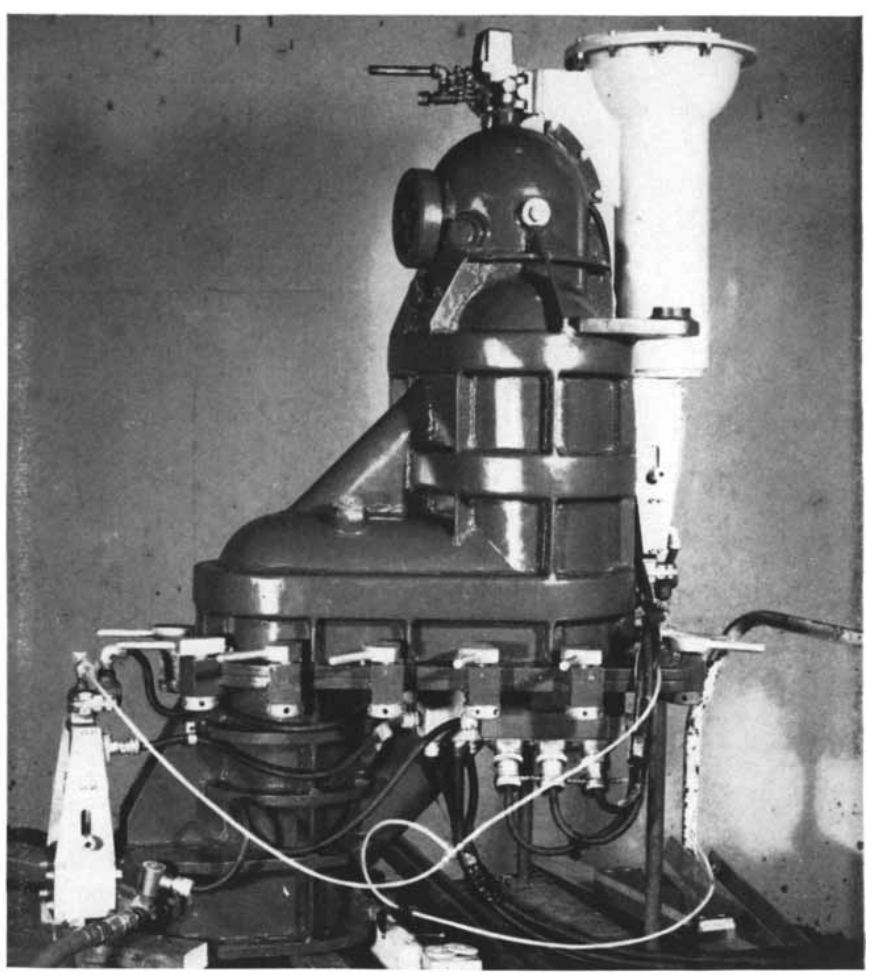
by Terence A. Rogers

The human organism, by virtue of an evolutionary process that long preceded the emergence of the species, is adapted to living under the pervasive and familiar force of gravity. What we call our weight is this force pressing us to earth; it is equal to the mass of the body multiplied by the acceleration due to gravity. Through sensory receptors in the inner ear and in the joints, this force furnishes the primary clue to the body's orientation in space. Acting on the fluids and tissues of the body, it intimately conditions vital processes; in the case of blood pressure, for example, the arterial pressure in the feet of a seated man is about twice what it is in the head.

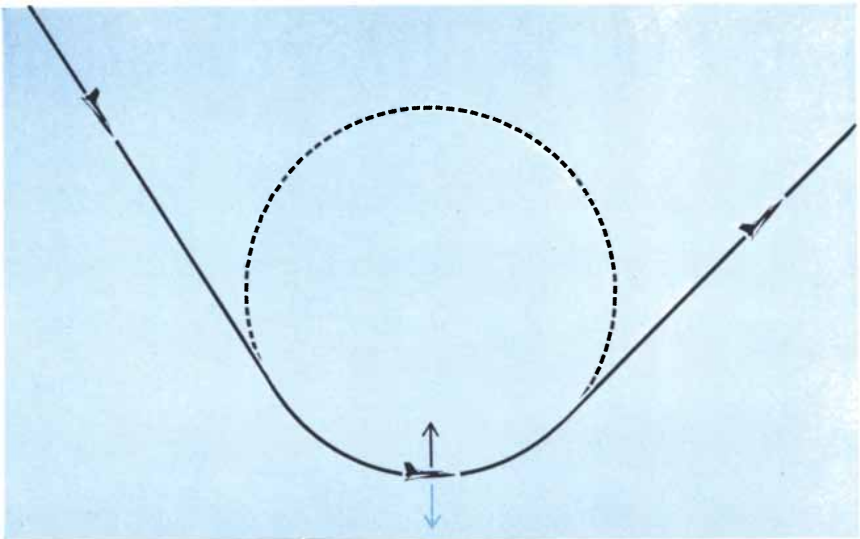
Such observations would perhaps hold greater interest for physicists than physiologists if men had not learned to fly. In flight the human organism has been encountering the stress of forces induced by accelerations many times that of gravity. Emboldened by the resilience of their bodies, men now submit to the extreme stress of the acceleration sufficient to hurl them free of the earth's gravitational field. In the state of weightlessness thus achieved the body may come under stresses still more extreme. Within the past generation, therefore, the physiological effects of acceleration have become the focus of urgent and elaborate research programs. These studies suggest the high degree to which the body has been molded in structure and function by the force of gravity and have begun to indicate the conditions thereby imposed on the engineering of space flight.

The "blackout" experienced by pilots of dive bombers in World War II was perhaps the first physiological hazard of acceleration to come to public notice. Most people have a subjective notion of what happens: The centrifugal force developed as the aircraft pulls out of the dive crushes the pilot down into his seat, and, since his blood is not restrained as the rest of his body is, it is literally centrifuged into his abdomen and legs. The decrease in the blood delivered to his head causes first a "graying" of his vision, then total "blackness" and finally unconsciousness.

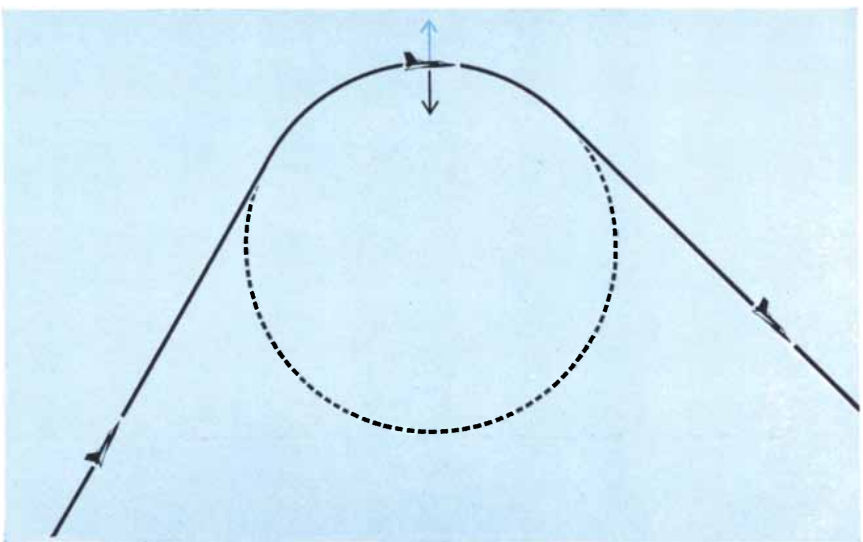
Before proceeding further into the physiology of blackout, however, it is well to review the elementary physics



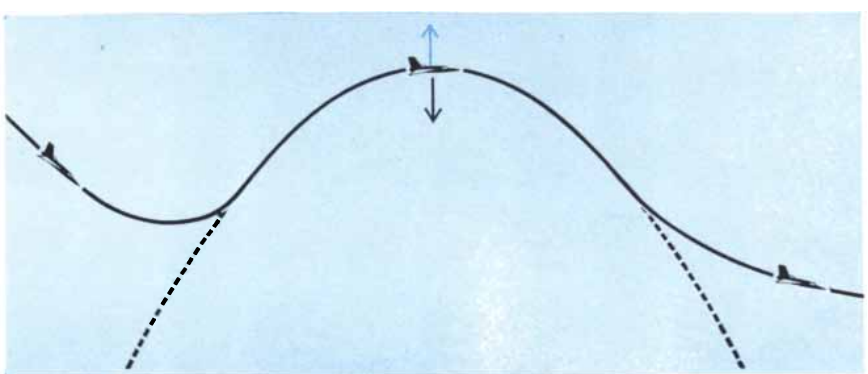
"IRON MAIDEN" is the nickname given this testing device. The test subject in the apparatus has a breathing tube to the outside, and the apparatus itself is completely filled with water. Such whole-body immersion greatly increases the subject's tolerance to G stress.



INSIDE LOOP of a dive or banked turn follows the arc of a "turning circle" (*broken line*) whose center is "above" the pilot and his plane. The centrifugal force that results is experienced in the direction indicated by the arrow and crushes the pilot down into his seat.



OUTSIDE LOOP follows the arc of a turning circle whose center is "below" the pilot and his plane. The direction of the centrifugal force is the reverse of that in an inside loop, and the pilot is driven "up" toward the roof of his plane rather than down into his seat.



PARABOLIC LOOP is executed to achieve zero G. The centrifugal force (*colored arrow*) is exactly balanced by the gravitational attraction of the earth (*black arrow*) during the portion of the controlled flight in which the plane's path describes a parabola (*broken line*).

of the experience. The concepts are familiar, but they are sometimes embarrassingly elusive. A convenient model for this review is provided by the man-carrying centrifuge machines that have been employed by all the major air powers to explore the hazards of acceleration facing their pilots. Such a machine consists of a counterbalanced beam that swings around a central pivot and carries a gondola at its end to contain the research subject and instruments. When the beam is swung around, the gondola tends to pull away and travel in a straight line, as it would if it were to come loose. (On the gondola of the huge 50-foot machine of the Naval Air Development Center in Johnsville, Pa., someone once fastened a notice that said: "If found, please return to N.A.D.C., Johnsville, Pa.")

The force acting along the beam to prevent this is the centripetal force. Since the gondola does in fact continue to move in a curved path, there is a force equal and opposite to the centripetal force; this is the centrifugal force. The two forces can be expressed in terms of mass times acceleration, just as the mass of a body multiplied by the acceleration of gravity yields the force that holds the body to the earth. But in the special case of rotary motion the nature of the acceleration is not always immediately clear. Although the speed of the gondola may be constant, its velocity (in the strict directional sense of this term) must be changing because the gondola is changing direction in its curved path. The change in velocity is an acceleration toward the pivot of the centrifuge, and this centripetal acceleration multiplied by the mass is equal to the centripetal force. The centrifugal force is the resultant inertial force opposing this. Since the acceleration due to gravity is both familiar and fairly constant at the earth's surface (32 feet per second per second), it is a useful reference for measuring other accelerations. The conventional "G" unit, which expresses the inertial resultant of a gravitational unit of acceleration (g), is particularly apposite in considering the physiological effects of acceleration, because the pilot's impression is one of increased weight. The inertia of the pilot's body is therefore subjectively as well as physically equivalent to weight.

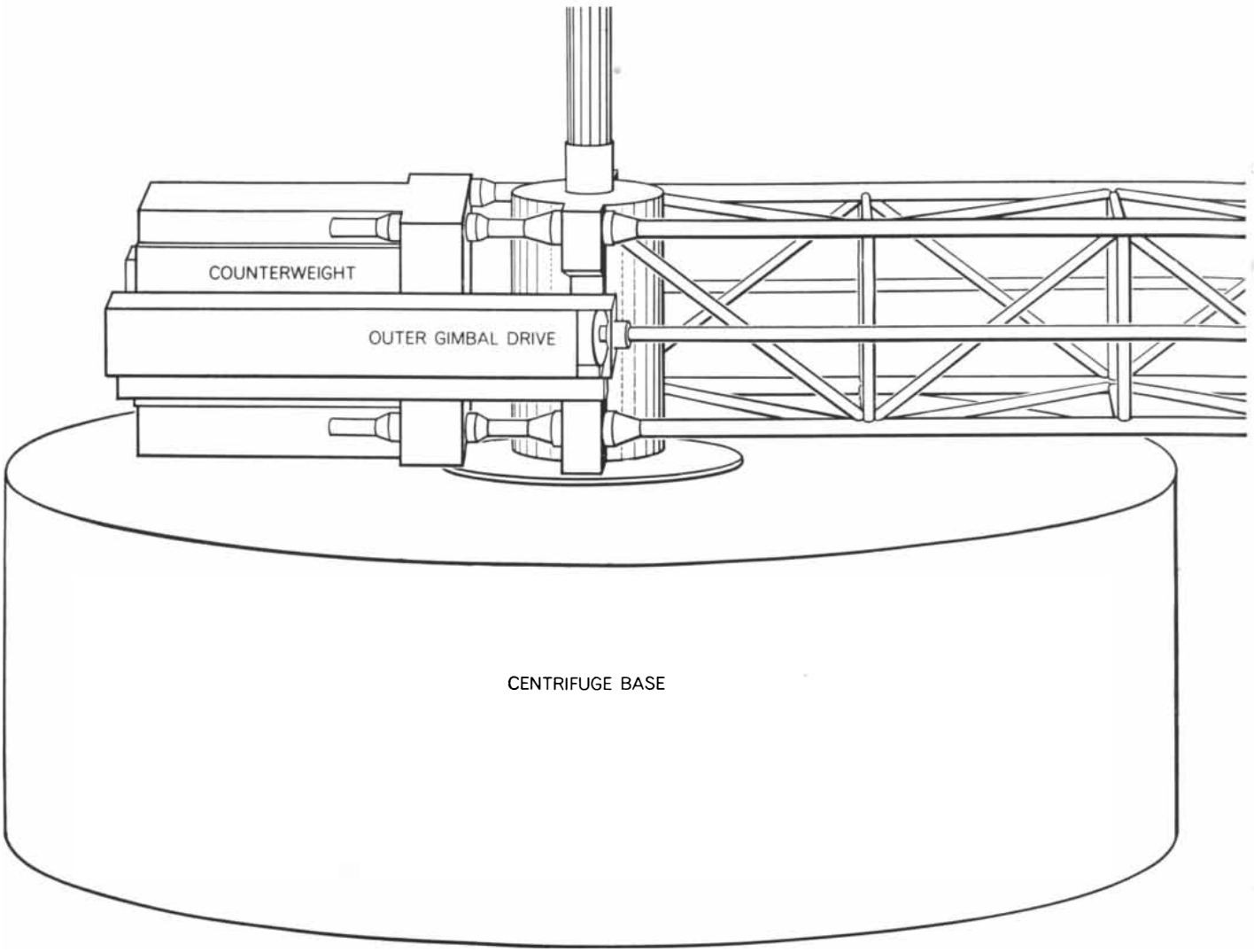
The reason for the fall in cerebral blood pressure that causes blackout can now be examined in more detail. Blood pressure is ordinarily measured in the upper arm at about the level of the

heart, and in a healthy man it shows a mean reading of about 100 millimeters of mercury. Because the hydrostatic pressure of the column of blood in the body is superimposed on the pressure exerted by the heart, the blood pressure in the feet of a seated man is higher: about 140 millimeters of mercury. The blood pressure in the head is half this figure, or 70 millimeters of mercury. If the pilot is exposed to three G on pulling out of a dive, and his mean arterial pressure at heart level remains the same, the blood pressure will drop to 10 millimeters in his head and increase to 220 millimeters in his feet. Because a pressure of only 10 millimeters is not enough to keep the cerebral blood vessels open, the brain tissues are deprived of blood and therefore of oxygen. Unlike muscle tissue, brain cells cannot tolerate even momentary deprivation of oxygen; their function begins to fail immediately, leading to unconsciousness. The same response is seen in fainting, similarly due to a sudden fall in cerebral arterial pressure. The retinal blood flow fails with a lesser fall in arterial pressure because the normal pressure of fluid in the eyeball contributes to the closure of the vessels. Consequently visual blackout precedes unconsciousness.

Another effect of this shift in the hydrostatic pressure decreases the flow of blood to the head still further. Because the veins (but not the arteries) are highly distensible, a large proportion of the total blood volume is suddenly pooled in the lower part of the body, greatly reducing the return of blood to the heart. Since the heart cannot pump out more blood than it receives, its output, and the pressure developed, decreases.

In a healthy young man the pooling of blood in the lower part of the body does not continue indefinitely. The veins reach their limit of distension within a few seconds, and a continuous column of blood returns to the heart once again. What is more, the pilot's blood pressure is usually well above the "resting" mean of 100 millimeters simply from the emotional tension and excitement of diving his airplane, which alone may give him a 20-millimeter advantage. Finally, the nervous system does not passively accept the fall in cerebral blood pressure. Pressure-sensitive nerve receptors in the aorta and in the carotid artery of the neck detect the fall in blood pressure. They evoke a series of reflexes that speed up the heart rate and increase the constriction of the arterioles throughout the circulatory system, both responses serving to raise the blood pressure. These reflexes are not instantaneous, but if a pilot holds his pull-out radius just at the visual blackout stage, his vision will return in about five seconds. In addition, he can improve his G tolerance by tightening his abdominal muscles to diminish the pooling of venous blood. Since the

JOHNSVILLE CENTRIFUGE discussed in the text is the largest in the U.S. The test subject enters the egg-shaped gondola from the platform in the left background. The centrifuge is controlled from the glassed-in compartment projecting from the ceiling.

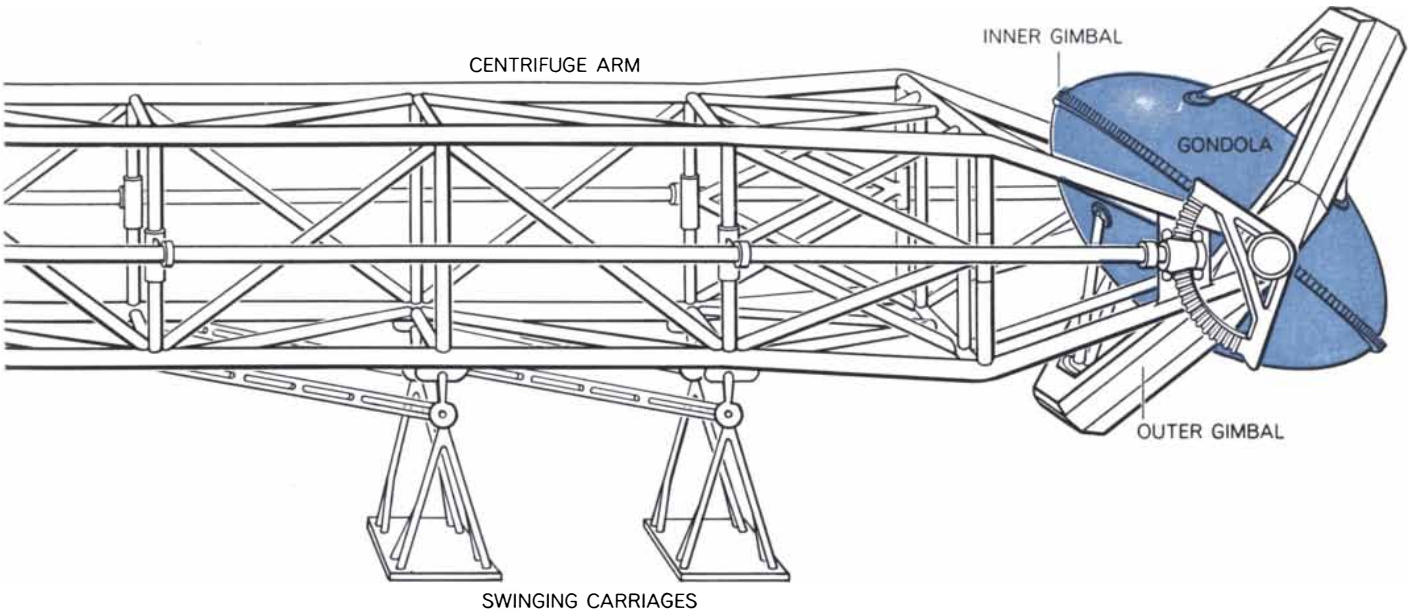


increased hydrostatic pressure gradient between the heart and the head is so critical, another advantage is gained by crouching forward, thereby lessening the vertical distance and consequently the gradient.

Even highly trained pilots black out at about five G. The adaptive recovery of vision with continued G stress is only effective at about .5 G above the initial blackout level, and certainly the upper limit is nearly always less than 5.5 G. This is not too serious for a dive-bomber pilot, because by the time he loses his vision or consciousness, the airplane is already pointed in a safe direction. With the decreased acceleration of level flight the pilot recovers quickly.

In the aerial combat of World War II fighter pilots faced greater acceleration hazards than dive-bomber pilots. An evasive turning maneuver, unlike a dive-bomber trajectory, can be prolonged indefinitely, but to no avail if the pilot is unconscious. From these experiences came the "G suits" with elastic stockings and then tightly laced pants, forerunners of the elaborate protective equipment for jet-fighter pilots. The G stresses encountered in modern jet fighters are not proportionately greater than those experienced in earlier piston-engine fighters. Although very high stresses can be developed in pulling a jet out of a power dive, the consequences can be as disastrous for the frame of the airplane as they are for the pilot. To reduce weight airplanes are not braced to withstand more than about nine G, which is already above the limit of pilot tolerance.

Blackout is not the only effect of acceleration that a pilot can encounter in flight. It is sometimes necessary to execute an outside loop [*see middle illustration on page 62*]. The centrifugal force with respect to pilot and plane then acts from "below" rather than from "above," as in blackout. Airplanes are not usually designed to withstand much of this kind of stress, which can tear the wings from the craft. But even at low G stresses the sensations for the pilot are most uncomfortable. His blood is centrifuged into his head with a painful and peculiarly frightening distension of the cerebral blood vessels. The carotid pressure-receptors detect a great increase in blood pressure and invoke complementary reflexes to slow the heart and lower the systemic blood pressure. Engorgement of the cerebral vessels prevents new blood from entering under the reduced pumping pressure of the slowed heart. The brain cells rapidly use up the available oxygen and loss of consciousness results. Pilots have reported a reddening of the visual field; they have termed the experience a "red-out." Experiments show, however, that engorgement of the retinal blood vessels does not lead to reddening of vision; there is no ready explanation of the phenomenon. Early workers described this stress as "negative G," to distinguish it from the "posi-



HUMAN CENTRIFUGE depicted here closely resembles the one located at the Naval Air Development Center in Johnsville, Pa. The centrifuge base contains the direct-drive motor that rotates the centrifuge arm, which is 50 feet long. The test subject is usually placed in the gondola, although for certain tests the swinging carriages are used instead. The inner and outer gimbals make it possible to vary the orientation of the gondola (and thus of the test subject) in order to test the effects of different types of G stress.

tive G" encountered in pulling out of a dive. The term is descriptive, since the sensation is one of a suddenly "reversed" weight, but it misrepresents the physics of the situation. Nevertheless, it has been formally incorporated in the jargon of the field by international convention.

In a manned rocket the physiological stresses are generated by acceleration along the line of travel rather than at an angle, as in an aircraft. Although this simplifies the physics, the stresses are necessarily more considerable. The efficiency of a rocket engine increases with its velocity. Great engineering advantages are to be gained, therefore, from rapid acceleration—and the consequent increased physiological stress—after liftoff. Most of what is known about the management of these stresses has come from work with the human centrifuge. The Johnsville centrifuge is by far the largest and most sophisticated of the six now operating in the U.S. Because of its 50-foot arm it can achieve accelerations of up to 40 G at relatively slow turning speed. This, together with the enormous power of the motor, permits changes in acceleration of up to 10 G per second. A gear-driven gimbaling arrangement allows the gondola to be oriented dynamically at the start of a swing so that the subject experiences G stress in one direction, as though he were traveling in a straight line instead of a circle. This helps also to eliminate some of the disorientation resulting from the effects of angular acceleration on the inner ear.

The gondola is large enough to hold the subject, his restraint system (which can be quite bulky), large amounts of apparatus related to the research work in progress, an oscilloscope for the display of control and tracking problems, and controls and safety devices for the operation of the centrifuge itself. To the test subject one of the most important of these safety devices is a button to stop the run, known as the "chicken button." The machine is otherwise usually controlled externally, by an operator or by a computer, which can be programed to command the centrifuge through a series of complex operations more precisely than a human operator could.

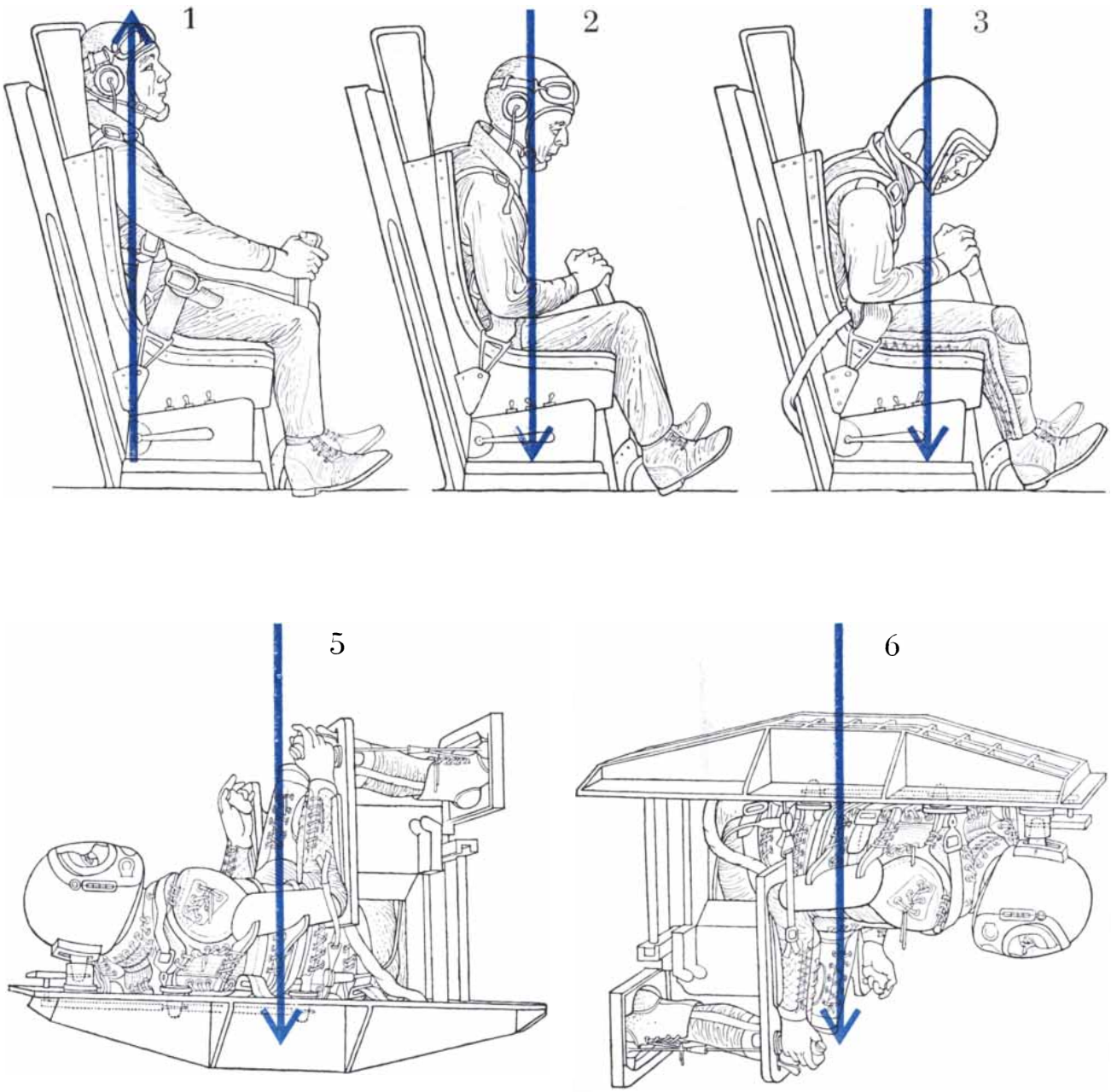
Centrifuge experiments long ago demonstrated the physiological advantages of orienting the subject at right angles to the line of travel. In the capsule of a space vehicle, as the rocket stands on the launching pad, the passenger reclines in the supine position, with the acceleration vector through the shortest axis of his body [*see second illustration from bottom on page 70*]. The small pressure gradient from back to front presents no hydrostatic difficulties for blood circulation. At accelerations greater than six G, however, a new problem appears: subjects find it harder and harder to breathe, and many report sharp chest pains. These effects result principally from a crowding of the abdominal viscera against the diaphragm. Test pilots report the sensation of an "elephant on the chest." At eight G and above, most subjects are barely able to manage adequate breathing in spite of tremendous inspiratory efforts.

Since the heart and great vessels of the chest are surrounded by air-filled lungs, they too are subject to displacement that can cause severe distress under

higher acceleration. Above 10 G the consequent mechanical stimulation of the heart muscle can cause extra contractions that interfere with normal rhythm. An acceleration force exerted across the body, from right to left or left to right, can cause even more severe cardiac disturbance.

The couch used in the Mercury space vehicle of the National Aeronautics and Space Administration supports the astronaut in a way that lessens these difficulties. The astronaut's trunk and thighs are slightly elevated from the horizontal [*see illustration on these two pages*]. This reintroduces a slight hydrostatic gradient between the heart and head, but the abdominal viscera are displaced toward the pelvis rather than against the diaphragm.

An astronaut on a round-trip flight into space must endure stress from deceleration on his return as well as from acceleration on the outbound leg of his flight. Actually the force that exerts the physiological stress is the same in both cases. The difference in physiological stress is merely a question of the astronaut's orientation to the line of travel. In the Mercury flights the capsule was turned



TOLERANCE to sustained acceleration varies with conditions. An unprotected pilot can withstand three negative G (*1*) and five positive G (*2*) before experiencing "red-out" and "blackout" respectively. A laced G suit (*3*) increases his tolerance to about six positive G. The Mercury couch (*4*) enabled the U.S. astronauts to withstand 11 G for brief periods. Tolerance in the "eyeballs in"

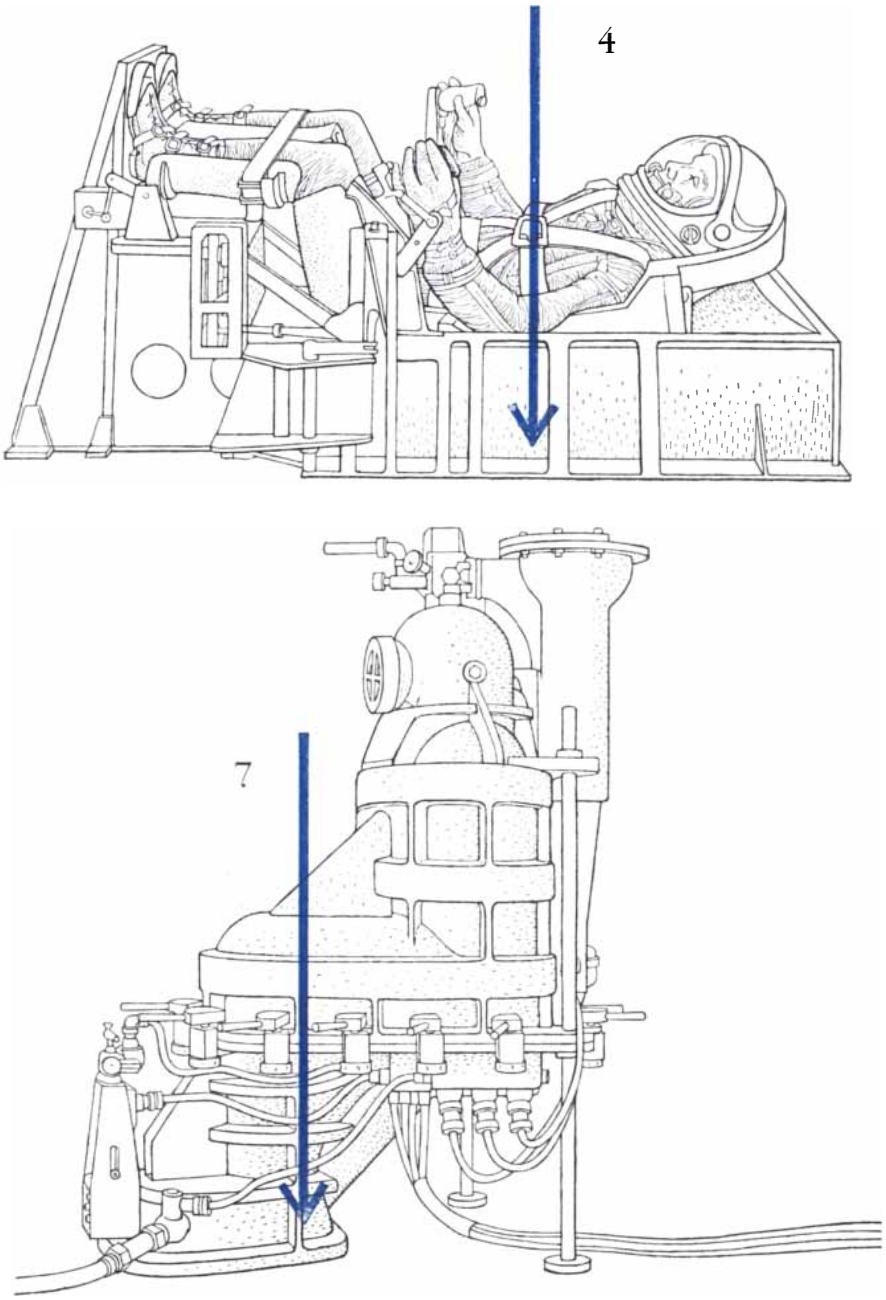
end for end before starting re-entry. By this means the G stress resulting from deceleration through the upper atmosphere was applied in the same direction as it was during the astronaut's outward flight—that is, with his body pressed down into the couch, as if he were lying in a supine position.

Experiments in the centrifuge have shown, however, that there is some advantage to the pilot's facing the other way—in the "eyeballs out" position as distinguished from the customary "eyeballs in"—provided his body is restrained by a proper harness. Carrier pilots experience deceleration in this manner when their aircraft catch the arresting wire in a deck landing. In the centrifuge subjects experience relatively minor breathing difficulty at high accelerations in the eyeballs-out position. The abdominal viscera are displaced toward the front wall of the abdomen, sometimes to a startling extent. Excessive displacement can be controlled by a "stomacher" device. A major disadvantage of the eyeballs-out orientation, still to be overcome, is the flow of tears that interferes with vision at high acceleration.

There is no simple answer to the question of how much G stress a man can withstand. The duration and rate of onset are as important as the degree of stress itself. A distinction must also be made between the G stress that can be tolerated without bodily damage and the G stress at which the subject can still function and perform various tasks. In general, tolerance increases as the duration of stress decreases. Decelerations, for instance, can be made shorter and shorter until they approach what are normally regarded as impacts. Using a rocket-powered sled on rails, Colonel John Paul Stapp has established that adequately restrained subjects, facing either forward or backward, are able to tolerate as much as 40 G if the rate of onset is less than 600 G per second and the duration is less than .2 second. This is equivalent to decelerating from 120 miles per hour to a dead stop in 19 feet. Such stresses might ultimately have to be reckoned with in planetary landings. In passing, it should be noted that the extremities of the body can tolerate very high G stresses of short duration. Calculation shows that an angry human female develops about 100 G at the foot when stalking off in high heels.

In terms of sustained acceleration the tolerance of an unprotected pilot is about five positive G and three negative G. A G suit raises the positive-G tolerance to about six. Tolerance to straight-line acceleration is higher. But above eight G with eyeballs in, chest pains and breathing difficulties detract from the pilot's performance. Individual subjects have withstood peaks of up to 17 G, and the author observed one test pilot who tolerated 14 G with eyeballs in for more than two minutes. Tolerance is higher than eight G in the eyeballs-out position, but the tear flow interferes with vision.

In the suborbital Mercury flights, the peak acceleration of the Redstone rocket was only six G in take-off, but during reentry the pilots had to sustain a brief peak of more than 11 G as the capsule decelerated through the upper atmosphere. Previous centrifuge studies had shown that the peak was too short in duration to be serious. Several people, including the author, who had not had



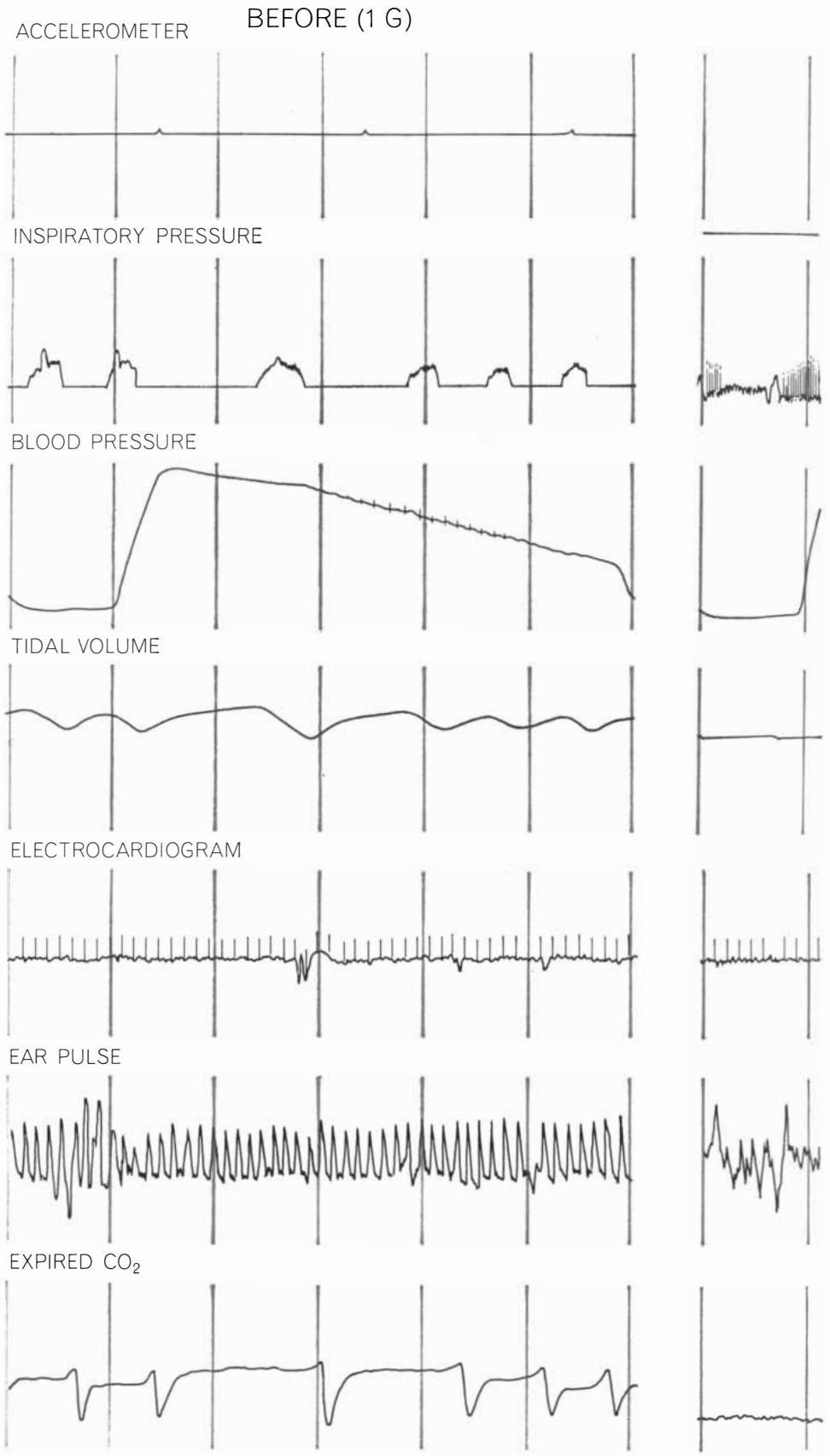
position (5) is about eight G; in the "eyeballs out" position (6) it is greater, but a flow of tears begins to interfere with vision at eight G. The greatest G tolerance was shown by a test subject in a water-filled "iron maiden" (7), who withstood 32 positive G for five seconds.

much previous exposure to G stress, underwent a simulation of this experience in the centrifuge at Johnsville. It was generally agreed that it was not too bad; it was also agreed that once was enough.

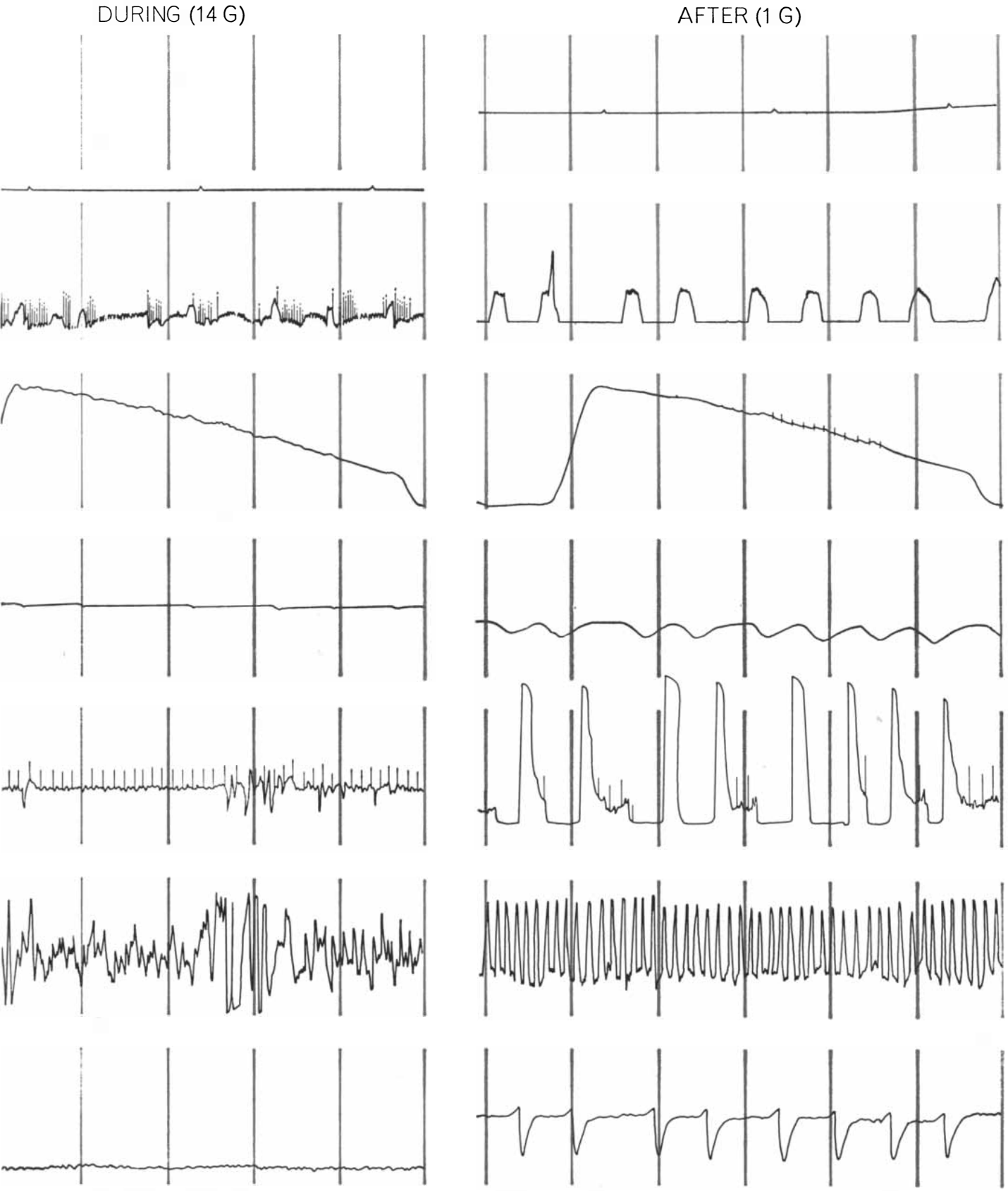
The highest G tolerance in a centrifuge has been shown by subjects immersed in water. In one series of experiments at Johnsville the subject was sealed up in a water-filled tank (obviously with provision for breathing). Such whole-body immersion prevents the hydraulic displacement of blood and tissues. The increased inertia of the body is exactly matched by the increased inertia of the water; consequently the subject does not experience the sensation of increased weight and can move his legs, arms and hands with perfect ease at very high accelerations. One subject sustained 32 positive G for five seconds in the device. This has prompted the suggestion that the fuel tank might be the best place to put the astronaut during acceleration to the velocity of escape from the earth's gravitational field.

There has been no device comparable to the centrifuge for experimenting with the effects of weightlessness. Until the recent manned Soviet and U.S. rocket flights, the only way men could be subjected to weightlessness for more than a few seconds was to fly a carefully controlled parabolic course in an airplane. But even this never gave more than a full minute at zero G [*see bottom illustration on page 62*]. Subjects who have experienced subgravity flights while unrestrained have shown no uniform response. Some were exhilarated, some were uncomfortably aware of their lack of orientation and others were frankly scared and nauseated. These human reactions were paralleled by those of mice, as observed in films taken at zero G in suborbital flight. Mice with something to cling to, however, were less disturbed than those without. This is significant for human space flight. An astronaut would begin his weightless period while still thoroughly restrained against the exit acceleration. He could therefore adjust slowly and cautiously to the problems of movement and orientation in the weightless state.

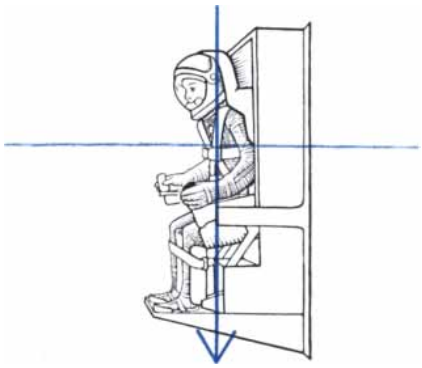
In addition to the largely psychological problems of disorientation, there are physical and physiological problems of some magnitude. A weightless astronaut stands a good chance of vomiting, or at least of painful regurgitation of the stomach contents into the lower esophagus. Attempts to drink from a cup could lead to aspiration of some of the freely float-



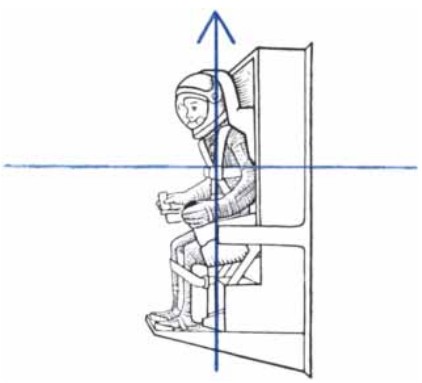
PHYSIOLOGICAL DATA of a test pilot in superb physical condition was recorded during a centrifuge run that included a period of more than two minutes at 14 G (eyeballs in). Each of the three sections shown here represents an interval of 30 seconds. The accelerometer reading is a measure of the acceleration in g's. A small peak appears in the trace every 10 seconds. "Inspiratory pressure" is the amount of "suck" required to inhale. The blood-pressure trace shows the pressure of the cuff on the pilot's arm as it is inflated and then



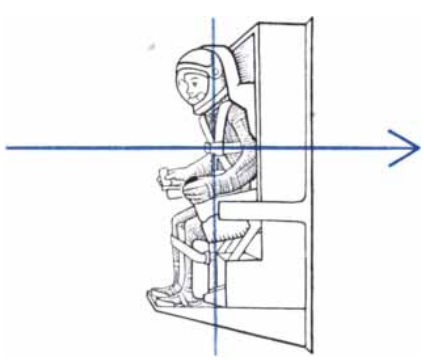
deflates. The small "blips" superimposed on the trace are the sounds of the blood as it flows past the cuff. The first and last blips indicate the systolic (highest) and diastolic (lowest) blood pressures respectively. At high accelerations the blips are not always clearly distinguishable. "Tidal volume," the volume of air moved at each breath, is reduced to almost nothing at 14 G. Large deflections in the "Electrocardiogram trace" at right are caused by the muscular effort of breathing; in several places the regular trace is still visible. The "Ear pulse," a semiquantitative measurement of the pulse of blood in the ear, reflects the blood pressure in the brain. "Expired CO_2" is the amount of carbon dioxide in the air breathed out; at 14 G the pilot cannot breathe any of it out, but he does so afterward.



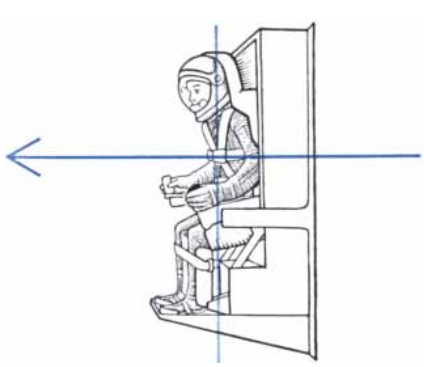
POSITIVE G is the acceleration stress that a subject experiences as acting from above.



NEGATIVE G is the acceleration stress that a subject experiences as acting from below.



SUPINE G (also known as eyeballs in) is experienced in the chest-to-back direction.



PRONE G (also known as eyeballs out) is experienced in the back-to-chest direction.

ing liquid into the lungs. It now seems clear that drink, and probably food, will have to be extruded into the mouth from containers resembling toothpaste tubes. Elimination seems to present the same sort of problem in reverse.

Observation of animals on orbital flights and the limited experience of humans so far has shown that there is nothing positively lethal about exposure to weightlessness. Of the two Russians who orbited, only Major Gherman Titov complained of a seasick-like sensation. But the long-term effects of zero G, particularly the effects on neurological responses and reflexes, are unknown. Movement of the tiny otoliths (ear stones) in the inner ear, for example, give the primary clue to the body's orientation in the gravitational field of the earth. Nerve receptors in the joints and tendons throughout the body are similarly affected by the weight of the limbs, their position in space and so on. In the weightless state the flow of information from the otoliths and other receptors would be profoundly altered or might even cease. Moreover, an unrestrained body would be subject to uncontrollable twists and turns resulting from the slightest contact with walls or equipment. Small angular accelerations of this kind, detected by the semicircular canals in the inner ear, can cause nausea and vertigo. Vertigo has been observed in some subjects during zero-G aircraft flights, but this may have resulted from the violent positive-G maneuvers that precede the parabolic, zero-G portion of the flight.

Investigators are concerned that the reflexes controlling the circulation might deteriorate under weightlessness. It is possible that an astronaut who tolerated 10 G during his exit acceleration could tolerate a 10-G re-entry less easily after a week or more of zero G. There are at least three possible effects to be considered in this context.

In the first place, long periods at zero G might be expected to depress the response of the pressure receptors in the circulatory system. This is a common outcome of mere confinement to bed; the convalescent's "weakness" is partly due to the sluggish response of the pressure receptors in the aorta and carotid artery that adjust the blood pressure to the hydrostatic gradient between the head and feet.

The second factor to be considered is that of blood-volume changes. In the maintenance of normal fluid volume the excretion of water and salts is balanced against intake by a complex array of controls that is only dimly understood. These mechanisms also appear to be affected by prolonged bed rest, and men floating in water for several hours tend to excrete more than their normal urine volume, leading in extreme cases to a decrease in blood volume. The physiological similarity between floating and zero G is debated, but it is nonetheless certain that the volume receptors would be affected. Men subjected to long periods at zero G may therefore suffer a diminution in blood volume that could affect their performance during re-entry. It may be possible to offset this effect by drug and hormone therapy already widely used in clinical medicine for the correction of comparable fluid balance defects due to disease.

Finally, it is possible that prolonged exposure to zero G may affect the sensitivity of the pressure-receptor cells themselves. These specialized nerve cells are actually distortion-sensitive; they respond, for example, to the rhythmic distortion caused by changes in blood pressure as the heart beats. Strictly speaking, they are also distorted by their own weight. Weightlessness might shift their "zero response" ever so slightly.

Such are the physiological considerations that condition man's venture into space. The velocity necessary for a rocket to escape from the earth's gravitational pull is about 25,000 miles per hour. If 10 G is set as a reasonable upper limit, it will take a rocket nearly two minutes to attain escape velocity, a fairly long time from the standpoint of engineering efficiency. This G stress is well up on the discomfort scale for even a supine man, but it is tolerable. Stress on re-entry will undoubtedly have to be limited to eight or 10 G if the pilot is to exert any effective control.

The G stress most likely to cause trouble in longer voyages, however, is weightlessness. It is to be hoped that any cardiovascular effects can be met by appropriate therapy along well-established lines. The psychophysiological effects, on the other hand, may be more serious. If they do prove to be intolerable, the vehicle could be accelerated at a fraction of one G to about the halfway point and then decelerated for the remainder of the voyage. Alternatively, slow rotation of the vehicle would apply a small centrifugal effect. Either of these maneuvers would give rise to a slight but comforting sensation of weight for the crew. They would, however, require the expenditure of additional fuel and should be avoided if possible.

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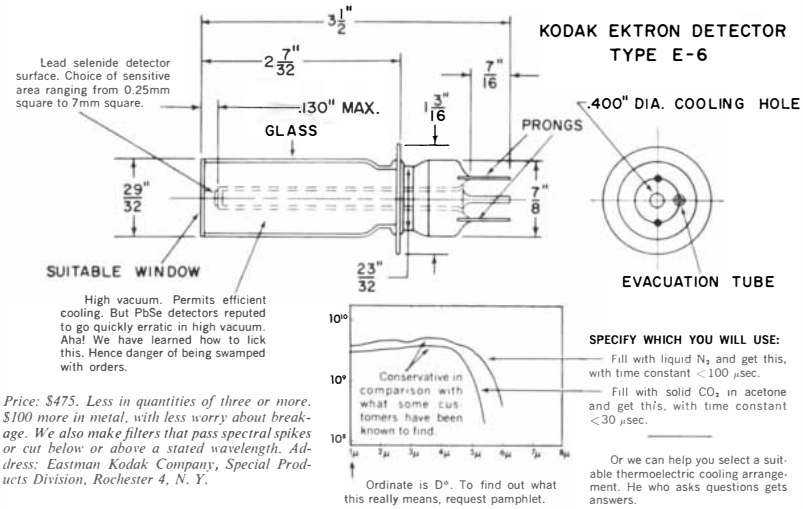

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Natural finish

Though you never see our name on a can of lacquer, we know a great deal about protective coatings. All we do with our knowledge on this subject is give it away. By spreading the knowledge, we hope to promote the spreading of cellulose esters over surfaces of wood, paper, metal.

Eastman Tenth-Second butyrate* is our newest cellulose ester. It is for lacquer formulators. If you are not in that business, perhaps you would consider entering it. We would help you.

Before going far in your thinking about lacquer you realize that the higher the solids content of a lacquer, the better. The more solvent needed to dissolve the film-forming substance, the more waste.

The butyrylated, acetylated cellulose chains run much shorter in our new product than heretofore. The lower average molecular weight results in higher solubility, which permits higher solids content in lacquer. It also means poorer film strength. But that's OK because we can show you how to compensate for the sapping of strength. A butylated urea-formaldehyde resin, included at the right proportions in the formulation along with the proper catalyst, will cross-link to the cellulose acetate butyrate during the drying of the coating *and not before*. The matrix should also contain an epoxy resin or a plasticizer. To provide a point of attachment on the cellulose chain, we restore one out of twelve of its hydroxyls. This condenses with the butoxy groups of the butylated urea-formaldehyde polymer to split out butyl alcohol.

Thus you have your cake and eat it. The short-chain CAB that is more soluble in the can becomes very much less soluble in the finish of a table on which some gay dog has set down the cup that cheers. No longer need a drop of lotion spilled on the dresser trouble the conscience of a good wife. When she brings a piping hot casserole to the table, let her be comforted by the elevation of melting point that the cross-linking confers.

In these days of epoxy resins, silicone resins, methacrylate resins, maleated vinyl resins, amino resins, polyesters, alkyds, and polyurethanes, why do we monkey with cellulose? What a silly question!

For one thing, we have shown how admixtures of cellulose acetate butyrate can improve all these by contributing faster air-drying, better flow-out and sprayability, greater toughness, and improved outdoor durability.

For another, cellulose is by far the world's most abundant high polymer. It is formed from CO_2 and H_2O by sunshine on green leaves, a beautiful synthesis.

For full information on Tenth-Second butyrate *or anything else related to cellulosics (other than cellulose nitrate) in surface coatings, write Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).*

*Time taken for a 5/16-inch steel ball to fall through ten inches of a 20% solution in a 90/10 mixture of acetone/2B denatured alcohol at 25°C in a 1-inch tube.

A slide projector like a merry-go-round

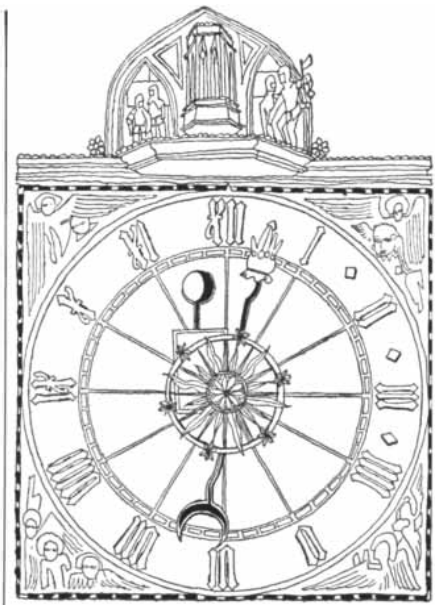
This is the Kodak Carousel projector. It projects slides. Carousels symbolize carefree abandon. Care lest slides jam can be abandoned. Gravity feeds them. Gentle gravity. Slides are automatically lifted back to 80-slide storage tray. Pushbuttons at end of long cord advance slides,* reverse, even refocus. (Latter is largely for kicks. Actually, slides get prewarmed not to pop out of focus.) See Kodak dealer for exact price. You will find it is less than $150. Lucky you happen to be in the market at this particular time.

*Alternatively, projector can be set to advance every 5, 10, or 20 seconds. This scheme is more urbane than an alarm clock for the chairman.

Prices subject to change without notice.

Kodak
TRADE MARK

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



SCIENCE AND

Science and Citizenship

The relationship between science and public policy dominated the annual meeting of the American Association for the Advancement of Science held in Denver at the end of December. On the first day of the five-day meeting the association's Committee on Science in the Promotion of Human Welfare presented a report calling for "the establishment of a new collaborative science, the science of human survival, which will apply the full strength and wisdom of all the sciences to the solution of the crisis created by the obsolescence of war."

The report declared that there is "no historical evidence" that any measures could enable a society to survive an unlimited war fought with modern weapons; that "if we permit such a war to occur . . . we run the risk of ending human history altogether"; and that "science has powerful means for correcting faulty human conceptions such as the continuing belief that human societies can be conserved by modern war." Since "we can no longer risk actual historical experiments to prove out the alternative methods of survival open to the human race," only collaboration between the natural and social sciences can "devise new social inventions to protect all mankind from self-destruction."

In the plenary symposium, "Problems of Survival," led by Barry Commoner of Washington University, Tom T. Stonier of the Rockefeller Institute reported on a study of the probable effects of a 20-megaton nuclear ground burst in a metropolis: a crater half a mile in diameter and deep enough to contain a 20-story building, severe blast damage over an area seven and a half miles in radius and a circle 11 miles in radius devastated by fire storm. Seymour Melman of Columbia University, taking issue with studies of the feasibility of nuclear war, predicted that the industrial disorganization caused by a nuclear attack would make recuperation an insuperable problem. Margaret Mead of the American Museum of Natural History pointed to the negative effects of the "focus on survival" on the moral fabric of society preceding the outbreak of war. A dissent was entered by W. E. Strope of the U.S. Office of Civilian Defense, who maintained that planning could mitigate the problems of survival.

At other sessions papers and symposia dealt with such questions as "Existing Levels of Radioactivity in Man and His Environment," "Decision-making in International Political Crises," "Law, Science, and Decision-making," land use, water supplies, population growth and the teaching of science in elementary and secondary schools.

