SCIENTIFIC AMERICAN

FIBER OPTICS

FIFTY CENTS

November 1960

The day they threw orchids away!

So great was the need for rubber in 1876 that when 70,000 wild rubber tree seeds arrived from Brazil, the Royal hothouses of London were quickly emptied—orchids and all—to make room for raising the young plants that led to the first rubber plantation.

Now, the chemical laboratory is the "hothouse" for a new kind of rubber. In performance and chemical structure, new Shell Isoprene Rubber is so nearly identical to natural rubber that manufacturers can assign it to jobs once restricted to tree-born rubber. Shell Chemical's new product is even used in heavy-duty truck tires—most punishing assignment of all—where no previous man-made rubber made the grade!

Adding polyisoprene to the nation's rubber supply is another important way Shell Chemical stretches our vital resources.

SHELL

Shell Chemical Company

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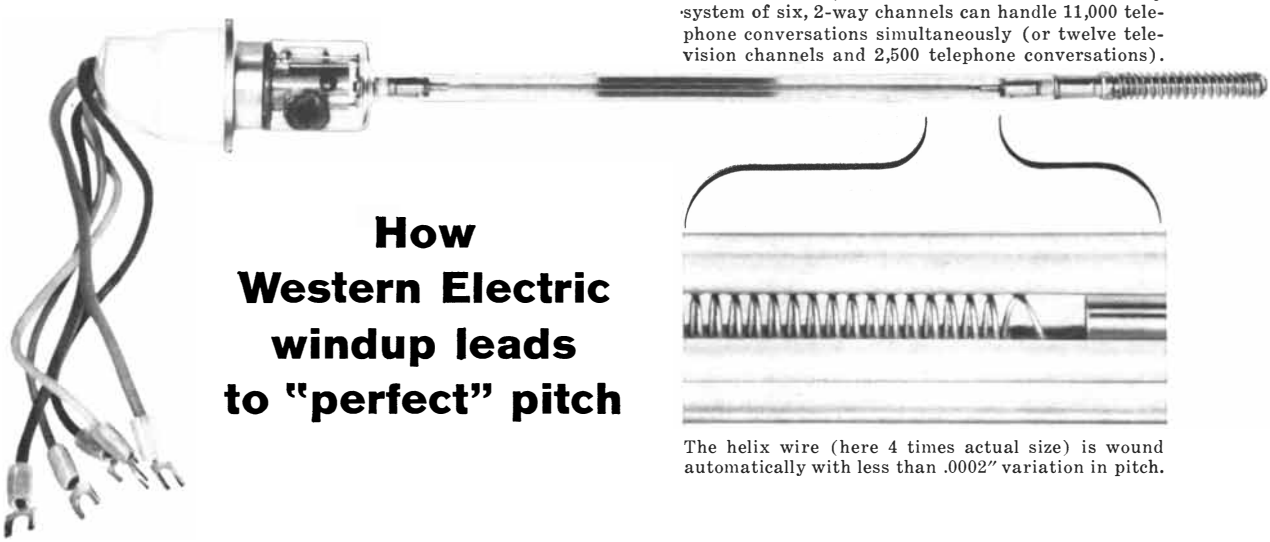


This traveling-wave tube, developed by Bell Telephone Laboratories, is a major advance in microwave transmission. With it, the "TH" Microwave Radio Relay system of six, 2-way channels can handle 11,000 telephone conversations simultaneously (or twelve television channels and 2,500 telephone conversations).

How Western Electric windup leads to "perfect" pitch

The helix wire (here 4 times actual size) is wound automatically with less than .0002″ variation in pitch.

Operating today in the Bell System is the strange-looking microwave amplifier you see at the top of the page: the traveling-wave electron tube. It is extremely important to the System, because it can carry many more simultaneous telephone conversations than other types of tubes. It's an unusual tube . . . and Western Electric engineers solved an unusual problem to manufacture it successfully.

An extremely precise coil of wire — a helix — is the tube's heart. As the microwave signal "travels" down the coil, its strength is increased thousands of times as energy is transferred to it from an electron beam aimed down the center of the coil. Variations in a coil's turn-to-turn spacing, or less than "perfect" pitch, would cause serious signal distortion.

To solve the problem of producing high-quality traveling-wave tubes at reasonable cost and in quantity, Western Electric engineers developed and built a machine capable of winding 2,000 turns of wire in helices up to twelve inches long, or as many as 500 turns per inch in shorter lengths. *And the wire is wound with less than .0002″ variation in pitch.* And, even these minute deviations do not repeat regularly!

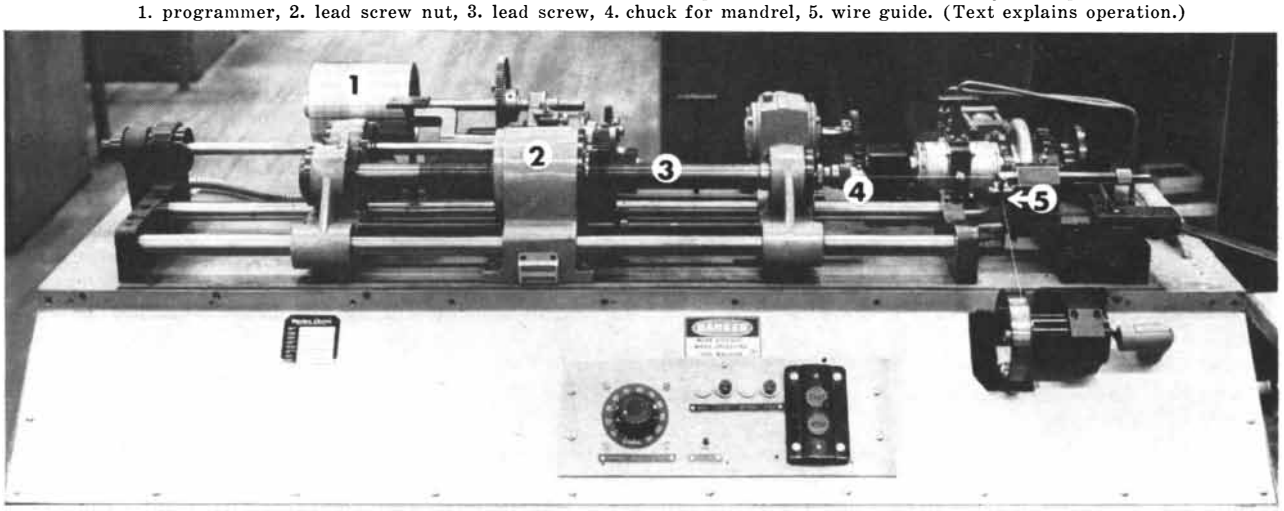
The machine is shown in the photograph below. A "mandrel" or rod on which the wire is wound is drawn at a uniform rate past a diamond wire guide. The number of turns is controlled by a programmer that also accurately changes the pitch of the winding at any position as determined by an exact turn count. The remarkable precision achieved is made possible primarily by "extreme precision" ball bearings and a perfectly mated lead screw and nut. The mandrel is mounted in a chuck attached to the lead screw.

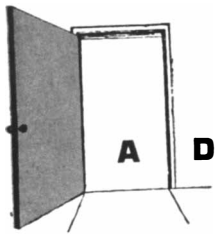
By developing and building this machine, Western Electric engineers met a tough manufacturing challenge and made top-quality traveling-wave tube production for the Bell System economically feasible. The achievement is significant because traveling-wave tubes are increasing tremendously not only the capabilities of long distance telephony, but also are performing superbly in command guidance systems developed by Bell Telephone Laboratories for Nike Hercules anti-aircraft missiles.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM

W.E.-designed Helix Winding Machine (shown here with protective hood removed). Major components are: 1. programmer, 2. lead screw nut, 3. lead screw, 4. chuck for mandrel, 5. wire guide. (Text explains operation.)





A DOOR IS OPENED...
TO NEW DEVELOPMENTS IN DIISOCYANATES

"Modern chemistry has made few discoveries of greater significance than polymerization. Few polymer formers have greater versatility, actual or potential, than diisocyanates."

This quotation is from a new free booklet prepared by our National Aniline Division. Entitled "Diisocyanates," it describes the origins and development of these polymer formers which are being used to achieve that revolutionary new plastics family, polyurethanes.

Polymeric building blocks

The booklet begins with a discussion of polymers in nature, from which chemists took their cue to devise their own building blocks. One of the most intriguing building blocks for forming large polymer molecules is the class of organic chemicals called diisocyanates. With them it is possible to duplicate the properties of almost all known types of plastics.

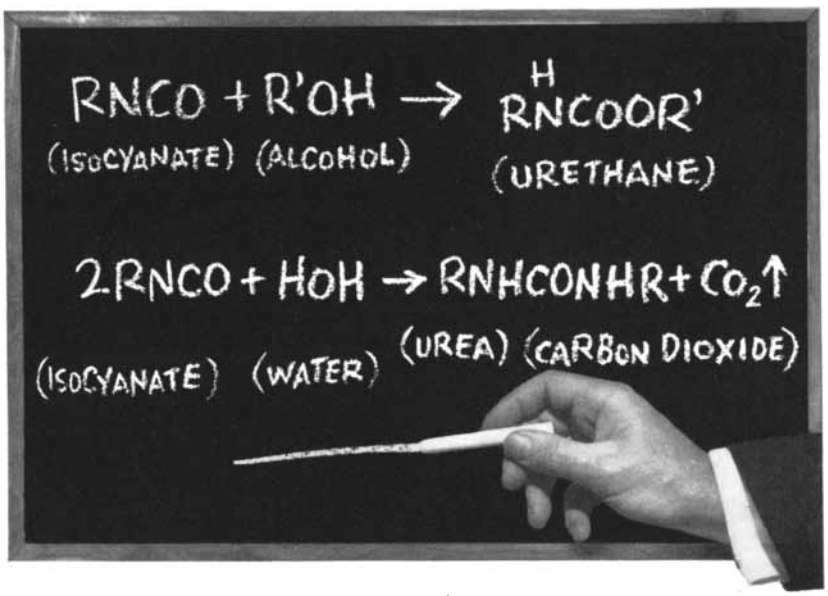
In order to help the reader appreciate the diverse materials that can be formed with diisocyanates, the booklet includes a brief history of their origins, followed by an outline of present day chemistry in the field.

Polyurethane foams

From there, the booklet takes us into a discussion of the most interesting and important polyurethanes (polymers based on diisocyanates)—the foams. It tells why and how these materials foam and describes the tremendous variations that are possible. Polyurethane foams range from one to 60 pounds per cubic foot in weight. They can be made rigid enough to support heavy loads or flexible enough to serve as mattresses and coat linings.

Flexible foams

Flexible foams may be produced which have little "bounce-back" and high shock absorbency. These are well adapted to such uses as automobile crash pads, where they minimize the danger of "snapback" injuries, inherent in pads with little absorbency, more bounce. Other flexible foam applications include pillows, furniture cushioning, vermin- and rot-proof carpet underlays, floor mops, clothes brushes, and warm yet lightweight linings for winter clothing.



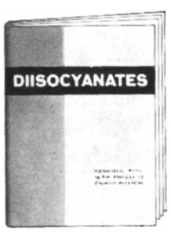
Key equations of urethane chemistry show the simultaneous reactions of isocyanates with alcohol and with water. The reaction produces a solid product and carbon dioxide, which "blows" the foam material. From "Diisocyanates," a free booklet just off the press.

Rigid foams

You'll read how polyurethanes can be cross-linked to form semi-rigid and rigid foams as well. The former of these can be sprayed onto walls as acoustical insulation or foamed in place in wall cavities where insulation is wanted. Rigid foams find application as harbor buoys, buoyancy chambers for boats, and as filling for aircraft wing tips. You may be surprised to learn that prefabricated sandwich wall panels for homes are now under test and that foamed-in-place polyurethane resins have been used for the setting of bones.

Other polyurethane products

The booklet describes the other forms of polyurethanes as well; for with more cross-links, polyurethanes become plastics that do not warp or swell and have high impact strength. Polyurethane rubbers for example: soles and heels that outlast conventional shoe materials 10 to 1... hundred-thousand-mile tire treads that promise to be a commercial reality soon.



Anyone interested in the general subject of diisocyanate chemistry, or who is working with polyurethane materials, will find the booklet, "Diisocyanates," valuable. *For a free copy,* just write, on company letterhead, to Allied Chemical Corporation, Dept. 116-S, 61 Broadway, New York 6, New York, or phone HAnover 2-7300.

Allied Chemical

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Established 1845 **SCIENTIFIC AMERICAN** November, 1960 Volume 203 Number 5

ARTICLES

DEPARTMENTS

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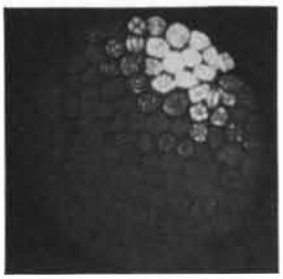

THE COVER

The photomicrograph on the cover shows the end of a bundle of very fine glass fibers that is used as a "light pipe" (*see page 72*). Each fiber is only two microns (.002 millimeter) in diameter. The patterns in the fibers surrounding the two bright fibers at upper left are caused by the coupling and interference of the light waves as they travel down the fibers.

THE ILLUSTRATIONS

Cover photograph by Narinder S. Kapany, Armour Research Foundation of the Illinois Institute of Technology

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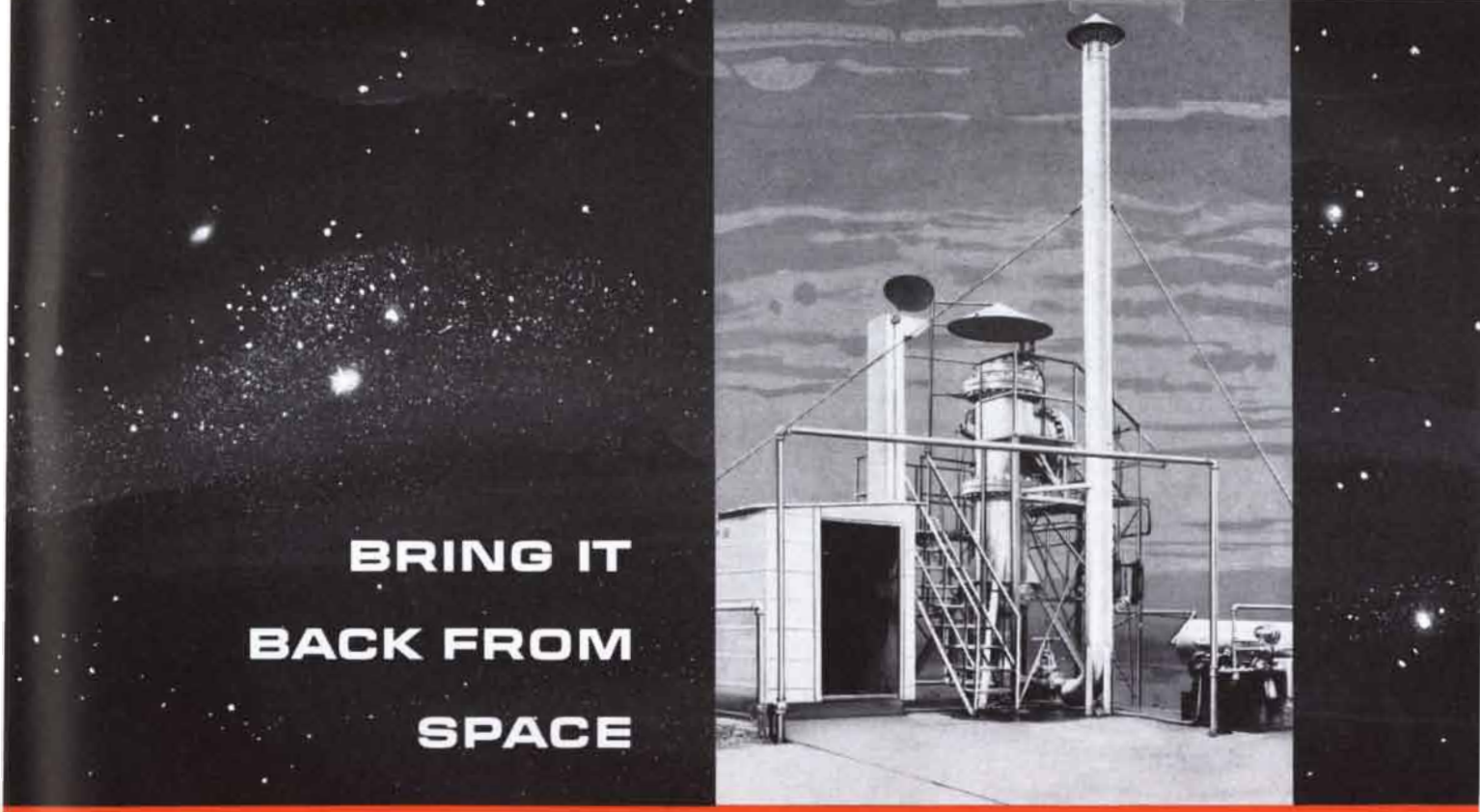

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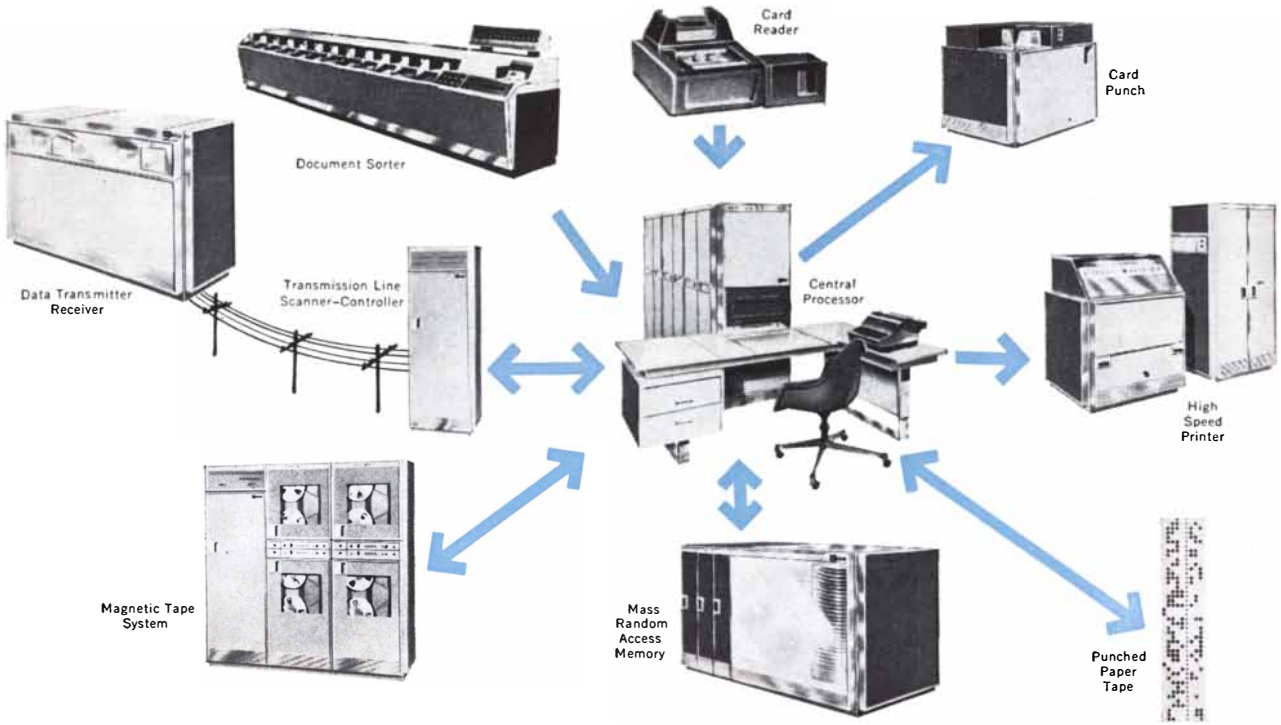

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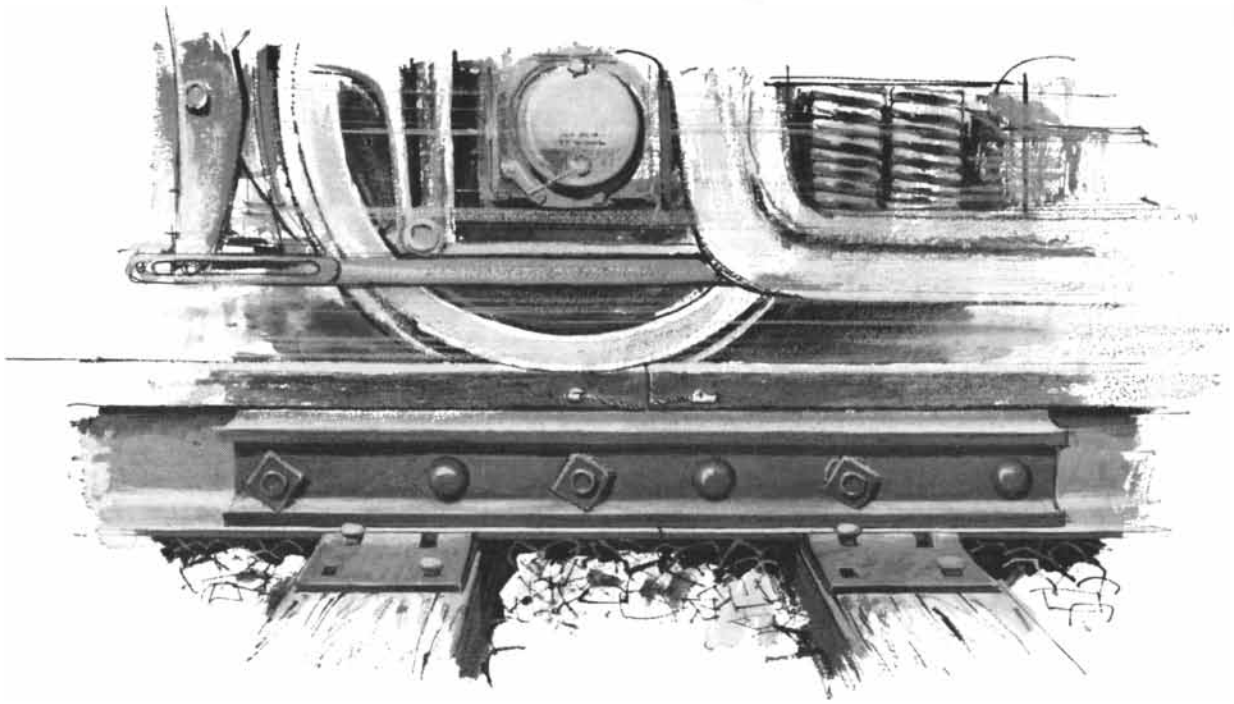

Now a structural adhesive so strong it can "freeze" rail joints

Armstrong has developed a structural adhesive so strong and tough that railroads are now using it to reinforce — or "freeze" — the joints of mainline track.

Despite constant pounding by fast-moving trains, this remarkable adhesive gives track joints up to six times the resistance to movement possible with bolts and joint bars alone.

This powerful Armstrong adhesive—called J-1156—offers a unique combination of strength and resilience. This qualifies it for many structural and mechanical applications.

Because J-1156 provides 100% fastening over the joint area rather than at only bolt or rivet points, it can substantially increase the strength of an assembly. This means that costs may be lowered in two ways:

(1) Conventional fasteners or stiffening ribs may be reduced in number, weight, or size or even eliminated. (2) The weight of the parts themselves may be reduced. A combination of both may even be possible.

A J-1156 bond is permanently resilient. Thus, it can withstand continuous vibration as well as battering shocks and heavy static loads. For example, rail joints reinforced with J-1156 remain tightly closed under horizontal loads well in excess of 250,000 pounds.

This powerful adhesive goes on quickly and easily, requires no mechanical pressure. On larger structural assemblies, workmen wearing gloves can apply J-1156 to bonding surfaces by hand. In other applications, brush, trowel, or caulking gun can be used.

J-1156 cures overnight without heat, or in half an hour at 300° F., and develops shear strengths of up to 4,960 psi. The cured bond effectively resists weathering and has excellent chemical resistance. It is unaffected by climatic extremes.

By freeing the designer from complete dependence upon such fastening devices as rivets, bolts, and welding, J-1156 points the way to lower cost, lighter weight, better performing structural assemblies.

If this unique adhesive suggests possible uses for you, we'll gladly send you adequate samples for testing. Just write on your company letterhead to: Armstrong, Industrial Division, 8011 Inland Road, Lancaster, Pa.

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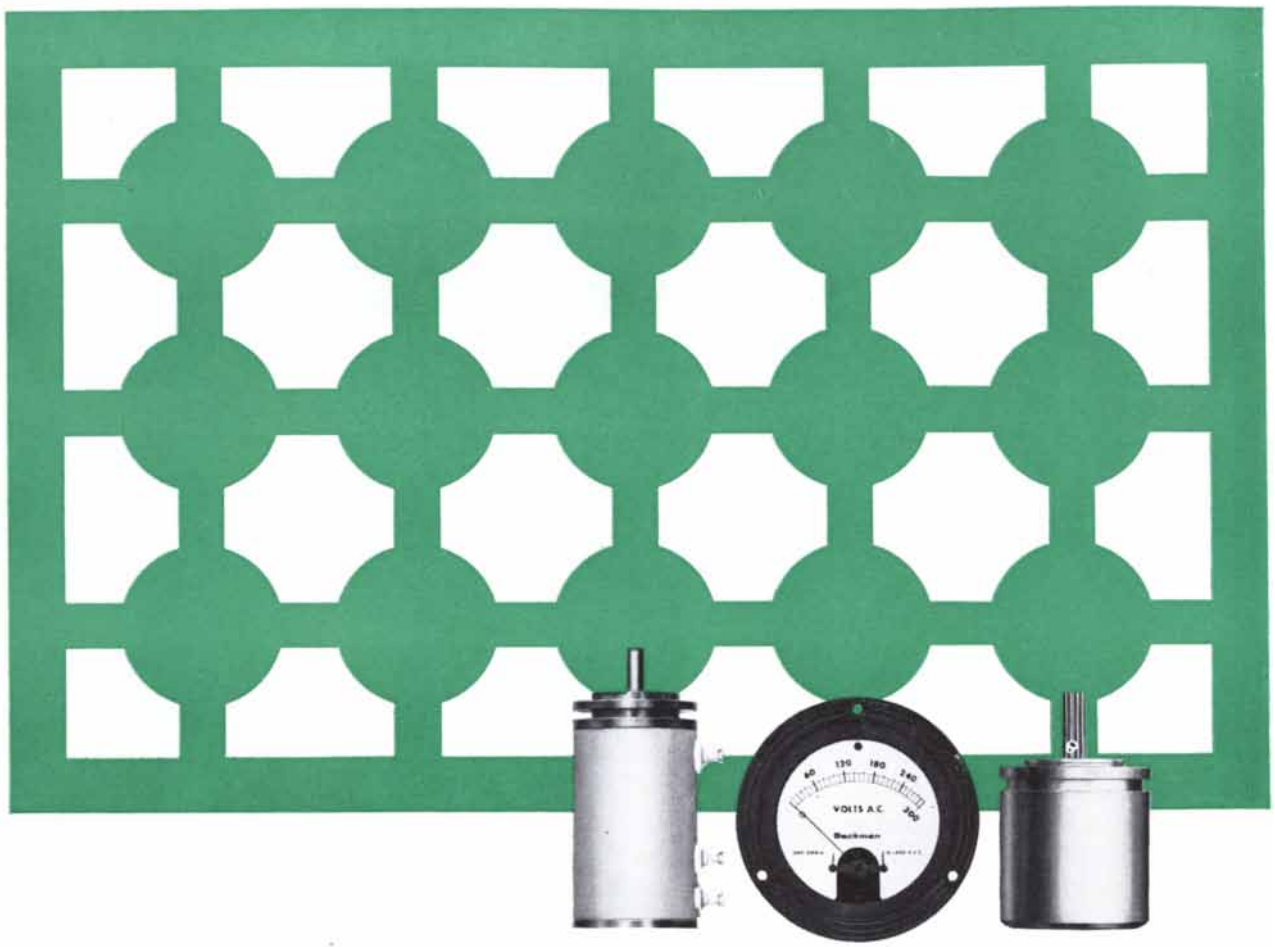

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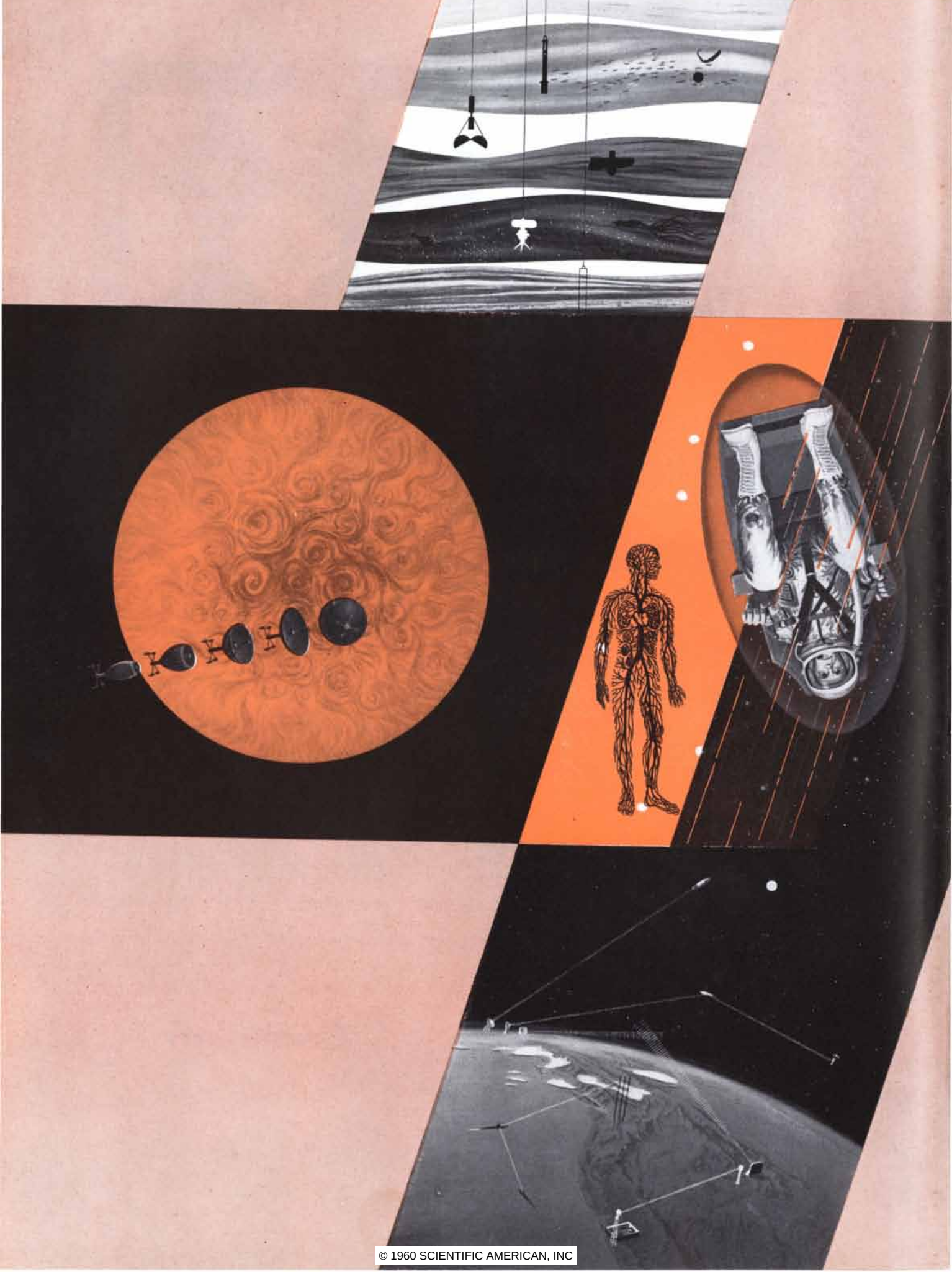

RESEARCH AND DEVELOPMENT AT LOCKHEED

...*is setting the pace in space for years ahead*

Lockheed Missiles and Space Division's progress transcends even that of an era marked by phenomenal scientific growth. To an important degree, the Division's research and development activities are considered to be the basis of its success.

As systems manager for the Navy POLARIS Missile and the Air Force AGENA Satellite in the DISCOVERER, MIDAS and SAMOS programs, the Division is engaged in extensive research in many diverse engineering and scientific fields. Some highlights of current research and development activities include: Operations research and preliminary design; nuclear and space physics; physical electronics; chemistry; materials; mathematics; engineering mechanics; electronic communications and instrumentation; and computer research and development.

Research is a concept which holds many different meanings to those concerned with science and technology. At Lockheed, a distinction is made between the *nature* of the work and its *objectives*. Consequently, such terms as basic research, applied research, systems or operations analysis, engineering and development are used. A given individual might find that his personal inclination often leads him quite naturally from one type of research to another. Recognition of this desire is reflected in the scope of work conducted in the Research Branch at Lockheed Missiles and Space Division. Principal research activities are: Pure and applied research; advanced design; engineering analysis; electronic prototype development; and machine computation.

Organization is determined by the *technical field* rather than by the *type of research*. For example, a structural dynamicist, as a member of the Structures Department, may, on one occasion, work on future space vehicle configurations, at another time be associated with current projects such as the POLARIS or Satellite programs, or he may be engaged in basic research at the research laboratory. In each case, the individual has the opportunity to maintain as much or as little contact as he wishes with others in his field of interest.

Important staff positions at Lockheed's Research and Development Branch in Palo Alto are available. Those scientists and engineers with experience related to the above areas are invited to write to: Research and Development Staff, Dept. K-36, 962 West El Camino Real, Sunnyvale, California. U.S. citizenship or existing Department of Defense industrial security clearance is required.

Lockheed / **MISSILES AND SPACE DIVISION**

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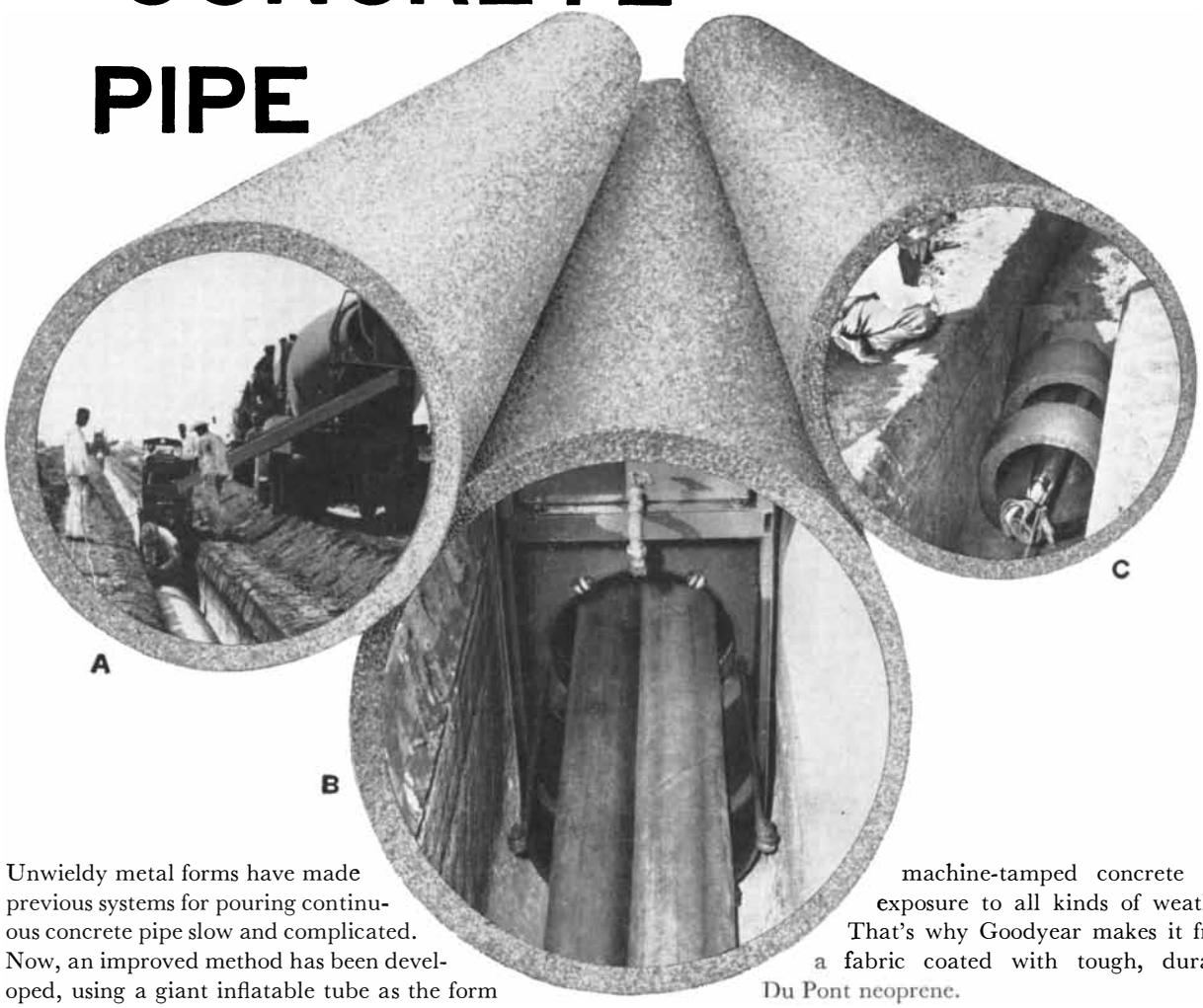
NOW... INSTANT CONCRETE PIPE

Another new development with Du Pont neoprene: Inflatable form for continuous concrete pipe, made by the Goodyear Aircraft Corporation

A. A double-hoppered forming machine, developed by Fullerform Continuous Pipe Corp., of Phoenix, Ariz., travels along the ditch. The dirt bottom has been rounded and acts as the lower part of the pipe form.

B. The machine envelops and lifts an air-inflated tube made of neoprene coated fabric. Half of the machine's double hopper tucks concrete underneath, while the other half forms the top of the pipe. The concrete is distributed uniformly by electrically-driven tampers.

C. Two hours after a section has been poured, the coated fabric form can be deflated and withdrawn for further use.



Unwieldy metal forms have made previous systems for pouring continuous concrete pipe slow and complicated. Now, an improved method has been developed, using a giant inflatable tube as the form over which concrete is poured. With this lightweight, easily-handled device, pipe can be built in 300-foot lengths at the rate of *eight to twelve feet a minute*. Two hours after a section has been poured, the tube can be deflated and withdrawn for further use.

The unique hose-like form that is the key to this new process is built by the Goodyear Aircraft Corporation. It is extremely flexible, yet must resist flex-cracking from repeated inflation and deflation, abrasion from the machine-tamped concrete and exposure to all kinds of weather. That's why Goodyear makes it from a fabric coated with tough, durable Du Pont neoprene.

When difficult design problems arise, Du Pont neoprene's balanced combination of properties often provides the solution. Parts and products made of neoprene synthetic rubber resist abrasion, sun and weather, oil and grease, ozone and chemicals. Perhaps neoprene's versatility is the answer to some of your own design problems. For engineering information, write E. I. du Pont de Nemours & Co. (Inc.), Elastomer Chemicals Department SA-11, Wilmington 98, Delaware.

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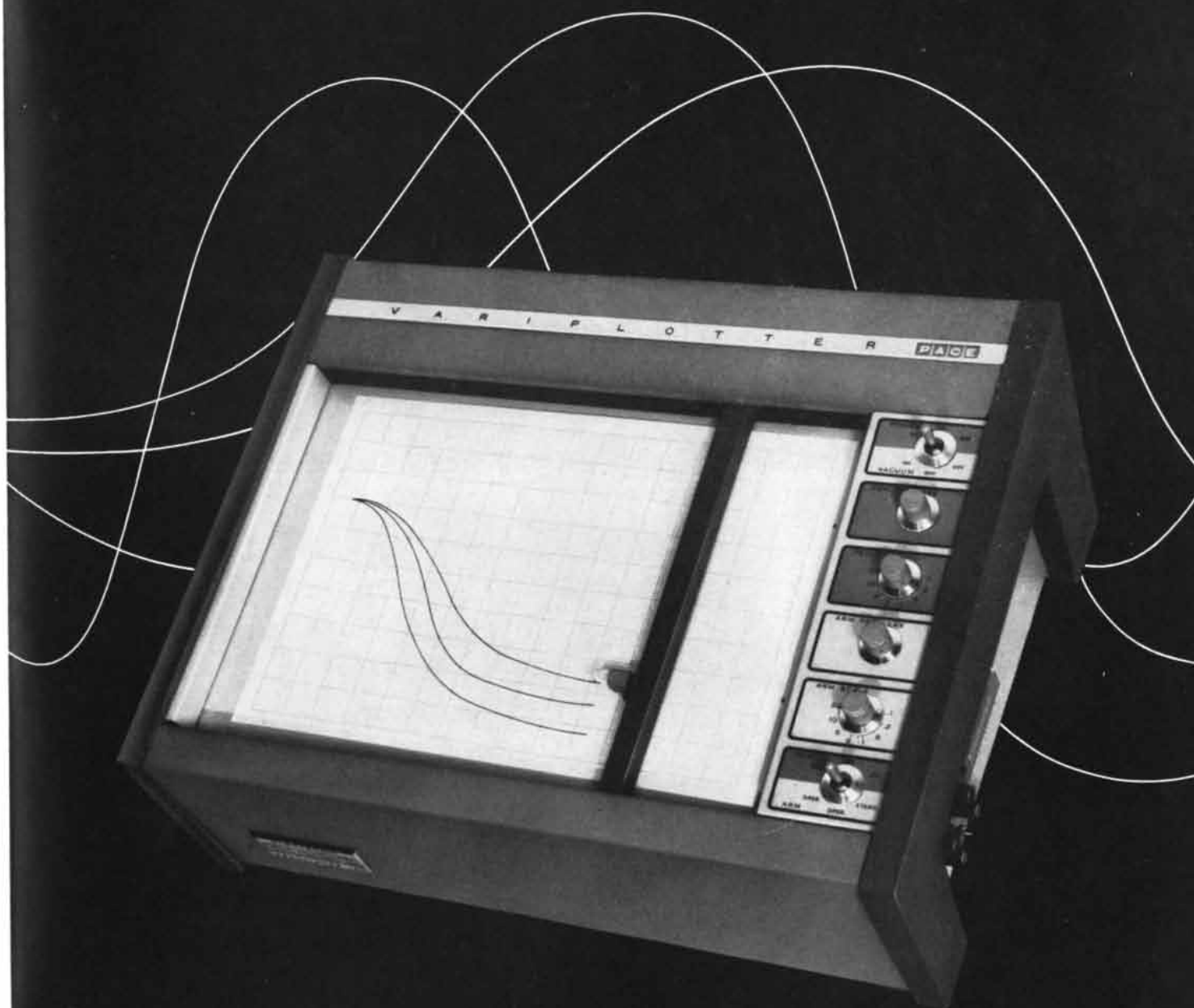
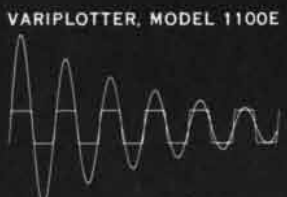


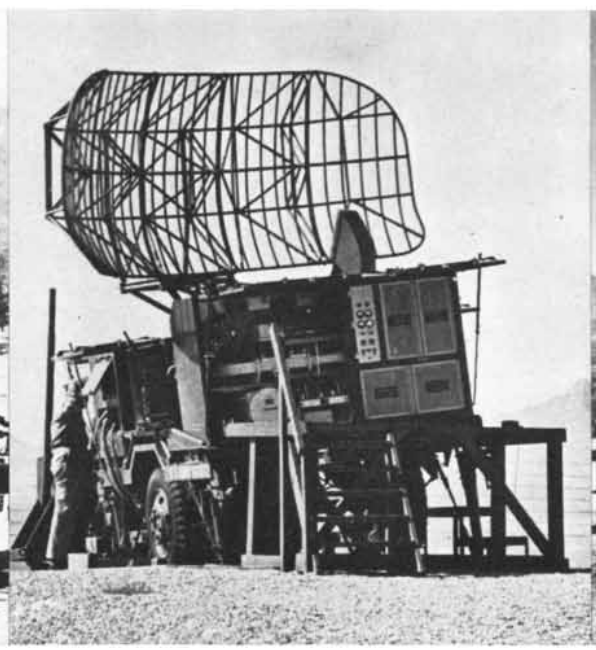
VARIPLOTTER, MODEL 1100E



EAI ELECTRONIC ASSOCIATES, INC. *Long Branch, New Jersey*

Highway, skyway or byway, Hawk gets there fast—The Army's extremely mobile air defense weapon, for which Raytheon Company is prime contractor, has also been adopted for use by the U. S. Marine Corps. Tree-top attackers are Hawk's special quarry. It uses a solid fuel propellant, and can accompany fast-moving field forces. All eleven units in the Hawk system can be transported by standard military cargo aircraft and by helicopter, rolled over the highways or over the roughest terrain. The equipment is lean and rugged, skillfully designed with carbon, high strength, and alloy steels—available from United States Steel. When your missile support system goes on

This continuous wave acquisition radar picks up targets down to tree-top levels.



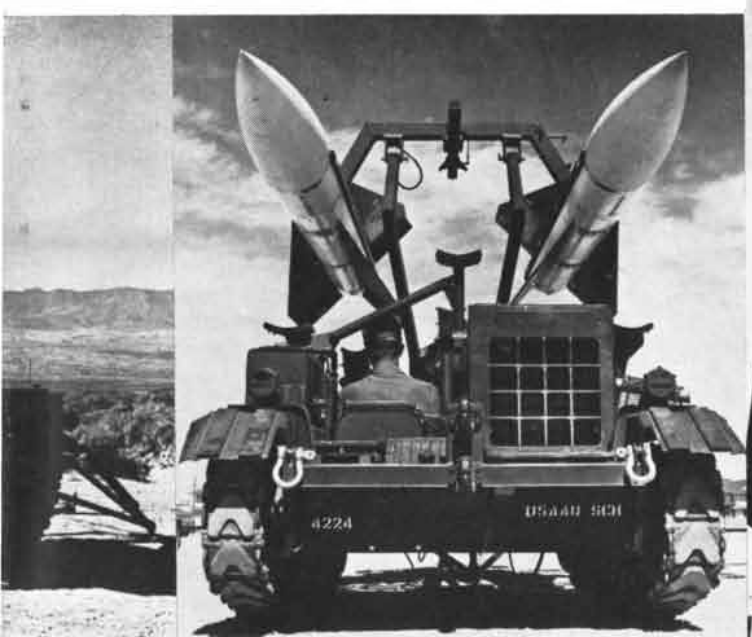
The pulse acquisition radar detects high altitude targets and provides volume coverage in support of the continuous wave radar.