Less Chance to Hide

It appears increasingly doubtful that an atomic-weapons test of significant dimension can be concealed either underground or in outer space. A five-kiloton nuclear explosion in an underground salt cavern near Carlsbad, N.M., last December 10 was clearly recorded by seismographs as far away as Tokyo, New York, Uppsala in Sweden and Sodankyla in Finland. The seismograph records included tracings of the "first motion," considered critical in distinguishing between earthquakes and underground explosions. In explosions the first motion is always outward from the site of the blast. In earthquakes some seismic stations will record the first motion as an outward movement of the earth's crust and some as a movement toward the site of the earthquake, since earthquakes involve faulting and slipping rather than a uniform outwardly directed force.

During the atomic-test-ban negotiations in 1958 a number of specialists suggested that clandestine underground tests could be made virtually impossible to detect by conducting them in a large chamber. Albert L. Latter of the Rand

Corporation, an author of the "big hole" theory, estimated that such "decoupling" would reduce the seismic waves from the explosion by a factor of 300—more than enough to put large underground shots well below the threshold of the detection system under discussion at Geneva. Proponents of the big-hole possibility argued that a cavern of sufficient size could most easily be excavated by flushing a salt dome with water.

Clandestine shots in space appear to be entirely open to detection. In a report at the meeting of the American Association for the Advancement of Science, Herman Hoerlin and Donald R. Westervelt of the Los Alamos Scientific Laboratory produced figures to show that the auroral glow produced when gamma rays from a nuclear burst strike the upper reaches of the atmosphere would betray tests conducted at great distances from the earth. With the aid of a horizon-to-horizon scanner and suitable photomultiplier equipment, Hoerlin and Westervelt said, a 20-megaton burst could be detected as much as 14 million miles from the earth, and a 100-megaton burst could be recorded at a distance of 28 million miles. Larger bursts could be monitored at still greater distances, possibly up to twice the distance from the earth to the sun.

The Atomic Energy Commission released preliminary results of its monitoring of the recent series of tests conducted in the atmosphere by the U.S.S.R. The tests proved to be "cleaner" than anticipated, with a fission yield of "about 25 megatons, out of the total yield of about 120 megatons for the approximately 50 atmospheric tests." "Of special interest," the commission said, "is the small fission yield of the 55–60 megaton test conducted on October 30." This finding indicates that the U.S.S.R. "has made advances in certain areas, especially in improving the yield-to-weight ratios of weapons in the megaton range."

Excited State

Particle physics is passing through one of its recurrent states of high excitement. The last big flare-up had to do with the so-called weak interactions of elementary particles and the property known as parity. This one concerns strong interactions, of which the nuclear

binding force is an example. Latest news from the laboratories is yet another particle, called the eta meson, and on the theoretical front, according to some physicists, a hint of a possible major breakthrough in understanding.

All this started a few years ago with the first experiments on the scattering of high-energy electrons by nucleons (protons and neutrons). As expected, the scattering patterns showed that nucleons consist of a cloud of mesons. But the detailed electromagnetic structure of the clouds came as a surprise. A number of physicists pointed out that the structures could be accounted for if the electrified clouds contained two new kinds of meson in addition to the ones already known. These new particles would presumably appear in the debris of energetic reactions.

Calculations indicated that one of the new particles should come in positive, negative and neutral forms and should decay into two pi mesons (pions). The other should be only neutral and decay into three pions. Both mesons would have an extremely short lifetime (about 10^{-22} second), so that even the charged forms could leave no visible track in a cloud chamber or bubble chamber. Therefore they could be detected only through their decay products. Most high-energy particle collisions result in a spray of pions in varying numbers. In a large number of collisions yielding a particular number of pions, say two, the total energies of the pion pairs would normally be expected to fall on a smooth curve. If the experimental plot of energies turned out to have a sharp peak, or "resonance," at a particular value, this would suggest that the excess pion pairs responsible for the peak resulted from the decay of particles with a mass appropriate to this energy.

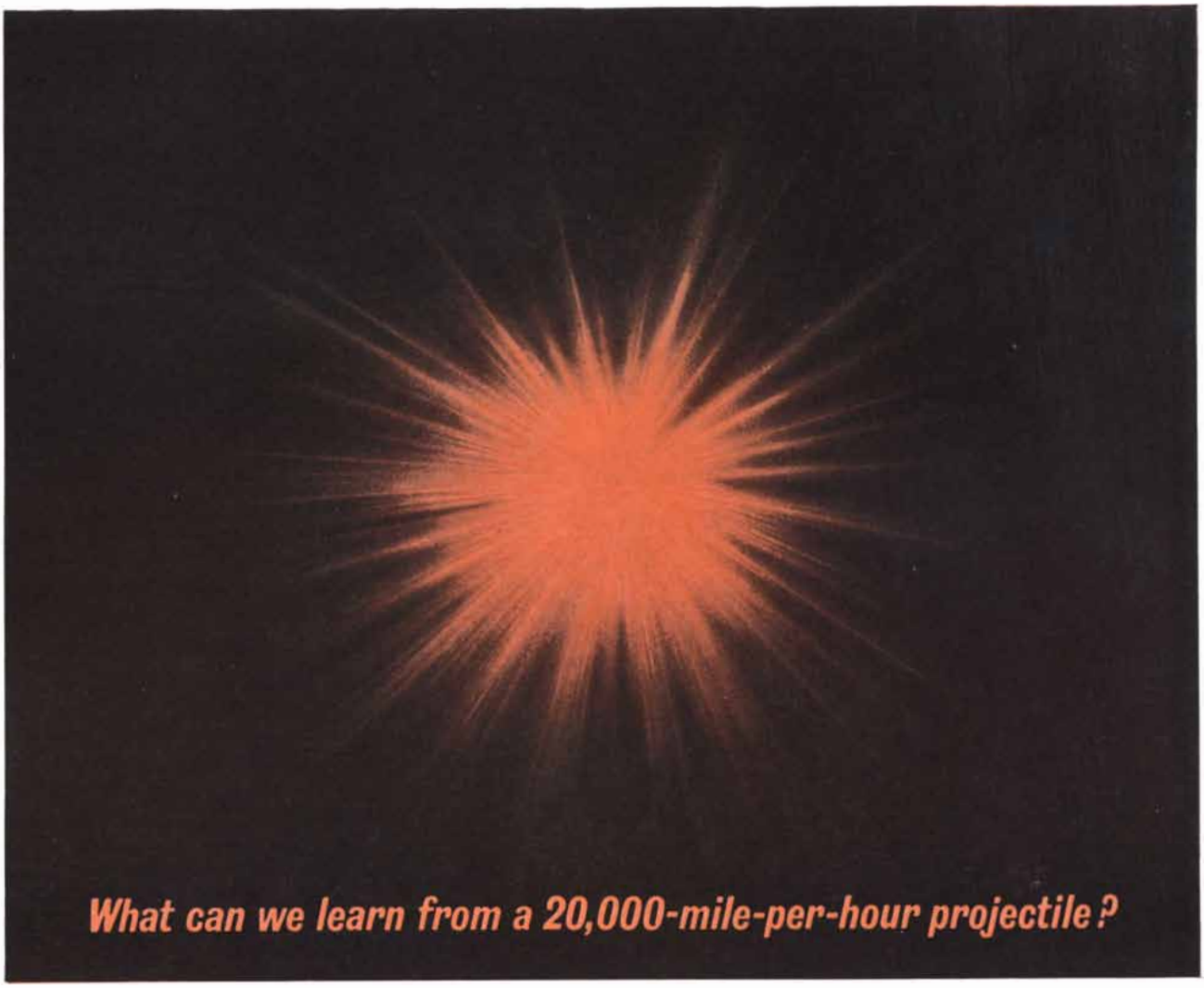
In 1960 several experimental groups proceeded to examine collisions yielding two pions. Their search was promptly rewarded by the discovery of a resonance at 750 million electron volts (Mev), equivalent to a mass 1,500 times that of the electron. The particle that was presumably responsible for this resonance was named the rho meson. Further studies showed that it indeed occurs in positive, negative and neutral forms, and that it has the spin, parity and other properties demanded by the electron-scattering results.

A few months ago a three-pion resonance at 770 Mev was found [see "Science and the Citizen," November, 1961]. Called the omega meson, the underlying particle is neutral and has all the other properties appropriate to the second of the predicted mesons, except for one thing: it is too heavy.

Late last year *Physical Review Letters* carried a report from a group at Johns Hopkins University led by A. Pevsner announcing another three-pion resonance, at 550 Mev, to which the name eta meson has been assigned. This is equivalent to 1,100 electron masses, about the upper limit for the mass of the neutral meson required by the electron-scattering data. Whether or not the eta has the other requisite properties remains to be seen.

As soon as the possibility of the new mesons was recognized, theoreticians began to try to fit them into a general scheme of the elementary particles. A number of different approaches have been explored. At one extreme the resonances are considered to represent true elementary particles; at the other, they are regarded as not really individual particles at all but simply as "excited states"—dynamical associations of other particles. An exponent of the first approach is J. J. Sakurai of the University of Chicago. He has proposed a theory of the strong interactions that divides them into three separate components, or fields. Since every field has its own quantum particle (the photon is the quantum of the electromagnetic field and the pion is the quantum of the nuclear-force field), the theory has a place for three new mesons. Sakurai conjectures that the rho, omega and eta mesons are in fact these field quanta. As in all theories dealing with strong interactions, mathematical difficulties make quantitative predictions hard to come by. Whether or not the three new mesons are really the ones predicted by Sakurai remains an open question.

The attempt to account for the resonances as composites of other particles was pioneered by Geoffrey F. Chew of the University of California. In the past few weeks interest in this line of attack has greatly increased. It appears that some recent developments in the mathematics of quantum mechanics may be applicable to the problem of composite particles and, if so, may make possible a complete solution, not only for the new mesons but also for the entire class of strongly interacting particles. This solution would put all mesons on the same footing: they would be equally "fundamental" and equally composite in that each one could be viewed as a dynamical association of the others. Whether or not the particles do behave according to the new mathematical theory is susceptible to experimental test. The only catch is that the energies required



GM's DSD speeds the answer!

In the Flight Physics Laboratory of General Motors Defense Systems Division, projectiles are boosted to fantastic speeds. Velocities of 31,000 feet per second have already been achieved. Flights at 40,000 feet per second or faster are felt to be attainable in the near future. Studies are under way of missile signatures, high-speed impact, properties of ionized gases. New or refined methods of detection, identification, communication and navigation are now under development, and are now being studied in this unique facility. And the results of these studies may well be of great significance in pointing the way to new methods of defense. Unusual studies like these, unusual facilities, and unusually capable men present a great challenge and opportunity to scientists and engineers who are qualified to make a solid contribution at any level. DSD is now, as always, searching for new talent in these areas.

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

High-Velocity Impact—This is an actual photograph of the crater blasted into a block of solid aluminum by a nylon projectile in tests conducted in DSD's unique Flight Physics Laboratory. Here projectiles from two light gas guns are studied at close range, while flying faster than man has ever been able to fly them before . . . up to 31,000 feet per second. If you can use facilities like these, contact DSD.

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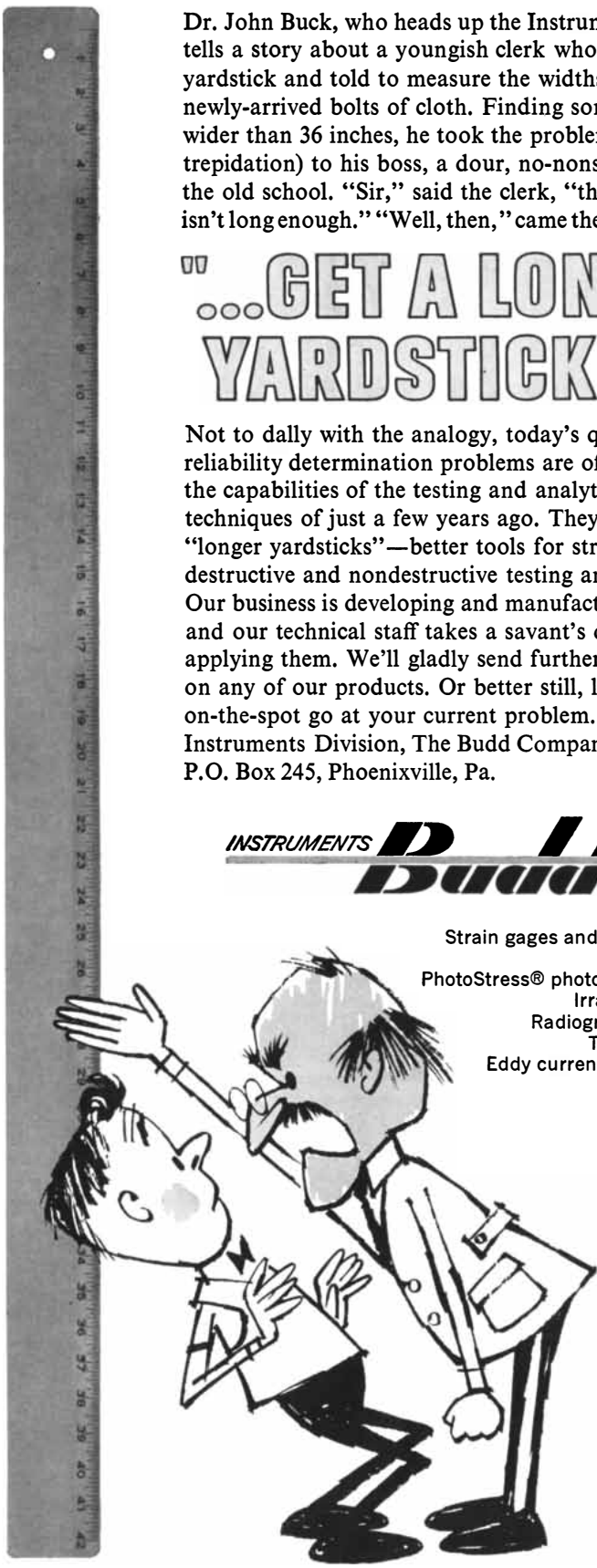


for the test may be slightly higher than the 30 billion electron volts (Bev) available in the largest of the present particle accelerators. In any case, if matters turn out favorably, some theoreticians believe it may be possible to reach the long-sought goal of a theory that accounts for the entire assemblage of particles and predicts their masses.

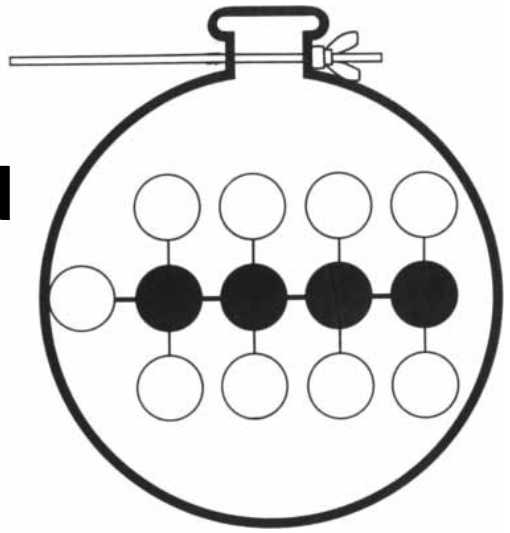
Breaking the Code

Further progress has been made in understanding the process that enables RNA (ribonucleic acid) to direct the synthesis of proteins within the cell. Evidence that a special form of RNA, called messenger RNA, represents a one-to-one recoding of information carried by the genes is presented in the article by Jerard Hurwitz and J. J. Furth beginning on page 41 of this issue of SCIENTIFIC AMERICAN. The next transcription of the code, from RNA to protein, is more complicated. The code in RNA is carried by four nitrogenous bases: adenine (A), uracil (U), guanine (G) and cytosine (C). Proteins, in contrast, are codelike chains of molecular subunits, comparable to letters, that can be any of 20-odd different amino acids. In some way the four-letter RNA code is transcribed into a 20-letter protein code.

Last August, at the Fifth International Congress of Biochemistry in Moscow, Marshall W. Nirenberg reported how he and J. Heinrich Matthaei had found that a synthetic RNA molecule made of repeating units of a single base, uracil, stimulated the formation of a synthetic protein composed of repeating units of a single amino acid, phenylalanine. The work, done at the National Institute of Arthritis and Metabolic Diseases, marked the first major break in the coding problem.

Extending their investigation, Nirenberg and Matthaei now report progress in identifying the RNA code groups that correspond to 15 of the amino acids. The new work will be published shortly in *Biochemical and Biophysical Research Communications.* A similar set of investigations has also been carried out at the New York University School of Medicine by Severo Ochoa, Carlos Basilio, Peter Lengyel and Joseph F. Speyer. Their findings are being published in the February issue of *Proceedings of the National Academy of Sciences.* The two groups of investigators use the same general method to convert amino acids into synthetic proteins: they employ cell-free extracts of ribosomes obtained from the colon bacillus. Ribo-

proving ground for Polymers in Plastics



Celanese has opened a Polymer Development Center at Clark, New Jersey as the fourth and newest unit in a research and development complex for creating new horizons in chemical and polymer technology.

The primary purpose of this Center is to provide Celanese customers with expert technical and practical assistance in using plastics in volume markets such as automotive, packaging, appliances and construction. It is a place where advanced technology can be related to industrial problems—where Celanese customers can obtain information about what's new in plastics, in manufacturing techniques and marketing trends.

The modern laboratory building, covering more than two acres, houses chemical and physical laboratories, and actual pilot production equipment such as machines for injection molding, blow molding, wire coating, pipe extrusion, film casting and thermoforming.

There is a full complement of testing equipment to measure physical and chemical properties, as well as laboratory production plants in glass for polymer synthesis and development of special plastic formulations.

But the heart of the center is its staff of 120 specialists who represent a concentration of scientific and engineering skills as broad as the plastics industry itself. This experienced group plays an important role in the Celanese program of growth and expansion by putting polymers to work in new ways for the plastic industry and its customers. Celanese Corporation of America, 522 Fifth Avenue, New York 36, N. Y.

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somes are tiny particles composed of protein and nucleic acid that act as the cell's protein "factories." When removed from the cell and supplied with suitable raw materials, including RNA, the ribosomes will manufacture any protein for which the RNA is coded.

Synthetic RNA's containing mixtures of two of the bases (UA, UG, UC) or three of the bases (e.g., UCA, UGA) are added to the system together with amino acids, of which one is radioactively labeled. If the labeled amino acid is found to be incorporated in a synthetic protein, it is inferred that the incorporation was stimulated by the particular RNA present.

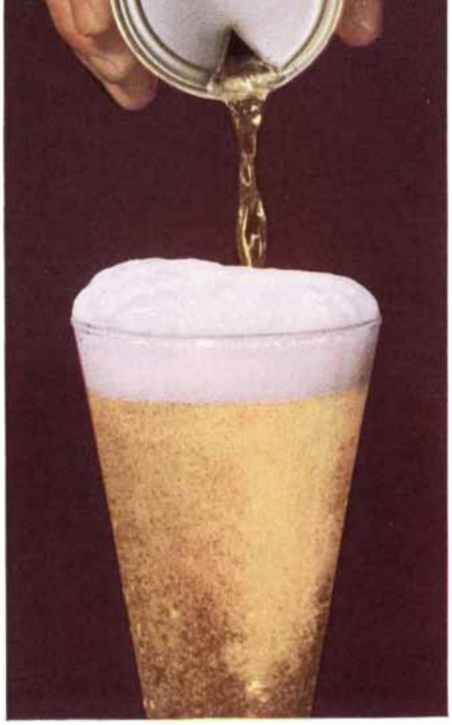
For example, RNA's containing a large proportion of uracil (U) and a small one of adenine (A) stimulate formation of proteins containing tyrosine, isoleucine and lysine. Although the actual sequence of U and A in the RNA is not known, it is assumed that most three-letter sequences will contain two units of U and one of A: UUA, UAU or AUU. Which sequence goes with which of the three amino acids has not been determined. In fact, it has not yet been demonstrated that the coding is achieved by a three-letter sequence or that the letters are sequential. Other coding arrangements are possible.

Nirenberg and Matthaei have found evidence, however, that the code is "degenerate," meaning that a single amino acid can be designated by two or more code units. Thus leucine is incorporated by molecules containing either U and C or U and G.

Hard Rock

A team of Soviet geochemists has produced an ultradense form of silica in the laboratory and has thereby provided additional evidence that Arizona's famous Barringer Crater was formed by the impact of a giant meteorite. The new material, named stishovite for S. M. Stishov, leader of the team that produced it, is a silicon oxide with six atoms of oxygen per silicon atom instead of the two in ordinary silica. Stishovite was heated and squeezed into existence under a pressure of 160,000 atmospheres (2,350,000 pounds per square inch), more than twice the pressure required to manufacture diamonds.

Shortly after publication a copy of Stishov's report reached E. C. T. Chao of the U.S. Geological Survey, who has been studying coesite (another dense form of silica) and other high-pressure minerals from meteorite craters. The report gave Chao a clue to the



TWELVE MICRONS SEPARATE "AH-H-H!" FROM "PFUI!"

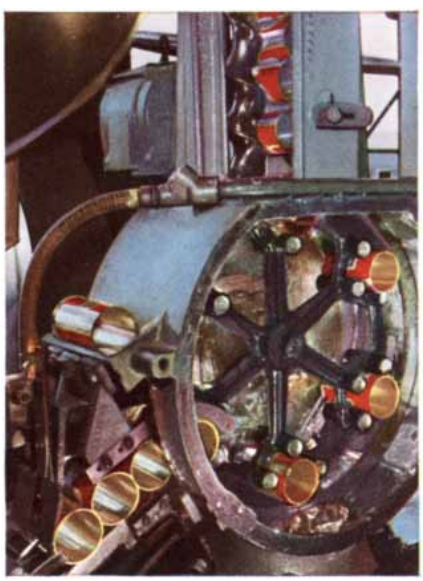
Between a flavorful beverage and its metal container, Glidden can coatings only .0005" thick make the difference between a tasty treat and an unappetizing disappointment.

Concentrated research by Glidden chemists on petroleum monomers provided the basis for a new can coating system that gives full protection and meets FDA and consumer requirements.

Butoxy base coats provide highly impervious can linings that are applied by existing coating equipment, yet cost up to one-third less. New Glidden vinyl top coats are readily applied over the base coat for complete protection of beverage from taste and appearance failures.

1 Copper sulfate test shows up any eyeholes or breaks in the coating as black spots. Glidden-developed coating completely protects test can end (at top) even after fabrication, processing and extended storage.

2 In the Glidden can coatings laboratory, this 15-inch roll-coater, one of only six in the nation, enables Glidden chemists to duplicate coating methods to be used on customers' production lines.



3 Retractable spray-gun deposits continuous coatings of Glidden taste-inert vinyl top coat over entire inner surface of the can body. Glidden technical service personnel work closely with customers' technical and production men to assure that coating is perfectly suited to application equipment.

4 At six Glidden Industrial Finishes plants, formulations of special can coatings to highest quality-control standards are produced in batches from a few drums to tank-wagon lots.

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

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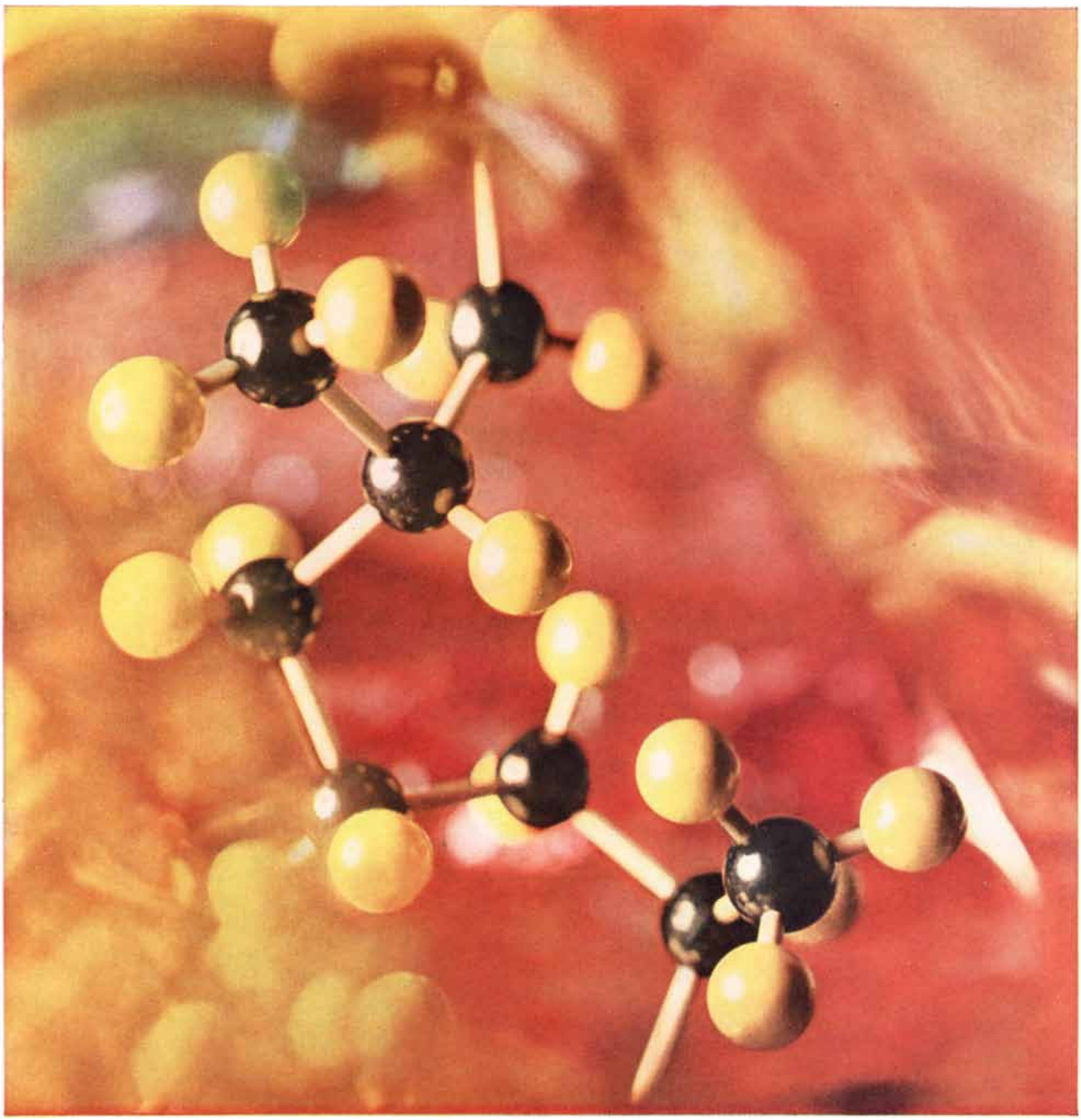

Seen any good molecules lately?

Basic research at Enjay affiliates gives birth to many remarkable molecules. Some reach you as advanced plastics and rubbers that make possible entirely new levels of product performance. Others take the form of more efficient chemicals that cut costs in many processes.

Take EPR (ethylene-propylene rubber), for example. Enjay is now producing the world's first commercial quantities of this promising new synthetic, which offers outstanding resistance to ozone, weathering and chemicals. Another interesting molecule is pseudocumene. Now available from Enjay for the first time in bulk, this low-cost aromatic hydrocarbon provides a new source of intermediates for the manufacture of drugs, dyestuffs, resins and plasticizers.

Research into molecular structures never stops at Enjay. It's one of the ways we bring you constantly improved chemicals, plastics, rubber and petroleum additives. To find out what the results of this research can do for you, please write to Enjay, 60 West 49th St., New York 20, N.Y.

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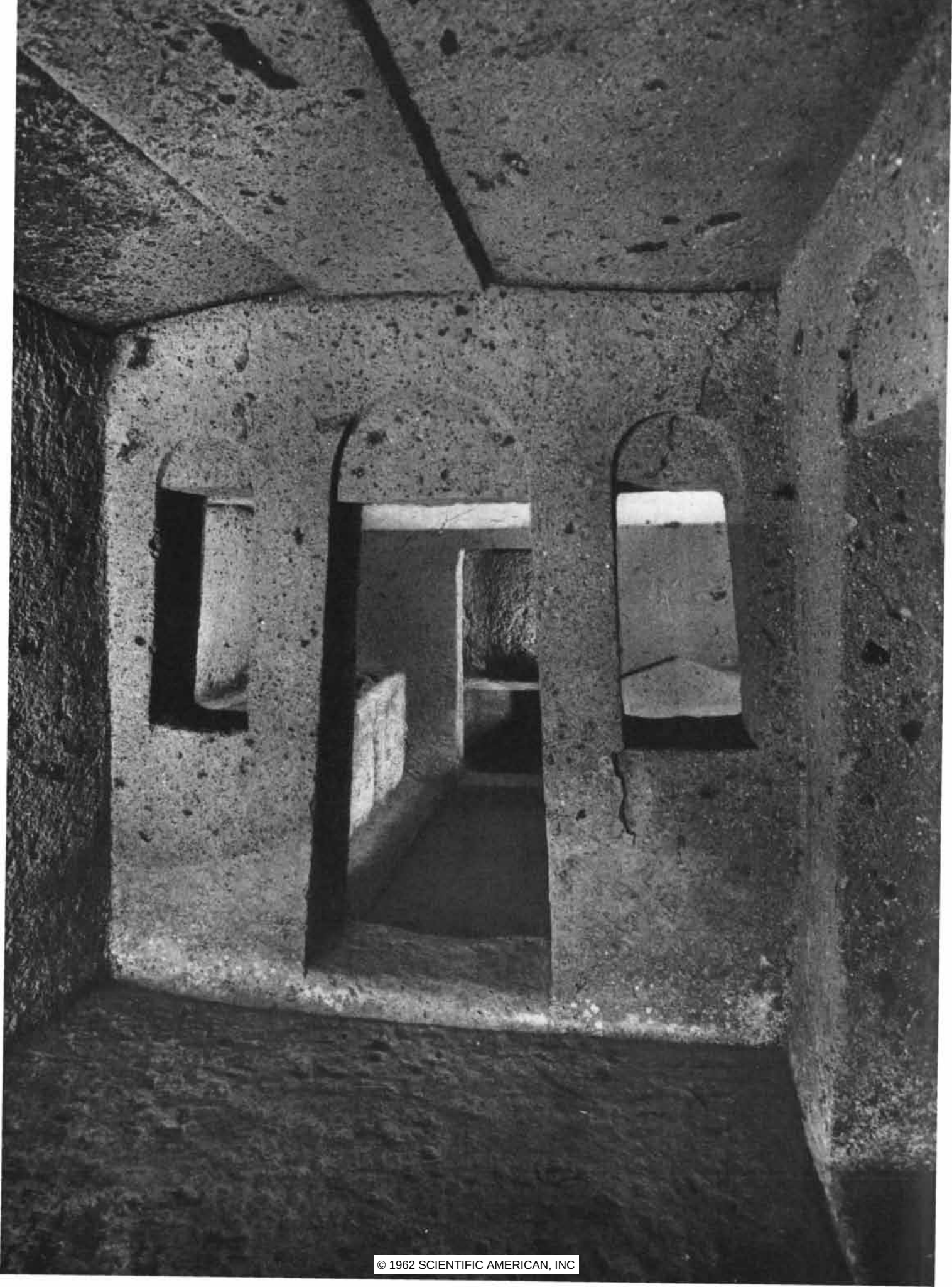
composition of a number of small, hard, glossy grains he had found in the Arizona crater and had so far been unable to identify. The grains exhibited an X-ray diffraction pattern identical to that to be expected for stishovite, and indeed turned out to be stishovite.

Pressures great enough to produce stishovite ordinarily occur only hundreds of miles within the earth. They can occur near the surface of the earth, Chao noted, only under the impact of a large meteorite. The presence of stishovite, along with coesite and the peculiarly fragmented rocks known as shatter cones, in the Arizona crater further confirms the crater's meteorite origin [see "Astroblemes," by Robert S. Dietz; SCIENTIFIC AMERICAN, August, 1961].

In another development in the same area of investigation W. Gentner and his associates at the Max Planck Institute for Nuclear Physics in Heidelberg have dated the origin of the Ries Kessel, a 17-mile-wide basin in southwestern Germany recently shown by the presence of coesite to be an ancient meteor crater. A specimen of glass from the Ries Kessel, presumably made at the same time the basin itself was formed, was found by potassium-argon dating to be about 15 million years old. The date, Gentner and his colleagues point out, agrees well with the potassium-argon age of Czechoslovakian tektites, glassy stones believed to be the solidified droplets of molten rocks splashed up by the impact of the Ries Kessel meteorite [see "Tektites," by Virgil E. Barnes; SCIENTIFIC AMERICAN, November, 1961].

Last Word

A suit against the Federal Government by Jess M. Ritchie, manufacturer of the battery additive AD-X2, claiming damages of $2,369,064 for a National Bureau of Standards finding that AD-X2 is without value in extending storage-battery life, has been dismissed with prejudice by the U.S. Court of Claims. The phrase "with prejudice" means that the suit cannot be revived and finally puts an end to the battery-additive storm that nine years ago nearly wrecked the Bureau of Standards. The dismissal came after pretrial conferences in which the Government disclosed the nature of its case against Ritchie. Ritchie's attorneys thereupon asked for permission to withdraw the suit; they concurred in the Government's request that the dismissal be with prejudice. Ritchie, however, continues to market AD-X2.



THE ETRUSCANS

This enterprising people held sway over most of Italy before the rise of Rome. They are an integral part of the tradition of Western civilization, but their origins remain a mystery

by Raymond Bloch

In the heritage passed on to the modern world from the classical civilization of the Greeks and Romans, we must not fail to reckon the legacy of the Etruscans. In the seventh and sixth centuries B.C., half a millennium before the ascendancy of Rome, these industrious and enterprising people almost succeeded in bringing the entire Italian peninsula under their sway. The Etruscans ruled Rome itself for more than a century, and modern Bologna stands on the site of Felsina, their distant northern capital across the Apennines in the valley of the Po. Their fleets and armies were outfitted for wars of expansion and conquest by the mines and forges of the most advanced metallurgical technology in the central Mediterranean. Etruscan commerce in metals and metal products—as much a currency as a commodity in those days—generated fruitful commercial and cultural relations with the city states all around the Mediterranean from Carthage to Athens. Working in terra cotta as well as in metals, and in fresco as well as in the round, Etruscan artists evolved their own vital modes, stylized in line and form, lively and often fanciful in color, to express a personal vision of nature, full of movement, action and life. Their tradition exerted an important influence on the art of Rome and comes closer, in many ways, to major movements in the art of today than the calm and supreme harmony of Greek classicism.

The history of Etruria is therefore in the mainstream of the history of the West, and something of the Etruscan spirit persists in our own. Yet the first question about the Etruscans remains unanswered: Who were they? This was a question the Romans could not answer when they turned to the writing of history after their own conquest of the Italian peninsula. The Etruscan language bore no resemblance to any other known to the Romans, even though it was written in the phonetic alphabet of the Greeks. In the light of modern linguistic knowledge, the Etruscan language still stands alone. The surviving texts are meager, and the modern scholar can deduce the meaning of only a few of the words. But enough is known to state categorically that Etruscan is not an offshoot of the Indo-European language, from which all the other significant languages in Western history were derived.

The Riddle of Etruscan Origins

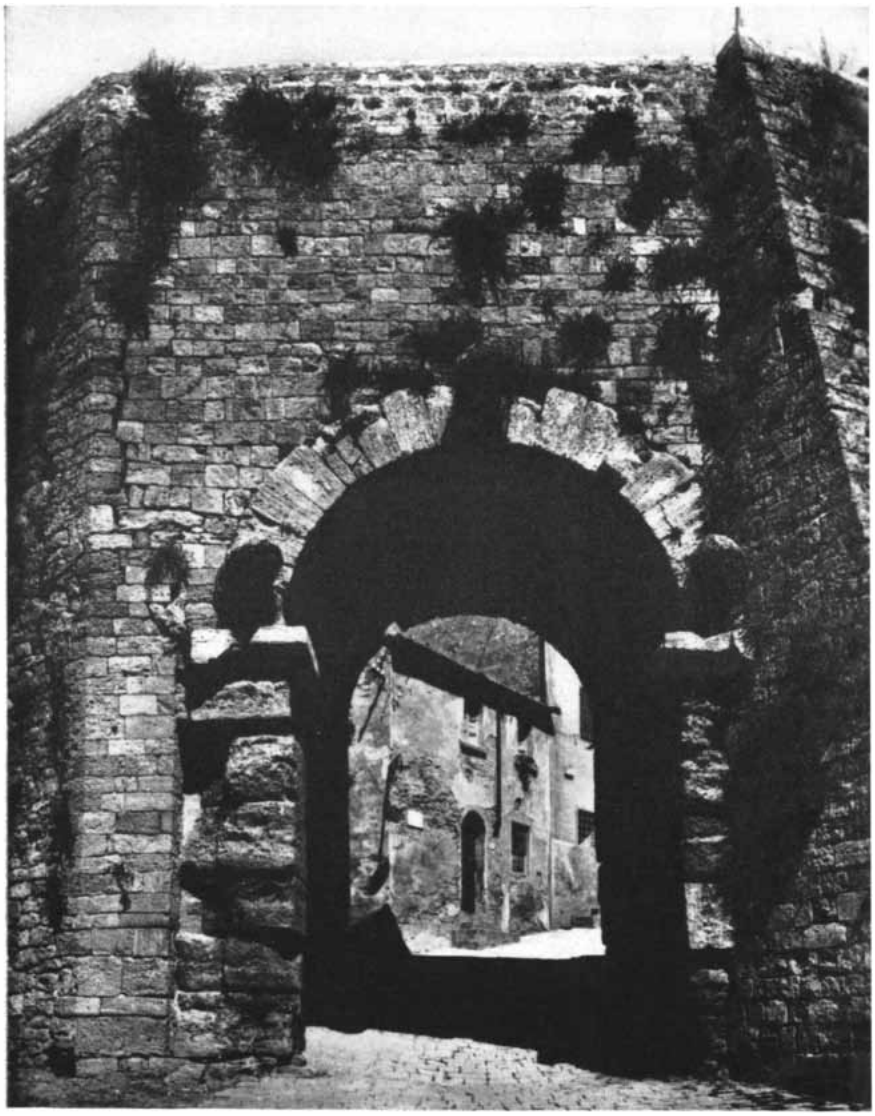
In attempting to solve this riddle the ancients propounded two theories about the origin of the Etruscans. One school, going back to Herodotus, the Father of History, held they had come from Lydia in Asia Minor in a maritime migration that brought them to the western shore of Tuscany in Italy during the 13th century B.C. On the other hand, Dionysius of Halicarnassus, who wrote at the time of Augustus Caesar, argued that the Etruscans were natives of Tuscany, rooted there long before the Phoenicians and the Greeks migrated by sea to colonize distant shores of the Mediterranean. Modern scholars, reworking the same textual materials, find themselves divided along roughly the same lines.

The waning hope that this riddle can be solved rests with archaeological investigations now going forward on an unprecedented scale in Tuscany and northern Italy. Out of a peculiarly intense preoccupation with mortality, the Etruscans left underground a rich record of their life on earth. Their burial mounds and spacious vaults are found in profusion over the wide areas they occupied in ancient Italy, forming true necropolises—cities of the dead. Like the Egyptians, the Etruscans went into the hereafter with the familiar and cherished objects of their lives, or representations of those objects, surrounding them in their tombs. Excavations by grave robbers and amateurs as well as by archaeologists have already brought to light great treasures of Etruscan art and history. Through greed and carelessness much of the record has also been irretrievably lost. It remains to be seen whether or not the discipline of archaeology will find clues to the Etruscan riddle in the record still to be exhumed. But the search will also bring modern man into a more intimate acquaintance with one of his most interesting and contemporary forerunners.

Compared with the infinite riches of the necropolises, the remains of Etruscan cities have yielded little to archaeological knowledge. Even in their most prosperous days the Etruscans built their houses of wood or with mud walls, and they used wood to erect the superstructures of their temples and public buildings on foundations of stone. This perishable material has of course vanished, and the appearance of Etruscan buildings is recalled chiefly with the aid of funerary urns made as models of houses and temples. Moreover, the sites of many Etruscan cities, particularly the principal ones, have been continuously occupied to this day, and the scavenging of the past in new construction has all but obliterated the work of the founders. The Etruscans invariably built their cities on easily defensible hilltops and escarped pla-

TOMB in the Etruscan necropolis of Cerveteri is cut into soft volcanic stone. The contents of the tomb have been removed.

NECROPOLIS OF CERVETERI is a city of tombs, complete with streets. One tomb is at right, its main chamber covered with earth. Two other tombs are visible in background.



GATE IN VOLTERRA is part of a city wall built by the Etruscans. It dates from the end of the third century B.C. The Etruscans customarily built their walled cities on hilltops.

teaus. The modern cities on those sites still have the look of aeries dominating the surrounding countryside.

Among the ancients the Etruscans had a deserved renown as architects and engineers. The Romans attributed to them the invention of systematic town planning, of drains and sewers, and the basic design of the Roman residence, which turned on the atrium: the roofed court in the center of the house. It was the Etruscans who built the first version of the great central sewer of Rome, the Cloaca Maxima. Although they never learned to use mortar or cement, they were masters of the arch and vault and were able to achieve structures in dry stone that the linear construction of the Greeks would not have permitted. The Porta dell'Arco at Volterra, the gates of Martia and Augustus in Perugia and the massive walls that follow a contour line for miles around their hilltop cities stand today as monuments to their skill. Altogether there is much to support the thesis, so eloquently advanced in the 18th-century engravings of Giambattista Piranesi, that the Etruscans had a profound influence on the style of architecture we call Roman.

The Cities of the Dead

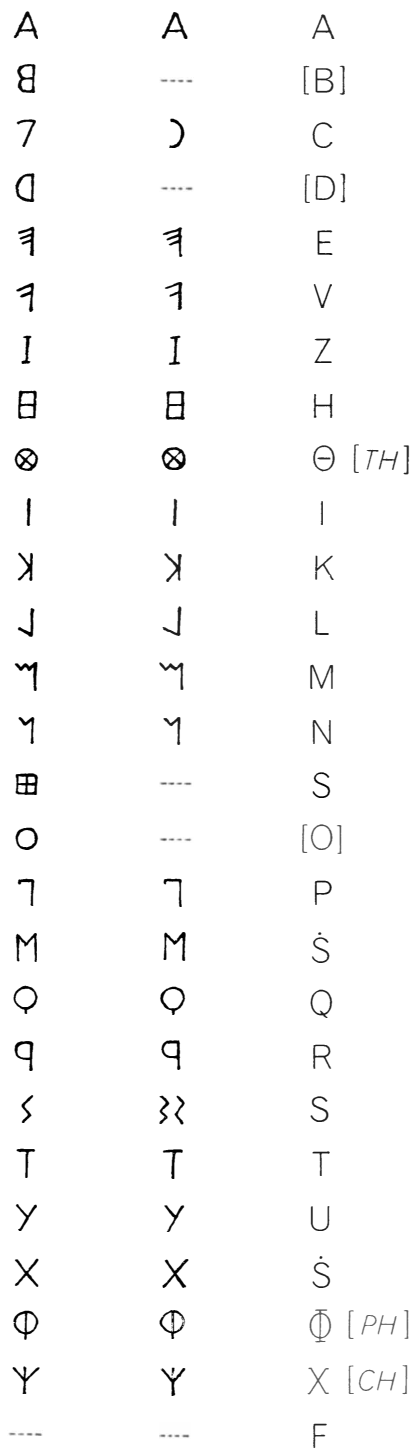
For a picture of the life that animated the Etruscan cities, however, we must turn to the necropolises, with their sepulchers arrayed along funerary avenues. In the vast area of southern Etruria, from Rome to Orvieto and Chiusi, the land is underlain by volcanic tuff, a rock that is soft and easy to work. Here the Etruscans quarried their tombs from the living rock. The hypogeum, or tomb proper, is typically reached by a long corridor and is made up of one or more chambers that apparently reproduce with loving fidelity the long-since-vanished home or palace of the departed. In northern Etruria, where the geology did not favor this type of construction, the tombs were built of blocks of sandstone or travertine and were often covered with a tumulus of earth or a cairn of rocks piled to a considerable height. In support of the idea that Asia Minor was the place of origin of the Etruscans, it should be observed that such rocky sepulchers, unknown in other European countries, are found in remote regions of Lydia and its neighbor Phrygia.

Aerial photography, which often reveals subsurface features through their effects on soil drainage and color, shows that archaeology has hardly begun to open up this underworld of the ancients.

Unfortunately it is equally apparent, from the sample investigated so far, that grave robbers over the centuries have missed few of the tombs. Further damage was done by princely antiquarians in the period of "Etruscomania" in the late 18th and early 19th centuries. The despoiling of the tombs at that time did enrich the museums of the world. But archaeologists cannot deplore sufficiently the fact that these excavations were carried out in a most unmethodical manner. The collectors were interested only in rare and valuable objects; they abandoned or even destroyed the remainder and closed the tombs again without attempting to make drawings of them or to take inventory of the objects they contained. From such barbarous procedures comes the legend of Etruria as a great center of the ceramic arts (a legend re-

MAP OF ITALY and surrounding areas shows the extent of the Etruscan sphere of influence at the height of Etruscan power. Also shown are the areas controlled by the Greeks and Carthaginians at that time. The cities on the map are Etruscan sites mentioned in the text.

flected today in the name "Etruria" on the products of the Wedgwood china works in Britain). The tombs of Spina, at the mouth of the Po, yielded large numbers of beautiful black vases with exquisite figures drawn in red. These vases have since been shown to be the fruit of that city's active commerce with Greece; the Etruscan tombs, in fact, have furnished more examples of Attic black-figured ware than the soil of Athens itself.



ETRUSCAN ALPHABET (*middle*) closely resembled the contemporary Greek alphabet (*left*). At right are the sounds of the Etruscan characters. "B," "D" and "O" sounds are not certain. The three "S" sounds vary.

The Meaning of Etruscan Art

Thanks to the protection of the tombs, so secure against the ravages of time if not against the hand of man, we possess a more complete sampling of Etruscan art in all its forms than we do of any other ancient European culture. Except for the frescoes of Pompeii and Herculaneum, the Etruscan frescoes supply the only insight we have into the techniques of painting in classical civilization. It is in southern Etruria, where the tombs were cut in the rock, that these frescoes are preserved. They are intact at least until the tomb is opened, whereupon deterioration begins. Fortunately it is now possible to remove the paintings from the walls and take them to the safety of the museum.

The Etruscan painter used pleasantly simple mineral colors that he laid on a fresh layer of plaster applied to the rock wall. With large, uninterrupted surfaces to work on, he was prompted to make complex pictorial compositions. But his purpose is always clear. Enclosed forever in the tomb, his pictures were to evoke for the deceased the joys of life. The dead man's occupation, which he intended to resume in the afterlife, is often depicted. Scenes of banquets and feasts are frequent. These guaranteed eternal satisfaction and pleasure to the departed; in the happy phrase of the Belgian scholar Franz Cumont, "the ghost of a diner could be nourished by the appearance of food." The frescoes also perpetuated the pleasant hours of sports, games and dances. When Etruria came on difficult times, the funerary frescoes took on a more somber tone: the features of the departed, which were formerly peaceful, wear expressions of anxiety and even of anguish.

Etruscan sculptors preferred to work in clay or bronze rather than in stone. They were particularly fond of the bas-relief, in which they produced delightfully animated figures framed in elegant arabesques. Their forte, however, was the portrait. The art of portraiture had deep funerary significance: it furnished a faithful image of the deceased to aid his survival in the other life. Frequently, in the seventh century B.C., the portrait of the deceased formed the lid of the crematory urn. Portraiture reached its peak in the last centuries of Etruscan civilization, when the characteristically Etruscan flair for detail, for the individual, found its fullest expression.

In addition to the treasures of the tombs, time has spared a few pieces of sculpture made for public display. The wooden superstructures of the Etruscan temples were frequently adorned with painted terra-cotta ornaments, employed as antefixes (on the ends of timbers), acroteria (on the peak and angles of the pediment) and fringes displayed within the triangle of the pediment. Among the most beautiful surviving examples of this work are the life-size statues from the pediment of the Temple of Apollo at Veii. They date from the end of the sixth century B.C. and are from the hand of the master sculptor Vulca, who was summoned by the Tarquin rulers of Rome to decorate the Temple of Jupiter and his consorts on the Capitoline Hill.

Public interest in Etruscan art has been on the increase since 1955, when a comprehensive collection from a number of museums went on tour in Europe. In making any generalizations on the subject one must remember that this art was created over a period of six centuries by men working in many separate and autonomous Etruscan states. Naturally it had its times and places of greater or lesser achievement. Hellenic art was a constant source of inspiration. But the Etruscans had a spirit that was theirs alone. In spite of their many contacts, the Greek and Etruscan temperaments in art remained distinct and different. Early in their history the Etruscans were producing bold, direct works of art that often have a modern look. Much later, in the third century B.C., when Hellenic art developed its taste for the picturesque and the dramatic, Etruria assimilated the trend without difficulty because it corresponded with the temperament of the Etruscan artist. This period also produced real masterpieces.

For the archaeologist the art of the Etruscans has a special ulterior interest. It is clear that the essential core of knowledge of these people—who left no literary texts and whose language in any case remains barely understood—must be based on detailed study of the pictorial documents provided by their art. For example, the statues and frescoes testify repeatedly to the favored position of the Etruscan woman and the role she played in both private and public life. In Greece the woman lived as a recluse in the gynaeceum (women's apartment); in Rome she lived the life of a modest housewife. In Etruria, on the other hand, the funerary art shows that women

TWO FRESCOES are from Tomb of the Triclinium in the Etruscan city of Tarquinia. They are now in the Museum of Tarquinia. The figure at left is a dancer. The figure at right is playing a cithara, a stringed instrument. The frescoes were made in about 475 B.C.

shared fully in the life of society, in banquets, festivals and games. This observation, incidentally, has a bearing on the origin of the Etruscans: one must look again to the countries of Asia Minor to find women occupying a similar position in the ancient world.

Insights afforded by their art into the religious spirit of the Etruscans similarly sets them apart from the classic tradition. The paganism of Greece and Rome never abandoned the liberty of the individual and the city to the omnipotence of the gods. Although Greek drama is suffused with implacable destiny, man's everyday relationship to the gods was one of give and take, a dialogue. It was otherwise in Etruria. In common with so many Oriental religions, the Etruscan religion took its authority from divine revelation set forth in sacred books that ordered man's entire life. It was the never ending duty of each man to seek out the will of the gods, and it was the function of the priests, the haruspices, to read the divine purpose from the livers of sacrificial animals and from the study of lightning and thunder. In Etruria man remained silent and listened to the eternal monologue of the masters of the heavens and the earth. Although his deities bore names borrowed from the pantheon of the Greeks (the principal ones being the trinity of Tinia, Uni and Menrva, corresponding to Jupiter, Juno and Minerva), they were closer in concept to the deities of the East.

The Rise of the Etruscans

A strong movement in contemporary Etruscology uses evidence of this kind, together with the linguistic isolation of the Etruscan language, to support the thesis that the Etruscans were indigenous in Italy. According to Massimo Pallottino of the University of Rome and Franz Altheim of the Free University of Berlin the Etruscans belonged to a loosely interrelated family of peoples who inhabited the shores of the Mediterranean, including the shores of Asia Minor, before the Indo-European invasion upset the ethnic patterns of the region. That invasion came in the second millennium B.C. Some pockets of the indigenous peoples would have remained, and the Etruscans are said to constitute one such pocket. This would explain the similarity between their religious and social customs and those of certain peoples in Asia Minor.

In my own view the ancient tradition of the arrival of sailors from the East cannot be completely discarded. The voyage could not have occurred at the early date set by Herodotus. The history of the Italian peninsula suggests the late eighth century B.C. This was an era in which bold seamen were crossing the Mediterranean in all directions, when the Greeks were founding colonies on the shores of Sicily and southern Italy and the Phoenicians were landing on the coast of Spain in search of mineral riches. A few ships from Asia Minor, impelled by the same winds and the same desires as those that drove the Greeks and Phoenicians, may well have landed soldiers and artisans on the coast of Tuscany. They would have been attracted by the smiling countryside and the metalliferous hills of Populonia.

Compelling historical evidence for this view is the speed and relative suddenness with which the Etruscan culture and civilization came into being. In contrast to the Romans, whose power grew slowly and through great effort, the Etruscans quickly attained a state of high prosperity in an Italy that was still half-primitive. As early as the seventh century B.C. the necropolises of Popu-

Ionia in the north and Cerveteri in the south contained sepulchers that were rich in precious objects made of gold, silver and ivory. The goldwork from the tomb designated Regolini-Galassi, now on display in the Gregorian Etruscan Museum of the Vatican, dates from as early as 650 B.C. The jeweler's technique displayed by these pieces speaks for a long artistic tradition, and the ornamental themes are clearly borrowed from the Near East—from Syria, Cyprus, Egypt and Greece. This is not to say that the Etruscan culture sprang *ex nihilo* from virgin ground; it undoubtedly germinated in the soil of previous human activity. But the ascent to high civilization in Tuscany was fully as rapid as the contemporaneous flowering of the neighboring Greek and Phoenician city states in southern Italy, Sicily, Sardinia and Corsica.

With these neighbors the Etruscans soon found themselves engaged in a chronic contest for power that was to provide the principal theme of their political history until the decline of their fortunes in the fourth and third centuries B.C. Throughout the time of Etruscan greatness, in the sixth and fifth centuries, the balance of power at sea was held by an alliance of the Etruscans and the Carthaginian colonies against the Greeks. After a great naval battle in 540 B.C., Etruscan colonies displaced those of the Greeks on the island of Corsica. In contrast to the Greeks, who did not seek to extend their sway to the hinterland of their ports, the Etruscans moved north to conquer and settle the plain of the Po and south into Latium and Campania. Crossing the Po Valley on their way to trade bronze and jewelry with the Celtic peoples of the Alps, Etruscan merchants found a verdant countryside inhabited by scattered and disunited tribes. The merchants were followed by armies in the second half of the sixth century, and Felsina became the capital of a new Etruscan confederation that reached to the shores of the Adriatic.

Greater historical importance attaches, perhaps, to the Etruscan drive southward. This conquest brought the Etruscans to Rome, and it is through their influence on Rome that they left a lasting imprint on history. Tradition dates the Etruscan occupation of Rome from 616 B.C., when the first Etruscan king, Tarquin the Elder, is said to have come to power, until 510 B.C., when Lucius Junius Brutus is supposed to have led the revolt that expelled the last Tarquin. Actually the occupation lasted a third of a century longer. Archaeological findings show that during this period and for years afterward Rome had the appearance of an Etruscan city, with a powerful surrounding wall and many temples decorated by Etruscan artists. The Tarquins (who took their name from Tarquinia, the city from which they came) installed in the Roman tradition their symbols of supreme power: the fasces, golden crown, golden ring and curule chair. The temple that was dedicated to their trinity of gods on the Capitoline Hill was to remain the central temple of Rome.

Throughout their domain the Etruscans carried on a vigorous and well-managed exploitation of their resources. The scale of their metallurgical undertakings can be judged from the fact that their slag heaps are huge enough to justify reworking by modern smelting practices. Their skill in metalworking equipped them with all kinds of tools, instruments and utensils for the cultivation of their fields and for the easing and adornment of their domestic existence. In Campania and in the Po Valley the Etruscans laid out the land in neat squares for farming. The lessons in surveying they gave the Romans are still to be seen in aerial photographs of vast areas of "centuriated" land (that is, land divided into square lots called *centuriae*) in the ancient Roman provinces of North Africa.

At all times the Etruscan polity was a loose one. Their cities, like those of the Greeks and Phoenicians, were bound in confederation by ties of language, culture and religion. Certainly the inhabitants of the cities felt they belonged to a

ETRUSCAN COUPLE is portrayed on the cover of a terra-cotta urn from Volterra. The urn was made in the first century B.C., when Etruscan art was characterized by extreme realism.

single people. Each year delegates from the cities gathered in a federal assembly at the sanctuary of the god Voltumna near Lake Bolsena. The league was essentially religious, however, and the lively particularism of the various cities made it difficult to formulate common political and military policies.

At the full tide of Etruscan power the Campanian federation reached as far south as Pompeii, Herculaneum and Sorrento. But the Etruscans were compelled to travel overland, because they were defeated at sea by Greek fighting ships from Cumae. The Battle of Cumae in 474 B.C., celebrated by Pindar as a victory of Hellenism over the barbarism of the West, was the turning point in Etruscan history. For the next two centuries the rising power of Rome cut off the southern provinces from Tuscany, and the Celts pouring over the Alps from Bohemia and the valley of the Danube inundated the provinces of the north. Campania was lost to the mountain tribes of the Samnites with the fall of Capua in 423 B.C. By 350 B.C., with the fall of Felsina, Cisalpine Gaul had come into existence, and the Etruscan occupation of the north was a memory. Meanwhile the Romans had begun their slow erosion of Tuscany itself. The last Etruscan bastion at Volsinii (modern Bolsena) fell in 265 B.C. and the long struggle was at an end.

Although Roman law and custom now held sway over the Etruscan homeland, the old culture and tradition persisted for a long time. The studios that produced Etruscan art were active until the first century B.C. Cities such as Perugia even had periods of great economic prosperity. But the civil wars of the Romans, particularly the pre-Caesarean contest between Marius and Sulla, laid the country waste. Thereafter Tuscany was completely Romanized. Under the Roman Empire, only the Fanum Voltumnae, the annual religious assembly, remained as a symbol of the vanished past.

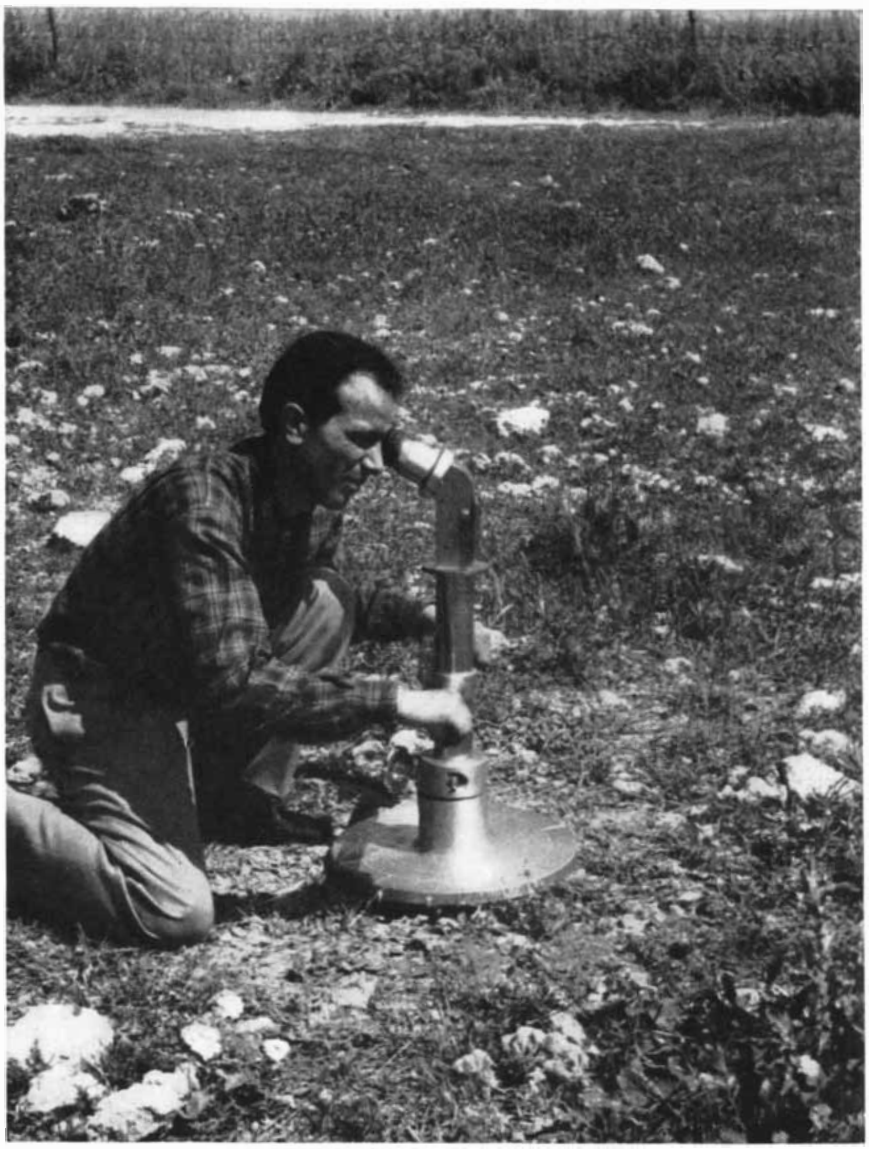
The Etruscan Language

The Etruscan language was spoken and written on the Italian peninsula until the end of paganism and was a language of scholarship until it was obliterated in the Christianization of Rome. Today the language is largely incomprehensible and remains so notwithstanding the efforts of the ablest linguists. It is not a question of decipherment, as has been the case with other lost languages. Since the 18th century it has been possible to read Etruscan texts, even though they

MAENAD'S FACE framed by a shell decorated the roof of a temple in the Etruscan city of Veii. The height of the object is 18 inches. It appears to date from the fifth century B.C.

GOLD PENDANT portrays Achelous, the god of rivers. Many Etruscan divinities closely paralleled the Greek. The height of pendant is two inches. It dates from fifth century B.C.

POTENTIOMETER is used to locate Etruscan tombs. At right are rows of electrodes stuck into the soil. Anomalies in readings from electrodes indicate presence of buried objects.



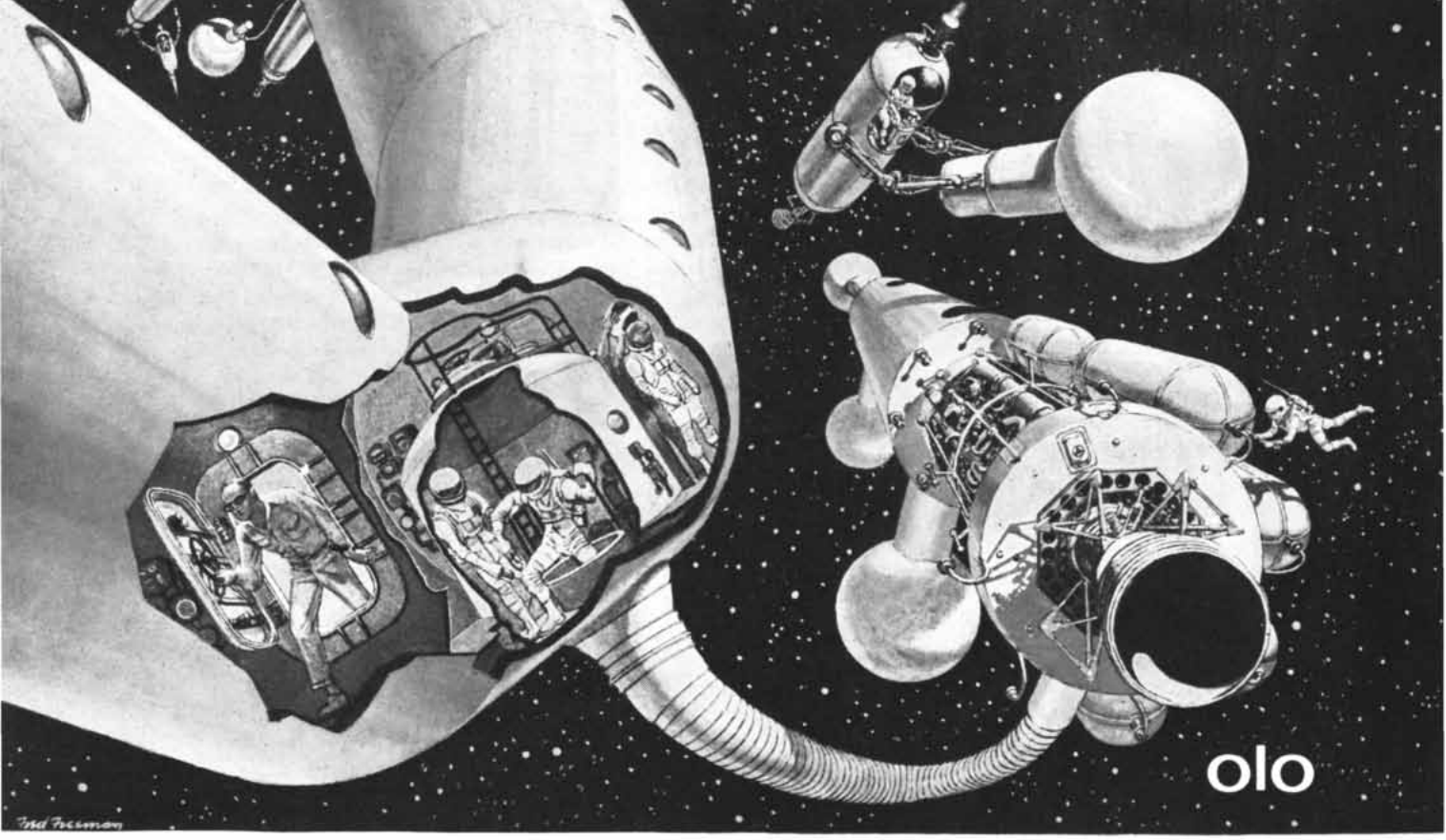
PERISCOPE is used to look into a tomb located with the potentiometer. The funds and technical assistance for this work have been provided by the Lerici Foundation of Milan.

cannot be fully understood. The problem lies not in reading but in interpretation.

Some 10,000 texts survive. They are generally short and stereotyped: epitaphs that give the family and first name of the deceased and his father and mother, sometimes his age at death and less often his position and whatever honors he may have received. Many of the texts, appearing on objects offered to one or another of the gods, are formulas of offering or dedication, but those phrases are also short and stereotyped. Only a few inscriptions—one engraved on a stone column found in Perugia and one on a tile from Capua—have as many as 100 words. A single manuscript has survived from Etruscan literature. It is the so-called Zagreb Book, made of linen cloth on which is written a ritual text that lists the sacrifices and offerings to be made to the gods on various days in the year. This work has had an extraordinary history. During the Roman era in the Egyptian city of Alexandria it was cut into strips that were used to wrap the mummy of a woman. The mummy wrapping was recognized in its true significance only in the middle of the 19th century, when the mummy came under careful inspection at the Archaeological Museum of Zagreb in Yugoslavia, where it reposed as a treasure of Egyptian antiquity.

In addition to these sources there are versions of Etruscan words that appear in Latin and Greek texts. The information thus provided is scant but certain: we have sure translations of about 30 Etruscan words. A few phrases have been at least partially interpreted by comparison with Latin or Umbrian texts concerned with the same ritual. For the rest, the customary tools of linguistic research are of no avail. The linguistic isolation of Etruscan has frustrated even recent efforts to interpret it by comparison with another language, such as Sanskrit, Greek, Latin or a Semitic language, or another isolated language, such as Basque.

This veil has been lifted to some degree by internal analysis of Etruscan inscriptions, by comparison of similar phrases in different inscriptions and with the help of dates that often appear on tombs or in inscriptions. Such studies have settled most questions about Etruscan phonetics. It is even possible to write an authoritative, although incomplete, Etruscan grammar. The declension of nouns has been fairly well determined, and it is known that the language permitted the accumulation of several suffixes at the end of a word to express



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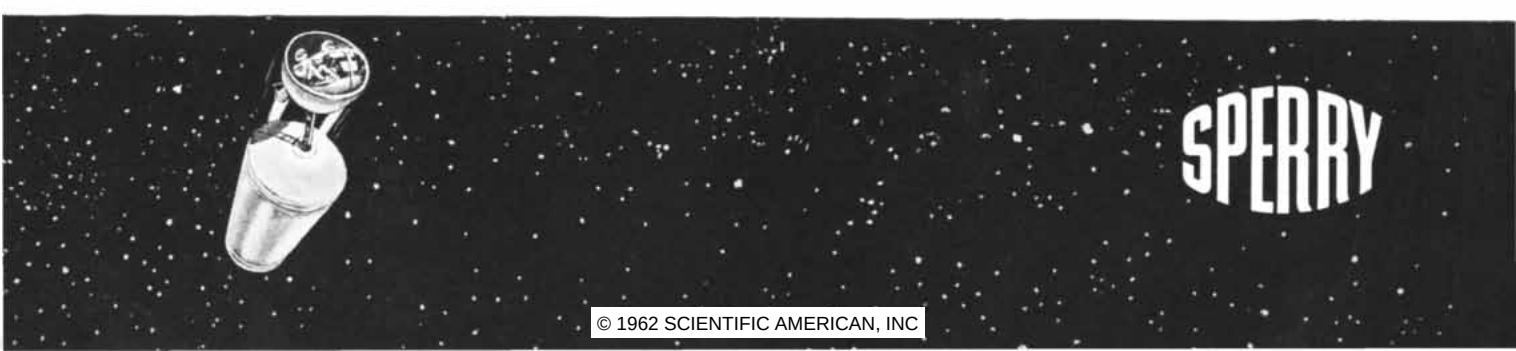

various grammatical relationships. But verbs seldom appear in inscriptions except in the third person preterit ("So-and-So dedicated this object"), and virtually nothing is known about the conjugation of verbs.

The great gap lies in the semantics of Etruscan—in the meaning of its words. Meaning can be assigned to only a small number of the known roots. The paucity of understanding is suggested by the fact that the symbols for the first six digits, as engraved on the faces of two ivory dice, cannot be matched with certainty to their respective numbers!

What is needed, of course, is a Rosetta stone. The possibility is suggested in a tantalizing way by the recent discovery in the soil of Tarquinia of eulogies written in Latin but dealing with the lives and careers of remote Etruscan ancestors. These texts have thrown valuable light on the public institutions of the Etruscan era. One cannot resist entertaining the notion that such a text may yet be found written in the two languages.

One linguistic discovery, however, has provided a possible clue to the origin of the Etruscans. An inscribed funerary stele found on the island of Lemnos in 1885 and reliably dated in the sixth century B.C. bears an inscription in the Greek alphabet but not in the Greek language. Close study has fixed points of contact between this mysterious language and Etruscan; here and there inflections are the same, and the formation of words seems to follow the same rule. Such an isolated document might be ascribed to a single individual, perhaps an Etruscan immigrant. But shortly before World War II other brief inscriptions in the same language were found. This Etruscoid language now appears to have been the one spoken by the island's inhabitants before their conquest by the Greeks in the sixth century. One is tempted to see in these inscriptions a vestige of the Tyrrhenians, who, according to the ancients, lived on the nearby shores of Asia Minor and emigrated from there to Italy. They may conceivably have colonized Lemnos on the way.

These documents would appear, in any case, to settle another question: Did the Etruscans adopt the Greek alphabet before or after they settled in Tuscany? They must have learned to write their language in Greek phonetics at a very early time, when this cultural development was diffusing among the peoples of the Aegean basin.

The resolution of the enigmas of Etruria plainly must await further digging in the already richly produc-

DIFFERENT TYPE OF PERISCOPE is used to make photographs of tombs. At left is the upper end of the instrument. The hole in the tube at right is the window for the objective lens.

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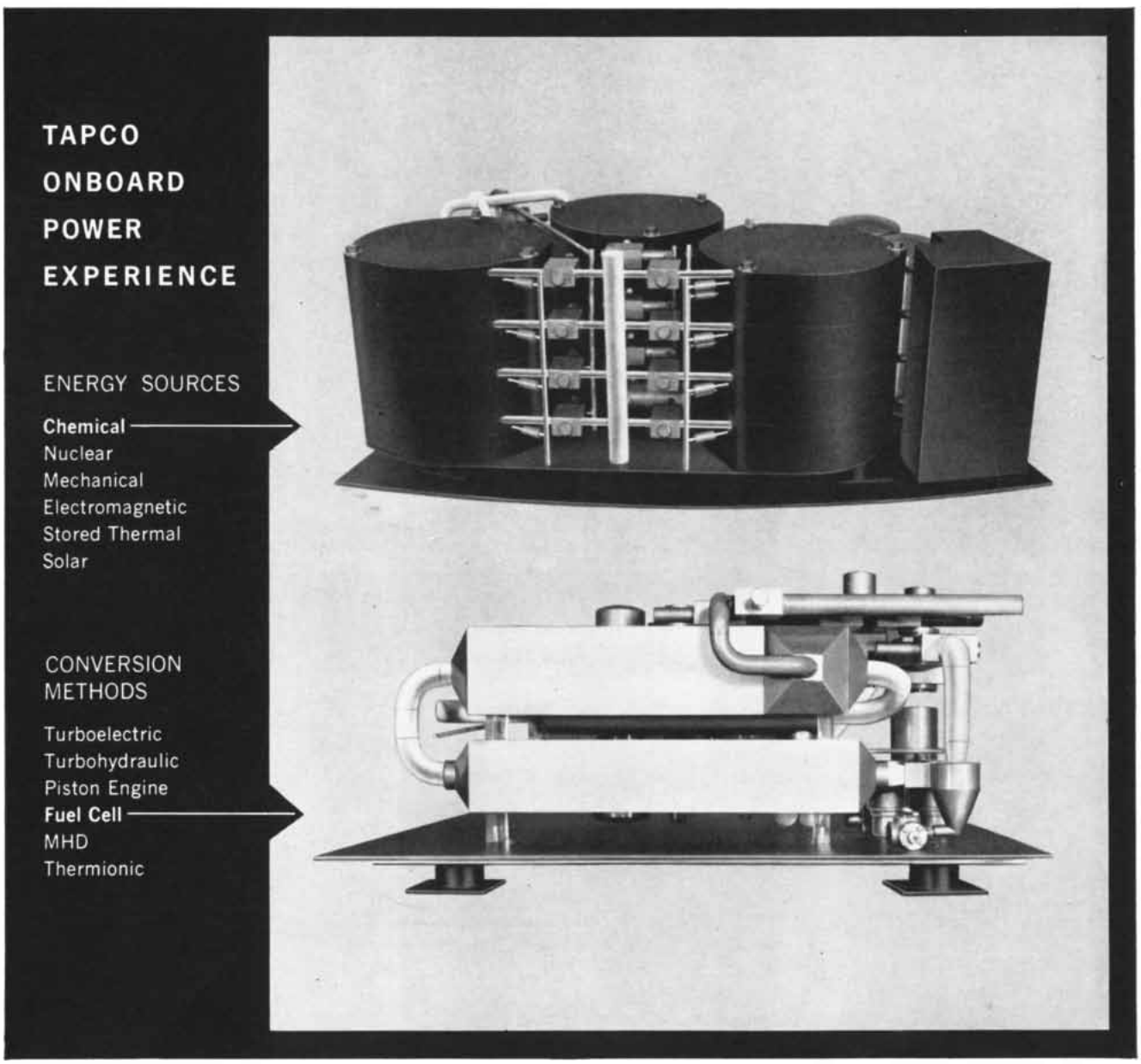

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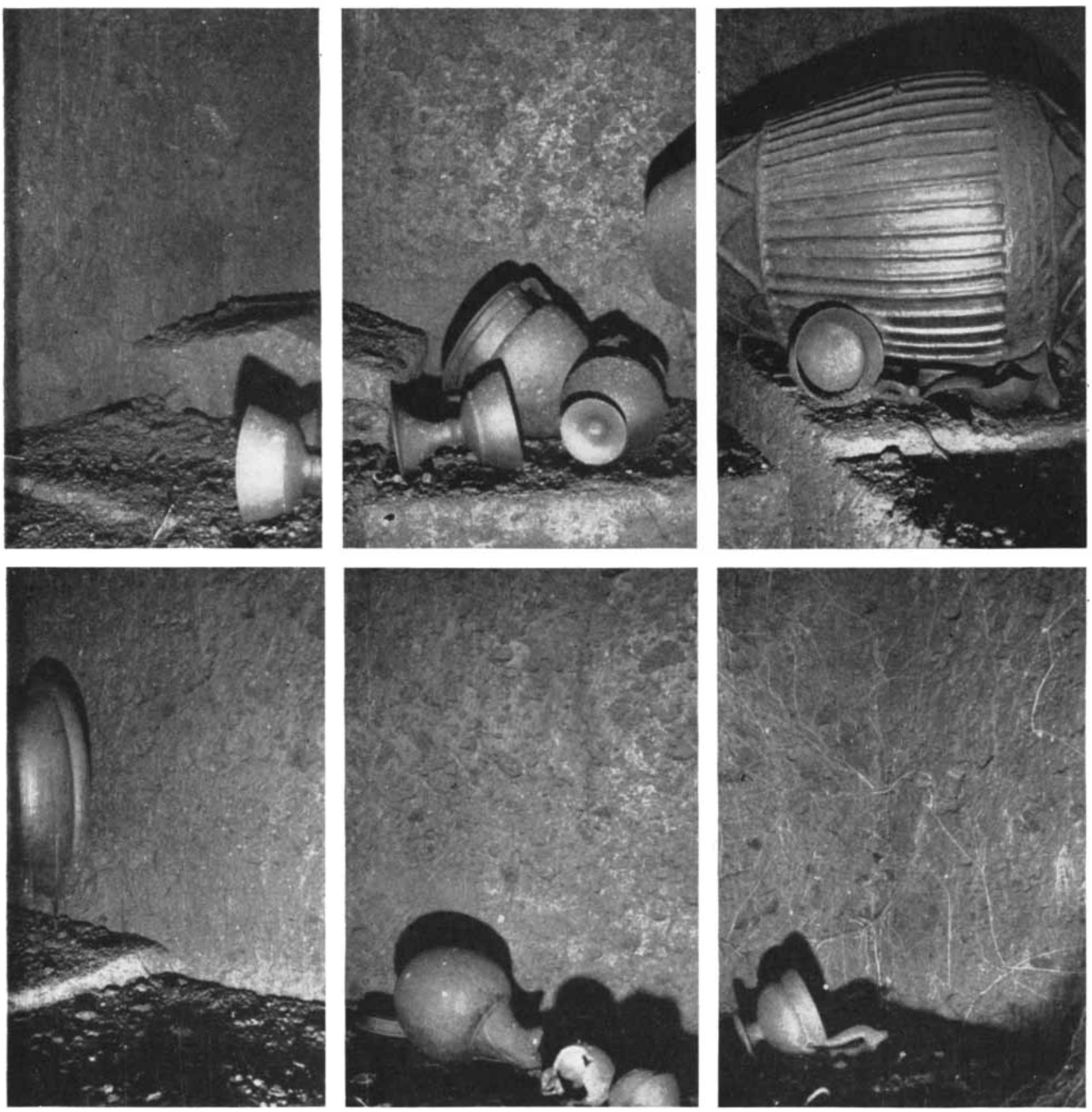
tive sites of this vanished civilization. Archaeologists must speed up their work. Clandestine digging has assumed alarming proportions in recent years, and the mechanization of Italian agriculture threatens undiscovered tombs with collapse under the weight of tractors.

New Tools in Etruria

With funds and technical assistance provided by the Lerici Foundation of Milan, new tools are being used to seek out and evaluate likely sites for the archaeologist's pick and shovel. A potentiometer borrowed from geophysics, for example, has made it possible to draw accurate layouts of walls, trenches, terraces and tombs hidden underground. To make sure that the site is worth digging, a "photographic probe" is run into the ground at a point suggested by the potentiometer diagram; a dozen photographs taken by the probe then give a complete panoramic view of the interior of the buried tomb. For faster reconnoitering, archaeologists have lately been equipped with a periscope.

The usefulness of these tools is apparent from a report by the Lerici Foundation showing that 98 per cent of the tombs thus explored between 1958 and 1960 had been robbed; 60 per cent of them had been so completely stripped that they were not worth excavating. On the other hand, several thousand hitherto unknown tombs have been located. Among them are 20 frescoed tombs in Tarquinia, the first to be found since 1894. Such work will surely bring our picture of the Etruscans into clearer focus and may yet tell us who they were.



UNOPENED TOMB at Cerveteri is photographed with a periscope. The six photographs form a panorama; each was made after the periscope was turned. On the basis of such photographs the archaeologist can judge whether it is worth while to open the tomb.

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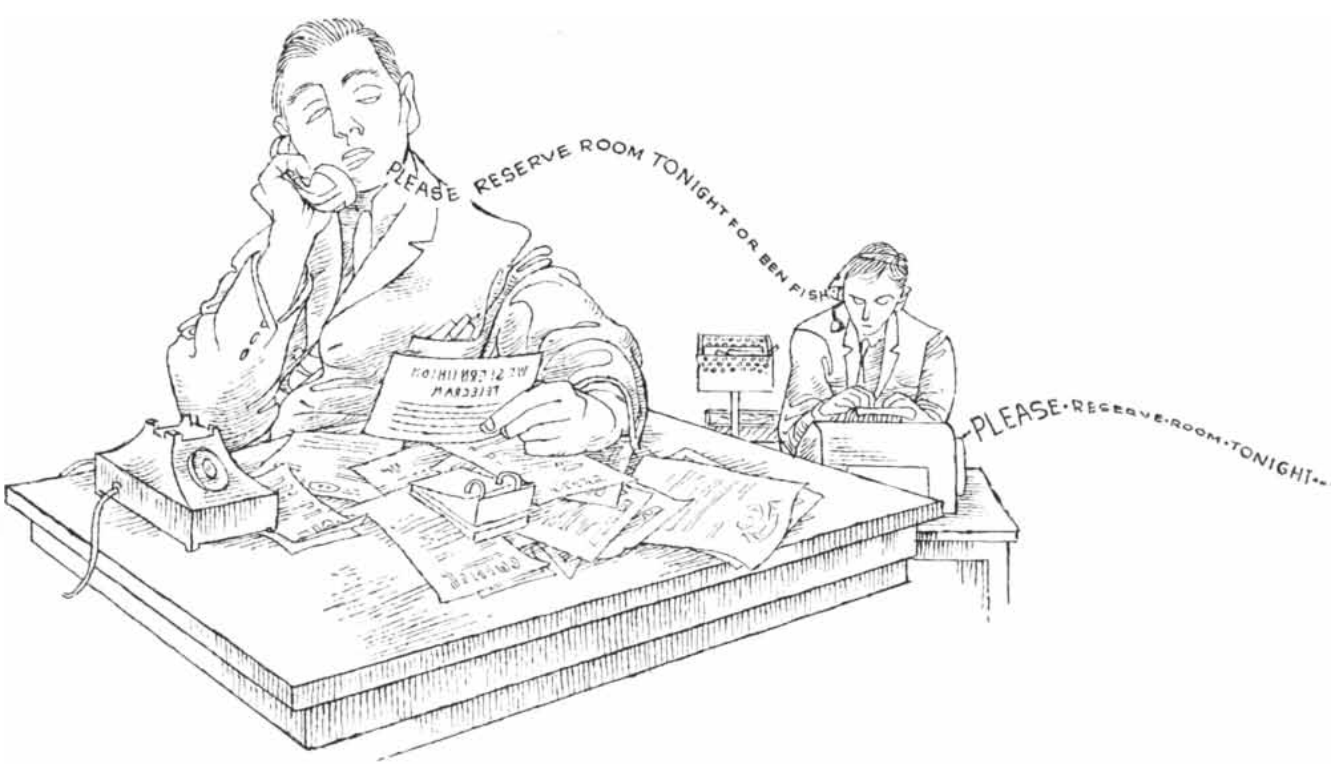
Error-correcting Codes

Information theory has shown that virtually error-free communication can be achieved by encoding messages in a special way. Clever use of redundancy is the key

by W. Wesley Peterson

Error-free performance is the goal of every good communication system. It was apparent from the earliest days of telegraphy and radio that the signals emanating at the receiving end of a system were never quite the same as those fed in at the transmitter. Over the years the term "noise" came to be applied to the various electrical and electromagnetic disturbances that degrade the quality of transmitted signals. At times the signals are not just degraded but are totally unintelligible. Until quite recently the engineer who wanted to improve the quality of a communication channel concentrated his attention on reducing noise, or, to be more precise, on increasing the signal-to-noise ratio. The most direct way to achieve this is to increase the power of the signal. Beyond that the engineer can try to improve the circuit and its components or enlarge the capacity of the communication channel with respect to the amount of information transmitted. Frequency-modulation (FM) radio is an example of the second approach; noise is reduced by the use of a channel many times broader than that used in amplitude-modulation (AM) radio.

Within the past 15 years a host of new signal-processing devices—notably the electronic computer—have stimulat-



TRANSMISSION ERRORS afflict all communication systems. When errors are made in ordinary speech or writing, however, it is usually possible to tell from a knowledge of spelling and language structure that an error has occurred. The redundancy of

ed a different approach for transmitting signals with a minimum of error: the use of error-detecting codes. The principle underlying such codes has a long history. What is new is (1) a body of theory that tells the engineer how close the codes come to ideal performance and (2) techniques for constructing codes.

The classic first papers on information theory, written in 1948 by Claude E. Shannon at the Bell Telephone Laboratories, included an important theorem on transmission of information over a noisy channel. The theorem states that such a channel has a definite capacity for transmitting information, measured in "bits" per second. A bit is defined as the amount of information required to specify one of two alternatives, such as yes or no, or, as is more common in computer systems, 1 or 0. The theorem states in addition that it is possible to encode information, transmit it over the noisy channel and decode it at any specified transmission rate less than the channel capacity in such a way that the probability of error is as near zero as one wishes.

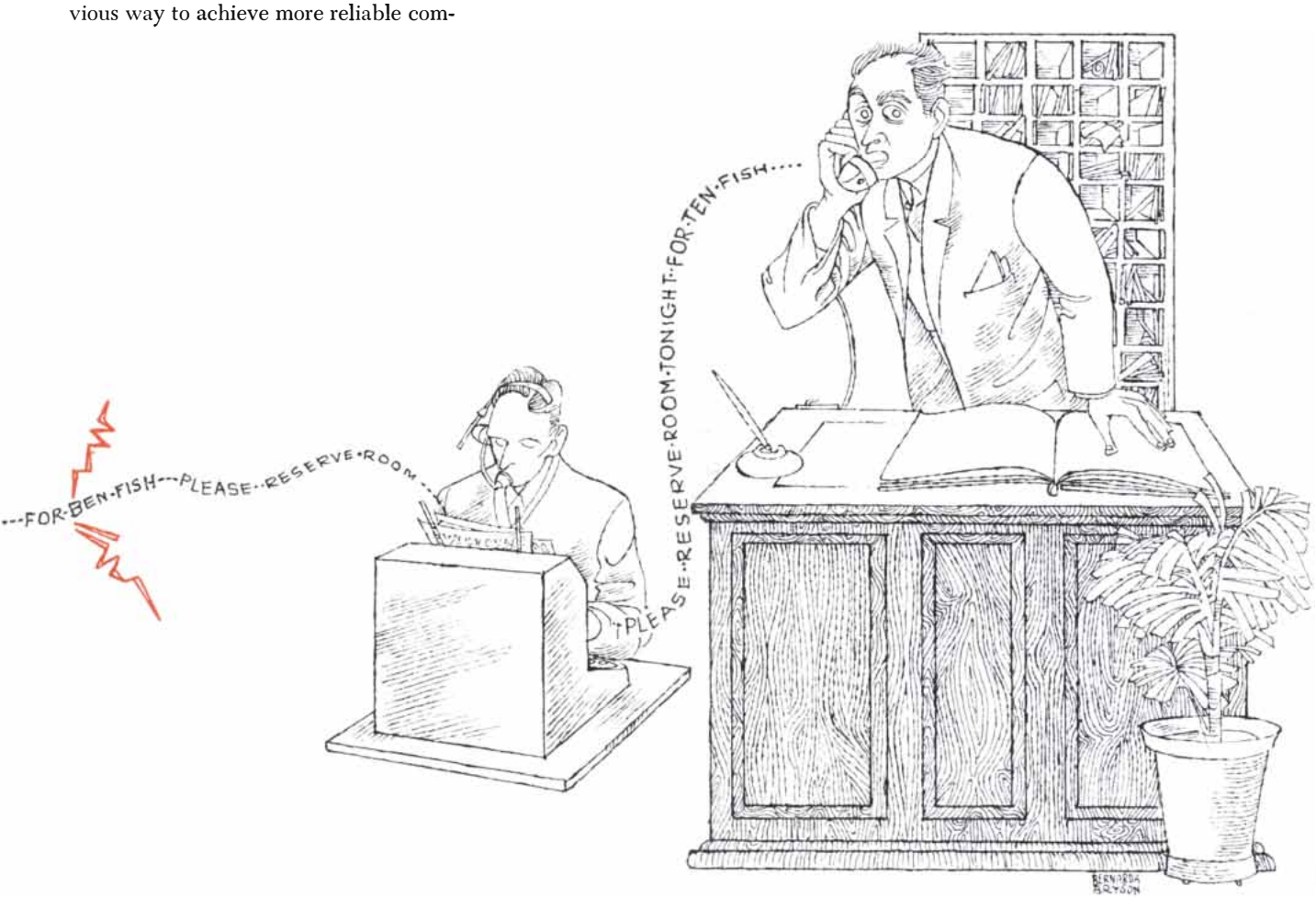
This was a surprising idea. The obvious way to achieve more reliable communication is to repeat the message as many times as may seem necessary to ensure its being received correctly. The more times the message is repeated, the smaller will be the total amount of new information received. But Shannon's theorem shows that there is an alternative. With error-correcting codes it is possible to reduce the probability of error to the degree one wishes and to transmit much more information than could be sent if the message were simply repeated. Shannon's theorem gave no indication of how this coding for correction of errors could be accomplished, but it did show that it was possible.

Since that time many people have worked on the problem of devising error-correcting codes. A number of coding methods have been found, some simple and others complicated and difficult to understand. The basic principles are the same for all these codes, and I shall attempt to explain them by using several of the simpler codes as examples.

A familiar error-detection scheme is the one often found in business expense accounts [*see illustration on next page*]. The expenses for each day, suitably itemized, run across the sheet and are totaled in a column at the far right. This column of daily totals is then added to provide a grand total for, say, a week. As a check on this figure, the column of expenditures under each item (meals, hotel and so on) is totaled separately. These separate totals, when added, should match the sum of the daily totals.

If the expense account were transmitted over some communication system—or if it were retyped—and an error occurred in any single number, it would be possible to determine which number is wrong and to correct it. It is the extra, or redundant, information that makes error correction possible. The expense account illustrated on the next page contains 30 numbers, of which 10 are redundant. In general, any system for introducing redundancy into messages in a way that makes it possible to detect or correct errors is an error-detecting or error-correcting code.

Ordinary speech is redundant and can



language provides a sort of error-correcting code. When the redundancy is reduced, as in a telegram, the difficulty of detecting a transmission error increases. In the example illustrated, "noise" in the telegraph line has caused the letter *B* to be received as *T*.

be regarded as an error-correcting code. We have all had the experience of listening to another person in a noisy room and being able to understand what was said even though many syllables and even whole words were drowned out. Redundancy also appears in written language. If, for example, you received the following telegram, you would have no difficulty understanding the message: TWINS ARZIVED LAST NIGET EVERYON IS6FINE.

More serious errors could obliterate a word completely, but the chances are that it could be guessed from the context. Shannon has estimated that ordinary written English is 75 to 80 per cent redundant. Languages have very likely developed in this way because of man's need for reliable communication; that is, for communication with a certain amount of error detection and error correction built into it. In most situations they work quite well.

When we turn from language to information expressed numerically, we find that there is usually too little natural redundancy to be useful for error detection or correction. In any given sequence of numbers each digit is independent enough so that it cannot be guessed from context. It is, in fact, the increased processing of numerical data in business and industry, and the necessity for handling such data speedily and accurately, that has inspired much of the search for error-correcting codes.

It is not surprising that the first error-correcting systems were devised by men who dealt with numbers. Their chief concern was the detection of errors in computation rather than in transmission. These, however, are related problems. One method used for checking arithmetic operations is to repeat them. Another is to use the inverse operation:

a

	MEALS	HOTEL	TRANS.	MISC.	TOTAL
MONDAY	4.75	7.00	84.79	2.79	99.33
TUESDAY	5.25	7.00	2.60	1.80	16.65
WEDNESDAY	6.50	7.00	5.98	3.11	22.59
THURSDAY	4.80	7.00	111.29	1.29	124.38
FRIDAY	7.25	.00	12.40	5.17	24.82
TOTAL	$28.55	$28.00	$217.06	$14.16	$287.77

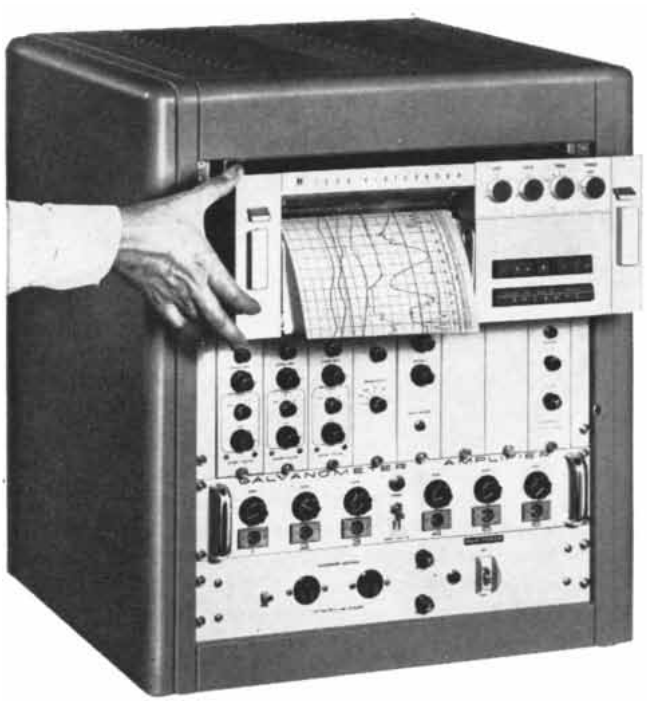
b

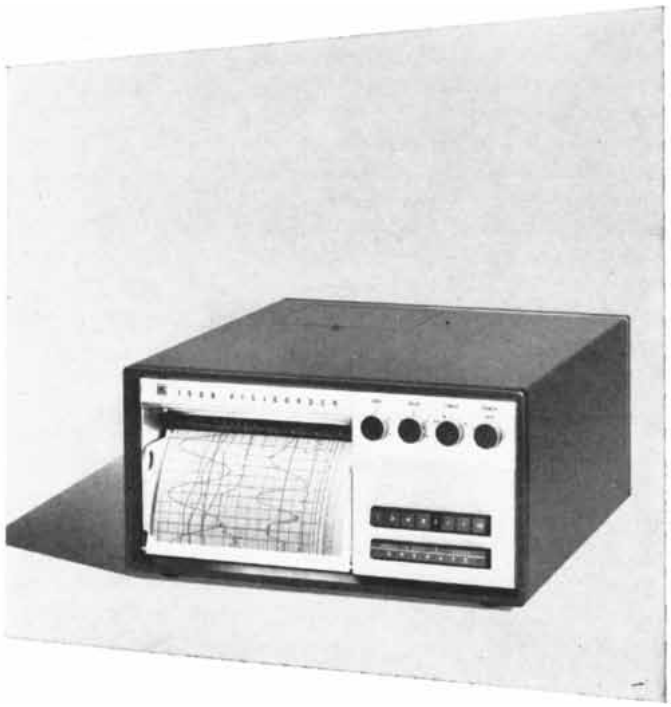
	MEALS	HOTEL	TRANS.	MISC.	TOTAL
MONDAY	4.75	7.00	84.79	2.79	99.33
TUESDAY	5.25	7.00	2.60	4.80	16.65
WEDNESDAY	6.50	7.00	5.98	3.11	22.59
THURSDAY	4.80	7.00	111.29	1.29	124.38
FRIDAY	7.25	.00	12.40	5.17	24.82
TOTAL	$28.55	$28.00	$217.06	$14.16	$287.77

c

	MEALS	HOTEL	TRANS.	MISC.	TOTAL
MONDAY	9.00	11.00	23.00	1.00	53.00
TUESDAY	5.00	11.00	12.00	2.00	30.00
WEDNESDAY	6.00	7.00	13.00	1.00	27.00
THURSDAY	6.00	7.00	5.00	3.00	21.00
FRIDAY	7.00	12.00	79.00	2.00	100.00
TOTAL	$33.00	$48.00	$141.00	$9.00	$231.00

SIMPLE ERROR-CHECKING SYSTEM is that often found in expense accounts. Daily totals form a column at the far right and item totals form a row across the bottom. The two sets of totals must add up to produce the same grand total. If, in transcription or transmission, an error were to occur in any single number, it could be detected and corrected. Such an error is shown in *b*, where the totals for "Tuesday" and "Misc." are $3 less than the separate row and column entries indicate. Evidently the Tuesday entry for miscellaneous must be $3 too large. A similar error appears in *c*; the reader is invited to find it.





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First in Control

to check addition by subtraction, and multiplication by division. Both of these methods are analogous to repeating data in transmission.

Still another method, known as casting out 9's, is a much shorter but less thorough check for errors in arithmetic. It seems to have originated among the Arabs about A.D. 800, and has been widely used since about 1100, although it has not been commonly taught in this country since the 18th century.

In the casting-out-9's method one calculates for each number a "residue" that is obtained by throwing away as large as possible a multiple of 9. In other words, one divides by 9 and calls the remainder the residue. Thus the residue of 1,273 is 4 because $1{,}273 \div 9 = 141$ with 4 left over. The residue of the sum of two numbers equals the sum of the residues. (It may be necessary to cast out a 9 in the sum of the residues.) Similarly, the residue for the product of two numbers is the product of the residues. If the residues do not check, there is an error. Three examples follow:

$$391 + 731 = 1{,}122$$
$$\text{(RESIDUES)} \quad 4 + 2 = 6$$
$$391 \times 731 = 285{,}821$$
$$4 \times 2 = 8$$
$$66 \times 77 = 5{,}082$$
$$3 \times 5 = 15$$

(RESIDUE OF 5,082 = 6,
RESIDUE OF 15 = 6)

Checking can be accomplished by casting out other numbers, for example by casting out 7's or 11's. Casting out 9's has been the most popular, however, because there is a simple short cut for calculating the residue. The sum of the digits in a number has the same residue as the number. Thus the residue of 285,821 is the same as the residue of $2+8+5+8+2+1=26$, which is the same as the residue of $2+6=8$.

Error-detecting and error-correcting codes for data transmission usually make use of the idea of casting out *n*'s, *n*, of course, being a given number. If decimal numbers are to be transmitted, the residue after casting out 10's of the sum of the digits could be transmitted as a "check." This permits detection (but not correction) of any single error. For the number 179,287,624, the sum of the digits is 46. Four 10's would be cast out, leaving 6 to be sent as the check digit. If any one digit is altered in transmission, the sum of the digits will not check against the check digit.

To produce an error-correcting code for decimal digits one can adopt the principle discussed earlier for the expense account. The information digits are arranged in a rectangle. A casting-out-10's sum check is given in each row and each column, as shown in the first example, at the left below.

72965	9	72965	9	1402	1
90271	9	90271	9	7209	8
71107	6	77107	6	6661	9
20366	7	20366	7	1231	7
53599	1	53599	1	5893	5

Note that the digit 1 in the lower right-hand corner can be obtained as the casting-out-10's sum of either the last row or the last column. It is the casting-out-10's grand total for the array. One digit is wrong in the array shown in the middle example. It can be found by recalculating the row and column checks and seeing which fail. The third row fails: the sum is 22, so the check digit would be 2 if there were no error in that row. The second column fails: it adds up to 9, which would be the check digit if there were no error. The single error must be at the intersection of the third row and second column. That it should be 1 instead of 7 can be seen either from the fact that the column sum is 6 too large or from the fact that the row sum is 4 too small. The third array shown at the right also contains one error; the reader may wish to find it for himself.

Most computers and most data transmission systems handle information coded in binary digits. This means that everything is expressed as a combination of 1's and 0's. The illustration on the opposite page shows the most common way of representing the numbers 0 to 15 in the binary system.

In processing binary data the usual error-detection systems are based on casting out 2's. For example, the sum of the digits in the binary sequence 111001010 is 5. Since this is an odd number, the residue after casting out 2's is 1, which constitutes the check symbol. The number would therefore be transmitted as 1110010101 (the original number with its residue added at the right). The number 110101101 would be transmitted as 1101011010, since it has an even number of 1's. It is readily observed that the residue or check digit always makes the total number of 1's even. For this reason the method is often called a parity check. If a single error occurs in transmission, the total number of 1's is odd and the error can be readily detected.

To go a step further and obtain an error-correcting code one simply arranges the binary information in the form of a rectangular array. Three typical arrays are shown below.

1110	1	1110	1	11111	1
1010	0	1110	0	10101	1
0111	1	0111	1	11100	0
0101	0	0101	0	10110	1
1011	1	1011	1	11001	1
1101	1	1101	1	11000	0

A casting-out-2's check digit is placed at the end of each row and each column, and a casting-out-2's grand total appears in the bottom right-hand corner. This digit can be obtained either from the row sums or from the column sums. Note also that each row now has an even number of 1's and each column also has an even number of 1's. There is one error in the middle array. All row and column sums check except the second row and the second column, both of which have an odd number of 1's. Therefore the error must be at the intersection of the second row and second column. Changing this digit from 1 to 0 effects the correction. There is also an error in the array at the right.

This type of rectangular-array code provides the error check for most of the magnetic-tape storage systems found in today's large computers. Although the code could be used to correct errors, it is commonly employed only to detect them. The minimum undetectable error pattern consists of four errors so placed as to define a rectangle anywhere within the large array. In this case every row and every column would still exhibit even parity in spite of the errors.

Although simple, the rectangular-array codes are not particularly efficient. For example, if nine information digits are arranged in a three-by-three array, seven check digits would be required, making a total of 16 digits. In 1950 Richard W. Hamming of the Bell Telephone Laboratories described a class of single-error-correcting codes that require a minimum number of check symbols. One of these codes has 11 information digits and only four check digits, or

a redundancy of 37 per cent. The next code in the series has 26 information digits and five check digits, for a redundancy of only 16 per cent. As the codes increase in length, the redundancy decreases still further. The Hamming code takes many forms. I shall describe what is called the cyclic form.

Let X_1, X_2, X_3, ..., X_{11} be the information symbols and X_{12}, X_{13}, X_{14} and X_{15} the check symbols. The formulas for computing the check symbols appear at the top of the next page. These are not ordinary equations but mean rather that the quantity on the left of the equal sign is the residue after casting out 2's of the sum on the right of the equal sign.

The illustration at the bottom of the next page shows in chart form which symbols appear in each check equation. For example, X_{10} is involved in the equation for calculating X_{14}, and thus in the row that has X_{14} at the left there is a "yes" in the column headed X_{10}. Each column in this chart is a different arrangement of yeses and noes. In fact, the 15 columns contain all the combinations possible with just four yeses or noes—except for all noes—and represent, in effect, another way to count to 15 in binary

DECIMAL	BINARY
00	0000
01	0001
02	0010
03	0011
04	0100
05	0101
06	0110
07	0111
08	1000
09	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

BINARY SYSTEM employs only two symbols, 0 and 1, and therefore requires writing down more symbols than in the decimal system to express any number greater than one. In decimal notation a 1 increases in value by multiples of 10 for each place that it moves to the left. Thus the decimal number 1,000 is $10 \times 10 \times 10$. In binary notation a 1 increases by multiples of 2 as it moves to left. Thus in binary, 1000 is $2 \times 2 \times 2$, or 8.

$$X_{12} = X_9 + X_8 + X_6 + X_4 + X_3 + X_2 + X_1$$

$$X_{13} = X_{10} + X_9 + X_7 + X_5 + X_4 + X_3 + X_2$$

$$X_{14} = X_{11} + X_{10} + X_8 + X_6 + X_5 + X_4 + X_3$$

$$X_{15} = X_{12} + X_{11} + X_9 + X_7 + X_6 + X_5 + X_4$$

ERROR-CORRECTING CODE devised in 1950 by Richard W. Hamming of the Bell Telephone Laboratories uses four check symbols to protect 11 information symbols (and the check symbols themselves) from single errors. X_1, X_2, ..., X_{11} represent the information symbols; X_{12}, X_{13}, X_{14}, X_{15} represent the check symbols. The symbols are either 0 or 1. These four equations employ the casting-out-2's method to yield the binary check symbols. The check symbol is 0 if the sum of the symbols at the right is 0 or even, 1 if the sum is odd.

notation. Each symbol, including the check symbols, is used in a different set of check equations. If a particular symbol is wrong, each equation involving it will fail. From the pattern of failures one can determine where the error lies.

Let us take an example. Suppose the information symbols X_1 through X_{11} are 11010010111, in that order. Then on the basis of the check equations X_{12} is the residue of 4 after casting out 2's, which is 0. Symbol X_{13} is the residue of 5, or 1, X_{14} is the residue of 3, or 1, and X_{15} is the residue of 4, or 0. Therefore the 15 digits that would be transmitted are 110100101110110, of which the last four at the right are checking digits. Suppose 110101101110110 is received. In order to locate the error the following questions must be posed and answered:

Does the X_{12} equation fail? Yes.
Does the X_{13} equation fail? No.
Does the X_{14} equation fail? Yes.
Does the X_{15} equation fail? Yes.

This combination of yeses and noes appears under X_6 in the illustration below. Therefore X_6 must be the incorrect symbol, for only this particular single error would cause the first, third and fourth equations to fail. Even an error in a check symbol can be corrected.

The "memories" of the International Business Machines giant Stretch computer and the Bell System experimental electronic switching system at Morris, Ill., use Hamming codes to protect against single errors. These computers can detect and correct such errors automatically.

Cyclic codes have some remarkable algebraic properties, and for some cyclic codes these involve rather deep algebraic theory. One interesting and useful property is that the successive check equations are formed by shifting the last previous sequence of yeses and noes one space to the right. The resulting pattern can be seen in the illustration below. Moreover, if a correctly coded message is shifted cyclicly—that is, X_1 into X_2, X_2 into X_3, ..., X_{14} into X_{15}, and X_{15} into X_1—the resulting message will also satisfy the check equations.

The most important consequence of the cyclic structure is that it can be exploited in designing a simple electronic encoder and error corrector, which requires only a modest number of electronic components, such as transistors. The device for calculating parity checks takes the form of a "shift register," a type of electronic circuit commonly used in computers. A diagram of the shift register for the cyclic Hamming code appears at the top of page 104. As the 0's and 1's of the code are fed into the register, one at a time, the register carries out a simple adding and shifting operation. After each step a 0 or 1 appears in a series of four storage units, which are designated *a*, *b*, *c* and *d*. In connection with the Hamming code this device has three uses. In each case the shift register is assumed to contain all 0's initially.

1. To calculate the check digits, the information symbols are entered in sequence, with a shift taking place after each entry. After the 11th symbol has been entered, the check symbols appear in the storage units: X_{12} appears in *a*, X_{13} in *b*, X_{14} in *c* and X_{15} in *d*.

2. To check for errors in a received message all 15 received symbols are entered in the register, which again shifts after each entry. If, and only if, the received message satisfies the check equations, the four storage units will contain all 0's after the 15th message symbol enters.

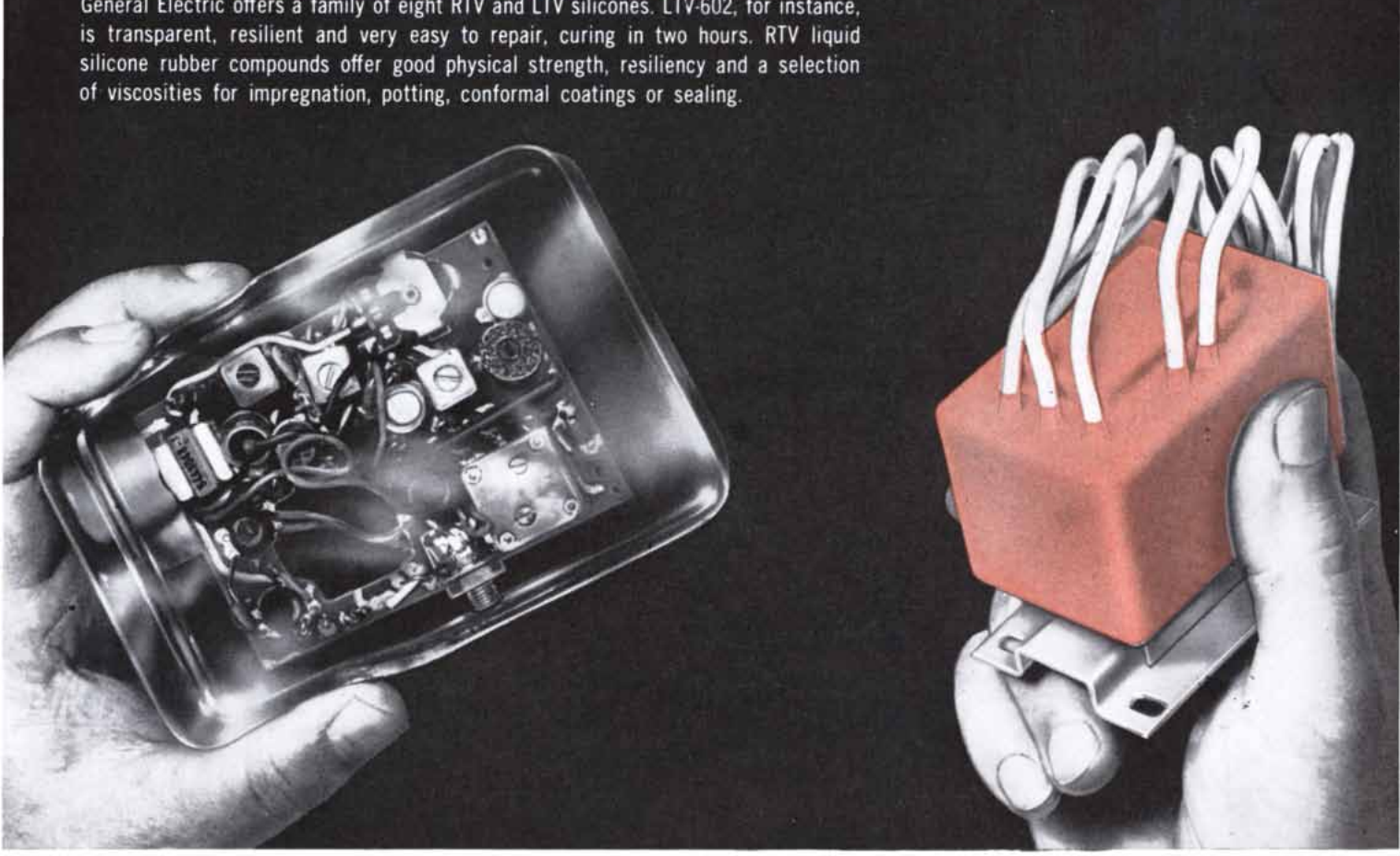
3. If the checking operation indicates that an error has occurred, and if it is a single error, the symbol in error can be determined as follows. After the operation described in the second step is completed, the shift register is shifted with 0's as input until 1000 appears in the four storage units. The number of the erroneous symbol is one greater than the number of shifts required to obtain this sequence of digits [*see illustration on page 106*].

Some remarkable cyclic codes have been discovered in the past few years. One class, discovered independently by A. Hocquenghem of the Conservatoire National des Arts et Métiers in Paris and by Raj Chandra Bose and D. K. Ray-Chaudhuri at the University of North Carolina, corrects multiple errors in any arrangement, the maximum number of errors correctable depending on the number of check symbols. Other

	SYMBOL														
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
EQUATION X_{12}	YES	YES	YES	YES	NO	YES	NO	YES	YES	NO	NO	YES	NO	NO	NO
EQUATION X_{13}	NO	YES	YES	YES	YES	NO	YES	NO	YES	YES	NO	NO	YES	NO	NO
EQUATION X_{14}	NO	NO	YES	YES	YES	YES	NO	YES	NO	YES	YES	NO	NO	YES	NO
EQUATION X_{15}	NO	NO	NO	YES	YES	YES	YES	NO	YES	NO	YES	YES	NO	NO	YES

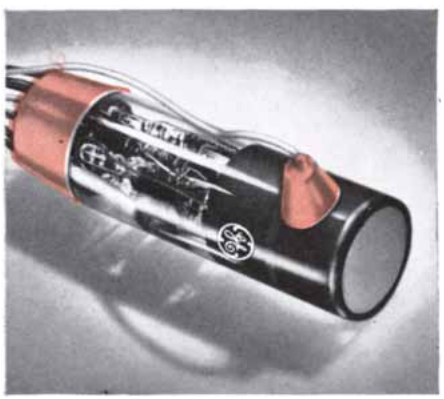
CHECKING SCHEME for the Hamming cyclic code is based on this array showing which symbols appear in each check equation. Each pattern of yeses and noes in the 15 columns is different. How the array is used to correct single errors is described in the text.

General Electric offers a family of eight RTV and LTV silicones. LTV-602, for instance, is transparent, resilient and very easy to repair, curing in two hours. RTV liquid silicone rubber compounds offer good physical strength, resiliency and a selection of viscosities for impregnation, potting, conformal coatings or sealing.



8 fast cures for potting and encapsulating problems

General Electric Silicones protect against temperature, moisture, ozone, thermal and mechanical shock



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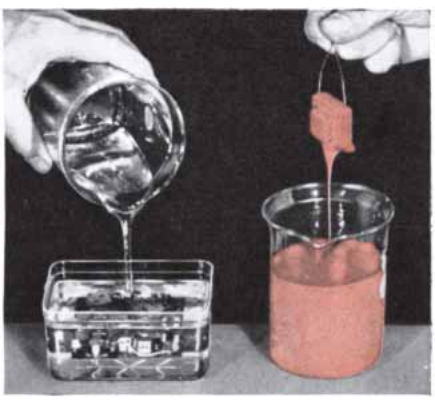

How are G-E silicones used? By dipping, pouring, spraying or buttering. Cure times can be varied from minutes to hours, depending on catalyst used and the heat applied (from room temperature to 125°C). They bond easily to properly primed surfaces, are easily removed from unprimed surfaces.

	COLOR	VISCOSITY POISES	CONSISTENCY
LTV-602 RTV-11	Clear White	15 120	Easily Pourable
RTV-20 RTV-40 RTV-60	Pink White Red	300 450 550	Pourable
RTV-77 RTV-88	White Red	8,000 10,000	Spreadable Thixotropic Paste
RTV-90	Red	12,000	Stiff Paste

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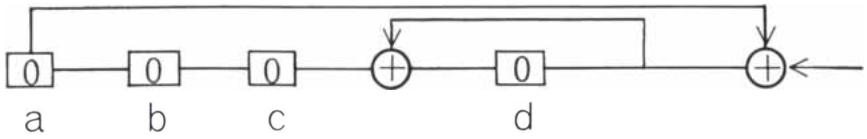
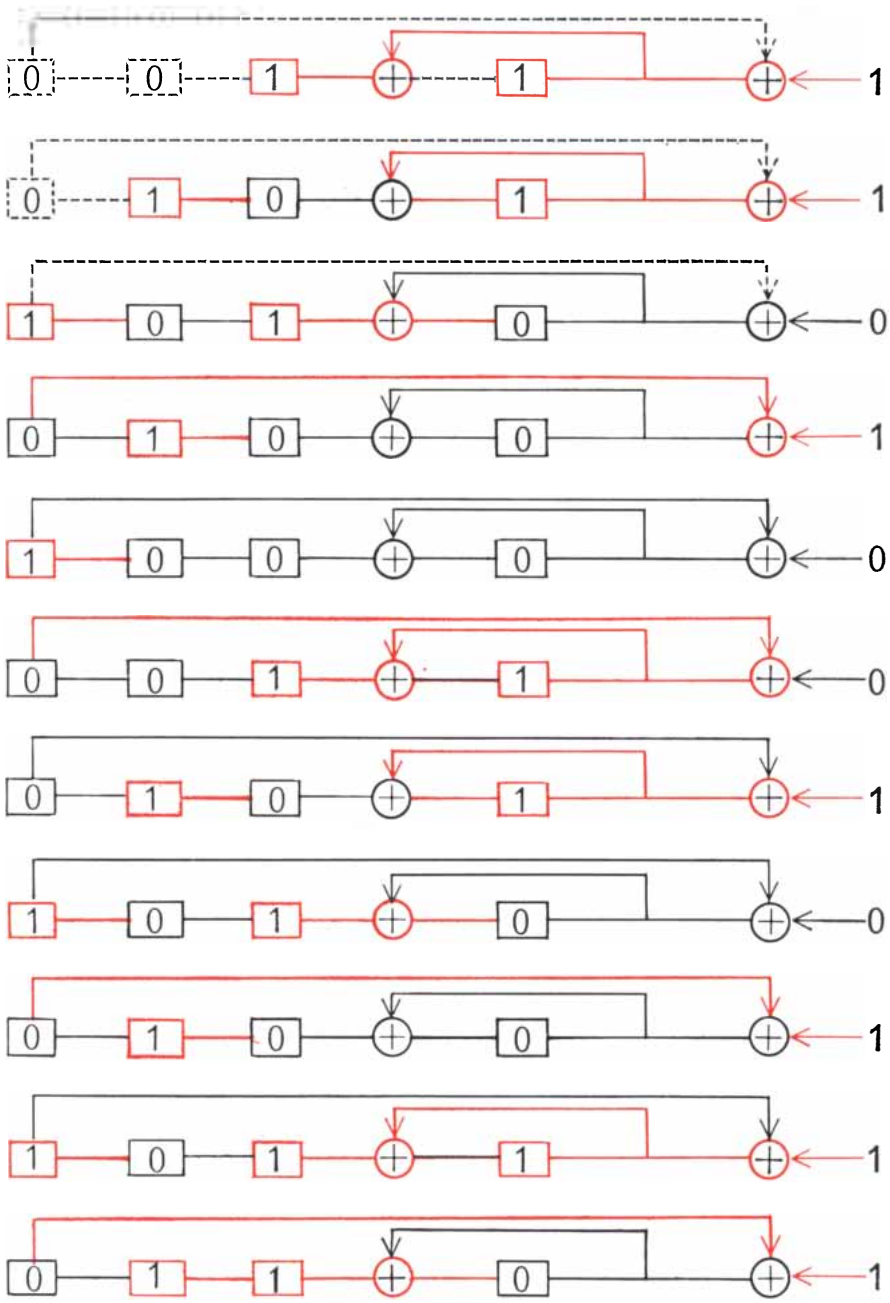
GENERAL ELECTRIC



SHIFT REGISTER is a simple electronic device for putting binary messages into a Hamming code and for checking the accuracy of the received message. The input is either a 0 or 1 of the primary message. The circles containing a plus sign represent "adders." The signal coming out of them is a 0 if the sum of the input signals is 0 or 2 and 1 if the sum is 1. The square blocks (*a, b, c, d*) are shifting storage devices; they store either 0 or 1. When a shift signal is given, the stored symbols appear as signals on the output lines (*extending to left*), and the storage devices store the new symbols carried by signals entering from the right.



DERIVATION OF CHECK SYMBOLS is shown for the 11-symbol message 11010010111. At the start the four storage devices contain 0's, as shown at the top of page. Entry of the first symbol, 1 (*reading the message from the left*), makes each adder put out a signal for 1 (*color*), leading to the storage of 1's in *c* and *d*. Entry of the second symbol, also 1, makes the first adder put out a 1, but the second adder, having received two 1's as an input, puts out a 0, which is stored in *c*. The 1 previously stored in *c* passes to *b*. (Broken lines indicate parts of register not yet activated.) The register continues to shift in this fashion until all 11 symbols have been entered. The symbols remaining in the four storage devices, 0110, are the four check symbols that must be added to the message, which becomes 110100101110110.

codes protect against errors clustered in widely spaced groups or bursts.

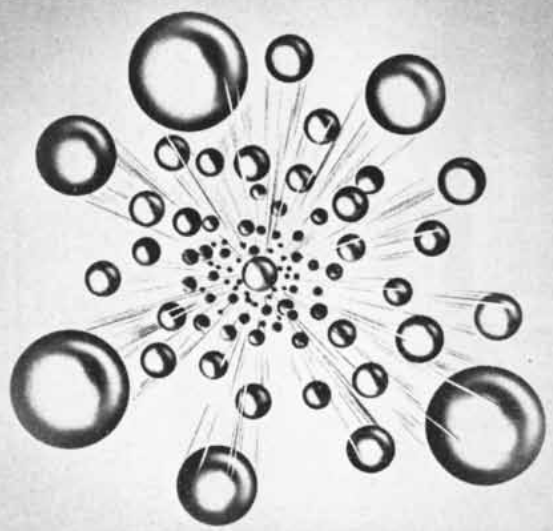
Because of their cyclic structure these codes are also relatively easy to use. A prototype decoder for a 127-symbol, five-error-correcting Bose-Chaudhuri code is being built by Thomas C. Bartee at the Lincoln Laboratory of the Massachusetts Institute of Technology. Employing transistors, the decoder will occupy no more space than an ordinary file drawer. Prototype decoders for burst-error-correcting codes have been built by IBM and by the Bell Telephone Laboratories.