Tubular outriggers give the launcher good stability with maximum weight conservation.

the drawing board, get maximum design capabilities from all ground support materials. Consult with the one producer of all these materials. Whether it's carbon steel or special constructional alloy steels, Stainless Steel, electrical cable or wire rope... consult with

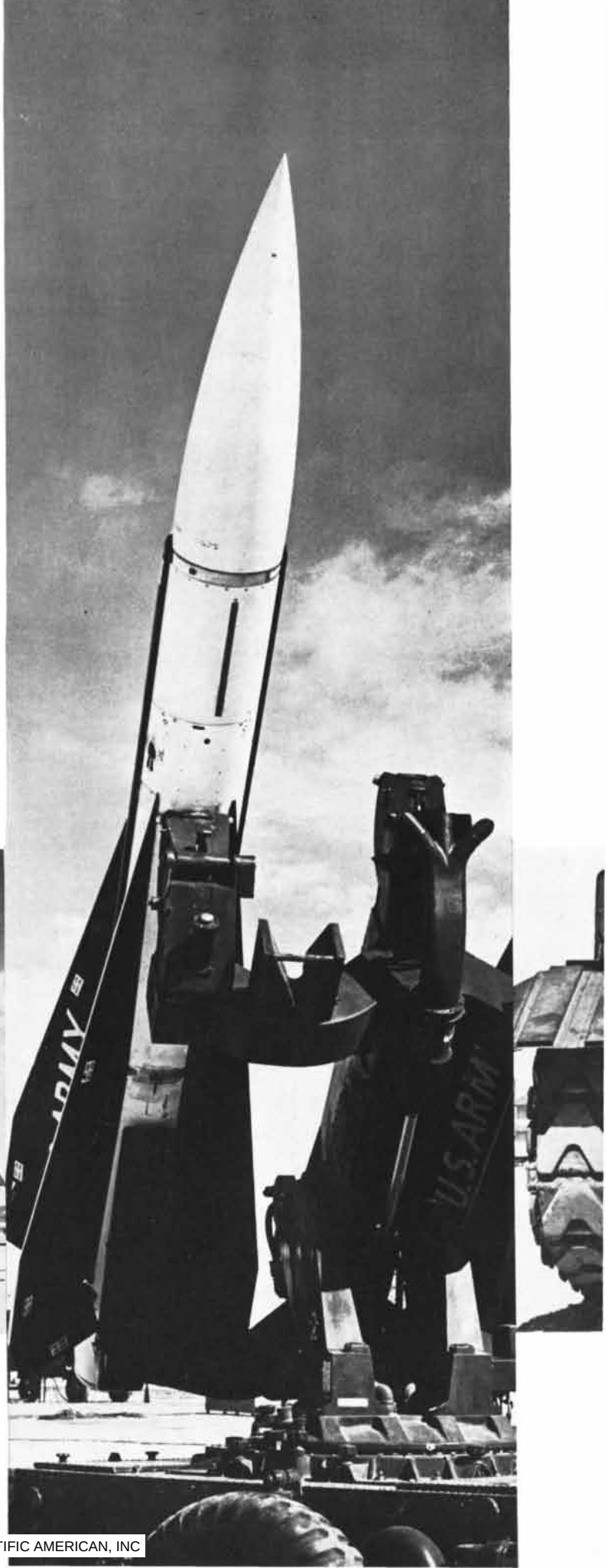
United States Steel

TRADEMARK



The Loader-transporter has an extremely low silhouette. It weighs only 5,250 pounds.

This mark tells you a product is made of modern, dependable Steel.



LETTERS

Sirs:

The article by John R. Platt, "How We See Straight Lines" [SCIENTIFIC AMERICAN, June], may convey a number of wrong impressions to persons not familiar with the field of visual perception. In the first place, it may appear that Platt has developed a new hypothesis of scanning as a basis for perceiving straightness. Actually E. E. Andersen and F. W. Weymouth, extending the earlier ideas of Hermann Lotze and E. Hering, enunciated such a principle in 1923 and applied it to the perception of straight lines and broken-line patterns. They discussed the fact that the retinal image of any object is continuously in motion, so that any one point on the image affects many points on the retina corresponding to numerous cone receptors. They then theorized: "The average or mean of these points, which determines the local sign of the straight line, is therefore not restricted to such units as interconal distance or cone diameter, but may be accurate to a small fraction of these units, just as the mean of a number of measurements made in inches may be accurate to a small fraction of an inch. Such a percept of position we would designate as 'retinal mean local sign' to emphasize its derivation from the averaging of various factors, among which we would include not only the many successive stimuli due to motion but also the mutual effect of adjacent elements and the comparison of the stimuli presented to the two eyes. . . . Since both the straightness and the position of a straight line are complex judgments (even though unconsciously performed) the limits of accuracy are not set wholly by the fineness of the retinal mosaic but by training and in general such neural processes as occur at a much higher level than the retina. . . . The constant slight drifting of the eye . . . enables the retina to work at its highest efficiency. . . . The motion is also the basis of its fineness of perception in which it surpasses the limits set to the resolving power of a camera by the grain of the sensitive plate."

A more serious misunderstanding may arise in connection with the specific model proposed in Platt's article. He suggests: "It would be interesting to try to construct artificial mosaic receptors, complete with scanning motions. . . . The receiving network would somehow have to grow or to establish new connections guided by experience. If we could design such a system, it might teach us far more than we now know about how the human eye and brain organize external information." The danger in such statements lies in the implication that any good physical scientist can sit down and figure out the basic principles by which a complex biological organism must be operating. Model building has its place, but surely a good model is based upon, and tested against, all the empirical evidence that is already available to the model builder. The history of the life sciences is bestrewn with models that once had some face validity, but which now appear to have little relation to biological fact.

The point of all this is to caution the reader not to regard the Platt hypothesis of visual scanning as a necessary or sufficient explanation for seeing lines as straight. Indeed, there is now conclusive evidence against the whole notion of scanning as the basis for visual acuity. The stabilized-image technique, developed by the writer and his colleagues, and independently by R. W. Ditchburn and B. L. Ginsborg, has enabled us to present motionless target images to the human retina. When a broken-line target is presented in this way, the same fantastically good detection of the break can be made *with no image motion at all* as when the line is seen with the eye moving about normally. Furthermore, a straight line immediately appears straight under these conditions, just as in normal vision. The same is true for grating targets and for the detection of

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single fine lines. Scanning, which is the trick employed by engineers to convey a picture to a television screen, is evidently not the trick that the human being uses to perceive the external world.

It may be objected that our concepts of straightness arise in early childhood and, once established, persist in spite of the grossness of the retinal mosaic. This hypothesis, which is not easily tested, carries with it the implication that a temporal mechanism which is of primary importance in childhood has lapsed into disuse or has been transformed into a spatial mechanism in adult life.

A few of the elementary facts to consider in hypotheses of vision are: (1) More than 100 million receptors (not 10 million, as stated in the article) are available in each eye. (2) In the central human fovea, where vision is most acute, each individual cone receptor subtends only 12 to 18 seconds of arc (not 60 seconds, as implied by Platt's figures). (3) The retinal image of a straight line is never sharp; diffraction effects result in a fuzzy border that spreads itself over a number of cone receptors. (4) Spatial interaction effects are known to exist between adjacent retinal elements. (5) Border contrast is heightened by these spatial interaction effects, with a resulting increase in the perceived sharpness of the lines. (6) The continuous involuntary motion of the eyes has one clearly demonstrated function, that of preventing the "washing out," or disappearance, of contours that are originally seen as sharp and clear.

LORRIN A. RIGGS

Brown University
Providence, R.I.

Sirs:

There are two methods of localizing a sharp line or a boundary or a boundary gradient to an accuracy finer than the size of the photodetector cells: (*a*) averaging over several cells, and (*b*) differentiating the signal during transverse scanning. Method *a*, an early suggestion of Hering, was proposed again by Weymouth, H. L. Averill and Andersen in the early 1920's to explain their very beautiful experimental results on visual acuities which were mentioned in my article in the June SCIENTIFIC AMERICAN. These authors coupled this with longitudinal scanning to explain vernier acuity. I am myself inclined to prefer method *b*, proposed by Samuel A. Talbot and his coworkers about 1940, and to combine it with longitudinal scanning.

But these questions are auxiliary to the main question I was trying to answer in my article. This was: How does the initially inexperienced brain know that the cells receiving a signal are in a *straight* line (or other geometrically regular pattern) rather than in a somewhat irregular line? My answer was the proposed method of functional geometry, which makes minimum demands on the information supplied by the receptor cells, using them indeed essentially only as "null detectors" to detect any repetition or self-congruence of a pattern after a translation. This method has three central and important features: (1) that it does not depend on knowing the locations of any individual cells, (2) that it is invariant to their sensitivity or occasional failure and (3) that it identifies straightness (or other geometrical relations) in an external and public field and is invariant to distortion of the image on the retina or cortex. Features 1 and 2 are suggestively related to learning and to our abilities of "closure" and extrapolation of patterns.

I admire the pioneering experiments of Dr. Riggs in stabilizing images, and I admit that the experiments in his laboratory do seem to show that scanning may not be very important for vernier acuity in adults (although they were not extended to the very high acuities reported by Weymouth and his coworkers, and they did not eliminate the Z-rotations, which might have been able to compensate in some degree for the loss of the X- and Y-scanning motions). But vernier acuity is only one part of our perception of straightness; and I do not think a hypothesis which shows the three important features I have mentioned should be abandoned lightly. It would be valuable to suggest alternative hypotheses that would have these same or additional features, so that experiments could be devised which would decide between them.

I am sorry if Dr. Riggs does not share my optimism about the possible construction of artificial mosaic receptors. A number of 10- to 100-element photoreceptor systems are already in operation which are capable of recognizing or learning simple patterns, although none of them have the random and initially unknown receptor arrangement which my hypothesis was prepared to cope with. I think that work with such systems may teach us as much about

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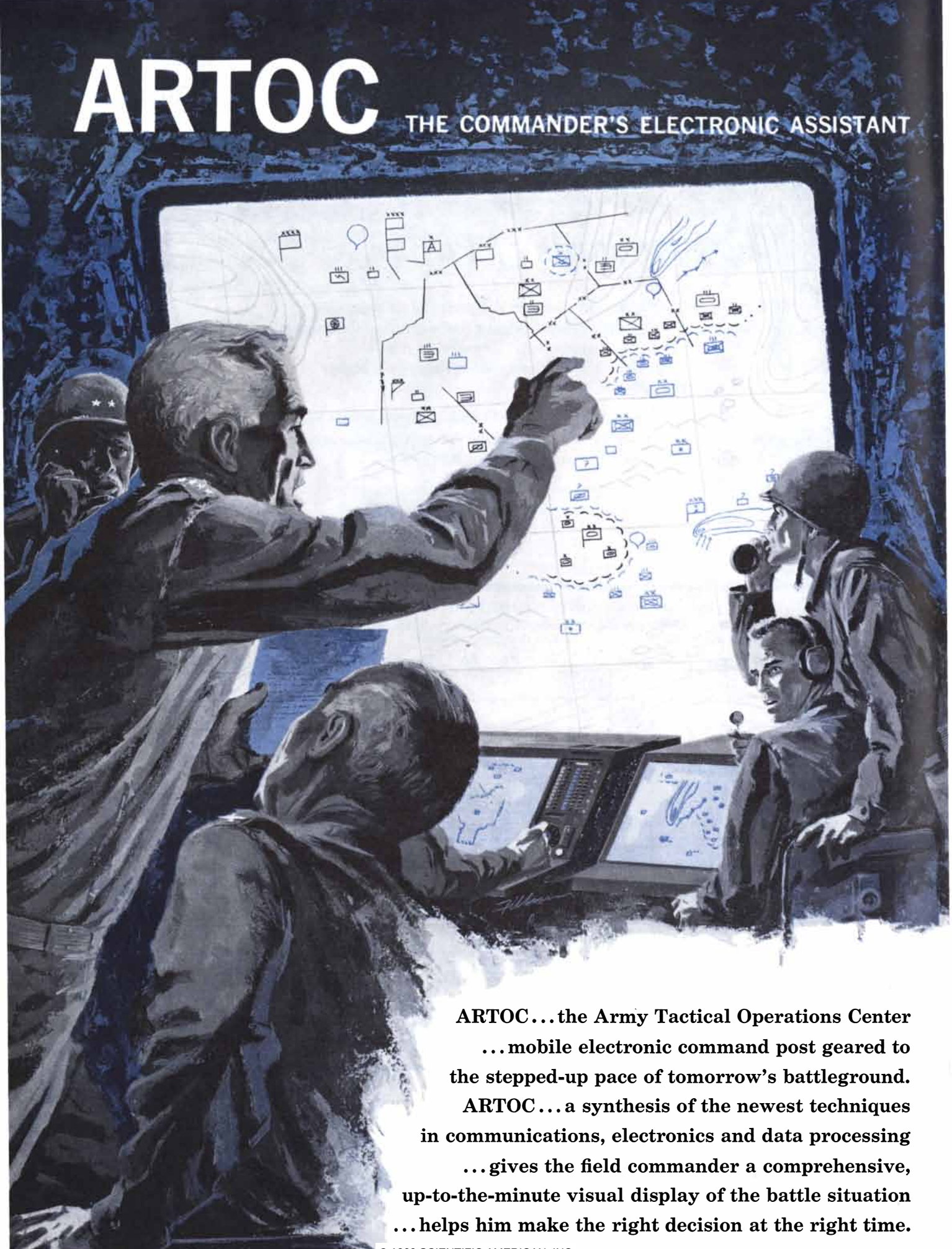

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the possibilities and requirements of neural connections in the retina as work with artificial cameras taught us about the optics of the eye and work with artificial sound sources and receivers taught us about the acoustics of the ear. We can only understand what we know how to manipulate.

JOHN R. PLATT

Department of Physics
University of Chicago
Chicago, Ill.

Sirs:

I have been enjoying Martin Gardner's article on the four-color problem ["Mathematical Games"; SCIENTIFIC AMERICAN, September]. Actually it is impossible to prove that it is impossible to prove the theorem. For if the theorem is false, this can undoubtedly be shown explicitly by exhibiting a map that cannot be colored with four colors. Hence if the theorem is unprovable it must be true. This means that we cannot prove it to be unprovable, for this is tantamount to proving it to be true, which is a contradiction.

The same remark holds for any theorem whose falsity could be demonstrated by a gegenbeispiel; *e.g.*, Fermat's last theorem. Such theorems may be unprovable, but only if they are true. We can then never know that they are unprovable, so that mathematicians would endlessly try to prove them. This is a terrifying state of affairs. Doing physics might seem to be a good alternative, but Gödelry may invade that realm yet. . . .

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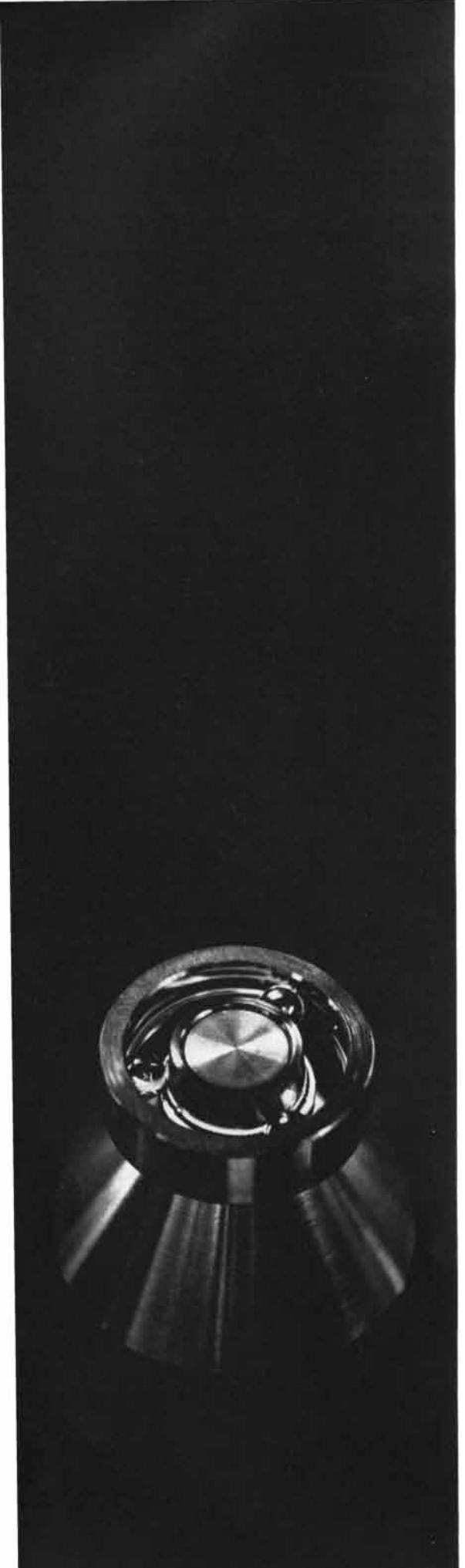
ERRATUM

The caption for the illustration on page 207 of the article "The Present Evolution of Man" [SCIENTIFIC AMERICAN, September] states that there are 46 pairs of chromosomes in a dividing human body cell. In actuality there are 23 pairs of chromosomes in such a cell, and 46 chromosomes in all.



One of a series

Catching the Drift of Gyro Bearings

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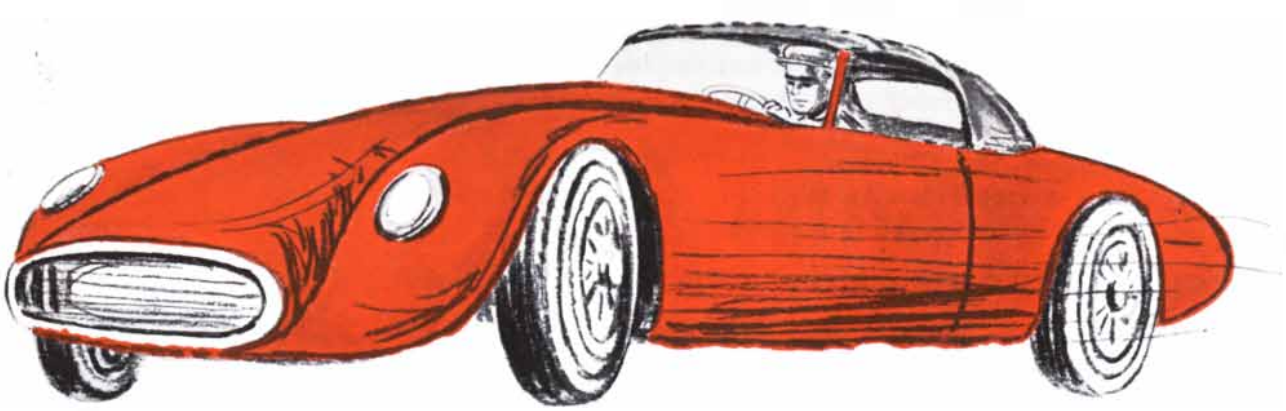

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Shock pattern is discernible along the shock layer on wing (light area), boundary layer on wing (dark region), and shock layer on body (dark region). Bright white line on underside of wing and body is reflection of light screen.

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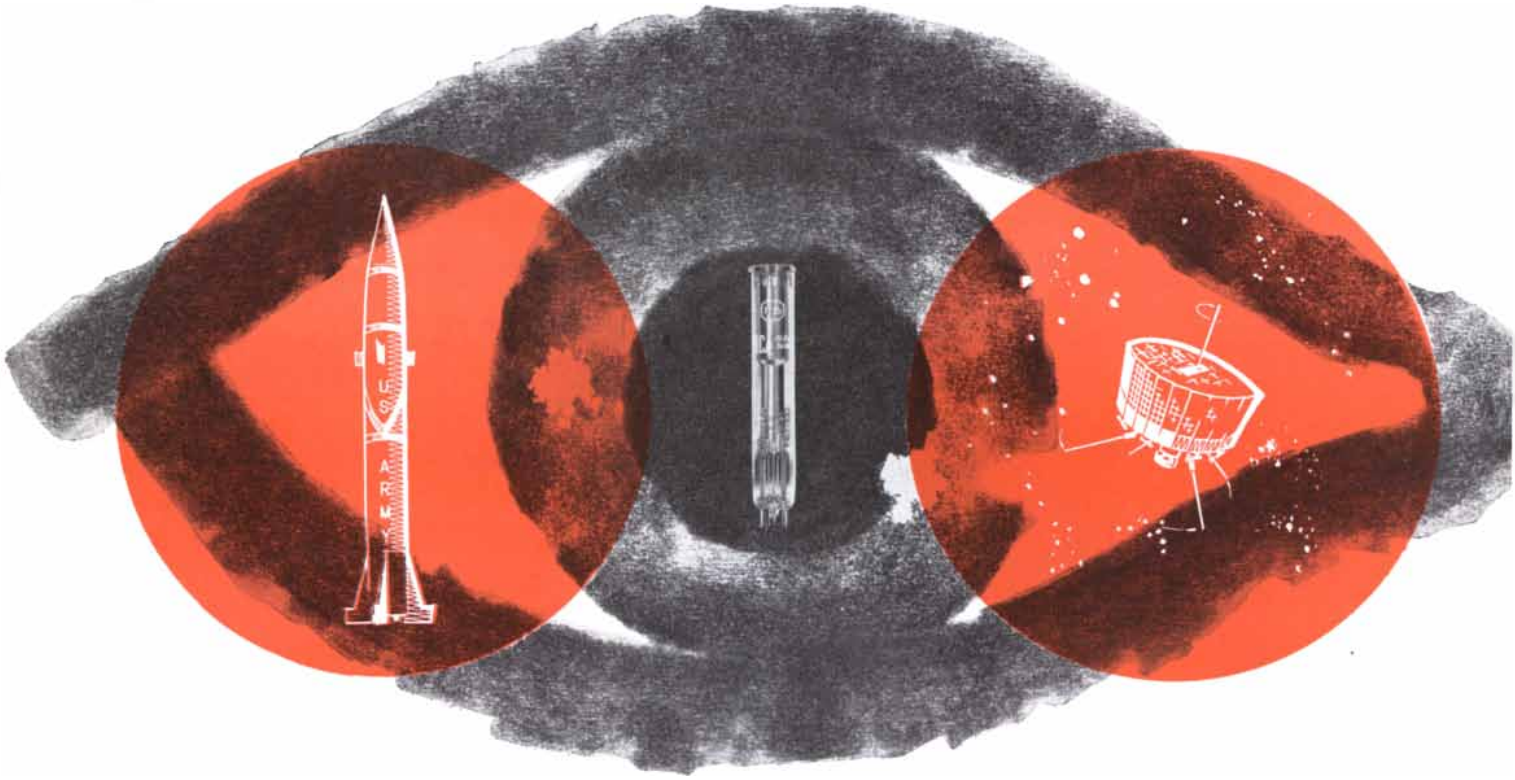

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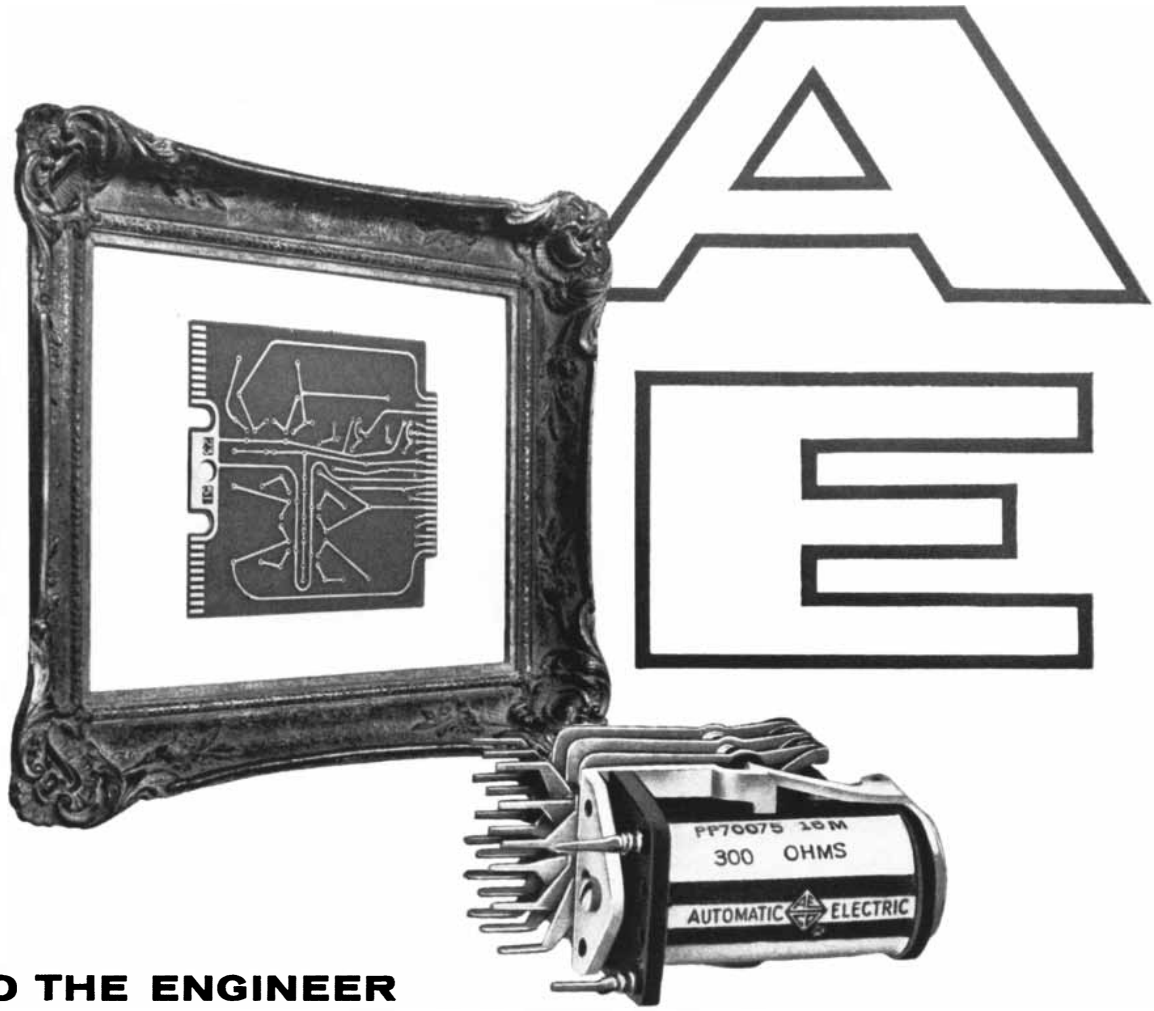

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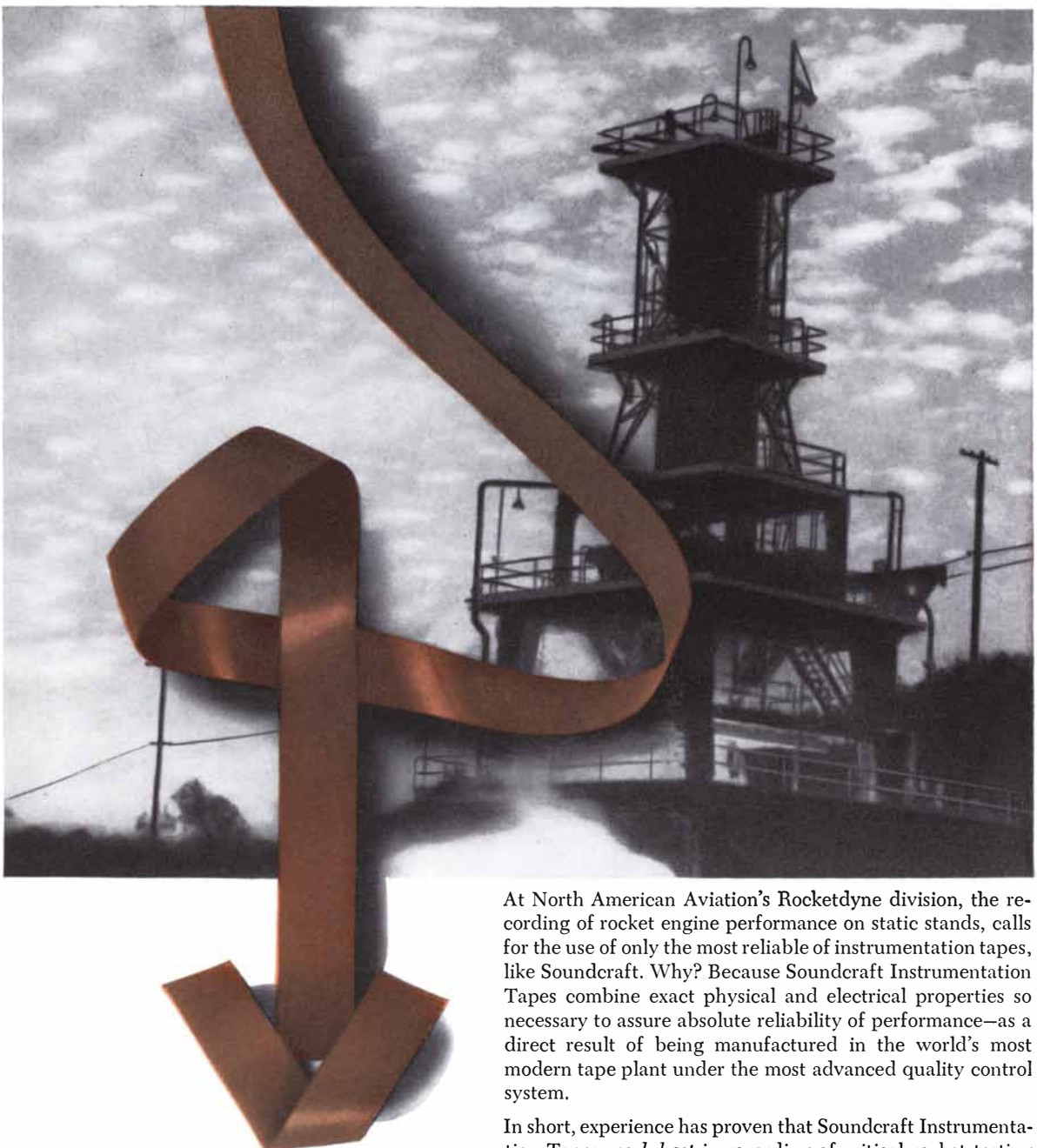

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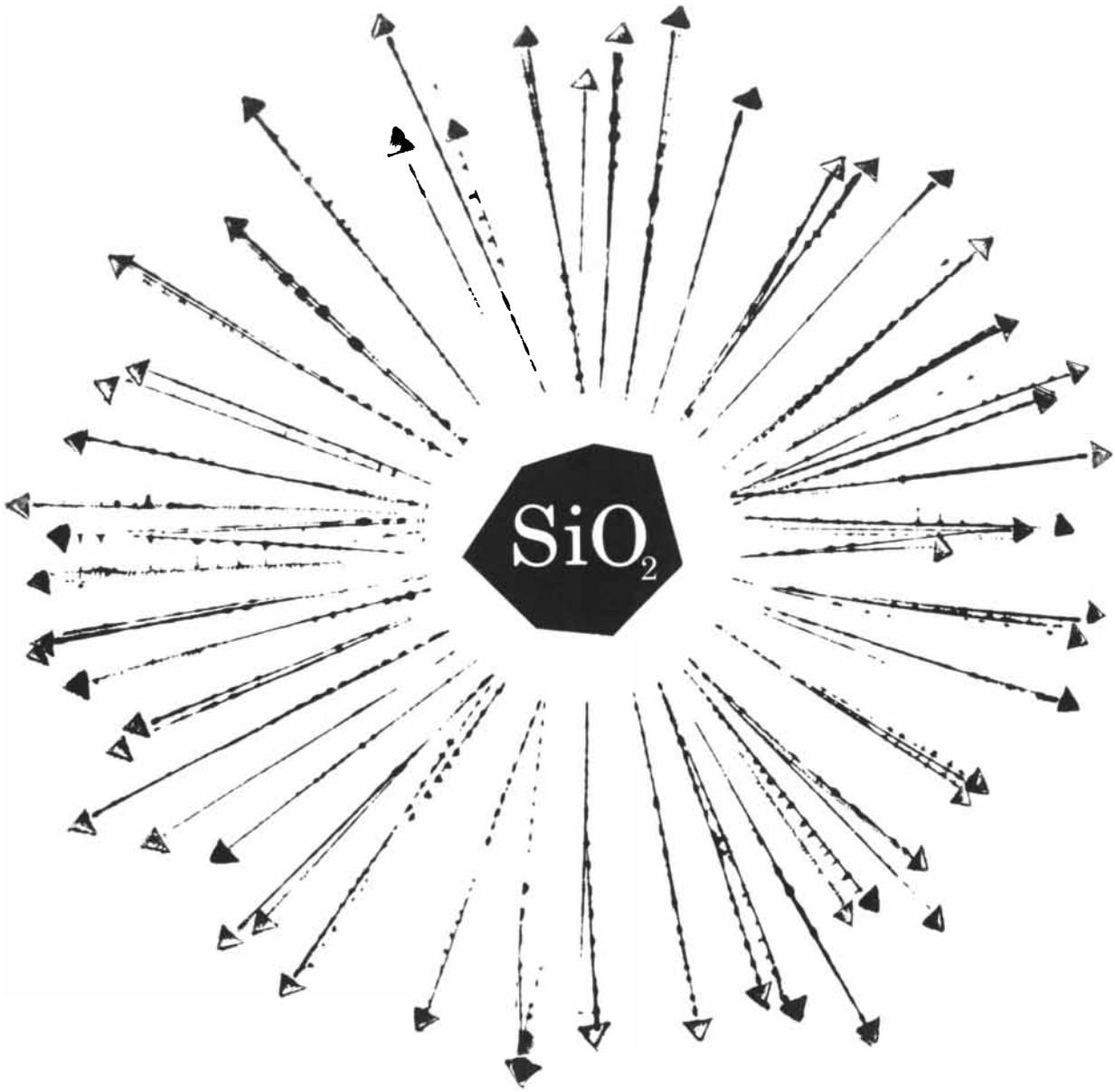

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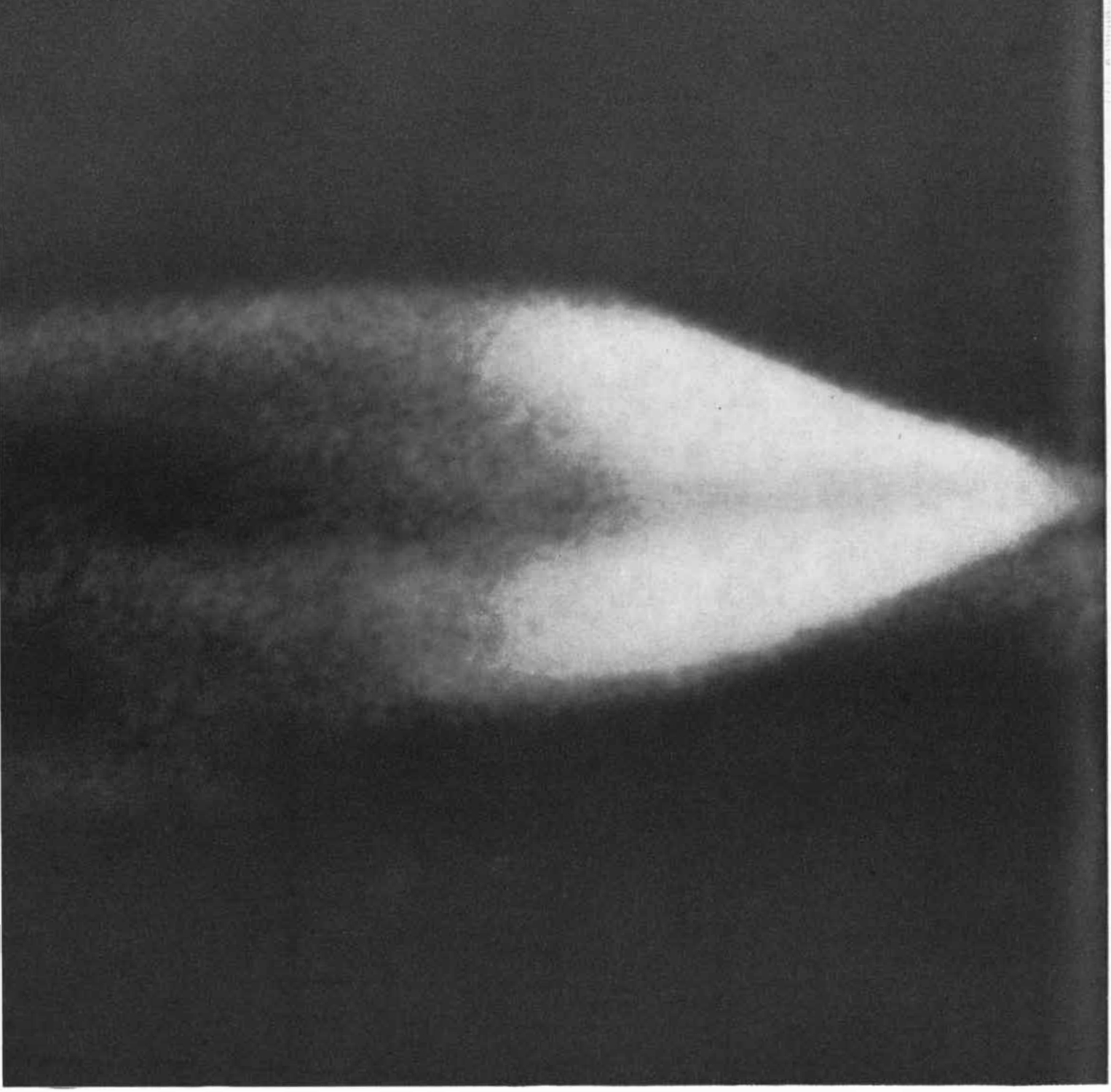

ROCKET TRAIL TELLS ALL

This fiery exhaust plume of a missile hurtling through the upper atmosphere was photographed at extreme range by one of the powerful ROTI tracking systems. ROTI, a highly automated combination of electronics and optics, has a 24-inch aperture and focal lengths up to 500 inches. It photographs missiles for several hundred miles and provides flight performance data not available through other methods.

The double diamond pattern, not visible to the naked eye at such distances, is caused by the force of shock waves on the missile's exhaust. This effect previously had been observed only in wind tunnel tests.

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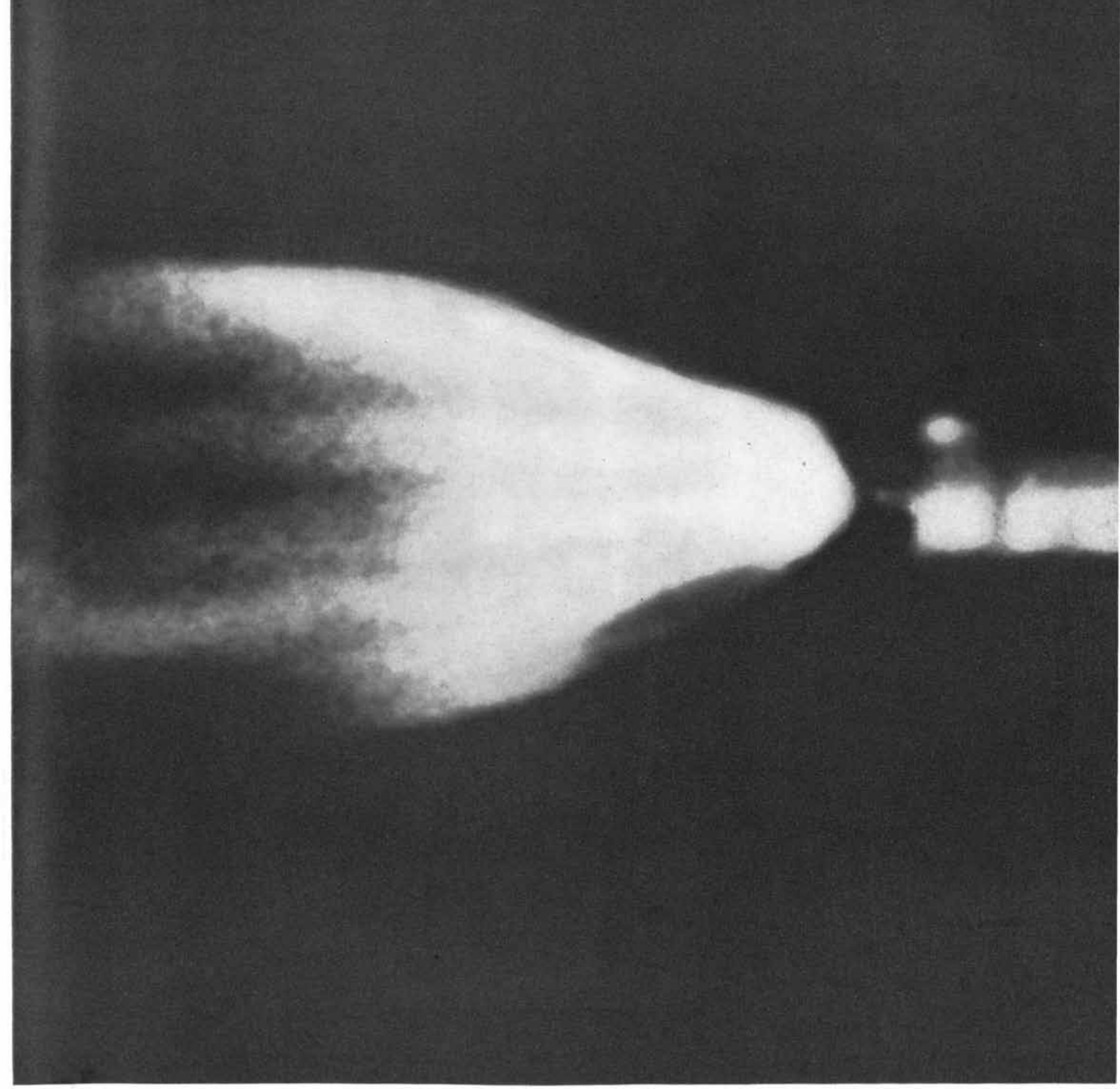

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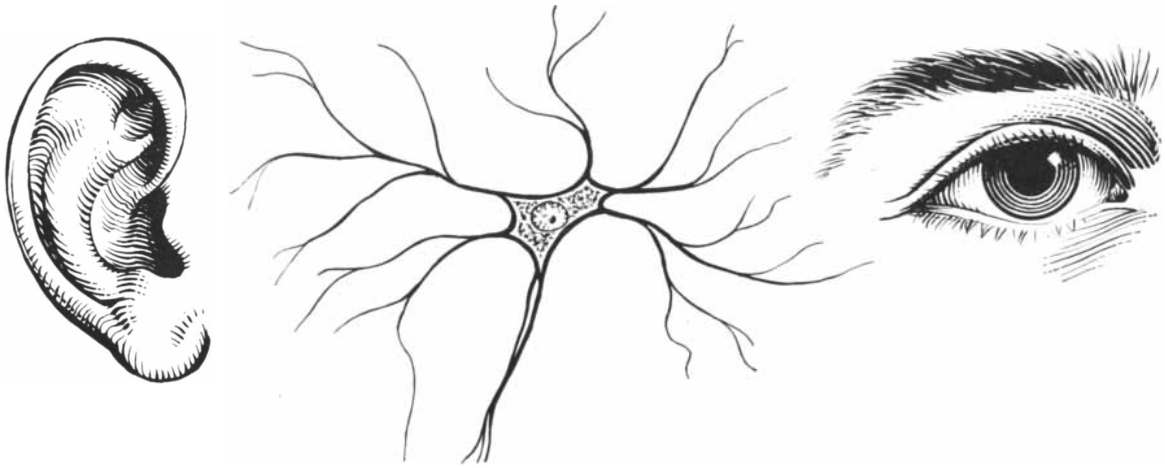
SCIENTIFIC AMERICAN

NOVEMBER, 1910: "The aviation meet which has just closed at Belmont Park was the first big affair of the kind we have had in America. At this meet the American public for the first time had an opportunity to view the crack flyers of Europe in competition with our best American aviators. The monoplane, which has been brought to a high state of perfection abroad, was seen in daily competition with the clumsier looking, though fully as efficient, biplane—that machine which was the pioneer of real human flight. The results of this competitive struggle were by no means one-sided as was at first supposed they would be. In the speed contest for the Bennett trophy the tiny Wright biplane, equipped with an eight cylinder V-motor of 60 horse-power, was a worthy rival of the 100-horse-power Blériot racers. Piloted by Orville Wright in a preliminary tryout, this machine showed a speed of between 66 and 70 miles an hour. On the whole the Belmont Park meet was a complete vindication of America in the aviation line."

"Experiments made by Elster and Geitel in the mines of Stassfurt, corroborated by the researches of MacLennan, and Kennedy, Campbell and Henriot, have proved that the salts of potassium are radioactive. It might be suspected that the radioactivity of potassium salts is due to impurities, for example, to traces of radium, uranium or thorium, but it now appears to have been definitely proved that the observed radioactivity of potassium salts is specific and, furthermore, that it is atomic, or in other words, that it is independent of its state of combination. It still remains to be proved whether the radioactivity of potassium, like that of radium, is accompanied by a change in the structure of the atom."

"In a recent number of the *Electrical World* there is an article on the patents of Thomas Edison. His first patent was secured in June, 1869, on an electrographic recorder. Since then 905 patents

WHAT GOES ON HERE?



Bell Telephone Laboratories' new electronic "nerve cell" is a step toward finding out

One fascinating area of communications has long resisted exploration—what happens inside the nervous system when you see, or when you hear.

This area is of special interest to telephone science; knowledge of how the nervous system handles sound and picture signals can help determine what information is essential to perception. This in turn may lead to more efficient communication instruments and systems.

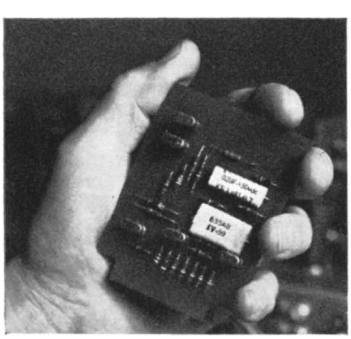
To probe the mystery of nerve activity, Bell Telephone Laboratories scientists have developed an electronic model of a living nerve cell or neuron. Consisting of transistors, resistors, capacitors and diodes, the "artificial neuron" exhibits many of the characteristics of a living neuron; for instance, "all-or-none" response and fatigue.

In one experiment at Bell Laboratories, a network of artificial neurons is subjected to a stimulus from light through a set of photocells. The network can distinguish specific patterns of light and dark, thus duplicating roughly some of the eye's basic reactions to light. Similar studies are underway to explore our hearing processes.

At present, too little is known about neural action to permit exact electronic duplication. But experiments with artificial neurons can provide suggestive clues, contributing to a stimulating interplay between electronics and neurophysiology which may help workers in both disciplines.

The human nervous system, including the brain, is the most efficient and versatile data processing system known; and data processing is an essential part of communications. The artificial neuron provides a new approach to investigating and understanding basic nerve network functions. It is a fresh example of how Bell Telephone Laboratories constantly explores new frontiers to improve America's communications system, now and in the years ahead.

Network of neurons is assembled by L. D. Harmon of Bell Laboratories, the initiator of this new research. Many kinds of assemblies are possible.



A single artificial neuron. It delivers electrical impulses when stimulated, like a living cell. Neurons are also being used for research into hearing.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

have been issued to him, 713 of which pertain to electrical apparatus. His greatest activity was in the years 1881 and 1882, when he was concerned with the development of the incandescent lamp and power machinery. In 1882 he was granted 75 patents, and the year before he secured 69 patents. From 1890 to 1892 there was another period of activity, as shown by the number of his patents, which was 65, 32 and 65, respectively, these being devoted mainly to the phonograph and to electric light and power machinery. Considering all the patents that are probably pending, patents that were withdrawn, and patents not yet filed but in the course of preparation, the number of Edison's inventions is close to 2,000."

"The annual report of the Isthmian Canal Commission, as made by Col. George W. Goethals, chairman and chief engineer, reveals an unexpectedly rapid rate of progress along the whole line of the Panama Canal. The controlling factor in this great work, as regards the date of completion, is the double flight of locks in three lifts at Gatun. During the fiscal year, such general and detail drawings of the lock gates as were necessary to advertise for all the gates required were completed, and the contract secured by the McClintic-Marshall Construction Company for the whole of the work for $5,374,474. This huge work, which calls for the erection complete of 46 gates, was to have been completed January 1, 1914, according to the advertisement. The successful bidders bind themselves to complete the work by June 1, 1913. By this it will be seen that the prospects of opening this canal far in advance of the original estimate for January 1, 1915, are very promising."

Scientific American.

NOVEMBER, 1860: "In the 14th and 15th centuries England imported iron and steel from Germany and Spain. It now supplies both of these countries with great quantities of these metals. This revolution in manufacture and trade was brought about by new inventions. In 1740 about 17,358 tuns of iron were made in Great Britain; in 1858, 8,040,959 tuns."