When cyclic codes are used only for error detection rather than for error correction, the equipment can be simpler still. For example, at the Lincoln Laboratory an experimental system embodying error detection is being built for high-speed, two-way data transmission over a telephone line. When an error is detected, a request for a repeat transmission is automatically made over the return channel. The code used in this system is a Bose-Chaudhuri code with 255 symbols, of which only 24 are check symbols. The encoder and error detector use a 24-stage shift register of the type shown at the top left. It is estimated that the code will fail to detect an error on the average of once every 300 years. This, of course, is much longer than the terminal equipment can be expected to operate without failure.

For a specified number of information symbols and a specified number of check symbols, there are many ways in which to set up equations for calculating check symbols. Depending on the transmission characteristics of a given channel, some are good and some are poor choices. For each choice there is an optimum procedure for correcting errors and a certain probability that an uncorrectable pattern of errors will occur. For codes of appreciable length it is difficult to calculate the probability of an uncorrectable error. For a binary code of 50 symbols, of which half are check symbols, many hours of computer time are required to calculate the error probability. It is possible, however, by a mathematical stratagem to calculate the *average* error probability for *all* codes with a given total number of symbols. The stratagem is actually the basis for Shannon's original proof of his fundamental theorem on error-correcting codes.

As an example, consider a channel that transmits binary symbols and in which the probability of error is .01; that is, on the average, 99 times out of 100, transmitted symbols are received correctly, but once in 100 symbols a

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



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

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

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

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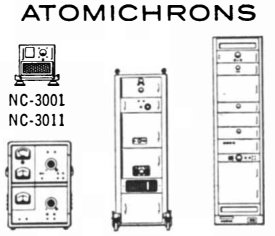

SHIFT REGISTER CONTENTS a b c d	INPUT	
0 0 0 0	1 1 0 1 0 1 1 0 1 1 1 0 1 1 0	
0 0 1 1	1 0 1 0 1 1 0 1 1 1 0 1 1 0	
0 1 0 1	0 1 0 1 1 0 1 1 1 0 1 1 0	
1 0 1 0	1 0 1 1 0 1 1 1 0 1 1 0	
0 1 0 0	0 1 1 0 1 1 1 0 1 1 0	
1 0 0 0	1 1 0 1 1 1 0 1 1 0	
0 0 0 0	1 0 1 1 1 0 1 1 0	
0 0 1 1	0 1 1 1 0 1 1 0	
0 1 1 0	1 1 1 0 1 1 0	
1 1 1 1	1 1 0 1 1 0	
1 1 1 0	1 0 1 1 0	
1 1 0 0	0 1 1 0	
1 0 1 1	1 1 0	
0 1 1 0	1 0	
1 1 1 1	0	
ALL ZEROS IF NO ERROR → 1 1 0 1		
1 0 0 1		FIVE EXTRA SHIFTS TO PRODUCE 1000 INDICATES ERROR IN SIXTH POSITION
0 0 0 1		
0 0 1 0		
0 1 0 0		
1 0 0 0		

ERROR CHECKING is accomplished with the same shift register used for calculating the check symbols, illustrated on page 104. There it was seen that the 11-symbol message 11010010111 requires 4 checking symbols, 0110, so that the total message transmitted is 110100101110110. This illustration shows the successive storage contents of the shift register if the message as received contains one error: 110101101110110. When all 15 symbols have been entered into the register, the reading of 1101 indicates that an error has occurred. The register is then shifted (with 0's as input) until it reads 1000. The number of the erroneous symbol is one greater than the number of shifts required: it is the sixth symbol from left.

0 is received as a 1, or vice versa. Then the probability of an uncorrectable error, *averaged over all possible codes* of 511 symbols, of which 171 are check symbols, is approximately .00000000000000035; that is, for an average code it can be shown mathematically that only one in approximately three million billion code blocks of 511 symbols would contain uncorrectable errors. Now, if we write out a set of parity-check equations for a code of this size, there is about a 50–50 chance that it will be as good as the mathematical average. Certainly many of the codes must be better than this. Yet we do not know how to write check equations for any code that we can prove is as good as the average.

The Bose-Chaudhuri codes are by far the best codes for which the check symbol calculation and the error-correction procedure are explicitly known. For the Bose-Chaudhuri code of length 511 with 171 check symbols, and with the same assumptions as in the preceding paragraph, the probability of an error pattern uncorrectable by the known correction procedure is .00000009. It can be shown that this is not the best mathematical correction procedure, but we know of no better practical procedure; and we do not know what the probability of error would be for this code with the best error-correction procedure. Although this is the best-understood code, we have not yet been able to prove that it is as good as average!

This state of affairs has presented a challenge and a source of some frustra-

? Ever see a workhorse fly

Hurdling transportation barriers is the job of Sikorsky's S-64 Skycrane. Lifting a 10-ton payload, the Skycrane will keep busy moving supplies, loading ships, and erecting steel. It will string wire and pipe, tow boats, track submarines, and carry everything from letters to logs. Fitted with passenger pods, Skycranes will speed troops to trouble spots and workers to job sites.

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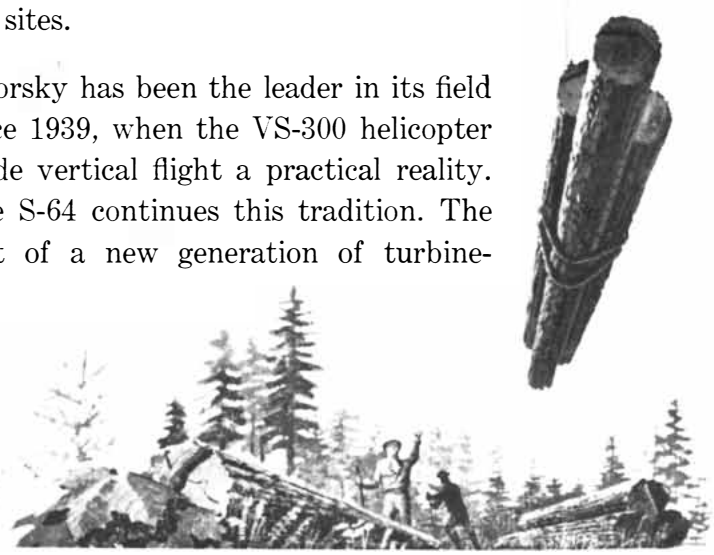
The Sikorsky Skycrane is only one example of the expanding product spectrum at United Aircraft. This pioneering corporation serves industry, commerce, and defense with unmatched research capability and the multiple skills of 60,000 people. United Aircraft is a significant and growing force in power, propulsion, nuclear energy, electronics, vertical flight, navigation, and controls.



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tion to specialists in the field. Surely it must be possible to construct a better-than-average code. Yet it seems that when we construct a code by regular rules, its very structure makes it poor for combating random errors.

Some information theorists, notably Robert M. Fano, John McReynolds Wozencraft and Patrick Ximenes Gallagher of the Massachusetts Institute of Technology, believe that the best solution is to pick a code at random or construct the check-symbol equations at random. Some fairly effective systems based on randomly chosen codes have been devised. An experimental model of one such system is being built at the Lincoln Laboratory, and there will be great interest in the outcome of this experiment. It is quite possible that such systems will be increasingly important in the future.

It has been only in the past two or three years that the theory of error-correcting codes has advanced sufficiently to provide the basis for practical systems. Computer technology also has continued to advance, decreasing the cost and increasing the speed of equipment used to implement error correction. At the same time, there is a growing need for communication channels of extreme reliability for computers and automatic control systems. As the need grows and as coding theory and computer technology continue to develop, error detection and error correction will play an essential role in the success of complex systems.

ARAB MATHEMATICIANS of about A.D. 800 are credited with inventing one of the earliest error-detecting schemes, known as casting out 9's. This useful technique, seldom taught any more, would be very useful to school children. How it works is explained in the text.

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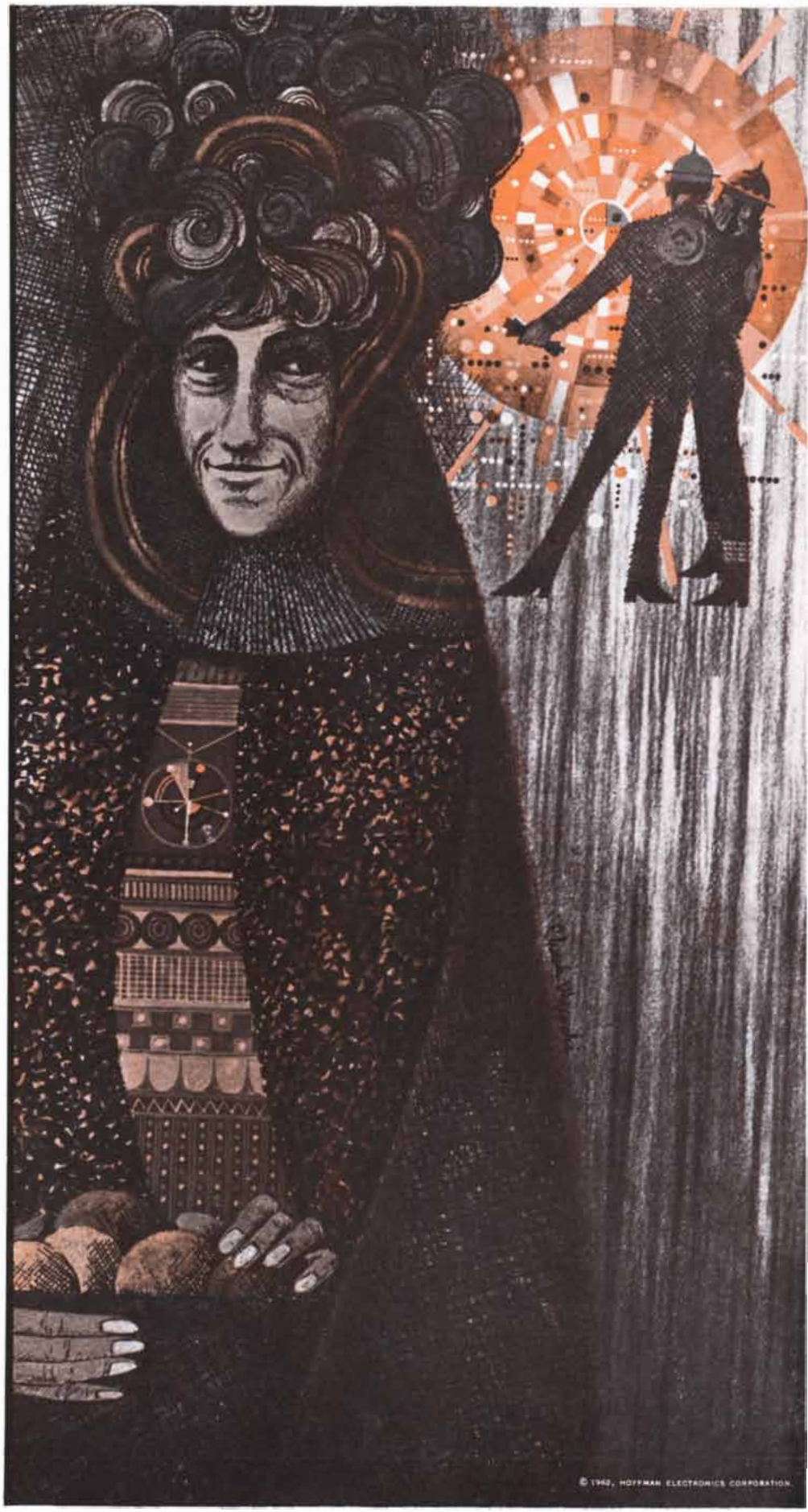
MY SON, THE PHYSICIST!

NO. 2 IN A SERIES OF SCIENCE-FICTION ORIGINALS CREATED EXPRESSLY FOR HOFFMAN ELECTRONICS CORPORATION.

by ISAAC ASIMOV



Her hair was a light apple-green in color, very subdued, very old-fashioned. You could see she had a delicate hand with the dye, the way they did thirty years ago, before the streaks and stipples came into fashion.

She had a sweet smile on her face, too, and a calm look that made something serene out of elderliness.

And, by comparison, it made something shrieking out of the confusion that enfolded her in the huge government building.

A girl passed her at a half-run, stopped and turned toward her with a blank stare of astonishment. "How did you get in?"

The woman smiled. "I'm looking for my son, the physicist."

"Your son, the———"

"He's a communications engineer, really. Senior Physicist Gerard Cremona."

"Dr. Cremona. Well, he's——— Where's your pass?"

"Here it is. I'm his mother."

"Well, Mrs. Cremona, I don't know. I've got to——— His office is down there. You just ask someone." She passed on, running.

Mrs. Cremona shook her head slowly. Something had happened, she supposed. She hoped Gerard was all right.

She heard voices much further down the corridor and smiled happily. She could tell Gerard's.

She walked into the room and said, "Hello, Gerard."

Gerard was a big man, with a lot of hair still and the gray just beginning to show because he didn't use dye. He said he was too busy. She was very proud of him and the way he looked.

Right now, he was talking volubly to a man in army uniform. She couldn't tell the rank, but she knew Gerard could handle him.

Gerard looked up and said, "What do you——— Mother! What are you doing here?"

"I was coming to visit you today."

"Is today Thursday? Oh Lord, I forgot. Sit down, mother, I can't talk now. Any seat. Any seat. ———Look, General."

General Reiner looked over his shoulder and one hand slapped against the other in the region of the small of his

back. "Your mother?" "Yes."

"Should she be here?"

"Right now, no, but I'll vouch for her. She can't even read a thermometer so nothing of this will mean anything to her. Now look, General. They're on Pluto. You see? They are. The radio signals can't be of natural origin so they must originate from human beings, from our men. You'll have to accept that. Of all the expeditions we've sent out beyond the planetoid belt, one turns out to have made it. And they've reached Pluto."

"Yes, I understand what you're saying, but isn't it impossible just the same? The men who are on Pluto now were launched four years ago with equipment that could not have kept them alive more than a year. That is my understanding. They were aimed at Ganymede and seem to have gone eight times the proper distance."

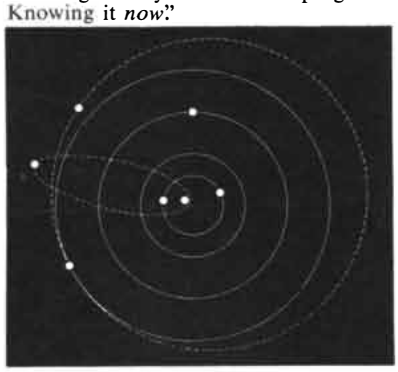
"Exactly. And we've got to know how and why. They may———just———have———had———help."

"What kind? How?"

Cremona clenched his jaws for a moment as though praying inwardly. "General," he said, "I'm putting myself out on a limb but it is just barely possible non-humans are involved. Extra-terrestrials. We've got to find out. We don't know how long contact can be maintained."

"You mean," (the General's grave face twitched into an almost-smile), "they may have escaped from custody and they may be recaptured again at any time."

"Maybe. Maybe. The whole future of the human race may depend on our knowing exactly what we're up against. Knowing it *now*."



"All right. What is it you want?"

"We're going to need Army's Multivac computer at once. Rip out every problem it's working on and start programming our general semantic problem. Every communications engineer you have must be pulled off anything he's on and placed into coordination with our own."

"But why? I fail to see the connection."

A gentle voice interrupted. "General, would you like a piece of fruit? I brought some oranges."

Cremona said, "Mother! Please! Later! ———General, the point is a simple one. At the present moment Pluto is just under four billion miles away. It takes six hours for radio waves, travelling at the speed of light, to reach from here to there. If we say something, we must wait twelve hours for an answer. If they say something and we miss it and say 'what' and they repeat———bang, goes a day."

"There's no way to speed it up?" said the General.

"Of course not. It's the fundamental law of communications. No information can be transmitted at more than the speed of light. It will take months to carry on the same conversation with Pluto that would take hours between the two of us right now."

"Yes, I see that. And you really think extra-terrestrials are involved?"

"I do. To be honest, not everyone here agrees with me. Still, we're straining every nerve, every fiber, to devise some method of concentrating communication. We must get in as many bits per second as possible and pray we get what we need before we lose contact. And there's where I need Multivac and your men. There must be some communications strategy we can use that will reduce the number of signals we need send out. Even an increase of ten percent in efficiency can mean perhaps a week of time saved."

The gentle voice interrupted again. "Good grief, Gerard, are you trying to get some talking done?"

"Mother! Please!"

"But you're going about it the wrong way. Really."

"Mother." There was a hysterical edge to Cremona's voice.

"Well, all right, but if you're going to say something and then wait twelve hours for an answer, you're silly. You shouldn't."

The general snorted. "Dr. Cremona, shall we consult———"

"Just one moment, General," said Cremona. "What are you getting at, mother?"

"While you're waiting for the answer," said Mrs. Cremona, earnestly, "just keep on transmitting and tell them to do the same. You talk all the time and they talk all the time. You have someone listening all the time and they do, too. If either one of you says anything that needs an answer, you can slip one in at your end, but chances are, you'll get all you need without asking."

Both men stared at her.

Cremona whispered, "Of course. Continuous conversation. Just twelve hours out of phase, that's all.———God, we've got to get going."

He strode out of the room, virtually dragging the general with him, then strode back in.

"Mother," he said, "if you'll excuse me, this will take a few hours, I think. I'll send in some girls to talk to you. Or take a nap, if you'd rather."

"I'll be all right, Gerard," said Mrs. Cremona.

"Only, how did you think of this, mother? What made you suggest this?"

"But, Gerard, all women know it. Any two women———on the videophone, or on the stratowire, or just face to face ———know that the whole secret to spreading the news is, no matter what, to Just Keep Talking."

Cremona tried to smile. Then, his lower lip trembling, he turned and left.

Mrs. Cremona looked fondly after him. Such a fine man, her son, the physicist. Big as he was and important as he was, he still knew that a boy should always listen to his mother.

AMOEBOID MOVEMENT

In a new theory to explain the mechanism of motility in amoebae and similar cells, the author proposes that streaming cytoplasm contracts at the front of the cell and literally pulls it along

by Robert D. Allen

Looking through a microscope, one can see that an amoeba appears to move by pouring itself into temporary projections called pseudopodia (from the Greek for "false feet"), which disappear as the cell streams forward. The longer one looks, the more puzzling this form of locomotion must seem. Intuition readily suggests the mechanism of other types of cell motion: a muscle moves by contraction of its myofibrils, a paramecium by the rhythmic rowing of its hundreds of oarlike cilia, a sperm by the flailing of its long, whiplike flagellum. The machinery that moves the amoeba, in contrast, seems to involve almost the entire substance of the cell, with no visible, specialized structures of its own.

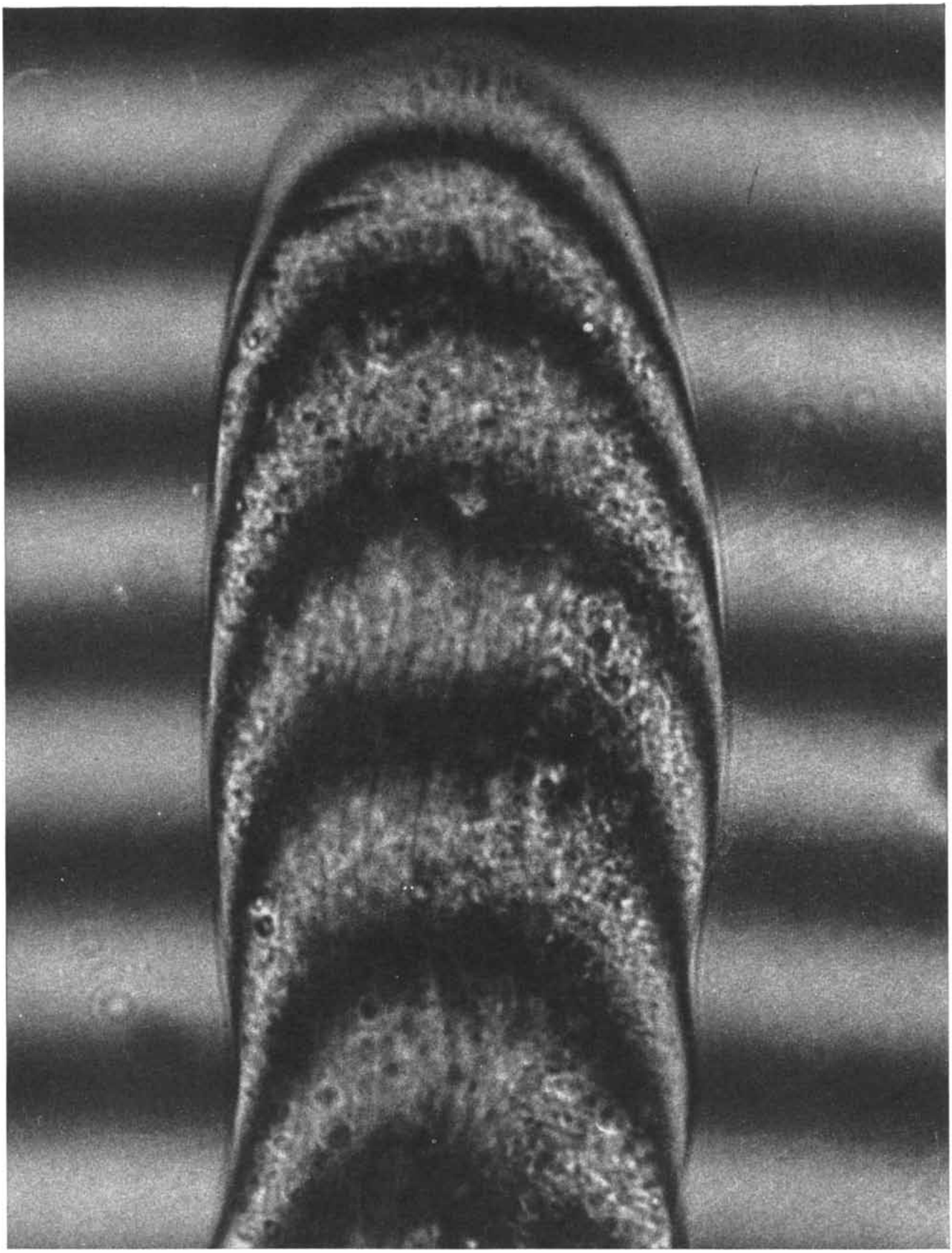
In general, the motility of cells remains less well understood than such invisible subcellular processes as photosynthesis or respiration, which furnish the energy for motion and the other activities of cells. The biologist, of course, seeks ultimately to explain cell motion in terms of the energy transformations conducted by the molecular components of the cell. Study of the properties of proteins extracted from muscle cells and slime molds has even begun to yield some glimpses of what muscle contraction may involve on the molecular scale. These findings have some bearing on cell motility in general [see "How Cells Move," by Teru Hayashi; SCIENTIFIC AMERICAN, September, 1961]. Amoeboid motion, however, has not lent itself to study in the test tube. It has been necessary to study this mode of motility in the living cell: to analyze the various movements, identify the forces involved and localize the sites at which these forces come into play. With further progress along this line it should soon be possible to frame some fruitful hypotheses for the biochemist.

Until recently investigators proceeded on the theory that the amoeba moved by extruding or squirting itself into its pseudopodia by the pressure of contraction from the rear. Now it appears that the essential mechanism works just the other way around: the cytoplasm—the extranuclear contents of the cell—pulls itself forward into the leading end of each pseudopodium! This unlikely conclusion is the outcome of a course of investigation on which I was led by a lucky laboratory accident that occurred eight years ago in Stockholm.

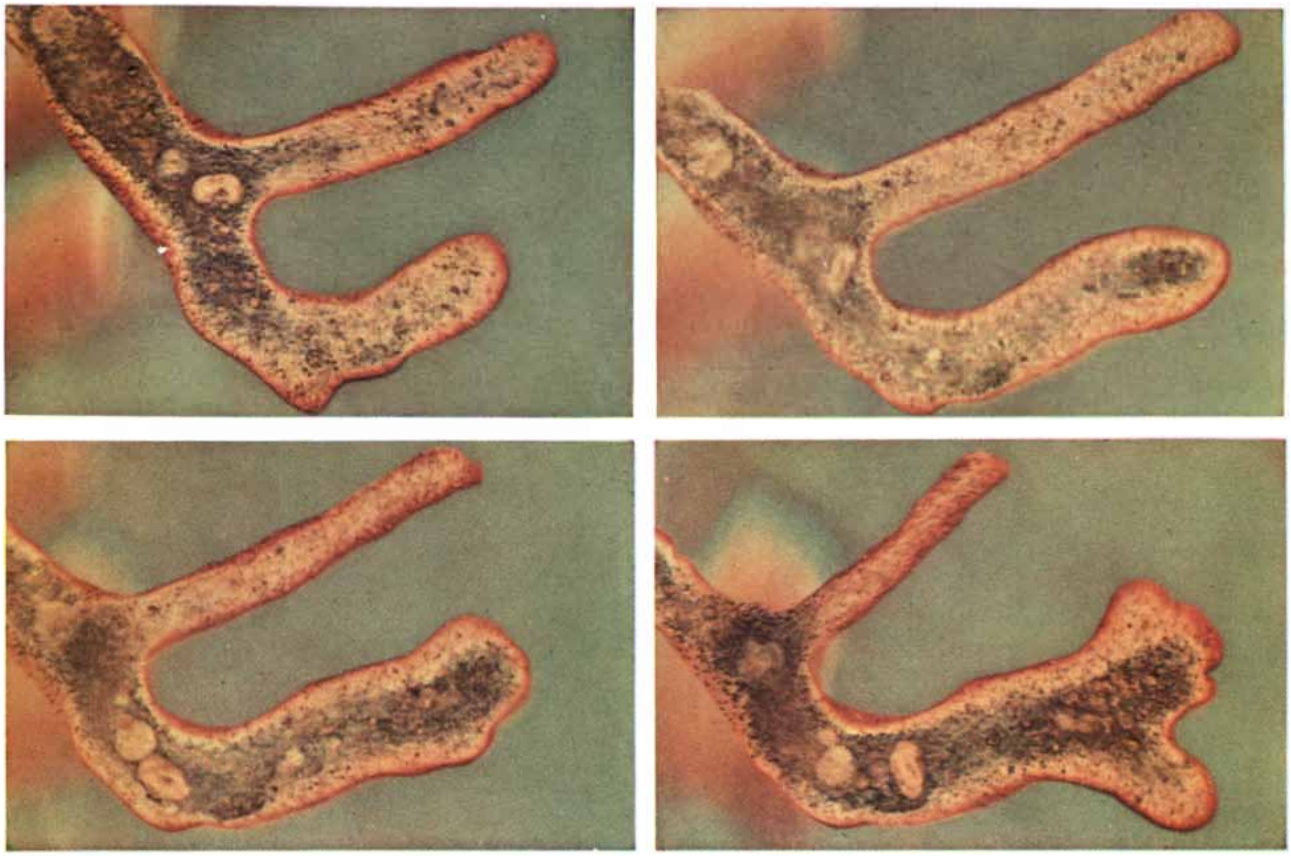
Amoeboid motion has always fascinated me, I suppose because amoeboid cells exhibit behavior of a rudimentary kind. Many of the larger amoebae respond to light and to mechanical and chemical stimuli; they pursue and capture prey, often highly differentiated multicellular animals about their own size. What is more, amoeboid motion has general biological and medical significance because it plays an important role in the life processes of higher organisms. It is studied in free-living cells because they are convenient, but whatever is learned there may help toward an understanding of cellular movement in general. Amoeboid movement is observed, for example, in one of the most primitive kinds of cellular aggregation, in the slime molds [see "Differentiation in Social Amoebae," by John Tyler Bonner; SCIENTIFIC AMERICAN, December, 1959]. Amoeboid movement has a developmental function further up the evolutionary scale in sorting out the differentiating cells of embryos and molding the shape of the embryonic cell layers [*see top illustration on page 115*].

Most of the leucocytes, the white blood cells that defend the body against bacterial infection, are amoeboid. They propel themselves along the walls of the capillaries and squeeze through the tiny spaces between the cells that line these vessels. At the site of infection or trauma they ingest bacteria and damaged tissue cells by phagocytosis, the amoeboid eating process in which a cup-shaped pseudopodium surrounds and ingests a foreign particle in a cavity called a vacuole. Amoeboid movement also seems to be important medically in certain parasitic diseases and in cancer. There are species of amoeboid cells that live as parasites in the gastrointestinal tracts of animals, including humans. Some are harmless but others, such as *Endamoeba histolytica*, cause dysentery and tissue lesions. And one of the ways in which a cancer spreads from its original site is by amoeboid movement of malignant cells.

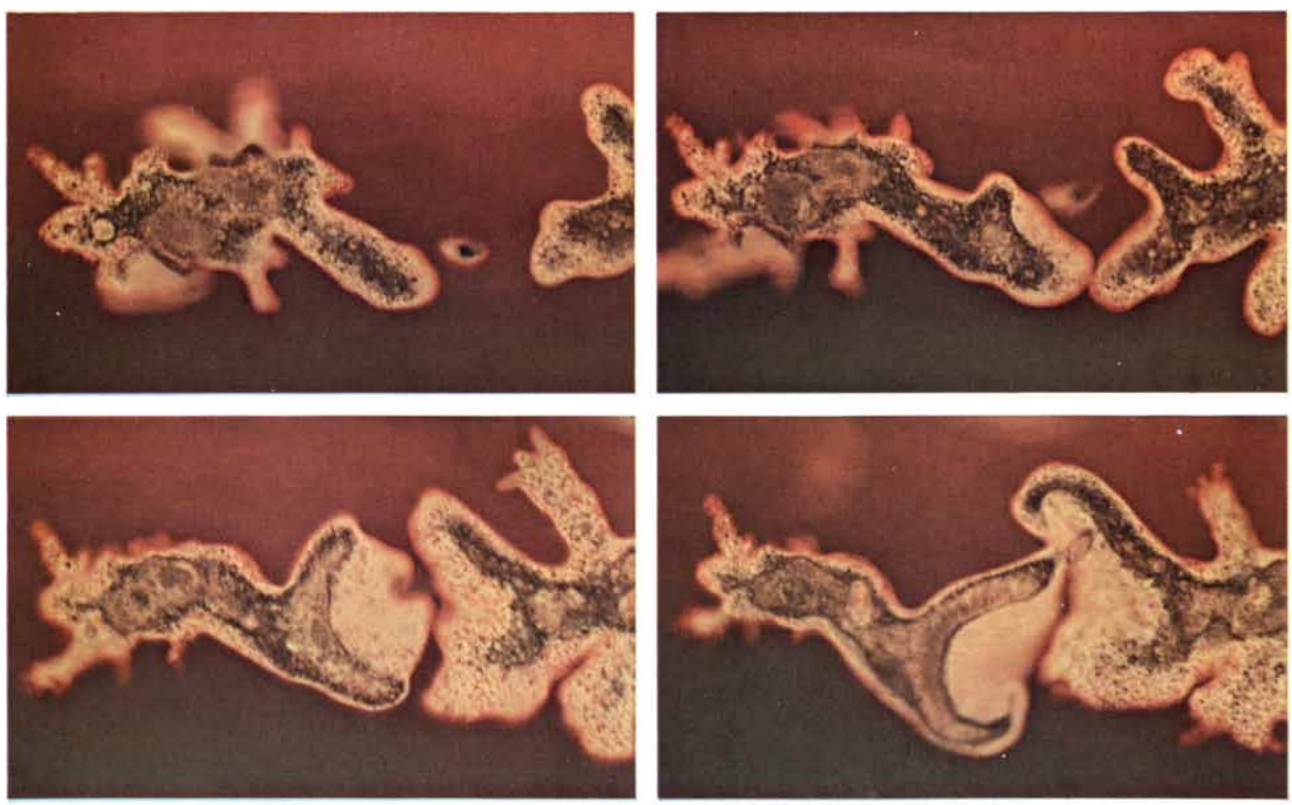
Most of the work in our laboratory at Princeton University has been done with two common species of amoeba. One is *Amoeba proteus*, the most studied of the genus because it is so common and so easy to grow in laboratory cultures maintained on ciliates and flagellates. The other is the giant species with the colorful name of *Chaos chaos*. Lakes, ponds and bogs abound with many other kinds of amoeba, each having its characteristic shape and way of moving. They vary greatly in size. *Chaos chaos* can be several millimeters long; *A. proteus* is roughly a tenth as large and is just visible to the naked eye; a new species that I recently encountered in Japanese waters is only .005 or .006 millimeter long. The pseudopodia of amoeboid organisms range in shape from cylinders with rounded or pointed ends (called lobopodia when short and thick, and filopodia when long and thin) to flat sheets of cytoplasm, with diameters ranging from about .1 to .0001 millimeter. Although it is likely that all these different pseudopodia move by the same basic mechanism, differences in their



PSEUDOPODIUM, or "false foot," of the amoeba *Chaos chaos* is seen in an interference photomicrograph made by the author and Ronald Reed Cowden. The enlargement is 850 diameters. The curvature of the dark interference fringes varies with the thickness of the specimen and the refractive indices, and hence the water content, of the various parts of the pseudopodium. The discontinuity in the fringes (*a flattened top seen most clearly in the third fringe from the bottom*) shows there is more water in the endoplasmic stream than in the ectoplasmic tube. The water is assumed to be squeezed from the endoplasm by contraction at the front of the cell.



AMOEBOID MOVEMENT is accomplished by the "flowing" of the cell contents into a pseudopodium. These photomicrographs made by the author are of *Amoeba proteus*, enlarged 150 diameters. The sequence shows the upper of two pseudopodia becoming thinner and then retracting as the bulk of the cell moves into the lower one and the cell advances toward the lower right of the field.



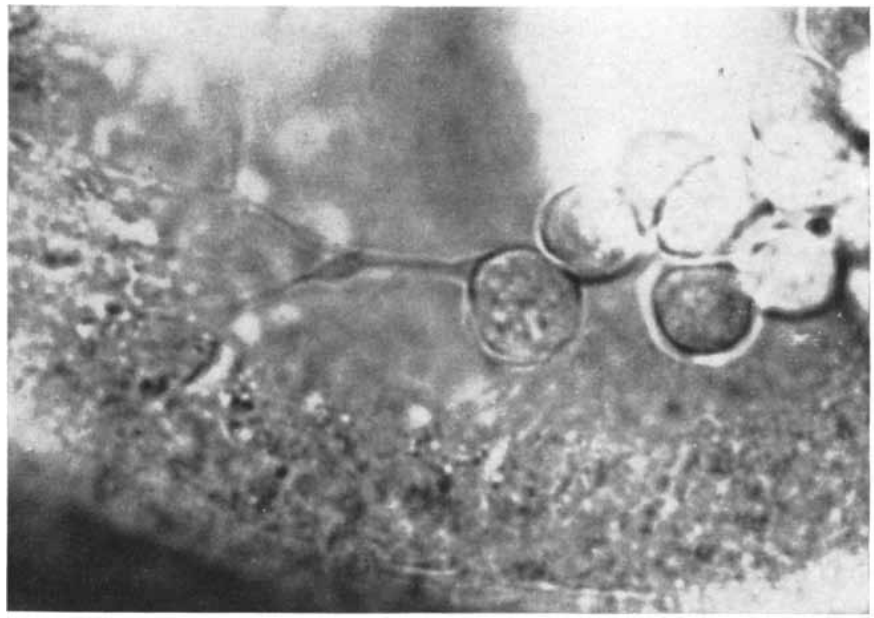
PHAGOCYTOSIS, or cellular eating, is demonstrated by two specimens of *A. proteus*, enlarged 150 diameters, in photographs made by the author. A ciliate is seen between the amoebae (*upper left*). They move in on it (*upper right*). For a time the ciliate is trapped by a pseudopodium of the left-hand amoeba (*lower left*); it gets away, only to be engulfed (*lower right*) by the other cell.

movement suggest that the mechanism must vary somewhat from organism to organism. There are still more amoeboid cells in the sea, but the pseudopodia of some of these behave rather differently from those of the amoebae. Our work has so far been concerned principally with the lobopodia of amoeboid cells.

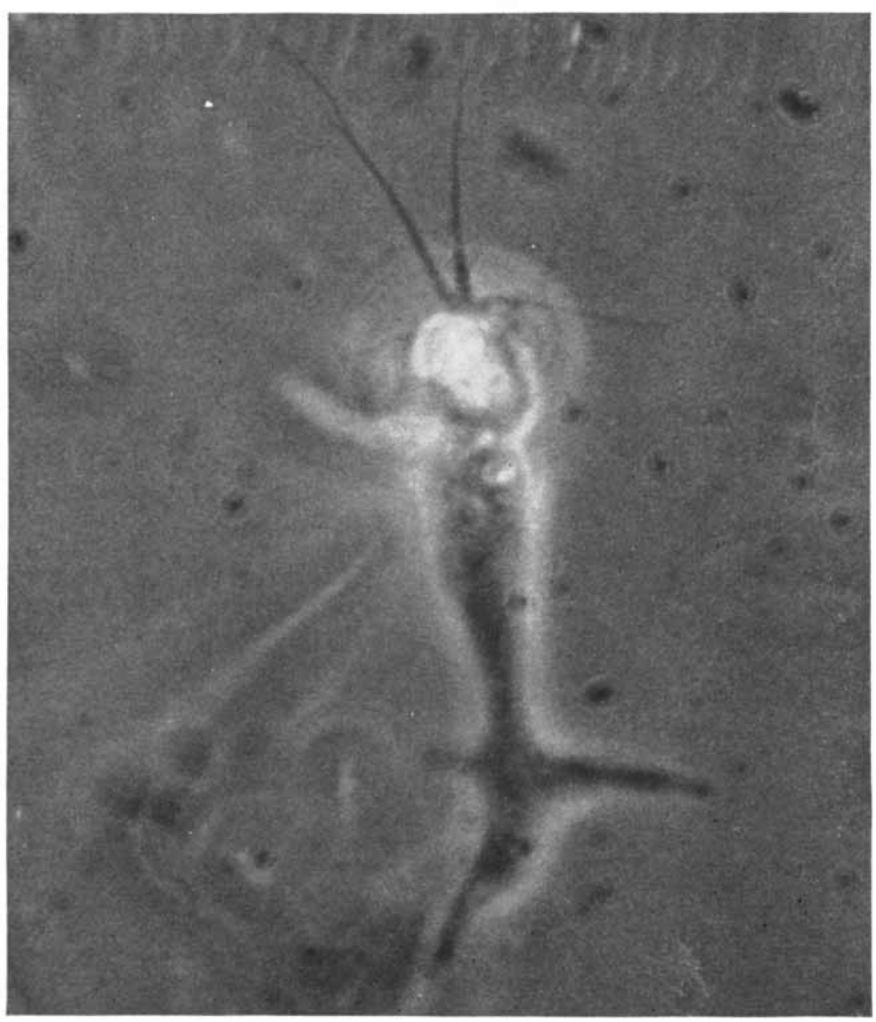
An amoeboid cell, in simplest terms, is a quantity of protoplasm contained by a flexible and deformable membrane, the plasmalemma. Patient observation, made easier by the presence of visible particles and vacuoles in the cytoplasm, shows that when the cell moves, a stream of cytoplasm is displaced in the direction of movement. At the advancing end of the cell this "endoplasmic stream" everts—turns inside out like a cuff—and at the same time changes in consistency to form a tube of stiffer material, the ectoplasm. The ectoplasmic tube anchors itself at some point of attachment through the plasmalemma to the substratum, and the entire cell is displaced forward. At the tail of the cell the ectoplasmic tube is converted into flowing endoplasm. In this manner the amoeboid cell advances through the tube that it makes as it moves.

From the 1920's on the only theory of amoeboid movement given serious consideration by most biologists was the one variously known as the "pressure," "ectoplasmic contraction" or "sol-gel" theory. Its chief proponents were C.F.A. Pantin of the University of Cambridge and the late S. O. Mast of Johns Hopkins University. They explained the observed changes in consistency between the endoplasm and the ectoplasm as a cyclic transformation of the cytoplasm from one colloidal state to another: from the sol (more fluid) to the gel (more solid) state at the advancing end of a pseudopodium and from gel back to sol at the tail. The forward motion of the sol, according to Pantin and Mast, was caused by pressure at the rear set up by contraction of the ectoplasmic tube [*see illustration at top of page 117*]. For many years the ectoplasmic-contraction theory remained both untested and unchallenged; it became the classic textbook explanation. Its appeal lies in the apparent similarity between endoplasmic streaming in a cell and the flow of fluids in any tube under pressure.

This description of the mechanism of amoeboid movement was even buttressed for a time by a molecular explanation. In 1950 Reginald J. Goldacre and I. Joan Lorch of the Chester Beatty Research Institute in London proposed



EMBRYONIC CELLS may be capable of amoeboid movement, which then has a developmental function. This photomicrograph of sea urchin embryonic cells, enlarged 1,500 diameters, was made by Tryggve Gustafson of the University of Stockholm. The thin filopodia (*left*) of these cells apparently exert a pulling force to mold the layers of the embryo.



BATTLE SCENE, a photomicrograph made by the author, shows a struggle between a small filopodial amoeba (*top*) and a larger lobopodial specimen. When the picture was taken, the smaller organism had been ingested except for its delicate pseudopodia, with which it subsequently forced its way to freedom by pulling. The magnification is 2,600 diameters.

a molecular model in which folding and unfolding of protein molecules explained the two major physical processes postulated by the pressure theory: the generation of pressure by contraction and the cyclic change in the consistency of the cytoplasm. They suggested that cytoplasm assumed the gel state at the forward end of the pseudopodium because the protein molecules unfolded as they moved from the endoplasm into the ectoplasm. With many chemical bonds thereby exposed, the molecules would be tightly bonded to one another to form the relatively rigid tube of ectoplasm. The molecules at the rear end of the ectoplasmic tube were said to become partly folded, accounting for the contraction. Then, as the molecules moved from the ectoplasm into the endoplasm, they became tightly folded. With the chemical bonds no longer available for intermolecular attraction, the loosely bonded cytoplasm became a flowing sol [*see illustration at top of opposite page*].

Indirect evidence seemed to confirm the Goldacre-Lorch model. The investigators observed that when a dye called neutral red was taken up by an amoeba it accumulated in the tail; they assumed that the unfolded ectoplasmic molecules, having more bonds available for the dye, had carried it to the tail and released it on contracting and folding. In another experiment injections of adenosine triphosphate (ATP), the cellular energy donor, brought about changes in cell behavior. This was taken as an indication that the ATP had directly stimulated the presumed contractile machinery in the tail. Actually the results of both experiments, while compatible with the proposed model, can be explained in other ways. The Goldacre-Lorch model, while it appeared to explain the classic theory, did not in fact prove its correctness.

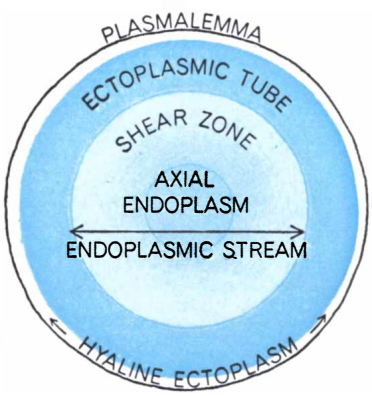
My first inkling that the pressure theory might be wrong came in John Runnström's laboratory in Stockholm. We were working with the amoeba as our laboratory animal for a study of the attachment of cells to glass. One day I was examining an amoeba in a glass capillary that contained water. I was using an unfamiliar microscope, and when I attempted to raise the objective, I racked it downward instead. I can still hear with undiminished anguish the crunching sound as the objective (with its lens fortunately recessed) broke the capillary.

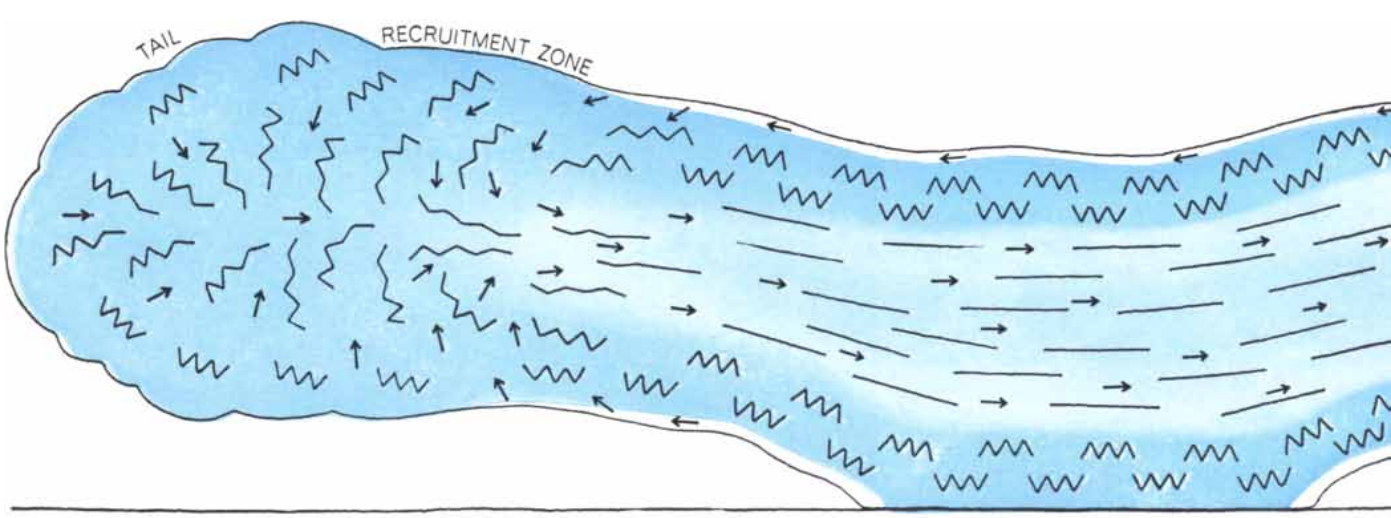
The shock naturally ruptured the amoeba's plasmalemma. Its cytoplasm, no longer enclosed within a membrane, was held in place instead by the walls of the unbroken segment of the capillary. To my astonishment, the naked cytoplasm continued to stream much as it had in the intact cell. With no membrane to contain the assumed pressure of contraction, the streaming should have stopped. Then, to my further astonishment, the cytoplasm began to stream in both directions, and more vigorously than before!

At first it seemed probable that convection currents or some other physical explanation would account for this highly unexpected extracellular streaming. But I soon became convinced—after performing some better-controlled experiments in which I fractured the capillary with a knife instead of a microscope—that the force responsible for this streaming could not be pressure and must be some other kind of force generated within the cytoplasm itself.

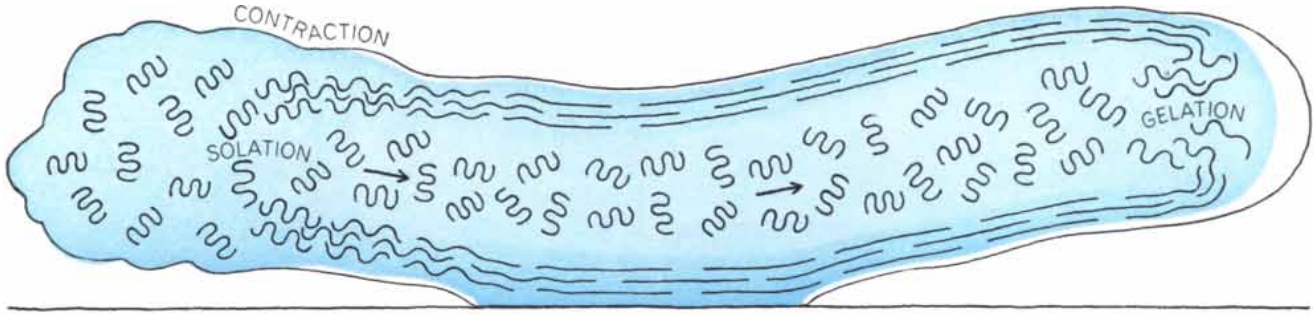
It was five years before my colleagues and I began to understand just how the streaming occurs. At the outset it seemed barely possible that streaming could have a different mechanism in intact and in broken cells. This was unlikely, however, because we could see the streaming continue without interruption when we ruptured the membrane. Moreover, we several times observed two-way streaming in intact cells. It is perfectly clear that pressure cannot make fluid flow in opposite directions in the same closed system. The pressure theory and its molecular model both require the presence of a membrane and an ectoplasmic tube. Cytoplasm in broken cells streams without either.

The insight that suggested an alternative mechanism came only after experiments aimed at learning something about





FRONT-CONTRACTION THEORY and details of amoeboid structure are diagramed in longitudinal and transverse sections of a simplified monopodial amoeba. The consistency pattern (*indicated by shading intensity*), and the velocity profile (*colored arrows*) showing "plug flow," delineate the axial endoplasm and shear zone. The straight and crinkled black lines indicate how the



"PRESSURE" THEORY of amoeboid movement is diagramed. The density of the colored shading reflects the consistency pattern inferred from observations; the darker the shading, the greater the consistency. The cell contents were said to convert from a flowing sol to a firm gel at the front of the cell and back to a sol at the tail. Streaming of the endoplasm (*arrows*) was held to be caused by contraction of the ectoplasmic gel at the rear of the cell. The Goldacre-Lorch model explained sol-gel-sol conversion and tail contraction in terms of the folding and unfolding of protein molecules, shown here by straight (*unfolded*) and curly (*folded*) black lines.

the rheological properties (that is, properties of deformation and flow) of the cytoplasm in different parts of the amoeba. Whereas the amoeba is often described as "a droplet of streaming, fluid protoplasm," the cytoplasm does not behave the way more familiar fluids do. Most fluids, including most true solutions, are "structureless." Their rates of flow are proportional to the stress applied to them, and each has a constant viscosity, or resistance to flow. But some fluids, such as paint, glue, gelatin, rubber cement or bread dough, cannot be described in such simple terms. Under applied force they may exhibit plasticity or elasticity or both. These are "structured" fluids. Under stress they show a definite "yield point" at which they begin to flow; thereafter they may exhibit a variable viscosity that changes with the applied force [see "The Flow of Matter," by Marcus Reiner; SCIENTIFIC AMERICAN, December, 1959].

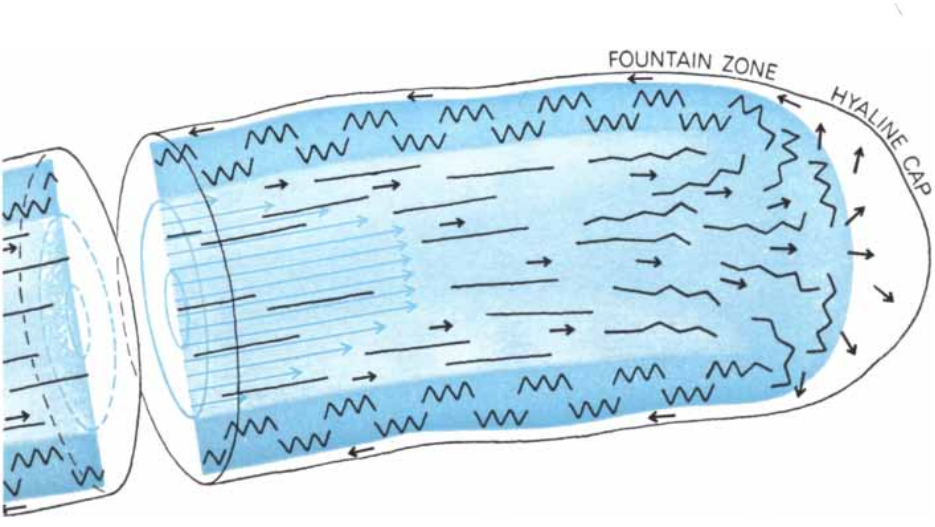
A completely structureless fluid is a sol and an obviously structured one is a gel. Earlier biologists had assumed that because the endoplasm "flows" it must be a structureless sol. But between sol and gel there are many stages, and there were indications that the endoplasm was somewhat structured. In the contractile system of the amoeba, elasticity would be the key property to detect and eventually to measure, because contraction is defined physically as an increase in the elasticity of a body to produce tension if the length remains constant or to perform work if the length is allowed to change.

Three sets of experiments carried out several years ago did reveal the existence of structure in the endoplasm of several species of large amoeba. One study, carried out in collaboration with John D. Roslansky, proved that the endoplasm does not flow as a homogeneous fluid sol but rather as a central core, or plug, of relatively structured material with its passage "lubricated" by a mantle of more rapidly sheared, more fluid material lying between the plug and the surrounding ectoplasmic tube.

Another investigation followed up some intriguing observations made by the late E. Newton Harvey of Princeton and Douglas Marsland of New York University. In 1932 they noted, with a microscope built into a centrifuge, that cytoplasmic particles in the amoeba do not move steadily under acceleration, as they should in a structureless sol, but rather move in jerks, as if repeatedly and temporarily caught up in gelated regions throughout the cell. We repeated and extended these observations. From photographic records taken at different times at known accelerations we were able to demonstrate that there are differences in consistency in the endoplasm. We found that the central, or axial, region of the endoplasm has sufficient structure to resist the passage of particles through it until a certain range of acceleration is reached. The outer region of the endoplasm, on the other hand, behaves almost as a sol would.

A final set of experiments confirmed the results of the first two. J. L. Griffin of Brown University and I found that one conveniently omnivorous species of amoeba, *A. dubia*, willingly ingests spheres of plastic, glass, iron or gold, most of which remain in the cytoplasm for hours, surrounded by tight-fitting vacuole membranes. In a sol, heavy iron and gold spheres should fall rapidly and at a predictable velocity. Actually these heavy particles sedimented to the bottom of the amoeba rarely, and then only in the outer, more fluid region of the endoplasm, which we call the shear zone.

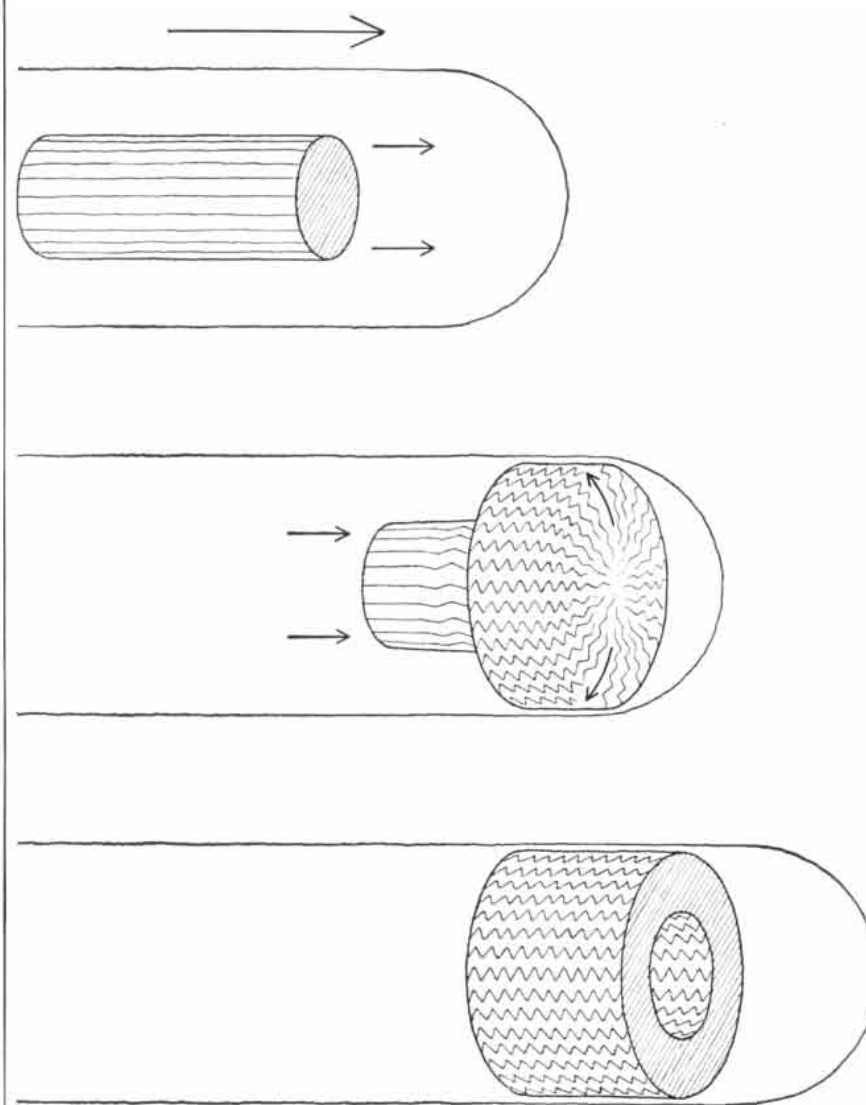
These findings fell into place in a new theory of amoeboid movement while I



cytoplasm, extended in the endoplasm, contracts and pulls in the fountain zone and relaxes again in the recruitment zone. Water (*black arrows*) squeezed from the endoplasm forms the hyaline cap (*right*) and then moves to tail in a channel beneath plasmalemma.

was reading, for what must have been the fifth or sixth time, a paper published in 1932 by Mast and C. Ladd Prosser, who is now at the University of Illinois. This time I read with new insight because we had learned that not only the ectoplasm but also a substantial part of the axial endoplasm of the amoeba has structure capable of transmitting a tensile force within the cell. Pressure was not the only force that could propel the endoplasm. Instead of being pushed, the endoplasm could be pulled. This was, in fact, a likely possibility, because pulling is the primary activity of contractile systems.

The paper by Mast and Prosser reported their measurements, under a variety of experimental conditions, of the ratio of the cross-sectional area of the ectoplasmic tube to that of the endoplasmic stream. What struck me at this new reading was that the ratio is always greater than one. In any slice across a pseudopodium, the ectoplasm always takes up more space than the endoplasm. It suddenly occurred to me that for this to be true the endoplasm must shorten as it thickens just before or during its turning at the front of the cell to form the ectoplasmic tube. The combination of shortening and thickening was suggestive of active contraction—a "front contraction" that would pull the endoplasm toward the forward end of the ectoplasmic tube and so explain streaming [*see illustration at bottom of preceding two pages*].



FOUNTAIN-ZONE EVERSION is shown in highly schematic form for a segment of cytoplasm. The relaxed endoplasm streams forward (*top*). At the front of the cell it thickens, contracts and everts, turning inside out like a cuff, and becomes a segment of ectoplasmic tube (*center*). The tube is anchored to the surface, so the amoeba moves ahead (*bottom*).

Two lines of evidence in particular have specifically confirmed the predictions of this front-contraction model of amoeboid movement. The first stems from detailed observations of cells disrupted by deliberate repetition of my original lucky accident. With the cell membrane disrupted, the naked cytoplasm will continue its original eversion, or "fountain," pattern of streaming, except that the ectoplasm now moves backward because it is no longer anchored through the membrane to the capillary wall. After a few minutes the fountain pattern breaks down and is replaced by a pattern of one or several loops of streaming cytoplasm. Sometimes streaming stops temporarily, and for a time shortening movements are propagated through the cytoplasm from one end of the preparation to the other, like the successive compressions and rarefactions of a sound wave.

By this time the ectoplasmic tube has ceased to exist. But the cytoplasm returning from what was the front of the intact cell has a definite "ectoplasm-like" appearance of gel consistency, whereas material moving forward still looks much like the endoplasm in an intact cell. On making detailed frame-by-frame analyses of motion-picture records of this flow, John W. Cooledge, Prudence J. Hall and I found the reasons for the apparent difference in consistency. First of all, the material streams forward at two to three times the velocity with which it returns, just as it does in the intact cell [*see illustration on next page*]. Second, the cross-sectional area of the returning material is correspondingly greater than that of the advancing flow—again as in the intact cell. Finally, the flow patterns of the "endoplasmic arm" and the "ectoplasmic arm" of naked cytoplasm significantly resemble their counterparts in the intact cell. In each case the endoplasm shows more internal shear along the edges, whereas the ectoplasm moves almost as a block, as one would expect of a gel.

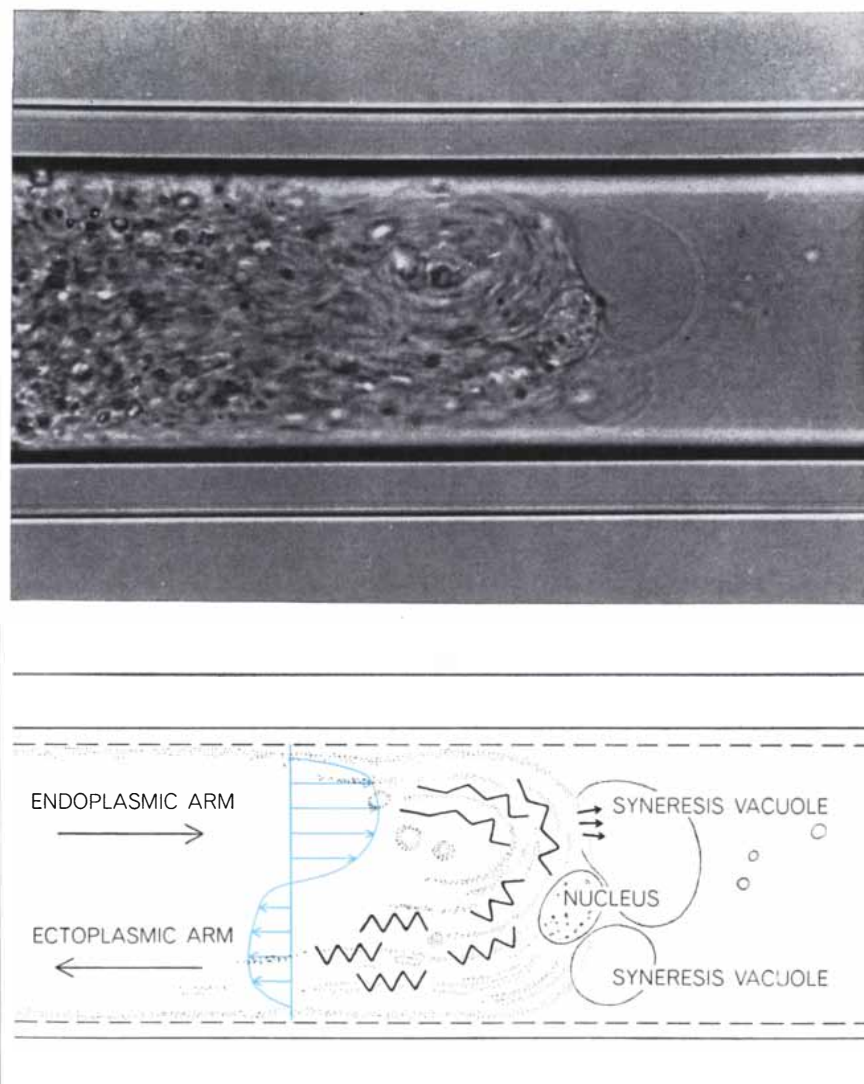
The same set of related events is therefore observed in the fountain zone of the intact cell and at the bend of the cytoplasm in the naked units of streaming. Each of them—the shortening, the thickening, the change in consistency and the change in velocity—can be explained by front contraction.

The change in consistency, formerly described as simple gelation, may well be instead the same kind of stiffening that occurs in muscle when it contracts. If so, the rigidity of the ectoplasm (or of the ectoplasmic arm in naked cytoplasm)

would tend always to anchor the force of contraction in the fountain zone of the intact cell. A cause-effect connection between contraction and streaming is suggested by the observation that in naked cytoplasm the shortening always precedes the streaming by a fraction of a second.

The second line of evidence confirming the front-contraction theory has to do with the appearance of a watery area called the hyaline cap at the front of the pseudopodium. Syneresis, the "weeping" of a gel when it contracts, offers the only tenable explanation for the rhythmic appearance of this water in the cell. The permeability of the cell membrane to water is too low to admit sufficient water from outside the cell. According to the pressure theory of amoeboid movement, the water of syneresis was supposed to originate in the tail. Our front-contraction theory indicated the water should be released from the everting cytoplasm at the forward end of the pseudopodium. One indication in our favor was the observation in naked-cytoplasm preparations of clear, water-rich vacuoles forming in the region of the bend in the endoplasm-ectoplasm loop, exactly where, we postulated, contraction takes place [*see illustration below*].

It happens that differences in water content cause different regions in the cytoplasm of the intact cell to transmit light at different velocities. Such differ-



NAKED CYTOPLASM is seen streaming in a one-second time exposure (*top*), made by J. L. Griffin of Brown University, of a broken specimen of *Chaos chaos* in a capillary. The drawing below it identifies the various elements and shows a typical velocity profile (*color*) measured by John W. Cooledge and Prudence J. Hall on another preparation in the author's laboratory. The black arrows indicate the movement of water of syneresis into vacuoles. The crinkled black lines, as in the preceding drawings, represent contracting cytoplasm.

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ences in the index of refraction can be measured with the aid of an interference microscope and can be used to compute the dry mass and the water content from one region to another in the cell. By this technique Ronald Reed Cowden and I have found that the endoplasm contains 20 per cent more water than the ectoplasm. The interference micrograph of the pseudopodium looks just like a picture of a capillary tube: the tube of ectoplasm with its higher index of refraction can be plainly distinguished from the inner cylinder of endoplasm with its lower index [*see illustration on page 113*]. The endoplasm must therefore give up a fifth of its water to form the hyaline cap. Since syneresis does not accompany mere gelation but is a specific sign of gel contraction, I think it is reasonably safe to conclude that contraction does take place in the fountain zone as proposed in the front-contraction theory.

The water liberated to the hyaline cap apparently finds its way from the front to the rear of the pseudopodium through a fluid channel between the plasmalemma and the ectoplasmic tube. Toward the rear, in what we call the zone of recruitment, it would be reabsorbed again as the ectoplasmic material softens and relaxes preparatory to joining the endoplasmic stream.

Seen in the light of the front-contraction theory, the behavior as well as the simple locomotion of amoeboid cells seems open to explanation. The pursuit of prey is more understandable if both the control mechanism and the motive force act near the front of a pseudopodium. And one can more easily see why various pseudopodia so often function independently of one another. More specifically, it becomes possible to explain the response of an amoeba to the gentle touch of a ciliate. The amoeba reacts within a second or less, shooting out a thick, wide hyaline cap that sometimes helps to trap the organism. It now seems almost certain that the hyaline cap is produced by contraction at the amoeba's surface, and that this contraction is one of the first overt responses to stimulation and a prelude to pseudopodium formation. Finally, we can imagine how a chemical or mechanical stimulus applied unequally to the sides of a pseudopodium could cause bending: the stimulus would alter the contractile tension in the endoplasm and on the rim of the advancing ectoplasmic tube. It seems not at all unreasonable, therefore, that the amoeba may—in the very special way we have proposed—pull itself along by its own bootstraps.

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Back then it was something like doing a juggling act on a high wire. We made beaker walls extra thick for strength and found they wouldn't stand thermal shock. We'd try a glass formula with a little better resistance to alkalies and find we were losing on the acid side.

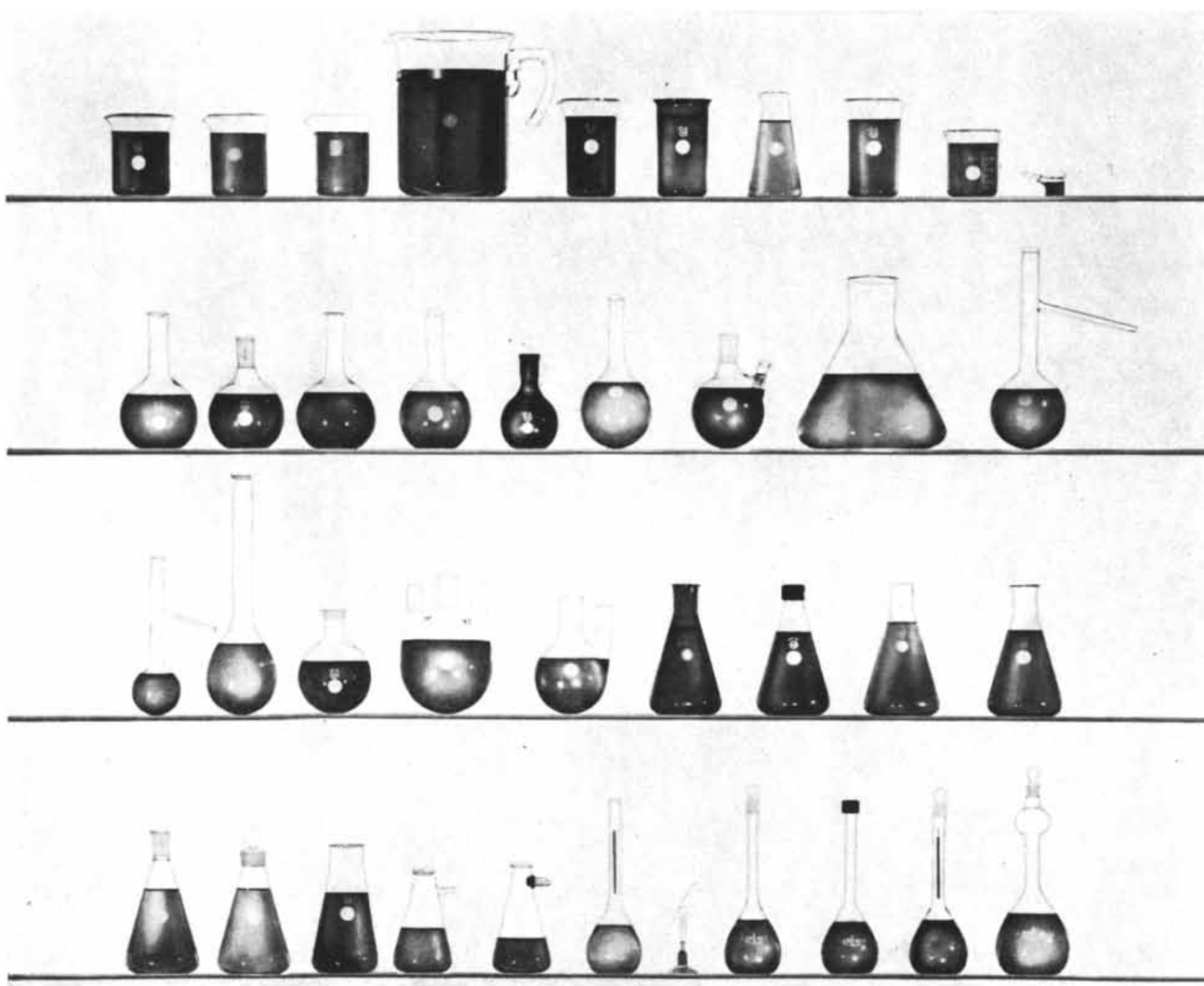
When we solved all these problems, we had the first balanced glass . . . formula No. 7740 . . . and beakers and flasks with unusual strength and the ability to ignore heat and cold. We called them PYREX® ware.

Since then, improvements in precise batch mixing and melting technology have been made to keep the glass at maximum quality standards. Forming methods that keep shapes and dimensions to even more critical tolerances have been devised. Some of these techniques are simple, others have taken years to perfect.

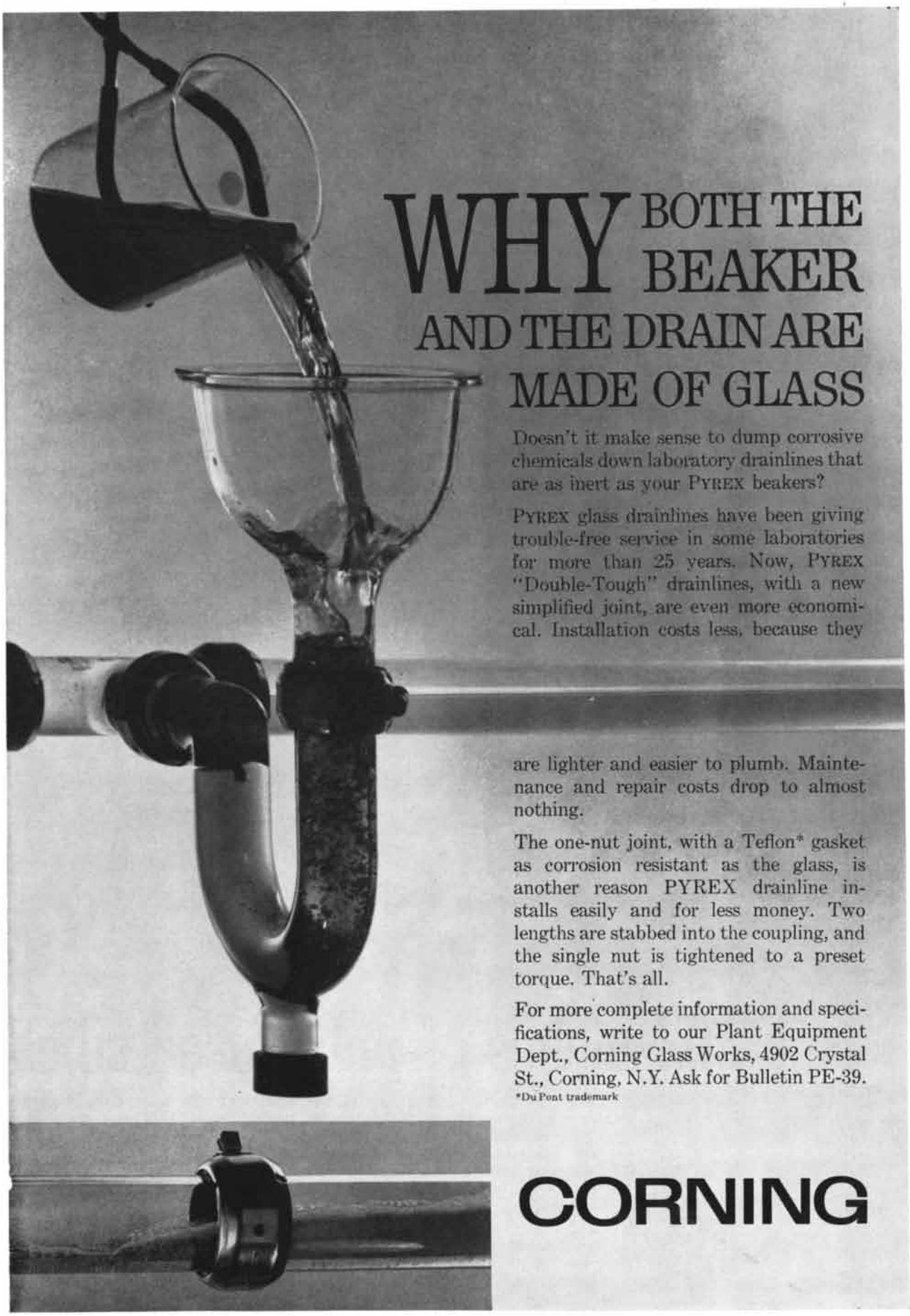
During the past forty-six years, those PYREX beakers and flasks have become the standard against which every other piece of labware is measured . . . they are the standards for wall thickness, side to bottom ratios, configurations, and resistance to chemical, thermal, and mechanical abuse.

On this page you can see a few of the offspring of the original PYREX beakers and flasks. Most are made of glass No. 7740. Others are for the exceptional uses: Low Actinic glassware for light-sensitive products, CORNING brand boron-free glassware for high alkali resistance. And, for extremely high temperatures, VYCOR® brand 96% silica beakers and flasks.

All of which leads us to our claim that from our long experience comes the longest, widest, and deepest line of laboratory glassware available. And the best.



Your dealer will combine all this ware with other labware listed in Catalog LG-2 for quantity discounts ranging up to 28%. If you do not have a catalog, write to our Laboratory Glassware Department, Corning Glass Works, Corning, N. Y.



WHY BOTH THE BEAKER AND THE DRAIN ARE MADE OF GLASS

Doesn't it make sense to dump corrosive chemicals down laboratory drainlines that are as inert as your PYREX beakers?

PYREX glass drainlines have been giving trouble-free service in some laboratories for more than 25 years. Now, PYREX "Double-Tough" drainlines, with a new simplified joint, are even more economical. Installation costs less, because they are lighter and easier to plumb. Maintenance and repair costs drop to almost nothing.

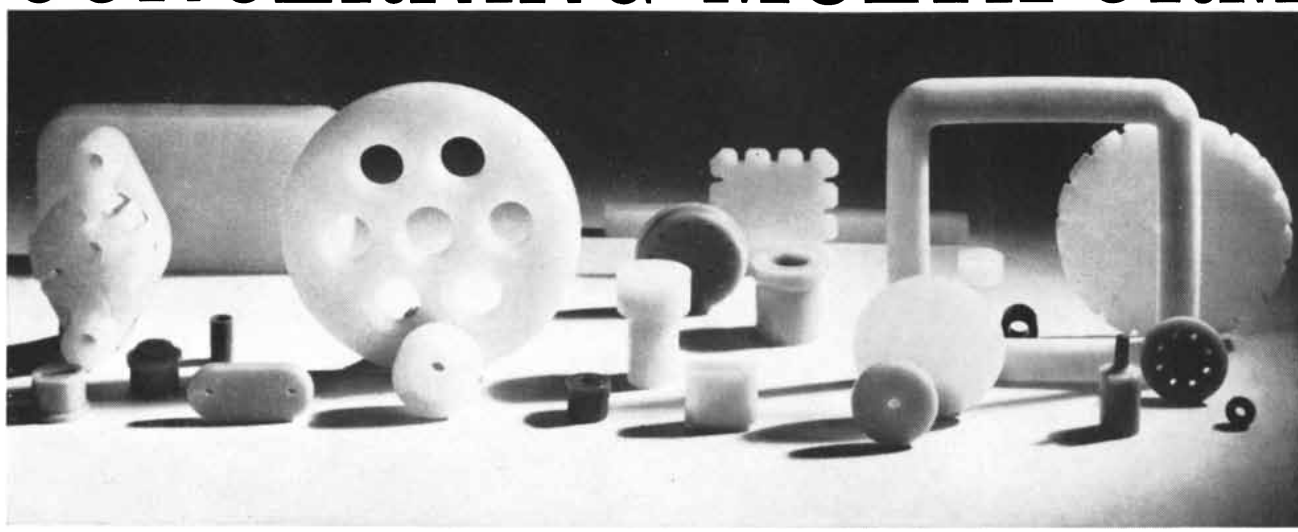
The one-nut joint, with a Teflon* gasket as corrosion resistant as the glass, is another reason PYREX drainline installs easily and for less money. Two lengths are stabbed into the coupling, and the single nut is tightened to a preset torque. That's all.

For more complete information and specifications, write to our Plant Equipment Dept., Corning Glass Works, 4902 Crystal St., Corning, N.Y. Ask for Bulletin PE-39.

*Du Pont trademark

CORNING

CONCERNING MULTIFORM



If shape is the only factor that has kept you from benefiting from the chemical, dielectric, moisture, thermal, or transparent properties of glass, then you haven't heard of Corning Multiform glass.

Choose any of our commercial glasses for their properties, and we can form them into cylinders, domes, rods, slabs, or irregular shapes. We can even make Multiform from VYCOR brand 96% silica glass or pure fused silica for you.

We can dry-press objects up to 4 inches O.D. with a ± 0.005-inch tolerance up to 1 inch thick with a ± 0.010 or 2% tolerance. Through slipcasting we can form circular cross sections or cylinders up to 60 pounds in weight.

Standard Multiform parts are opaque or translucent. Or a variety of colors are available for color coding or identification. If you want transparency, we can process them further to what we call Clearform.®

With proper selection of glass, these parts will seal to practically any other material including Dumet, platinum, molybdenum, Kovar, etc.

For further information, please write to Industrial Components Department, Corning Glass Works, 4902 Crystal Street, Corning, N. Y.

A long, cool look into a hot cell

It seems one of the few places you don't have to worry about radiation is looking into a hot cell. And one of the reasons is the way we've mastered the technique of making windows for these cells which let through visible light but block out radiation.

In fact, it's gotten to the point where all you do is leave a hole in the hot cell and we do the rest. You tell us the wall thickness and the peak energy level you want to work with and the viewing area you'll need.

We provide *all* the calculations, designs and materials, and deliver a complete window ready to install. For details on this service and the three glasses we work with in hot-cell windows, write our Optical Glassware Dept., Corning, N. Y.

62 inches of pure fused silica

It used to be a real trick to form pieces this big of fused silica and still hold purity to 99.99+%. Now, it has become practically routine, since we found new ways to make the silica and new ways to form it.

To sum up: we can make large windows or astronomical mirrors. We can hold purity to 100%. This is the most transparent material known to man. Its expansion rate is 5.5×10^{-7}, so thermal changes are for all practical purposes nonexistent.

If you would like to know more about this pure material and what we can do with it, contact our Optical Glassware Department, Corning Glass Works, 4902 Crystal St., Corning, N. Y.

CORNING

WEAR

The inexorable loss of material from surfaces in sliding contact eventually destroys the usefulness of most things. Now that laws of wear have been defined, its effect on systems can be predicted

by Ernest Rabinowicz

Contemporary civilization rests to a considerable degree on surfaces that bear on each other and wear each other away. In the huge turnover of material objects wear is not, of course, the only process that carries things into discard. A lady's hat is usually considered obsolete before it shows signs of wear. Clinical thermometers are more often broken than worn out. Perhaps in only a few cases, such as the blunting of a phonograph needle, does wear alone destroy the usefulness of things. An automobile may be traded in because it no longer seems stylish enough (obsolescence), because it is damaged in an accident (breakage) or because it no longer performs well (wear). Nonetheless, it is through the ubiquitous process of wear that most of the products of modern technology at last make their way to the junk heap.

Wear is the removal of material from a solid surface as the result of mechanical action. The amount of material removed is invariably quite small. Whereas obsolescence or breakage in an automobile is readily visible, wear is usually undetectable except by careful inspection. A 4,000-pound automobile is completely worn out by the time a few ounces have been worn off those of its surfaces that are in sliding contact. Wear is slow, but it is steady and continuous; the term is quite apt as it is applied to clothing, in which to "use" is to "wear."

The process of wear has come under formal study only during the past 15 years. Encyclopedias have no entries under "Wear" (strictly speaking, the *Britannica* does, but the term refers to a river in England), and engineering handbooks are almost completely silent on the subject.

This situation came about, first of all, because wear has only recently assumed its present importance in technology. The early steam engine worked at moderate pressures, and the cylinder and piston could be fitted to a tolerance of three-eighths of an inch or more. Even a considerable amount of wear—say a quarter of an inch—did not affect its performance very much. The cylinder of a modern automobile, on the other hand, must contain gas at quite high pressure. The cylinder and piston must be machined to a tolerance of .001 inch, and malfunction becomes severe when wear reaches as little as .015 inch. The close tolerances of modern mechanisms, in other words, greatly increase the importance of small amounts of wear.

Wear has been neglected also because engineers and scientists have thought it was too complicated and erratic for systematic investigation. That wear could be predicted in accordance with a set of laws seemed impossible. The best way to design a new device, therefore, was to rely on previous experience and trust to luck. This attitude is held by most design engineers even today. It works well enough when a new design calls for mere modification of an old one. But it is often quite unsuccessful when the design must employ new materials and function successfully in novel environments, such as outer space.

Finally, the process of wear occurs so slowly and involves such minute amounts of material that it could be observed only by "before and after" comparison. The investigator would make careful measurements of the dimensions or weight of an object before exposing it to wear and then repeat the procedure after the experiment. The availability of radioactive isotopes in the past 20 years has for the first time made it possible to measure wear while it is taking place.

There are limits to the sensitivity of all methods of measurement. In the measurement of changes in weight or dimension the limits are set not only by the sensitivity of the scale or the calipers but also by the fact that the specimen is subjected to some tiny amount of wear by the act of fastening it to the testing apparatus or simply picking it up with tweezers. Such manipulation will affect the weight of the specimen by at least 10^{-6} gram (.000001 gram) and perhaps by as much as 10^{-4} gram (.0001 gram). The sensitivity of before-and-after methods is therefore limited to about 10^{-5} gram. In the studies using radioactive tracers a specimen is subjected to wear after it has been made radioactive in a nuclear pile. Particles removed from the surface, either to another surface or into a lubricant, can then be measured by radiation counters or by study of their image on photographic film. The sensitivity varies with the experiment, but it usually falls between 10^{-8} and 10^{-13} gram—a great improvement over the older techniques.

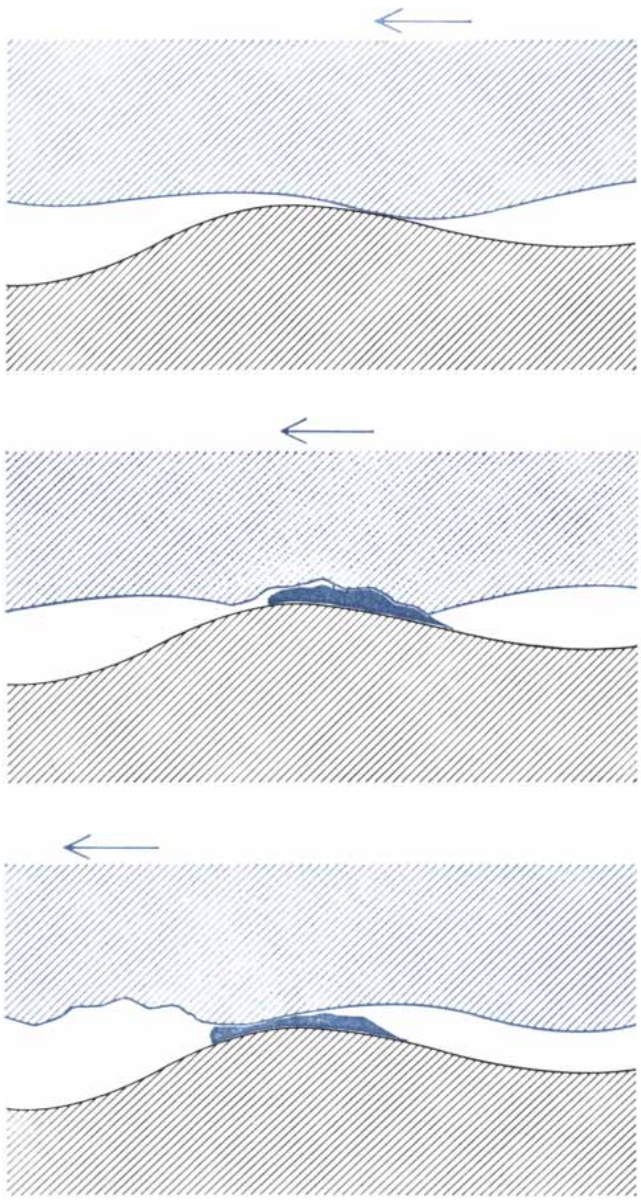
The first achievement of such study has been to distinguish four main kinds of wear: adhesive wear, abrasive wear, corrosive wear and wear by surface fatigue. The laws that govern each kind of wear have been defined, in a qualitative way at least, and it is possible to predict how certain surfaces will behave in sliding contact under various conditions. These laws are to some extent statistical in nature, and a series of experiments will show considerable fluctuation in the rate of wear. Over long periods of time the variations become less significant. To confuse matters, however, one kind of wear may act under certain circumstances in such a way as to affect the others.

The most common and the most important of the four kinds of wear is adhesive wear. When two smooth surfaces slide over each other, patches of one sur-

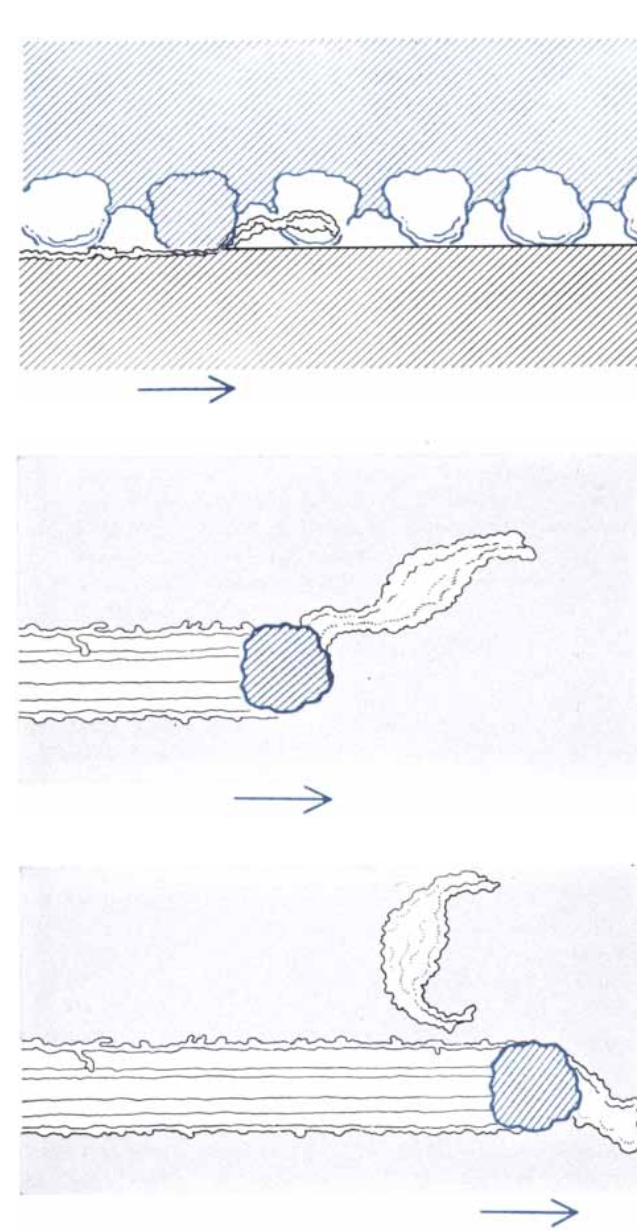
face adhere to the other and are pulled off. These small fragments of material can later be transferred back to the original surface, or they can be rubbed off to form loose wear particles. Adhesive wear results from the strong forces established between atoms that come into intimate contact with one another. At the site of any of these strong bonds, or "junctions," there is a small but finite probability that when the contact is broken the break will come not at the original boundary between the two materials but within the surface layers of one of them, and an adhesive-wear fragment will have been created. Such wear appears to be universal in sliding systems. It cannot be eliminated, but it can be reduced.

Abrasive wear, as distinguished from adhesive wear, occurs when a rough, hard surface, or a soft surface containing hard particles, slides on a softer surface and plows a series of grooves in it. The material gouged out of the grooves forms wear particles, generally loose ones. Abrasive wear can be very damaging, but it can be eliminated if the surfaces are made quite smooth and if no loose, hard grains are admitted to the system.

Corrosive wear involves chemical as well as physical action. In a corrosive environment a film forms on the surface of susceptible materials, and the film tends to protect the surface from further



ADHESIVE WEAR, the most prevalent of the four kinds of wear, occurs when a patch of one sliding surface (*solid color*) adheres to another surface because of the strong bonds that form between their atoms at "junctions," or points of very close contact.

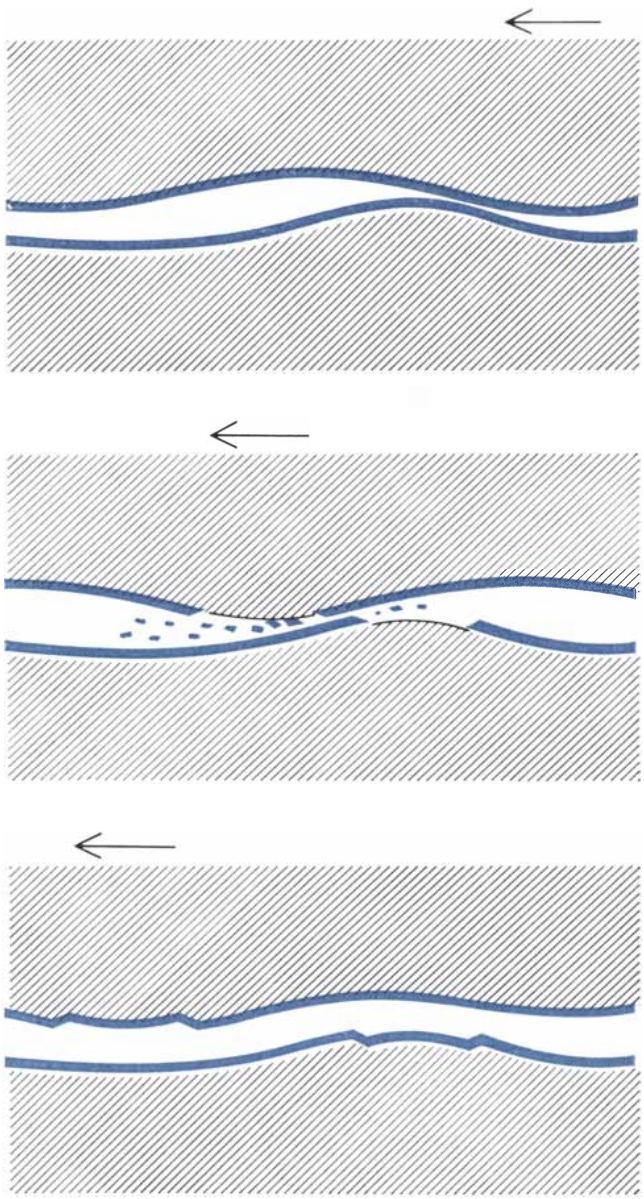


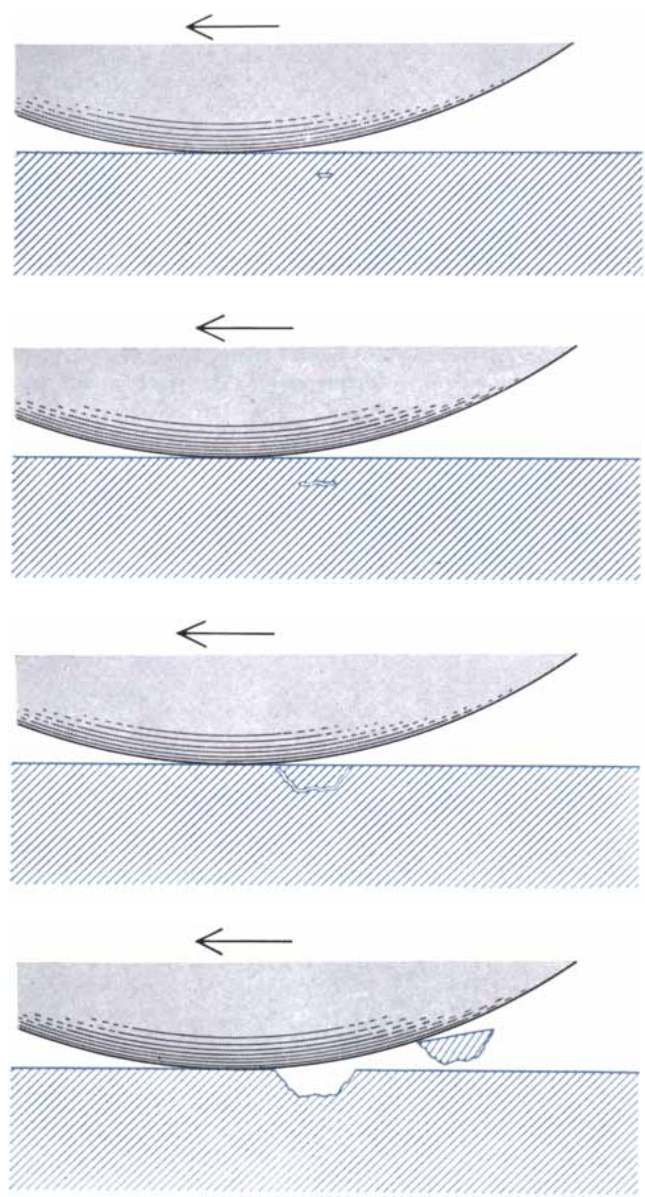
ABRASIVE WEAR is caused by a hard surface or particle sliding on a softer surface. In this case a particle of emery paper is shown (*in cross section at the top and then from above*) plowing a groove and gouging up a wear fragment, which then breaks loose.

corrosion. But if a corroding surface is subjected to a sliding contact with another surface, the film is worn away. Fresh surface is thereby exposed to renewed chemical attack. Corrosive wear can be prevented if the materials are chosen for chemical stability in the atmosphere in which they are to operate or if they can be protected by a lubricant.

Wear by surface fatigue is observed in surfaces engaged in rolling rather than sliding contact, such as ball bearings and meshing gears. The rhythmical cycle of loading and unloading the surfaces can induce the formation of cracks on or just below the surface, which can then break up. Large fragments are formed, leaving pits in the surface. The effects of surface fatigue usually go unobserved if one of the other kinds of wear is at work in the system, because adhesion, abrasion or corrosion will remove the surface material before it has a chance to become fatigued.

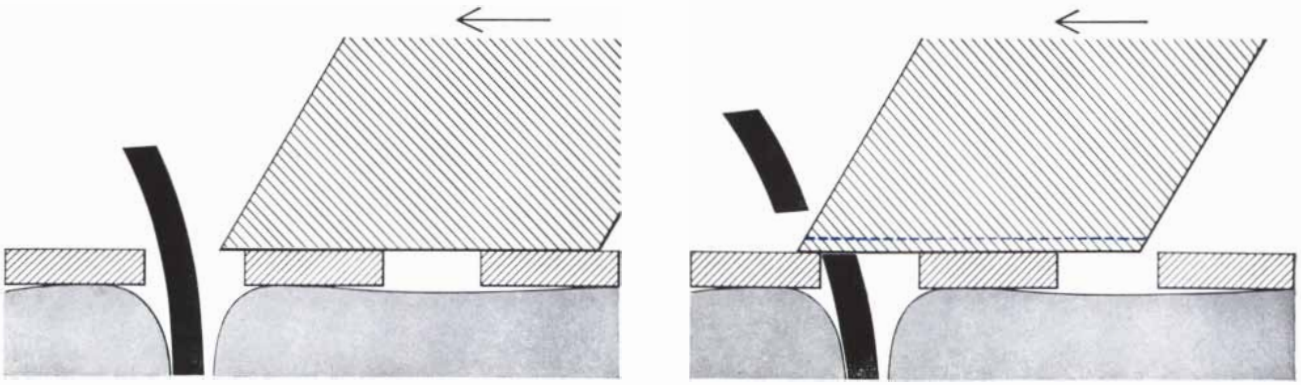
Both experience and experiment show that adhesive wear is the least preventable of the four kinds of wear. Indeed, mere contact between two bodies, without any sliding, results in some adhesive transfer; this we demonstrated by radioactive-tracer experiments at the University of Cambridge. In one experiment we pressed a copper rod with a hemispherical end against a steel surface. If the rod is pressed perpendicularly against the steel, with no tangential mo-





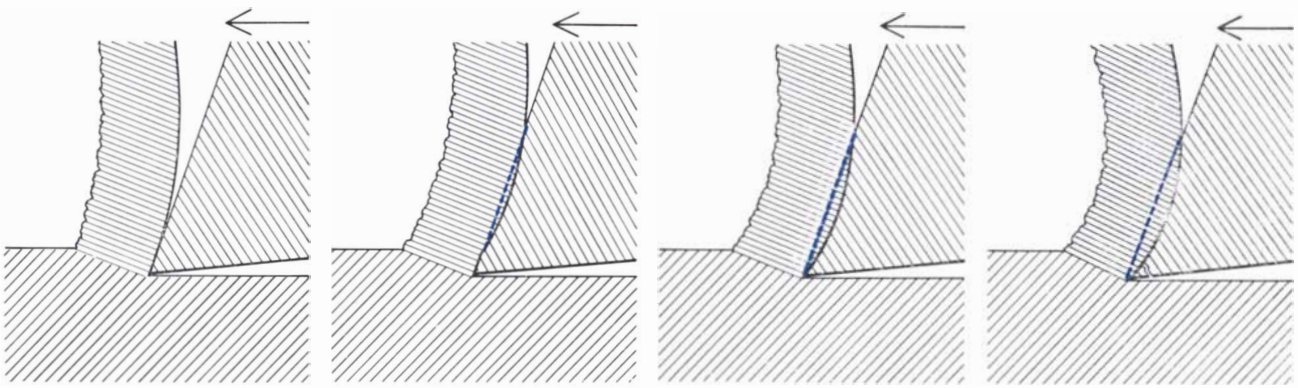
CORROSIVE WEAR combines mechanical with chemical action. If films of corrosion (*color*) form on two sliding surfaces, sliding will wear away parts of the films, which would otherwise tend to arrest corrosion. Fresh surfaces are exposed to corrosive attack.

SURFACE-FATIGUE WEAR results from repeated loading and unloading stresses on the same material, as from a ball bearing. It causes cracks that break the surface, leaving pits. Fragments are hundreds of times larger than those from other forms of wear.

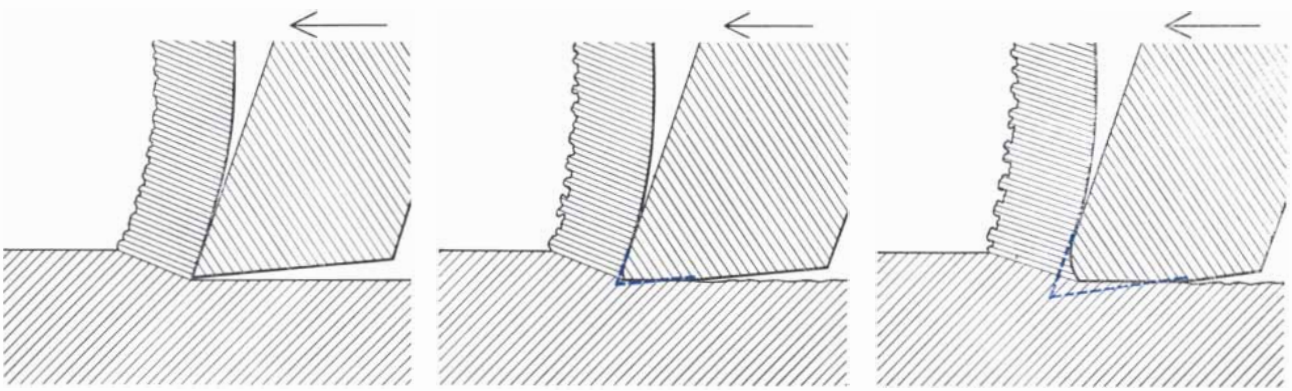


USEFUL WEAR is illustrated by a self-sharpening shaver blade. As the cutting blade (*top*) slides back and forth, wear against its surface (*broken colored line*) preserves the cutting edge, which is kept in close contact with the opposite surface by spring loading.

RODENT'S TOOTH has hard enamel (*heavy black line*) along the outer surface and softer dentine inside. The result is that wear progresses more rapidly on the inner side, leaving a hard cutting edge of enamel that tends to preserve the tooth's pointed shape.



GOOD CUTTING FLUID tends to cause wear that preserves the edge of a tool. The original surface (*broken colored line*) is worn away, but in an area that permits efficient cutting to continue until the tip finally breaks (*far right*) and the tool must be sharpened.



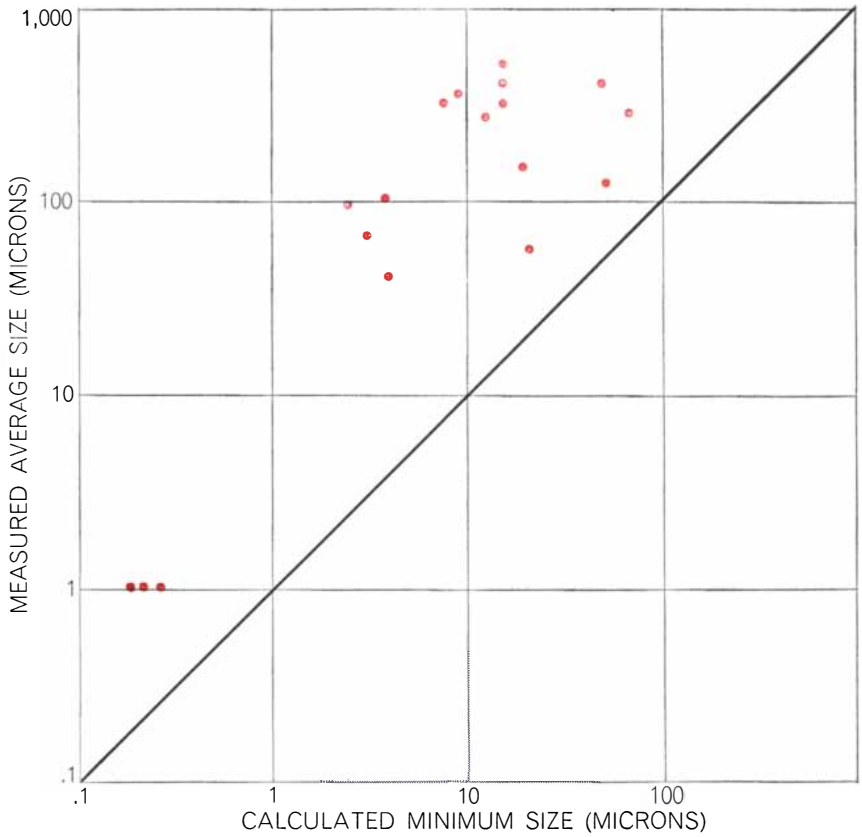
POOR CUTTING FLUID, used with the same tool, allows wear to take place along the bottom surface and at the cutting tip. The effectiveness of the cutting blade is more quickly diminished by this kind of wear and the tool must be sharpened more often.

tion and with a force of only two pounds, there is a transfer of 10^{-9} gram of copper to steel and of 10^{-10} gram of steel to copper. With a lubricant interposed between the surfaces, the transfer can be cut by a factor of 100 but not eliminated. If the rod is pressed against the plate at an angle but does not slide, the adhesive wear is substantially higher: 10^{-6} gram or even more. Values of this sort are common when a hammer hits a nail or when a screwdriver is inserted into the head of a screw.

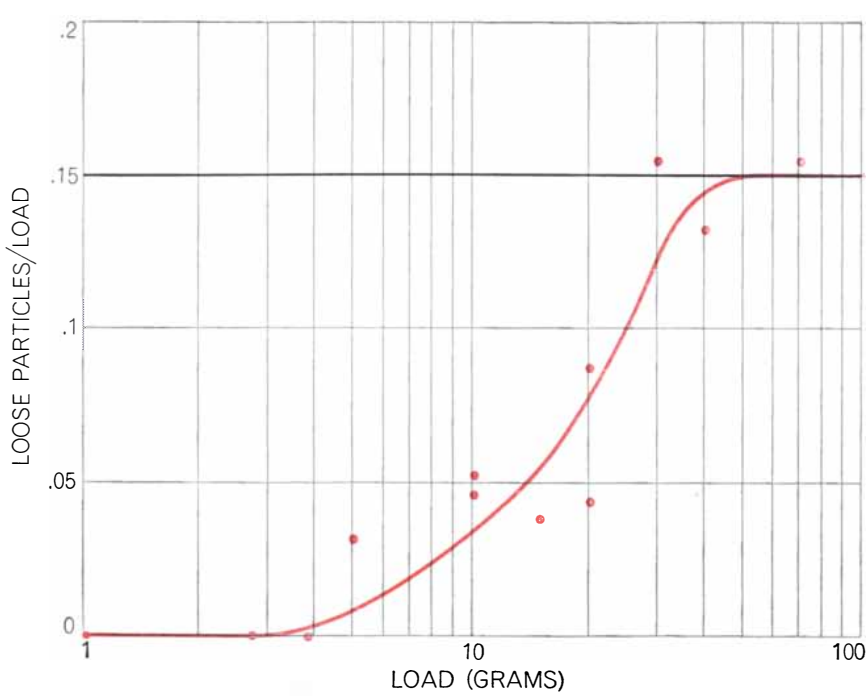
Such small amounts of transfer can have practical significance. If a surgeon uses a plain steel screwdriver to tighten the stainless steel pin with which he fixes a broken bone in place, fragments of the tool adhere to the pin. The difference in chemical potential between the plain steel fragments and the stainless steel is enough to make galvanic currents flow, and the wound is thereby inflamed. To avoid such inflammation a stainless steel screwdriver must be used. The wear particles then have the same galvanic potential as the screw they adhere to, and no current flows.

If two solids slide in contact with each other, adhesive wear is inevitable. The amount of wear can nonetheless be controlled. Because hard materials wear slower than soft ones, the first possibility that comes to mind is to make the sliding surfaces out of hard substances. It turns out that this does not help much. Substituting a hard metal such as nickel for a soft one such as lead diminishes wear only about 25 times. The change from a soft, low-carbon steel to a hardened tool steel accomplishes even less, reducing wear only about five times. It is much more effective to cover the sliding surfaces with a good lubricant, which flows between them and prevents most of the junctions from forming. The introduction of a lubricant can reduce wear by a factor of 10,000 or even more. As a matter of fact, it is only the availability of lubricants that makes the use of sliding metal surfaces at all practicable. One metal, titanium, cannot be effectively lubricated by any known substance. Accordingly no one has yet made a sliding surface of titanium, although the metal has found many static applications.

In the case of nonmetals the situation is different. The unlubricated sliding of a nonmetal on a nonmetal (or a nonmetal on a metal) results in only about a hundredth as much wear as the sliding of metal on metal. But lubricants are much less effective in nonmetal systems than on metal surfaces, reducing the wear only about 10 times. When



WEAR-PARTICLE SIZE can be predicted. In this graph the measured sizes of particles of various materials are plotted against minimum sizes calculated on the basis of theory. The diagonal black line shows where the points would fall if actual size equaled calculated minimum; as expected, the measured values are all somewhat greater than the calculated ones.



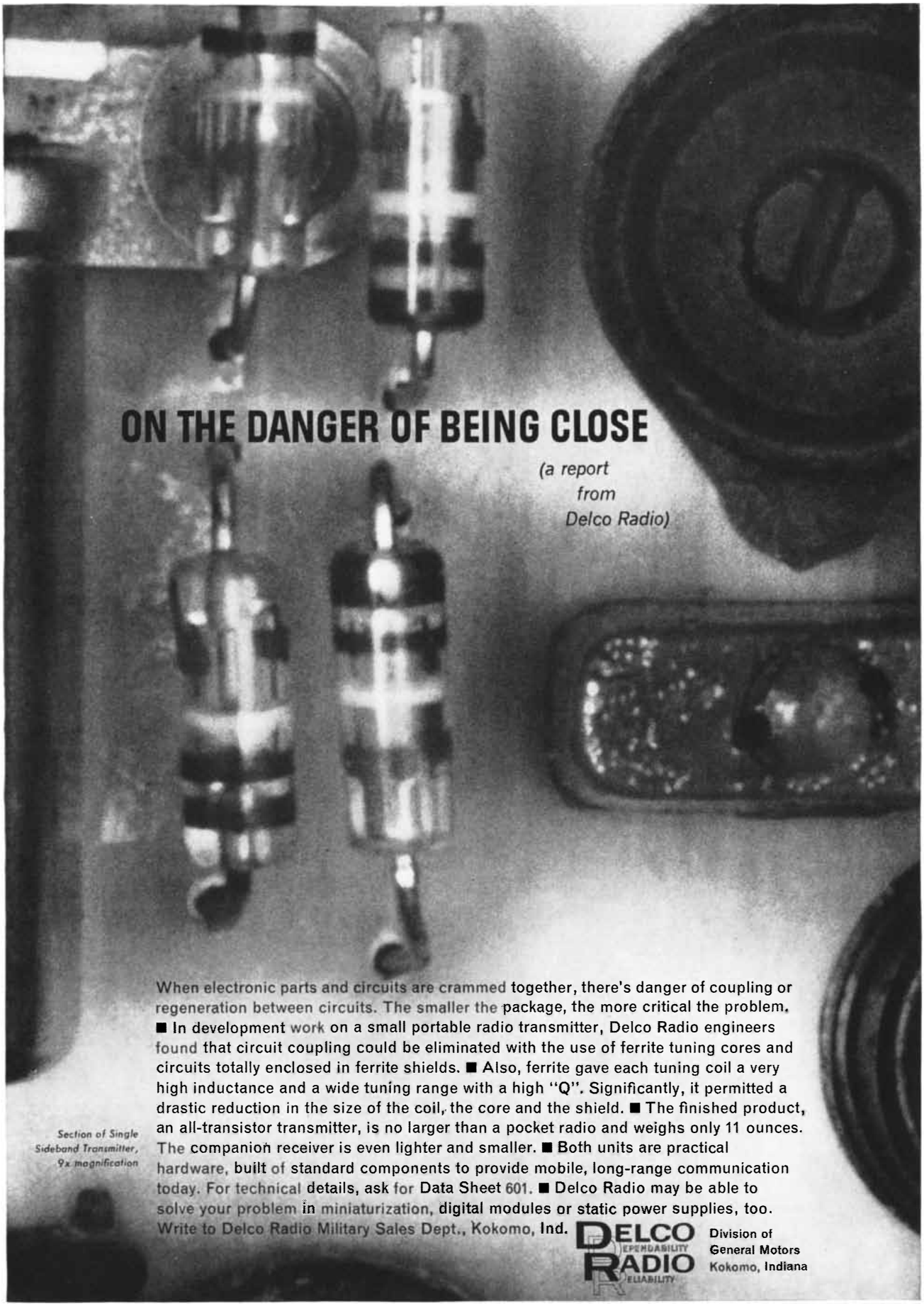
LOOSE WEAR PARTICLES do not form below certain loads. This graph is for gold sliding on gold. Particle formation might be expected to vary with load (*horizontal black line*). Actually no loose particles form until the load exceeds five grams (*colored dots and curve*).

lubrication is not feasible, a nonmetal—nylon in a gear train, for example—may have an advantage. If a lubricant can be used, metal wears less.

Wear is generally a harmful process, but it has a number of practical applications. There is, first of all, the whole family of abrasive tools used to shape materials: files, abrasive papers, grinding wheels and the loose abrasive grains used in "sandblasting." With a graded series of abrasive surfaces or particles it is possible first to cut a material rapidly, then shape it and eventually give it a polished surface. Even corrosive wear has its place. A number of laboratories use "acid saws" to cut crystals of soft metals without deforming them. The cutting is done by a thread immersed in acid: the acid corrodes the crystal and the thread wears away the corroded surface.

Writing with pencil, crayon or chalk depends on adhesive wear: particles of the chalk or pencil are transferred to the blackboard or paper. Anyone who tries to write with chalk on a greasy blackboard or with pencil on a hard, glossy paper finds out how important it is that a high enough rate of wear be maintained. A rubber eraser also works by adhesive wear. First the carbon particles from the pencil mark are transferred to the eraser; then the contaminated rubber surface is worn off, leaving the eraser clean.

Wear blunts cutting edges, but it can also keep them sharp. Certain tools, such as electric shavers and meat grinders, are designed so that wear along the surface of a blade continually reshapes the cutting edge [*see top illustration on page 130*]. A more elegant method can be observed in a living material, the teeth of rodents. (Living things are not usually subject to deterioration by wear because they have the property of continued growth. Teeth are an exception.) A rabbit's incisor, for example, is covered with hard enamel along the curved outer surface, whereas the inner side of the tooth is soft dentine. Abrasive and adhesive wear take place more rapidly on the inner side, maintaining a leading edge of enamel and keeping the tooth sharp [*see second illustration from top on page 130*]. No man-made tool employing this principle of self-sharpening through differential hardness has been devised. A similar effect, however, is obtained by the lubrication of metal-cutting tools with certain fluids. In some manner that is not understood, the right fluid induces wear on the tool that preserves the cutting edge; the wrong fluid permits wear



ON THE DANGER OF BEING CLOSE

(a report from Delco Radio)

When electronic parts and circuits are crammed together, there's danger of coupling or regeneration between circuits. The smaller the package, the more critical the problem. ■ In development work on a small portable radio transmitter, Delco Radio engineers found that circuit coupling could be eliminated with the use of ferrite tuning cores and circuits totally enclosed in ferrite shields. ■ Also, ferrite gave each tuning coil a very high inductance and a wide tuning range with a high "Q". Significantly, it permitted a drastic reduction in the size of the coil, the core and the shield. ■ The finished product, an all-transistor transmitter, is no larger than a pocket radio and weighs only 11 ounces. The companion receiver is even lighter and smaller. ■ Both units are practical hardware, built of standard components to provide mobile, long-range communication today. For technical details, ask for Data Sheet 601. ■ Delco Radio may be able to solve your problem in miniaturization, digital modules or static power supplies, too. Write to Delco Radio Military Sales Dept., Kokomo, Ind.

Section of Single Sideband Transmitter, 9x magnification

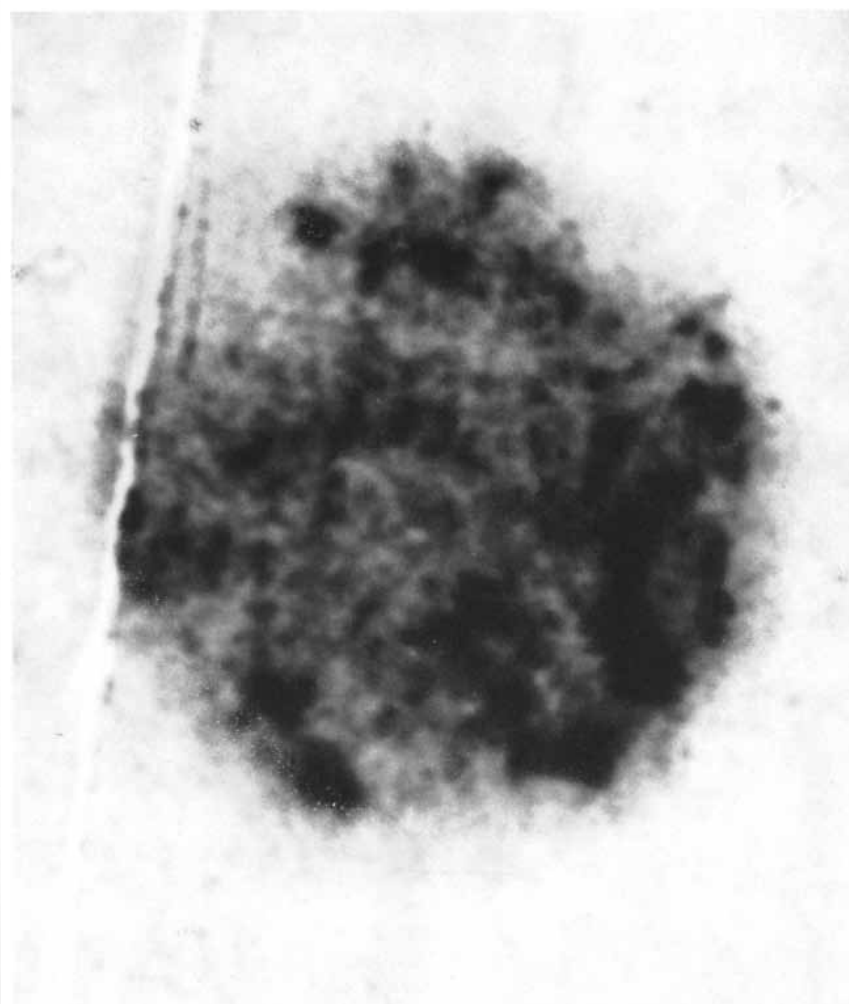
DELCO RADIO — DEPENDABILITY / RELIABILITY

Division of General Motors
Kokomo, Indiana

that blunts the edge [*see two lower illustrations on page 130*].

Wear serves a useful function, finally, in detection and diagnosis. Sherlock Holmes's friend Dr. Watson once bought a new house and with it a medical practice. Holmes took one look at the steps to the front door of Watson's office, noted that they were more worn than those of a competing physician's office next door, and correctly deduced that Watson had acquired the busier practice. More routinely, one can tell by inspecting the heels and soles of a pair of shoes if their wearer is walking properly, and the pattern of wear on an automobile tire reveals faulty wheel alignment. The examination of components to detect signs of wear, and particularly wear in the wrong places, is an important technique in the analysis of mechanisms that have failed. In one typical case experts seeking the cause of an airplane crash noted curved scratches on the inside surface of an engine cylinder. The curves had the same radius as the piston rings; apparently one ring had broken and caused the accident.

In our laboratory at the Massachusetts Institute of Technology we have recently been trying to find out not only how much wear takes place during sliding but also exactly how the wear is produced. From our experiments we deduce that between two sliding surfaces a great number of junctions are made and broken—often as many as 100,000 per centimeter of relative motion. The number of wear particles varies with the materials involved, but it is unexpectedly small. In the extreme cases only one particle is formed for every 100 junctions, and in some instances, even without



AUTORADIOGRAPH by the author (enlarged 150 diameters) shows adhesive wear in the absence of sliding. Radioactive copper particles were transferred to a steel sheet when a copper hemisphere was pressed, perpendicularly and without tangential motion, against the steel with a force of two kilograms. The photograph shows a transfer of 10^{-9} gram of copper.

lubrication, the ratio is as low as one to 10,000. This is surprising, since when an effect (in this case wear) is found in a predictable fraction of instances (junctions), that fraction is usually much higher than one in 100 or one in 10,000. The low ratio of wear to junctions raises two contradictory questions: Why does wear not occur more often? On the other hand, if wear particles are formed so seldom, why does wear occur at all? We are just beginning to see possible answers to these questions in the size of the particles that are worn off various kinds of material.