"The St. Louis (Mo.) *Democrat* states that a total of 80,000 buffalo robes have been received in that city during the present year. We understand that, owing

to the last winter being so warm, no less than 50,000 robes were left on the hands of the dealers."

"The experiments with Professor Way's electric light have demonstrated that a brilliant and constant light may be maintained without any other expenditure than that of mechanical power; but if the power is obtained by a steam engine, the cost of the fuel makes the light expensive. As our cotton and woolen manufactories are driven by water power, almost all have a surplus of power in the winter months, the only season during which they are lighted. Would not the owners find this the best and cheapest plan for lighting their establishments? An hour glass, containing a supply of mercury, would be placed in the middle of each room, just under the ceiling, and insulated wires, passing perfectly air-tight through the glass, would lead to a magneto-electric machine. The wires would connect with the mercury in each end of the glass, and when the magneto-electric machine was turned by the water wheel, the current of electricity passing along the wires would run through the slender stream of mercury flowing down from the upper chamber of the hour glass to the lower, the light being given out by the electric current as it darted from drop to drop of the mercurial stream."

"The railroad companies in France are about to put in operation a plan which cannot fail of being received with favor by the public. It is proposed to run, each week, a train of cars between distant points, for which tickets can be obtained in advance, and to which the companies will guarantee to admit only a limited number of passengers. All the places being occupied, the engine not carrying any 'dead weight,' the traveler can be transported at the price of merchandise. The companies, not only without loss, but even with a certain and calculable profit, will apply to these trains a tariff, the great cheapness of which cannot fail of producing an immense business. By this arrangement the fare is about one-fifth the usual price."

"It seems that the early French settlers and the Indians in western Pennsylvania were acquainted with the natural oil or petroleum wells, which are now thought by many persons to be a new discovery. At Franklin, Pa., old oil vats have been discovered, with trees a century old growing in them. An old well has also been discovered, with the remains of an Indian ladder in it."

"Test fleet" starts its daily rounds on bikes equipped with the new Bendix automatic transmission and power brake. Over a year of road testing showed new automatic to be much safer and easier in operation.

NEWSBOY "TEST FLEET" OK's NEW BENDIX COASTER BRAKE

For over a year, a fleet of Elmira, N. Y., newsboys has been giving a new-type Bendix automatic gearshift bicycle brake some rugged testing. They've ridden their Bendix-equipped bikes uphill and down, over rough roads, made hundreds of stops while carrying heavy loads of newspapers. The new brake came through with flying colors, just as it had done in our test laboratories, and proved that it makes cycling safer, easier, and a lot more fun.

If you are thinking about buying a bike for your youngster, please consider these safety features: the Bendix® Automatic has two gears—*low* for easier pedaling on hills and rough ground, *high* for easier pedaling on the flat. The feet do the shifting so that the rider's hands are completely free for steering and balancing. Full-time power braking—a Bendix exclusive — gives the rider 30% to 50% more stopping power. Leading bike manufacturers now use the Bendix Automatic. Look for the new "Bendix" at your dealer's.

Bendix has also pioneered with brakes for just about everything that rolls and must be stopped—cars, buses, trucks, aircraft, steam rollers, tractors, and off-the-road machines among others. We are currently producing over 400 different models of brakes for the automotive industry alone and are also a major producer of automotive brake linings.

We introduced four-wheel brakes to this country and followed with Duo-Servo® brakes. They added new safety and were so successful and popular that, over the years, most makes of cars have been equipped with Bendix-type brakes. Add the fact that Bendix pioneered power brakes and, more recently, automatic, self-adjusting brakes, and it's easy to see why we have built more brakes for more types of vehicles than any other company.

Changing gears is easy with the new Bendix automatic gearshift bicycle brake. The rider merely back-pedals a couple of inches, then pedals forward in the desired gear.

Incidentally, if you do not have power brakes on your present car, you can still enjoy their many benefits. Ask "the man who does your brake work" to install them. It takes less than an hour.

THE Bendix CORPORATION
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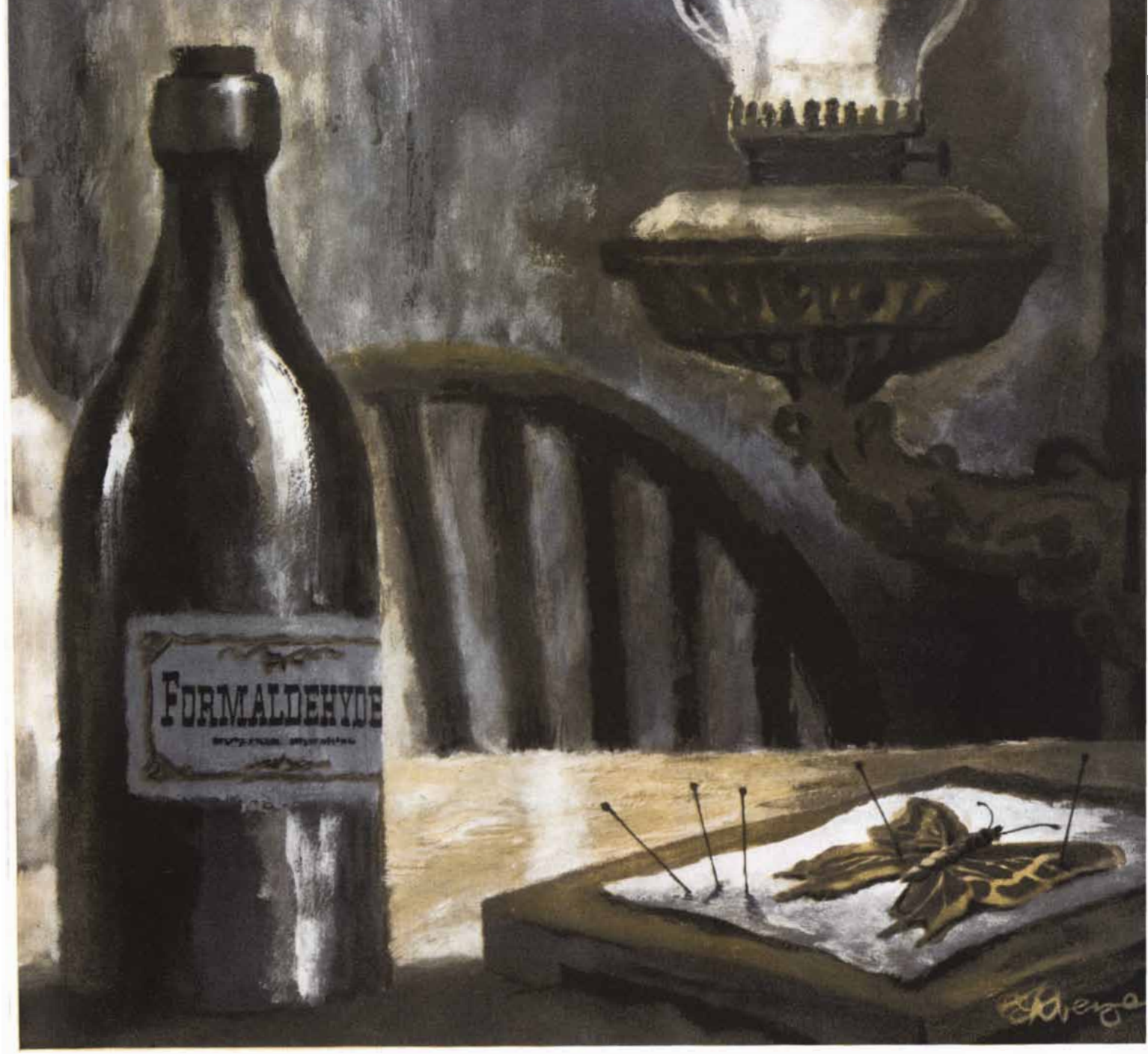
Formaldehyde grew up

Old-fashioned, simple formalin was good enough for junior frog-collectors. But modern industry, with its two-billion-pound a year appetite, needs far more sophisticated forms of formaldehyde—*many* developed, *all* produced by Celanese.

There is now a big family of Celanese formaldehydes, designed exactly to fit the requirements of special industries. There's stabilized formaldehyde (formalin 37%), paraformaldehyde (solid polymer) both flake and powder, Formcel solutions (formaldehyde in specified alcohols) and trioxane (anhydrous.)

Celanese scientists *know* formaldehyde. They've discovered, for example, a new and better way to stabilize it, and conquer the troublesome problems of formaldehyde in water solutions. It means shipments at cooler temperatures with process and economic advantages for users.

Celanese is one of the world's largest, most experienced producers of formaldehyde and other high-volume basic chemicals. For technical data, please write outlining your specific interest. Celanese Chemical Company, Dept. 582-K, 180 Madison Avenue, New York 16, N.Y. Celanese® Formcel®



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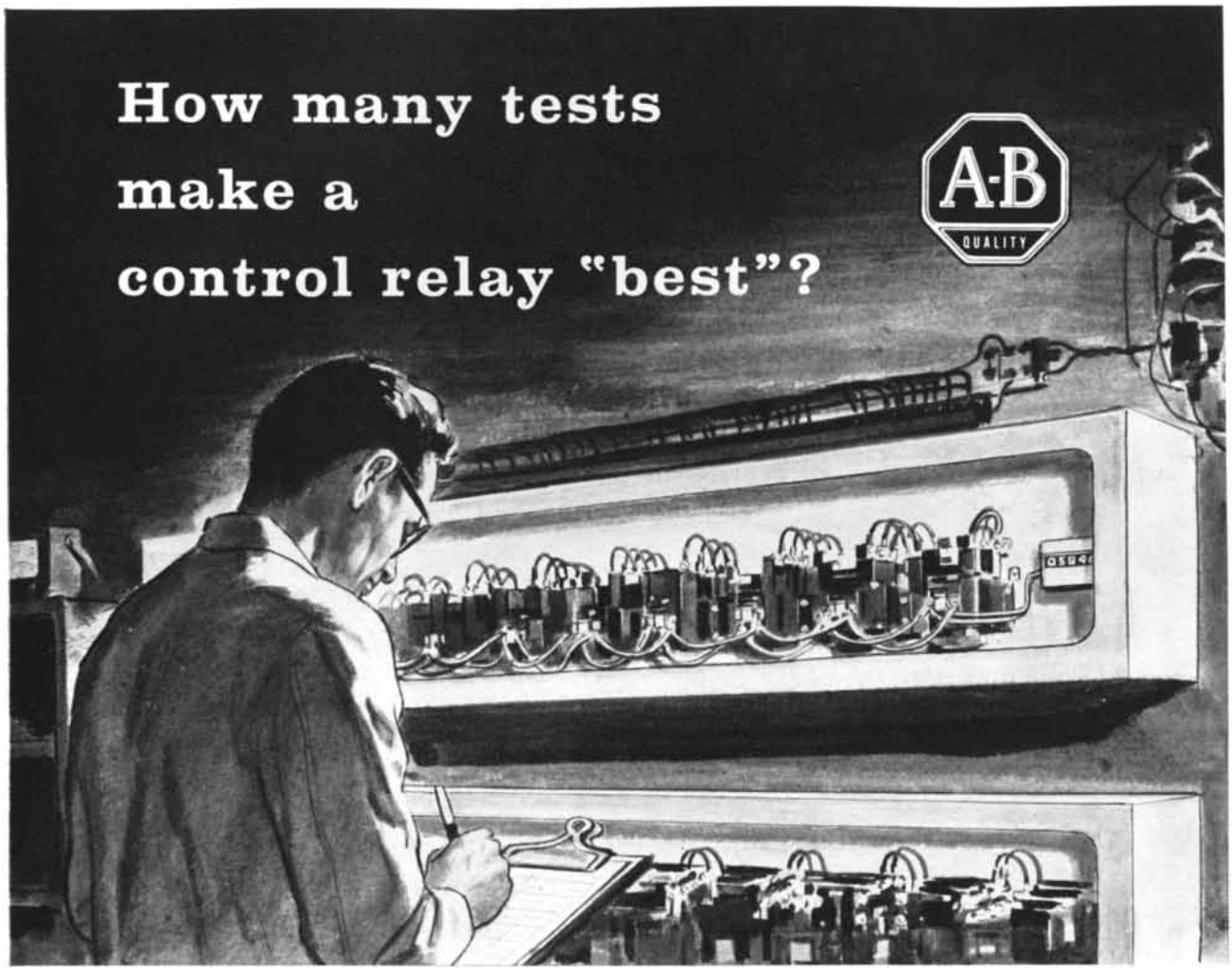
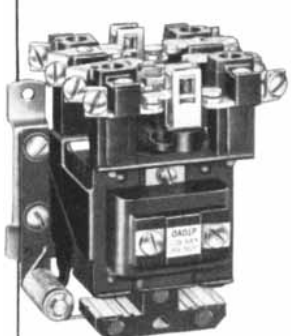


This engineer is "reading" the number of millions of trouble free operations on Allen-Bradley industrial relays on accelerated life tests.

Round-the-clock product performance tests are "standard" at Allen-Bradley

Hour after hour . . . day after day . . . until years of service have been compressed into a matter of weeks . . . these Allen-Bradley standard industrial relays undergo accelerated performance tests. Mechanical life and electrical life are checked and rechecked . . . to be certain that these relays will deliver the *extra millions of trouble free operations* for which A-B motor control is famous.

These relay performance tests are just one phase in the never-ending quality and reliability testing which Allen-Bradley motor control undergoes. Yes—Allen-Bradley's reputation for quality control is well founded. It will pay you production dividends to insist upon Allen-Bradley—the *quality* motor control.



IMPROVED BULLETIN 700 CONTROL RELAYS

Allen-Bradley relays are made in many types, including the general purpose relay illustrated at the left; universal relays with both normally open and normally closed contacts; and convertible relays having contacts that can be easily changed from normally open to normally closed.

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Quality Motor Control

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Engineers, Scientists—and

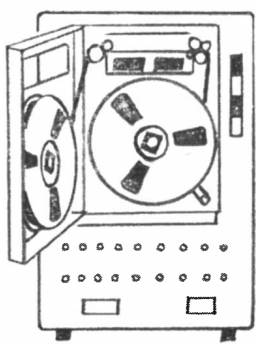
"SCOTCH" BRAND *Magnetic Tape—*

ride the rails to test **SLIP-GRAB STRESS**

The wheels of the big 1800-horsepower diesel electric locomotive slowly start to roll. There's little chug to this choo-choo — but there is a phenomenon called slip-grab which locomotive makers wanted to investigate. As the locomotive strains to overcome inertia and get the load moving, the driving wheels may alternately slip and grab at the rails.

In a recent series of tests, the mechanical stresses produced by the slip-grab effect were only a few of the performance factors recorded on "SCOTCH" BRAND Magnetic Instrumentation Tape.

These tests, conducted by General Electric Locomotive and Car Equipment Department on the diesel-electric locomotive, employed a portable tape recorder made by the Precision Instrument Company. This sensitive instrument, capable of recording 14 channels, each crammed with data, had a natural companion for the task —sensitive "SCOTCH" BRAND Magnetic Tape. During an actual ride on the rails the recorder and tape took an accurate record of these parameters: several channels of strain gauge data, motor shaft torque, motion of the motor on its mounts, vibration, locomotive speed and motor current.



"SCOTCH" BRAND Magnetic Tape was selected for this task, not only because of its greater versatility, but for its superior error-free performance as well as its capacity to hold so much information in such a compact form. It is the choice, too, to control industrial automation, helps the scientist explore earth, sea and space—and remains the leader as newer, more sensitive tapes are developed for science, business and industry. For details on tape constructions to serve your needs, write Magnetic Products Division, Dept. MBO-110, 3M Co., 900 Bush Avenue, St. Paul 6, Minn.

DOW

NEWS ABOUT PRODUCT DESIGN AND MATERIALS

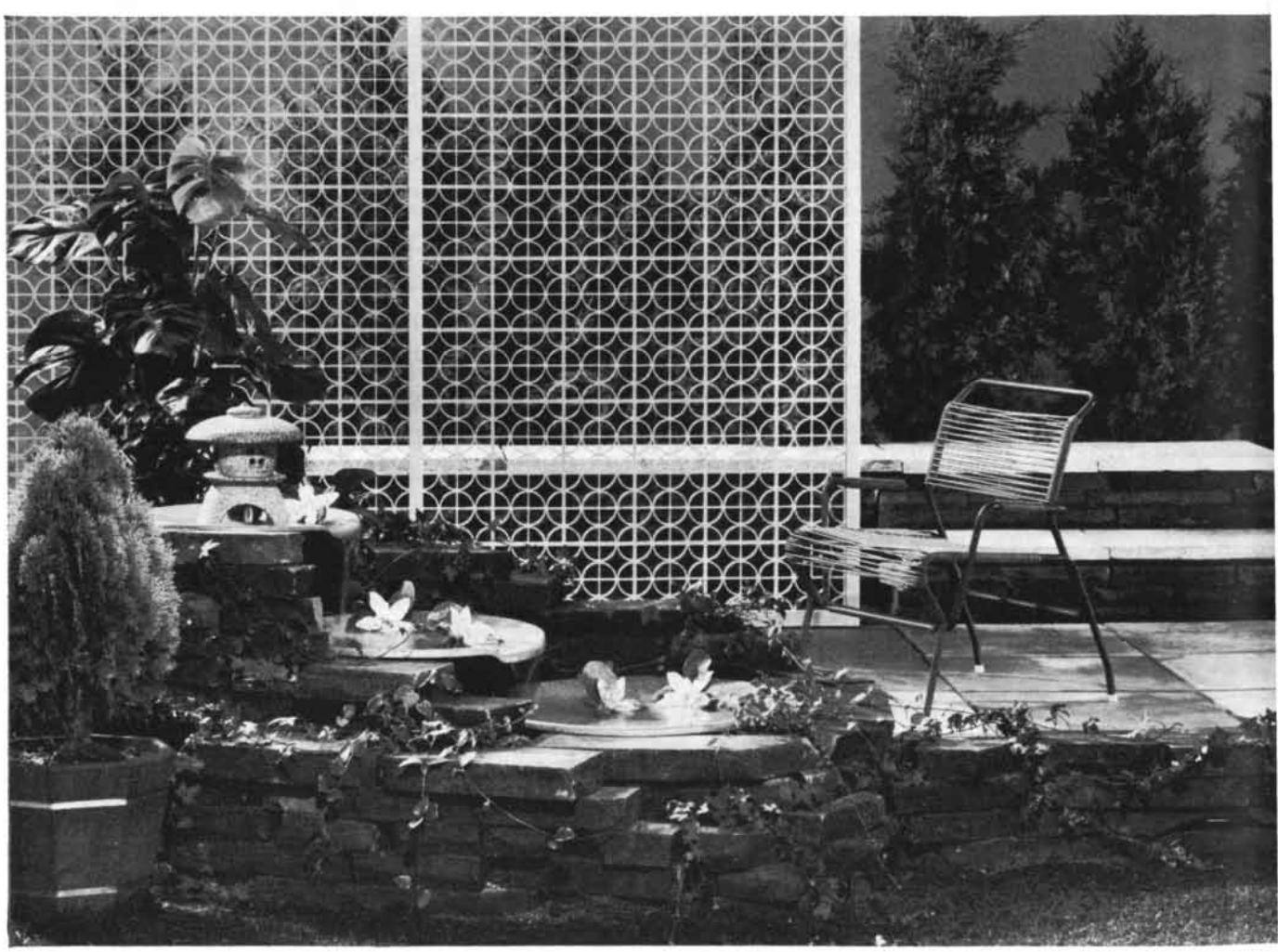
Scarcely a day goes by that Dow chemically engineered plastics don't contribute to the design of a new product, or to an improved design for an old one. And nowhere is their versatility and economy so well employed as in products for the home. Here, the moldability, color, finish and strength of Dow thermoplastics encourage good design, simplify production, add sales appeal across the board.

NO PLACE LIKE HOME FOR TODAY'S NEW PLASTICS

What do *you* make, sell, design—or buy—for the modern home? Waterfalls, perhaps . . . or chairs . . . or floor scrubbers . . . or can openers? Whether it's as standard as a chair or as novel as an electric can opener, chances are one of the many materials in the Dow family of thermoplastics will make it . . . or make it better.

Take a patio screen made of the new Dow plastic called Zerlon®. This new Dow material is ideal for the patterned latticework grille that increases privacy or serves as a room divider. The inset plastic is attractive and stays that way, all year 'round—even out of doors. Zerlon is formulated to withstand weather, including the heat of a hot summer sun. Other features of Zerlon: high tensile strength, good optical qualities, easy fabrication either by molding or extrusion.

Plastics have a hand in these attractive patio chairs, too. The cord is made from PVC . . . Dow polyvinyl chloride resin.



Both cord and fabrics are made from PVC in a wide spectrum of colors and combinations. They feel good to the sitter, keep their shape, and fit outdoor decor. And the beauty of it from the housewife'spointofview—materialsmade with PVC wipe clean with a damp cloth.

Want your own waterfall? Make sure it's molded of vacuum-formed Styron® 475, as this one is. Because the fall recirculates water, it's important that the material should not be absorbent. And it should be able to take normal bumps and shocks without shattering. Styron 475 gives this attractive patio piece high impact strength, flexural strength, nonabsorbency and offers beautiful printed design possibilities.

In the kitchen, Styron 475 provides many modern kitchenware and housewares items. For example, it makes a smooth, colorful, durable housing for appliances that scrub linoleum and tile, shampoo floors, vacuum carpets and floors. Color choices with Styron are virtually unlimited. Another formulation, Styron 369, makes the housing for clock radios, is especially formulated for heat resistance, impact strength, good dielectric properties. Clock housings and face dials are molded from Styron 666.

Tyril® is a favorite Dow thermoplastic for many home products, from electric can opener housings to lint filters for washers. Strong, tough, craze-resistant Tyril withstands chemical attack of oils, waxes, soaps and solvents. It stands up well under ordinary heat, stays dimensionally stable. A high gloss finish and wide spectrum of built-in colors make it first choice for many modern home products.

MATERIALS MAKE THE DIFFERENCE between an ordinary product and one with special advantages in the way of production and saleability. And Dow's "widest line of thermoplastics" can widen that difference for you. Are you planning a new product that needs special qualities of moldability, color, style, production economy? Then investigate the extensive formulations range available in Dow plastics . . . and the difference it can make in your product. For full information, write THE DOW CHEMICAL COMPANY, Midland, Michigan, Plastics Merchandising Department 1758EQ11.

See "The Dow Hour of Great Mysteries" on TV

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Midland, Michigan

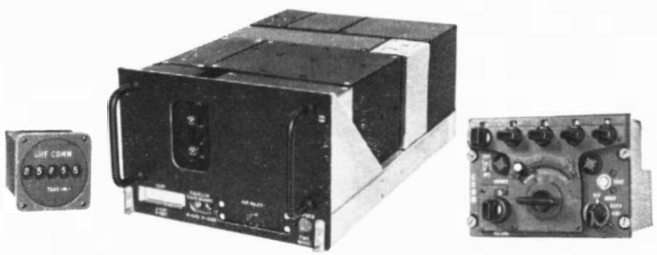
DOW

Magnavox continues to maintain a position of leadership in the airborne communications field.

Magnavox engineering, in conjunction with the Air Force, has developed an advanced airborne communication system that is designed to meet the requirements of the future. Utilizing wide band techniques, such functions as television relay for bomb damage assessment, data link for control and identification, and many other forms of air-to-air and air-to-ground communications can all be realized over the same equipment as used for voice.

Magnavox

AN/ARC-50 SYSTEM



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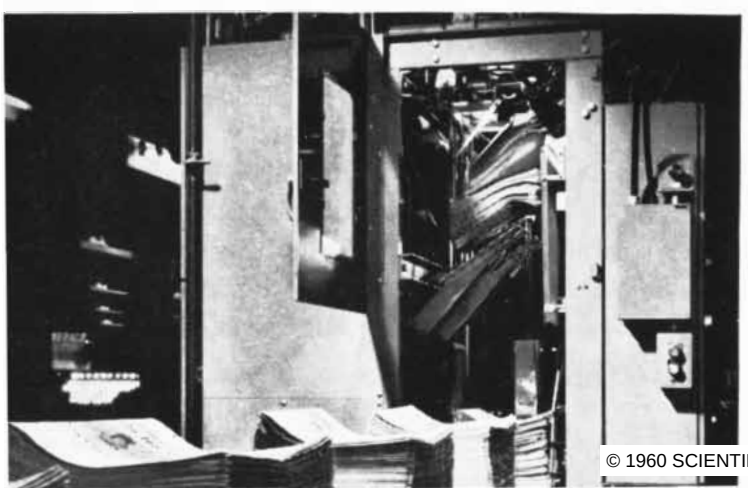
Emphatically, yes. These bearings, backed by Torrington's creative engineering, will play a vital role in your future progress ◇ Today, the average car contains more than twice as many Torrington Bearings as all other anti-friction bearings combined. Over 400 needle rollers are used in bearing assemblies ◇ Indeed, without Torrington Needle Bearings, such advances as automatic transmissions, power steering, power windows and other power-operated equipment might still be in the development stage! ◇ Of equal importance is the creative cooperation Torrington offers to research and engineering people who inspire and achieve automotive improvement. This has established a partnership in progress which will continue to spark advances through improvement in the design, material and performance of anti-friction assemblies.

THE TORRINGTON COMPANY, Torrington, Connecticut • South Bend 21, Indiana

PROGRESS THROUGH PRECISION—IN BEARING DESIGN AND PERFORMANCE

No more hand stacking. This newspaper counter-stacker counts and stacks newspapers automatically—and can be programmed to automatically vary the stacks to meet route schedules.

No more dry pumping. Cutler-Hammer's new development—an automatic pump off control for stripper oil wells—stops the pump when oil has been lifted. Saves the pump, ups production.



What's new in control for automation?

A blast furnace that charges itself

More efficient automation because the Cutler-Hammer control systems man was called in at the start of planning. The art of charging a blast furnace is now a science.

Cutler-Hammer control engineers, with the furnace builders, worked three years to put all charging control functions into one integrated system. Now, the proper material in the proper amounts, all in a proper sequence are delivered to the furnace bell—automatically.

Every step of the operation can be checked visually on master control panels. Nothing is left to chance. The added cost of this kind of charging control is relatively insignificant. Complete flexibility in selection of furnace charging programs now makes possible optimum blast furnace performance.

Why you should call in the electrical control man early. Cutler-Hammer has been increasing productivity and lowering costs for many different companies in many different industries for years. This is a major reason why Cutler-Hammer should be called when you *start your automation planning.*

The company on the move. There's a new vitality at Cutler-Hammer—a new desire to solve problems. We've planned for the gigantic expected growth of the sixties and now we're ready—with new plants, new engineering talent, new and better products. We'd like to tell you about ourselves if you're planning ahead. Contact the Cutler-Hammer sales office nearest you.

Automation is more efficient when the control expert is called in early.

WHAT'S NEW? ASK...

CUTLER-HAMMER

Cutler-Hammer Inc., Milwaukee, Wisconsin • Division: Airborne Instruments Laboratory • Subsidiary: Cutler-Hammer International, C. A. Associates: Canadian Cutler-Hammer, Ltd.; Cutler-Hammer Mexicana, S. A.

THE AUTHORS

SARAH E. STEWART ("The Polyoma Virus") is a staff member of the Commissioned Corps of the U. S. Public Health Service and a medical director of cancer research at the National Cancer Institute. She received her B.S. from New Mexico State College and her M.S. at the University of Massachusetts. From 1936 to 1944 she was a bacteriologist for the Public Health Service and did graduate work at the University of Chicago, receiving her Ph.D. in microbiology in 1939. She acquired an M.D. degree at Georgetown School of Medicine in 1949, joining the staff of the Commissioned Corps later that year. The virus-induced tumors discussed in the present article have been Dr. Stewart's principal interest for more than a decade. In 1948 she did research in this field under a grant from the National Cancer Institute; two years later, when she joined the Institute, she began to work on the subject full-time.

NARINDER S. KAPANY ("Fiber Optics"), supervisor of optics research at the Armour Research Foundation of the Illinois Institute of Technology, graduated from Agra University in India in 1948, and for the next three years supervised the design, production and testing of optical instruments at the Ordnance Factory in Dehra Dun. He did graduate work in optics at Imperial College, London, and in 1952 joined the Barr and Stroud Optical Company in Glasgow as a lens designer. He was awarded a Royal Society scholarship to start research in fiber optics at Imperial College, and in 1954 received his Ph.D. from the University of London. Kapany was a member of the Institute of Optics at the University of Rochester for two years before he joined the Armour Research Foundation in 1957. There he has initiated considerable research in fiber optics, and has also worked in image evaluation, aspheric optics and interference microscopy.

NATHANIEL KLEITMAN ("Patterns of Dreaming") retired this year as professor of physiology at the University of Chicago. Born and raised in Russia, he came to the U. S. in 1915 to study at the College of the City of New York, receiving his B.S. in 1919. After acquiring his M.A. at Columbia University in 1920 and his Ph.D. at the University of Chicago in 1923, he went

Business end of an Atlas ICBM. Atop this Air Force intercontinental ballistic missile is a compact but tremendously complex re-entry test vehicle. With its instrumented payload, it will hurtle thousands of miles to a pin-point target in a matter of minutes. It will soon be on the assembly line at Avco, where operational re-entry vehicles for Titan and Minuteman are already being produced.

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abroad to study at the universities of Utrecht and Paris, returning in 1925 to join the faculty at Chicago, where he has taught for the past 35 years. Kleitman has been "thinking of going to Bali, whose inhabitants," he says, "have strange sleeping habits. I devote my free time to writing up data gathered many years ago and to the preparation of a revised edition of my 21-year-old monograph *Sleep and Wakefulness*."

DANIEL I. ARNON ("The Role of Light in Photosynthesis") is professor of cell physiology at the University of California and biochemist at the University's Experiment Station. He was born in Poland in 1910 and came to the U. S. to do his undergraduate and graduate work at California, where he acquired his Ph.D. in plant physiology in 1936. Except for service with the Army Air Force in World War II, a year at the laboratory of David Keilin at the University of Cambridge and a year as Senior Fulbright research worker at the Max Planck Institute for Cell Physiology (where he worked with Otto Warburg) Arnon has spent his entire professional career at California. His early research in trace elements in plants led to the discovery, with Perry R. Stout, of the role of molybdenum in green plants and of vanadium in green algae. His later studies of photosynthesis have come about as a result of his interest in the function of such trace elements in plant nutrition.

F. FRASER DARLING ("Wildlife Husbandry in Africa") is vice president and director of research of the Conservation Foundation in New York. Born in Scotland in 1903, he took his Ph.D. at the University of Edinburgh, where he later became senior lecturer in ecology and conservation. From 1944 to 1950 he directed the West Highland Survey, a study of the influences of land use and environmental change on the ways of life in the Scottish Highlands. Darling's work has taken him to Alaska and other parts of North America, to Northern Rhodesia and the Mara region of Africa, and to remote islets in the North Atlantic, where he lived for several years while studying the life history of the Atlantic gray seal. He first came to the U. S. as a representative of UNESCO and served for a number of years as a member of the scientific advisory council of the Conservation Foundation before being appointed to his present post in 1959. He has written seven books about his various studies, of which the

NEW IDEAS IN COPPER ALLOY ROD AND WIRE

Interesting things happen when you add a spot of zirconium or chromium to copper—four high-conductivity coppers that boost production, cut cost of machining—even plain old free-cutting brass rod is going fancy.

There's a quiet revolution going on in copper metallurgy. Research and development teams are expanding the useful knowledge of copper and copper alloys in an effort to define the properties most suitable for specific engineering applications.

STABILITY at elevated temperature, combined with good electrical conductivity, is probably a combination most sought after by design engineers and by our industry's research teams. Two alloys are now commercially available, and the alloy systems are unique. Chromium copper and zirconium copper are heat-treatable alloys with good stability of mechanical properties up to temperatures in the order of 600 F.

CHROMIUM copper in the fully heat-treated condition following a solution anneal will exhibit properties combining a tensile strength of about 75,000 psi with conductivity of approximately 80% IACS. Zirconium copper has good stability characteristics at elevated temperatures and conductivity of 90 to 95% IACS; the strength properties developed by heat treating are, however, somewhat lower than chromium copper.

SEVERAL other heat-treatable copper alloys with intermediate properties are gaining recognition in the connector and electronics fields. These alloys fall into a conductivity range of 35 to 65% IACS, with tensile strengths 90,000 to 100,000 psi. The most popular alloy systems are the copper-nickel-phosphorus and copper-nickel-silicon series with modifications for free machining or other specific requirements. These alloys have a solution annealing temperature about 100 to 200 C lower than the chromium and zirconium coppers.

THE WIDESPREAD use of panel or harness construction for linking segments of electrical control devices has made the requirement for free-cutting coppers mandatory. Screw machine shops are fabricating these connector components of various designs by the millions. Currently the most popular free-cutting coppers are leaded copper with conductivity of about 98% IACS, and tellurium and sulfur coppers at about 95% IACS. Some of these free-cutting coppers have residual oxygen and can become brittle or gassed under the usual conditions contributing to this phenomenon. All, however, can be obtained with a combination of deoxidizers or oxygen-free copper. In the case of the deoxidized variety, some slight sacrifice in conductivity will be noticed. Ordinary usage very seldom requires conductivity in excess of 90% IACS – and this presents no problem for these coppers.

ALL of these coppers can be cold worked without too much trouble. They can be supplied in a suitable wire temper for cold heading and secondary operations designed around the basic alloy system. Up to now there has not been too much interest in these alloys for wire forming or heading operations. Close dimensional tolerances may be the reason for the reluctance of the heading people to get into the electrical connector business. Alloys are available with the ductility and mechanical properties necessary for this type of forming. It would appear that some of the products could be made more economically by cold-heading or wire-forming operations.

RECENT TRENDS have also affected the old brass and copper reliables. There can't be any product more prosaic than free-cutting brass rod; it is the cheapest of such commodities and at one time was the easiest to process—all one had to do was to extrude, draw to finish dimensions, and ship. In many cases this practice won't work today. Deep drilling, roll threading, knurling, staking, slotting, etc., have complicated the picture, but the latest efforts of the screw machine builders have laid this ghost to rest. We now hear of beta-free rod for close tolerances on deep-drilling applications. Similar grain structures, but not necessarily the same temper, are required for roll threading, knurling and staking or whenever extra ductility is needed. Along with the consideration of grain structure, it has been necessary to take advantage of the broad chemical composition range for free-cutting brass. Most suppliers divide the standard range into two parts, utilizing the lower copper range for the larger sizes that will normally be machined on the heavier, faster screw machines where chip breaking and clearing the tools are the most important considerations. This might be considered the rough, breakdown type of stock.

FOR the smaller diameters, specialization has been the watchword. Depending on specific needs, you can now obtain free-cutting brass rod with all-alpha, fine-grained structure or an alpha-beta fine-grained extruded structure, or possibly a combination of both. For certain applications you might need a coarse-grained, all-alpha structure. Lead dispersion and lead content are other variables that can and will be controlled to meet fabricating or end-use requirements.

IN the cold-heading industry, advantage is being taken of the wider selection of copper and copper alloys that is available today. The nickel silvers, phosphor bronzes, and silicon bronzes combine good ductility and high strength with excellent corrosion resistance. The whole range of common brasses has specific applications and can be tailored to various heading operations.

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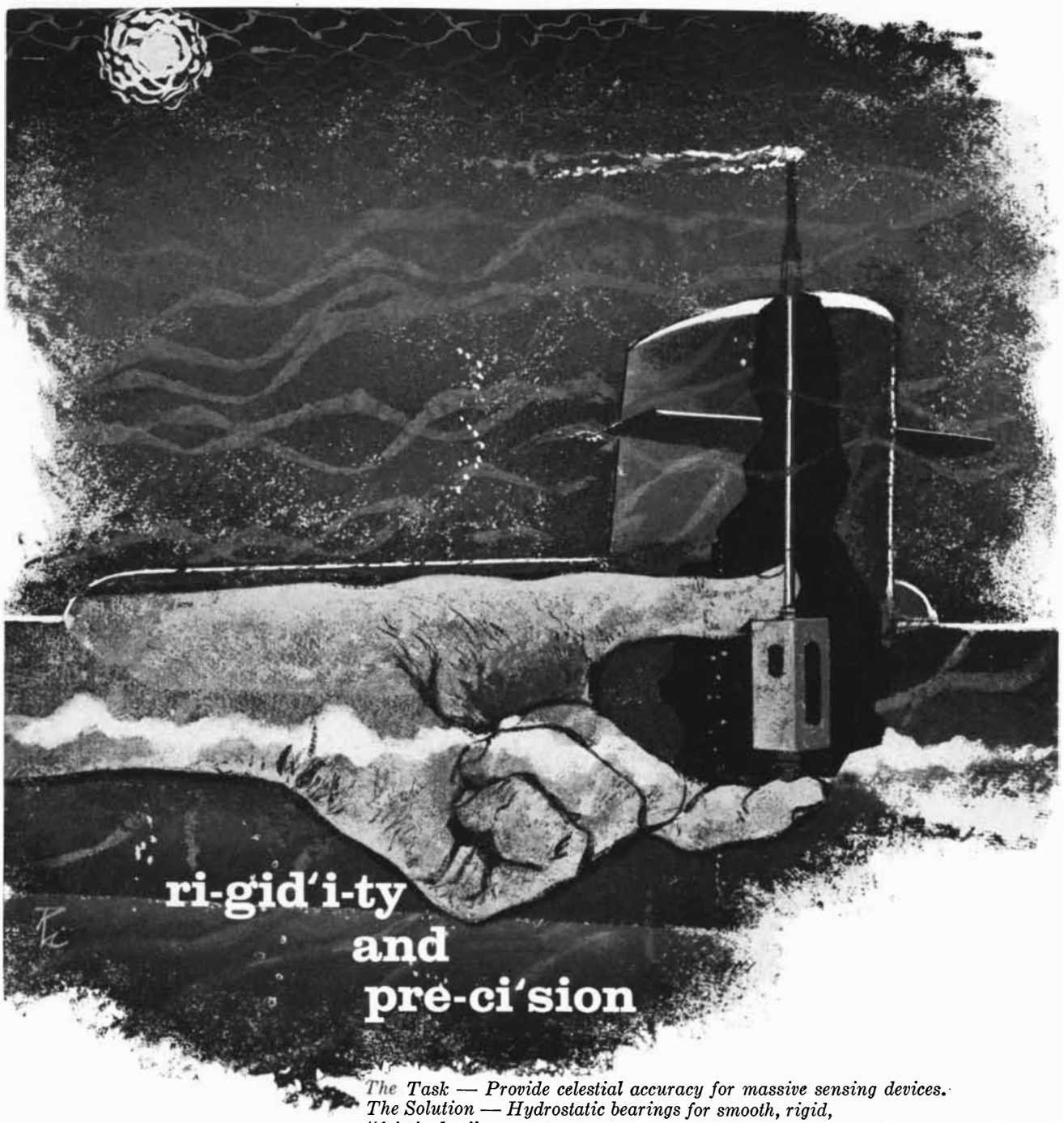
latest, *Wildlife in an African Territory,* appeared this year.

F. REIF ("Superfluidity and 'Quasi-Particles'") is associate professor of physics at the University of California. In 1939, at the age of 12, he left his native Austria, spent the first two years of World War II in France, and then came to the U. S. in 1941. Following undergraduate work at Columbia University he studied physics at Harvard University, where he acquired his Ph.D. in 1953. From 1953 until this September, when he joined the faculty at California, Reif was a joint member of the department of physics and the Institute for Metals at the University of Chicago. His interest in superfluidity is relatively recent; most of his research has been in solid-state physics and nuclear-magnetic resonance.

R. L. S. BRUCE-MITFORD ("The Treasure of St. Ninian's") is keeper of the British and Medieval Antiquities in the British Museum. A graduate of the University of Oxford, he was assistant keeper of Ashmolean Museum in 1937 and of the British and Medieval Antiquities in 1938. During World War II he served with the British army. In 1954 he assumed his present position as well as that of deputy keeper of the British Museum. At present he is engaged in writing the first volume of the *Oxford History of English Art* and a report of his excavations of a Cornish village of the ninth to 11th centuries.

JOHN H. REYNOLDS ("The Age of the Elements in the Solar System") is assistant professor of physics at the University of California. He was born in Cambridge, Mass., in 1923 and attended Harvard University. After graduating in 1943 he served with the Navy for three years. From 1946 to 1950 he did graduate work at the University of Chicago, where he came in contact with Enrico Fermi, Harold C. Urey and Mark G. Inghram, the three men, he says, who most influenced his subsequent work. Since joining the faculty at California in 1950, his research interests have come to center on studies of isotopes in geologic and meteoritic samples. The results of his mass-spectroscopic studies of the Richardton stone meteorite are discussed in the present article. Reynolds is now midway through a two-year research professorship at California's Miller Institute for Basic Research in Science, which "has let me really bear down on meteorite research."



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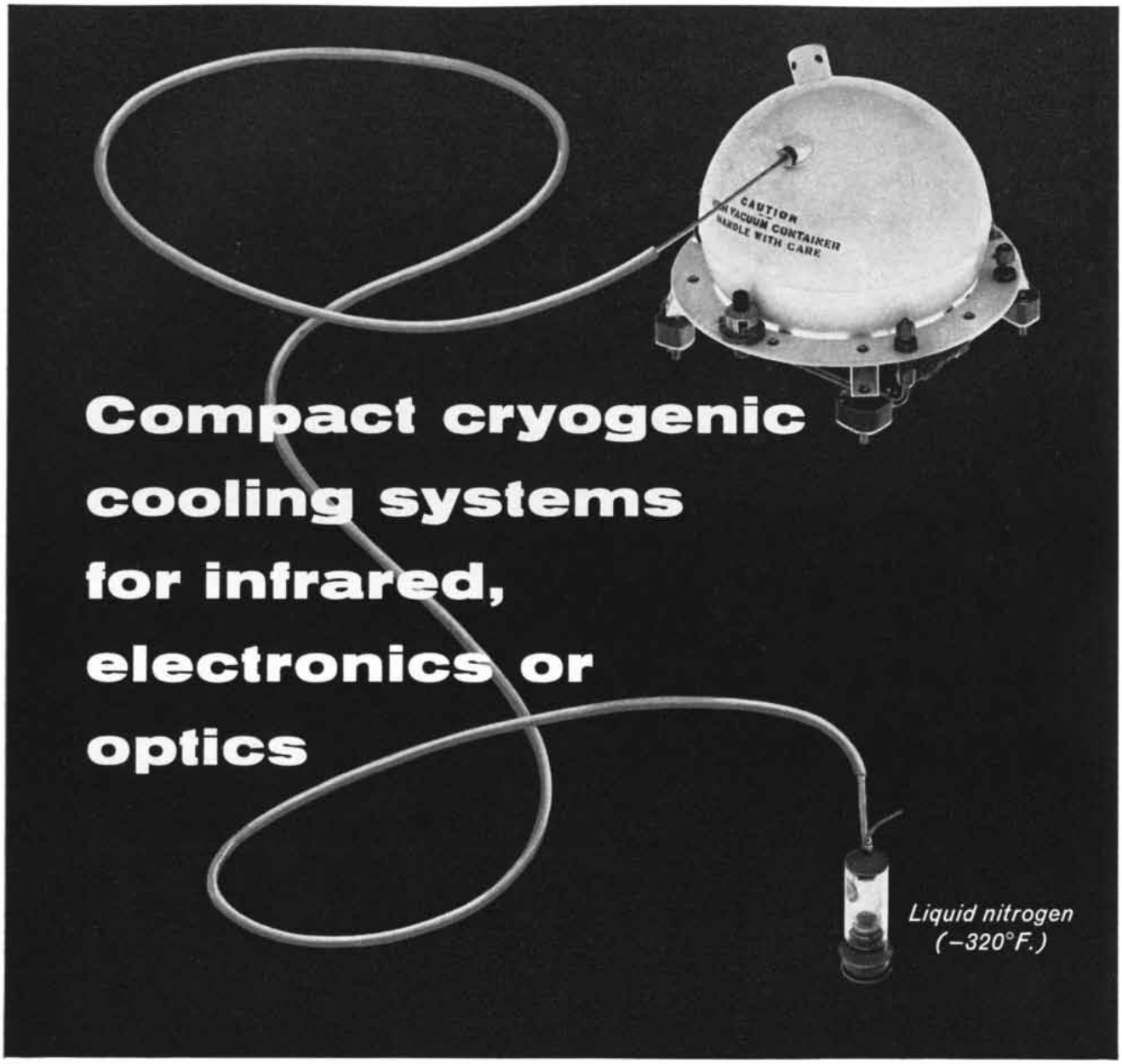

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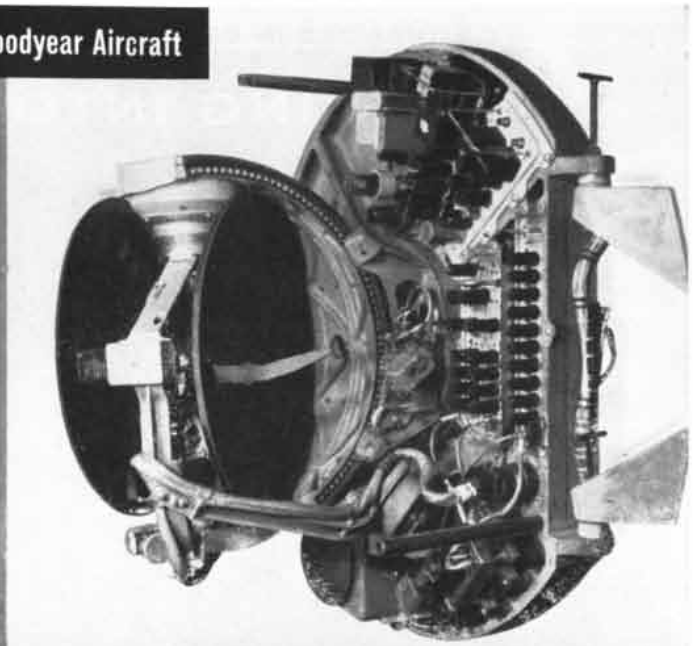

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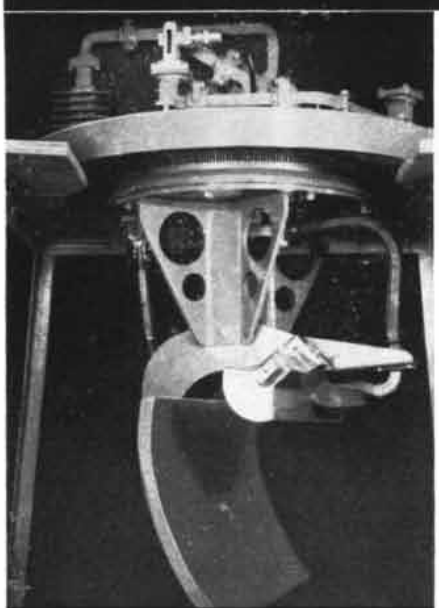

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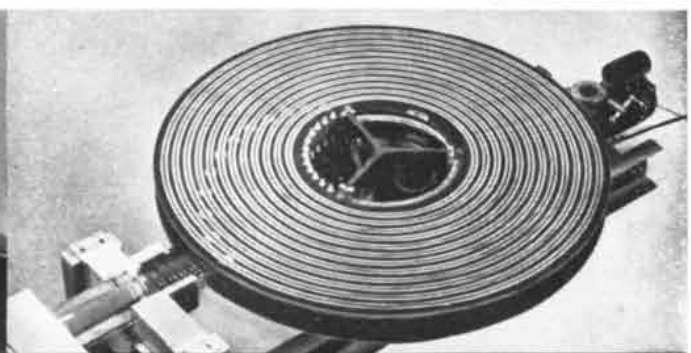

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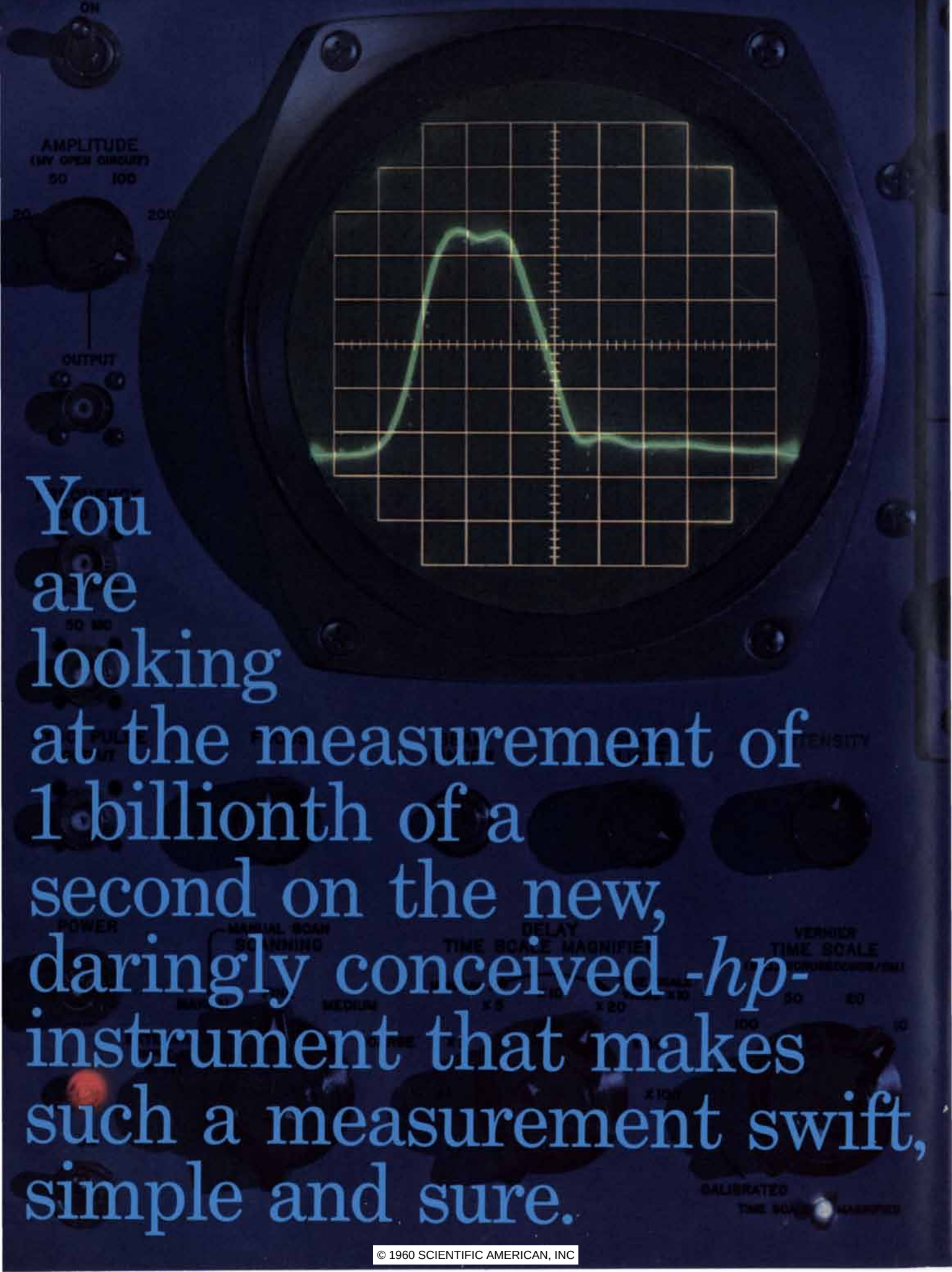

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is dependent on precise measurement in extremely high-speed electronics, "fast" circuits which commonly generate repetitive phenomena lasting as briefly as one billionth of a second.