A soft metal such as lead yields large adhesive-wear particles and a hard metal such as steel gives up small ones. In any case the same material always wears in fragments of about the same characteristic size. Only within the past two or three years has the significance of this size become clear. It is related to the amount of elastic energy the material can absorb under tension before it yields. The principle can be illustrated by a "thought experiment": Imagine that a sample of brittle material is stretched to its breaking point and then somehow it shatters into fragments all the same size. Calculation will show that the size of the fragments has a lower limit. This is because the shattering of the material transforms the elastic energy into surface energy. Since there is a limit to the elastic energy that a given material can absorb, there is a limit to the total surface of the fragments and therefore a lower limit to the size of the fragments.

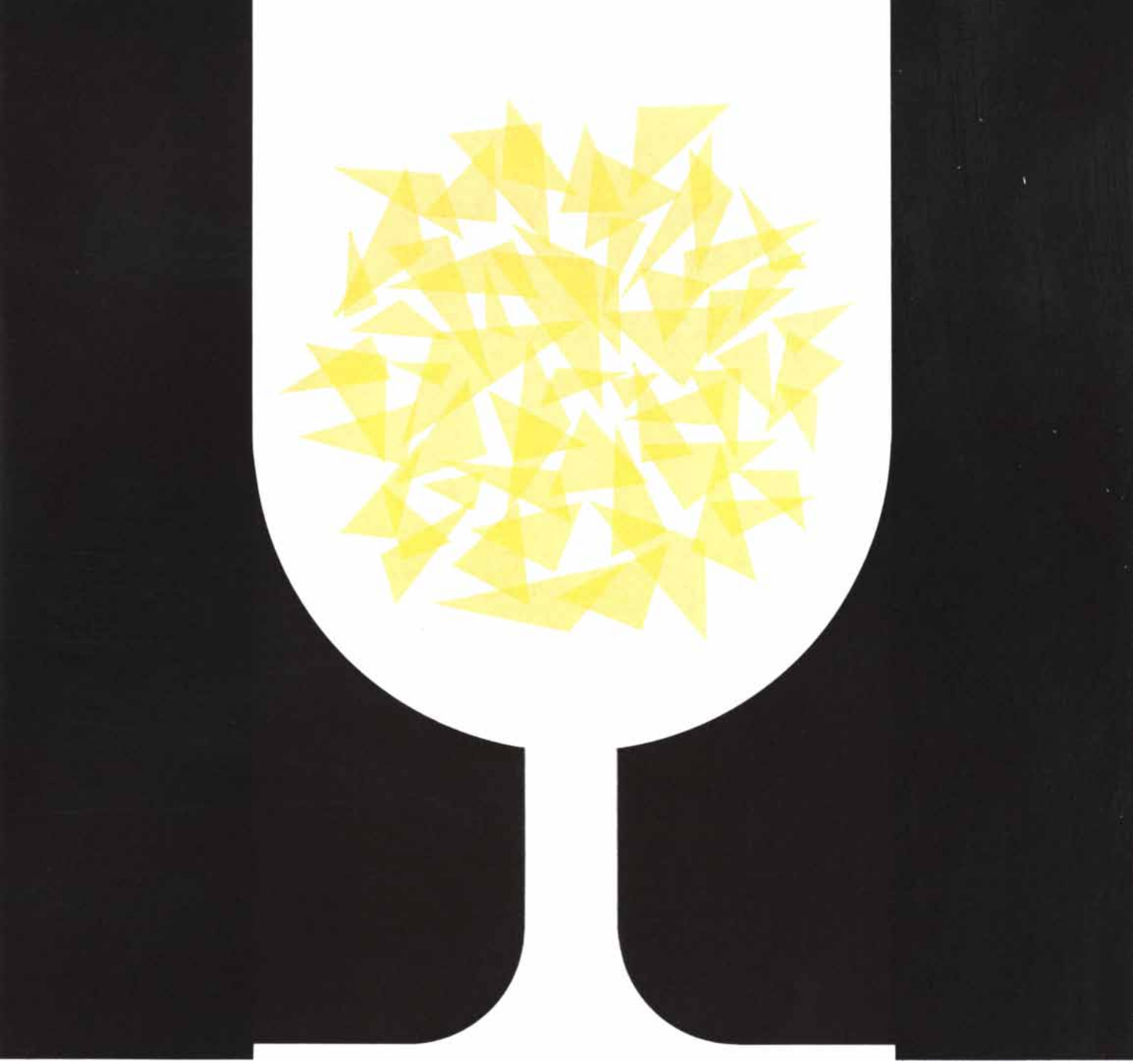
The energy required to form a wear particle at a highly stressed site on a surface must be provided, as in the case of shattering, by the elastic energy of the material in its vicinity. The minimum fragment size calculated on the basis of elastic energy should be, for any material, closely related to the characteristic size of its wear particles. When we plotted such calculated values against the observed size of loose wear particles, we found that this was indeed true [*see top illustration on page 132*].

In a system in which wear particles of a certain size are being formed, the surfaces take on a corresponding roughness. In other words, the peak-to-trough height of the hills and valleys on the surface will be the same as the diameter of the average wear particle. As each particle is worn away, the surface roughness remains the same. This finding has important consequences for design. It governs, for example, the closest tolerance to which sliding parts of a given

material can be made. Suppose that a piston moves inside a cylinder to pump a liquid. The temptation is to make the clearance between piston and cylinder wall as small as possible in order to prevent leakage. But the characteristic size of the wear particles sets an effective limit. If the clearance is smaller than the typical wear particle, any loose particles will become trapped between the surfaces and plow grooves in them, and the system will grind to a halt. We demonstrated this fundamental limitation recently when we attempted to reduce the clearance of a piston-cylinder system from .0005 to .00015 inch. The piston failed, it developed, because the average size of the wear particles was .0002 inch. As engineers learn how to machine surfaces more precisely they will come up against this limitation more often.

The realization that wear involves particles of a minimum size suggests the possibility of designing systems of surfaces in sliding contact that will show no wear. For an experimental system one can employ gold; it forms no oxide in air, which would otherwise complicate the system. Calculation shows that the minimum size of the wear particle of gold would be about 12 microns. If such a particle on a sliding surface made of gold is to come loose, the surface must be stressed to its elastic limit, and further calculation shows that this requires a force of five grams. We have experimented with two gold surfaces in sliding contact and have found that no loose wear particles form at perpendicular loads of less than five grams. Instead the adhesive wear fragments merely pass to and fro between the two surfaces. Only when the force exceeds five grams do loose gold particles begin to be formed [*see bottom illustration on page 132*].

In the short time since wear theory arrived on the engineering scene it has not been able to contribute much to prolonging the useful life of mechanisms. In fact, most of the combinations of materials and lubricants suggested by theory so far had already been found to be best through trial and error. But the situation is changing. New materials—plastics, ceramics, cermets, alloys and intermetallic compounds—are being developed in quick succession. They will be applied in sliding systems that operate at great speeds, in high vacuums and extreme temperatures, and with exotic lubricants such as liquid sodium. Trial-and-error methods cannot keep pace with these developments, and theory will have to provide the needed answers.



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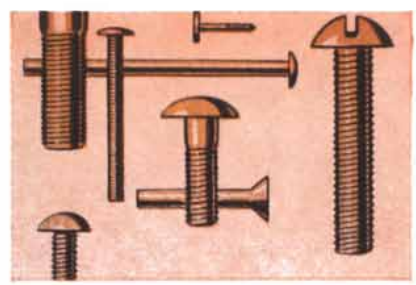
Anaconda American Brass produces copper and copper-alloy wire developed especially for cold-heading applications. Numerous alloys are available in several tempers, providing a wide choice of varied combinations of strength and formability.

Generally, service conditions and precise strength requirements determine the correct Anaconda alloy for a particular cold-heading wire. When these factors are unknown or unspecified, *upset ratio* (final upset diameter: original wire diameter) becomes the key alloy selection criterion. And, the most favorable alloy often will exhibit a low plasticity index for optimum flow properties during cold work, coupled with a high percentage reduction in area to minimize shear fracture.

Where You Come In

If you are using conventional methods to fabricate such parts as screws, bolts,



rivets, semiconductor bases, and conductor components in electrical controls . . . why not look into the unique advantages of cold-heading. Or, if you have already discovered how cold-heading cuts production costs . . . perhaps an Anaconda copper alloy can make your product even better. Anaconda specialists will gladly help you select the best copper metal for your needs. Just send a sample or description of the part—plus data about service conditions, quantities produced, and properties required. For more information, please write to Anaconda American Brass Company, Waterbury 20, Connecticut.

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In applications ranging from voltage regulators with relatively small coils to distribution transformers, electrical equipment manufacturers are discovering that strip-copper coils cut size and weight. Smaller transformers, wound with copper strip, can be designed into smaller housings—thus making possible smaller overall units. In many cases, strip copper improves operating characteristics as well.

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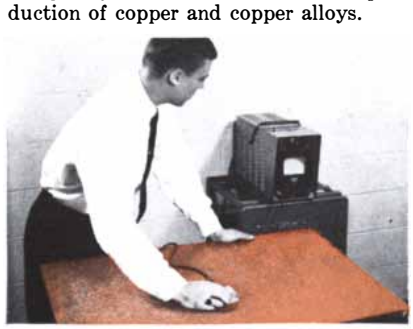
Anaconda is now supplying strip copper, deburred and finished in a wide range of widths and gages to meet almost any application. The inherent quality of the strip is maintained, during shipment and handling, with special edge-protecting packages designed by Anaconda.

Copper strip promises economies in size and weight, whatever your use of coils or winding capacity may be. Anaconda metallurgists are available to help you select the best type of copper and production technique for your requirements. For technical assistance, or for further information, get in touch with Anaconda American Brass Company today.

Anaconda studies will extend range of nondestructive testing

At Anaconda American Brass Company's new Research and Technical Center, a group of scientists is extending the application of nondestructive tests for copper metals. Two principal techniques, eddy-current and ultrasonic testing, are under investigation. This work is providing better quality control methods for mill production of copper and copper alloys.



Preliminary ultrasonic test of copper plate for internal flaws; pickup crystal of test instrument is applied to each square inch of surface area. Subsequent tests involve up to 100% ultrasonic scanning of plate during total immersion in water.

Essentially, eddy-current tests detect flaws on and to a limited depth below the surface of the metal. The tests are particularly applicable to tube products, where a 100% inspection can easily be performed. Eddy-current tests for capillary tube are Anaconda's latest achievement in this area. In addition, Anaconda is using similar techniques for evaluating phosphorous content of copper alloys and for identifying alloys of various conductivities.

Ultrasonic tests, on the other hand, can detect flaws throughout the metal. At one Anaconda mill, ultrasonic techniques have been used successfully for thick plates of Everdur® and other copper condenser-tube-sheet alloys. Such tests are now being adapted to forgings, bar stock, sheet and strip.

Ultrasonic tests are useful when special products must meet rigid specifications. For example, Anaconda copper plate is used as heat sink material when stainless steel honeycomb laminates are brazed to form skin surfaces of advanced aerospace vehicles. These copper heat sinks must be absolutely flawless to distribute brazing heat evenly over the honeycomb surface. Hidden imperfections may cause blistering of the surface of the copper, with resultant impairment of the honeycomb skin, and rejection of the part. Anaconda consistently meets heat sink requirements through the use of second-generation ultrasonic tests (see photo). The price of perfection, in this case, is relatively high—$30 to $60 per unit—but the cost is more than justified by the critical nature of the application.

Extending the range of nondestructive testing is one more example of how Anaconda strives to assure highest quality in copper metals. Specialized technical assistance with your metal selection and production problems is yours for the asking. Contact: Anaconda American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario. 61-1964

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Population Density and Social Pathology

When a population of laboratory rats is allowed to increase in a confined space, the rats develop acutely abnormal patterns of behavior that can even lead to the extinction of the population

by John B. Calhoun

In the celebrated thesis of Thomas Malthus, vice and misery impose the ultimate natural limit on the growth of populations. Students of the subject have given most of their attention to misery, that is, to predation, disease and food supply as forces that operate to adjust the size of a population to its environment. But what of vice? Setting aside the moral burden of this word, what are the effects of the social behavior of a species on population growth—and of population density on social behavior?

Some years ago I attempted to submit this question to experimental inquiry. I confined a population of wild Norway rats in a quarter-acre enclosure. With an abundance of food and places to live and with predation and disease eliminated or minimized, only the animals' behavior with respect to one another remained as a factor that might affect the increase in their number. There could be no escape from the behavioral consequences of rising population density. By the end of 27 months the population had become stabilized at 150 adults. Yet adult mortality was so low that 5,000 adults might have been expected from the observed reproductive rate. The reason this larger population did not materialize was that infant mortality was extremely high. Even with only 150 adults in the enclosure, stress from social interaction led to such disruption of maternal behavior that few young survived.

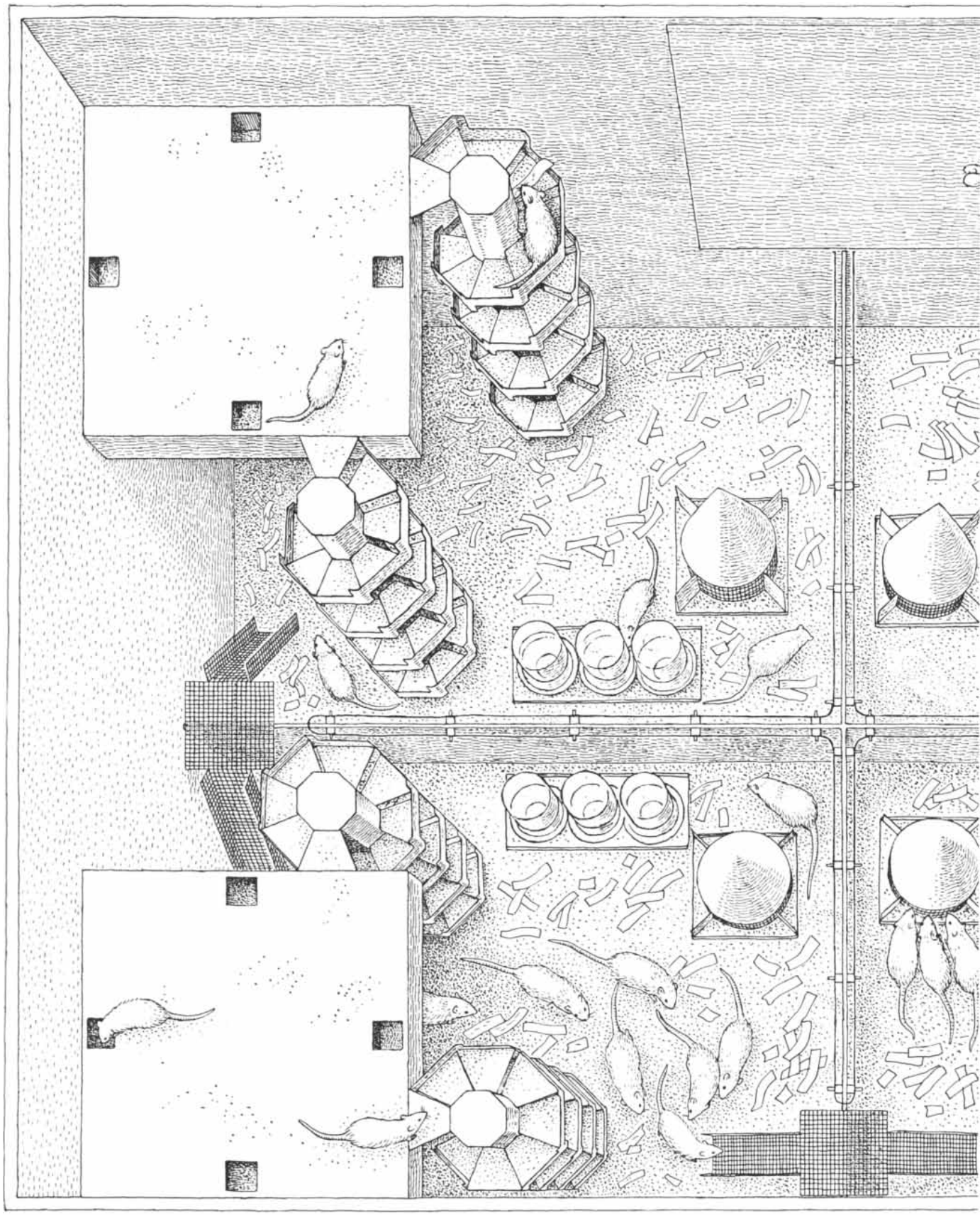
With this background in mind I turned to observation of a domesticated albino strain of the Norway rat under more controlled circumstances indoors. The data for the present discussion come from the histories of six different populations. Each was permitted to increase to approximately twice the number that my experience had indicated could occupy the available space with only moderate stress from social interaction. In each case my associates and I maintained close surveillance of the colonies for 16 months in order to obtain detailed records of the modifications of behavior induced by population density.

The consequences of the behavioral pathology we observed were most apparent among the females. Many were unable to carry pregnancy to full term or to survive delivery of their litters if they did. An even greater number, after successfully giving birth, fell short in their maternal functions. Among the males the behavior disturbances ranged from sexual deviation to cannibalism and from frenetic overactivity to a pathological withdrawal from which individuals would emerge to eat, drink and move about only when other members of the community were asleep. The social organization of the animals showed equal disruption. Each of the experimental populations divided itself into several groups, in each of which the sex ratios were drastically modified. One group might consist of six or seven females and one male, whereas another would have 20 males and only 10 females.

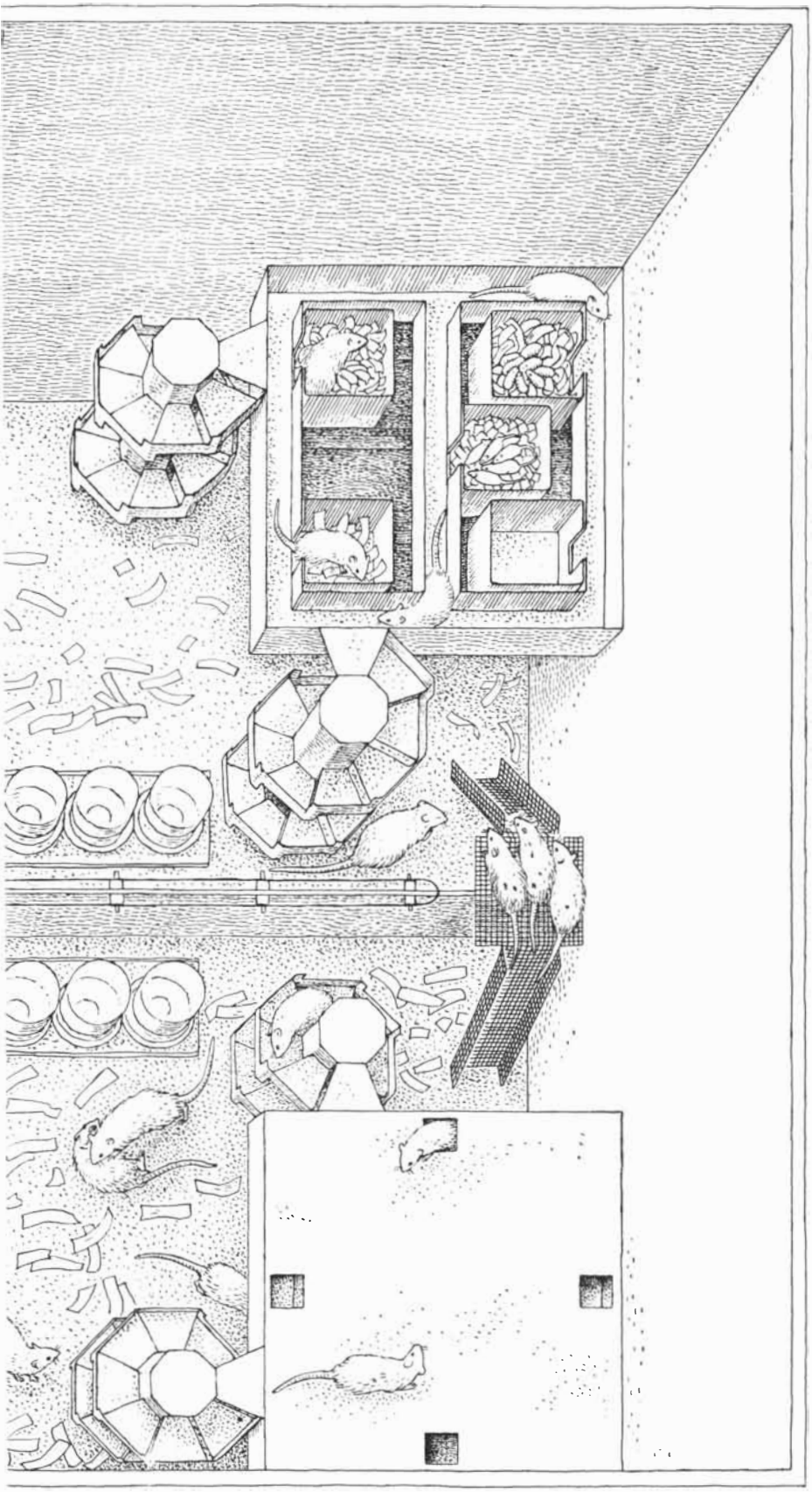
The common source of these disturbances became most dramatically apparent in the populations of our first series of three experiments, in which we observed the development of what we called a behavioral sink. The animals would crowd together in greatest number in one of the four interconnecting pens in which the colony was maintained. As many as 60 of the 80 rats in each experimental population would assemble in one pen during periods of feeding. Individual rats would rarely eat except in the company of other rats. As a result extreme population densities developed in the pen adopted for eating, leaving the others with sparse populations.

Eating and other biological activities were thereby transformed into social activities in which the principal satisfaction was interaction with other rats. In the case of eating, this transformation of behavior did not keep the animals from securing adequate nutrition. But the same pathological "togetherness" tended to disrupt the ordered sequences of activity involved in other vital modes of behavior such as the courting of sex partners, the building of nests and the nursing and care of the young. In the experiments in which the behavioral sink developed, infant mortality ran as high as 96 per cent among the most disoriented groups in the population. Even in the absence of the behavioral sink, in the second series of three experiments, infant mortality reached 80 per cent among the corresponding members of the experimental populations.

The design of the experiments was relatively simple. The three populations of the first series each began with 32 rats; each population of the second series began with 56 rats. In all cases the animals were just past weaning and were evenly divided between males and females. By the 12th month all the populations had multiplied and each comprised 80 adults. Thereafter removal of the infants that survived birth and weaning held the populations steady. Although the destructive effects of population density increased during the course of the experiments, and the mortality rate among the females and among the young was much higher in the 16th month than it was earlier, the number of young that survived to weaning was always large enough to offset the effects of adult mortality and actually to increase the population. The evidence indicates, however, that in time failures of reproductive function would have caused the colonies to die out. At the end of the first series of experiments eight rats—the four healthi-



EFFECT OF POPULATION DENSITY on the behavior and social organization of rats was studied by confining groups of 80 animals in a 10-by-14-foot room divided into four pens by an electrified fence. All pens (numbered 1, 2, 3 and 4 clockwise from door) were complete dwelling units. Conical objects are food hoppers; trays with three bottles are drinking troughs. Elevated burrows, reached by winding staircases, each had five nest boxes, seen in pen 1, where top of burrow has been removed. Ramps connected all pens but 1 and 4. Rats therefore tended to concentrate in pens 2 and 3. Development of a "behavioral sink," which further increased population in one pen, is reflected in pen 2, where three rats are eating simultaneously. Rat approaching ramp in pen 3 is an estrous female



pursued by a pack of males. In pens 2 and 3, where population density was highest, males outnumbered females. In pens 1 and 4 a dominant male was usually able to expel all other males and possess a harem of females. Dominant males are sleeping at the base of the ramps in pens 1 and 4. They wake when other males approach, preventing incursions into their territories. The three rats peering down from a ramp are probers, one of the deviant behavioral types produced by the pressures of a high population density.

est males and the four healthiest females in each of two populations—were permitted to survive. These animals were six months old at the time, in the prime of life. Yet in spite of the fact that they no longer lived in overpopulated environments, they produced fewer litters in the next six months than would normally have been expected. Nor did any of the offspring that were born survive to maturity.

The males and females that initiated each experiment were placed, in groups of the same size and sex composition, in each of the four pens that partitioned a 10-by-14-foot observation room. The pens were complete dwelling units; each contained a drinking fountain, a food hopper and an elevated artificial burrow, reached by a winding staircase and holding five nest boxes. A window in the ceiling of the room permitted observation, and there was a door in one wall. With space for a colony of 12 adults in each pen—the size of the groups in which rats are normally found—this setup should have been able to support 48 rats comfortably. At the stabilized number of 80, an equal distribution of the animals would have found 20 adult rats in each pen. But the animals did not dispose themselves in this way.

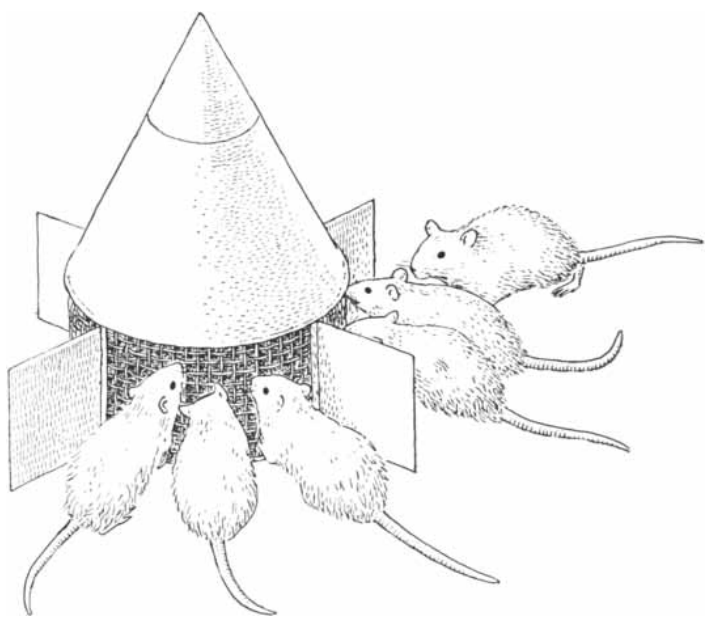
Biasing factors were introduced in the physical design of the environment to encourage differential use of the four pens. The partitions separating the pens were electrified so that the rats could not climb them. Ramps across three of the partitions enabled the animals to get from one pen to another and so traverse the entire room. With no ramps to permit crossing of the fourth partition, however, the pens on each side of it became the end pens of what was topologically a row of four. The rats had to make a complete circuit of the room to go from the pen we designated 1 to the pen designated 4 on the other side of the partition separating the two. This arrangement of ramps immediately skewed the mathematical probabilities in favor of a higher population density in pens 2 and 3 than in pens 1 and 4. Pens 2 and 3 could be reached by two ramps, whereas pens 1 and 4 had only one each.

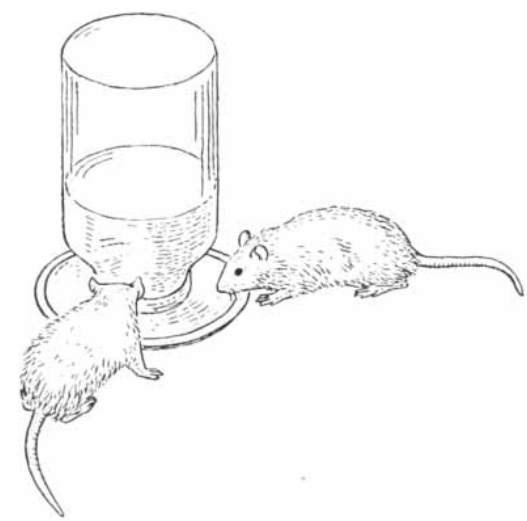
The use of pen 4 was further discouraged by the elevation of its burrow to a height greater than that of the burrow in the other end pen. The two middle pens were similarly distinguished from each other, the burrow in pen 3 being higher than that in pen 2. But here the differential appears to have played a smaller role, although pen 2 was used somewhat more often than pen 3.

With the distribution of the rats

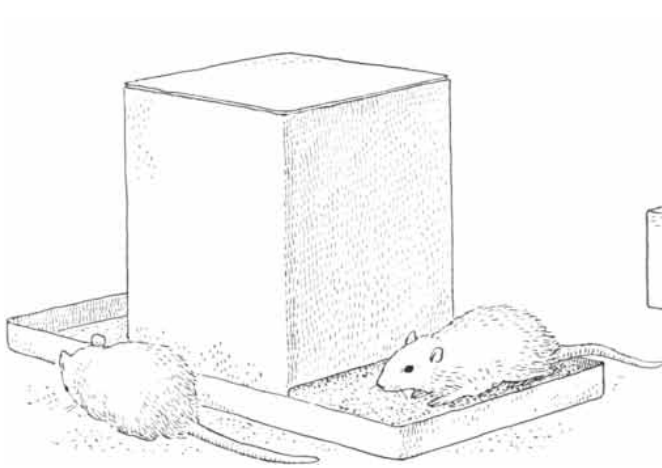
biased by these physical arrangements, the sizes of the groups in each pen could have been expected to range from as few as 13 to as many as 27. With the passage of time, however, changes in behavior tended to skew the distribution of the rats among the pens even more. Of the 100 distinct sleeping groups counted in the 10th to 12th month of each experiment, only 37 fell within the expected size range. In 33 groups there were fewer than 13 rats, and in 30 groups the count exceeded 27. The sex ratio approximated equality only in those groups that fell within the expected size range. In the smaller groups, generally composed of eight adults, there were seldom more than two males. In the larger groups, on the other hand, there were many more males than females. As might be expected, the smaller groups established themselves in the end pens, whereas the larger groups were usually observed to form in the middle pens. The female members of the population distributed themselves about equally in the four pens, but the male population was concentrated almost overwhelmingly in the middle pens.

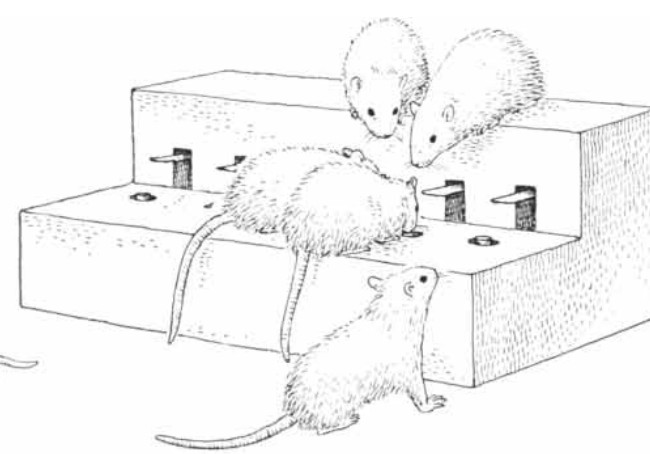
One major factor in the creation of this state of affairs was the struggle for status that took place among the males. Shortly after male rats reach maturity, at about six months of age, they enter into a round robin of fights that eventually fixes their position in the social hierarchy. In our experiments such fights took place among the males in all the pens, both middle and end. In the end pens, however, it became possible for a single dominant male to take over the area as his territory. During the period when the social hierarchy was being established, the subordinate males in all pens adopted the habit of arising early. This enabled them to eat and drink in peace. Since rats generally eat in the course of their normal wanderings, the subordinate residents of the end pens were likely to feed in one of the middle pens. When, after feeding, they wanted to





FOOD HOPPER used in first series of experiments is seen at the left in this drawing. Water tray is at the right. The hopper, covered with wire grating and holding hard pellets of food, made eating a lengthy activity during which one rat was likely to meet another. Thus it fostered the development of a behavioral sink: the animals would eat only in the presence of others, and they preferred one of the four hoppers in the room to all the others. In time 75 per cent of the animals crowded into the pen containing this hopper to eat.





WATER FOUNTAIN used in second series of experiments is seen at the right in this drawing. Food hopper is at the left. The fountain was operated by pressing a lever. Thus it made drinking a lengthy activity, associated with the presence of others. But it did not create a behavioral sink. Although the rats would drink only if other animals were present, they engaged in this activity in their home pens immediately after awakening. The fountain therefore acted to produce an even distribution of the population.

return to their original quarters, they would find it very difficult. By this time the most dominant male in the pen would probably have awakened, and he would engage the subordinates in fights as they tried to come down the one ramp to the pen. For a while the subordinate would continue its efforts to return to what had been its home pen, but after a succession of defeats it would become so conditioned that it would not even make the attempt. In essence the dominant male established his territorial dominion and his control over a harem of females not by driving the other males out but by preventing their return.

Once a male had established his dominion over an end pen and the harem it contained, he was usually able to maintain it. Although he slept a good deal of the time, he made his sleeping quarters at the base of the ramp. He was, therefore, on perpetual guard. Awakening as soon as another male appeared at the head of the ramp, he had only to open his eyes for the invader to wheel around and return to the adjoining pen. On the other hand, he would sleep calmly through all the comings and goings of his harem; seemingly he did not even hear their clatterings up and down the wire ramp. His conduct during his waking hours reflected his dominant status. He would move about in a casual and deliberate fashion, occasionally inspecting the burrow and nests of his harem. But he would rarely enter a burrow, as some other males did, merely to ferret out the females.

A territorial male might tolerate other males in his domain provided they respected his status. Such subordinate males inhabited the end pens in several of the experiments. Phlegmatic animals, they spent most of their time hidden in the burrow with the adult females, and their excursions to the floor lasted only as long as it took them to obtain food and water. Although they never attempted to engage in sexual activity with any of the females, they were likely, on those rare occasions when they encountered the dominant male, to make repeated attempts to mount him. Generally the dominant male tolerated these advances.

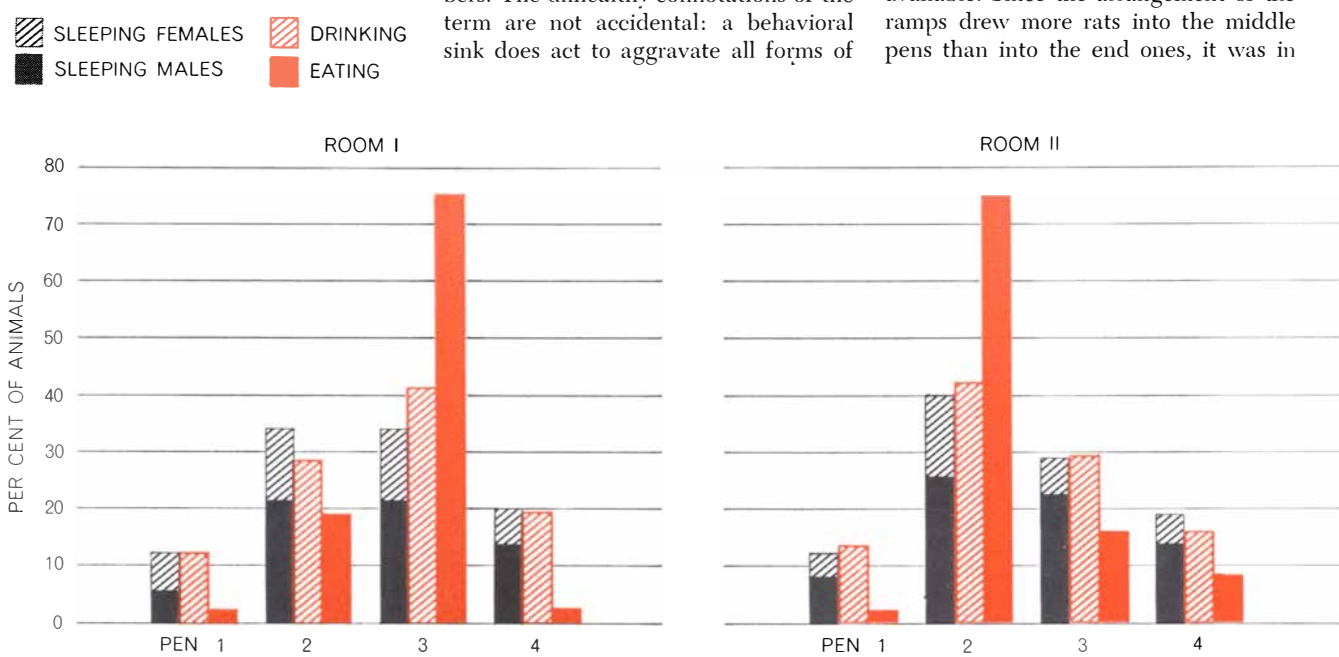
In these end pens, where population density was lowest, the mortality rate among infants and females was also low. Of the various social environments that developed during the course of the experiments, the brood pens, as we called them, appeared to be the only healthy ones, at least in terms of the survival of the group. The harem females generally made good mothers. They nursed their

young, built nests for them and protected them from harm. If any situation arose that a mother considered a danger to her pups, she would pick the infants up one at a time and carry them in her mouth to a safer place. Nothing would distract her from this task until the entire litter had been moved. Half the infants born in the brood pens survived.

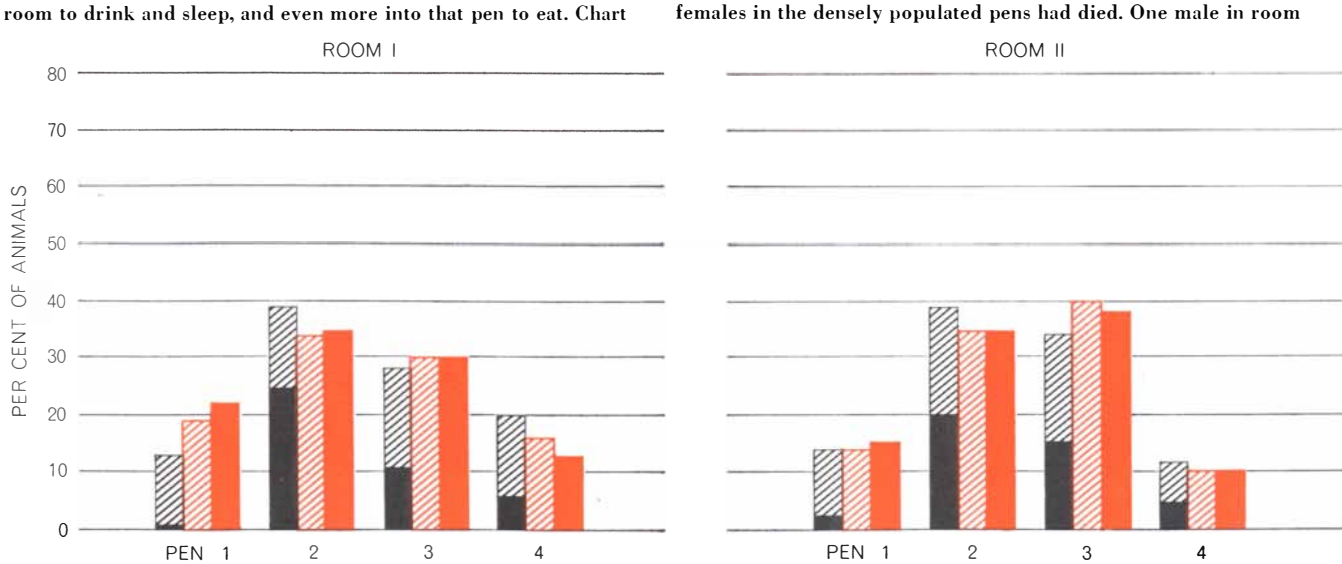
The pregnancy rates recorded among the females in the middle pens were no lower than those recorded in the end pens. But a smaller percentage of these pregnancies terminated in live births. In the second series of experiments 80 per cent of the infants born in the middle pens died before weaning. In the first series 96 per cent perished before this time. The males in the middle pens were no less affected than the females by the pressures of population density. In both series of experiments the social pathology among the males was high. In the first series, however, it was more aggravated than it was in the second.

This increase in disturbance among the middle-pen occupants of the first series of experiments was directly related to the development of the phenomenon of the behavioral sink—the outcome of any behavioral process that collects animals together in unusually great numbers. The unhealthy connotations of the term are not accidental: a behavioral sink does act to aggravate all forms of pathology that can be found within a group.

The emergence of a behavioral sink was fostered by the arrangements that were made for feeding the animals. In these experiments the food consisted of small, hard pellets that were kept in a circular hopper formed by wire mesh. In consequence satisfaction of hunger required a continuous effort lasting several minutes. The chances therefore were good that while one rat was eating another would join it at the hopper. As was mentioned earlier, rats usually eat intermittently throughout their waking hours, whenever they are hungry and food is available. Since the arrangement of the ramps drew more rats into the middle pens than into the end ones, it was in



BEHAVIORAL SINK developed in the first series of three experiments, drawing half the rats either into pen 2 or pen 3 of each room to drink and sleep, and even more into that pen to eat. Chart describes the situation in the 13th month of the experiment. By then the population distributions were fairly stable and many females in the densely populated pens had died. One male in room

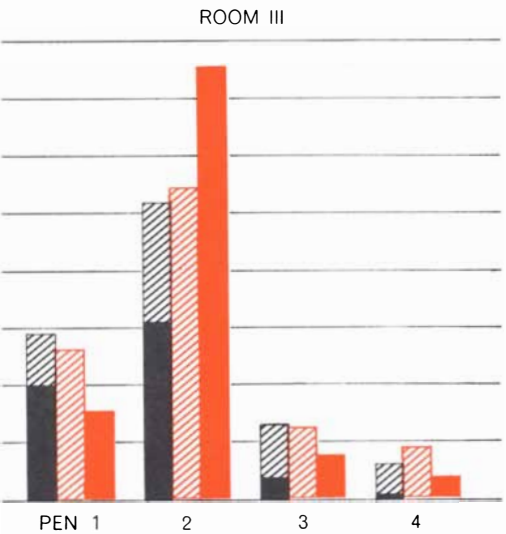


POPULATION DISTRIBUTIONS in the second series of three experiments, in which no behavioral sink developed, were more even than they were in the first series, and the death rate among females and infants was lower. Chart shows the situation in the 13th month, when one male had established pens 3 and 4 of room III as his territory, and another was taking over pen 2, thus

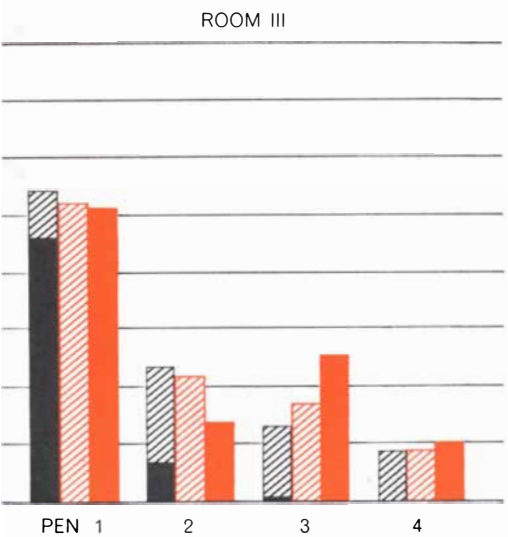
these pens that individuals were most likely to find other individuals eating. As the population increased, the association of eating with the presence of other animals was further reinforced. Gradually the social aspect of the activity became determinant: the rats would rarely eat except at hoppers already in use by other animals.

At this point the process became a vicious circle. As more and more of the rats tended to collect at the hopper in one of the middle pens, the other hoppers became less desirable as eating places. The rats that were eating at these undesirable locations, finding themselves deserted by their groupmates, would transfer their feeding to the more crowded pen. By the time the three experiments in the first series drew to a close half or more of the populations were sleeping as well as eating in that pen. As a result there was a decided increase in the number of social adjustments each rat had to make every day. Regardless of which pen a rat slept in, it would go to one particular middle pen several times a day to eat. Therefore it was compelled daily to make some sort of adjustment to virtually every other rat in the experimental population.

No behavioral sinks developed in the second series of experiments, because we offered the rats their diet in a different way. A powdered food was set out in an open hopper. Since it took the animals only a little while to eat, the probability that two animals would be eating simultaneously was considerably reduced. In order to foster the emergence of a behavioral sink I supplied the pens with drinking fountains designed to prolong the drinking activity. The effect of this arrangement was unquestionably to make the animals social drinkers; they used the fountain mainly when other animals lined up at it. But the effect was also to discourage them from wandering and to prevent the development of a behavioral sink. Since rats generally drink immediately on arising, drinking and the social interaction it occasioned tended to keep them in the pens in which they slept. For this reason all social pathology in the second series of experiments, although severe, was less extreme than it was in the first series.



III had established pens 3 and 4 as his territory. Subsequently a male in room I took over pen 1, expelling all the other males.



forcing most of the males into pen 1. Pen 1 in rooms I and II had also become territories; later pen 4 in room II became a territory.

Females that lived in the densely populated middle pens became progressively less adept at building adequate nests and eventually stopped building nests at all. Normally rats of both sexes build nests, but females do so most vigorously around the time of parturition. It is an undertaking that involves repeated periods of sustained activity, searching out appropriate materials (in our experiments strips of paper supplied an abundance), transporting them bit by bit to the nest and there arranging them to form a cuplike depression, frequently sheltered by a hood. In a crowded middle pen, however, the ability of females to persist in this biologically essential activity became markedly impaired. The first sign of disruption was a failure to build the nest to normal specifications. These females simply piled the strips of paper in a heap, sometimes trampling them into a pad that showed little sign of cup formation. Later in the experiment they would bring fewer and fewer strips to the nesting site. In the midst of transporting a bit of material they would drop it to engage in some other activity occasioned by contact and interaction with other individuals met on the way. In the extreme disruption of their behavior during the later months of the population's history they would build no nests at all but would bear their litters on the sawdust in the burrow box.

The middle-pen females similarly lost the ability to transport their litters from one place to another. They would move only part of their litters and would scatter them by depositing the infants in different places or simply dropping them on the floor of the pen. The infants thus abandoned throughout the pen were seldom nursed. They would die where they were dropped and were thereupon generally eaten by the adults.

The social stresses that brought about this disorganization in the behavior of the middle-pen females were imposed with special weight on them when they came into heat. An estrous female would be pursued relentlessly by a pack of males, unable to escape from their soon unwanted attentions. Even when she retired to a burrow, some males would follow her. Among these females there was a correspondingly high rate of mortality from disorders in pregnancy and parturition. Nearly half of the first- and second-generation females that lived in the behavioral-sink situation had died of these causes by the end of the 16th month. Even in the absence of the extreme stresses of the behavioral sink, 25 per cent of the females died. In contrast, only 15 per cent of the adult males in both series of experiments died.

A female that lived in a brood pen was sheltered from these stresses even though during her periods of estrus she would leave her pen to mate with males in the other pens of the room. Once she was satiated, however, she could return to the brood pen. There she was protected from the excessive attention of other males by the territorial male.

For the effect of population density on the males there is no index as explicit and objective as the infant and maternal mortality rates. We have attempted a first approximation of such an index, however, by scoring the behavior of the males on two scales: that of dominance and that of physical activity. The first index proved particularly effective in the early period of the experiments, when the males were approaching adulthood and beginning the fights that eventually fixed their status in the social hierarchy. The more fights a male initiated and the more fights he won, the more likely he was to establish a position of dominance. More than half the animals in each ex-

periment gave up the struggle for status after a while, but among those that persisted a clear-cut hierarchy developed.

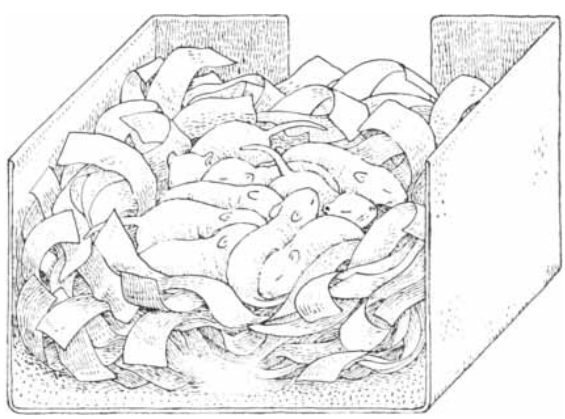
In the crowded middle pens no one individual occupied the top position in this hierarchy permanently. In every group of 12 or more males one was the most aggressive and most often the victor in fights. Nevertheless, this rat was periodically ousted from his position. At regular intervals during the course of their waking hours the top-ranking males engaged in free-for-alls that culminated in the transfer of dominance from one male to another. In between these tumultuous changings of the guard relative calm prevailed.

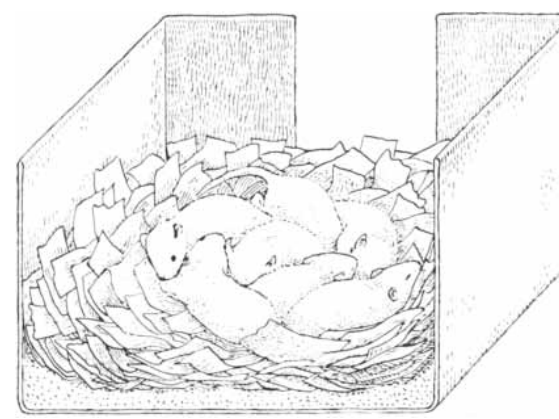
The aggressive, dominant animals were the most normal males in our populations. They seldom bothered either the females or the juveniles. Yet even they exhibited occasional signs of pathology, going berserk, attacking females, juveniles and the less active males, and showing a particular predilection —which rats do not normally display— for biting other animals on the tail.

Below the dominant males both on the status scale and in their level of activity were the homosexuals—a group perhaps better described as pansexual. These animals apparently could not discriminate between appropriate and inappropriate sex partners. They made sexual advances to males, juveniles and females that were not in estrus. The males, including the dominants as well as the others of the pansexuals' own group, usually accepted their attentions. The general level of activity of these animals was only moderate. They were frequently attacked by their dominant associates, but they very rarely contended for status.

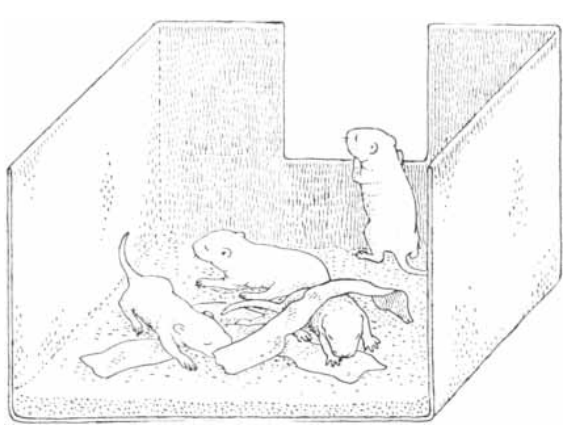
Two other types of male emerged, both of which had resigned entirely from the struggle for dominance. They were, however, at exactly opposite poles as far as their levels of activity were concerned. The first were completely passive and moved through the community like somnambulists. They ignored all the other rats of both sexes, and all the other rats ignored them. Even when the females were in estrus, these passive animals made no advances to them. And only very rarely did other males attack them or approach them for any kind of play. To the casual observer the passive animals would have appeared to be the healthiest and most attractive members of the community. They were fat and sleek, and their fur showed none of the breaks and bare spots left by the fighting in which males usually engage. But their social disorientation was nearly complete.

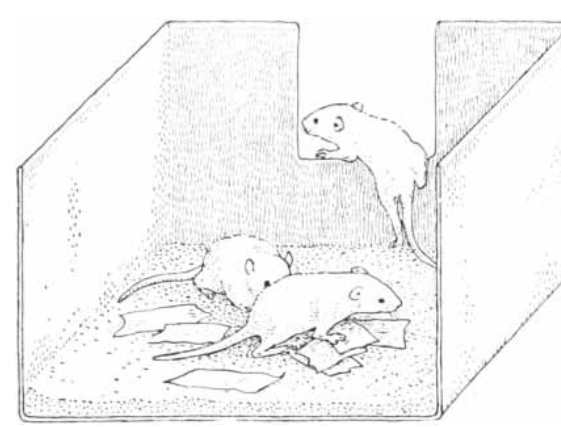
Perhaps the strangest of all the types that emerged among the males was the group I have called the probers. These animals, which always lived in the middle pens, took no part at all in the status struggle. Nevertheless, they were the most active of all the males in the experimental populations, and they persisted in their activity in spite of attacks by the dominant animals. In addition to being hyperactive, the probers were both





NORMAL MATERNAL BEHAVIOR among rats includes building a fluffy, well-shaped nest for the young. The drawing at the left shows such a nest, holding a recently born litter. The drawing at the right shows this same nest about two weeks later. It has been flattened by the weight of the animals' bodies but it still offers ample protection and warmth, and the remaining pups can still rest comfortably. In these experiments half the offspring of normal mothers survived infancy and were successfully weaned.





ABNORMAL MATERNAL BEHAVIOR, shown by females exposed to the pressures of population density, includes failure to build adequate nests. The drawing at the left shows the recently born young of a disturbed female. She started to make a nest but never finished it. The drawing at the right shows her young about two weeks later. One pup has already left and another is leaving. Neither can survive alone. In these experiments the mortality rate among infants of disturbed mothers was as high as 96 per cent.

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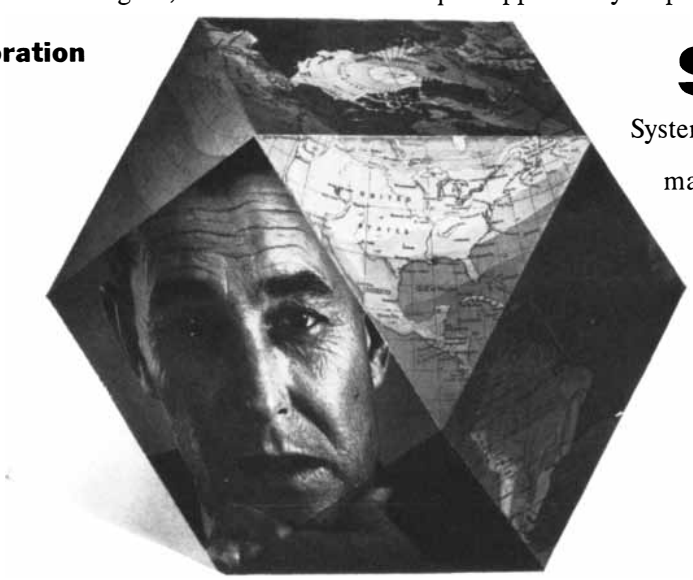

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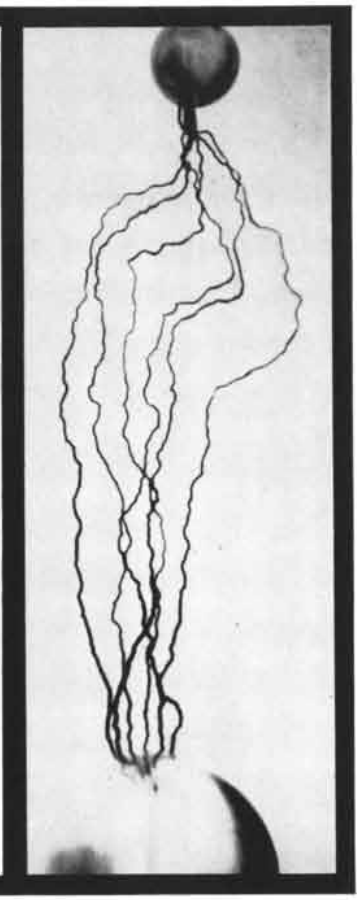


hypersexual and homosexual, and in time many of them became cannibalistic. They were always on the alert for estrous females. If there were none in their own pens, they would lie in wait for long periods at the tops of the ramps that gave on the brood pens and peer down into them. They always turned and fled as soon as the territorial rat caught sight of them. Even if they did not manage to escape unhurt, they would soon return to their vantage point.

The probers conducted their pursuit of estrous females in an abnormal manner. Mating among rats usually involves a distinct courtship ritual. In the first phase of this ritual the male pursues the female. She thereupon retires for a while into the burrow, and the male lies quietly in wait outside, occasionally poking his head into the burrow for a moment but never entering it. (In the wild forms of the Norway rat this phase usually involves a courtship dance on the mound at the mouth of the burrow.) The female at last emerges from the burrow and accepts the male's advances. Even in the disordered community of the middle pens this pattern was observed by all the males who engaged in normal heterosexual behavior. But the probers would not tolerate even a short period of waiting at the burrows in the pens where accessible females lived. As soon as a female retired to a burrow, a prober would follow her inside. On these expeditions the probers often found dead young lying in the nests; as a result they tended to become cannibalistic in the later months of a population's history.

Although the behavioral sink did not develop in the second series of experiments, the pathology exhibited by the populations in both sets of experiments, and in all pens, was severe. Even in the brood pens females could raise only half their young to weaning. Nor does the difference in infant mortality between the middle pens of the first and second series—96 per cent in the first as opposed to 80 per cent in the second—represent a biologically significant improvement. It is obvious that the behavioral repertory with which the Norway rat has emerged from the trials of evolution and domestication must break down under the social pressures generated by population density. In time, refinement of experimental procedures and of the interpretation of these studies may advance our understanding to the point where they may contribute to the making of value judgments about analogous problems confronting the human species.

MATHEMATICAL GAMES

A clutch of diverting problems, and the answers to those of last month

by Martin Gardner

No mathematical knowledge beyond what one would normally acquire in high school is needed for the solution of any of the following problems, with the possible exception of the second, which involves very elementary probability theory. Collections of problems such as these are a periodic feature of this department. The answers will be given next month.

1.

This perplexing digital problem, inventor unknown, was passed on to me by L. Vosburgh Lyons of New York City. The digits from 1 to 8 are to be placed in the eight circles shown in the illustration below, with this proviso: no two digits directly adjacent to each other in serial order may go in circles that are directly connected by a line. For example, if 5 is placed in the top circle, neither 4 nor 6 may be placed in any of the three circles below, because each of these circles is joined directly to the top circle by a straight line.

There is only one solution (not counting a rotation or mirror reflection as being different), but if you try to find it without a logical procedure, the task will be difficult.

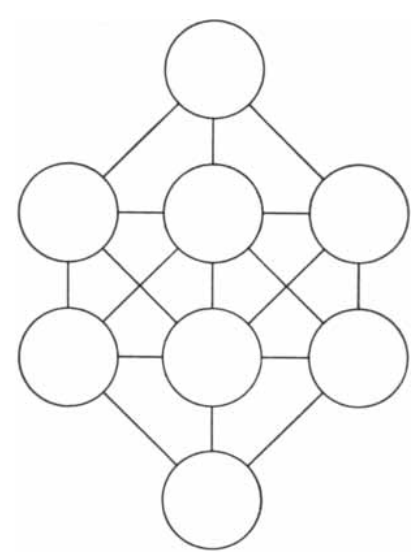
2.

Frank Stockton's famous short story "The Lady or the Tiger?" tells of a semibarbaric king who enjoyed administering a curious kind of justice. The king sat on a high throne at one side of his public arena. On the opposite side were twin doors. The prisoner on trial could open either door, guided only by "impartial and incorruptible chance." Behind one door was a hungry tiger; behind the other, a desirable young lady. If the tiger sprang through the door, the man's fate was considered a just punishment for his crime. If the lady stepped forth, the man's innocence was rewarded by a marriage ceremony performed on the spot.

The king, having discovered his daughter's romance with a certain courtier, has placed the unfortunate young man on trial. The princess knows which door conceals the tiger. She also knows that behind the other door is the fairest lady of the court, whom she has observed making eyes at her lover. The courtier knows the princess knows. She makes a "slight, quick movement" of her hand to the right. He opens the door on the right. The tale closes with the tantalizing question: "Which came out of the opened door—the lady or the tiger?"

After extensive research on this incident, I am able to make the first full report on what happened next. The two doors were side by side and hinged to open toward each other. After opening the door on the right the courtier quickly pulled open the other door and barricaded himself inside the triangle formed by the doors and the wall. The tiger emerged through one door, entered the other and ate the lady.