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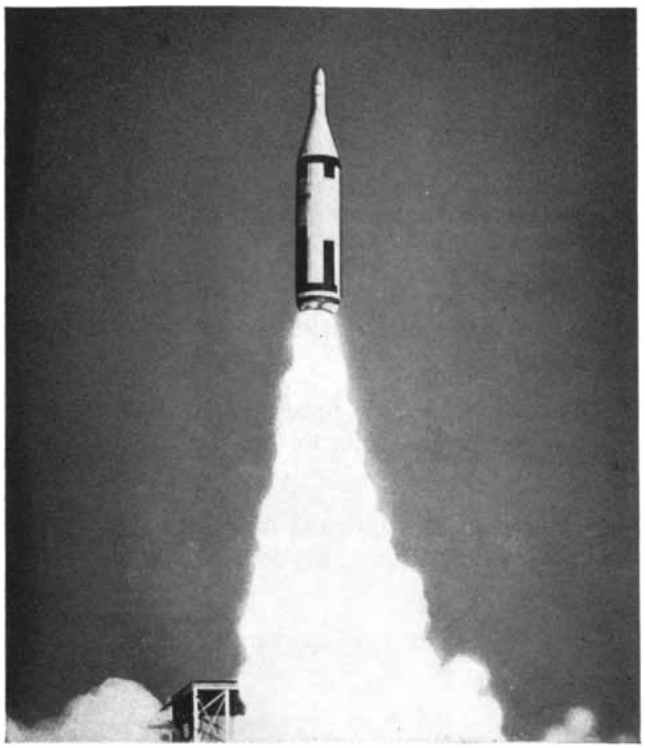

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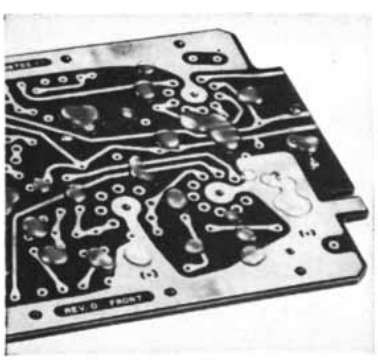

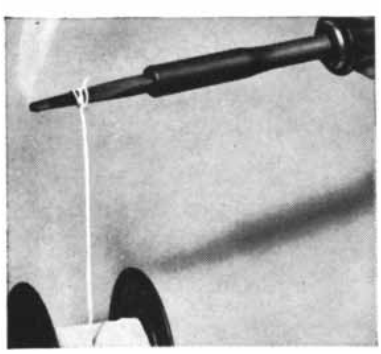

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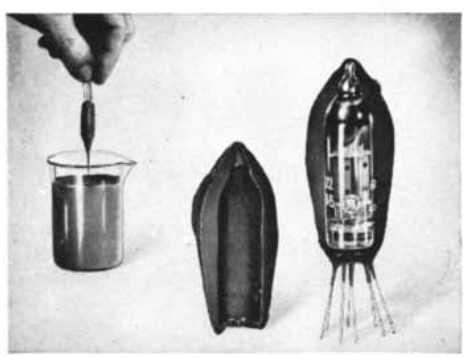
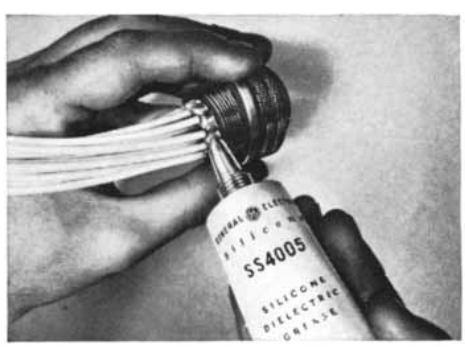
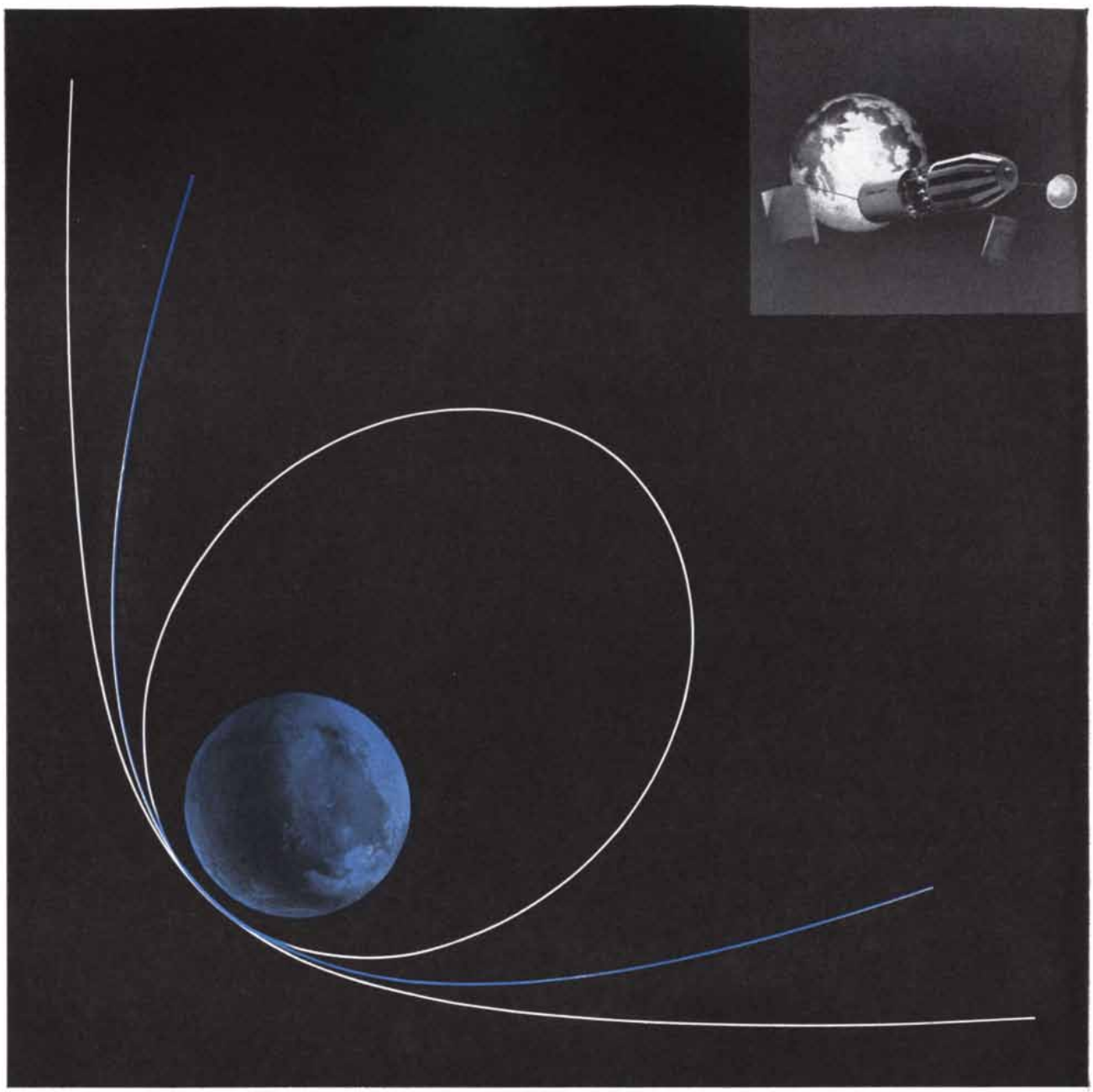




GENERAL ELECTRIC



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Marie Curie...on idealists

"Humanity, surely, needs practical men who make the best of their work for the sake of their own interests, without forgetting the general interest. But it also needs dreamers, for whom the unselfish following of a purpose is so imperative that it becomes impossible for them to devote much attention to their own material benefit. No doubt it could be said that these idealists do not deserve riches since they do not have the desire for them. It seems, however, that a society well organized ought to assure workers the means for efficient labor, in a life from which material care is excluded so that this life may be freely devoted to the service of scientific research."

—*Pierre Curie, 1923*

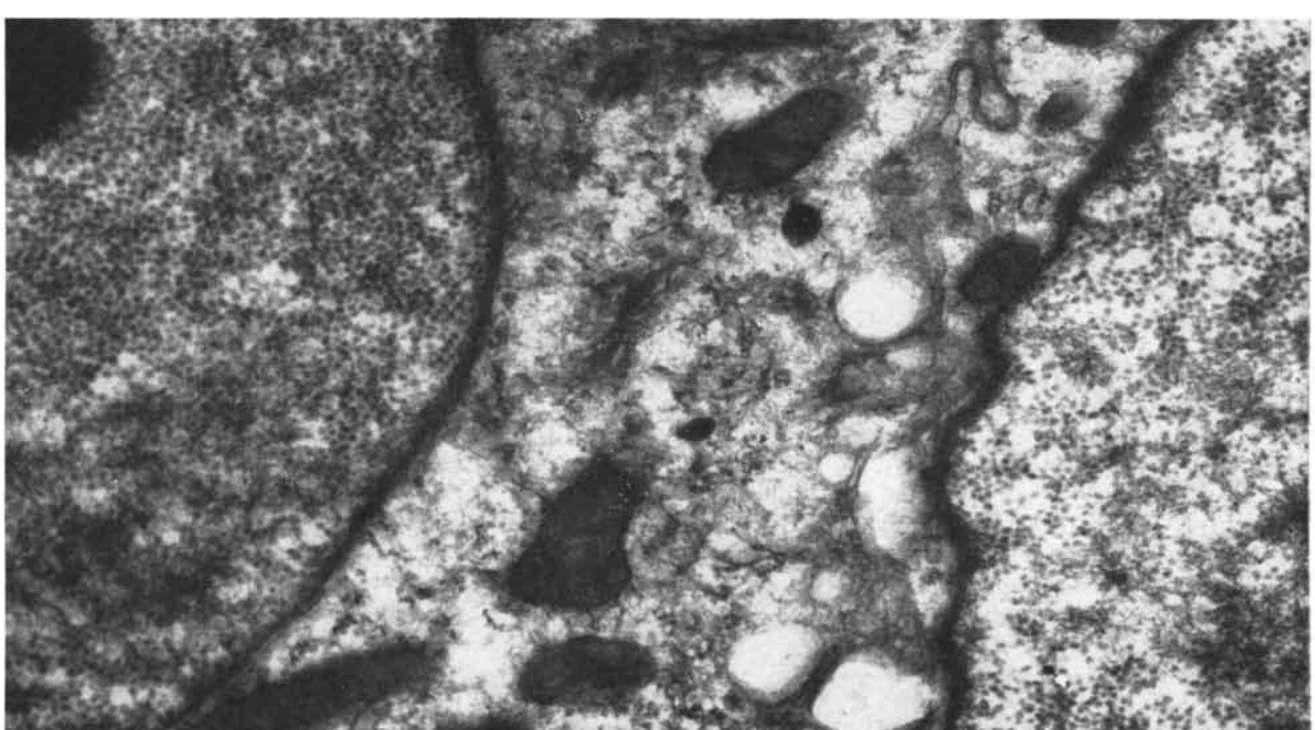
Established 1845 SCIENTIFIC AMERICAN November, 1960 Volume 203 Number 5

The Polyoma Virus

This recently discovered organism causes a variety of malignant tumors in laboratory animals. Studies of its action lend weight to the idea that viruses may be responsible for human cancers

by Sarah E. Stewart

The idea that some infectious organism causes cancer is as old as the germ theory itself. Once Louis Pasteur had demonstrated the infectious nature of many of the worst maladies of man and beast, what could be more logical than to suppose that a germ provokes the transformation of the body's own tissue into a proliferating cancer? Much time, effort, disappointment and heartache went into the futile search for a cancer germ. One organism after another, isolated from cancerous tissue, was held up as the causative agent, only to be proved a harmless denizen or a secondary invader. Meanwhile investigators demonstrated a bewildering diversity of other factors in the induction of cancer—mechanical irritation, X-rays, sunlight, hereditary and embryological factors, and exposure to any of a large



POLYOMA VIRUSES appear as small dark granules in this electron micrograph of two cells from the kidney of an infected mouse. The viruses, enlarged about 39,000 diameters, are present in great numbers in the cell nuclei at left and right, but not in cytoplasm at center. The electron micrograph was made by Leon Dmochowski of the M. D. Anderson Hospital in Houston, Tex.

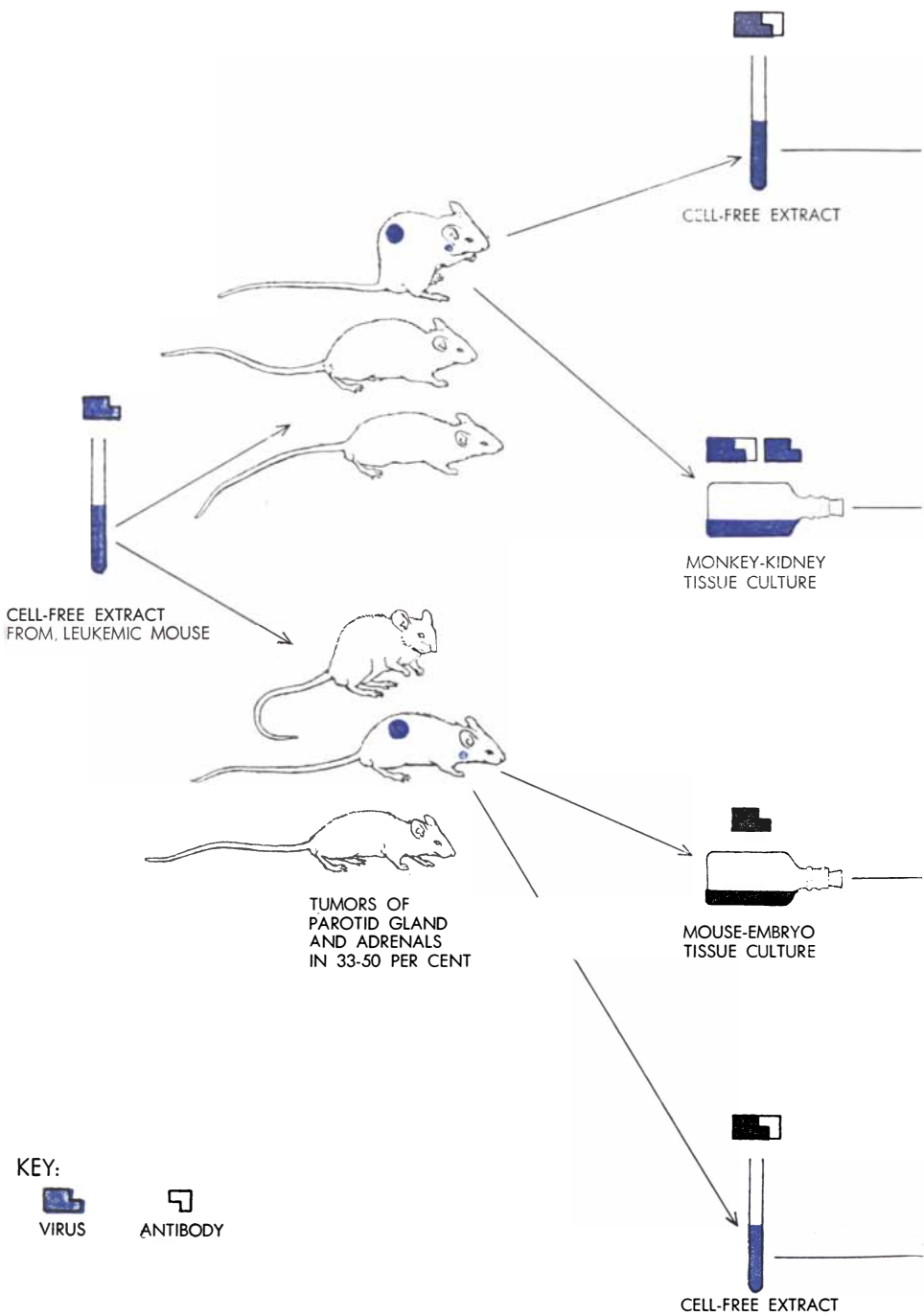
catalogue of chemicals. Many workers became convinced that cancer arises from changes within the cell, perhaps triggered by the operation of factors outside the cell, but without the incorporation of any external agent.

Except for the discovery that viruses, the smallest infectious organisms, cause a few rare cancers in lower animals, the infectious theory of cancer fell into disrepute. I might add parenthetically that embracing an unpopular scientific idea, like adopting an unpopular economic or social theory, is fraught with difficulties. Accordingly the major effort in cancer research flowed into other channels.

During the past few years, however, cancer research has taken a new turn, and infection is coming once more to the fore as a possible cause of the disease. As if to demonstrate the danger of discouraging unpopular theories, a virus has turned up that causes a score of different kinds of cancer in mice and other rodents. This virus has a high degree of virulence, causing pathological changes other than cancer in tissue cells; it can be produced in quantity in tissue culture; it has been isolated and visualized in electron micrographs; and it has been disassembled into its major chemical components. The "polyoma" virus and the mechanism by which it produces its malignant effects are now being studied in many laboratories in this country and abroad as a model for the detection and investigation of the viruses that may cause malignancies in man.

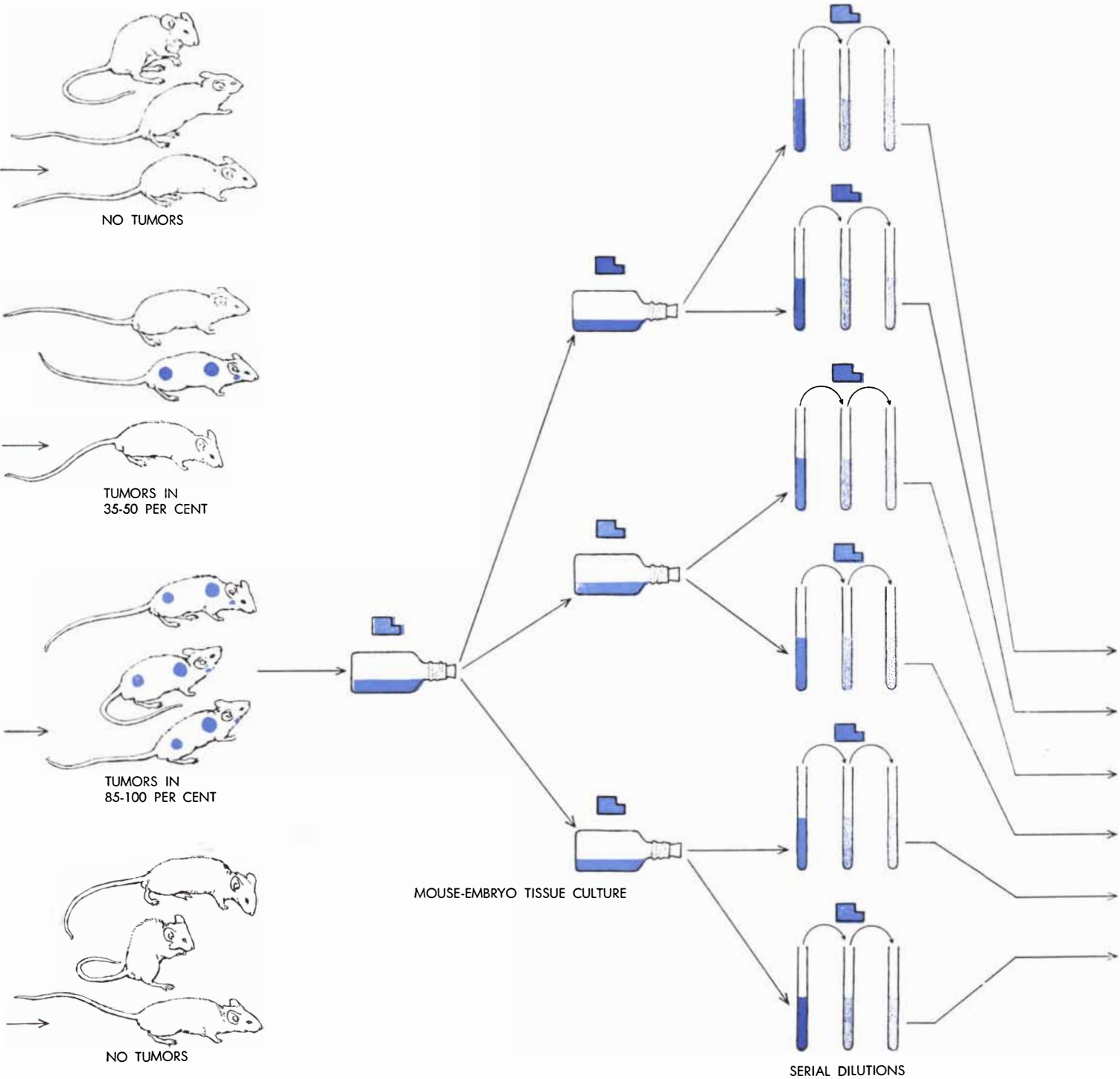
Some of the ablest members of the first generation of cancer investigators were attracted by the virus possibility. In 1908 Vilhelm Ellerman and O. Bang of Denmark succeeded in transferring fowl leukemia from one animal to another by cell-free organ extracts and filtrates of blood. The cancer was accordingly attributed to a "filterable" virus, that is, an agent so small that it could pass through the pores of a filter that held back cells and the smallest known bacteria. Soon afterward Peyton Rous of the Rockefeller Institute secured similar evidence for the existence of a virus that causes tumors in the muscle tissue of chickens. It was not until 1932 that a virus-caused cancer was demonstrated in mammals. Rous, J. W. Beard and Richard E. Shope of the Rockefeller Institute, and later Francisco Duran-Reynals of Yale University, working with a virus that Shope had found in a nonmalignant papilloma of wild rabbits, succeeded in producing malignant tumors in rabbits. They were unable, however, to transfer the malignancy by cell-free filtrates. In 1936 John J. Bittner of the University of Minnesota discovered in a highly inbred strain of mice a naturally transferable cancer virus that is transmitted by milk to the nursing offspring. These few successes stood out among a great many failures in the effort to find viruses in mammalian cancers, and interest in the possibility waned.

Then, in 1951, Ludwik Gross of the Cancer Research Unit of the Veterans Administration described the induction of leukemia in newborn mice by means of a cell-free extract of tissues from mice



DISCOVERY AND CULTURING OF VIRUS is illustrated by the sequence of drawings on these two pages and the two following pages. When a cell-free extract from leukemic mice was injected into healthy mice (*far left*), the mice surprisingly developed not leukemia but tumors of the parotid and adrenal glands (*second from left*). But an extract of the tumorous glands failed to produce new tumors in healthy mice, apparently because it

suffering with spontaneous leukemia. As a microbiologist, I have for many years been intrigued with the possibility that viruses may be involved in causing cancers of different kinds in man. A logical step in this direction was to attempt confirmation of Gross's observation. This was done at the pathology laboratory of the U. S. Public Health Service Hospital in Baltimore; we employed an inbred strain of mice, believed to be the same as the one Gross had used, and a hybrid strain. To our surprise leukemias developed in the hybrid mice but not in the inbred line. Instead, at the age of 10 months, many of the animals showed a strange enlargement of the parotid glands (the salivary glands that become involved in mumps). Upon dissection and examination of the glands, we found them taken



contained antibodies from the infected mice and only small quantities of virus. Virus was freed of antibodies by growing it in tissue culture (*third from left*). Tissue culture also made it possible to grow the virus in large numbers. When injected into mice, virus grown on mouse-embryo tissue caused tumors in 85 to 100 per cent (*fourth from left*). To prove that a single virus was responsible, virus from the tumors was passed through several batches of tissue culture (*third and second from right*); extract from culture was then diluted so that final test tube contained very few viruses (*far right*). Sequence continues on the next two pages.

over by a hitherto unreported malignancy. Gross simultaneously made the same finding in some of his mice.

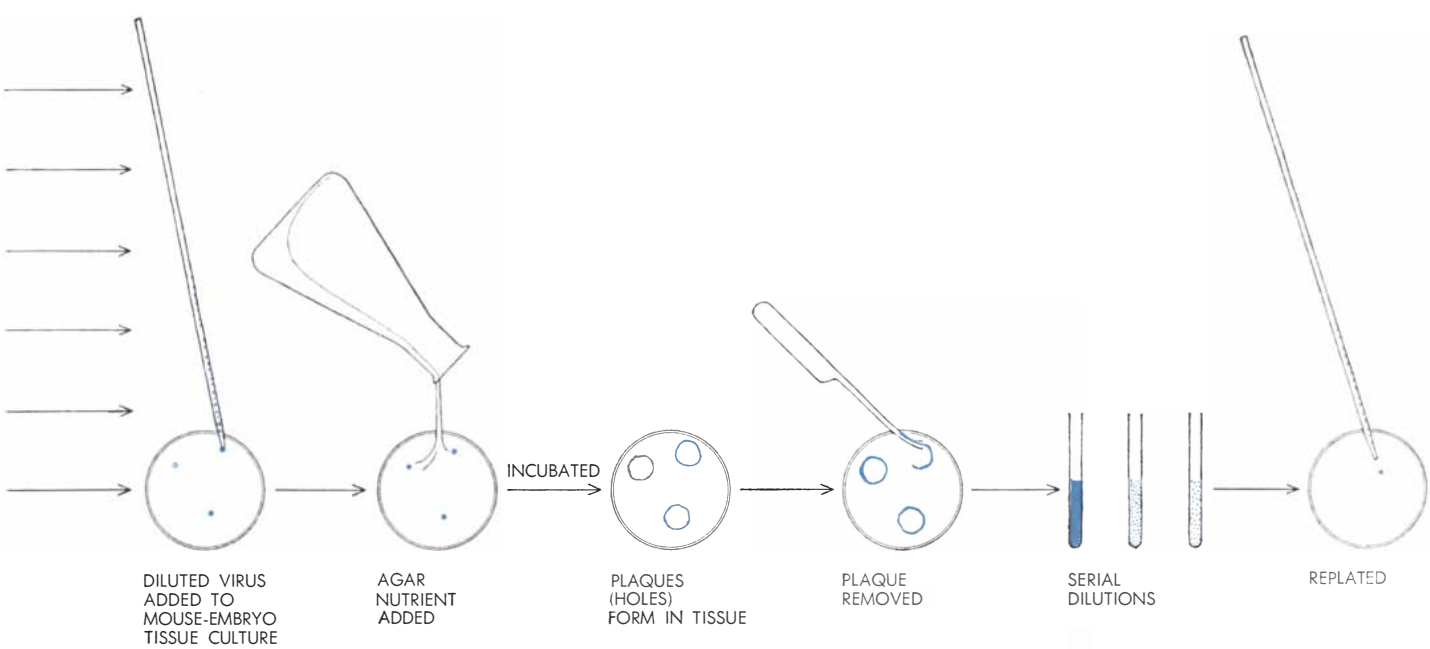
Here was something really interesting: a filterable agent (or agents) that can cause leukemia or parotid cancer in mice! Our next step was to try to demonstrate the presence of this agent in the tissue of the malignant parotid glands. We prepared cell-free extracts of the parotid tumors and inoculated them repeatedly into newborn mice—those wriggling pink bits of life that have contributed so much to this research. The results were discouraging. What had become of the agent? If we went back to the filtrate of the leukemic-mouse tissue, we could induce the parotid cancers without fail, sometimes producing tumors in the adrenal glands as well. Was the presence of the supposed virus in the parotid tumors masked in some way? Or was the virus present in such small quantity that it did not show up when it was transferred to the next series of newborn mice?

We decided to try to increase the supply of virus by the tissue-culture methods that have made it possible to produce poliomyelitis and other viruses in quantities sufficient for public-health vaccination programs. As is well known, viruses are distinguished from bacteria not only by their small size but also by the fact that they will reproduce only inside the living cell. In collaboration with Bernice E. Eddy of the Division of Biologics Standards of the National Institutes of Health, who had been doing much of the polio work and had a magnificent tissue-culture laboratory all set up, we cultured filtrates of the parotid tumors. We were able to increase the incidence of tumors in our experimental animals, but the results were not so good as we had hoped. If the agent were indeed a virus, and if we had succeeded in multiplying its numbers by tissue culture, we would be entitled to expect more conclusive evidence of virus activity.

But ours was a mouse virus. The tissue on which we were growing it had come from monkey kidney, the standard medium for the cultivation of polio virus. Perhaps monkey-kidney cells were not altogether to the taste of the virus. We changed our culture to cells taken from mouse embryos. Now the virus showed its true colors. Filterable extracts from these cultures produced tumors in 85 to 100 per cent of the mice to which the extracts were administered. And the extracts induced not only parotid and adrenal tumors but also many other kinds of cancer!

We have logged more than 20 different kinds of tumor in the inoculated mice. These tumors have involved most of the glands of the head and neck: all of the salivary glands, the lachrymal glands, the mucous glands of the air passages, and the thyroid gland. The thymus gland, an organ just above the heart which is present at birth but disappears during normal growth, was frequently involved; in many instances a tumor of this organ filled the chest cavity. Contradicting the rule that tumors of the mammary glands develop only in female mice under the excitation of the female sex hormone, the virus engendered cancers in the mammary glands of males as well. Tumors of the lungs were usually of the type that involves the mesothelium, the outer covering of the organ, and they covered the entire lung with finger-like projections that could be seen with the naked eye. Cancers of the skin that started in the cells of hair follicles often covered the entire body surface. The sweat glands, present only in the hairless surfaces of the mouse foot, also developed tumors. All of these are cancers of the epithelial cells and are classified as carcinomas. But the virus also induced sarcomas: cancers of connective tissue, bone, kidney, the lining of blood vessels and the cysts of the liver. We even found a tumor in nerve tissue that arose from the virus.

The relatively massive doses made possible by our tissue cultures had exposed a virulence in the virus that is camouflaged by its more covert action in nature. Individual mice often developed large numbers of tumors, not by spreading from a single primary site, as usually happens, but at many primary sites and in two or more tissue systems simultaneously. Moreover, the tumors appeared much more rapidly than they did after direct transfer of tissue filtrate from an infected animal.



**SEQUENCE IS CONTINUED from preceding page. Dilute virus suspension is pipetted into tissue culture (*far left*) and nutrient for cells is added (*second from left*). Viruses multiply and eat holes (plaques) in tissue (*third from left*). Each plaque is presumably made by descendants of a single virus. One plaque is cut from solidified agar (*fourth from left*), emulsified and diluted (*fifth*

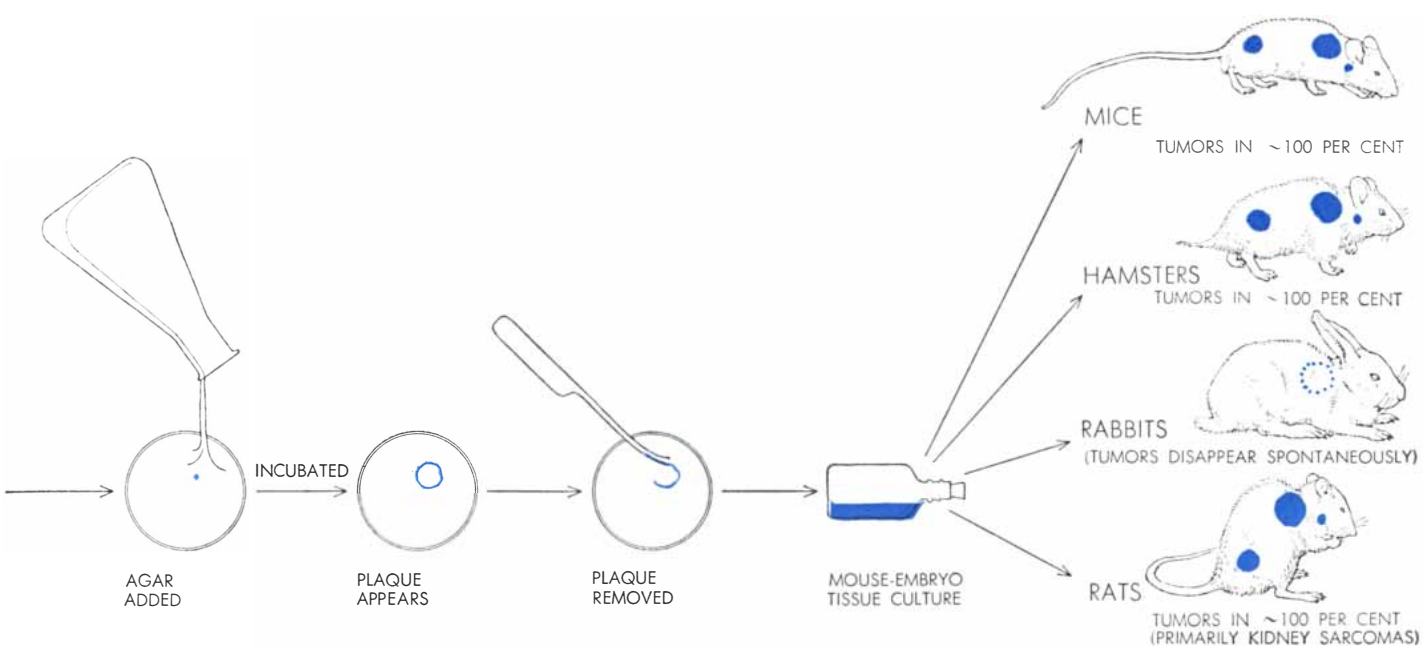
The question now was whether we had uncovered a single virus or a multitude of them. One way to make such a determination is to carry the putative mixture of viruses through a succession of tissue cultures; some of them die out, and eventually one outgrows all the others. We subjected our material to as many as 90 passages, testing the preparation at different stages, and always got the same varied spectrum of malignancies. We tried serial dilution—cutting the original tissue-culture solution to one part in 10 million or 100 million, culturing the dilution and then inoculating the mice—and got the same picture. There must be only one virus, we felt sure. Had we really proved it?

Then the virus obligingly demonstrated another of its capacities. We discovered that it was virtually eating holes in the single layer of cells in the tissue cultures; in other words, we found that it may kill a cell as well as cause it to proliferate. (Duran-Reynals had observed a corresponding action in the Rous and the Shope viruses: they sometimes cause fatal hemorrhagic and inflammatory infections in chick embryos and newborn rabbits respectively, much as other viruses do.) This finding had many important implications, but it was of greatest immediate interest because it gave us a way to determine whether the virus was a mixture of viruses or a single agent capable of producing a multiplicity of tumors. It was now possible to segregate a single virus particle in the tissue culture, much as single bacteria are isolated by the familiar plating technique. The tissue culture is inoculated with an extremely dilute virus solution and is then overlaid with a special nutrient agar and incubated. When holes, or plaques, appear thereafter in the culture, they are so far apart that each one may be taken to represent the cell damage caused by the replication of a single virus. By fishing up a single plaque, multiplying the sample in tissue culture and inoculating a newborn mouse with this material, we could be sure that a single virus was the cause of the observed effects.

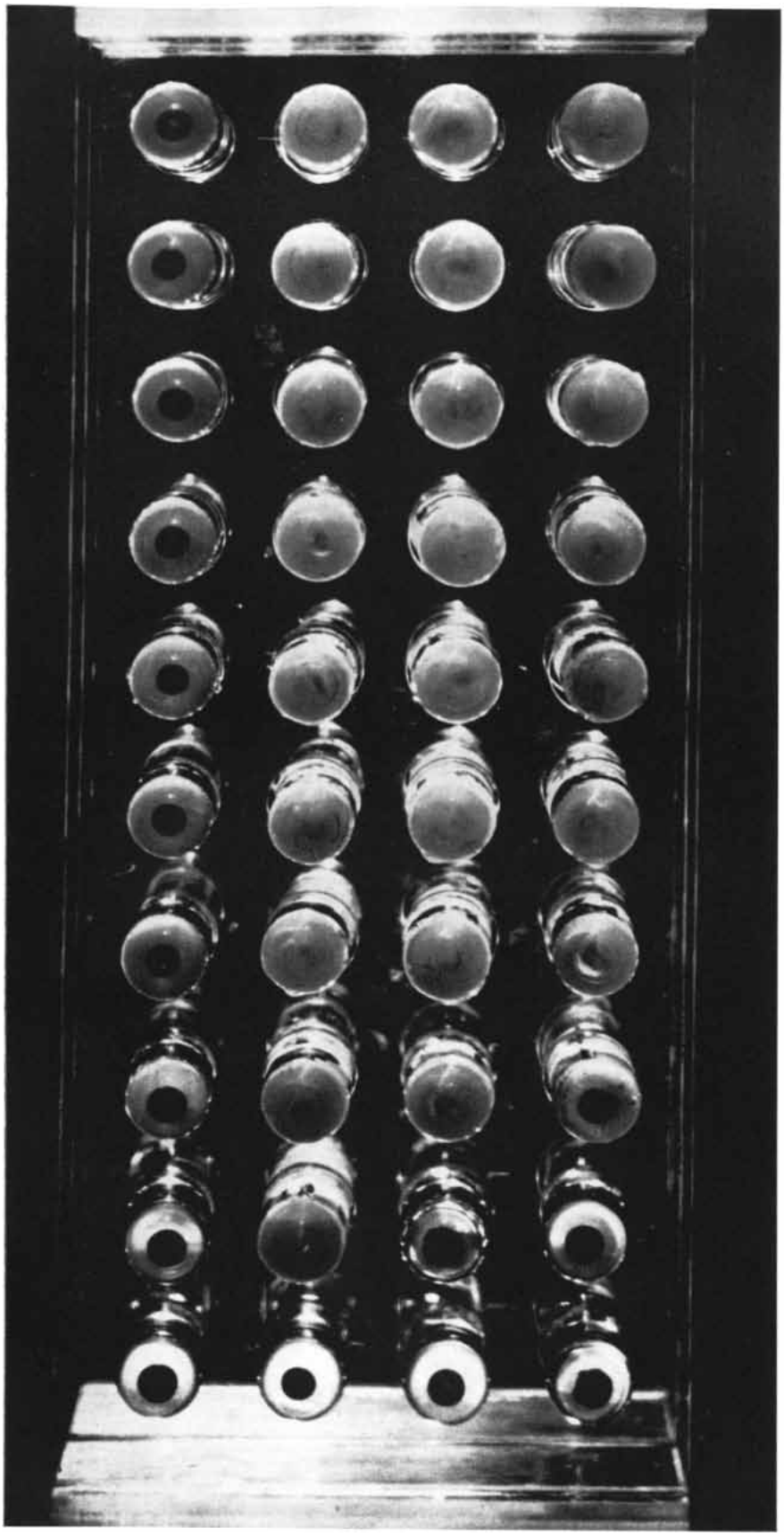
The results were as before: the same high incidence of tumors and the same varied spectrum of primary malignancies, sometimes as many as 10 different kinds in a single mouse. We could now be sure we were dealing with a single virus, and proposed the name "polyoma" in witness to its capacity to produce many different kinds of tumor. Since other cancer viruses (*e.g.*, the virus of the Lucké frog-tumor) can induce more than one kind of tumor, the original polyoma virus is now prefixed SE, for Stewart and Eddy. But no virus, to my knowledge, can induce with such infallibility the wide variety of tumors that distinguish the SE polyoma virus. It has also been established, incidentally, that the leukemia originally reported by Gross, which led us to the discovery of this virus, is caused by an entirely different virus. The polyoma virus was apparently present, along with the leukemia agent, in the tissues from which we isolated it, but it did not produce lesions in the leukemic mice.

In the course of our experiments we had been impressed to note that the virus readily infected each strain of mouse we exposed to it. This was interesting because tumor viruses such as the Bittner milk virus are usually highly specific and produce tumors in only one genetic strain. Would the SE polyoma virus cross a species barrier as easily as it had crossed the strain barrier? We inoculated rats, rabbits and hamsters. All responded with tumors. As a test of susceptibility outside the rodent family, we tried the virus on newborn monkeys; after three years these animals are still free of tumors. Interestingly enough, the tumors in the rabbits regressed after a few months. On the other hand, the hamster proved even more vulnerable to the mouse virus than the mouse itself. In the hamster the period of latency is shorter; highly malignant tumors appear within two weeks or less after inoculation. The variety of tumors, however, is more limited than in mice; the hamster shows only two major types, which involve the heart, kidneys, lungs, stomach, bowel and subcutaneous tissue.

One reason why the SE polyoma virus had not been observed in nature before we isolated it in the laboratory is to be found in this organism's great biological potency. The virus is an excellent anti-



from left). Process is repeated to ensure that only one type of virus is present (*next four drawings*). Virus is then multiplied in tissue culture (*second from right*) and injected into a variety of animals. Virus was virulent enough to cause tumors in almost all of them (*far right*). Results in mice were same as before, indicating that single type of virus caused all the different types of tumor.



HEMAGGLUTINATION TEST indicates amount of polyoma virus in a culture. Test depends on fact that viruses cause red blood cells to agglutinate (clump together). Unclumped cells settle to bottom as small disks in column of control tubes at left. (Tubes are viewed from below.) Other columns contain serial dilutions of virus from three polyoma cultures. Dilutions vary from 1:10 (*top*) to 1:5,120 (*bottom*). Solutions in second column from left contain most viruses, agglutinating even in a 1:2,560 dilution (*second from bottom*).

gen, that is, it readily provokes the production of antibodies, substances that combine with it and render it less harmful. The antibodies to the virus appear in the circulation of any animal inoculated with it, with or without the appearance of tumors. Even animals that do not receive an injection of the virus, but simply share the same laboratory quarters, show antibodies in their blood. Latent infection with the virus, indicated by the presence of antibodies, has been found in 80 per cent of the mice in some colonies. Human beings show the same response; some of us who have been working with the virus for years have developed antibodies against it.

Among mice in nature the virus is spread by saliva and excreta. The antigenic response provoked in the host would account for the rarity of spontaneous tumors in infected colonies. Antibodies are passed to the offspring by nursing mothers through their milk. In order to secure our results we had to produce in tissue culture quantities of the virus in the absence of antibodies.

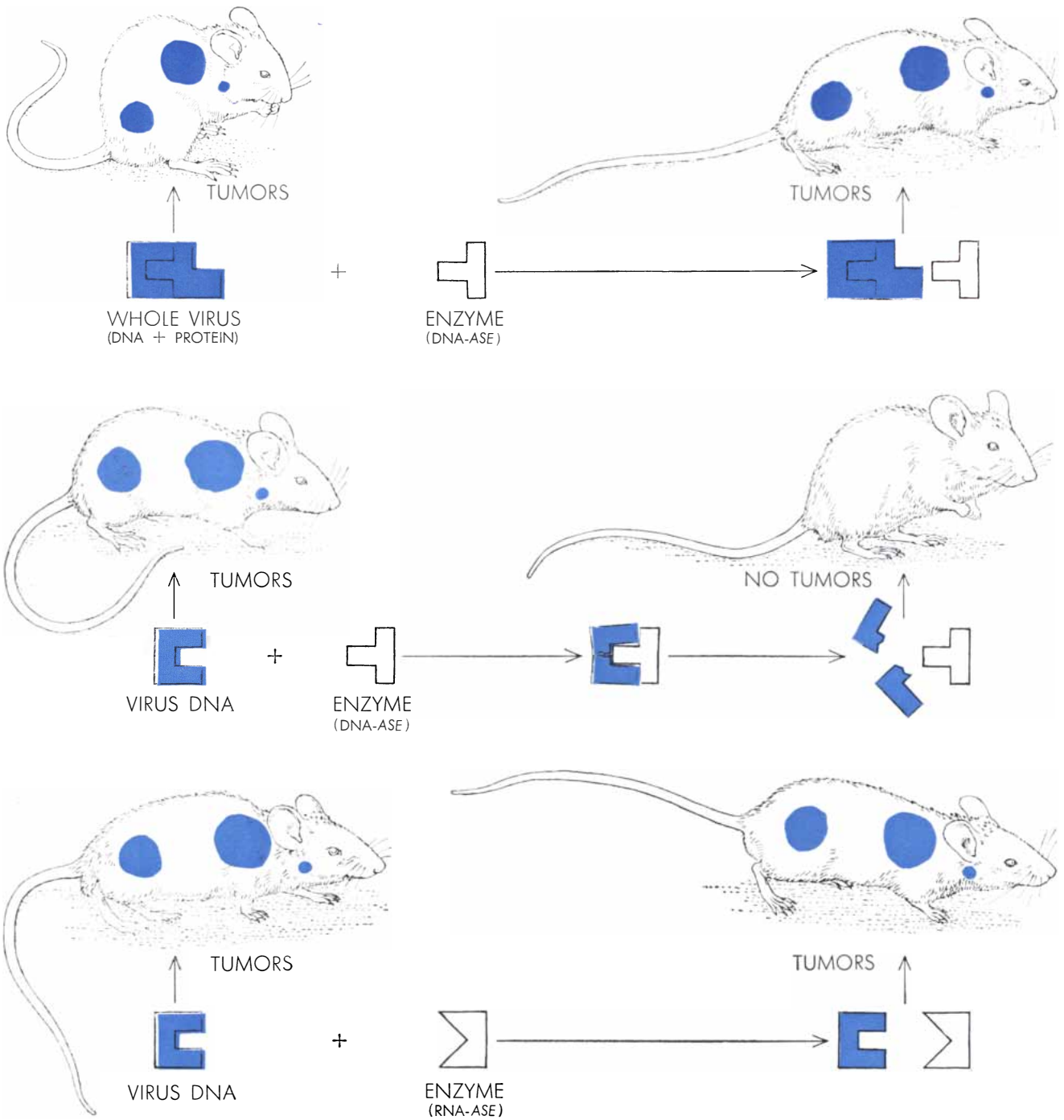
The presence of antibodies can be reliably demonstrated by mixing the serum containing them with virus solution and injecting the mixture into susceptible animals. Where the virus alone secures 100-per-cent tumor induction, the mixture produces no tumors. Nor do tumors develop when the serum and the virus are injected separately but at the same time. If the serum is injected just one hour later, however, it confers no protection. Apparently once the virus has entered a susceptible cell it is protected from the action of the antibodies in the circulating blood.

Tissue cultures offer a simpler and equally reliable way to demonstrate antibodies. No plaques or other pathological changes appear in the cultures when the virus is pretreated with immune serum. The simplest method of all is the so-called hemagglutination test. In common with other viruses the SE polyoma virus causes clumping of the red blood cells of many animals; the antibody completely inhibits this activity. Mice also develop resistance to polyoma virus that is not attributable to specific virus antibodies. This is acquired as they grow older. In order to get multiple tumors we had to take care to inoculate our subjects, taken from a virus-free colony, within 12 hours of birth. Injection by the virus after the mice are 48 hours old appears to be harmless. Such injected animals develop active immunity but no tumors. On the other hand, we found that hamsters re-

mained almost as susceptible to infection at 24 days as at birth.

How does the virus cause cancer? This is a question to excite speculation. It must be remarked, however, that the explanations for the action of the numerous other carcinogenic agents and factors are equally speculative. In the case of the virus, speculation is enriched and in part supported by the deeper understanding of the nature of viruses and their relation to life processes in the cell that has been established by recent work in this rewarding field of investigation. What is known about the behavior of other viruses, including the viruses that infect bacteria, offers many insights into the action of the SE polyoma virus.

In electron micrographs the virus appears as a small round body with a diameter of .0000027 millimeter, which places it in the class of the smaller viruses. Like other viruses, it consists of nucleic acid and protein. We have managed to break it down into these two major constituents and have shown that the nucleic acid is deoxyribonucleic acid (DNA). The same is true of the nucleic acid in most mammalian viruses, and it is significant that DNA appears to be the principal material constituent and active principle of the genetic apparatus in the nucleus of the cell. Upon inoculation



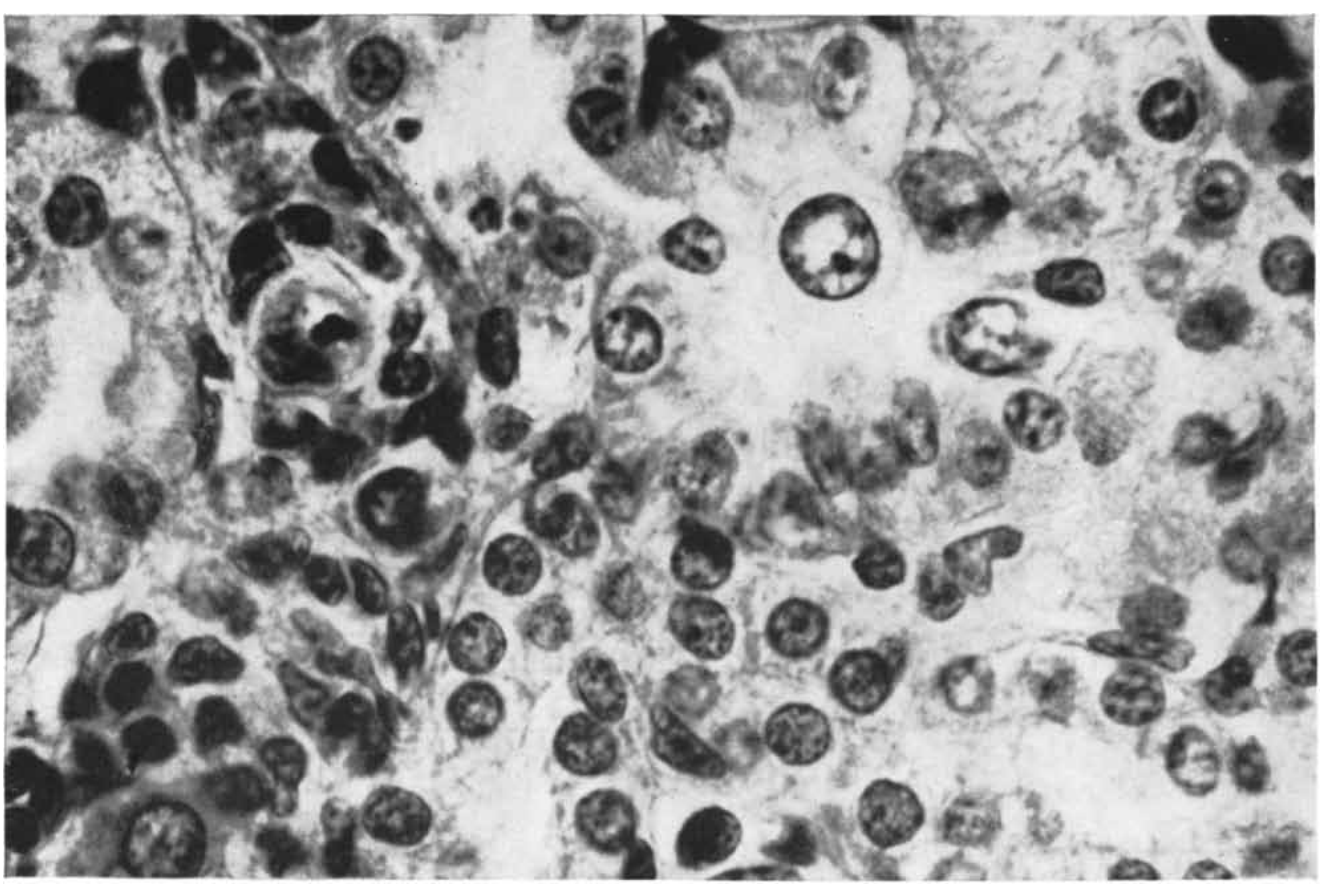
MAJOR CONSTITUENTS OF VIRUS are deoxyribonucleic acid (DNA) and protein. DNA is the active constituent. Protein protects it from deoxyribonuclease (DNA-*ASE*): the enzyme that breaks down DNA. After treatment with DNA-*ASE*, the whole virus retains the capacity to cause tumors (*top*). When virus DNA alone is treated with DNA-*ASE*, it no longer can cause tumors (*middle*). Another enzyme, ribonuclease (RNA-*ASE*), which breaks down ribonucleic acid (RNA), has no effect on DNA (*bottom*).

into a tissue culture, the naked DNA of the polyoma virus has proved to be still capable of infecting the cells, and it induces the replication of complete virus particles, containing both protein and nucleic acid. In nature the protein serves to protect the DNA from the action of deoxyribonuclease, the enzyme that breaks down DNA; it also gives a virus its specificity, determining its affinity with particular cells and exciting the production of antibodies in the host. Many other viruses have been regenerated by inoculation of their naked DNA into appropriate cells. Apparently the virus DNA takes over the metabolic machinery of the cell and puts it to work manufacturing virus. The process is dramatically demonstrated in the action of a bacterial virus: The virus sheds its protein "overcoat" outside the cell, the DNA disappears inside the cell and some time later the cell disintegrates, liberating a host of new virus particles.

The polyoma virus induces the same sort of "hot" infection when it forms plaques in tissue cultures. We have also found that cell destruction precedes the induction of tumors in the living animal. The visibly infected cells become enlarged, and their nuclei "balloon." It is probable that the enlargement of the nucleus is caused by the great number of replicating virus particles; at this point it is easy to harvest virus in quantity for chemical analysis and electron microscopy. Because of the severe damage and disruption caused by the virus replication, these cells cannot reproduce themselves and soon die. In organs where cancers develop most frequently (such as the salivary glands), enlarged and necrotic cells appear only in the early stages of tumor development; such cells are more common in the thyroid and kidneys, where tumors are rarer. It thus appears that it is the newly formed virus particles, liberated by the disrupted tissue cells, that stimulate adjacent cells or cells in other parts of the body into proliferation and tumor formation.

The virus in the less virulent infectious state in which it causes cancer (if it is the virus that does so and not some still-unrecognized by-product of viral activity) can be likened to a bacterial virus in the stage at which it causes a "temperate" (*i.e.*, latent) infection. Such a virus disappears inside the bacterium, apparently attaching itself to a DNA molecule in the nucleus and causing the cell no harm. It is replicated and multiplied as the cell reproduces itself, as if it were a normal part of the cell's own structure. Such a virus may infect a bacterial line in this latent fashion for generations and not make itself known except in the occasional disruption and breakdown of an individual cell. But the presence of the virus may also be signified by some recognizable modification in the genetic characteristics of the bacterial line. For example, a virus that has infected one strain may "transduce" a genetic trait from that strain to the genetic make-up of a second [see "'Transduction' in Bacteria," by Norton D. Zinder; SCIENTIFIC AMERICAN, November, 1958]. By inducing an analogous modification in the genetics of a tissue cell, the polyoma virus may disengage the cell from the controls that keep it functioning as a part of an organism and loose it on the career of wild proliferation that is cancer.

There are many viruses, in addition to those cited in this discussion, that produce a rapidly necrotizing and inflammatory reaction in the tissues of young, susceptible animals, bringing about the complete disruption and death of the infected cells and often, if enough cells



BALLOONING NUCLEI appear when cells are invaded by polyoma virus. In this photomicrograph of the kidney of a mouse, ballooning nuclei are visible in prominent cell at upper right center, and in another at left. The cells are magnified about 1,500 diameters.

are involved, the death of the host. In the older, more resistant animal or tissue, however, the same virus takes a more temperate and insidious approach. It allows the cell to live and proliferate and, at the same time, replicate virus. Such an arrangement might go on for long periods of time. I believe it is in such situations that viruses cause malignancies to arise.

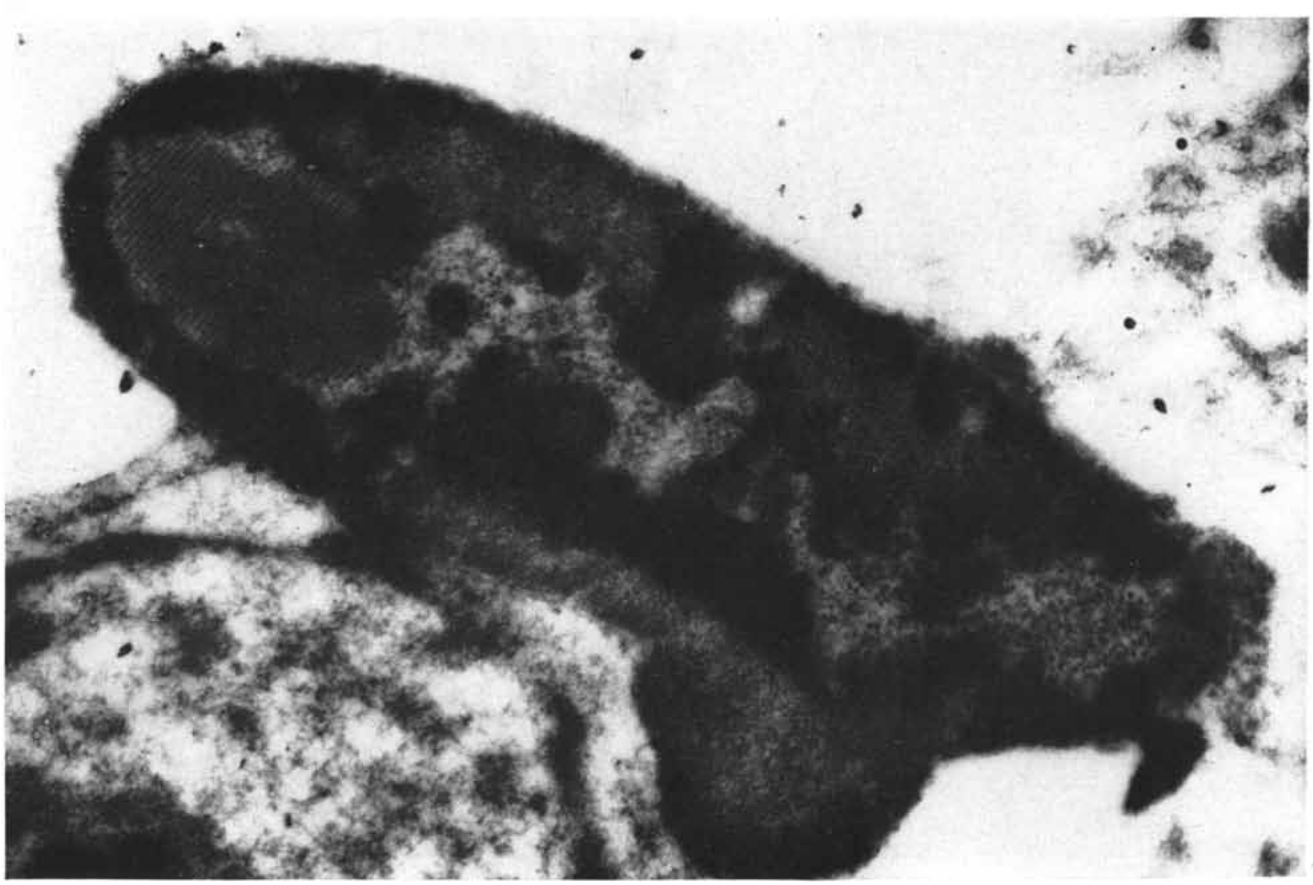
The cancer-inducing virus may occur in complete and demonstrable form in the early stages of tumor formation, as in the first phase of polyoma virus infection. But when it deranges the growth process of the cell, the virus is present only in a masked or incomplete form. Very likely its nucleic acid component is all that is there, incorporated into the genetic material of the cell itself. In this state the virus is no longer antigenic nor demonstrable by any known means. It announces its presence only in the pathological appearance and behavior of the infected cell.

For a virus to produce a cancer, therefore, a delicate balance must be established between the virulence of the virus and the resistance of the host. Too little resistance leads to a generalized infection and the death of the host. Too much resistance suppresses the capacity of the virus to produce an ordinary infection, and the virus either dies out or goes into hiding until a more opportune time for its malignant effect presents itself.

The acceptance of viruses as a cause for all cancers is a long way from universal. Many investigators still adhere to the idea that cancer arises from changes within the cell. They cite the multiplicity of external factors implicated in the induction of cancer as evidence that no external agent need invade the cell. But I believe that there are strong arguments in support of the virus theory.

Virologists have only recently begun to demonstrate the ubiquity of viruses and the variety of ways in which they manifest their presence in single-celled organisms and in the tissue cells of plants and animals. In the past 10 years some 70 new specifically human viruses have been established and studied in the laboratory. Add to these the human viruses of longer standing, plus the animal and insect viruses capable of infecting man, and one arrives at quite an impressive number. Nor is it necessary to assume a different virus for each cancer, though there are certainly enough to go around. It has been shown repeatedly that a single virus can produce a variety of effects, depending upon such circumstances as the dose and virulence of the virus, the presence of antibodies and other inhibitory substances, the ability of the virus to mutate and adapt itself to new tissues and new species, the presence of chemical agents foreign to the organism (as well as hormones and other substances produced within it), and the age, resistance and genetic make-up of the host. Furthermore, viral causation is entirely compatible with the operation of external factors in the physical environment of the organism. It is well known, for example, that a latent virus-infection in bacteria can be activated by many of the chemicals and the wavelengths of radiation that induce cancer in the tissue cells of animals and humans.

There is at present no way to prove that cancer ever arises without the presence of a masked virus, so the possibility exists that a virus is always present. Conversely, it has been shown that viruses are unequivocally responsible for many animal malignancies. In the words of Duran-Reynals, "viruses are in the cancer problem to stay."



VIRUSES IN NUCLEUS form crystalline pattern at upper left. This electron micrograph of polyoma virus in a tissue-culture cell was made by Leon Dmochowski and Clifford E. Grey of the M. D. Anderson Hospital. Nucleus is magnified about 35,000 diameters.

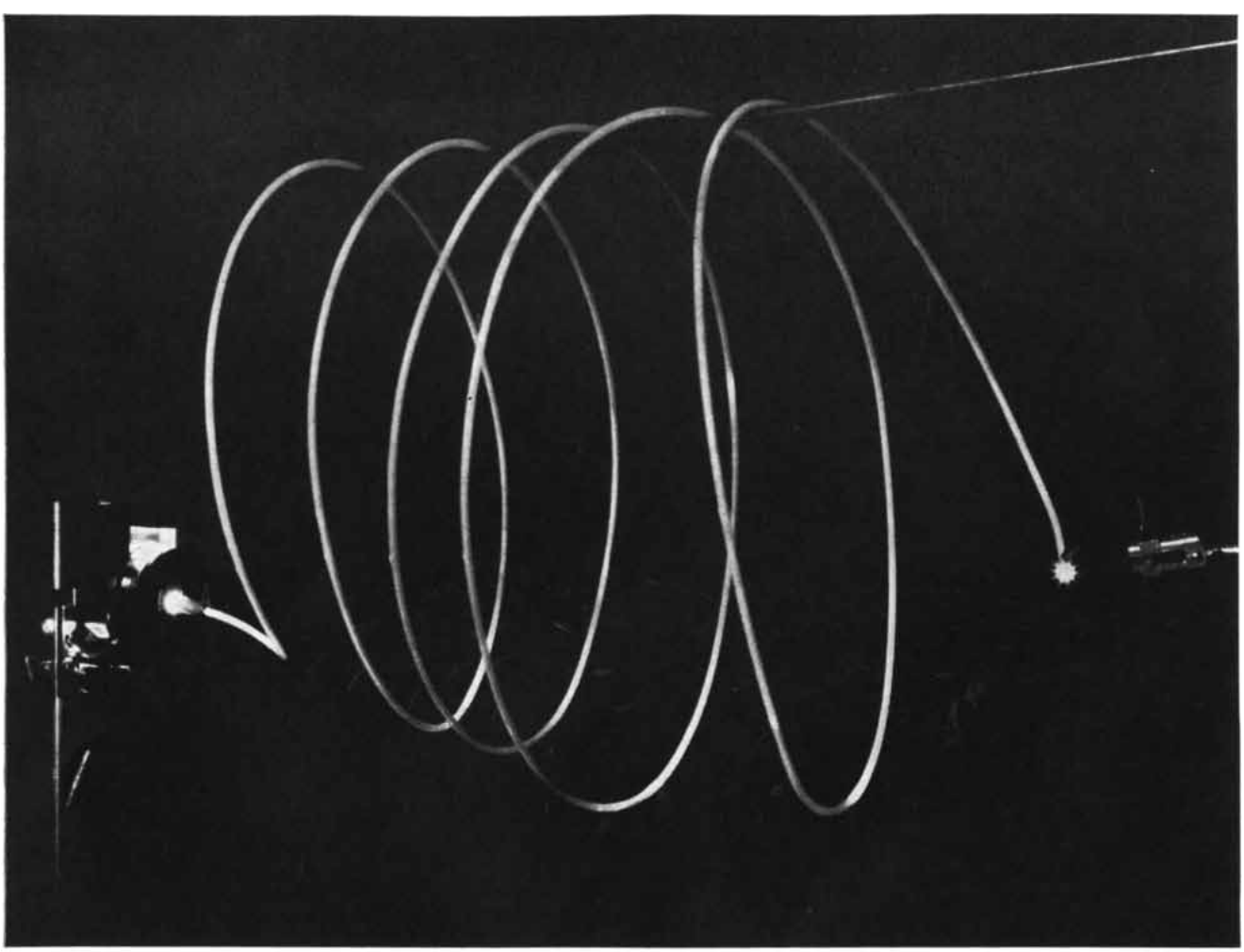
FIBER OPTICS

If light is directed into one end of a glass fiber, it will emerge at the other end. Bundles of such fibers can be used to conduct images over a tortuous path and to transform them in various ways

by Narinder S. Kapany

As long ago as 1870 the British physicist John Tyndall demonstrated that light, which, as everyone knows, travels in straight lines, can be conducted along a curved path. His "light pipe" was simply a thin stream of water issuing from a hole in the side of a tank. Light shined into the tank emerged at the hole and followed the downward-curving stream. Most of us have seen the effect in illuminated fountains, and it has also been applied in advertising displays, with glass or plastic rods rather than liquid jets serving as conductors. Recently, however, light conductors of a special type have been transformed from trivial curiosities to important optical devices.

In this form they are made of bundles of very thin, and therefore flexible, glass fibers, usually coated with a layer of



LIGHT IS TRANSMITTED from light source at left through a 23-foot-long "light pipe" made up of fibers. "Pipe" is looped over a rod. "Star" at right is light coming out of fiber bundle at far end, which is clamped to laboratory stand and points at camera.

glass of a different kind. Such bundles can not only transport an optical image over a tortuous path, but can also transform it in a number of useful ways.

Although a curved rod of glass or other transparent material appears to bend light rays passing through it, it does not actually do so. Instead the light follows a zigzag path down the rod, traveling always in straight lines and caroming repeatedly off the surface. Since the surface is transparent, the rays might be expected to cross it and escape from the conductor. The reason they do not is to be found in the phenomenon known as total internal reflection.

When light falls obliquely on the dividing surface, or interface, between two transparent media, part of it is invariably reflected back through the medium in which it was traveling. Another part may pass into the second medium, the rays being bent or refracted at the surface. (This is the effect that accounts for the familiar illusion that a stick thrust into the water is bent.) The amount of the refraction depends on the difference between the speeds of light in the two media; its direction depends on whether the speed is greater in the first or the second medium. When a ray travels from the medium of lower velocity to that of higher, it bends away from the perpendicular to the surface [*see top illustration at right*].

If the angle between the incident ray and the perpendicular is great enough, the refracted ray bends 90 degrees from the perpendicular, or along the interface. The angle of incidence at which this happens is called the critical angle. It depends, obviously, on the ratio of the speeds, or to put it another way, on the ratio of the indexes of refraction of the two media. (A higher refractive index means a lower speed, and vice versa.)

At angles of incidence greater than the critical angle no light passes into the second medium; it is entirely reflected back through the first. If the interface is very smooth and is protected from contaminating influences, virtually no light is lost in this total internal reflection. The process is thus much more efficient than reflection from an ordinary opaque mirror, where considerable energy is absorbed at the surface.

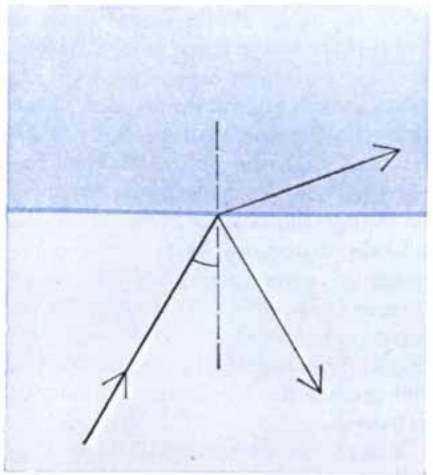
Transparent rods operate as light conductors by means of total internal reflection. They can contain a ray, bouncing it from one side to the other, as long as it always strikes their surface at an angle greater than the critical one. In a straight rod the angle of incidence is the same from one reflection to the next. This angle is determined by the angle at which the light enters the end of the rod. Hence the smaller the critical angle, the wider the external cone of rays that can be trapped and transported by the conductor. Furthermore, as the diagram on the next page shows, bending a rod decreases the angles of incidence of the shuttling ray. Hence the degree of curvature allowable also depends on the smallness of the critical angle.

The narrow conductors used in fiber optics are usually made in two parts: a cylindrical fiber of glass with a high index of refraction surrounded by a thin coating of glass with a low index. Total reflection takes place between the two. The coating serves to protect the fire-polished reflecting surface and also separates the conducting cylinders in the bundle from one another. With glasses now available we can make fibers with a critical angle as small as 50 degrees. Such a conductor can trap a cone of light 180 degrees wide.

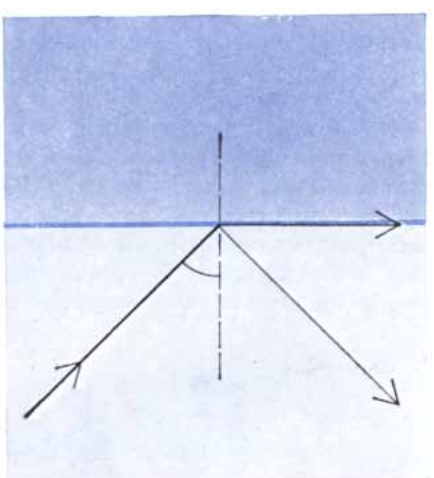
In a properly made fiber almost all the light loss is due to absorption in the glass and very little to reflection. The high-refraction glass used in fiber cores absorbs less than a quarter of 1 per cent of light energy per inch. A bundle seven feet long delivers 50 per cent of the entering light at the far end, and 25-foot bundles transmit enough for certain applications. Tests on individual fibers have shown a measurable amount of transmission over 150 feet. Considering that a ray inclined at 30 degrees to the axis undergoes 692,880 reflections per 100 feet, even in a comparatively thick fiber, one can see that there must be almost no loss at each reflection.

Two examples of the image-conveying property of an aligned assembly of fibers are to be found in nature. The human retina consists of an assembly of rods and cones, and the image formed by the eye lens is focused upon them. It has been established that the rods and cones have a higher refractive index than the surrounding material, and that the light falling on them is transported down their length by total internal reflection and then converted into the visual stimulus. The eye of an insect has a somewhat similar, though simpler, construction. Another example of natural fiber optics is a borax deposit commonly known as ulexite, which sometimes occurs as a fibrous crystal. It can transmit a fairly good image, but it admits too small a cone of light to serve as a practical light conductor.

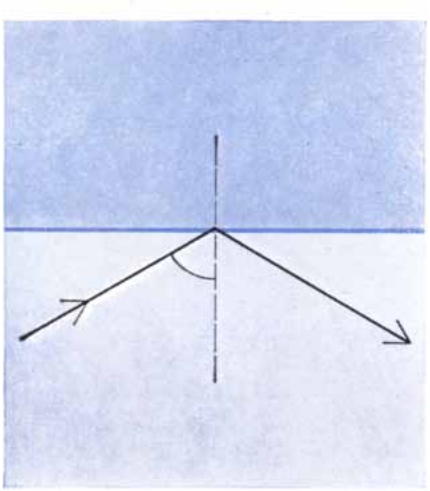
While a bundle of thin fibers has the



AT SHALLOW ANGLE to perpendicular most of light traveling through one transparent medium will cross interface (*heavy colored line*) into another such medium.



AT CRITICAL ANGLE most of the light will travel along the interface, and remainder is reflected within the first medium.



AT STEEP ANGLE all the light is reflected from the interface and continues its journey wholly within the original medium.

desired flexibility, it also necessarily dissects an image into separate spots of light. If the image is not to be distorted, the fiber ends must occupy the same position at both ends of the bundle. This is not in itself a disadvantage. It is not difficult to align the fibers. Moreover, as we shall see, we have the opportunity to change the positions, producing deliberate distortions that are advantageous in some cases. Another consequence is an inherent graininess in the image, which limits the resolution of fine detail. The finer the individual fibers, the greater the resolution that can be achieved.

Fibers are drawn from thick glass rods in a specially designed furnace. If they are to be coated, the inner rod of higher-refraction glass is inserted in a tubing of lower-refraction glass, and the two are drawn together. The emerging filament is wound in orderly layers on a revolving drum. When the successive layers are taken off the drum and stacked precisely one above the other, the fibers are properly aligned.

With this arrangement we can draw fibers down to about a thousandth of an inch in diameter, controlling their thickness within narrow limits. A bundle of such fibers can resolve lines a twentieth of a millimeter apart. To achieve still finer grain, a few hundred coated fibers can be fused together and then drawn out a second time. Such a "multiple fiber," made up of units eight hundred-thousandths of an inch (two microns) in diameter, resolves 250 lines per millimeter. By means of a technique to be described later, the resolution can be increased to 500 lines per millimeter. It is possible to draw still thinner fibers, but they no longer act as simple light pipes. Their diameters are now comparable to the wavelength of the light, and they act as wave guides, transmitting energy in complex patterns that are no longer isolated from one another. A diameter of one micron, corresponding to about two wavelengths of visible light, is the approximate lower limit for simple image transmission.

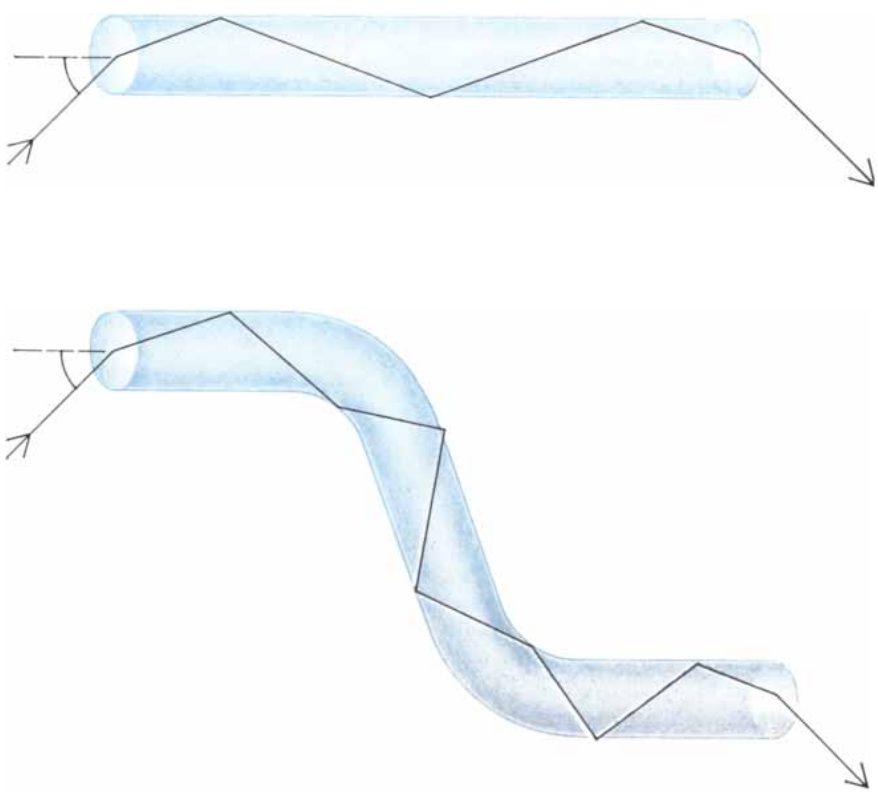
By means of a flexible light pipe we can look around corners and see things that are hidden from direct view. Physicians may soon be examining interior parts of the body with "fiberscopes." The periscope type of instrument now used for stomach examination has several blind spots, and its rigidity causes the patient considerable discomfort. A fiber bundle will be able to reach every part of the stomach, and even the duodenum beyond it, and will be much easier on the patient. Illumination has always been a problem in this type of work. In the fiberscope it is solved by enclosing the instrument proper in a sheath of unaligned fibers that conduct light from a bright lamp into the stomach. Other regions can also be reached. A thin fiberscope should even make it possible to scan the interior of the heart!

Bending is not the only advantage to be gained from transporting an image through fiber bundles. Because of their ability to accept a wide cone of entering light, they can increase the effective brightness of faint or fleeting objects. For example, the face of a cathode-ray or television tube gives off its light in all directions. If we place a camera in front of the tube to photograph it, the lens gathers only a small fraction of the total light emitted. By placing one end of a fused, air-tight fiber bundle against the tube face (or depositing a phosphorescent layer directly on the bundle, which then becomes the face of the tube), and putting a photographic plate at the other end of the bundle, much more light is delivered to the film.

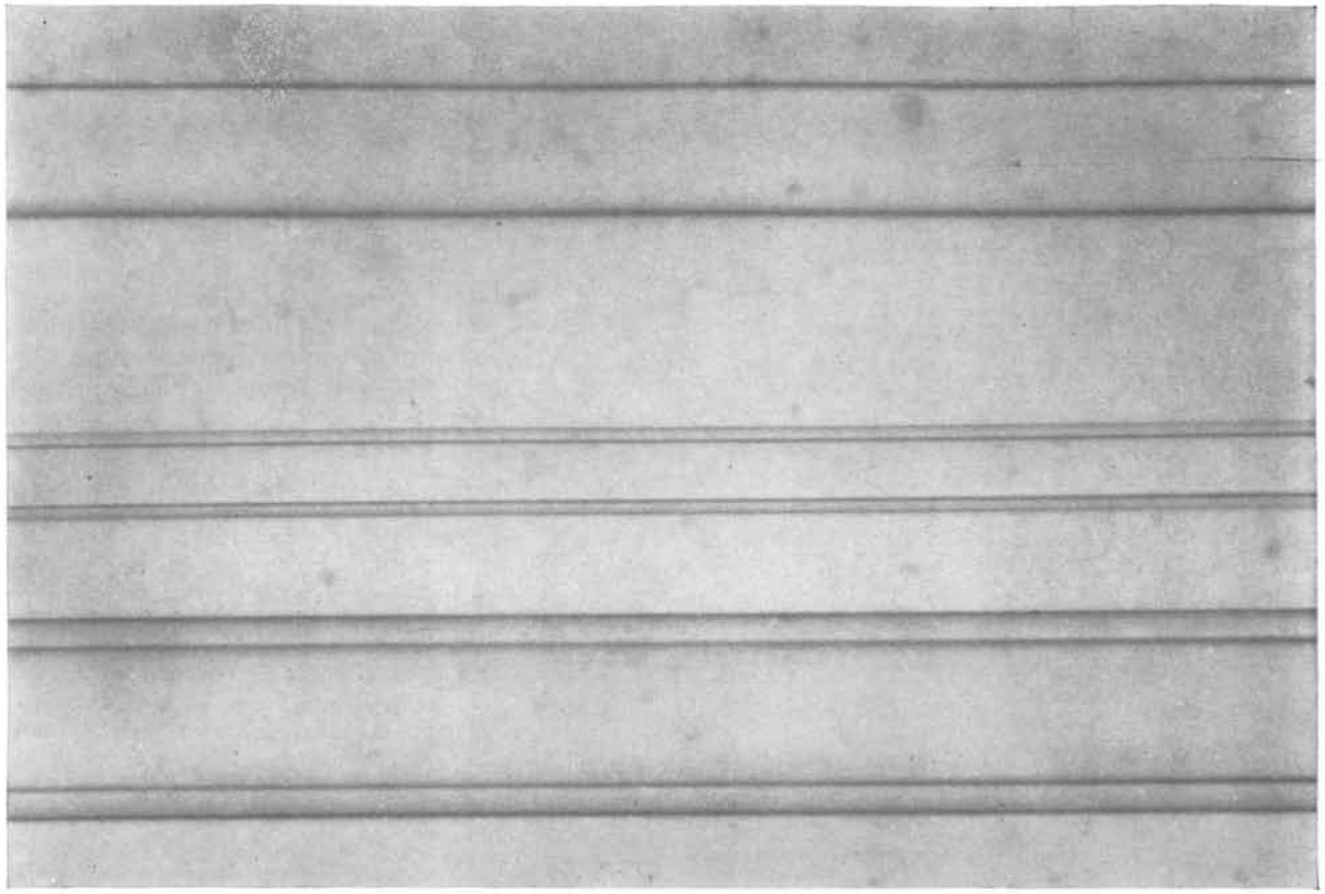
For certain applications the effect can be further enhanced by drawing out a bundle so that it is narrower at one end than at the other. Now it serves as a funnel, gathering light over a large area and concentrating it on a small one.

Still another technique is available to make images sharper as well as brighter. Lens designers know that in certain optical systems resolution is improved by forming the image on a curved rather than a flat surface. In this form the image does not focus sharply on an ordinary photographic plate. But if one end of a fiber bundle is curved to fit the image surface, and the other is made flat, the image can be delivered undistorted to the focal plane of a camera or to the eyepiece of a high-powered microscope. The fibers can also be arranged to correct unwanted distortions introduced by the lens system. Both functions can be combined with the funneling effect of a conical bundle in a device called the "Focon."

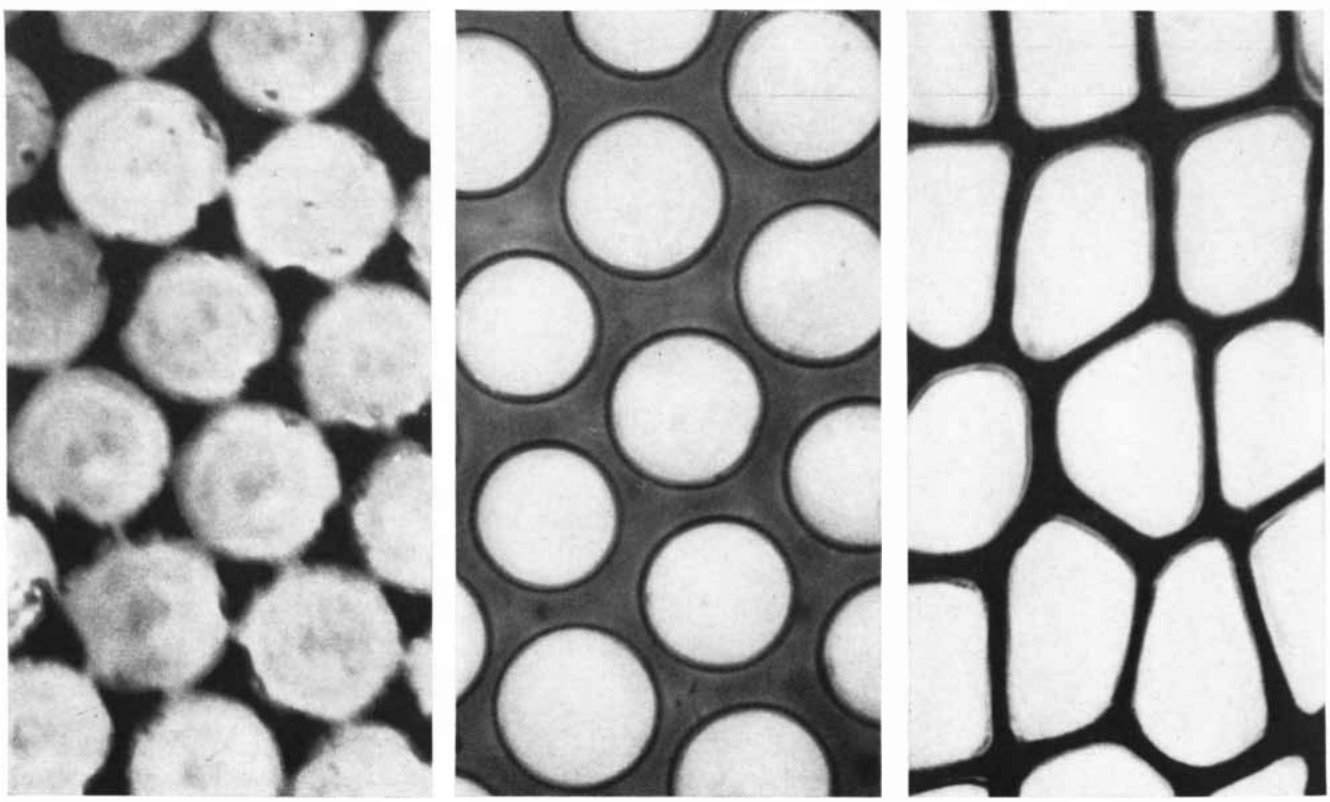
As we have mentioned, the image emerging from a fiber bundle is inevitably grainy. However, a technique called dynamic scanning offers a means of eliminating the grain and improving resolution. The method involves moving both ends of the bundle in an identical random pattern, shifting the system a few fiber diameters at a time. In cases where this synchronous motion can be accomplished, the image is completely smoothed and the resolving power is increased by 100 per cent. For purposes of visual observation the bundle ends



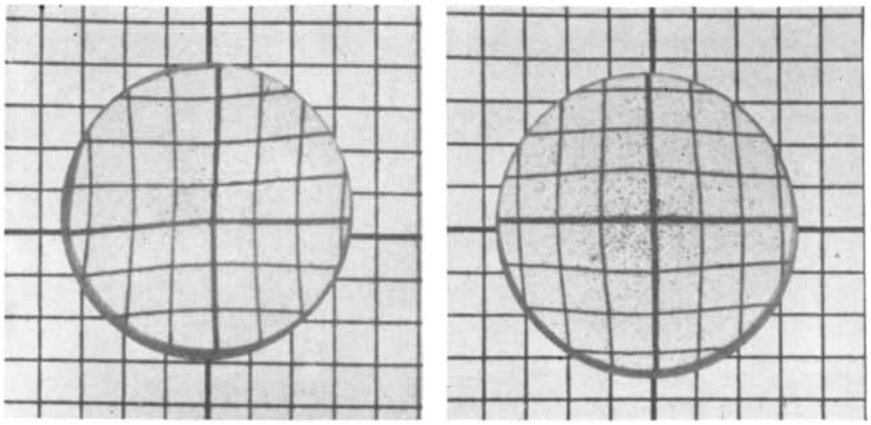
ANGLE OF EXIT of light emerging from a fiber (*top*) is same as angle of entry. Even if the fiber is bent many times (*bottom*) the light will travel all the way through it.



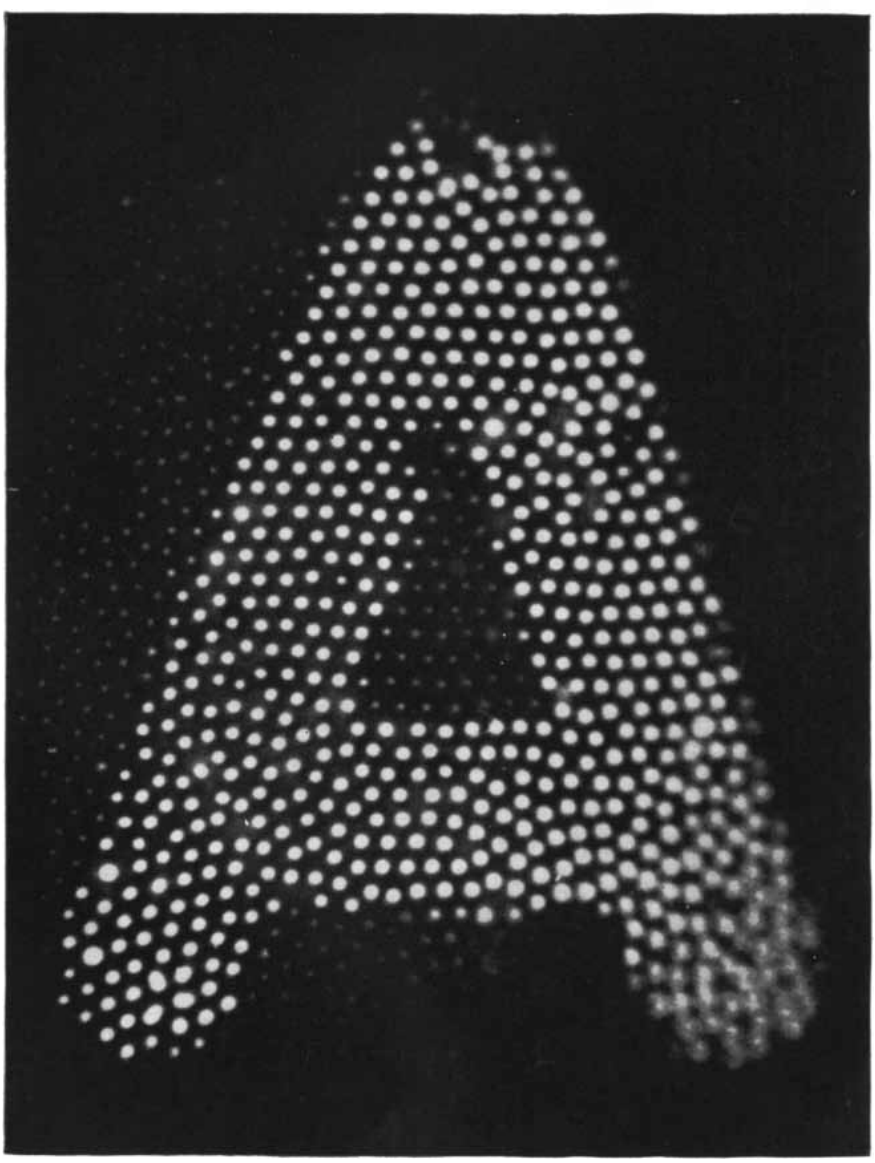
THREE GLASS FIBERS in this photomicrograph are of different diameters. Top fiber is uncoated and 37 microns wide. (A micron is a 10,000th of a centimeter.) Middle fiber is coated and 25 microns wide; bottom fiber is also coated and 62 microns wide.



FIBERS ARE SEEN FROM THE END in these photomicrographs. Fibers at left are uncoated and are embedded in plastic. Coated fibers in middle are fused; coat has lower softening point than core. Fibers at right, with core of lower softening point, are distorted.



PLATES COMPOSED OF FIBERS, here lying on graph paper, can correct optical distortions. The plate at left can remove "barrel" distortion; that at right, "pincushion" distortion.



FIBERS ONE MICRON IN DIAMETER, the thinnest ever incorporated into a bundle, project letter "A" in photomicrograph of end of bundle. They are enlarged 3,500 times.

need only scan at a frequency considerably slower than the flicker frequency of the eye (about four to five times per second). On the other hand, in photography a minimum of about five oscillations are required during the period of exposure.