The king was a bit nonplused, but, being a good sport, he allowed the courtier



A perplexing digital problem

SIMULATION:
1200 air battles inside a computer

The best way to test new equipment is to put it into actual use. But how can the performance of advanced airborne guidance systems be evaluated without spending millions of dollars in production and flight test of equipment? How can the effect of possible design changes be determined? How much can systems and equipment be improved before over-all performance becomes subject to diminishing returns?

Scientists have been exploring these questions—and many more—at the Simulation Laboratory of the IBM Space Guidance Center in Owego, N. Y. For example, they constructed mathematical and logical models of every factor in a major B-52 air strike. Into an IBM computer went simulation data on enemy missiles, radar, fighter defenses, as well as detailed weather and terrain data and complete aircraft performance parameters. After more than 1200 simulated battles were "fought" inside the computer, the scientists had the answers to their questions.

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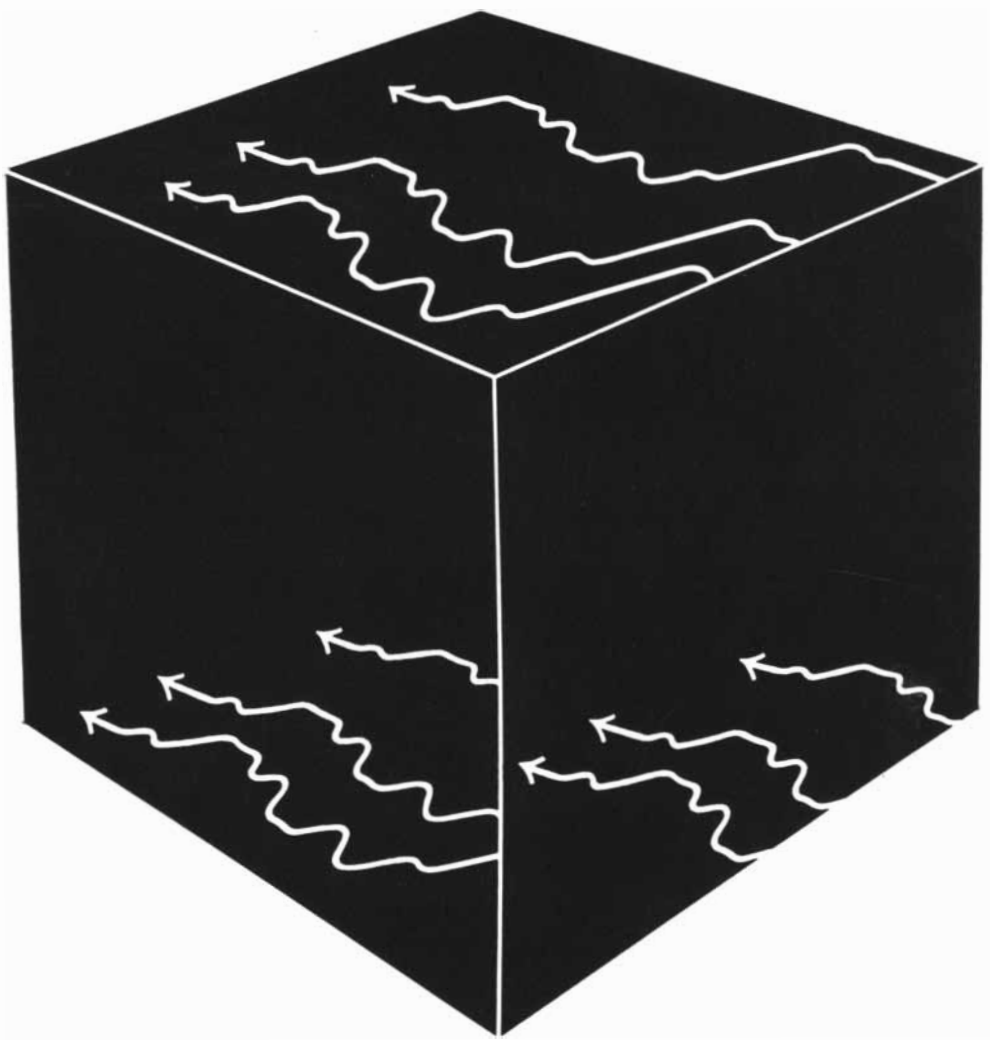

a second trial. Not wishing to give the wily young man another 50–50 chance, he had the arena reconstructed so that instead of one pair of doors there were now three pairs. Behind one pair he placed two hungry tigers. Behind the second pair he placed a tiger and a lady. Behind the third pair he placed two ladies who were identical twins and who were dressed exactly alike.

The cruel scheme was as follows. The courtier must first choose a pair of doors. Then he must select one of the two and a key would be tossed to him for opening it. If the tiger emerged, that was that. If the lady, the door would immediately be slammed shut. The lady and her unknown partner (either her twin sister or a tiger) would then be secretly rearranged in the two rooms according to a flip of a special gold coin with a lady on one side and a tiger on the other. The courtier would be given a second choice between the same two doors, without knowing whether the arrangement was different or the same as before. If he chose a tiger, that was that again; if a lady, the door would be slammed shut, the coin-flipping procedure repeated and the courtier given a third and final choice of one of the same two doors. If successful in his last choice, he would marry the lady and his ordeal would be over.

The day of the trial arrived and all went according to plan. Twice the courtier selected a lady. He tried his best to determine if the second lady was the same as the first but was unable to decide. Beads of perspiration glistened on his forehead. The face of the princess—she was ignorant this time of who went where—was as pale as white marble.

Exactly what probability did the courtier have of finding a lady on his third guess?

3.

Miranda beat Rosemary in a set of tennis, winning six games to Rosemary's three. Five games were won by the player who did not serve. Who served first?

4.

A wealthy man had two bowling lanes in his basement. In one lane 10 dark-colored pins were used; in the other, 10 light-colored pins. The man had a mathematical turn of mind, and the following problem occurred to him one evening as he was practicing his delivery:

Is it possible to mix pins of both colors, then select 10 pins that can be placed in the usual triangular formation in such a way that no three pins of the

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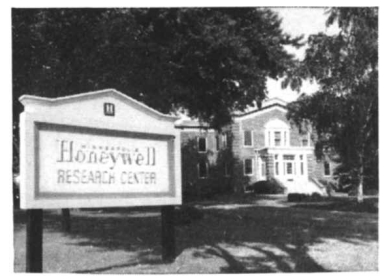


Magnetic Remanence at Cryogenic Temperatures

Many of the properties of metals are still little understood. Studies of the magnetic properties of dilute metal alloys in the cryogenic temperature range are providing new insights into magnetic characteristics as well as permitting observation of behavior heretofore expressed only in theory.

Conventional magnetism in such metals as iron, cobalt and nickel results from atoms which have magnetic moments and act as individual magnets. At the Curie temperature (iron 770° C) these moments commence spontaneous alignment with each other.

In a ferromagnetic state all the atomic magnetic moments are aligned in the same direction and set up a magnetic field. In the antiferromagnetic state the atomic magnetic moments prefer to align themselves in opposition to each other. This results in long range order in which alternate moments are aligned in opposition thus cancelling out any total magnetism.

It is not clearly understood why, in certain magnetic materials, the atoms are arranged in a ferromagnetic or antiferromagnetic state. This choice appears to depend upon the separation or distance between atoms. In a simple system (for example two atoms) the force that aligns the atomic magnetic moments is called an exchange force. When orbits overlap, electrons tend to be exchanged between atoms. This tends to split electron states. Individual electron states identical for each atom now become multiple states. One state corresponds to spin alignment, the other to an alignment of opposition. Whichever state has the lower energy level will determine whether the resulting magnetic state will be ferromagnetic or antiferromagnetic. When moving from a two atom system to a lattice, simplicity is lost and the problem becomes complex.

Honeywell's approach to understanding such phenomena is to study the magnetic properties of dilute alloys where small amounts of magnetic metals are introduced into a noble non-magnetic metal. By this method degree of orbital overlap can be controlled and average distance between orbits determined.

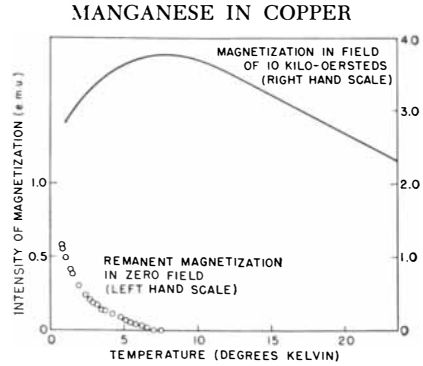
Cryogenic temperatures enter here because the Curie temperature is expected to be lowered by dilution; at this temperature or below the strength of interaction of the magnetic moments can be observed.

Honeywell scientists are working with copper manganese.

Above the Curie temperature, the alloy has conventional magnetic properties. While lowering the temperature in a constant field, measurements of the magnetic susceptibility are taken (a measure of magnetic moment induced in the alloy by a magnetic field).

Measurements show that the susceptibility goes through a maximum. The temperature at which this occurs and the susceptibility are determined by the amount of dilution.

INTENSITY OF MAGNETIZATION vs TEMPERATURE: 1 ATOMIC % MANGANESE IN COPPER



Honeywell scientists are also working with copper manganese alloys from 0.47 to 10.0% manganese at temperatures of 0.6° to 40° Kelvin using a liquid helium refrigerator. Typical results are shown at left. When the magnetic field is removed a small amount of remanent magnetism remains. This remanent magnetism is temperature dependent. If the specimen were ferromagnetic its temperature dependence curve would be different.

The internal magnetism cannot be accounted for by the direct exchange interaction of manganese atoms. It is more likely that the solvent, in this case copper, is not inert but furnishes a medium for transmittal of magnetic forces between the solute manganese atoms.

In all probability the conduction electrons of the solvent metal provide the medium of communication between magnetic atoms.

Honeywell scientists have estimated the magnitude of this internal field and calculated domain sizes. Indications are that the inner field effect continues in a systematic fashion to the lowest dilution. Work is continuing with several other alloys.

Observation and measurement of these magnetic phenomena can lead to further understanding and use of the thermal, magnetic and electrical properties of metals.

Coupled with other work in the cryogenic areas this information can aid scientists in a more complete and fundamental understanding of materials in general. This in turn can assist in overcoming the intrinsic limitations of materials in practical engineering applications.

If you are engaged in scientific work involving magnetism in the cryogenic range and would like to know more about Honeywell's research in this area you are invited to correspond with Dr. Olin Lutes, Honeywell Research Center, Hopkins, Minnesota.

same color will mark the vertices of an equilateral triangle?

If it is possible, show how to do it. Otherwise prove that it cannot be done. A set of checkers will provide convenient pieces for working on the problem.

5.

Professor Lucius S. Wilsun is a brilliant, though somewhat eccentric, topologist. His name had formerly been Wilson. As a graduate student he had noted that when his full name, Lucius Sims Wilson, was printed in capital letters, all the letters were topologically equivalent except for the *O*. This so annoyed him that he had his name legally changed.

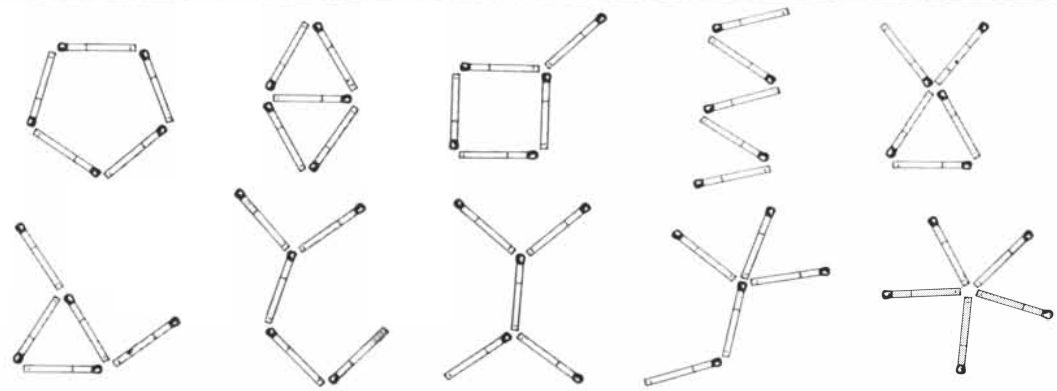
When I met him for lunch recently, I found him forming patterns on the tablecloth with six paper matches. "A new topological puzzle?" I asked hopefully.

"In a way," he replied. "I'm trying to find out how many topologically distinct patterns I can make with six matches by placing them flat on the table, without crossing one match over another, and joining them only at the ends."

"That shouldn't be difficult," I said.

"Well, it's trickier than you might think. I've just worked out all the patterns for smaller numbers of matches." He handed me an envelope on the back of which he had jotted down a rough version of the chart below.

"Didn't you overlook a five-match pat-

NUMBER OF MATCHES	NUMBER OF TOPOLOGICALLY DIFFERENT FIGURES	
1	1	
2	1	
3	3	
4	5	
5	10	
6	?	

A chart of the topologically distinct patterns that can be made with matches

tern?" I said. "Consider that third figure—the square with the tail. Suppose you put the tail *inside* the square. If the matches are confined to the plane, obviously one pattern can't be deformed into the other."

Wilsun shook his head. "That's a common misconception about topological equivalence. It is true that if one figure can be changed to another by pulling and stretching, without breaking or tearing, the two must be topologically identical—as we topologists like to say, homeomorphic. But not the other way around. If two figures are homeomorphic, it is *not* always possible to deform one into the other."

"I beg your pardon," I said.

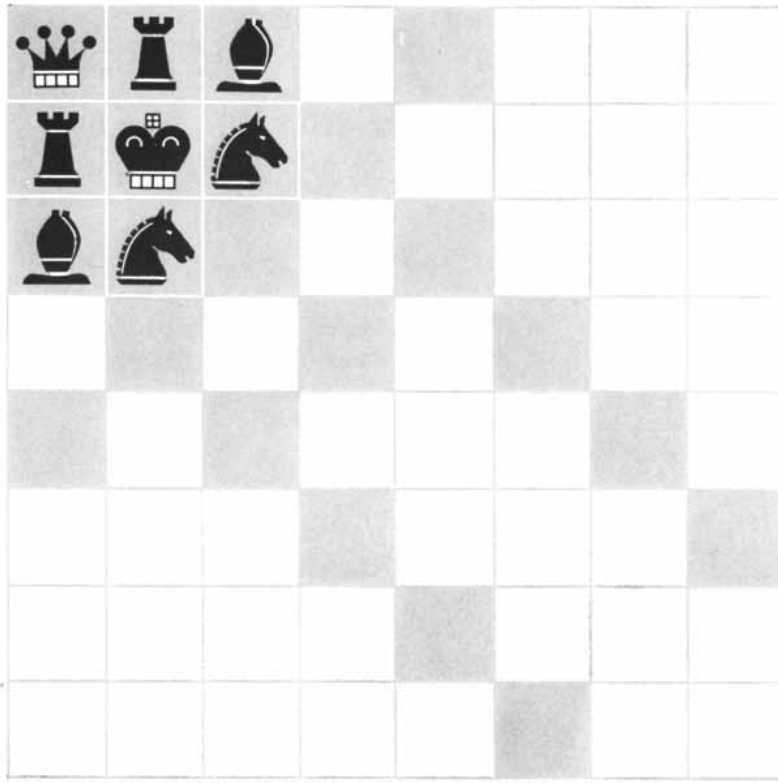
"Don't topologize. Two figures are homeomorphic if, as you move continuously from point to point along one figure, you can make a corresponding movement from point to point—the points of the two figures must be in one-to-one correspondence, of course—along the other figure. For example, a piece of rope joined at the ends is homeomorphic with a piece of rope that is knotted before the ends are joined, although you obviously cannot deform one to the other. Two spheres that touch externally are homeomorphic with two spheres of different size, the smaller inside the other and touching at one point."

I must have looked puzzled, because he quickly added: "Look, here's a simple way to make it clear to your readers. Those match figures are on the plane, but think of them as segments of elastic bands joined at the ends. You can pick them up, manipulate them any way you wish, turn them over if you please, put them back down again. If one figure can be changed to another this way, they are topologically the same."

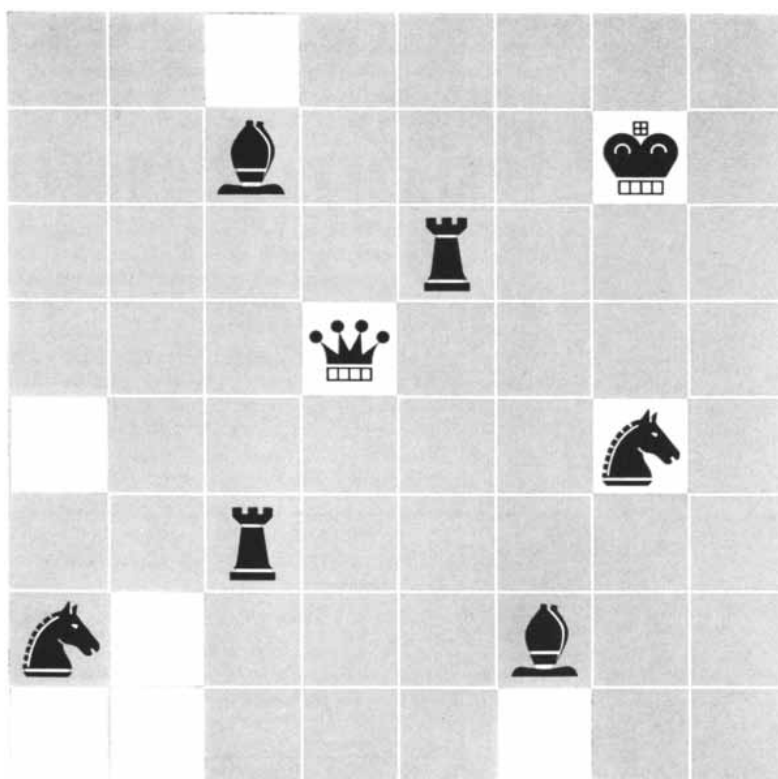
"I see," I said. "If you think of a figure as embedded in a higher space, then it *is* possible to deform one figure into any other figure that is topologically equivalent to it."

"Precisely. Imagine the endless rope or the two spheres in a four-dimensional space. The knot can be tied or untied while the ends remain joined. The small sphere can be moved in or out of the larger one."

With this understanding of topological equivalence, the reader is asked to determine the exact number of topologically different figures that can be formed on the plane with six matches. Remember, the matches themselves are rigid and all the same size. They must not be bent or stretched, they must not overlap and they may touch only at their ends. But once a figure is formed it must be



The minimum attack problem in chess



The maximum attack problem

thought of as an elastic structure that can be picked up, deformed in three-dimensional space, then returned to the plane. Thus a triangle is equivalent to a square or pentagon; the capital letters *E*, *F*, *T* and *Y* are all equivalent; *R* is the same as its mirror image; and so on.

6.

Many beautiful chess problems do not involve positions of competitive play; they use the pieces and board only for posing a challenging mathematical task. Here are two classic task problems that surely belong together:

1. The minimum attack problem: Place the eight pieces of one color (king, queen, two bishops, two knights, two rooks) on the board so that the *smallest* possible number of squares are under attack. A piece does not attack the square on which it rests, but of course it may attack squares occupied by other pieces. In the top illustration at the left, 22 squares (gray) are under attack, but this number can be reduced considerably. It is not necessary that the two bishops be placed on opposite colors.

2. The maximum attack problem: Place the same eight pieces on the board so that the *largest* possible number of squares are under attack. Again, a piece does not attack its own square, but it may attack other occupied squares. The two bishops need not be on opposite colors. In the bottom illustration at the left 55 squares (gray) are under attack. This is far from the maximum.

There is a proof for the maximum number when the bishops are on squares of the same color. No one has yet proved the maximum when the bishops are on different colors. The minimum is believed to be the same regardless of whether the bishops are on the same or opposite colors, but both cases are unsupported by proof. So many chess experts have worked on these problems that it is not likely any of the conjectured answers will be modified. Should any reader beat the records, it will be big news in chess-problem circles.

7.

At 10 o'clock one morning Mr. Smith and his wife left their house in Connecticut to drive to the home of Mrs. Smith's parents in Pennsylvania. They planned to stop once along the way for lunch at Patricia Murphy's Candlelight Restaurant in Westchester.

The prospective visit with his in-laws, combined with business worries, put Mr. Smith in a sullen, uncommunicative

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mood. It was not until 11 o'clock that Mrs. Smith ventured to ask: "How far have we gone, dear?"

Mr. Smith glanced at the mileage meter. "Half as far as the distance from here to Patricia Murphy's," he snapped.

They arrived at the restaurant at noon, enjoyed a leisurely lunch, then continued on their way. Not until five o'clock, when they were 200 miles from the place where Mrs. Smith had asked her first question, did she ask a second one. "How much farther do we have to go, dear?"

"Half as far," he grunted, "as the distance from here to Patricia Murphy's."

They arrived at their destination at seven that evening. Because of traffic conditions Mr. Smith had driven at widely varying speeds. Nevertheless, it is quite simple to determine (and this is the problem) exactly how far the Smiths traveled from one house to the other.

8.

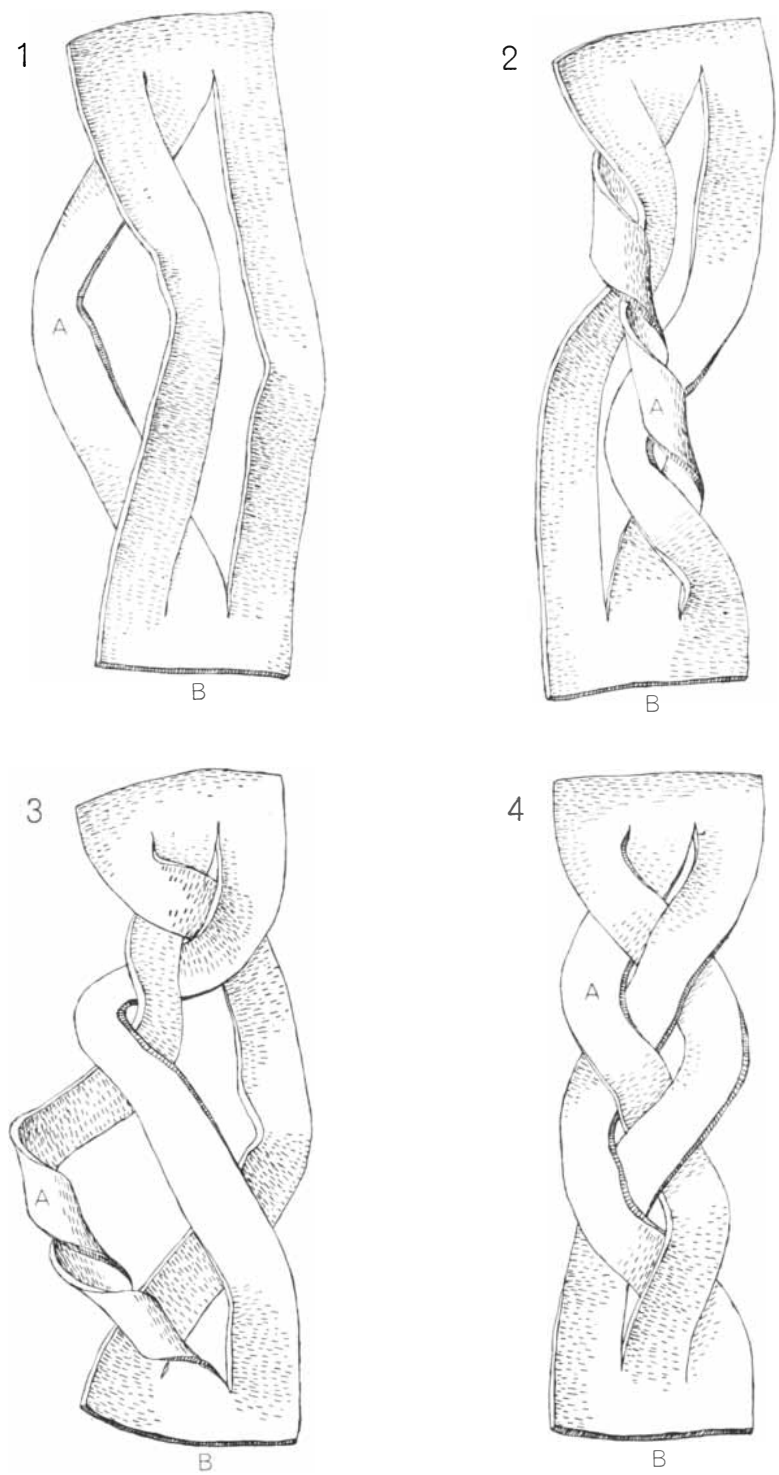
On last New Year's Day a mathematician was puzzled by the strange way in which his small daughter began to count on the fingers of her left hand. She started by calling the thumb 1, the first finger 2, middle finger 3, ring finger 4, little finger 5, then she reversed direction, calling the ring finger 6, middle finger 7, first finger 8, thumb 9, then back to the first finger for 10, middle finger for 11, and so on. She continued to count back and forth in this peculiar manner until she reached a count of 20 on her ring finger.

"What in the world are you doing?" her father asked.

The girl stamped her foot. "Now you've made me forget where I was. I'll have to start all over again. I'm counting up to 1962 to see what finger I'll end on."

The mathematician closed his eyes while he made a simple mental calculation. "You'll end on your ——," he said.

When the girl finished her count and found that her father was right, she was so impressed by the predictive power of mathematics that she decided to work twice as hard on her arithmetic lessons. How did the father arrive at his prediction and what finger did he predict?



***Slade's first trick. Pull* A *back to front over* B, *then pull* A *to left and front to back over* B**

Last month readers were asked to explain two remarkable tricks performed by the Reverend Arthur Slade, pastor of the Church of the Fourth Dimension. The trick of braiding the leather strip, impossible though it may seem, can be done merely by manipulating the strip as shown in the illustration at the left. (David A. Huffman, an electrical engineer at the Massachusetts Institute of Technology, first called this to my attention.)

If stiff leather is used, it should first be soaked in warm water to make it pliable. By repeating the procedure illustrated, longer plaits with any multiple of six crossings can be produced. Fancier plaits are possible with strips that have five, seven or any odd number of strands, but the manipulations are of course more complicated.

Slade's trick of producing a knot in a flat rubber band calls first for the preparation of a knotted band. Obtain a rubber ring of circular cross section and carefully carve a portion of it flat as shown in the top drawing in the illustration on the next page. Make three half-twists in the flat section [*middle*

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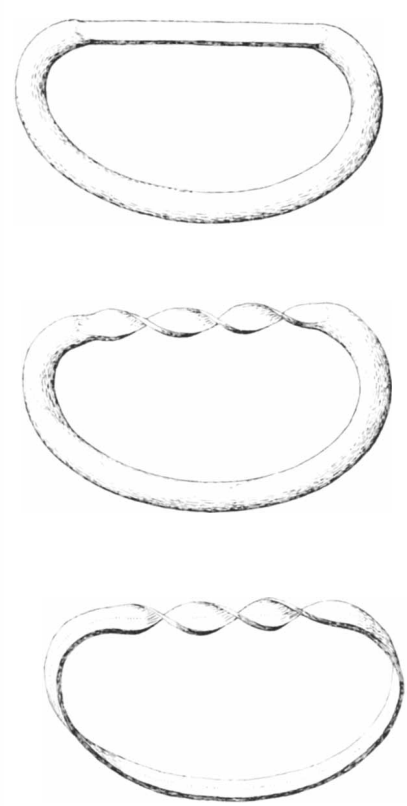
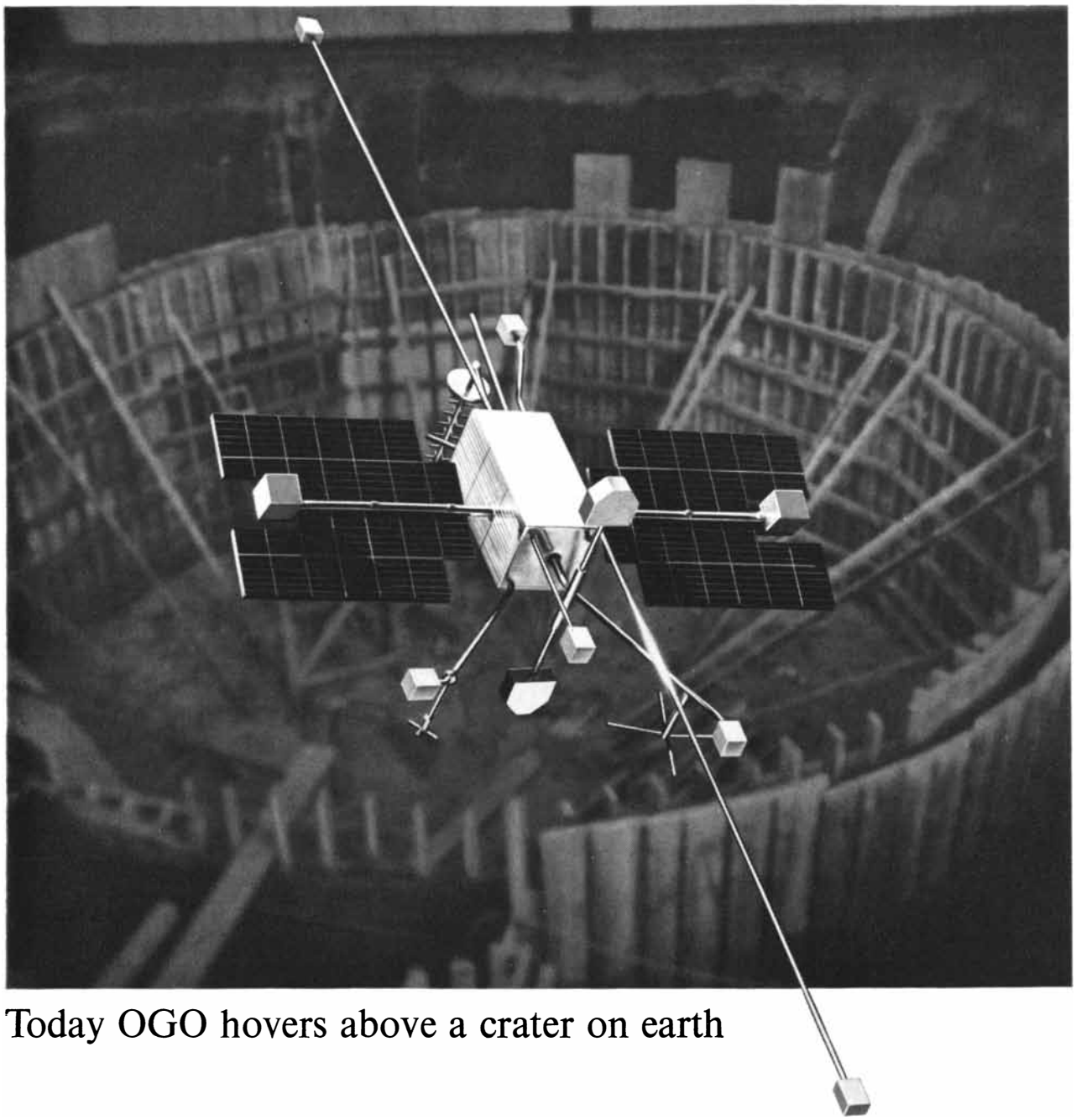
drawing], then continue carving the rest of the ring to make a flat band with three half-twists [*bottom drawing*]. Mel Stover of Winnipeg, Canada, suggests that this can best be done by stretching the ring around a wooden block, freezing the ring, then flattening it with a home grinding tool. When the final band is cut in half all the way around, it forms a band twice as large and tied in a single knot.

A duplicate band of the same size, but unknotted, must also be obtained. The knotted band is placed in a matchbox and the ends of the box are sealed with Scotch tape. It is now necessary to substitute this matchbox for the one containing the unknotted band. I suspect that Slade did this when he started to put the box under the table, then "remembered" that I had not yet initialed it. The prepared box could have been stuck to the underside of the table with magician's wax. It would require only a moment to press the unprepared box against another dab of wax, then take the prepared one. In this way the switch occurred *before* I marked the box. The vibrations I felt when Slade and I held the box under the table were probably produced by one of Slade's fingers pressing firmly against the box and sliding across it.



Slade's second trick



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THE AMATEUR SCIENTIST

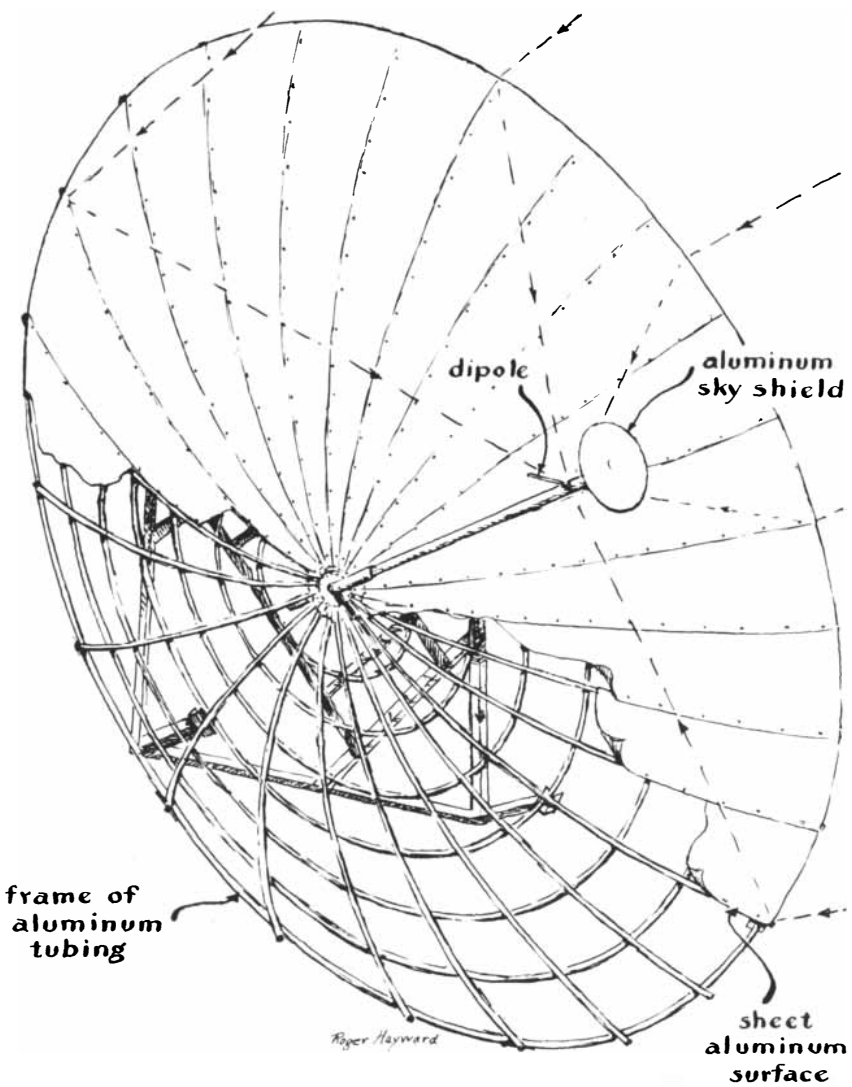
About two radio telescopes that were made by amateurs

Conducted by C. L. Stong

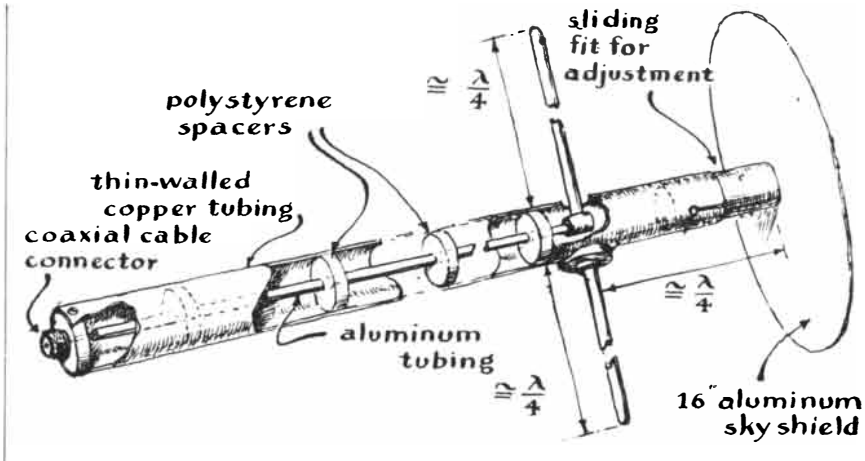
Amateurs traditionally make radios and telescopes, yet it appears that few of them make radio telescopes. Perhaps the techniques of radio astronomy are too new to have filtered down from professionals to amateurs, or perhaps they are too demanding. To date descriptions of only two radio telescopes made by amateurs have reached this department. One was built by Lyndall McFarland of Winston-Salem, N.C., and the other at Manhattan, Kan., by Walter Houston, Clifford Simpson and Ben Mullinix. The two instruments are comparable in performance but differ in design: one is a reflector and the other a diffractor. McFarland's instrument picks up signals from any given direction by means of a 15-foot paraboloid of aluminum and focuses them on a simple dipole antenna. The Kansas instrument uses a 12-element Yagi array, a series of dipoles supported by a spar that resembles an overgrown television antenna. The length and spacing of the dipole elements were chosen so that radio waves arriving from all but the desired direction interfere, whereas those from the desired direction add constructively at the location of one dipole that feeds a radio receiver.

Both antennas are steerable in altitude and azimuth and have detected the sun as well as the more energetic radio sources in Sagittarius, Cygnus, Cassiopeia and Orion. The resolving power of McFarland's telescope is about 11 degrees of arc; it detects the sun as being a disk some 20 times wider than it appears to the eye. The resolving power of the Kansas telescope is about 17 degrees. In contrast, the 250-foot reflector of the radio telescope at Jodrell Bank in England resolves the sun as an object about twice the diameter of the optical disk. Toy spyglasses can disclose much more detail. But resolving power is only one measure of a telescope's performance. Another is the instrument's ability to detect distant objects. The clouds of interstellar dust that block many regions of the universe from view are transparent to some bands of the radio spectrum. The amateurs who built the Winston-Salem and Kansas telescopes set out to have a firsthand "look" at whatever lies beyond the dust, even if the view turned out to be fuzzy.

"I began to work on my telescope," writes McFarland, "during my third year in college, partly as a project for a thesis, and I hoped to finish it before graduation. But a number of bugs developed, and it was not ready for a trial run until the summer following graduation. The telescope has four major components: the antenna and its mount, a high-gain, low-noise receiver, an automatic pen recorder and a noise generator that is used to test the system and as a standard for comparing the strength of radio sources in space. The design and



Construction of a radio telescope made by Lyndall McFarland of Winston-Salem, N.C.

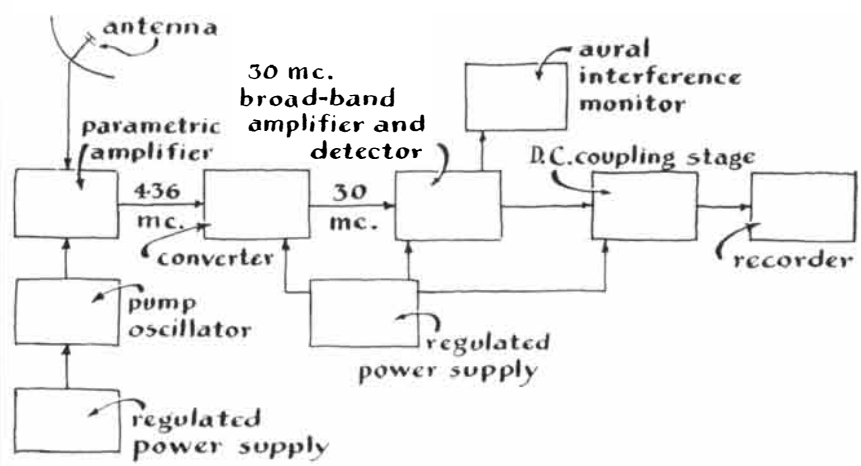


Coaxial feed line of McFarland's antenna

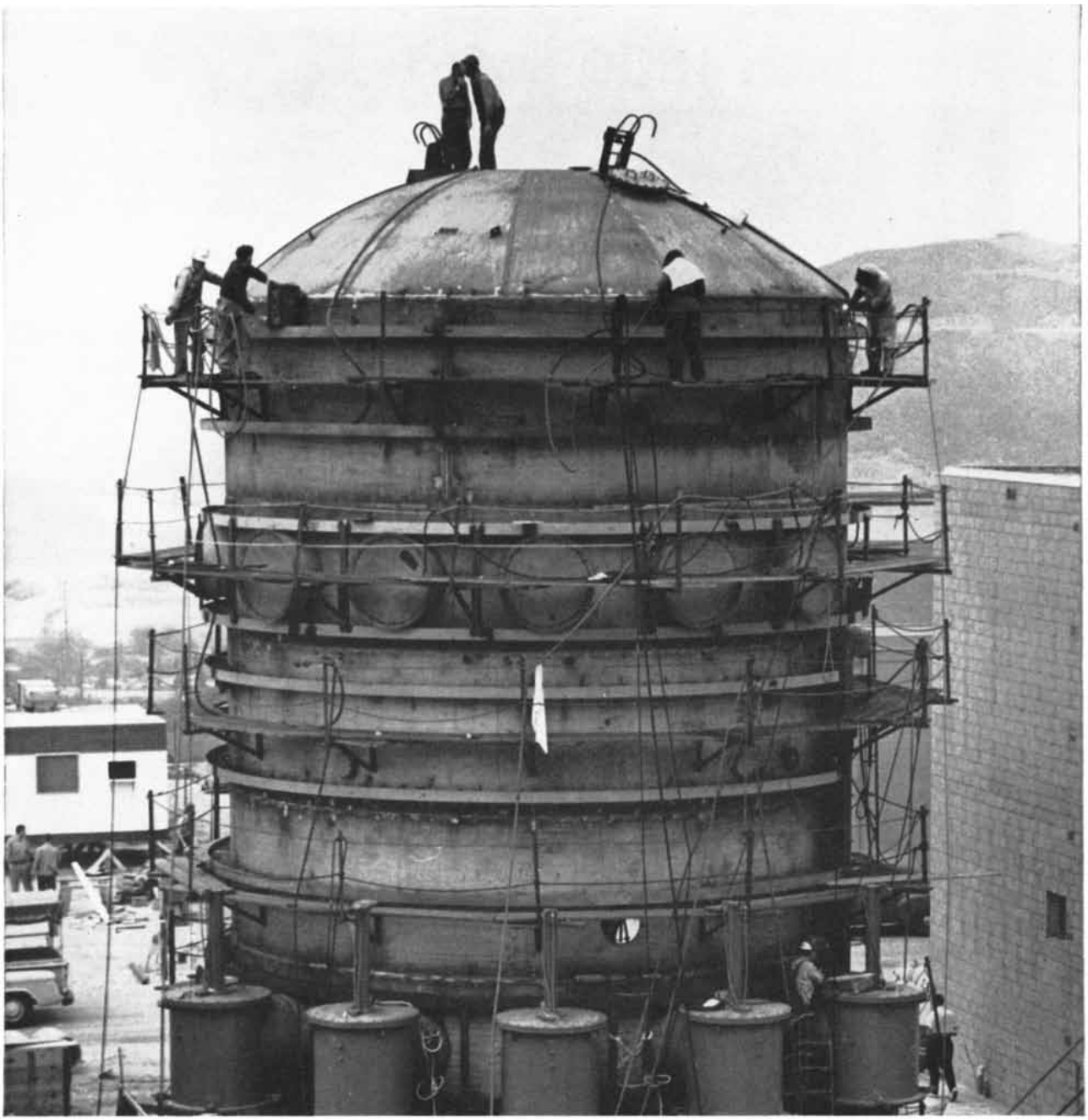
procurement phase of the project took 18 months of spare time and the construction about a year.

"Much of the initial planning went into the antenna. The antenna of a radio telescope corresponds to the objective mirror or lens of an optical telescope, and the performance of the completed instrument depends on it just as critically. In selecting a design for the antenna several configurations of the diffraction type were considered, including a broadside array of half-wave dipoles and an array of helices. These were dismissed in favor of a paraboloid because the complexity of interconnecting a broadside array increases in proportion to the number of dipoles, and the length of each dipole must be changed for each frequency on which the telescope operates. Moreover, I wanted an antenna that would pick up the broadest possible band of frequencies and discriminate strongly against all signals except those that come from a desired direction. A paraboloid best meets these requirements.

"Winston-Salem is a center of intense, man-made electrical disturbance, chiefly from sources such as automobile ignition systems, power lines and harmonic radiation from radio and television stations. By scanning the radio spectrum from 50 to 3,000 megacycles with a short-wave receiver, I spotted a relatively quiet region of the spectrum in the vicinity of 400 megacycles (a wavelength of 75 centimeters, or 29½ inches). At this frequency a signal equal to a millionth of a billionth of a watt (10^{-16} watt) would override the noise if the antenna were designed for maximum power gain; that is, if it strongly favored signals arriving parallel to the axis of the parabola. The power gain of a paraboloidal antenna (with respect to the response of a nondirectional antenna) varies directly with the radius of the parabola and inversely with the wavelength of the signal, as shown by the accompanying equation [*see top table on page 166*]. When the focal length of the parabola is equal to half the radius, the maximum power gain in decibels is equal to 10 times the logarithm (to the base 10) of the square of this ratio: 3.14 times the radius divided by the wavelength. At a



Block diagram of McFarland's radio telescope



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Power Gain of Paraboloid Antenna Relative to a Simple Dipole Antenna

$$\text{Gain}_{max.} = 10 \log_{10} \left(\frac{2\pi}{\lambda} \frac{2fr^2}{4f^2 + r^2} \right)^2$$

where:
f = focal length of paraboloid
r = radius of paraboloid
λ = wavelength of signal

Power-gain equations

wavelength of 27.5 inches (a frequency of approximately 436 megacycles) and a gain of 20 decibels, this formula yields a radius of 7.5 feet. With this dimension known, the distance from the focus to the vertex of a paraboloid can be calculated. In the case of my antenna it amounts to 3.75 feet. The resolving power of telescope objectives, whether optical or radio, increases in proportion to the diameter of the lens or reflector, and decreases with wavelength as indicated by the second formula [*below*]. A 15-foot paraboloid operating at 436 megacycles has a resolving power of 10 degrees 54 minutes, which is about 20 times greater than the apparent angle subtended by the sun.

"With the size of the antenna deter-

Resolving Power of Telescope Objectives

$$\theta = 1.22 \frac{\lambda}{a}$$

where:
θ = resolving power in radians
λ = wavelength
a = aperture
(λ and a in same units of length)

For White Light

$$\theta = \frac{14.1}{a}$$

where:
a is in centimeters
θ is in seconds of arc

Resolving power of 508-centimeter (200-inch) aperture for white light would be:

$$\theta = \frac{14.1}{508} = 0.02776 \text{ seconds of arc}$$

For radio waves of 300 megacycles (100 centimeters) the resolution of a 508-centimeter paraboloidal reflector would be:

$$\theta = \frac{1.22 \times 100}{508} = .24 \text{ radians} = 13^\circ\ 45'$$

and for 436 megacycles (69 centimeters) the resolution of a 15-foot paraboloid (457 centimeters) would be: $\theta = \frac{1.22 \times 69}{457} = .193$ radians $= 10^\circ\ 54'$

Resolving-power equations

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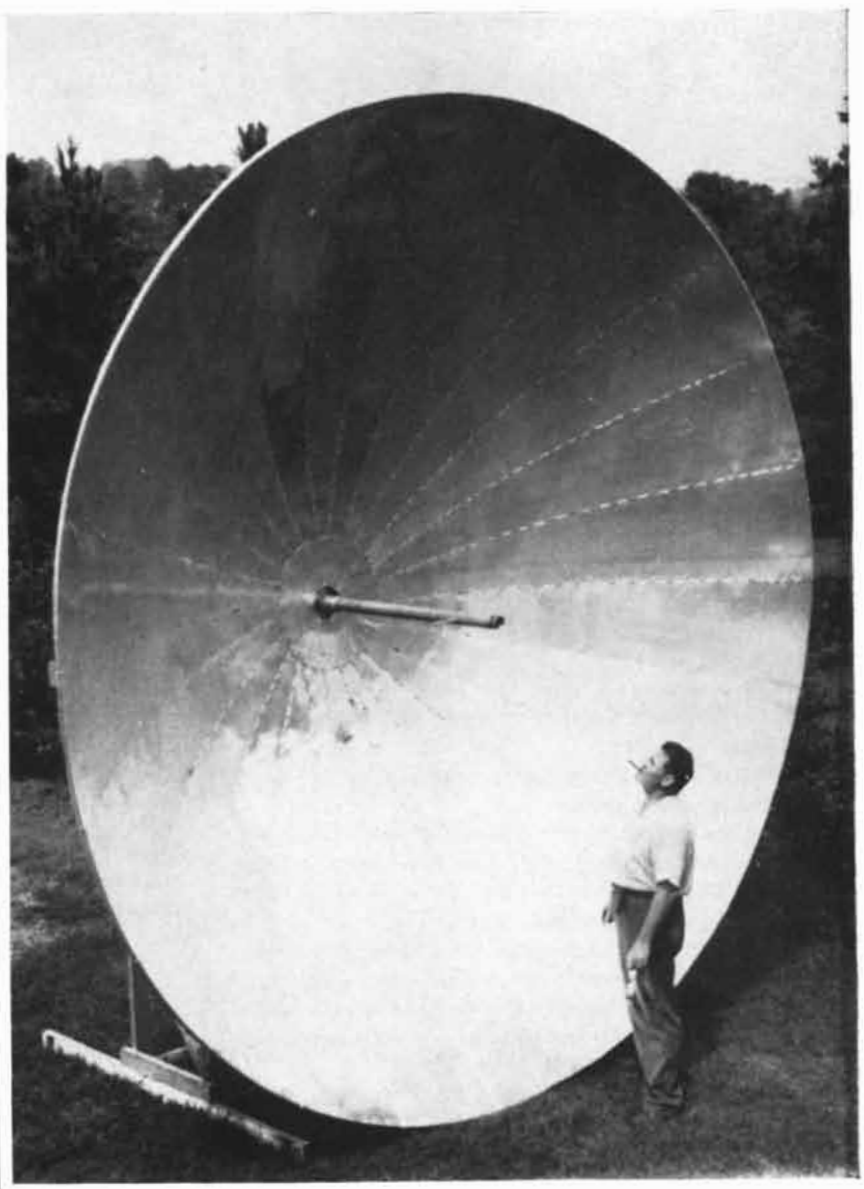
mined, its physical structure was considered next. Aluminum was selected as the most attractive material, from the point of view of both weight and cost. A disadvantage in using aluminum is that all parts of the antenna must be welded. Otherwise voltage may develop across the high-resistance joints between adjacent parts and be detected as noise. The welding can be done most satisfactorily by an electric arc that operates in an atmosphere of helium gas. This is inconvenient but not expensive.

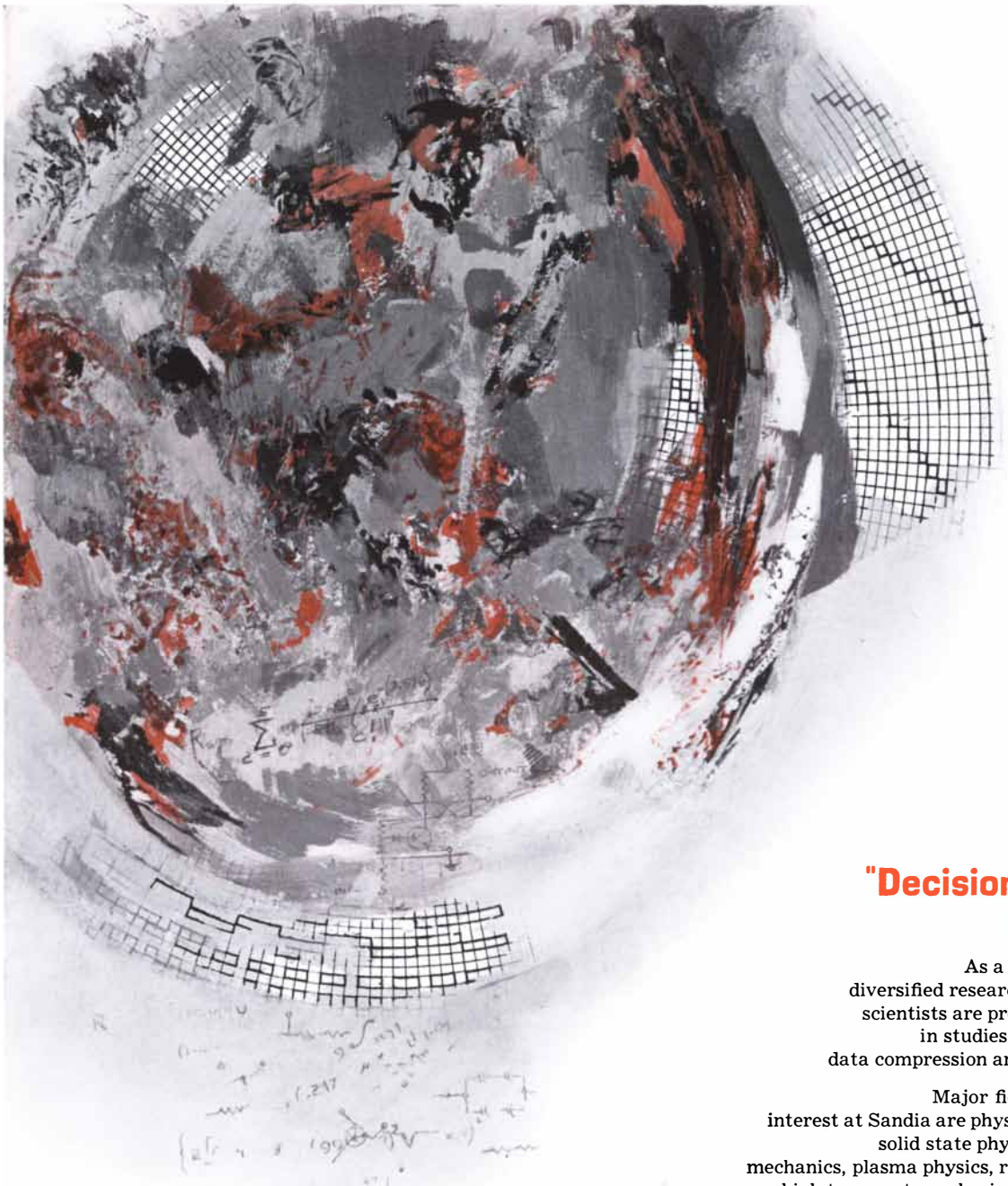
"The paraboloid was formed of sheet aluminum welded to a paraboloidal skeleton of aluminum tubing—a series of concentric rings supported by radial ribs bent so the sheet took the desired shape to within ⅛ inch [*see illustration on page 163*]. To build the skeleton I formed nine circles of ¾-inch tubing, with radii ranging from seven feet nine inches to six inches, on a machine similar to those used for bending model railroad tracks. The rings were nested against 24 radial ribs formed to the approximate final shape on the same bending machine. Many hours were then spent in hand-forming each rib to within 1/64 inch of a master parabolic template cut from sheet aluminum. A jig clamped the parts during the welding operation.

"Aluminum screening would doubtless have been a better choice from the point of view of wind resistance for covering the skeleton. But the only available material of this sort was ordinary house screening, which is much too light to hold its shape or to weld to the skeleton. The completed structure weighs approximately 260 pounds.

"Incoming signals are focused on a



McFarland and the reflector of his radio telescope



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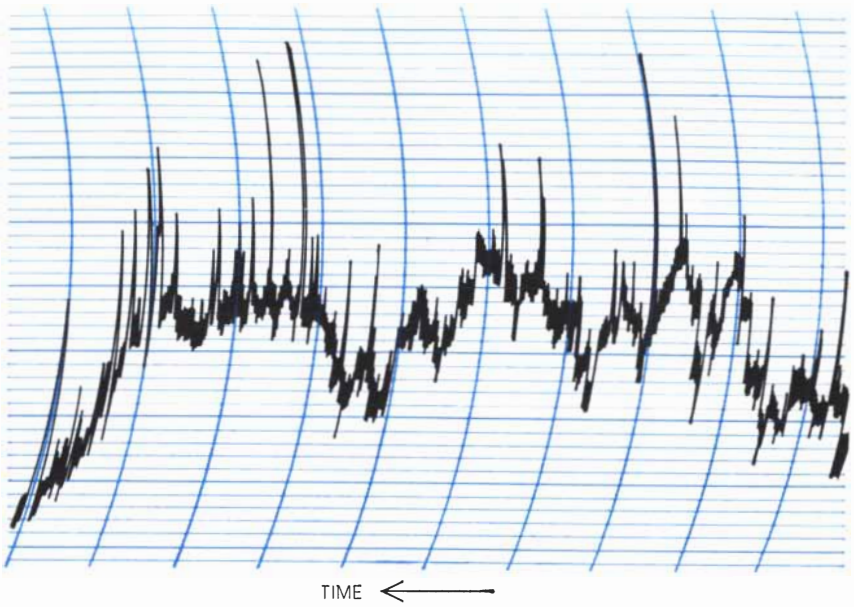
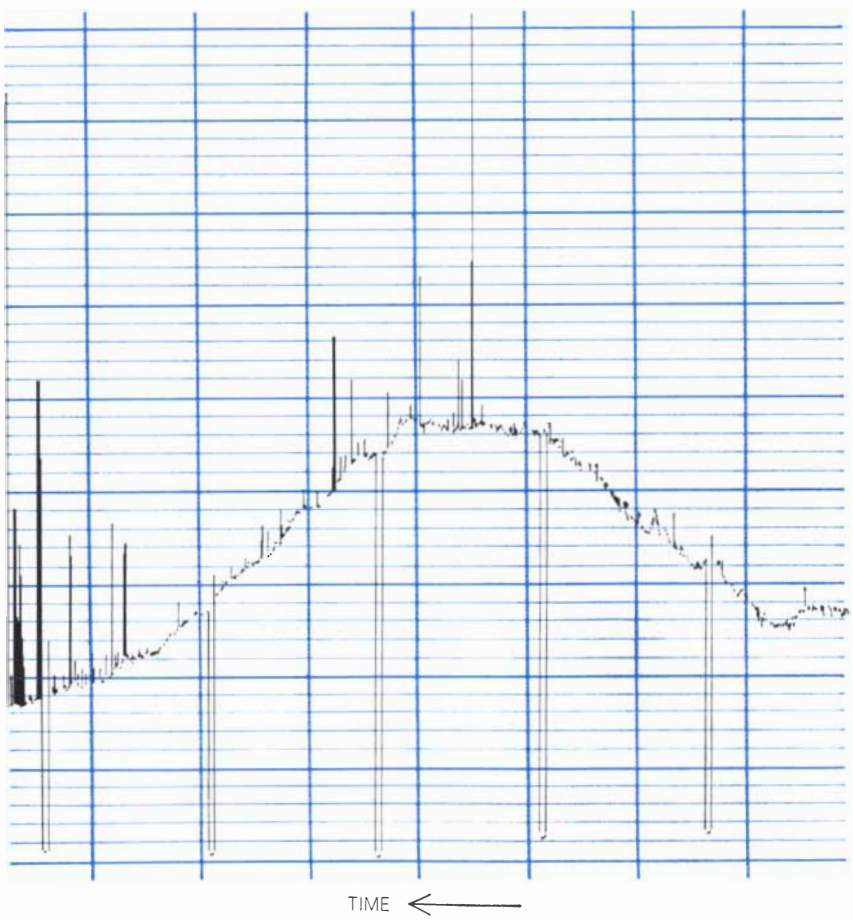


Radio signals from Cassiopeia, as recorded by McFarland's radio telescope



Recording of signals from Cassiopeia made by Kansas amateurs' telescope

dipole antenna that is supported on the axis of the paraboloid by a short length of coaxial transmission line made of two aluminum pipes [*see top illustration on page 164*]. The electrical impedance of coaxial lines is equal to the logarithm (base 10) of the quotient of 138 times the inside diameter of the outer pipe (in inches) divided by the outside diameter of the inner pipe. The inside diameter of my outer pipe is .66 inch and the outside diameter of the inner one is .27 inch. The impedance of my coaxial line is therefore 53 ohms. For maximum transmission efficiency the impedance of the coaxial line and that of its associated dipole antenna must match. The characteristic impedance of a dipole antenna in free space is 72 ohms, but this value is lowered by the presence of a nearby conductor, such as a metal plate. I found that I could match the impedance of my dipole to that of the coaxial line by placing an aluminum disk (16 inches in diameter) a quarter of a wavelength in front of the dipole. Later I found that the disk also helped to shield the dipole from off-axis signals and therefore improved the directivity of the antenna.