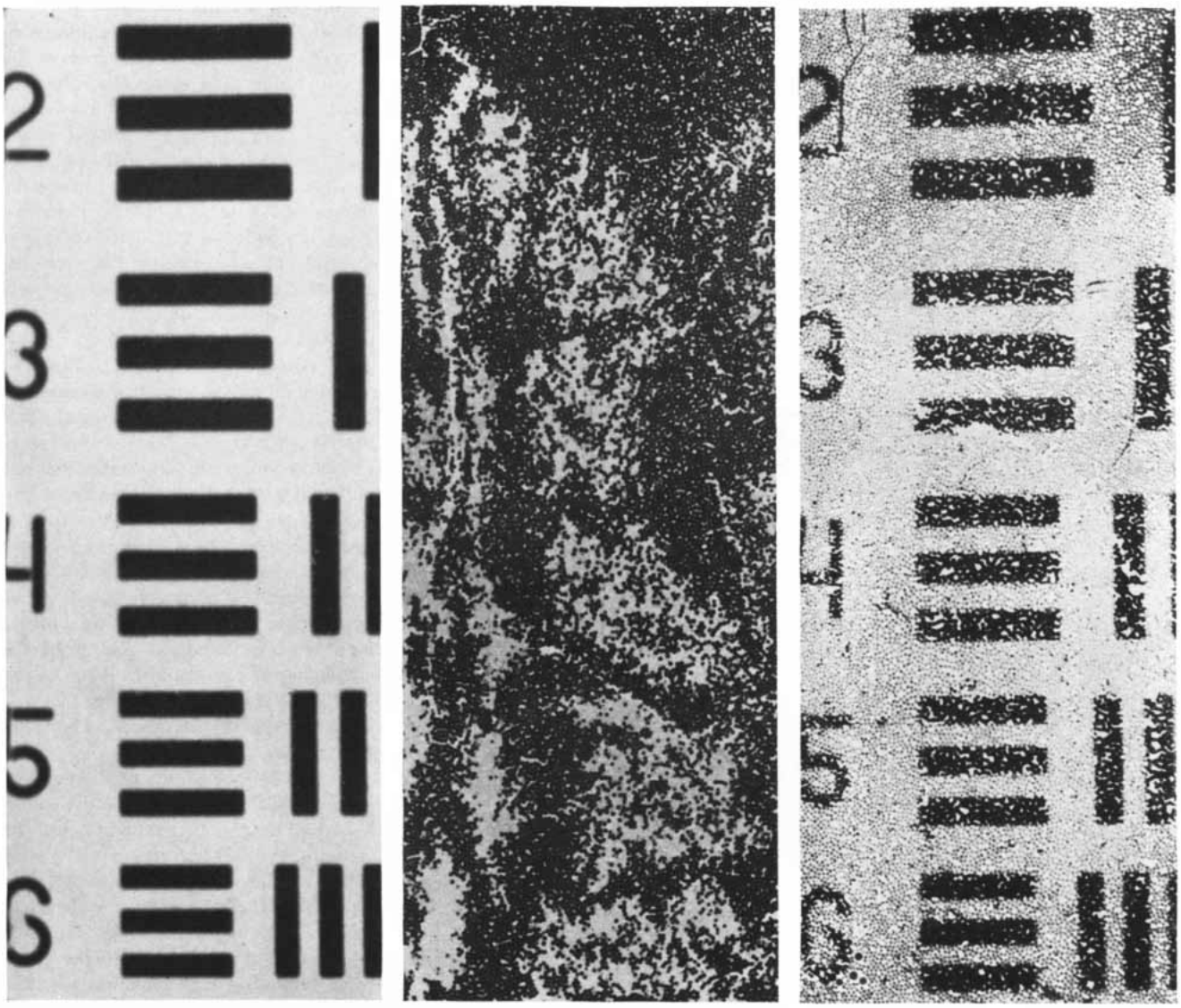
Of course not every application of fiber optics can accommodate dynamic scanning. Recently another way of improving image quality, known as "spatial filtering," has been developed. Passing the image through a pattern of thin films of varying thickness partially suppresses the graininess.

If the fibers in a bundle are not aligned, but rather are interwoven at random, the emerging image will be scrambled. Nevertheless the image will contain just as many units of information as the pattern at the other end. If it could be sent backward through the bundle, or transmitted through a second identical bundle, it would be reconverted to the original form. This suggests that fiber bundles would make convenient coder-decoder devices. With, say, a quarter of a million fibers whose positions can be manipulated, the scrambled image produced by a random fiber array would be virtually impossible to reconstitute without a decoder. The problem is finding a way to make several bundles incorporating the same complex pattern of interweaving. No satisfactory method is yet available, but one should not be too hard to find.

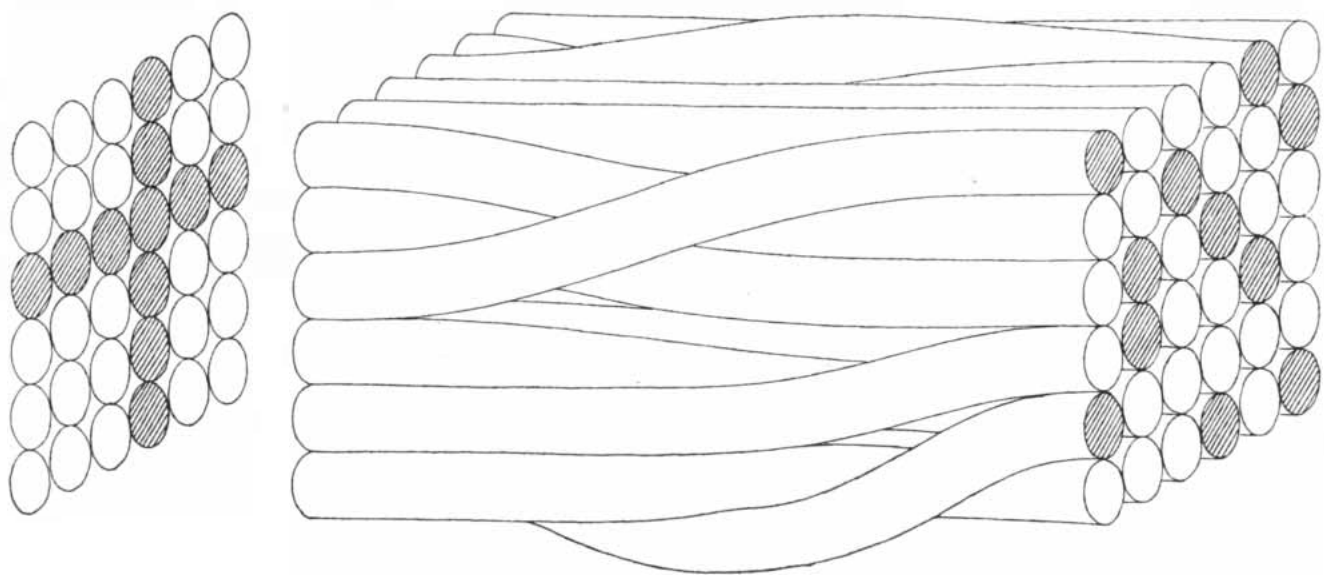
Other types of assembly take apart images and put them together in more convenient form. For example, in high-speed motion-picture photography, the film could be moved more slowly if the image were flattened to a horizontal line. This can be accomplished by a bundle that is square at one end but tapers and spreads to a line at the other. The camera lens forms its image on the square end, and the film, on a rotating drum, is placed opposite the slit end. To reconstitute the image, the finished print is projected backward through the bundle.

The tapered bundle may also act as a simple funnel, gathering light over a comparatively wide area and directing it into a narrow slit. It is a valuable tool in astronomical spectroscopy, where a substantial fraction of the light in the circular image formed by the telescope is lost at the slit of the spectroscope.

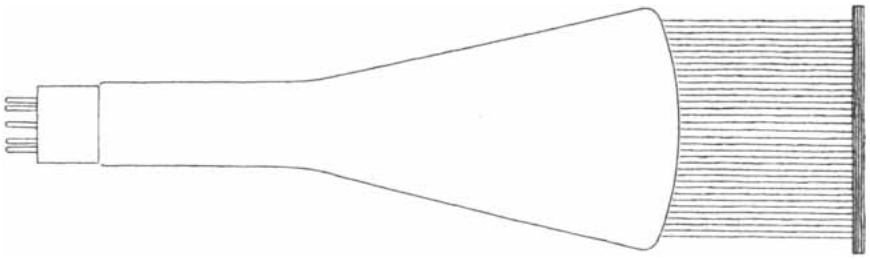
As a final example of the many and varied applications of these new devices, let us see how a single uncoated rod can serve as a refractometer, that is, an instrument for measuring the index of refraction of liquids. When a light-con-



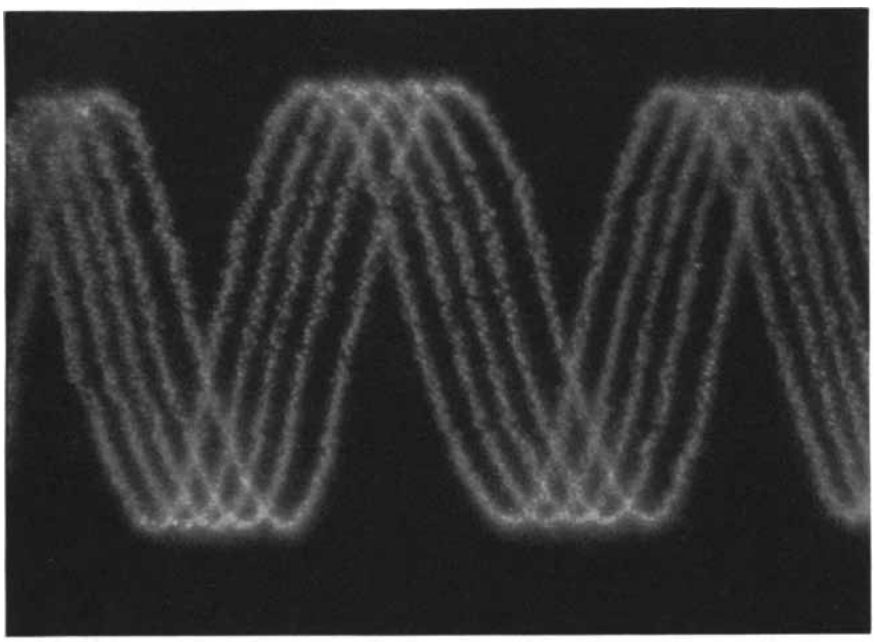
CODER-DECODER DEVICE employs scrambled fibers. Test pattern at left was placed at one end of bundle; photographic film at other end recorded pattern in center. Pattern at right was seen when center pattern was projected "backward" through the bundle.



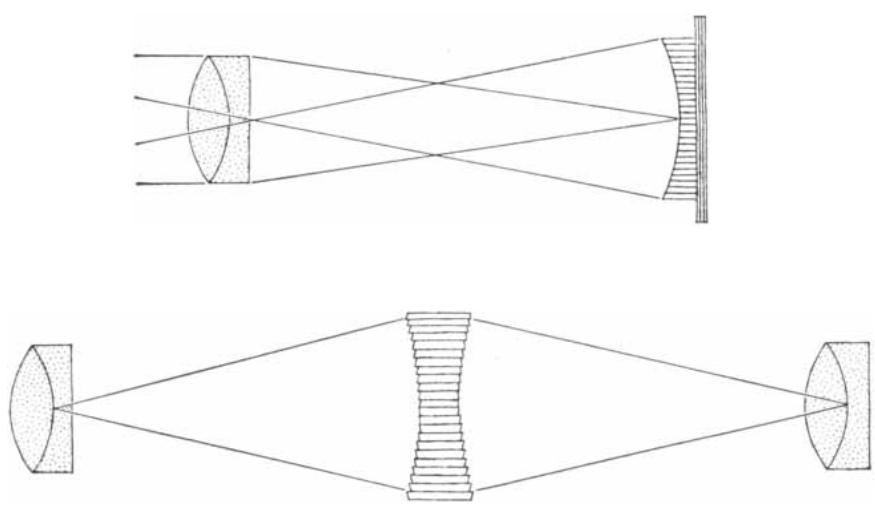
OPERATION OF CODER-DECODER is depicted schematically. At left is the image of a cross projected on a rectangular array of fibers. Scrambled fibers in bundle produce image at right. Viewed through the same bundle, the latter image would be a cross.



INTENSIFICATION OF IMAGE from cathode-ray tube is achieved when fibers gather light rays that would normally scatter, and channel them to surface of fiber "lens" (*right*).



SINE CURVES on face of cathode-ray tube have been transmitted here through a fiber bundle, as diagrammed at top of page. Each dot represents end of one fiber in the bundle.



CURVED IMAGES from lenses are flattened by bundles of fibers. At top fibers (*right*) project image onto photographic plate. At bottom fibers (*center*) flatten image between lenses.

ducting rod is immersed in a liquid, the critical angle depends on the difference between the indexes of refraction of the two materials. The closer the refractive index of the liquid approaches that of the rod, the greater the critical angle. And the greater the critical angle, the more nearly a light ray must graze the surface of the rod to be totally reflected. Thus, if a constant wide cone of light is directed at one end of the rod, the amount that reaches the other end will vary as the index of refraction of the liquid changes.

Light emerging from the rod falls on a photocell whose output indicates the index of refraction of the liquid. This simple instrument detects a change in refractive index with an accuracy of one part in 100,000 to a million over a limited range. To extend this range it is necessary to use several rods of different refractive indexes, mounted on a turret. By feeding the photocell output to an appropriate servo system, the instrument can be adapted for automatic chemical-process control. The instrument has the unique advantage of working on opaque liquids as well as on transparent ones.

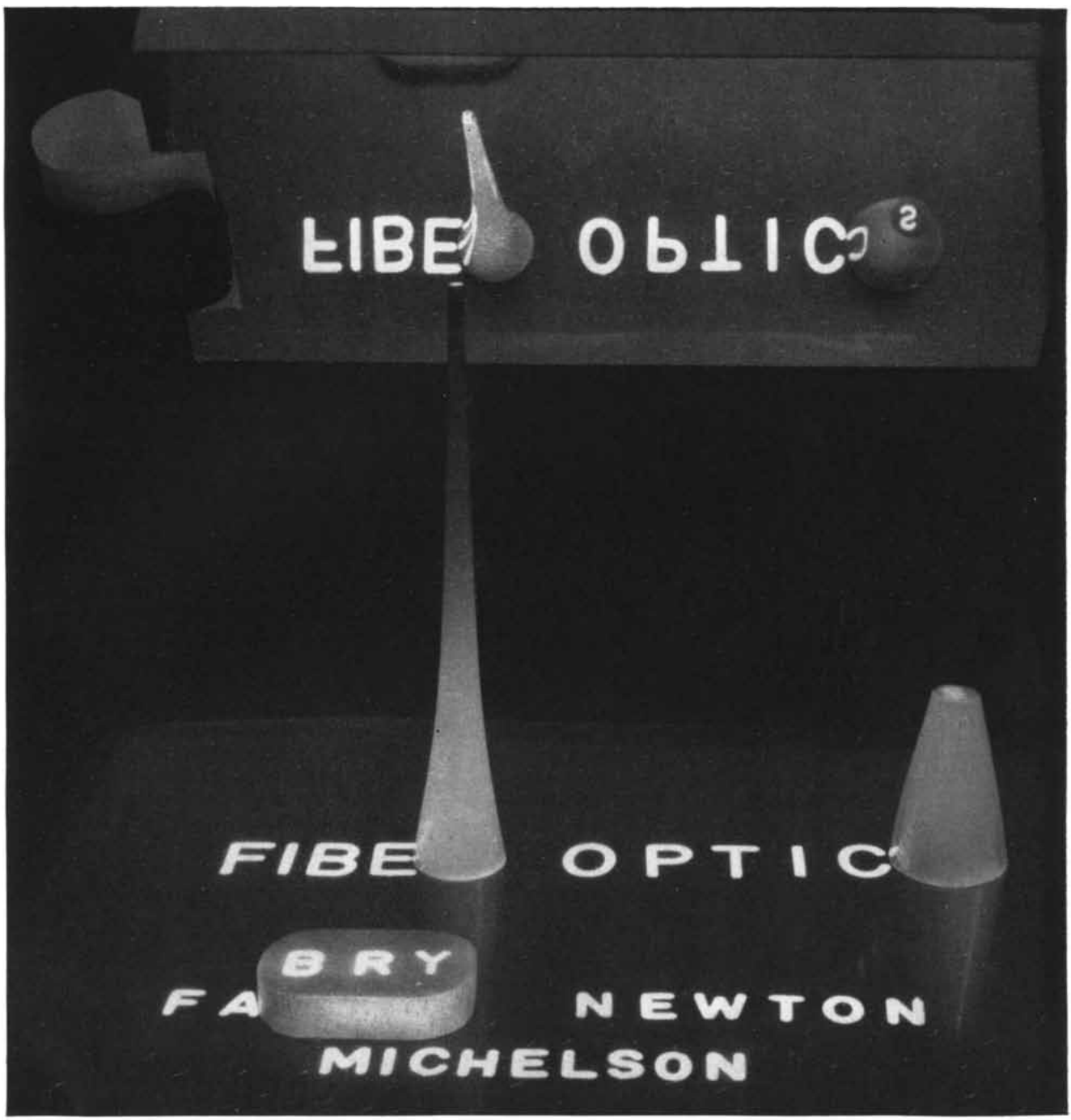
At the Armour Research Foundation of the Illinois Institute of Technology we are working on extending fiber optics techniques in several directions. We are experimenting with fibers of scintillating materials for use in tracking nuclear particles. Transparent materials that also conduct electricity should make possible a number of interesting devices. Perhaps the most immediately promising area is the infrared region of the spectrum. We have found materials that make satisfactory fibers to handle wavelengths up to about six microns. We are now trying to extend the range to 25 microns. With further technological advance, fiber optics will become an important adjunct in infrared scanning and guidance systems and in infrared spectroscopy.

In almost all of the discussion thus far, the wave properties of light have been ignored. Actually, of course, there is no such thing as a "ray" of light, if we are not talking about quantum effects. A ray simply represents the direction along which part of a wave front is advancing. An analysis of the behavior of light as an electromagnetic wave shows that the fundamental process of fiber optics—total internal reflection—is not so simple as was indicated earlier. Instead of bouncing off the interface between two media, a wave train actually penetrates the sec-

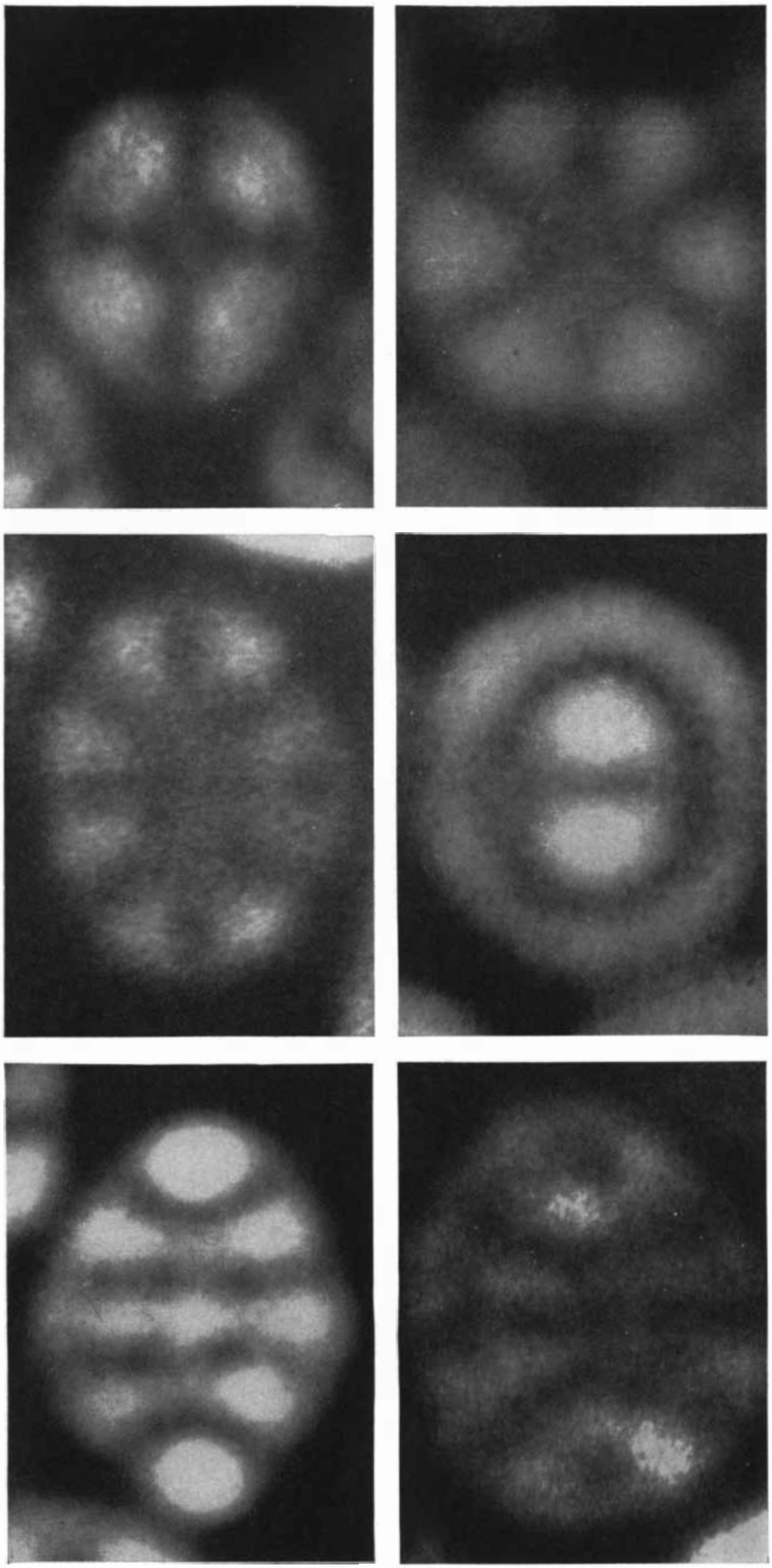
ond medium for a short distance before turning back into the original material. The strength of the electromagnetic field carried by the wave decreases rapidly in the second medium, dying away to a negligible amount at little more than a wavelength from the interface.

Suppose that two pieces of material of high refractive index are placed very close together—say within a quarter of a wavelength—and that they are separated by a layer with low refractive index. In this arrangement light will not be totally reflected in either piece of material, even if it strikes the low-refraction layer at an angle greater than critical. The neighboring high-refraction material picks up the energy that has penetrated the separating layer, frustrating its attempt to reflect back into the original medium.

Because of frustrated total reflection, as the phenomenon is called, the coating on the fibers in a bundle must be thick enough to keep them adequately separated. The required separation depends on the diameter of the core, the refractive index of core and coating, and on the angular spread of the incoming light. For fibers down to a few wavelengths in diameter a separation of one wavelength



CONICAL FIBER-BUNDLES can enlarge or diminish optical images. At bottom is a plate of glass with illuminated sample words (including the names of three pioneers in optics). The nonconical fiber bundle at lower left picks up but does not change size of letters in the word "Fabry." Above it the tall conical bundle over the letter "R" produces a tiny "R," visible upside down in mirror at top. The conical bundle at right has a similar but less pronounced effect upon the letter "S" in the word "optics."



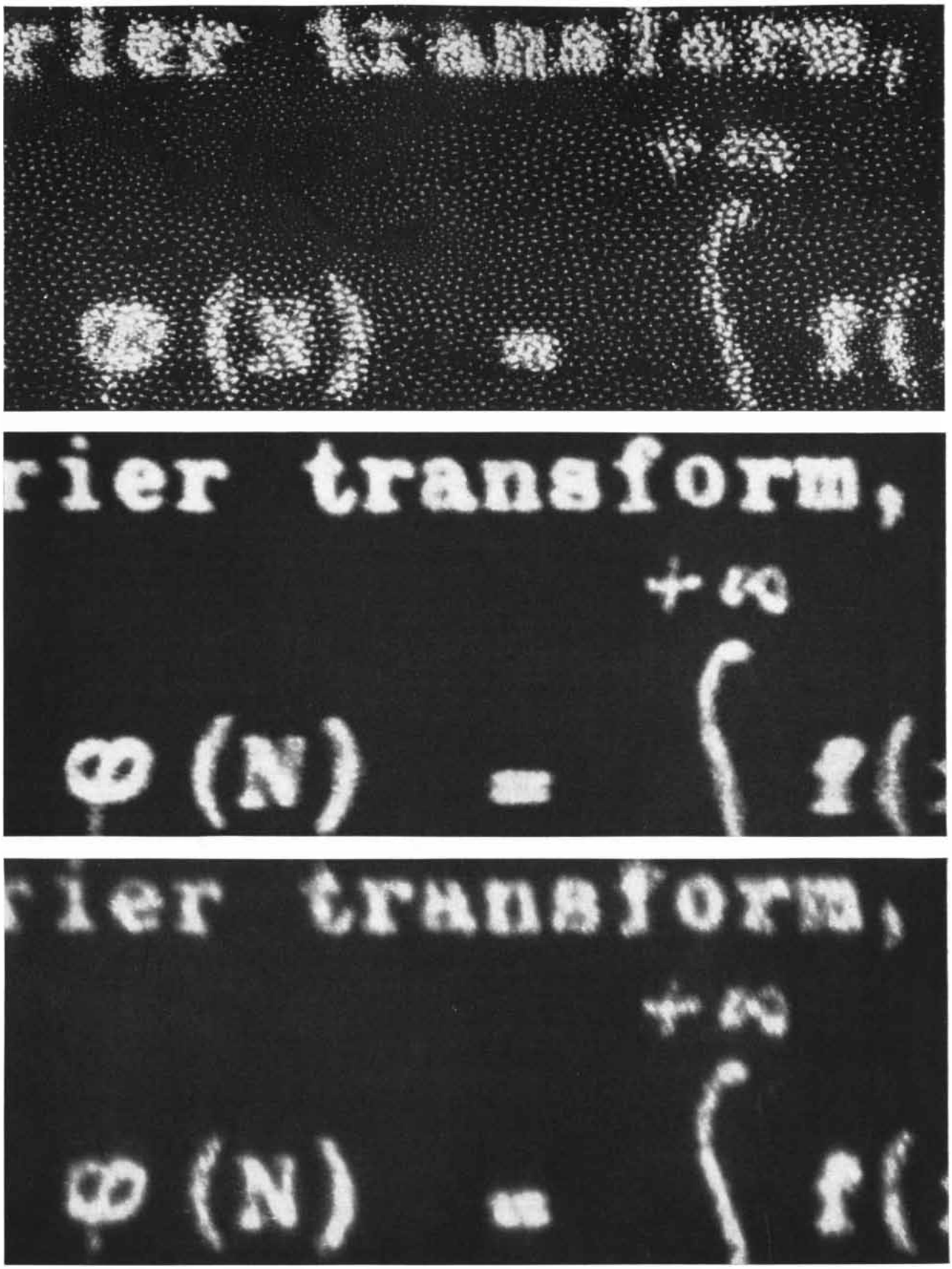
WAVE-GUIDE PATTERNS appear when diameter of fibers approaches wavelength of light. Then light that can travel in the fibers is limited to certain "characteristic angles" which produce interference and reinforcement patterns such as those seen in these six photomicrographs of ends of fibers. Wave guides for microwaves also behave in this way.

(about .5 micron for visible light) is sufficient under most conditions.

As we have already mentioned, when the fiber diameter becomes less than about two wavelengths, light conduction comes to resemble the transmission of microwaves by wave guides. My colleagues and I have extended conventional wave-guide theory to optical wavelengths. The calculations indicate that to be carried down a fiber, light waves must strike the sides not at any angle greater than critical, but only at certain "characteristic" angles. Each such angle corresponds to one mode of transmission in which the light energy is delivered in a distinctive pattern [*see illustration at left*]. In a fiber many wavelengths wide there is a great number of characteristic angles, and the various modes blur together. As the diameter decreases, however, the possible angles also decrease, until finally, when the conductor measures less than one wavelength across, only one angle and one mode are possible.

A second consequence of reducing fiber diameter is that more and more energy travels down the outside of the conductor rather than inside it. (A similar effect occurs in guides for microwaves.) This means that transmission through one fiber can excite reactions in neighboring ones. The photograph on the cover of this issue of SCIENTIFIC AMERICAN shows various modes and various wavelengths (colors) set up in a bundle when white light is sent through a few fibers.

As the technology advances, fiber optics will no doubt find wider applications in various areas of research and engineering. The field still offers a number of interesting and challenging problems to the investigator. The theoretical treatment of dielectric wave guides must be extended to explain fully how light behaves in transparent fibers with diameters comparable to the wavelength. A more detailed analysis is needed of the radiation patterns, with particular emphasis on the coupling of energy between one fiber and another. It has already been mentioned that, as fiber diameter decreases, more energy is transmitted outside the fiber than inside. Therefore absorption by the glass becomes less important. Eventually it should be possible to apply this effect to the conduction of light by fibers much finer than those discussed previously. This technique would be particularly valuable at infrared frequencies, where longer wavelengths place a higher limit on the diameter of fibers that can be used at present.



THREE DIFFERENT IMAGES through same bundle of 50-micron fibers are shown here. At top grainy "static" image is projected by immobile bundle. In center, bundle is vibrated in plane of image to produce "dynamic scanning." The image does not move, but motion of bundle wipes out edges of fibers, removing grain. At bottom, "space filtering" is produced with layers of different thicknesses of transparent material over the lens that receives image from bundle. Image is poorer than that in dynamic scanning.

PATTERNS OF DREAMING

Dreams are accompanied by certain characteristic types of brain wave and eye movement. This discovery has enabled investigators to answer several of the long-standing questions about dreaming

by Nathaniel Kleitman

Dreams have troubled the waking hours as well as the sleep of men since time immemorial. These hallucinatory experiences have inspired soothsayers and psychiatrists alike, and their bizarre contents, variously interpreted as prophetic insights and clues to personality, are the subject of a considerable body of literature. The scientific value of even the most recent contributions to this literature, however, is seriously qualified: The sole witness to the dream is the dreamer himself. The same limitation confronts the investigator who would inquire into the process of dreaming, as distinguished from the contents of dreams. Only the awakened sleeper can testify that he has dreamed. If he reports that he has not, it may be that he fails to recall his dreaming.

Nonetheless, in the course of our long-term investigation of sleep at the University of Chicago, we found ourselves venturing into research in the hitherto subjective realm of dreaming. We discovered an objective and apparently reliable way to determine whether a sleeper is dreaming—in the sense, of course, of his "reporting having dreamed" when he wakes up or is awakened. The objective indicator of dreaming makes it possible to chart the onset and duration of dreaming episodes throughout the night without disturbing the sleeper. One can also awaken and interrogate him at the beginning of a dream, in the middle, at the end, or at any measured interval after the end. By such means it has been determined that there is periodicity in dreaming, and the consequences of efforts to disturb this periodicity have been observed. The results indicate that dreaming as a fundamental physiological process is related to other rhythms of the body. As for the folklore that surrounds the process, this work has answered such questions as: Does everyone dream? How often does one dream in the course of a night's sleep? Is the "plot" of a dream really compressed into a moment of dreaming? Do external and internal stimuli—light, noise, hunger or thirst—affect the content of dreams?

As so often happens in research, the objective indicator of dreaming was discovered by accident. During a study of the cyclic variations of sleep in infants, a graduate student named Eugene Aserinsky observed that the infant's eyes continued to move under its closed lids for some time after all major body movement had ceased with the onset of sleep. The eye movements would stop and then begin again from time to time, and were the first movements to be seen as the infant woke up. Aserinsky found that eye movements provided a more reliable means of distinguishing between the active and quiescent phases of sleep than did gross body movements.

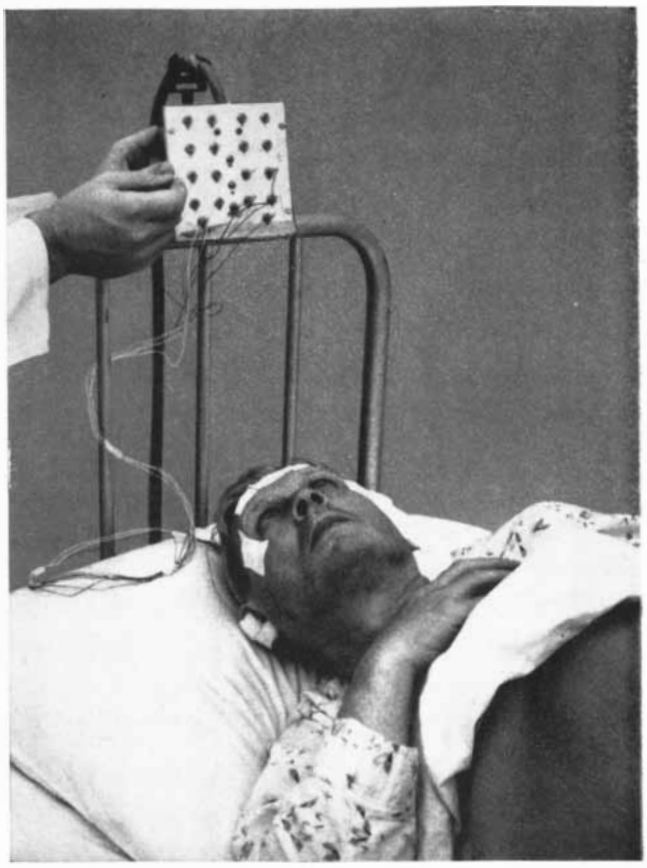
These observations suggested that eye movements might be used to follow similar cycles in the depth of sleep in adults. Disturbance to the sleeper was minimized by monitoring the eye movements remotely with an electroencephalograph, a device that records the weak electrical signals generated continuously by the brain. A potential difference across the eyeball between the cornea and the retina makes it possible to detect movements of the eyes by means of electrodes taped to the skin above and below or on either side of one eye. Other channels of the electroencephalograph recorded the sleeper's brain waves, his pulse and respiration rates and the gross movements of his body.

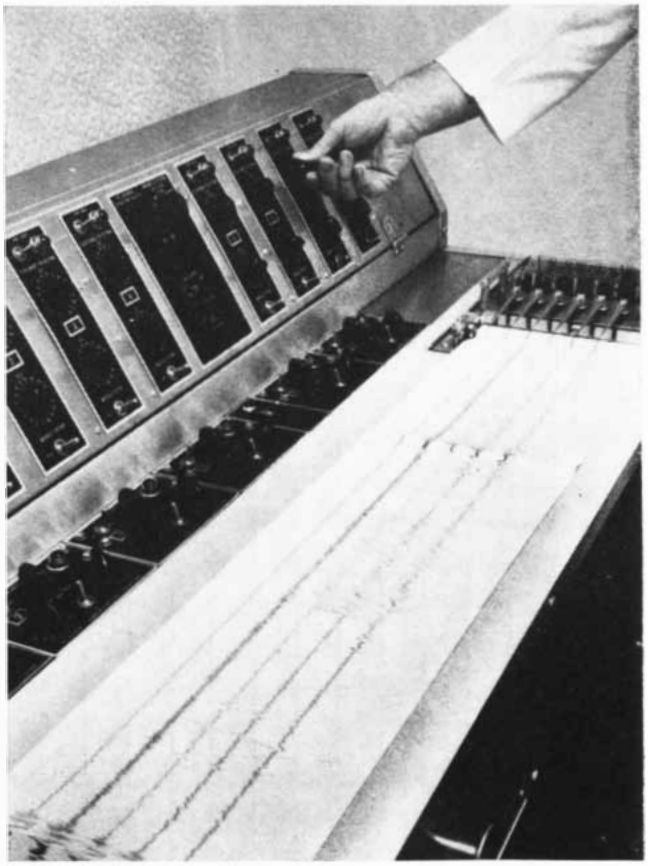
The tracings of the electroencephalograph showed not only the slow movements of the eyes that Aserinsky had observed in infants but also rapid eye-movements that came in clusters. Each individual eye-movement took a fraction of a second, but a cluster often lasted, with interruptions, as long as 50 minutes. The first rapid eye-movements usually began about an hour after the onset of sleep, and clusters appeared in cyclic fashion through the night [*see illustration on page 86*].

Coincident with this cycle of eye movement the electroencephalograph recorded a fluctuation in the brain-wave pattern. As each series of movements began, the brain waves changed from the pattern typical of deep sleep to one indicating lighter sleep. The pulse and respiration rates also increased, and the sleeper lay motionless.

Considered together, these observations suggested an emotionally charged cerebral activity—such as might occur in dreaming. This surmise was tested by the only possible means: arousing and questioning the sleepers. Those awakened in the midst of a cluster of rapid eye-movements testified they had been dreaming. Those awakened in the apparently deeper phases of sleep said they had not. Thus the objective indicator of dreaming came into use.

It is clear that such an indicator can reveal nothing about the content of dreams. But the process of dreaming is no more bound up with dream content than thinking is with what one is thinking about. The hallucinatory content of dreams would appear, in this light, to be nothing more than the expression of a crude type of activity carried on in the cerebral cortex during a certain phase of sleep. The contrast with the kind of cerebral activity that characterizes the waking state in healthy adults and older children is instructive. Responding to

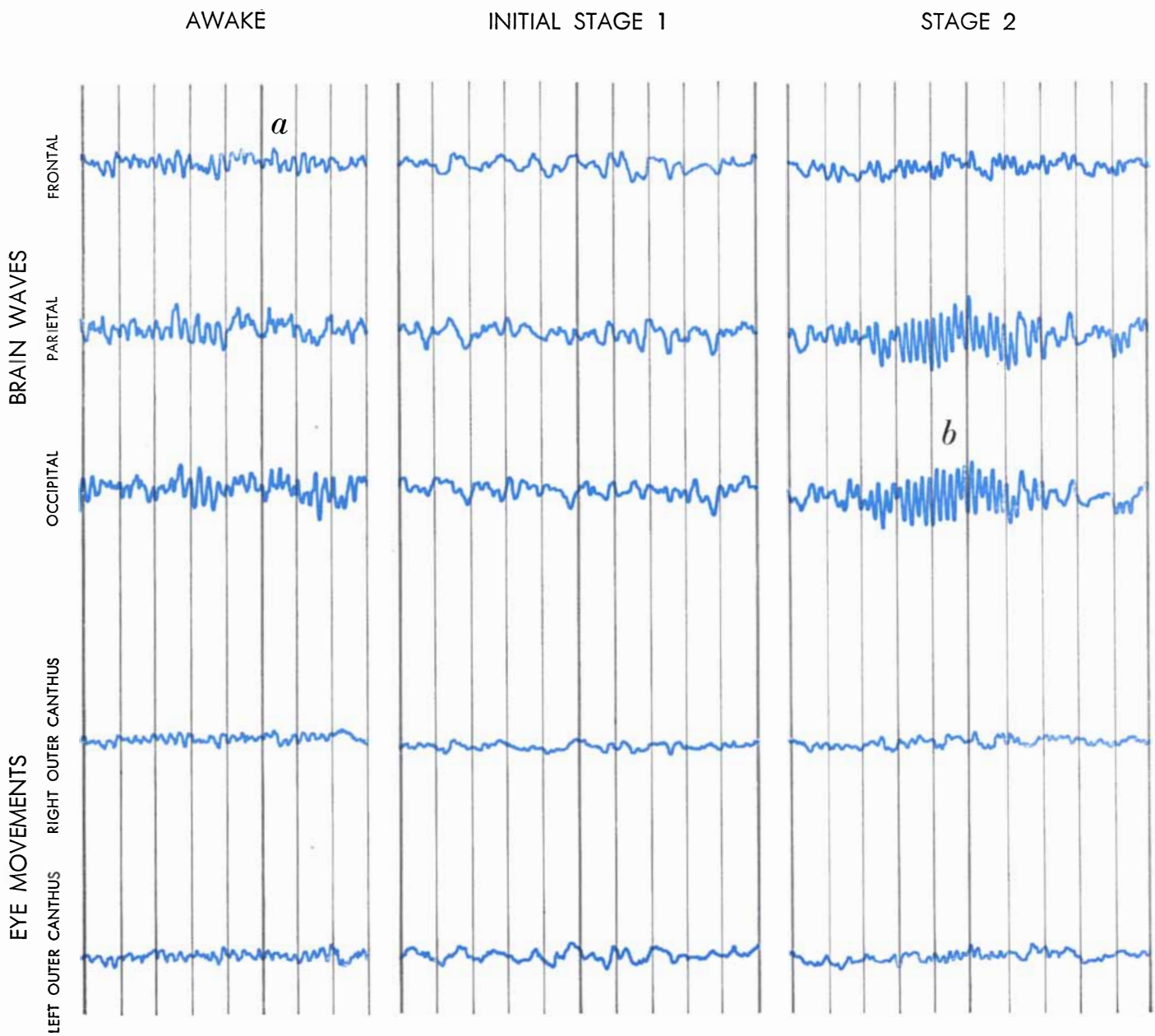




DREAMING IS DETECTED by attaching electrodes to the subject's scalp and to the skin at the corners of the eyes (*top left*). Leads are connected to cable (*top right*) that leads to electroencephalograph in another room. As the subject sleeps (*bottom left*), his brain waves and eye movements are recorded by pens of electroencephalograph (*bottom right*). The subject here is the author of this article.

the impulses that stream in from the various receptor organs of the sensory system, the cortex first subjects them to analysis. It refers the present moment of experience to its memory of the past and projects past and present into the future, weighing the consequences of action not yet taken. A decision is reached, and the cortex generates an integrated response. This is manifested in the action of the effector organs (mostly muscles) or in the deliberate inhibition of action. (A great deal of civilized behavior consists in not doing what comes naturally.) In dreaming, the same kind of cortical activity proceeds at a lower level of performance. The analysis of events is faulty; the dreamer recognizes a deceased friend but accepts his presence without surprise. The memory is full of gaps and brings the past to the surface in confusion. In consequence the integration of the cortical response is incomplete, and the dreamer is often led into the phantom commission of antisocial acts. Fortunately the impulses from the sleeping cortex die out on the way to the effector organs, and no harm is done.

Such protoplasmic poisons as alcohol may reduce cortical activity to an equally low level of performance. A markedly intoxicated person misjudges the situation, assumes unwarranted risks in action and later does not recall what happened. Even when quite drunk, however, some persons stop short of foolish and dangerous extremes of behavior. So, also, a dreamer will accept absurdities in the imaginary series of events until they become too painful and ludicrous; he then wakes up to the comforting discovery that he was dreaming. The fantasizing of very young children, senile aged people and of persons suffering certain disorders of the central nervous system may also be likened to dreaming. After sudden awakening, even normal people may

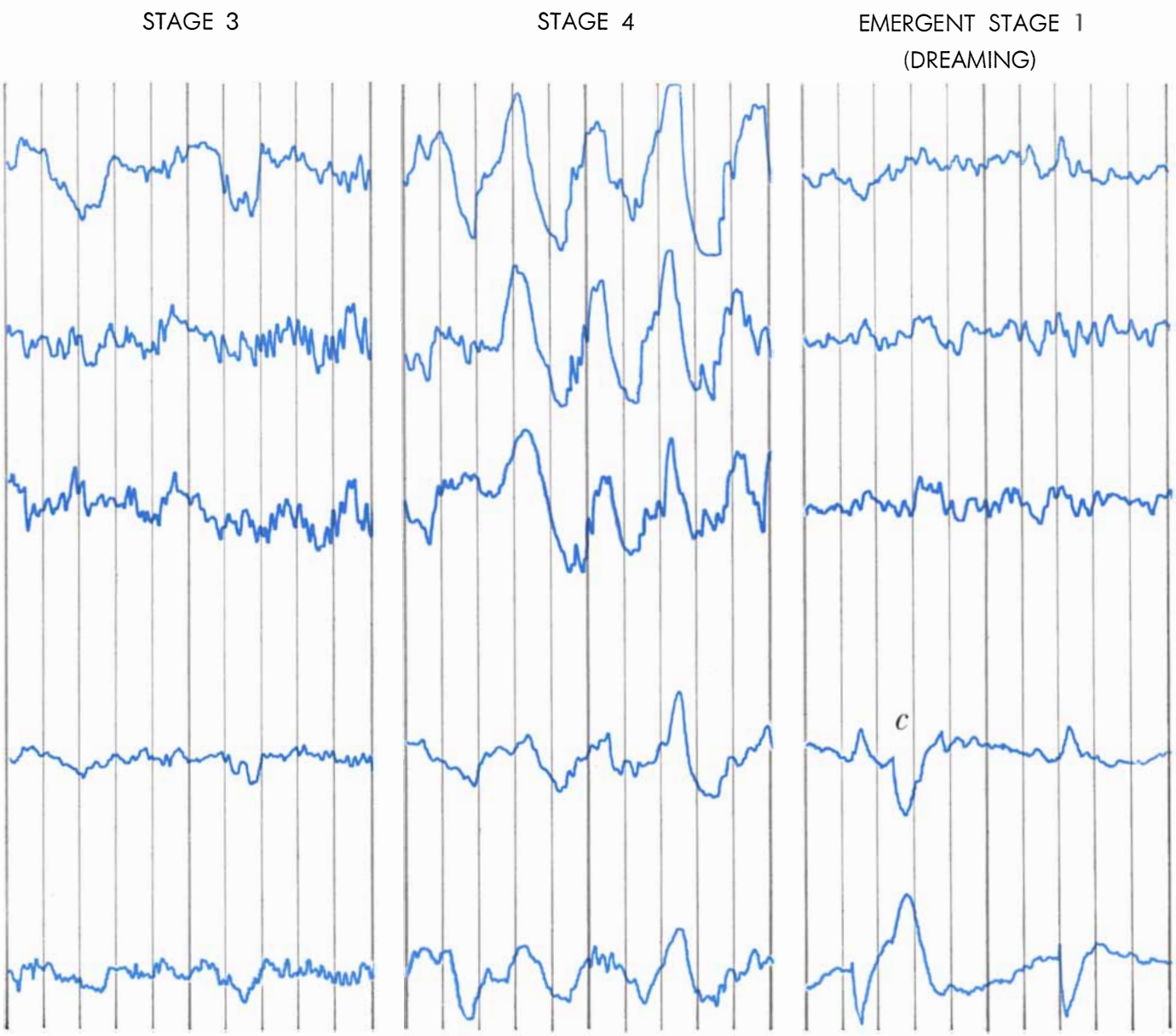


ELECTROENCEPHALOGRAMS show the patterns of brain waves (*top three tracings*) and eye-movement potentials (*bottom two tracings*) that are characteristic of each level of sleep. Labels at left indicate region of head to which recording electrodes are attached. Vertical lines are time-scale; 10 lines represent an interval of four seconds. A subject who is awake but resting with his eyes closed shows the brain-wave pattern known as alpha rhythm (*a*). As sleep begins, pattern known as Initial Stage 1 electroen-

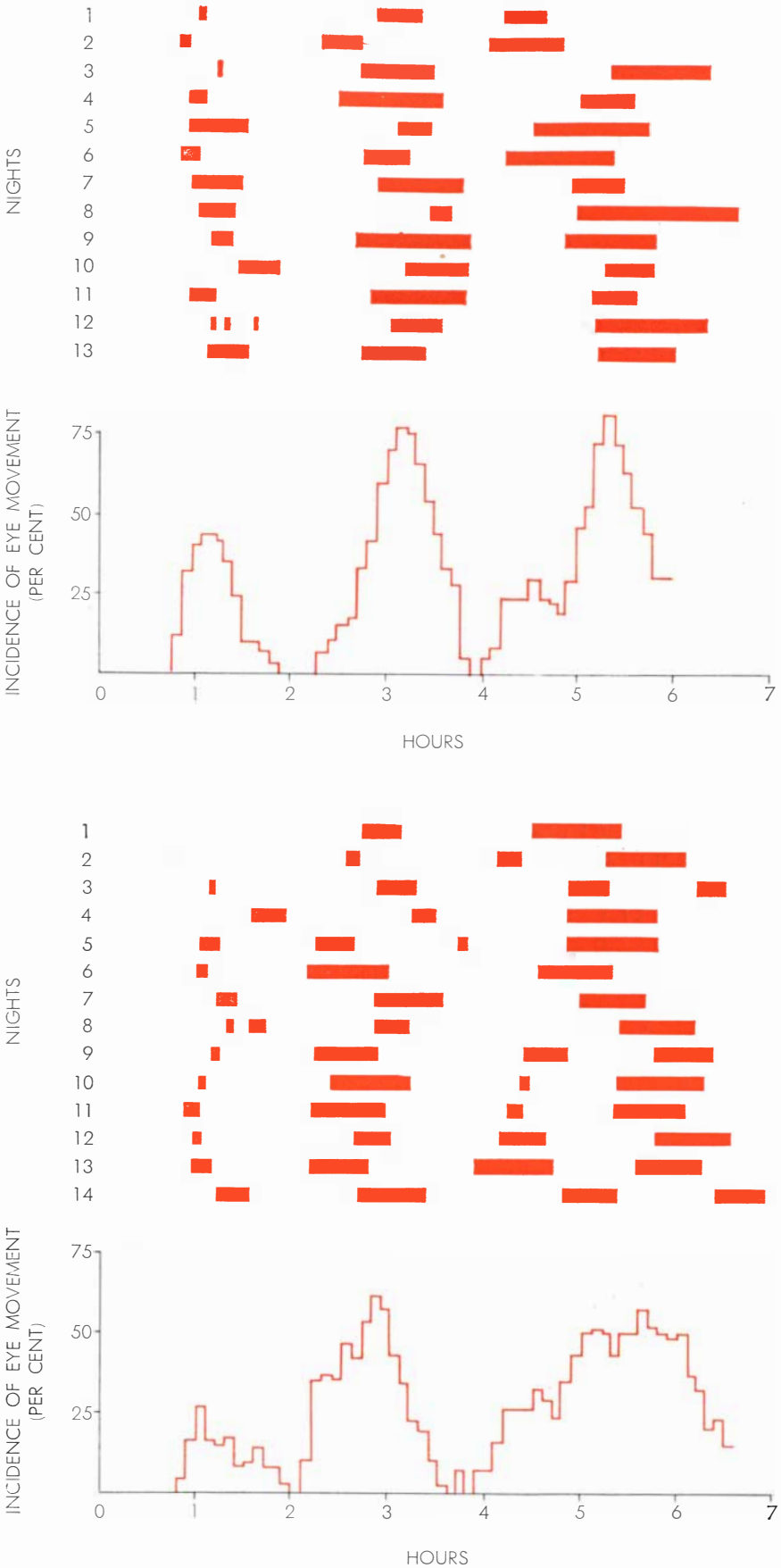
be bewildered and act in a deranged manner for some time. The content of dreams, explicit or hidden, may indeed have inherent interest. But for the purpose of an investigation of dreaming, it is sufficient to recognize the dream itself as a manifestation of low-grade thinking.