"The coaxial line is approximately five feet long and is fastened to the paraboloid through an aluminum plate welded to the skeleton. The outer end is terminated in threaded fittings that take a pair of threaded aluminum rods, each a quarter of a wavelength long, which function as the dipole. The outer pipe of the coaxial line extends approximately two feet beyond the dipole and serves as a mounting for the aluminum disk. The inner end of the coaxial line is equipped with a threaded coaxial coupling for attaching the antenna to the receiver through flexible coaxial cable.

"Sky noise from the cable is fed at 436 megacycles to a parametric amplifier [see "Junction-Diode Amplifiers," by Arthur Uhlir, Jr.; SCIENTIFIC AMERICAN, June, 1959] and gains some 20 decibels in power. The signal is then passed to a conventional converter that divides the frequency to 30 megacycles. After additional amplification the signal is converted to pulsating direct current to run a pen recorder. All the apparatus is powered from closely regulated power supplies, as shown in the accompanying diagram [*bottom of page 164*].

"During the initial tests and sightings the paraboloid was mounted on a meridian transit, but as soon as time permits it will be installed on a surplus 36-inch searchlight mount equipped with a motor drive for remote control.

"The parametric amplifier turned out to have substantially more gain than

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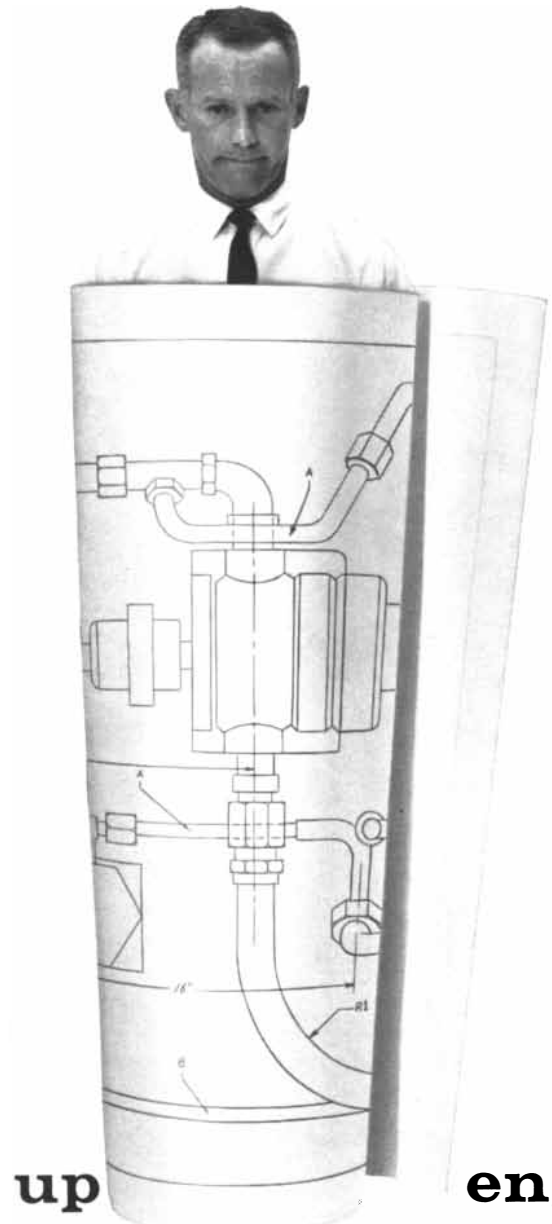

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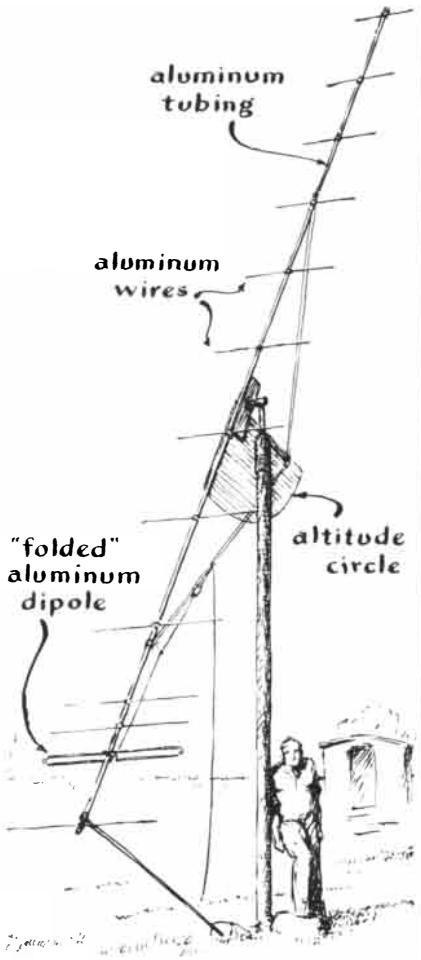
expected, so I was able to use a long section of coaxial cable between it and the converter without introducing excessive noise. The gain was so great, in fact, that I could even install a six-decibel attenuator in the cable to keep the ignition noise of passing cars from driving the converter into overload.

"There has not been time to use the telescope extensively since it has been completed. But test runs prove that its response is satisfactory, considering the comparatively low resolution of the system, as shown by the accompanying graph [*top of page 170*]. One sad incident is worthy of mention because it disclosed that parabolic antennas of sheet aluminum must be painted flat black. While I was observing the sun during the first trial run the 16-inch aluminum disk at the focus of the paraboloid suddenly melted!"

The antenna of the Kansas telescope, according to Houston, Simpson and Mullinix, was constructed primarily for tracking satellites as part of the Moonwatch program during the International Geophysical Year. It consists of a 35-foot spar of pipe that supports a single reflector and a dipole antenna at the back and a series of dipole directors in front. The spar is supported by two braces of pipe and carries an altitude circle [*see illustration at right*]. The directors and reflector are merely straight lengths of aluminum wire ⅛ inch thick. The wires stand up well under the Kansas winds, according to Houston, but birds can bend them. The whole business is mounted on an 18-foot telephone pole so that the reflector just clears the ground when the antenna points to the zenith.

"For a given power gain," Houston writes, "Yagi antennas can be built that are lighter and more compact than any other type and that have less wind resistance. These advantages are bought at the cost of a narrow band width. Yagi antennas can be designed for optimum operation at only one frequency—a real disadvantage when they are used for measuring star noise.

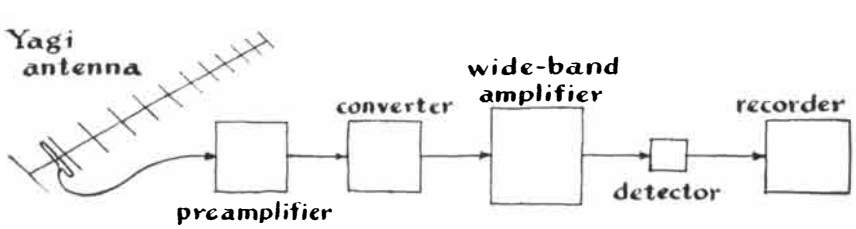
"When in operation, the antenna is fixed at a selected altitude on the meridian for 24 hours and picks up noise in



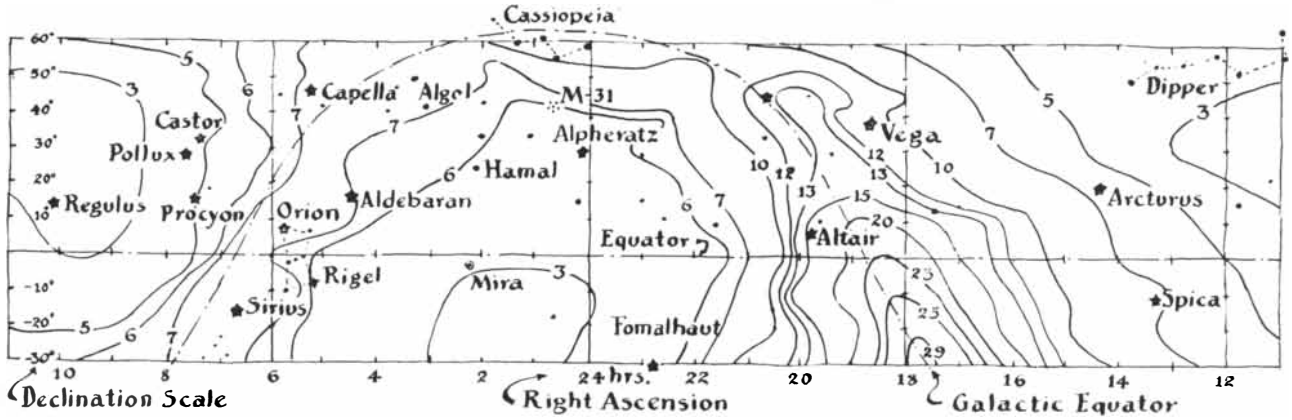
Yagi antenna of the Kansas telescope

varying amounts as the sky drifts past. The sky noise is amplified and converted to pulsating direct current for operating a pen recorder. Normally the antenna is pointed just above the horizon during the first run of a series and then is raised a few degrees higher for each subsequent run until the entire sky has been scanned from the horizon to the zenith. If the recorded traces turn out to be good, corrections are made for instrumental errors and the results are read off and plotted.

"The readings are somewhat fictitious, of course. Just as an optical telescope shows spurious disks around the stars, so do radio telescopes. By running the sun across the antenna we found that the disk of our instrument is about 17 angu-



Block diagram of the Kansas telescope



Map of the radio sky charted from data recorded by Kansas telescope

Contours in Watts x 10^{-24}

3 = 24	10 = 44	20 = 74
5 = 28	10 = 47	25 = 94
6 = 32	13 = 51	29 = 116
7 = 34	15 = 55	

lar degrees in a horizontal direction. We did not measure its vertical width but it should be about the same. 'Radio stars' and other discrete sources of radio signals are below the resolution of the system and are lost in the general background noise.

"Our telescope consists of the antenna, a preamplifier, a frequency converter, a wide-band intermediate amplifier, a detector and a recorder [*see bottom illustration on preceding page*]. The sensitivity of the system is limited by the noise generated in the vacuum tube of the preamplifier. (Disturbances from man-made sources are not serious in our locality.) Of the several tubes that we tested, the Western Electric 416-B generated the least internal noise. We used it in a conventional grounded-grid preamplifier circuit of the type described in *The Radio Amateur's Handbook*.

"To our dismay, however, we found that the 416-B is quite sensitive to changes in temperature, and we could not regulate our room temperature closely enough to overcome the difficulty. So we devised a simple indicator for measuring variations in the tube's performance. The solder-tipped hand of an alarm clock was rigged so that once an hour it closes a contact that actuates a relay. The relay transfers the input of the preamplifier temporarily from the antenna to the terminals of a 72-ohm resistor. The set then measures and records the noise developed in the resistor. The output of the resistor remains relatively constant during slight changes in room temperature. Hence the record of the resistor's amplified signal is a measure of the performance of the 416-B as it changes with temperature, and recordings of sky noise can be adjusted to correct for it. The value of the resistor was selected experimentally so that its amplified noise would be lower than recordings of sky noise.

"The output of the frequency converter is fed directly to the first intermediate amplifier stage of an old television receiver. The band width of a correctly aligned television receiver is about five or six megacycles, whereas that of our Yagi antenna is on the order of two to four megacycles. Reducing the band width of a radio telescope is comparable to filtering the reds and blues from the ends of the optical spectrum: the energy of the signal is reduced, and in the case of radio telescopes the maximum amount of sky noise is wanted. The weak link in our telescope, however, is the narrow band width of the antenna, so the television amplifier is adequate.

"The output of the television amplifier is rectified by a 1N64 diode and, after passing through a resistor and into a capacitor, it is fed to the pen recorder. The time required for the capacitor to charge is about a tenth of a second. This delay tends to smooth the recorded graph because the pen does not respond to current pulses of less than a tenth of a second, such as bursts of lightning.

"Our equipment—most of it salvaged from the scrap box—can only be characterized as crude. It operates on 108 megacycles, far below the 1,421-megacycle hydrogen line that is so widely observed by radio astronomers. But, like most amateurs, we have a fondness for making our initial forays with the help of salvaged junk and in areas that are neglected by the hunters of bigger game.

"We set out to make a radio map of the sky—and we made one that agrees broadly with those compiled by the best radio telescopes, considering differences in frequency and antenna resolution [*see illustration above*]. In plotting the map we made no effort to 'compute away' the influences of discrete radio sources in space. Although these powerful cosmic radiators do not show up as spots on our map, they do tend, like an overexposed star on a photographic plate, to distort our contour lines. This is particularly apparent in the lines that dip to the south from Cassiopeia. Even more striking is the influence of the two radio stars in Cygnus near 40 degrees declination and 20 hours right ascension. Another major difference is the hourglass configuration in Orion. One map made by a large radio telescope at 250 megacycles shows two local areas in Orion, one at the Equator around the 'belt' and one 10 degrees north and somewhat toward the east. The pinch in the hourglass of this map falls at about 10 degrees south declination, whereas ours lies directly on the Equator. This difference worried us, and we made a dozen extra runs in the region of Orion, even making runs in declination by hand. But our results were always the same. We now suspect that the appearance of this region of the sky may be different at 108 megacycles from its appearance at 250 megacycles.

"In spite of the fact that we ran traces at each declination for several days, and in some cases for many days, we never succeeded in recording a full 24-hour run at any one time. The sun was usually evident, and if it wasn't, we did not trust that portion of the curve. To map such regions of the sky we simply had to wait until the sun moved on. On other occasions the electronic equipment went psychopathic and awed us by recording giant forces that never reappeared; now and then thunderstorms ran the pen out of ink. In general we got one good trace out of 10 tries. But it was fun."

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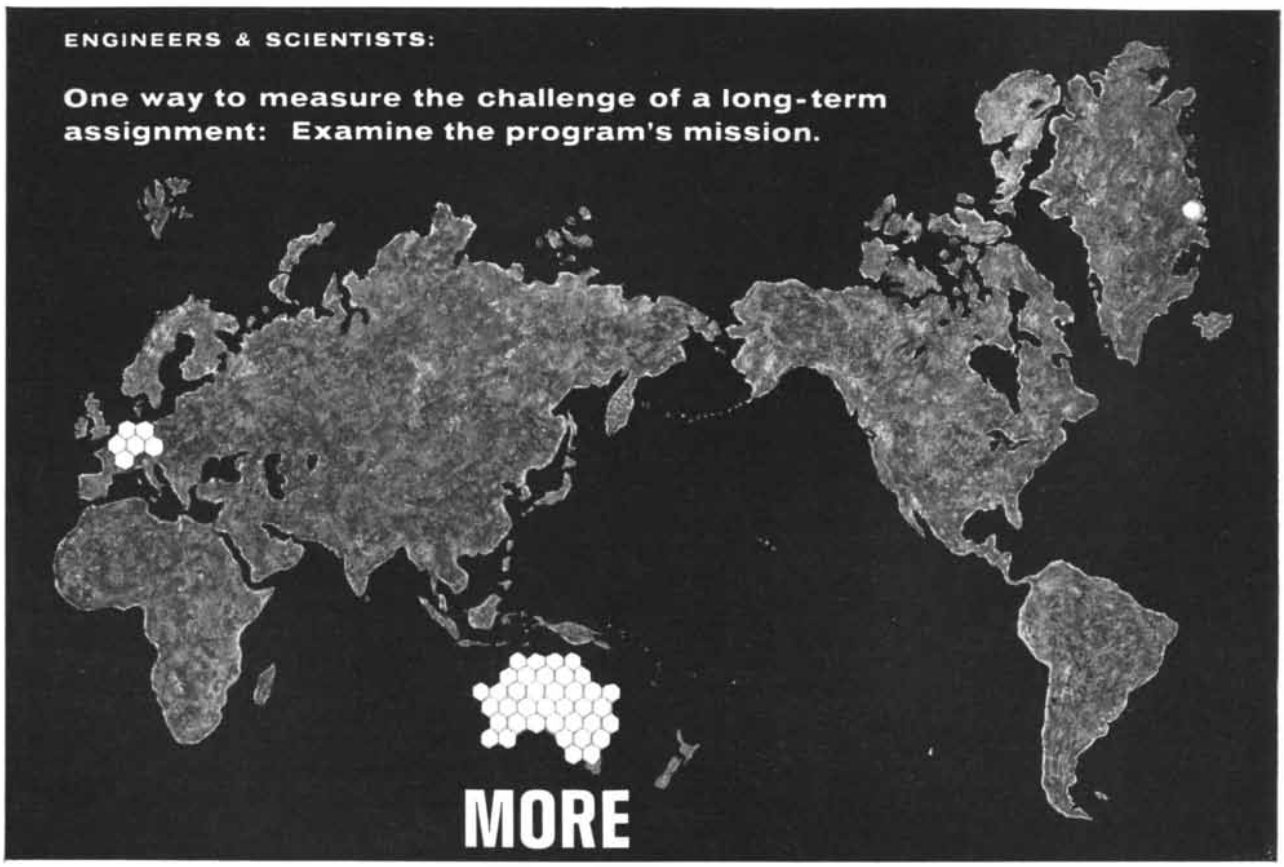

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GENERAL ELECTRIC

BOOKS

Lord Russell and Erich Fromm reflect on the probability of human survival

by James R. Newman

HAS MAN A FUTURE? by Bertrand Russell. Simon and Schuster, Inc. ($3).
MAY MAN PREVAIL? by Erich Fromm. Doubleday & Company, Inc. ($4.50). Anchor Books (95c).

When the patriarch Abraham pleaded with Jehovah to spare the wicked cities of Sodom and Gomorrah, he gained from him a promise that if 10 righteous men could be found in Sodom it would not be destroyed. Ten righteous men could not be found. "Then the Lord rained upon Sodom and upon Gomorrah brimstone and fire from the Lord out of heaven; and He overthrew those cities, and all the plain, and all the inhabitants of the cities, and that which grew upon the ground."

An Abraham interceding for man today would not have a much easier task. Virtuous and kindly men are rare; even rarer are those not afraid to speak out and denounce evil. Here, then, is an occasion for celebration: two books by two upright men, men of wisdom and courage, who know what to do and do it. One is by the world's most distinguished philosopher and jailbird, who for 70 years has benefited mankind by refusing to hold his tongue; the other is by an eminent psychoanalyst and social critic whose writings have been a lamp to sanity and decency.

Bertrand Russell's little book was written only a few months ago. The proofs of it that I saw bore corrections that he, as I understand it, made in prison while serving a term for the grave offense of endangering the safety of Her Majesty's realm by sitting down in Parliament Square. Some 43 years earlier he was incarcerated for engaging in pacifist propaganda. On that occasion the prison sentence was long enough for him to write his famous *Introduction to Mathematical Philosophy*, a work which the warden found perplexing but no clear threat to the security of the state. *Has Man a Future?* is a very different sort of thing. It is a brilliant tract against war, a devastating exposé of folly and as pungent a piece of subversion as has brightened the drab scene of political literature in a long while.

Man has come up from the apes. "Up" means that he differs a little from apes in appearance and has developed many skills. An ape can learn to get a banana with a stick; a man can learn this too. Man, however, has greater capacities. For example, he can write music, grind a lens, aviate, prevent smallpox. He has also learned how to organize unfriendliness on a vast scale and has perfected marvelous techniques of mass homicide. These are much respected and cultivated—so much so, in fact, that man has arrived at a point where he can exterminate the whole of his kind. Will he do it? If the name he gives himself, viz., Homo sapiens, means that he possesses even a modicum of wisdom, he will not. The question remains open whether human history up to the atomic age will be considered prologue or epilogue.

Russell describes the setting in which the question is to be decided. He reviews the story of nuclear weapons; how they came to be made, how they work, what scientists felt about their use against Japan, what generals and others have said of our chances of surviving a nuclear war. On this last point there is obvious disagreement. The exchange of a large number of atomic bombs between the U.S. and the U.S.S.R. may not kill everyone, even in the Northern Hemisphere. Millions may survive and procreate generations of idiots and monsters. Still, this merciful prospect is based on the use only of existing weapons. Since scientific ingenuity is endless, we may confidently expect improvements. Herman Kahn, the publicist of nuclear war, has suggested a "doomsday machine" that could in a moment destroy the whole population of the world; he regards this, however, as undesirable. But not everyone is so forbearing, and Hitler in the last days in his bunker would doubtless have preferred the end of man to the ignominy of surrender. Let the machine be made, let fears, hatreds and international anarchy continue, and the chances are that a group of dedicated lunatics will press the doomsday button. But death has other doors for men to take their exits. Chemical and biological warfare are still in their infancy. Artificial satellites carrying atomic bombs could inflict enormous slaughter. Cobalt bombs—a mere $6 billion worth—would, according to the chemist Linus Pauling, guide every living creature to the grave.

What men think of each other and of themselves, what they can be driven to do by fear, their moral sense, their respect for life, their true values and their clichés—these are of course the factors which will decide the future. Weapons lead no lives of their own. Wars do not simply come. Recently, in a letter to *The Times* of London, Lord Wootton of Abinger answered another baron (Lord Coleraine), who in castigating Russell referred to him as an "aging adolescent." Among other things Wootton referred to a B.B.C. interviewer who used the phrase: "If war comes. . . ." "Wars, Sir," Wootton wrote the editor, "do not come. They are not acts of God; they are not even acts of the devil. They are made by the conscious and deliberate decisions of men; and they cannot be made by one side alone. The time has come for the statesmen of the world to speak realistically; for them to speak not of the risk of war coming but of the possibility that they will themselves choose the wholesale massacre of innocent people and the potential extermination of the human race as lesser evils than any alternative."

Russell is much concerned with certain slogans which are used to manipulate and inflame opinion. Patrick Henry's famous exhortation about liberty or death is a perfect example. For Henry and for his listeners this had meaning. It was an individual decision based on moral conviction. It said: "I will give my life, if need to be, to promote a just cause, to assure liberty to others." It was based on devotion to his fellow men, and it represents one of the noblest ideals which man can achieve. But what can

such a slogan mean when used to justify a nuclear war? The national leader who says that death is preferable to slavery is not merely asserting that he would personally rather perish than submit to tyranny. He is asking others to do so—men, women, children, by the tens of millions. He is saying that whatever the cost, even if it is the end of the human species, freedom must be preserved. Freedom of what? Mount Monadnock? Horseshoe crabs? The gold in Fort Knox? As for the plain man who utters the slogan, what is he saying? "I would rather have my little Sidney and Dolores dead than be ordered about by foreigners"? Or: "If necessary, the people of Luxembourg and Siam must be thrown into the fire to keep the torch of liberty lit"? This is not an individual decision. It is not born of ethical convictions. It is not intended to promote a good. It is a piece of grandiloquent blather. Nothing exposes so clearly the absurdity of the slogan when advanced on behalf of a nuclear war than the crisis over Berlin. For even if we assume that a nuclear war will not eradicate mankind, that it will merely destroy the civilization we know, and lead, after "recovery," to governmental despotisms more severe than any that have yet existed, no one can doubt that the people of Berlin will be vaporized within a few hours after the missiles begin to fly. What assurances, then, are we giving to the inhabitants of this freedom-loving city? Perhaps, for them at least, the slogan should be modified. We rise to say to the leaders of the U.S.S.R.: "Give the people of Berlin liberty or we will give them death." I find it hard to believe the Berliners would embrace us for this ultimatum.

Among sane men as well as lunatics there can be disagreement about anything. Beauty, fish soup, the nature of reality, the writings of Franz Kafka, politics, fallout, afterlife, crime and punishment, bullfighting, virtue, even mathematical truth. But among sane men there can be no disagreement as to nuclear war. It is the worst disaster that could possibly happen. If it is to be averted in the long run, if we are to survive, certain conditions, says Russell, must be achieved. All the major weapons of war and all the other means of mass destruction must be yielded up by individual nations and transferred to a world authority. National armed forces must be reduced to a level no greater than that needed for internal police action. A world government must take over not only those activities which make wars possible between individual states but also positive functions to promote international order, political freedom, economic equality, social cohesion.

Obviously an immense task of re-education would confront the world authority. Consider the prevailing opinions about the importance of national freedom. It is a vague concept, but on that very account it has a powerful emotional appeal, expressed in everything from anthems and odes to dances and monuments. Yet, as Russell points out, those who argue in favor of unrestricted national freedom do not realize that the same reasons would justify unrestricted individual freedom. No one supposes that the laws which make murder illegal are an unreasonable infringement on personal liberty. The state requires such laws to maintain safety and order, to keep its citizens whole, to permit them to go about their business and sleep tranquilly. But there is "immense reluctance" to admit that such a code must apply equally to the relations of national states to each other and to the world at large. Political philosophers have uttered a good deal of nonsense about sovereignty. Even the admirable attempts to create a body of international law and to establish an effective world court have been thwarted by the accepted principle that it is optional with each national state to respect the law or submit to jurisdiction. The prevalent cliché in a democracy such as ours is that when the peoples' representatives vote to have a war, it is right and just and heaven will support it. Clearly no international authority can prevent us from killing foreigners, or foreigners from killing us, so long as we and they possess vast armaments. Equally clearly it will be difficult to persuade states to give up their armaments until people come to recognize that the present "anarchic national freedoms are likely to result in freedom only for corpses"; and to surrender a certain amount of sovereignty, as well as armaments, to an international institution which could prevent war would produce much more freedom in the world than now exists—"just as there is more freedom owing to the prevention of individual murder." Modern weapons have made certain political forms obsolete; and modern weapons are likely to make the human race obsolete if no substitutes for these forms are found.

Much else is illuminated in these pages. The problems of disarmament negotiations, territorial questions which have to be decided if peace is to be achieved, the urgency of taking certain first steps to reduce tensions, the danger inherent in the present policy of instant retaliation, the abandonment of nuclear tests, the prevention of the spread of nuclear weapons to powers which do not yet possess them. Russell's wit, eloquence, passion and human sympathy are as fresh as ever; there is not a dull passage, not a canned thought. I found only one train of argument unconvincing. He defends scientists against the charge that they are morally to blame for the peril to which nuclear weapons expose the world. As evidence he offers, among others, the ill-fated Franck report, the Mainau statement, the Pugwash movement, the exertions on behalf of peace by such men as Linus Pauling. It is plain enough, however, that while many scientists have played an honorable, front-running role in this sphere, many more have devoted their full energies to researches directly or indirectly connected with the improvement of weapons. Not infrequently they have disclaimed social responsibility for the ultimate product of their labors by asserting disingenuously that decisions as to use lay outside their control.

It has been said that wars are made in the minds of men. This has a fine, impressive ring, but it is not a very helpful notion, since everything else that men will to do, and do, is also made in their heads. In so far, however, as the statement implies that man is not fate's cockleshell, that the wars he makes are his responsibility, it is to be encouraged. But there is another side to the matter which deserves more attention than it usually gets. The drive to war is a social disease. It is a psychopathological disorder which afflicts individuals, feeds on itself and spreads to entire groups. Only a lunatic would claim that human happiness can be achieved by inflicting human suffering. Yet, unfortunately, there are strains of lunacy in all of us which can be awakened. It is this dangerous fact which underscores the importance of Erich Fromm's book. For as a man who combines two skills, profound understanding of the development of political thought over the last century and sensitive insight into human motivations, despairs, fears, longings, he is singularly qualified to discuss how we got into this mess and how we can get out of it.

His argument runs along these lines: Societies cling tenaciously to their ways. Men in each society believe that the way in which they exist is natural and inevitable. Change leads to chaos and destruction. Yet in time societies do change. Growth of population, economic needs, political conquests, technological advances force change; so do man's growing self-awareness, his striving for freedom and independence, his ambitions

and hopes for himself and his children. Most social changes have occurred in "violent and catastrophic ways." The cake of custom is hard-baked and hard to break. To adapt is to live; to resist adaptation is to perish; and history is the graveyard of dinosaurs and cultures. There have, however, been nonviolent changes, in which societies have anticipated the need for reform to meet fundamentally new conditions. Today we again face "one of the crucial choices in which the difference between violent versus anticipatory solution may spell the difference between destruction and fertile growth of our civilization." The Western bloc and the Russian bloc confront each other with apparently implacable hatred and suspicion. What Cromwellians thought of papists and Jacobeans of Girondists, Americans think of Communists: they are of the Devil. Ours, we are convinced, is the right way, the only way; theirs means slavery, brutalization, the extinction of freedom and all decencies. Both sides are fully armed and prepared to go to glory. Conciliation is regarded as the coward's part; negotiation is halfway to appeasement, appeasement halfway to surrender. So the armaments increase, bitterness becomes bitterer, and the threat of nuclear war becomes more ominous.

Is there a way out? Admittedly nothing can be settled by a nuclear war. We can no longer afford a Thirty Years' War to achieve a peace of exhaustion. We can no longer afford what is so prettily called a war with "conventional weapons." We cannot afford even a 30-minute exchange of missiles carrying multimegaton loads of atomic explosive.

If, then, no salubrious bloodletting can be permitted, nothing remains but a course of rational anticipatory behavior. To be sure, the chances that this will be adopted are for the moment bleak. Our common enemy, the weapons, stand in the way. So much treasure has been poured into them, so much reliance is placed on their awesomeness that they have become idols. But a much more important obstacle is the thought barrier built on "clichés, ritualistic ideologies, and even a good deal of common craziness that prevents people—leaders and led—from seeing sanely and realistically what the facts are, from separating the facts from the fictions and, as a consequence, from recognizing alternative solutions to violence." The removal of this obstacle requires a critical examination of our assumptions about such matters as the nature of communism, the future of the underdeveloped countries, the value of the deterrent for preventing

war. It also requires a serious analysis of our own biases and of "certain semi-pathological forms of thinking which govern our behavior."

Fromm examines the evolution of the Soviet system from its beginnings. Its revolutionary leaders were, in various degrees, imbued with the ideas and ideals of Marxism. But these ideas, as so often happens in history, soon degenerated into a ritual, an ideology which could serve to bind people together, to rationalize and justify irrational and immoral acts. Indeed, this ideology, supported by terror, has been used by the new bureaucracy to manipulate opinion, to further the very antithesis of the ideas from which the ideology sprang and on which the state continues to lavish its rites and ceremonies. Whatever it may once have been, the U.S.S.R. is now, Fromm argues, a conservative, state-controlled, industrial managerialism and not, as the official ideology asserts, a democratic, classless society. The only large group of people, says Fromm, who take the communist ideology seriously are we in the U.S.; the Russian leaders "have the greatest trouble in shoring it up with nationalism, moral teaching, and increased material satisfactions." The ideals of socialism have been essentially abandoned, as have the hopes for a revolution in the West. The goal was set by Stalin. He liquidated the socialists' revolution in the name of socialism. Cynical, ruthless, insatiably ambitious, he permitted nothing to stand in the way of transforming the U.S.S.R. from a weak, backward, disorganized, have-not nation into one of the two strongest military powers in the world and the strongest industrial power in Europe. It is true that, like Hitler, his methods "corroded the sense of humanity in the rest of the world"; it is also true that, in spite of the setback of a ruinous war, he bequeathed to his heirs a strong economic and political system.

If we are not to become victims of our own clichés and those of the Russians, we must see the adversary plain: a fat cat, concerned mainly with preserving itself and resisting the onslaughts of lean cats. With tremendous territory, with immense resources of raw material and with no need for markets, the U.S.S.R., Fromm argues, has no desire for world domination. What Khrushchev seeks is a preservation of the status quo, which includes the recognition of the western borders of the Soviet sphere of influence (including East Germany). He seeks to prevent West German rearmament. He seeks an understanding with the U.S., an end to the cold war and world disarmament. (It would probably not displease him either if, by some grand mutation, all the Chinese were overnight turned into shrubs.) Fromm is unimpressed with Khrushchev's felicitous boast: "We will bury you." This is an ideological pronouncement, a piece of bogeyman gabble. That the Soviet Union is imperialist Fromm does not doubt; that it is bent on world domination he dismisses emphatically. The conclusion fits neither the facts nor the rational inferences which one can draw from them. It suits Soviet policy to have us stub our toes in Asia and Africa; and the Kremlin is not averse to supplying arms and technical aid under circumstances which will multiply both our headaches and our commitments. But, on the large scale, beyond ringing their country with buffer satellites—as we attempt to ring it with airfields and missile pads—today's Soviet leaders do not aim at world conquest. So capable and disinterested a student as Barbara Ward recently pointed out in *The New York Times* a "most remarkable instance of Soviet restraint," namely Finland. Would world conquerors have left this country outside their orbit? she asks.

We see the Soviet Union, Fromm asserts, through distorting spectacles. We see a "blend between a revolutionary Lenin and an imperialist Czar" and therefore mistake Khrushchev's "rather conventional and limited movements for signs of the 'Communist-imperialist drive for world domination.' " If we could remove these spectacles we would see that the way is open for an accommodation between the two blocs. It is not an accommodation that entails surrender; nor does it imply that we must come to embrace their ways or they ours. It requires adaptation and change; it requires giving up the picture of a world divided between God and the Devil, between the Goods and the Bads. It is hard to give up cherished convictions. But if life is better than death and our convictions shape our fate, it would be well to make sure that what we believe makes sense. A man who offers to walk across the gorge of Niagara Falls on a tightrope to prove something should at least make sure that what he seeks to prove is provable.

There is another side to Fromm's book which deserves comment. It has to do with paranoid thinking and is closely connected with the possibility of re-examining calmly our convictions about the Soviet menace. Just as there is a *folie à deux*, there is an insanity of millions. The Children's Crusade, the extreme psychological reactions to the Black Death, witch-hunting during the

Counter Reformation, the hatred of the Huns during World War I are typical examples.

Paranoid thinking is a bad business. The man who says that everyone is out to get him, that his friends, colleagues, even his wife are conspiring to murder him is very likely insane. Of course it is *possible* that his fears are well founded. It is still unlikely; as unlikely as finding a Chesterfield cigarette in a newly opened package of Camels. The victim, however, is hard to persuade by reasoned arguments. For him possibility rather than probability is the guide of life. This is the essence of his illness. His contact with reality is thin and brittle. He is able to demonstrate with virtuosity that what *might* happen *will* happen. "Reality, for him, is mainly what exists within himself, his own emotions, fears, and desires."

Such an unfortunate is easily recognized. But when masses of people adopt paranoid thinking, it is another matter. Most Americans, Fromm says, think about Russia in a paranoid fashion. They ask what is *possible* rather than what is *probable*. Surely it is possible that Khrushchev wants to conquer us, to bury us, just as it is possible that when I have indigestion it is because my wife and children have been taking turns putting arsenic in my stew. But to ask what they hope to gain by this roundelay, as to ask what Khrushchev hopes to gain by flattening our cities and incinerating our people, is a disturbing question that no paranoid wants to hear.

Another pathological mechanism is projection. One accuses the person one hates and fears of having toward oneself the very designs one has on him. There is no better outlet for one's own hostilities than to pretend that they belong to the person they are directed against. Again, this is readily perceived in individual cases, but not when the same projective mechanism is shared by millions and supported by their leaders. Thus "the enemy"—whatever vague, faceless mass this may be—becomes the embodiment of all the horrors we ourselves wish upon it. The Soviet Union and Communist China are the enemy to whom our projective thinking is directed; yet somehow we find their terror more terrible, their inhumanity more inhumane, their cruelty crueller than that of a Trujillo, a Batista or even a Hitler. This is not to say that Stalin was a kindly man, only that lovers of freedom are not always consistent.

Fromm points to still another type of pathology that plays a great role in political thought—that of fanaticism. The

fanatic's pathology resembles that of a depressed person who suffers from numbness rather than sadness. He is incapable of feeling anything. The fanatic builds for himself an idol, "an absolute, to which he surrenders completely but of which he also makes himself a part." This gives him an illusion of feeling. History, both ancient and modern, offers many examples of the passionate, grandiose, fanatical leader who was able to hypnotize masses of people, to persuade them to follow any course, however mad or cruel or self-destructive. The fanatic is particularly effective if the content of his idol is "love," "brotherliness," "God," "salvation," "race," "honor" and so on, rather than frank destructiveness or hostility. He is so seductive, and hence so dangerous politically, "because he *seems* to feel so intensely and to be so convinced. Since we all long for certainty and passionate experience, is it surprising that the fanatic succeeds in attracting so many with his counterfeit faith and feelings?"

Pathological thinking in all its forms is unquestionably the single greatest threat to peace. When, with the aid of modern methods of mass communication, it is deliberately and systematically provoked, entire nations can be made to behave insanely, to embrace folly as wisdom, to exalt death over life. Technically this is the atomic age; emotionally it is in many respects the Stone Age. We look down on the Aztecs who on a feast day sacrificed 20,000 men to their gods so as to keep the universe in its proper course. Yet we sacrifice millions of men in wars and entertain the possibility of extinguishing the human race for causes *we* think are noble. The facts are the same, "only the rationalizations are different."

Has man a future? Perhaps. It is up to him. Does he deserve to prevail? Would it not be better if the hatred and fear and suffering and cruelty which constitute such a large part of the record of history were to come to a final end, leaving the planet "peaceful at last, sleeping quietly"? It is to an old and a wise man that one turns for the answer of youth and hope and courage.

"When," Lord Russell writes, "as in the Egyptian Book of the Dead, the possibly last man comes before the Judge of the Underworld, and pleads that the extinction of his species is a matter for regret, what arguments will he be able to offer?

"If I were the pleader to Osiris for the continuation of the human race, I should say: 'O just and inexorable judge, the indictment of my species is all too well deserved, and never more so than in the present day. But we are not all guilty, and few of us are without better potentialities than those that our circumstances have developed. Do not forget that we have but lately emerged from a morass of ancient ignorance and agelong struggle for existence. Most of what we know we have discovered during the last twelve generations. Intoxicated by our new power over nature, many of us have been misled into the pursuit of power over other human beings. This is an *ignis fatuus*, enticing us to return to the morass from which we have been partially escaping. But this wayward folly has not absorbed all our energies. What we have come to know about the world in which we live, about nebulae and atoms, the great and the small, is more than would have seemed possible before our own day. You may retort that knowledge is not good except in the hands of those who have enough wisdom to use it well. But this wisdom also exists, though as yet sporadically and without the power to control events. Sages and prophets have preached the folly of strife, and if we listen to them we shall emerge into new happiness.

" 'It is not only what to avoid that great men have shown us. They have shown us also that it is within human power to create a world of shining beauty and transcendent glory. Consider the poets, the composers, the painters, the men whose inward vision has been shown to the world in edifices of majestic splendor. All this country of the imagination might be ours. And human relations, also, could have the beauty of lyric poetry. At moments, in the love of man and woman, something of this possibility is experienced by many. But there is no reason why it should be confined within narrow boundaries; it could, as in the Choral Symphony, embrace the whole world. These are things which lie within human power, and which, given time, future ages may achieve. For such reasons, Lord Osiris, we beseech Thee to grant us a respite, and a chance to emerge from ancient folly into a world of light and love and loveliness.' "

Short Reviews

ASSAULT ON THE UNKNOWN, by Walter Sullivan. McGraw-Hill Book Company, Inc. ($7.95). IGY: THE YEAR OF THE NEW MOONS, by J. Tuzo Wilson. Alfred A. Knopf ($5.95). For 18 months, from the middle of 1957 to the end of 1958, the world studied itself and its environment in space. Thousands of seismologists, geologists, glaciologists, phys-

icists, meteorologists, astronomers and other experts made observations in concert that changed man's view of his planet and will change it more by the time the millions of bits of data have all been analyzed and finally synthesized into published reports. The International Geophysical Year was above all an amazingly successful experiment in worldwide co-operation. And it somehow institutionalized and crystallized the promise of scientific investigation, the large role of science in international affairs and the interdependence of many disciplines and many nations. The significance of these nontechnical aspects is an underlying assumption of these two very different reports on the IGY. Walter Sullivan of *The New York Times*, who covered the IGY full time, has written an authoritative, comprehensive summary of the findings in each of the major IGY fields. Thorough research, carefully annotated, makes his report a valuable guide to the technical literature of the IGY; historical reviews of previous investigations and personal observations give it depth and color. The over-all impression is one of vast sweep and almost encyclopedic detail (we are even given the name and address of the manufacturer of the prefabricated huts used by Soviet explorers in the Antarctic). Sullivan is particularly good on the public-policy aspects of his story; some of his best chapters recount the organizational history of the IGY, the problems of the U.S. satellite program and the science-v.-security conflicts of Project Argus, the world-encircling U.S. experiment involving nuclear explosions in space. Sullivan's is a sober if intrinsically exciting history of the IGY, enriched by the author's acquaintance with many of the men and places he writes about. J. Tuzo Wilson is a geophysicist rather than a journalist, but his book is the more journalistic of the two. In form it is a report on Wilson's far-ranging travels as president of the International Union of Geodesy and Geophysics during the IGY, with scientific background and IGY findings introduced at appropriate points along the way. Wilson is a fluent writer whose descriptive passages put most "travel writers" to shame, and he has a nice way with difficult technical concepts. His book is a pleasant introduction to the study of the earth and the star that nourishes and buffets it, and is informed with a warm concern for humanity and the inquiring mind.

CURRENT TRENDS IN SCIENTIFIC RESEARCH, by Pierre Auger. UNESCO ($5). This book, prepared under a 1958 resolution of the General Assembly

of the United Nations and based on information made available by hundreds of individual scientists, by national and international research organizations and by member governments, is in at least two respects a most impressive achievement. Even though many persons and groups were helpful to the author, it is a tour de force for a single individual to have prepared a competent survey of the main trends of inquiry in the natural sciences, the dissemination of scientific knowledge and the application of such knowledge to peaceful ends. It is also a warming experience for the reader to have spread before him the varied, abundant evidence of what so many people in so many lands are doing to increase our knowledge of the world, of the stars and light and earth, of the abstract relations of higher mathematics, of biological processes, of man's physical and mental ills, of food production and agricultural methods, of the uses of energy, of manufactures and technology, of building and transportation and communication. Nothing in these pages smells of death or destruction; everything has to do with enlarging our understanding of nature and thought, with reducing suffering and privation, with making men healthier and happier through intelligent use of the earth's abundance. To go through this book and see how many good things men are doing, and how much they may yet do, is an antidote to despair and makes it seem all but incredible that so much virtue and excellence could be destroyed by passion and folly.

FROM DUALISM TO UNITY IN QUANTUM PHYSICS, by Alfred Landé. Cambridge University Press ($3.75). The author of this book has for years been an acute critic of the widely accepted principles of wave-particle duality, complementarity and uncertainty. They have affected him as they affected Einstein, like a pebble in the intellectual shoe. In this essay, which is both philosophy and physics, he suggests how the pebble could be removed; how, for example, the wavelike behavior of particles could be treated not as an anomaly which simply has to be accepted but as an understandable phenomenon which is to be expected under postulates of symmetry, invariance, continuity and the like. "I think," he says, "that even in quantum theory one can return from the dialectical positivism of opposing pictures to plain ontological materialism which from Galileo to Einstein has been the ideological background of natural science." The more one examines the controversy over the foundations of physics, the clearer it becomes that the basic choices, each of which leads to different conclusions and interpretations, are more matters of aesthetics than of physics or logic. Landé's essay will therefore appeal to some theoreticians and repel others, but there is as little hope of proving him wrong, philosophically speaking, as of proving the Bohr-Heisenberg aesthetics right.

APOLLONIUS OF PERGA: TREATISE ON CONIC SECTIONS, edited by T. L. Heath. Barnes and Noble, Inc. ($9). A reissue of an important contribution to the history of mathematics, first published in 1896 and long out of print. Earlier editions of Apollonius' famous *Treatise on Conic Sections*, written some 22 centuries ago and mostly preserved (partly in Greek, partly in Arabic translations), presented the reader with various difficulties, not the least of which were the bulk of the treatise and the enunciation of the propositions in words (as Euclid gave his). Sir Thomas Heath, a distinguished scholar of Greek mathematics, worked over the "Conics" and put it into modern notation without in any way tampering with Apollonius' text. His labors made it possible for the student to see the scheme followed by the author as a whole and to appreciate how much he added to the science of geometry.

BIRDS OF THE CARIBBEAN, by Robert Porter Allen. The Viking Press, Inc. ($15). A description in text and color photographs of more than a hundred of the birds which make their permanent home or winter residence on the islands and in the countries of the Caribbean. To details about characteristics, habits and ranges the author adds information on the history of the Caribbean area, its geography, conservation of wildlife, records and accounts left by early ornithological expeditions. Some of the pictures are spectacular.

THE PYRAMIDS, by Ahmed Fakhry. The University of Chicago Press ($5.95). A historical account by a leading Egyptologist of the sequence of the pyramids, from the step pyramid at Saqqara, built about 2780 B.C., through the grand forms such as the great Pyramid of Cheops at Giza to the final decline of this species of funerary ostentation. It is the pyramid of Giza that one usually thinks of when these structures are mentioned, but there are many others on the plateau west of Cairo and still others as far south as the Sudan. Altogether more than 70 pyramids are known, and more

are thought to be still buried under the sands. Fakhry describes the principal pyramids in detail, giving archaeological, historical, engineering, architectural and mathematical details.

COMPUTERS AND COMMON SENSE, by Mortimer Taube. Columbia University Press ($3.75). The author of this book, a specialist in the field of mechanized data processing and information retrieval, has here set out to bite the hand that feeds him. The subtitle, "The Myth of Thinking Machines," expresses his general position. He is concerned with the practical limitations of computers, with the prevailing tendency to exaggerate their capabilities, with the overblown notion that there are now in existence machines that can be said to think. (Not even the knowledge needed to design such machines, says Taube, is available.) In particular he scoffs at the claims that there are useful translating machines in operation, that there are machines which can learn as a human being learns and machines which can make intelligent decisions. He makes the point that the enormous sums of money which Government departments, business and industrial enterprises and foundations spend for the development of such machines is no proof of their usefulness. Taube is an angry man, and he has allowed his anger to carry him to excesses and to various irrelevant and silly observations on progressive education, psychoanalysis and so on; nonetheless his book is a refreshing counteragent to the huffing and puffing about the marvels of computers.

ANTISLAVERY: THE CRUSADE FOR FREEDOM IN AMERICA, by Dwight L. Dumond. The University of Michigan Press ($20). This scholarly and learned work, the product of 30 years of research by an American historian, tells the story of slavery in America and the courageous men who fought it before the Civil War. It is a tale so nakedly shameful that one can barely stay with it, and yet it is so fascinating—and in the portions that deal with the abolitionists, so inspiriting—that one cannot leave off before the end. The author has dug out all the relevant material and presents it with great force. One cannot understand the past of the U.S. or the problems of integration that still remain if one does not appreciate the story Dumond tells.

THE ENCYCLOPEDIA OF THE BIOLOGICAL SCIENCES, edited by Peter Gray. Reinhold Publishing Corp. ($20). More than 800 articles, from abiogenesis to

zoogeography, dealing with the developmental, ecological, functional, genetic, structural and taxonomic aspects of the biological sciences. Topics are treated at greater than dictionary length, few of the articles having less than 500 words, and many leading specialists have been enlisted as contributors. Primarily designed as a compact reference source for biologists, the volume will also prove useful to teachers, students and nonprofessionals. Many illustrations; bibliographies.

Notes

THE NATURE OF THERMODYNAMICS, by P. W. Bridgman. Harper Torchbooks ($1.40). A soft-cover reissue of Percy Bridgman's well-known little book on thermodynamics.

THE ECONOMIC BLOCKADE, VOL. II, by W. N. Medlicott. Her Majesty's Stationery Office ($9). The second and concluding volume of a comprehensive history of the economic blockade of the Axis in World War II. The two main phases covered are from the time of the German attack on Russia to that of the Allied landings in North Africa and from then until the end of the war in the summer of 1945.

THE GREEK HISTORIANS, selected and edited by M. I. Finley. The Viking Press, Inc. ($1.65). A paper-backed edition of Finley's volume in the Viking Portable Library, presenting excerpts from Herodotus, Thucydides, Xenophon and Polybius.

PLANT MARVELS IN MINIATURE, by C. Postma. The John Day Company, Inc. ($12.50). A collection of photographs of many parts of plants. Magnifications up to 3,000 diameters afford remarkable views of the intricate and beautiful structure of forms ranging from the pollen grain of a lily to the endodermal cells of an iris root.

FUNCTIONS OF THE BLOOD, edited by R. G. Macfarlane and A. H. T. Robb-Smith. Academic Press Inc. ($16.80). A co-operative volume, the chapters of which treat various aspects of the biology of the blood and its cellular and noncellular components. Illustrations.

MATHEMATICAL MODELS, by H. Martyn Cundy and A. P. Rollett. Oxford University Press ($6.50). The second edition of an engaging book that gives detailed instructions for making models which illustrate figures and concepts of plane and solid geometry, mechanics, statistics, logic and computing. Excellent illustrations.

THE INTERPRETATION OF DREAMS, by Sigmund Freud. Science Editions, Inc. ($1.95). A paperback of James Strachey's admirable English translation of Freud's masterpiece.

HANDBOOK OF AUTOMATION, COMPUTATION, AND CONTROL, VOL. III, edited by Eugene M. Grabbe, Simon Ramo and Dean E. Wooldridge. John Wiley & Sons, Inc. ($19.75). The third volume of this co-operative handbook, which completes the work, is concerned with systems engineering, techniques used in industrial applications, the design and selection of components, and related topics.

EVOLUTION OF THE VERTEBRATES, by Edwin H. Colbert. Science Editions, Inc. ($2.45). A paper-backed reissue of an excellent history of the backboned animals by an eminent vertebrate paleontologist. Many illustrations.

ON THE SENSATIONS OF TONE, by Hermann L. F. Helmholtz. Dover Publications, Inc. ($2.95). A paper-backed reissue of one of the great works of science. Although this book was first published a century ago and no changes have been made in it since the German edition of 1877 (on which the English translation is based), it is still, as Henry Margenau points out in his introduction, required reading for anyone who wishes to prepare himself for work in physiological acoustics.

TRIUMPH, by Hy Steirman and Glenn D. Rittler. Harper & Brothers ($4.50). The story of the first transatlantic flight, made by the Navy seaplane *NC-4* from Rockaway Beach, N.Y., to Lisbon between May 8 and May 27, 1919. Photographs.

RIVAL THEORIES OF COSMOLOGY, by H. Bondi, W. B. Bonnor, R. A. Lyttleton and G. J. Whitrow. Oxford University Press ($2.25). A tidy, readable symposium of current theories of the structure of the universe, based on popular talks given in 1959 on the B.B.C.

SCIENCE AWAKENING, by B. L. van der Waerden. Oxford University Press ($7.50). The first edition of this lucid and exceptionally attractive history of Egyptian, Babylonian and Greek mathematics was reviewed in these columns in 1955. The book now appears in a second edition issued by a U.S. publisher, with corrections and additional material.

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

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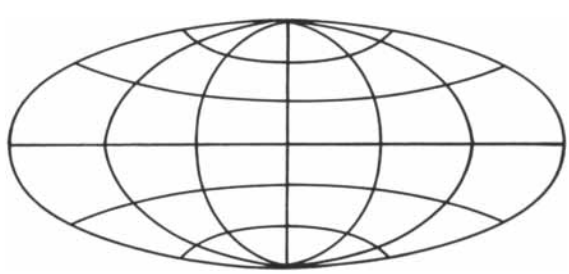

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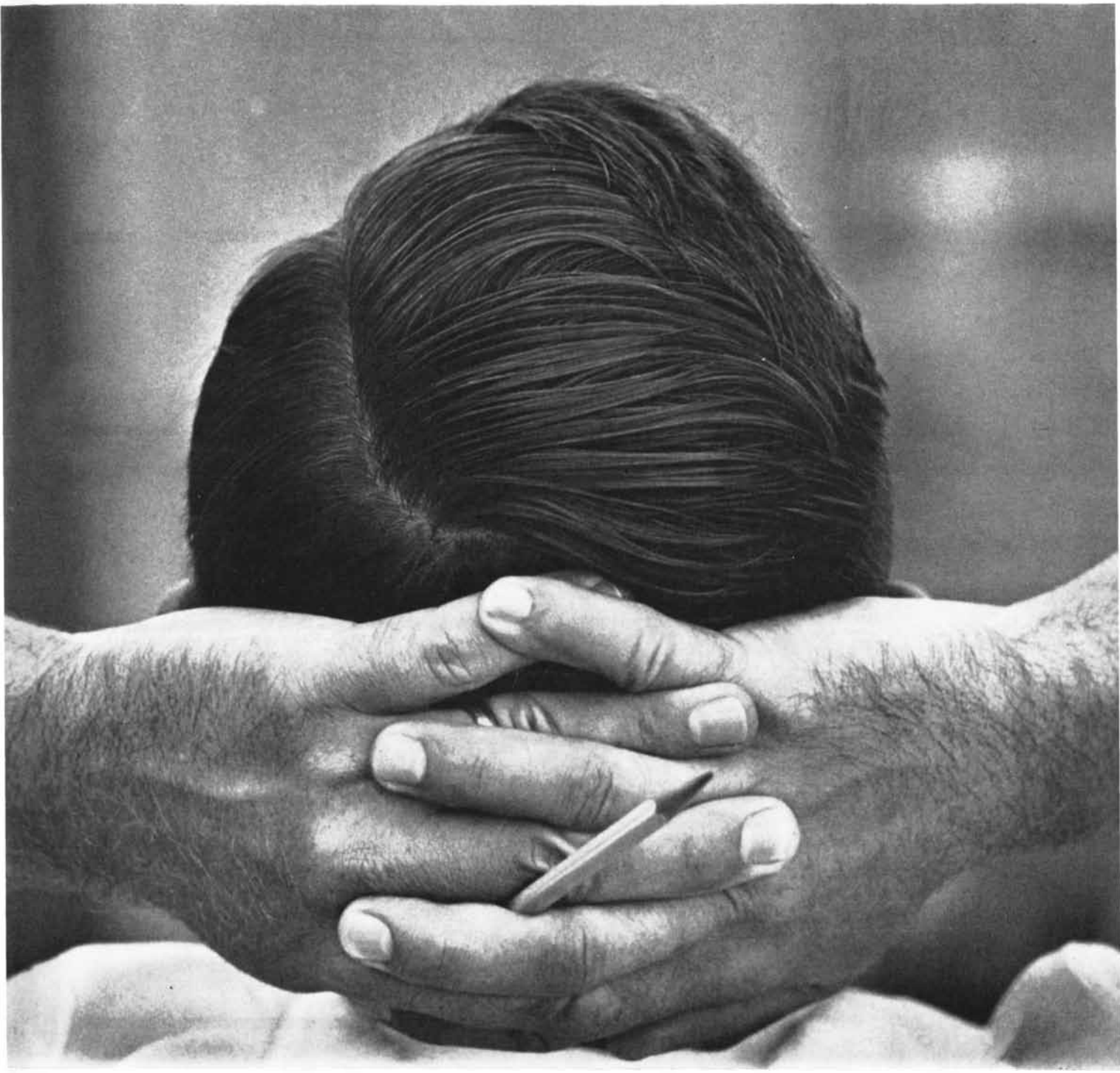

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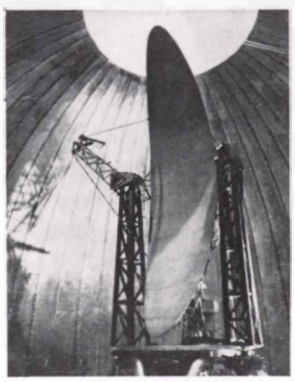

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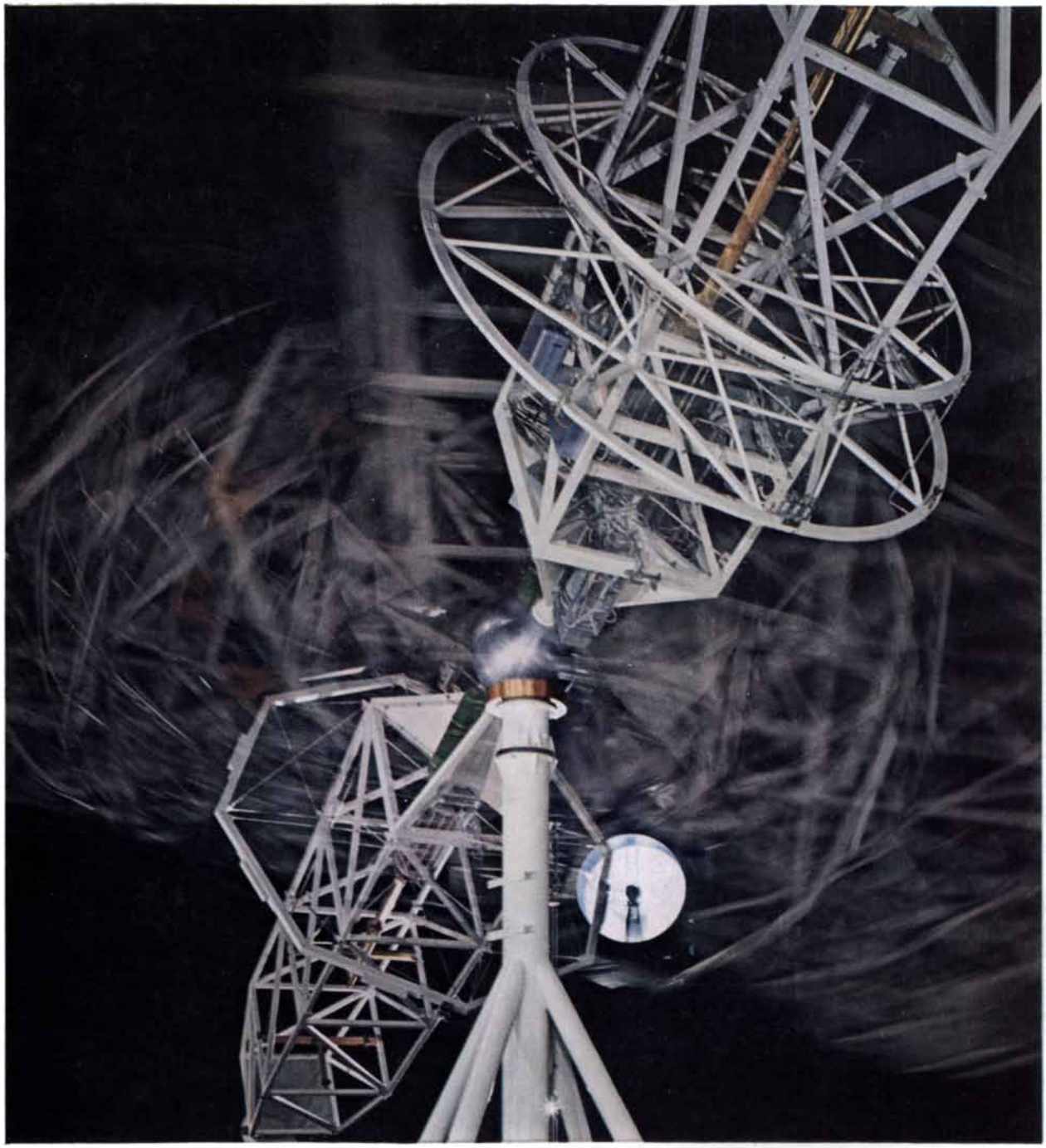

TO SIMULATE CENTAUR'S FLIGHT THROUGH SPACE THIS 6000-POUND DEVICE BALANCES ON A NITROGEN BEARING ... A large simulator at General Dynamics|Astronautics has been built to reproduce space conditions and the dynamic traits of the self-navigating NASA Centaur vehicle in flight. The center of gravity of the 52-foot, 6000-pound simulator lies within a half-ton steel bearing afloat upon a stream of pressurized nitrogen— so balanced that a coin placed on either end will move the simulator. The result is a remarkably accurate simulation of space conditions, with very little friction or gravitational torque. The simulator can move through 360 degrees of pitch, yaw, and roll, at a maximum speed of one degree per second. Placed 40 feet behind the simulator, a searchlight acts as the sun. Its heat is sensed by the Centaur sun tracker, which signals the autopilot to activate trim motors controlling the simulator's attitude — thus forecasting on earth events which will occur outside the atmosphere in actual Centaur flight. This simulator for NASA's Centaur, the free world's first high-energy space vehicle, was developed in the laboratories of General Dynamics|Astronautics, San Diego, California. *Scientific excellence ... with a sense of mission.*

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