The objective indicator that a sleeper is dreaming, it must be admitted, is not infallible. Some subjects reported they had been dreaming during periods when they showed no rapid eye-movements. Others moved their bodies restlessly when the records on the other channels of the electroencephalograph indicated they were dreaming. Sometimes the heart and respiration rate slowed down instead of speeding up. Occasionally a subject claimed to have been dreaming when his brain waves indicated a deeper phase of sleep. William Dement, another student in our laboratory who is now at Mount Sinai Hospital in New York City, showed that of the four criteria the most reliable is the brain-wave pattern.

A person who is awake but resting with his eyes closed shows the so-called alpha rhythm—brain waves with a relatively large amplitude and a frequency of eight to 13 cycles per second [*see illustration on these two pages*]. As he falls asleep, the amplitude of the waves decreases, and the rhythm slows to four to six cycles per second. Dement called this pattern the Stage 1 electroencephalogram (Stage 1 EEG). Deeper sleep is characterized by the appearance of "sleep spindles"—short bursts of waves that progressively increase and decrease in amplitude and have a frequency of 14 to 16 cycles per second; Dement divided this level of sleep into two stages (Stage 2 and Stage 3 EEG). The deepest level of sleep is characterized by the appearance of large, slow waves (Stage 4 EEG). During a typical night of sleep,



cephalogram (Initial Stage 1 EEG) appears. During deeper sleep subject shows short bursts of waves called sleep spindles (*b*). Deepest level of sleep (Stage 4 EEG) is characterized by the appearance of large, slow waves. EEG pattern changes from Stage 1 through Stage 4, then swings back to Stage 1. This "emergent" Stage 1 is accompanied by rapid eye-movements, as indicated by peaks in tracings of eye-movement potentials (*c*). Similar peaks during Stage 4 are not eye movements but brain waves that spread to eye electrodes.



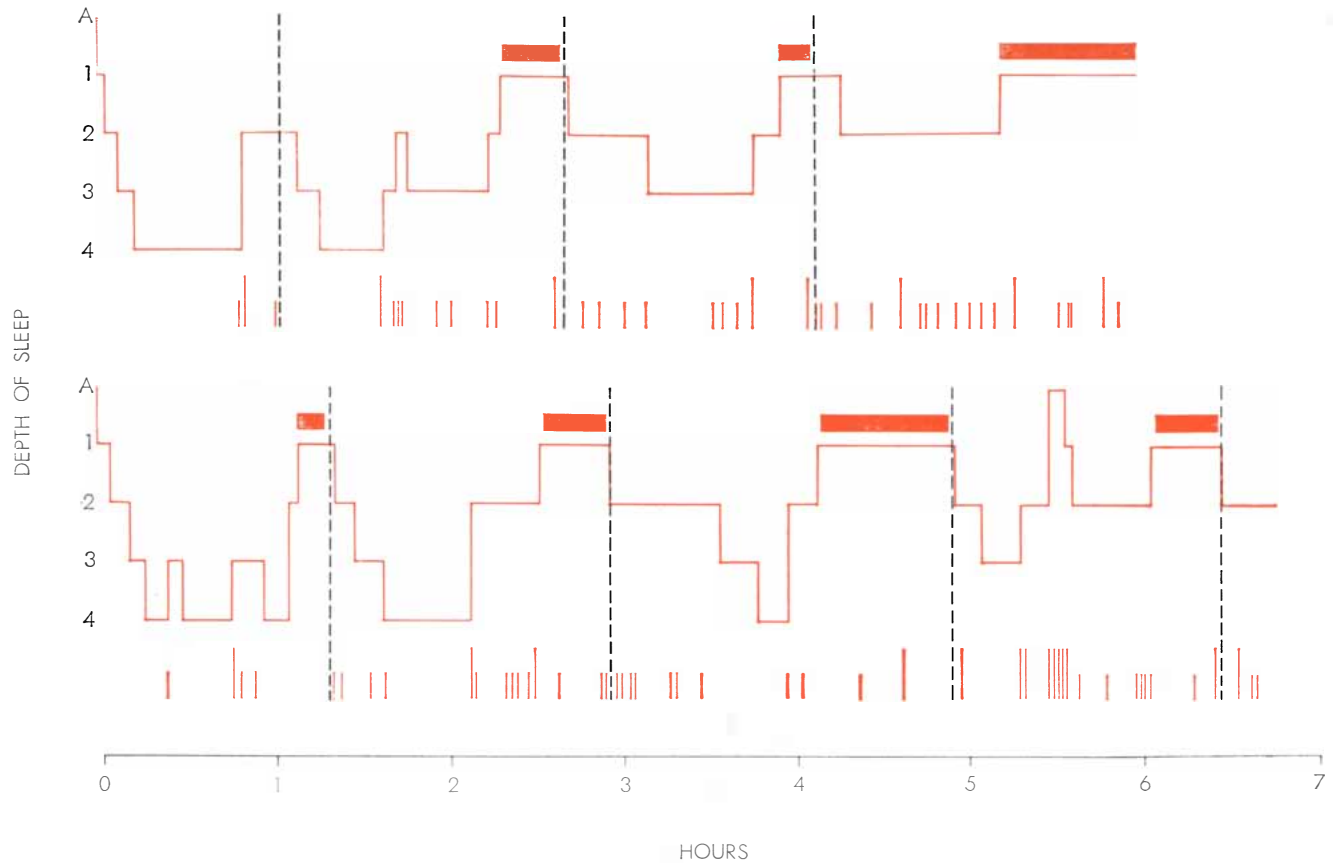
RAPID EYE-MOVEMENTS (*horizontal colored bars*) occur several times each night. Each horizontal row of bars represents a single night of sleep; one subject was studied for 13 nights (*top graph*), the other for 14 (*bottom graph*). Histograms at bottom of each graph show composite cycles of subject's eye movements during entire series of nights.

the depth of sleep fluctuates on a cycle lasting roughly 90 minutes. The EEG pattern passes from Stage 1 through Stage 4, then swings back to Stage 1. During later cycles the sleep may not be so deep; the EEG pattern may dip no farther than the intermediate stages before it returns to Stage 1 [*see illustration on opposite page*].

Dement found that dreaming occurs during the Stage 1 EEG, but not when this brain-wave pattern first appears at the onset of sleep. Only when the cycle returns to the Stage 1 EEG from a deeper EEG level does it mark a dreaming episode. During this "emergent" Stage 1 it is much more difficult to awaken the sleeper than during the "initial" Stage 1 EEG.

The inconsistencies between the EEG record and the other criteria may be largely explained by the relationship of these other activities to the dream episode. For example, most of the rapid eye-movements are horizontal, and it is apparent that these movements represent a busy scanning of the scene of dream action. On the infrequent occasions when the rapid eye-movements were vertical, the sleepers reported dreams that involved the upward or downward motion of objects or persons. When the record showed few or no rapid eye-movements, and the EEG denoted dreaming, the subjects reported that they had been watching some distant point in their dreams. In other words, the amount and direction of the eye movements correspond to what the dreamer is looking at or following with his eyes. Moreover, rapid eye-movements seem to be related to the degree to which the dreamer participates in the events of the dream. An "active" dream, in which the dreamer is greatly involved, is more likely to be accompanied by rapid eye-movements than is a "passive" one.

The absence of gross body movements during dreaming seemed more difficult to explain. One would assume that a sleeper would begin to move about as his sleep lightens and that a good deal of activity would occur during dreaming. Actually the exact opposite was observed. Dreaming often began just after a series of body movements ceased. The sleeper usually remained almost motionless, showing only the telltale rapid eye-movements, and stirred again when the eye movements stopped. We were indebted to Georg Mann, a public-information officer at the University of Chicago, for the metaphor that captured the essence of this situation. He compared the dreamer to a spectator at a theater:



EEG STAGES of two subjects show a cyclic variation during typical night of sleep. Measured in terms of EEG stages, depth of sleep fluctuates on a 90-minute cycle. Cycle begins when subject who is awake (A) falls into light sleep (EEG Stage 1), then into successively deeper levels of sleep (EEG Stages 2, 3 and 4). Cycle ends with swing back to Stage 1. Periods of rapid eye-movement (*horizontal colored bars*) occur during this stage. Vertical broken lines indicate when next cycle begins. Vertical colored lines at bottom of each graph indicate when body movements occurred; longer lines represent major movements; shorter lines, minor ones.

fidgeting in his seat before the curtain goes up; then sitting quietly, often "spellbound" by the action, following the motions of the actors with his eyes; then stirring again when the curtain falls.

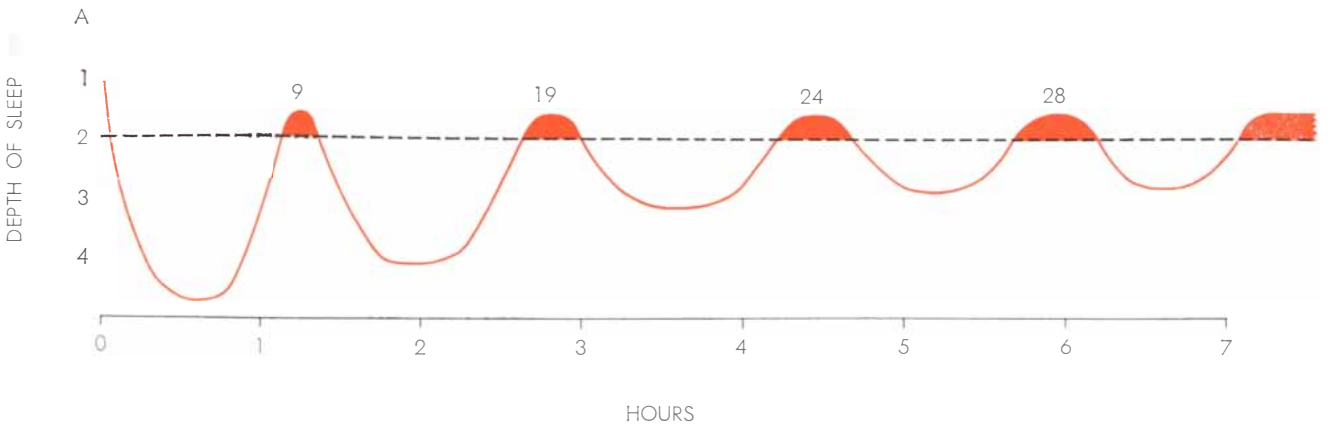
Some body movement may be related to dream content. Edward A. Wolpert of the University of Chicago attached electrodes to the limbs of sleeping subjects and recorded the electrical "action" potentials of the muscles. The record of one of his subjects showed a sequence of motor activity first in the right hand, then in the left, and finally in one leg (only one leg was wired for recording). When aroused immediately thereafter, the sleeper reported dreaming that he lifted a bucket with his right hand, transferred it to his left, and then started to walk. Sleepwalking may be an extreme expression of such motor outflow to extremities. Occasionally a subject would vocalize when he stirred, mumbling and even talking distinctly, but such activity usually occurred between episodes of dreaming.

Some people assert that they seldom or never dream. But all of the subjects—and all of those observed in other laboratories that employ the objective indicator—reported dreaming upon being awakened at appropriate times. It can be stated with some assurance, therefore, that everybody dreams repeatedly every night. Donald R. Goodenough and his associates at the Downstate Medical Center of the State University of New York compared one group of subjects who said they never dreamed with another group who said they always dreamed. Certain unexplained differences showed up in the EEG records of the two groups, and the "dreamers" were more likely to report dreaming in correspondence with rapid eye-movements than the "nondreamers." Rapid eye-movements were observed with the same frequency, however, in both groups. The evidence is overwhelming that the two groups should be classified as "recallers" and "nonrecallers."

These studies have also upset the notion that a long series of events can be compressed into a moment of dreaming. Whether the subject was loquacious or laconic in recounting his dream, the time-span of the narrative was consistent with dreaming time as indicated by our objective criteria. It appears that the course of time in dreaming is about the same as in the waking state.

It is often said that external events in the sleeper's immediate environment may suggest or affect the content of dreams. To test this idea Dement and Wolpert exposed a number of subjects to the stimuli of sound, light and drops of water during periods of dreaming. Elements suggestive of such stimuli appeared in only a minority of the dreams recounted thereafter. Drops of water, falling on the skin, proved to be the most suggestive. Falling water showed up in six dream reports out of 15 that followed arousal by this stimulus, and water had a place in 14 narratives out of 33 when the sleepers were subjected to the stimulus but not awakened by it. An electric bell used routinely to awaken the subjects found its way into 20 out of 204 dreams, most commonly as the ringing of a telephone or doorbell.

Internal stimuli from the viscera have



EPISODES OF DREAMING (*colored areas*) alternate with periods of deeper sleep. Dreaming and rapid eye-movements begin when sleeper emerges from deep sleep to level of EEG Stage 1. Numbers over colored areas show length of successive periods of dreaming.

been held to cause, or at least influence, dreams. Dreams about eating are said to be stimulated by contractions of an empty stomach. Dement and Wolpert had three subjects go without fluids for 24 hours on five occasions; only five of 15 dream narratives contained elements that could be related to thirst. In no case did the narrative involve an awareness of thirst or descriptions of drinking, although the subjects were very thirsty when they went to bed.

Most of the dream experience in normal sleep is never recalled. Recollection is best when the sleepers are awakened during the dreaming episode and becomes progressively poorer the longer they are permitted to sleep after a dream has ended. At the University of Chicago, Wolpert and Harry Trosman found that 25 out of 26 subjects had no memory of dreaming when they were roused for questioning more than 10 minutes after the Stage 2 EEG had superseded the Stage 1.

Once the objective indicator had shown itself to be a reliable measure of dreaming, it was employed to enact the pattern of dreaming through many nights of uninterrupted sleep. In a sampling of 71 nights of sleep, with 33 different subjects, the first emergent Stage 1 EEG—plus the accompanying rapid eye-movements and cardiac and respiratory changes—appeared a little over an hour after sleep had begun. This episode of dreaming lasted on the average less than 10 minutes. Three, four and even five dreaming periods followed at intervals of about 90 minutes. These lasted 20 to 35 minutes and added up to a total of one or two hours of dreaming for an average night's sleep. All of the subjects exhibited the cycle of alternate periods of dreaming and deeper sleep, some on a more constant schedule than others.

The mechanism that spaces the episodes of dreaming is unknown, but it may be related to the cycle of rest and activity which Aserinsky found in infants. The mean length of that cycle is approximately an hour, and at the end of a cycle the infants stir, either to awaken fully or to go back to sleep for another cycle. In infants on a self-demand feeding schedule, the duration of the period between feedings tends to be roughly whole multiples of the length of this cycle. Apparently the cycle lengthens with age, extending to the 90-minute dreaming cycles observed in adults. A similar increase occurs in the length of the cardiac, respiratory and gastric cycles, indicating that the dream cycle is in line with the basic physiological rhythms of the body.

What happens if the dreaming cycle is disturbed? This interesting question has been taken up by Dement and his associates. Monitoring the subject's cycle, they awaken him as soon as he starts to dream and thus keep him from dreaming. Since one must be certain that dreaming has started before attempting to stop it, such interference cannot completely deprive the subject of his dreaming, but total dreaming time can be reduced by 75 to 80 per cent. Dement established that the mean normal dreaming time of his eight male subjects was 20 per cent, or about 82 minutes in about seven hours of sleep. Attempts to curtail their dreaming in the course of three to seven consecutive nights required in each case a progressively larger number of awakenings—in some cases three times as many. During the "recovery" period after this ordeal, the dreaming time of five of the subjects went up to 112 minutes, or 27 per cent of the sleeping time, on the first night and gradually fell back to normal on succeeding nights. In six of the subjects arousal in the midst of nondreaming periods during "control" nights of sleep had no effect on dreaming during the recovery nights that followed. The curtailment of dreaming time produced anxiety, irritability, a greater appetite and a gain in body weight; the control awakenings had no such effects. As soon as the subjects of the experiment were allowed their usual dreaming time, they regained their emotional composure.

Dement tentatively interprets his findings as indicating that "a certain amount of dreaming is a necessity." Charles Fisher, a psychiatrist at Mount Sinai Hospital in New York, adds that "the dream is the normal psychosis and dreaming permits each and every one of us to be quietly and safely insane every night of our lives."

From the same evidence, however, one may equally well argue that the curtailment of dreaming engenders irritability and anxiety simply because it interferes with an acquired habit. Animals (and some people) that have acquired a "sweet tooth" may be similarly upset by deprivation of sugar. They will also consume excessive quantities of sugar after the supply is restored, just as Dement's subjects sought to make up for "missed" dreaming. In other words, the low-grade cerebral activity that is dreaming may serve no significant function whatever.

Further observation and experiment will have to decide which of these conflicting views is sound. The objective indicator is now available to help investigators find the answer to this and other questions about the nature and meaning of dreaming.

Kodak reports on:

the lithium salt of pyruvic acid . . . a book for the very fussy customer . . . materials that are not blinded by hot wind

The baron led the way

The great Baron Berzelius may well have sensed big game when he discovered pyruvic acid in 1835. The name comes from the Greek *pyr*, for fire, and the Latin *uva*, for grape. This figures. Pyruvic acid used to be prepared by dry distillation of tartaric acid. The oldtimers had it spotted as an intermediate in the fermentation of sugar. Such relationships had probably begun to look simple and straightforward.

It was just as well that no gypsy fortuneteller told the Baron that 72 years after his death work would begin in earnest on unraveling *just* how grape sugar breaks down into pyruvic acid and that this work would take 40 years until the phenomenon was at last understood as the first stage in the process by which chemists and other living creatures obtain from their food the energy with which to engage in all affairs, including ratiocination about biochemistry.

Anyway, the Baron was an excellent chemist. He prepared several salts of pyruvic acid, including the lithium. Now we wish to report that we, too, can prepare *Pyruvic Acid Lithium Salt* and, in fact, offer it as Eastman 8130, a standard for use in pyruvic acid determinations. *Pyruvic Acid* is Eastman 498, vintage unspecified.

Of very recent vintage is the new Eastman Organic Chemicals, List No. 42, which catalogs some 3800 organic compounds we stock. If you do not have a copy, why not? Write Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).

Color fancily repackaged

"You press the button, it does (or in an alternate version, "we do") the rest." It was one of the more successful slogans in advertising history. It made us a great deal of money. Millions bought the philosophy, and millions still buy it. A few hundred thousand don't buy it. Them, too, we love, admire, and respect. We have just published a fancy new book for them. Fancy is the word.

This book contains more than just pages. Snuggled among them are an actual standard color negative and positive, two special slide-rule computers, and a big nomograph in color about color correction. One of the pages has windows fitted with six different color-print viewing filters. Under the title "Kodak Color Dataguide," it is sold by camera shops for $4.95. (If you send a check to Eastman Kodak Company, Sales Service Division, Rochester 4, N. Y., we shall sigh at how people have forgotten how to walk these days and mail you a copy.)

Frightening as it looks, the book contains virtually no photographic theory. It is a repackaging of operating instructions for two basic categories of users (a better word in this case than "readers"):

1) The professional, be he photographer, scientist, or something in between.

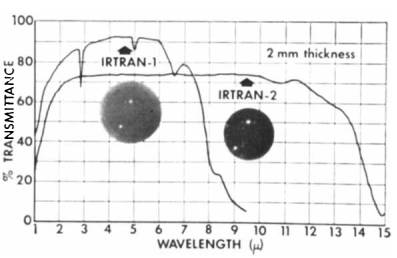
Commercial color labs in many cities do slick work in making color prints or transparencies from exposed film. But when requirements are too specialized to convey to labs geared for production, the hard way may be the better way.

2) The dedicated amateur who might be painting in oils or water-colors if only he had a better hand for it and who finds that serious color photography brings into play the exact combination of technology and a good eye that best unwinds him from workaday cares.

In art, the best effects often come from a skillful violation of the rules. But the result is usually a mess unless one has first perfected himself in the rules.

For little pots or big peepholes

If you want to make a useful little pot for putting things in that are to be poked with infrared or microwave radiation; or if you want to make an object move through the air at speeds like Mach 6 and need something to keep the hot wind out of the peephole while admitting infrared *and* microwaves to steer by, you must investigate *Kodak Irtran* material or face charges of that heinous sin, ignoring the "state of the art."



Kodak Irtran merchandise: an *Irtran-1* dome and an f/1.0 *Irtran-2* molded asphere

There are now two kinds of *Irtran* optical material, neither of them intended for wavelengths that your old dictionary would call "optical."

The newer, *Irtran-2*, has as its point of pride the transmittance curve displayed above, combined with a remarkable mechanical and chemical ruggedness. Its refractive index is around 2.2. Note the tremendous wavelength span over which transmittance losses are nearly all due to reflection. Heating to 600°C in air does nothing more than improve the transmittance—by formation of an anti-reflection coating. We can apply a much better coating, though, by evaporation.

*Irtran-1** material, the other one, needs no anti-reflection coating because its refractive index is only 1.38 at 1μ. *Its* big glory, aside from high infrared transmittance at 2 to 7μ even when very hot, stems from a 9.4 kmc dielectric constant of 5 and a loss tangent of 10^{-4}.

Decibel loss per meter for low-loss materials is

$$\frac{8.686\pi}{\lambda_o}\sqrt{K}\tan\delta$$

where K = dielectric constant
λ_o = wavelength in vacuum
tan δ = loss tangent
δ is the complement of the vector angle whose cosine the power engineer calls "power factor."

One untuned *Irtran-1* sample .012″ thick we tested in the X-band frequency range introduced an attenuation of less than 0.3db and exhibited a maximum standing wave ratio of 1.5 over the band.

The ideal radome material would have a kilomegacycle dielectric constant of unity, i.e. to microwaves it would be the same as nothing at all. Plastics commonly used for radomes run around 2 or 3, but they don't transmit infrared rays. On the other hand, there are materials that are good for infrared transmission but have dielectric constant around 13.

Currently we can supply either of these polycrystalline Irtran *materials as optical elements up to 6½″ in diameter, among other forms. Let us have no jurisdictional disputes among optickers, micro-wavers, and infraredders as to who sends for the supporting data from Eastman Kodak Company, Special Products Division, Rochester 4, N. Y.*

*Formerly designated "Irtran AB-1."

Price quoted is subject to change without notice.

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

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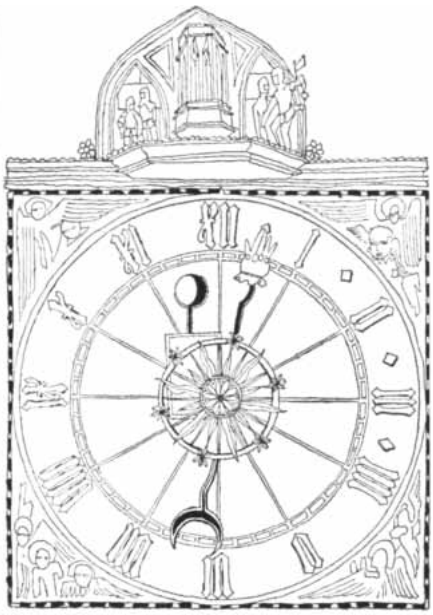


SCIENCE AND

"CERN" for Space

Scientists from 10 European nations, plus Australia, are drawing up plans for a European Commission for Space Research to carry on a cooperative international research program of the kind pioneered in nuclear physics by the 12-nation European Organization for Nuclear Research (CERN). The purpose is to open up the costly field of space research to nations unable to enter it individually. European countries proposed for Commission membership are Belgium, Britain, Denmark, France, Italy, the Netherlands, Norway, Sweden, Switzerland and West Germany. Australia's special contribution would be the Woomera rocket range as a launching site.

The space commission, which was first suggested by Pierre V. Auger of the University of Paris, former director of natural sciences for UNESCO, will begin work as soon as any six governments have given approval.

Mostly Science

By 1970, it is predicted, a majority of the 400,000 full-time teachers in U. S. colleges and universities will be scientists and mathematicians. The forecast portends a shift in the seat of academic power, historically held by the scholars of the humanities. Scientists will then have prime responsibility for shaping the whole college curriculum and for maintaining academic freedom. The forecast was made in *Science* by H. Bentley Glass, professor of biology at Johns Hopkins University.

Glass estimates that teachers of science and mathematics now number 78,000 of the 250,000 men and women engaged in full-time teaching in universities, colleges and junior colleges. If full-time medical and dental school teaching personnel are included, science teachers constitute 91,000, or 36 per cent, of the entire higher-education teaching force.

The proportion of science teachers is bound to increase sharply over the next decade, not just because science and engineering students are increasing in number, but also because science trainees already constitute a majority of the graduate-student pool from which most college teachers are drawn. In 1970, according to Glass, colleges and universities will employ some 400,000 full-time teachers, of whom more than 200,000 will be teachers of science and mathematics; counting medical and dental school faculties, the total of science teachers may pass 250,000. If academic scientists lack perspective or hold narrow views, warned Glass, they could imperil long-cherished principles of higher education. Glass is convinced, however, that the "sciences must become the core of a liberal education [and that] the humanities and social sciences . . . must be permeated with the knowledge and spirit of science if they are to be more than relics of a departed age."

Anti-Staph Penicillin

A powerful reinforcement in the battle against infection has been added with the discovery of a new semi-synthetic penicillin that can combat resistant strains of staphylococci. Reports from a dozen hospitals in Canada, Great Britain and the U. S. indicate that the new compound—2, 6-dimethoxyphenyl penicillin—is strikingly effective against *Staphylococcus aureus* and other resistant strains now a scourge of hospitals. The new penicillin (the U. S. trade name is Staphcillin) is one of several hundred penicillin variants prepared by research workers of Bristol Laboratories in the U. S. and Beecham Research Laboratories in England. It was the Beecham group that discovered a method of halting penicillin fermentation at a stage when the mold has produced an intermediate—6-aminopenicil-

THE CITIZEN

lanic acid—rather than the complete penicillin molecule. This permitted synthetic side-chains to be linked to the penicillin base, with methods first developed by John C. Sheehan of the Massachusetts Institute of Technology.

The new drug is not inactivated by penicillinase, the enzyme with which resistant staphylococci destroy other forms of penicillin. As a result no resistance to it has been encountered, either in laboratory examination of several thousand staph strains, or in the treatment of some hundreds of patients with resistant-staph infections. The new penicillin will not, however, replace other antibiotics in the treatment of other infections. It is not as effective against other infections as is penicillin G, and it must be given by injection at the high rate of one gram every three to four hours.

Radiation Limit Reduced

The Atomic Energy Commission has cut the allowable exposure of workers in atomic industry from the equivalent of 15 roentgens a year to an average, after the age of 18, of only five roentgens a year, with a maximum allowance of three roentgens in any three-month period. (These are so-called whole-body doses. By comparison, an average dental X-ray delivers about five roentgens to the jaw.) Since the limit for the general public is 10 per cent of that for atomic workers, the allowable exposure of the public is correspondingly reduced.

The new regulations, which will come into effect January 1, bring the AEC's rules into line with recommendations made last year by the National Committee on Radiation Protection.

Highest-Energy Cosmic Ray

A cosmic-ray shower recorded at nine minutes past midnight last December 3 has provided strong evidence that cosmic rays originate in the vast depths of extragalactic space as well as in the earth's own galaxy. The shower of charged particles was detected at Volcano Ranch, a Massachusetts Institute of Technology station near Albuquerque, N.M. Bruno Rossi, who heads the M.I.T. cosmic-ray program, and his colleagues have calculated that the particles were

produced by a primary cosmic ray with the highest energy on record: 2×10^{19} (20 billion billion) electron volts—nearly a billion times the energy that can be attained in the largest man-made accelerators. The primary ray came from a direction that seems to rule out an origin in our galaxy.

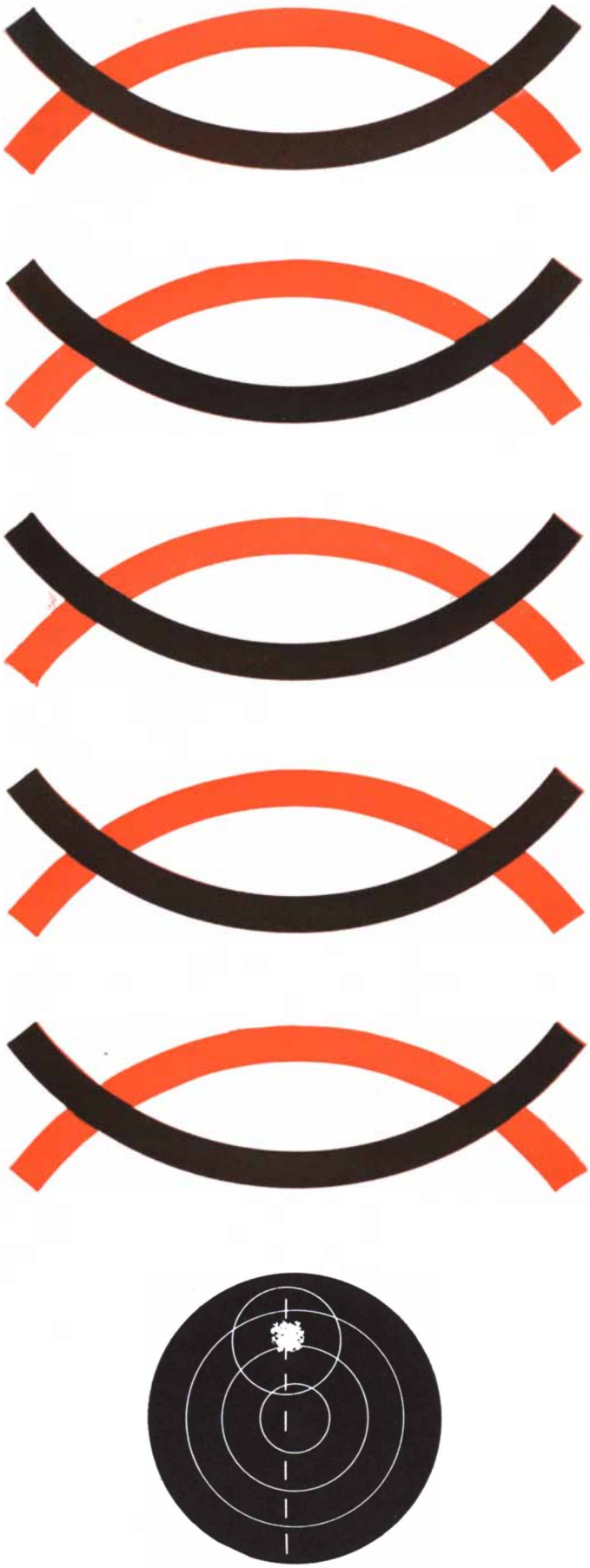
Physicists suspect that high-energy cosmic rays (unlike low-energy ones, which come from the sun) may result from a cyclotron-like action whereby low-energy particles emitted from a star are whirled to higher and higher velocities by interstellar magnetic fields. At sufficiently high speeds and energies—above 10^{17} to 10^{18} electron volts—particles would rocket out of the galaxy altogether. Some theorists have held, however, that rays more energetic than 10^{17} electron volts might be generated by some identifiable object, such as a supernova, acting as a "superaccelerator." If so, the incoming directions of such rays that strike the earth should point directly back to their points of origin.

To seek such rays, the M.I.T. group arranged particle detectors to register the enormous secondary showers of particles that powerful primaries produce in the atmosphere. The largest detector array, spread over an area a mile and a third across, had operated only a few months when the record ray struck. No body capable of emitting it is known in our galaxy in the direction from which the ray came. It must have come from outside, and, in Rossi's opinion, probably gained its tremendous energy from eons of wandering—and acceleration—among magnetic fields in galaxies beyond our own.

Tying Molecules in Knots

Chemists of the Bell Telephone Laboratories have prepared a remarkable new class of compounds consisting of two large rings linked together in a manner resembling two interlocked key rings. Termed catenanes (from the Latin *catena*, meaning "chain"), the new compounds are not molecules in the usual sense, because the rings are not bonded to each other chemically. In theory it should be possible to make catenanes with three or more interlocking rings, and perhaps even to make simple knots, Moebius strips, and other bizarre topological forms.

Catenanes are formed by mixing a large-ring carbon compound and long straight molecules with a reactive group at each end. A small proportion of the straight-line molecules thread through



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the rings; interlocked pairs are formed when the straight-line molecules are closed into rings by reaction of the end groups. In order to permit another molecule to pass through, a ring must contain at least 20 carbon atoms in its circular skeleton. Both the ring and the straight-line molecules used in the Bell experiments, E. Wasserman told the American Chemical Society, contained 34 carbon atoms. One was a hydrocarbon, the other a modified hydrocarbon known as an acyloin, but other combinations are also possible. No applications for catenanes have yet been discovered.

Magnetic Field of the Galaxy

Although astronomers are confident, from cosmic-ray and other studies, that a general magnetic field exists in interstellar space, the field may be considerably weaker than anticipated. Some estimates had placed the galactic field-strength as high as 30 millionths of an oersted (as compared with .6 oersted for the earth). New measurements, carried out with the 250-foot radio telescope at Jodrell Bank in England, indicate that the maximum value probably does not exceed 20 millionths of an oersted, and may well be much less.

The measurements, made by R. D. Davies and his associates, were based on the Zeeman effect: the splitting of spectrum lines by a magnetic field. As observed from the earth, a magnetic field in space can be expected to split radio waves emitted by interstellar hydrogen into two components, one higher than the normal frequency and one lower. Some 400 observations were made with the Jodrell Bank telescope aimed at three intense radio-emission regions in Cassiopeia, at one in Sagittarius and at one in Taurus. Some splitting was found, but it was not far enough above the limit of sensitivity of the measuring technique to make it certain that the galactic magnetic field had actually been detected. In any case the experiments show that the field must be significantly weaker than had been thought necessary to account for such visible effects as the polarization of starlight.

Seismographic Synchroton

Microseisms (tiny earth vibrations) have been unexpectedly detected by a particle accelerator, the 25-billion-electron-volt proton synchroton at CERN in Geneva. During planning of the huge instrument—currently the second largest in the world—it was realized that its

Footnotes to the Crusader's 203,512th flight

This was a test flight for a new *Crusader* — the all-weather F8U-2N pictured here. It was a busy day for *Crusaders* all over the world. Over 700 of these carrier-based fighters have joined Navy and Marine squadrons since the first *Crusader* won the Thompson and Collier trophies. With the more powerful engine and armament, the advanced autopilot and radar of the new -2N, this fighter series is being improved for the third time at minimum cost and without interrupting Fleet readiness. This is "design growth." This is why, fighter for fighter, the *Crusader* has logged more peace-keeping flight hours than any other 1,000-plus-mph aircraft in U. S. service.

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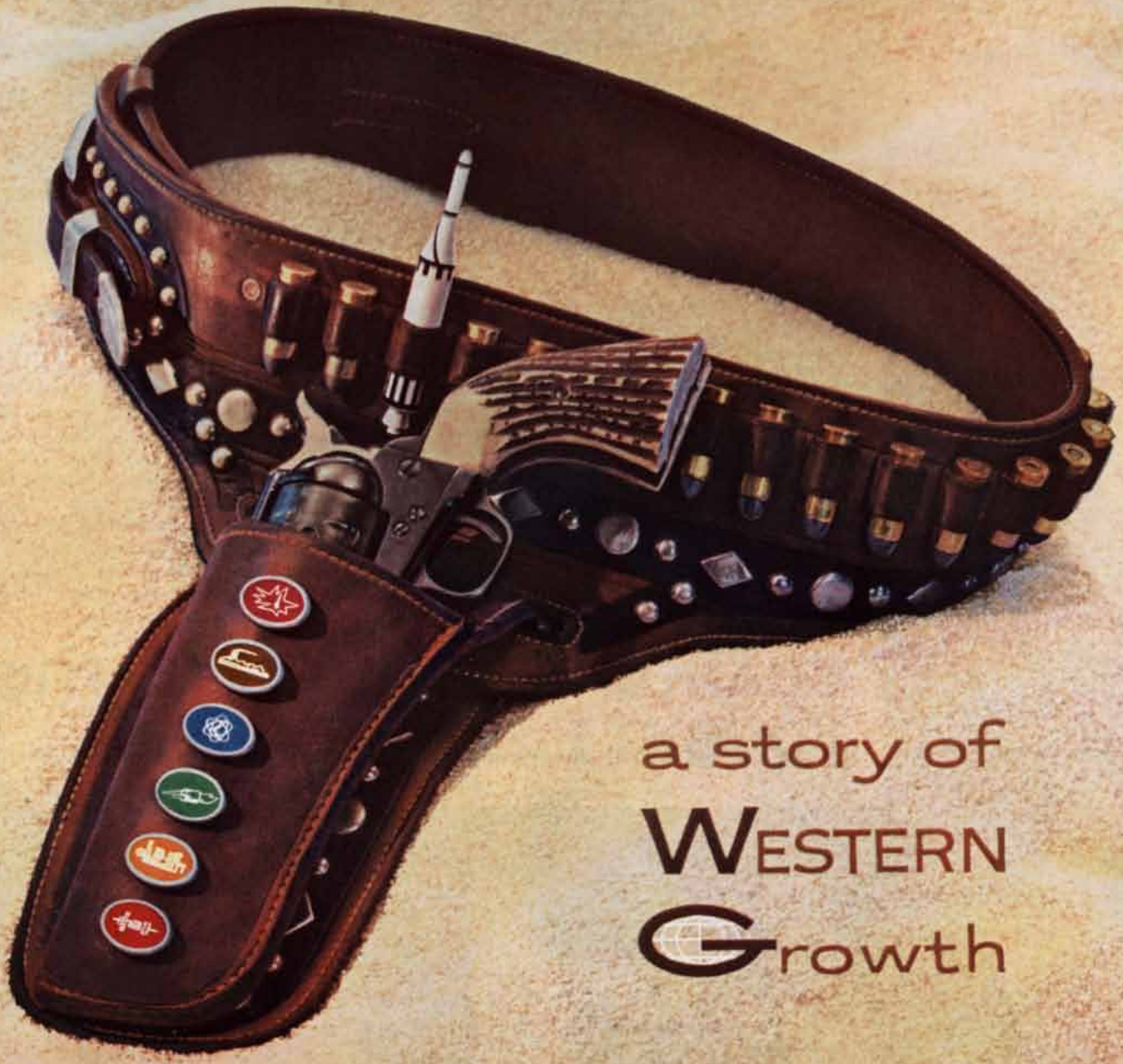

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2,000-foot-long circular vacuum chamber might be knocked out of round by local earthquakes and earth movements related to the melting of snow in the Alps near Geneva. Even very small distortions of the tube would interfere with the workings of the accelerator by permitting particles to escape before reaching their full energy. The accelerator tube was therefore rigidly fixed to a circular reinforced-concrete base 2,000 feet in circumference, and the two were left free to move together; thus earth movements might tilt the tube without altering its shape.

In tests that proved the arrangement's effectiveness, the movements of the huge concrete slab were traced with recording pens. The tracings revealed not only the expected movements resulting from local earthquakes and the melting of mountain snow, but additional periodic movements without any immediate explanation. André Decae, CERN geodesist, now believes that the puzzling motion reflects a fortnightly surge in tides in the Bay of Biscay, some 300 miles away.

Ozmology

Last spring the 85-foot telescope of the National Radio Astronomy Observatory at Green Bank, W. Va., was tuned for many days to radio waves emanating from the region of Nu Eridani and Tau Ceti, two solar-type stars about 10 light-years from the earth. The object was to determine whether anyone on planets "out there" might be trying to communicate with someone elsewhere in the universe. No evidence was obtained of anyone talking to anyone; the recordings revealed no systematic pattern of variation suggestive of a code. In *Physics Today* Otto Struve, director of the Observatory, nevertheless defended the listening experiment, called Project Ozma (after the queen of the fictional land of Oz). Struve entitled his article "Astronomers in Turmoil," and in it he gently chided his colleagues for becoming "too receptive to all kinds of more or less fantastic ideas." He went on, however, to defend Ozma, even though some have called it, he said, "the worst evil of our generation." Ozma, he explains, was both rational and scientifically valuable. For example, it aided in the development of and provided experience with radio receivers needed for measurements of the galactic magnetic field by study of interstellar radio emission.

But, Struve went on to say, science has now reached the point where inves-

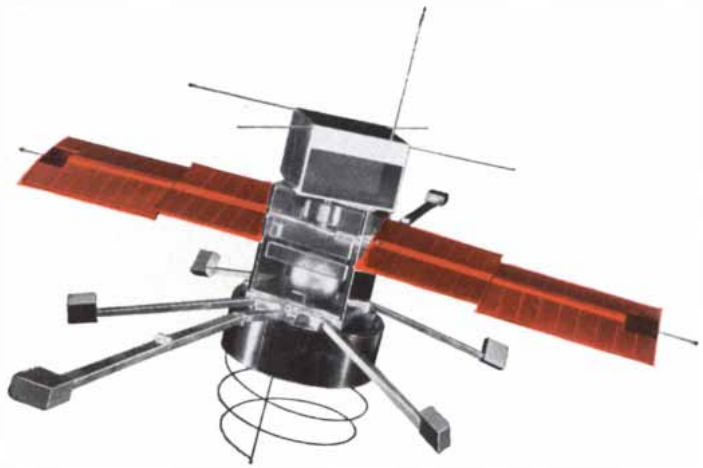
tigators must take into account the action of intelligent beings in addition to the classical laws of physics. Man has enveloped the earth in radio waves observable from distant points in the Milky Way; atomic-bomb explosions might be visible from a distance of several light years, and would not be explained by the customary action of the laws of physics. While the chance of observing something of this kind or of intercepting a communication is almost zero when only one or two solar-type stars are observed, a good many billions of stars in the Milky Way alone may support intelligent forms of life. Thus, concluded Struve, "there is every reason to believe that the Ozma experiment will ultimately yield positive results when the accessible sample of solar-type stars is sufficiently large."

The Soviet Space Ship

The Soviet Government newspaper *Izvestia* has recently released additional details on the "space ship" that carried the dogs Strelka and Belka, together with an "abridged edition" of the animal and vegetable kingdoms, into orbit and then returned them safely to earth. The orbit was nearly circular, with an apogee of 210 miles, a perigee of 225 miles, and an inclination of not quite 65 degrees to the Equator. Gas-powered nozzles held the vehicle with its long axis pointed toward the center of the earth. In the final descent to earth, the deceleration force was held to a maximum of 10 G.

The space ship itself could have been utilized as the vehicle for the final descent of its living cargo, since all of it landed intact. But a separate capsule—ejected at an altitude of 22,000 feet by a barometric device—was provided for the dogs and a number of other animals as a test of emergency-escape equipment for future manned rockets. The capsule touched down at a speed of about 15 miles per hour.

The assortment of animal and plant life was put aboard in order to furnish direct information on the biological effects of hard primary cosmic rays, which were also recorded in photographic emulsion. A long preliminary training period was required to accustom the dogs not only to confinement in a protective cradle and the wearing of an instrumented antigravity "suit," but to use of waste-evacuation devices. But, said *Izvestia,* the dogs quickly learned to eat a special mixture of meat, cereal and water, jelled with agar, to



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obviate the need for a separate water supply, which, in zero-gravity environment, might prove frustratingly undrinkable.

A New Family of Fusion Machines

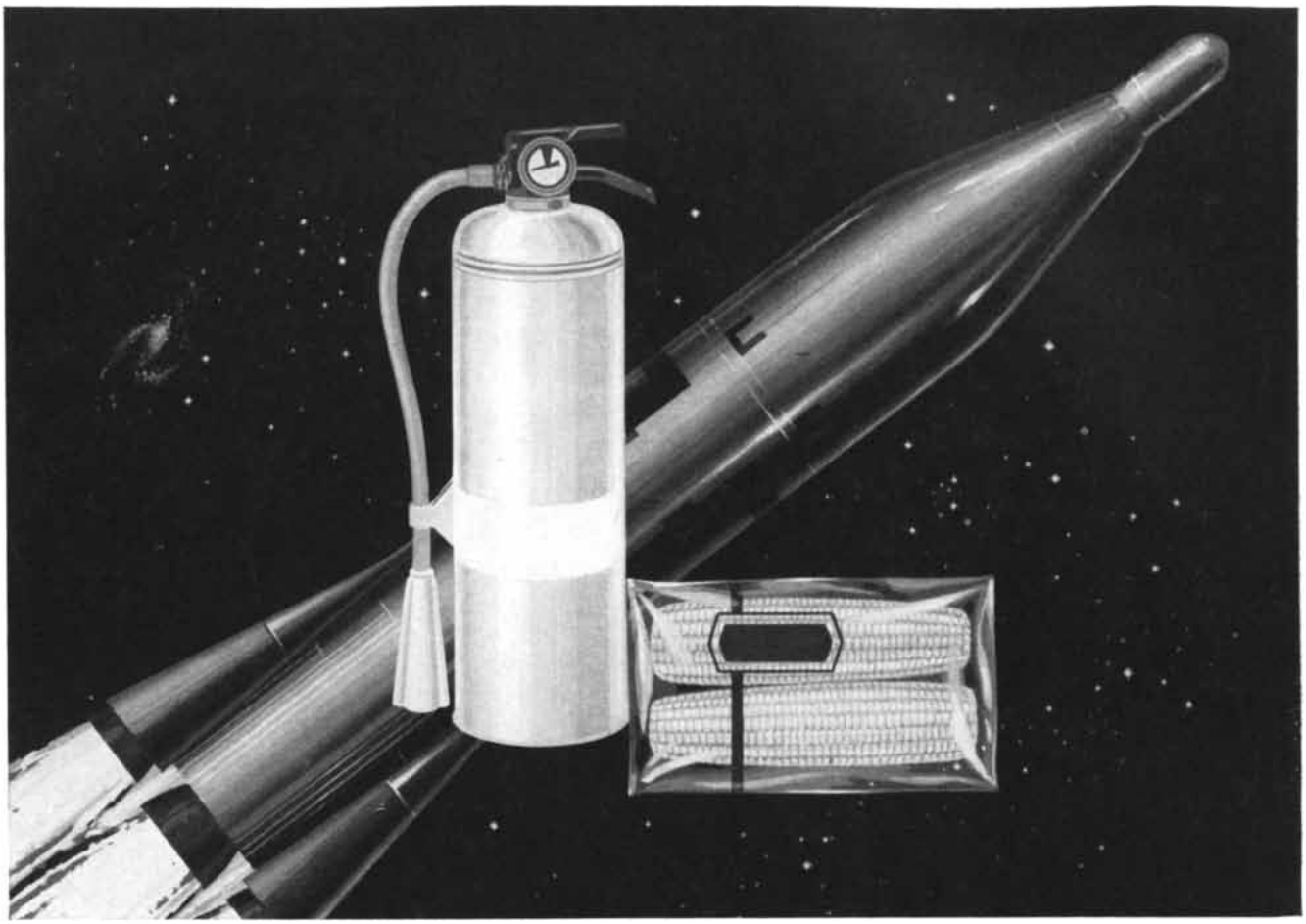
A number of the principal laboratories working on thermonuclear power have given up hope that controlled fusion reactions can be achieved with the "stabilized toroidal pinch" and many other of the designs that have been studied to date. Instead, work has begun on a new family of machines bearing an assortment of odd names: "cusped geometry" reactor, "caulked picket fence," and "helixion."

As reported recently in *Nature* by James L. Tuck of the Los Alamos Scientific Laboratory, the switch stems from a difficulty first noted by two Soviet physicists, B. A. Trubnikov and V. S. Kudryavtsev. Fusion machines use magnetic fields to confine plasmas, the hot ionized gases required for thermonuclear reactions. In machines of the pinch type the fields are set up inside as well as around the plasma. The Soviet physicists calculated, however, that plasmas threaded by magnetic fields must radiate away immense quantities of energy in the form of long infrared rays at thermonuclear temperatures. This makes it practically impossible, they concluded, to achieve a deuterium-deuterium fusion reaction in such reactors, and much more difficult to obtain a deuterium-tritium reaction than had been realized.

Not all physicists agree. Work is continuing on some machines with internal magnetic fields, but newer types of machines are receiving greater attention in this country, and the British have scrapped their pinch-machine project.

Researchers in the Netherlands and the U.S.S.R., as well as in Great Britain and the U. S., are said to be studying new designs. The distinguishing feature is an arrangement to attain a stable plasma solely with magnetic fields outside the gas. The oldest—the cusped geometry machine—was originally proposed in 1954 and abandoned in favor of devices that then seemed more promising; the name is derived from the cusped shape of its plasma space.

The caulked picket fence is a modification of the cusped geometry device to eliminate plasma leaks through the points of the cusps. Newest is the helixion, proposed by Tuck and based on a novel arrangement of helically wound coils. No helixion model has yet been built.



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Besides cryogenic and space applications, these "Freon" gases offer you new possibilities in dielectric insulation, metal treating, solvent processes, tracking of high-energy particles. They provide common characteristics of non-flammability, excellent thermal and chemical stability, and are virtually nontoxic. Worth investigating? Write Du Pont, "Freon" Products Div., N-2420, Wilmington 98, Delaware.

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"F-22"	$CHClF_2$	86.5	−41.4	204.8
"F-13B1"	$CBrF_3$	148.9	−72.0	152.6
"F-116"	CF_3-CF_3	138.0	−108.8	75.8
"F-13"	$CClF_3$	104.5	−114.6	83.9
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"F-14"	CF_4	88.0	−198.4	−49.9

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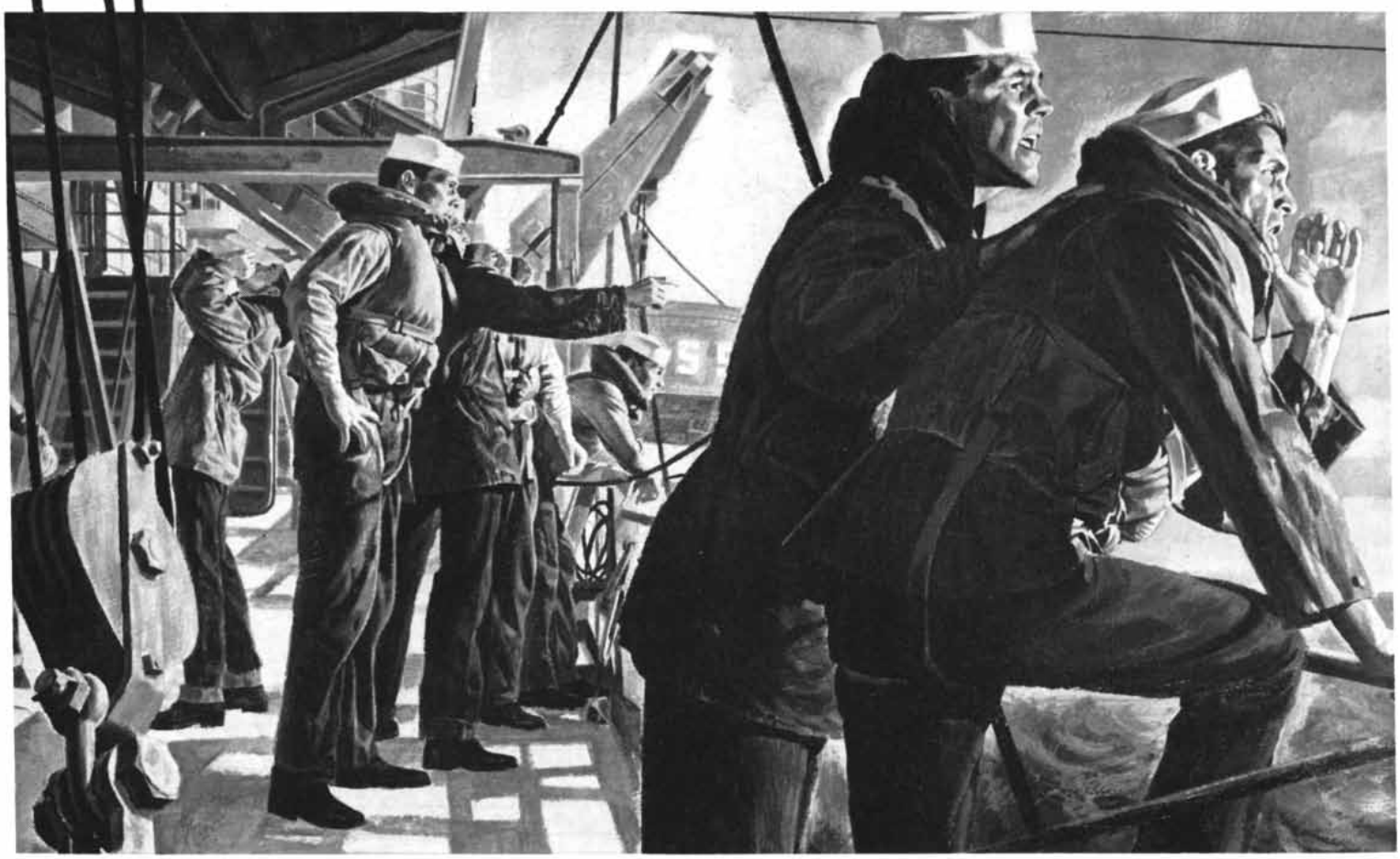

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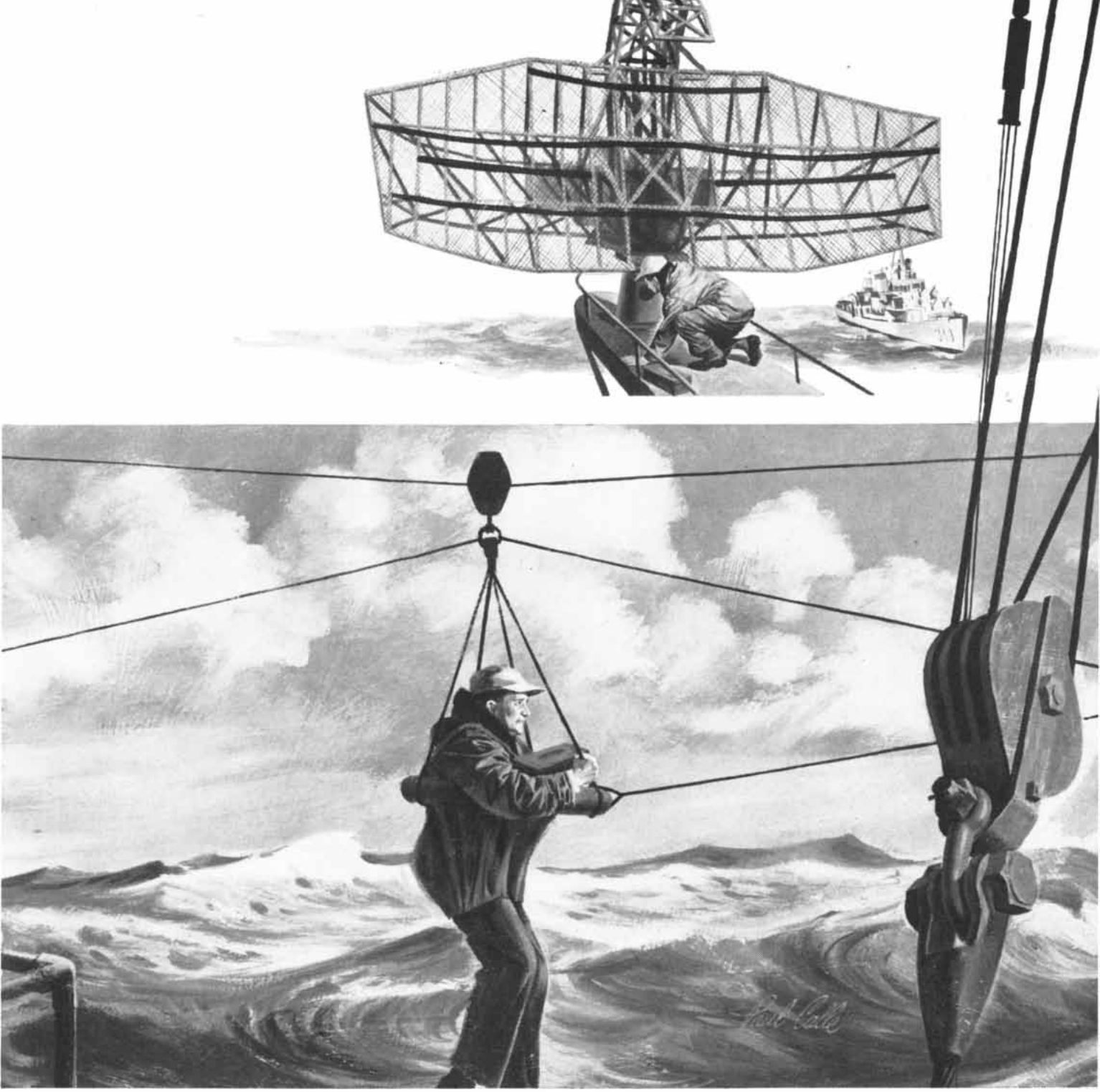

MINDING THE FUTURE

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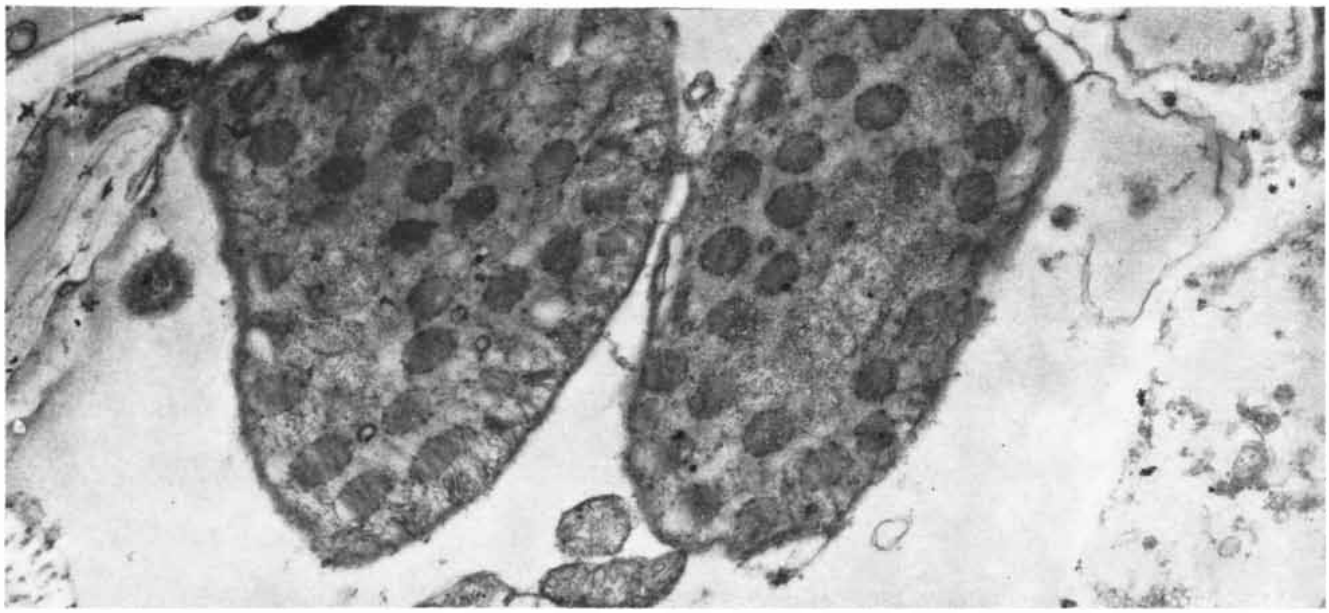
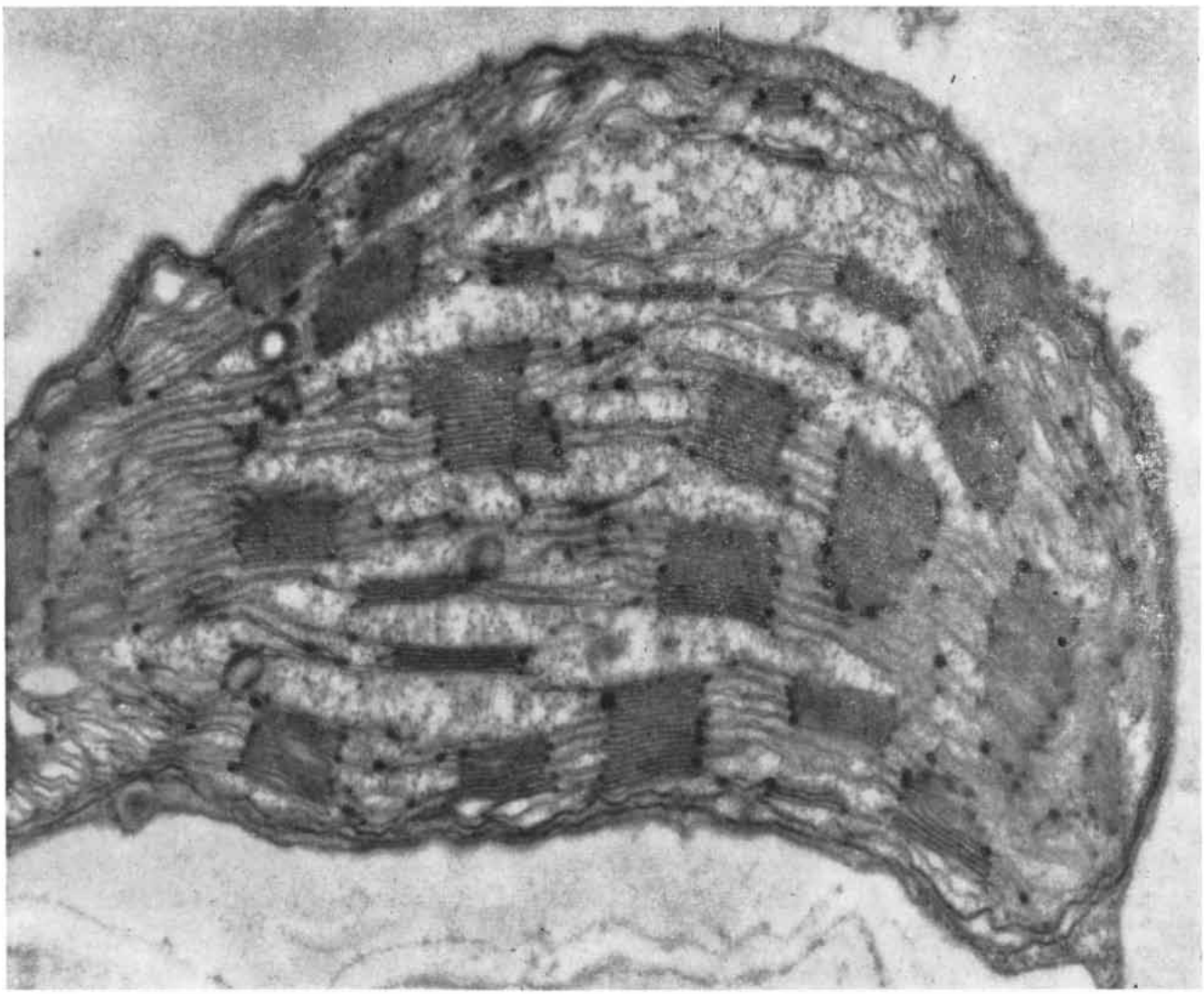


TWO CHLOROPLASTS within a maize cell are magnified 12,000 diameters in this electron micrograph made by A. E. Vatter. A single cell of a green leaf usually contains from 20 to 100 of these structures. They carry out the complete photosynthetic process.



MORE THAN 20 GRANA are clearly visible in this electron micrograph, which magnifies one maize chloroplast 33,000 diameters. Grana resemble stacks of coins. Since they contain all of the chlorophyll in green plants and algae, they are the receptors that trap and utilize the energy of light. The material around the grana, called stroma, performs the "dark" reactions of photosynthesis.

The Role of Light in Photosynthesis

The primary photosynthetic act, it now appears, is not to make carbohydrates from carbon dioxide, but to convert light energy into chemical energy, which the cell then uses in various ways

by Daniel I. Arnon

When the subject of photosynthesis was last surveyed in SCIENTIFIC AMERICAN, Eugene I. Rabinowitch wrote: "The photosynthetic process, like certain other groups of reactions in living cells, seems to be bound to the structure of the cell; it cannot be repeated outside that structure."

At that time (November, 1953), my co-workers at the University of California and I were in our fifth year of a vain effort to separate photosynthesis from other life processes in the cell. The next year our luck turned. We learned how to remove the chlorophyll-containing particles (chloroplasts) from spinach leaves by a technique that preserved in the isolated particles the ability to carry out the complete process of green-plant photosynthesis: the conversion of carbon dioxide and water to carbohydrates and oxygen, with no outside supply of energy except visible light.

Previously it had been known that isolated chloroplasts can evolve oxygen when exposed to light. This was called the Hill reaction, after R. Hill of the University of Cambridge, who discovered it in 1937. But isolated chloroplasts could not be made to assimilate carbon dioxide with the techniques then in use. Thus until 1954 carbon dioxide assimilation was believed to be a property of the intact cell.

Once the whole photosynthetic sequence had been dissected out, so to speak, the way to a biochemical attack on the mechanism of photosynthesis became much clearer. When the biochemist studies a physiological process, his goal is to take the process apart, separate its successive reactions, find out where and how each one takes place and identify the biological catalysts (enzymes) that make it possible. In the intact cell such an analysis is extremely difficult. An individual step of one physiological process may be hidden or modified by a similar step of another. Or the step may take place so rapidly that it escapes detection altogether.

The difficulty was especially acute in the study of photosynthesis because of the process of respiration. At the same time that a living cell is building up carbohydrate out of carbon dioxide and water, and throwing off oxygen, it is respiring: absorbing oxygen, with which it breaks carbohydrate down to carbon dioxide and water again. Isolated chloroplasts provided a photosynthetic system that does not respire.

The past six years have been busy ones in my own and other laboratories. This article will summarize what has been learned, with particular emphasis on the question that has always intrigued me most: What is the role of light in photosynthesis?

Early Investigations

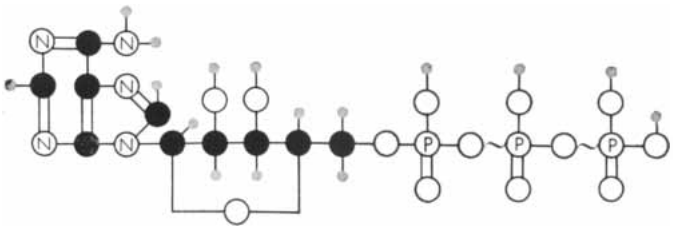
The story will be easier to follow if we go back to its beginning. In 1772 Joseph Priestley made his epochal discovery that green plants, "instead of affecting the air in the same manner with animal respiration, reverse the effect of breathing." Over the next 30-odd years the gross facts of photosynthesis were uncovered. Its raw materials and end products were identified. Its dependence on light was discovered in 1779 by the Dutch physician Jan Ingenhousz, who later offered a plausible suggestion as to the role that light energy plays. Sunshine, he said, splits apart the carbon dioxide (CO_2) that a plant has absorbed from the air, the plant "throwing out at that time the oxygen alone and keeping the carbon to itself as nourishment."

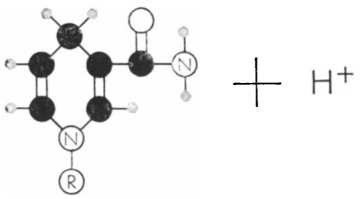
Later other investigators proposed that the "C" from the broken CO_2 combines with water to form a product with the empirical formula (CH_2O). (By enclosing a formula in parentheses the chemist indicates that the symbols inside do not necessarily represent an individual molecule, but merely a grouping that may be part of some larger structure.) The idea made eminently good sense because it is in exactly this proportion that carbon, hydrogen and oxygen occur in carbohydrates, the chief product of photosynthesis in green plants. And so, for the next 100 years and more, the role of light was regarded as settled.

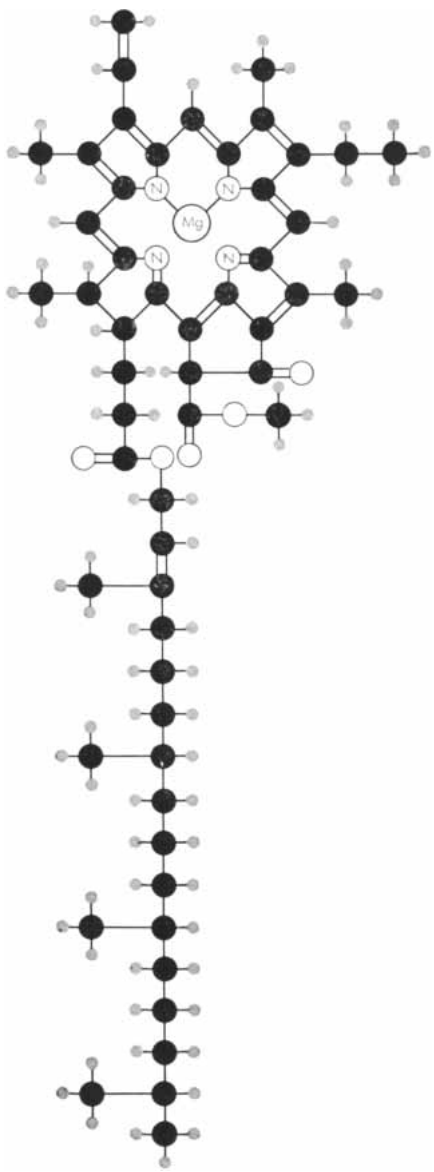
The hypothesis became a fixed principle of biology. All living organisms were divided into two groups: (1) green plants, which were thought to be the only organisms capable of assimilating carbon dioxide (and only in the presence of light); (2) all other forms of life, which do not have this power and must

AUTHOR'S NOTE

The author wishes to acknowledge the contribution of his associates and graduate students to the work in his laboratory reported in this article. In chronological order of their association with the investigations they are: Frederick R. Whatley, Mary Belle Allen, Lois J. Durham, John B. Capindale, Lawson L. Rosenberg, Harry Y. Tsujimoto, Achim V. Trebst, Hans R. Müller, Joseph and Colette Bové, Manuel Losada, Shoitsu Ogata, Mitsuhiro Nozaki and David O. Hall.







CARBON
HYDROGEN
OXYGEN
NITROGEN
RADICAL
SULFUR
IRON
PHOSPHORUS
MAGNESIUM

THREE KEY MOLECULES in photosynthesis are adenosine triphosphate (ATP), at top; reduced pyridine nucleotide (P-NH_2), in middle; and chlorophyll, at bottom. Energy from light, trapped by chlorophyll, serves to bind third phosphate group to adenosine diphosphate to make ATP. $TPNH_2$ differs from $DPNH_2$ in having a third phosphate group in the part of the molecule shown here as R (*radical*).

therefore subsist by consuming the organic products of the photosynthetic group. So firmly was the scheme entrenched that in several European languages the term "carbon dioxide assimilation" also meant what is now called photosynthesis.

This seemingly logical structure was undermined in the 1880's by two developments, although no one realized it at the time. First, Sergei Winogradsky, then at the University of Strasbourg, discovered the so-called chemosynthetic bacteria: cells which contain no chlorophyll, but which can make organic material by assimilating carbon dioxide in the dark. Second, Theodor Wilhelm Engelmann at the University of Utrecht found that purple bacteria which metabolize sulfur compounds perform a type of photosynthesis apparently without giving off oxygen.

As so often happens when an experimental result contradicts the prevailing fundamental notions, the implications of Winogradsky's discovery were simply ignored by most of his contemporaries. A notable exception was the Russian microbiologist A. F. Lebedev. With remarkable insight, Lebedev insisted that carbon dioxide assimilation could no longer be considered peculiar to photosynthetic cells. He suggested, in fact, that all cells possess this ability. What set apart the photosynthetic group was its use of light as the source of energy for the process. This view was too far ahead of its time, and had little impact.

Engelmann's discovery had still less. The then indigestible facts of bacterial photosynthesis were either denied or explained away by ingenious hypotheses. Photosynthesis without the evolution of oxygen seemed a contradiction in terms. Even Lebedev, while arguing for the assimilation of carbon dioxide in the dark, was convinced that it took place by splitting of the carbon dioxide molecule, with oxygen as an inevitable by-product.

Van Niel's Hypothesis

It took 40 years and many more experiments to establish the significance of chemosynthetic and photosynthetic bacteria. In the 1930's, as we shall see shortly, a variety of cells were found to assimilate carbon dioxide and manufacture carbohydrates, without light. At that time, moreover, C. B. Van Niel of Stanford University conclusively demonstrated that bacteria can carry on photosynthesis without evolving oxygen. The splitting of carbon dioxide by light was no longer a tenable hypothesis.

Van Niel supplied a new hypothesis. He proposed that light splits not carbon dioxide but water. According to this idea, which applied both to bacteria and green plants, light acts on water to make (H) and (OH) radicals. The (H) supplies the hydrogen to convert carbon dioxide to carbohydrate. In plants the (OH) reacts to form oxygen. Bacteria lack the enzymes to catalyze this reaction. Instead, they combine (OH) with hydrogen from an outside source to form water again. The model accounted for everything, including the fact that bacterial photosynthesis, unlike that in green plants, does require an outside hydrogen donor (such as hydrogen gas, sulfur compounds or certain organic acids).

Van Niel's hypothesis was widely accepted. Now it became necessary to trace the path of the (H) that is presumably formed in light. However, the splitting of water by radiation with energy as low as that of visible light is a reaction unknown in chemistry. Therefore there was no clue as to the properties of the initial (H) material, or as to how it is able to convert carbon dioxide to carbohydrate.

In time the thinking of workers in photosynthesis crystallized into two

points of view. One considered that the (H) is an "active" species of hydrogen atom that can force itself on the carbon dioxide molecule. Such a reaction is also unknown elsewhere in biochemistry. But the adherents of the idea saw in it the very uniqueness of photosynthesis, and buttressed their hypothesis with a number of theoretical arguments. Without going into the theory, it can be said that no convincing experimental evidence has so far appeared to support it, and there is much evidence against it.

On the second viewpoint the conversion of carbon dioxide and water to carbohydrates proceeds by a path that is not peculiar to photosynthesis. In fact, the path is considered to be essentially a reversal of the route by which carbohydrates are decomposed to carbon dioxide and water during respiration. If so, then the role of the hypothetical (H) would be to form compounds that can drive the "dark" reactions of respiration backward, in the direction of synthesis.

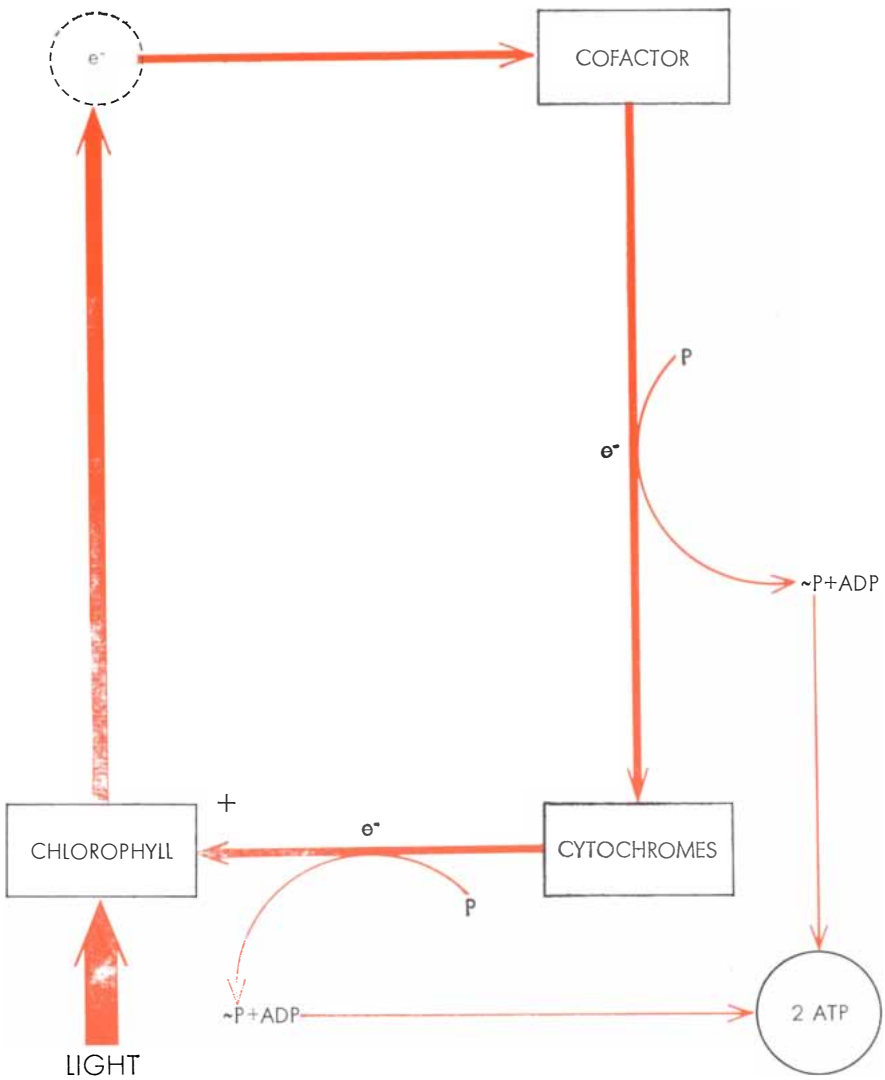
Energy Transformations

To appreciate what is implied in this proposal we must consider the process of respiration itself. The biological "burning" of carbohydrate in oxygen has been intensively studied since the turn of the century. The intermediate steps through which comparatively complicated starch and sugar molecules pass on their way to carbon dioxide and water have been isolated. The enzyme systems that catalyze the successive reactions have been identified. Perhaps most important, the disposition of the energy released during oxidation is now known.

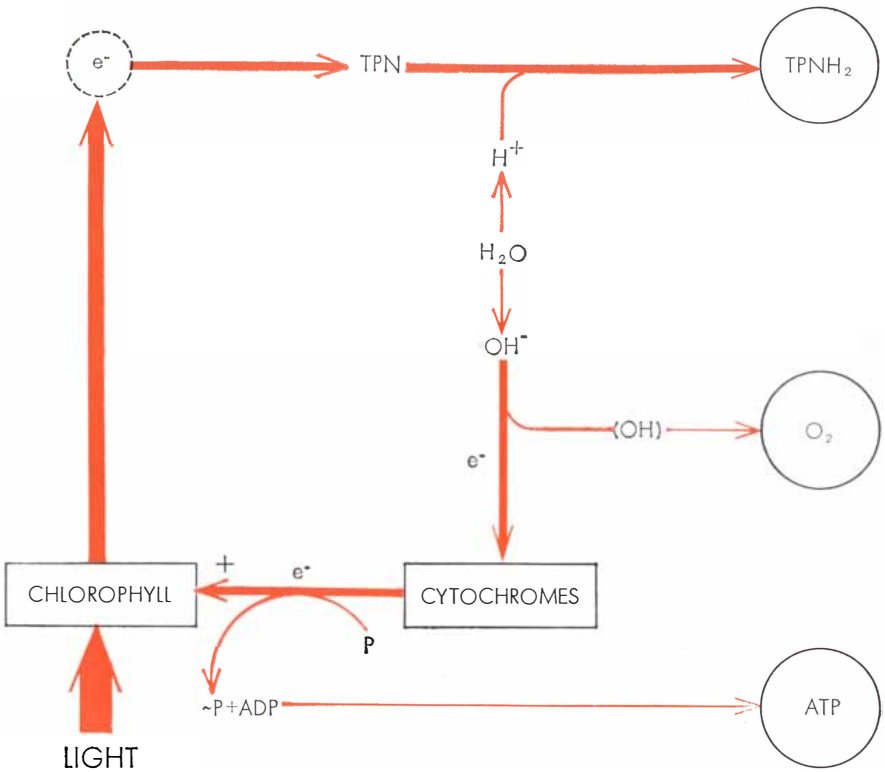
The energy is transferred to two compounds that are literally the power supply of life. One of them, familiar to readers of SCIENTIFIC AMERICAN, is adenosine triphosphate, or ATP [see "Energy Transformation in the Cell," by Albert L. Lehninger; SCIENTIFIC AMERICAN, May]. ATP has been called the universal energy currency of living cells. Every sort of vital process, from the contraction of a muscle to the synthesis of a hormone, draws on ATP. As its name implies, ATP contains three phosphate groups [*see illustration on opposite page*]. It is made in cellular bodies known as mitochondria, by the addition of a third phosphate to adenosine diphosphate (ADP). The bond of ADP to the third phosphate is where new energy is stored. It is as though the bond were a coil spring which is compressed when the phosphate is attached. When the phosphate group is removed, the spring extends, thus releasing the stored energy. In respiration the energy that compresses the spring comes from the oxidation of carbohydrate. Hence the formation of ATP in the mitochondria of a respiring cell is called oxidative phosphorylation.

The second of the key compounds is reduced pyridine nucleotide. There are two kinds: triphosphopyridine nucleotide ($TPNH_2$) and diphosphopyridine nucleotide ($DPNH_2$); here they are collectively abbreviated PNH_2. Each is a powerful biological "reductant," that is, it can readily force its hydrogen atoms on other molecules. PNH_2 participates in many oxidation-reduction reactions in all living cells. One of these reactions provides energy for phosphorylation itself. Thus some PNH_2 is oxidized to make ATP.

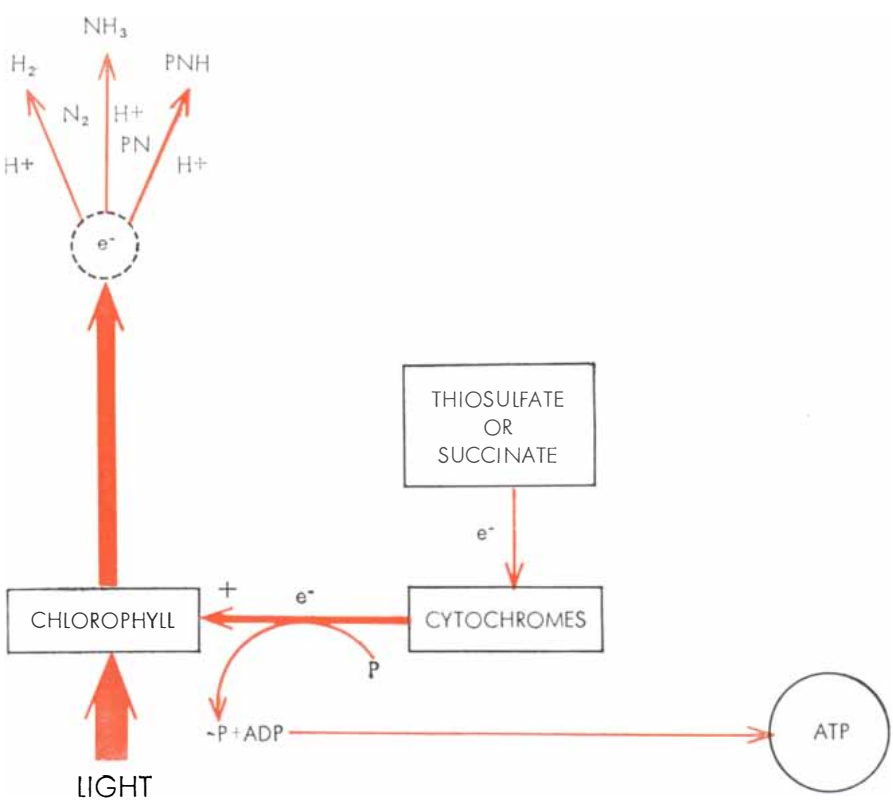
At this point it may be worth while to consider the terms "oxidation" and "reduction," on which our entire story turns. Essentially, oxidation means removing an electron from a molecule, and reduction means adding an electron. Whenever an electron is exchanged between two substances, one is oxidized and the other reduced. Moreover, almost every such exchange is accompanied by the release or absorption of energy. It makes no difference whether we



CYCLIC PHOTOPHOSPHORYLATION is represented by this diagram. The chlorophyll molecule absorbs a photon of light. This sends an electron to a high-energy state (*arrow at left*), where it is captured by vitamin K or another cofactor. The electron then moves to the cytochrome enzyme-system, losing energy (*arrow at right*) to a phosphorylating enzyme-system which employs the energy to couple a phosphate group onto ADP. As the electron passes back to chlorophyll from cytochromes, it again gives up energy to form another molecule of ATP. The chlorophyll acquires a positive charge when it ejects the electron and is thus able to pull the returning electron from the cytochromes. No outside electron donor is used, and the system functions as a self-contained cyclic mechanism.



NONCYCLIC PHOTOPHOSPHORYLATION in chloroplasts resembles the cyclic system, but water furnishes the electrons to be raised to a high energy by chlorophyll. Heavier arrows denote the electron-transport system. Some water molecules are normally dissociated into H^+ and OH^- ions, and it is from among these that the system takes the electrons and protons (H^+) it needs to make ATP and $TPNH_2$. The (OH) radicals that are left over combine to produce water plus the oxygen gas that is characteristically evolved by green plants.



NONCYCLIC ELECTRON-TRANSPORT MECHANISM in bacterium *Chromatium* takes electrons from thiosulfate and succinate. Energized in chlorophyll, they can reduce pyridine nucleotide, join nitrogen to make ammonia or make hydrogen gas. ATP is also formed.

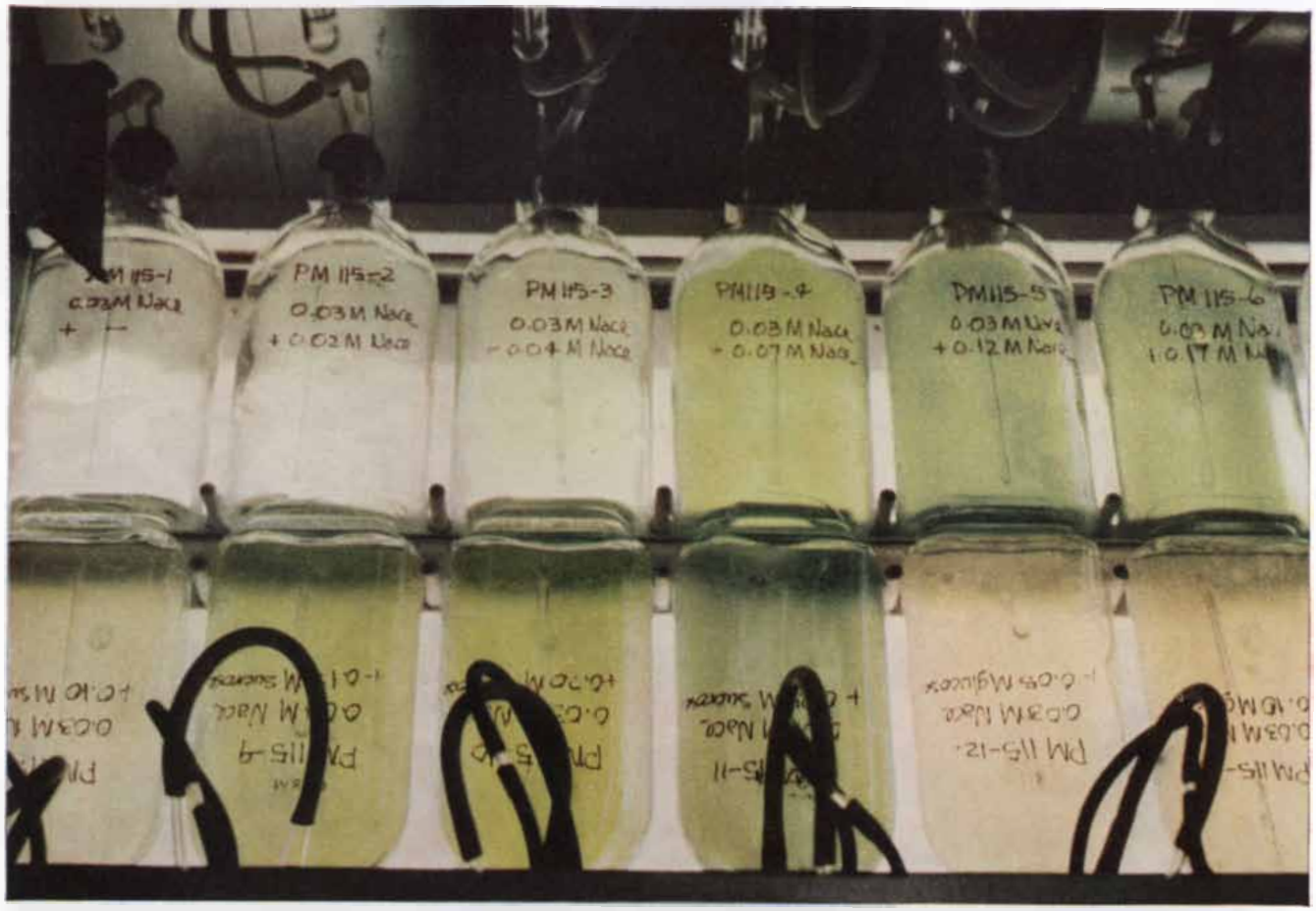
think of the energy as arising out of the pull exerted on the electron by "oxidizing power" or the push exerted by "reducing power." These terms have meaning only in relation to a specific pair of substances, which always interacts in the same way.

Often, though not invariably, an electron travels in company with a proton; in short, as part of a hydrogen atom. In that case, oxidation means removing hydrogen, and reduction means adding hydrogen. Thus pyridine nucleotide (PN) is "reduced" to PNH_2, and carbon dioxide to carbohydrate, by the addition of hydrogen atoms.

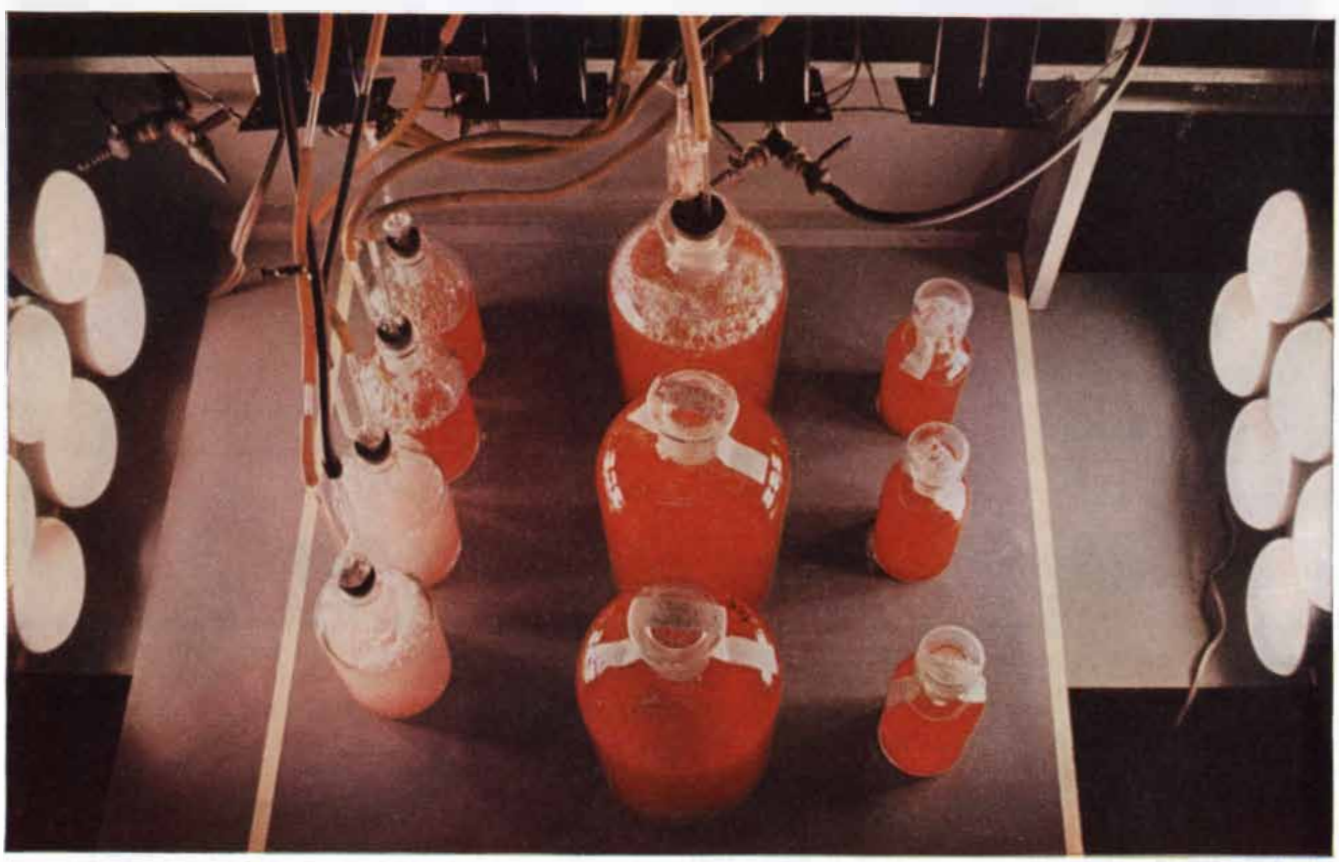
To return now to photosynthesis, the idea that it must involve a special way of converting carbon dioxide to carbohydrate was dealt a severe blow by modern studies of cellular metabolism that have utilized radioactive tracers. Investigators have found that all kinds of cells devoid of chlorophyll—for example, liver cells—can synthesize carbohydrates from carbon dioxide, if they are furnished the necessary energy in the form of ATP and PNH_2. Apparently the breakdown of carbohydrates can be reversed. And if in liver, why not in plants?

There grew a strong suspicion that there is no special, photosynthetic, way for assimilating carbon dioxide, and that all cells, whether they contain chlorophyll or not, may accomplish it essentially by reversing respiration. Soon the idea drew support from the work of Melvin Calvin, A. A. Benson and their co-workers in the Radiation Laboratory of the University of California, who traced the path of carbon in photosynthesis from carbon dioxide to carbohydrate. They identified many intermediate products identical with those formed when carbohydrate is burned in respiration. Once the "photosynthetic carbon-cycle" had been established, each of its features was discovered in various cells that assimilated carbon dioxide in the dark. In fact, P. A. Trudinger at the University of Sheffield in England, and J. P. Aubert and his colleagues at the Pasteur Institute in Paris, have now demonstrated the complete cycle in the nonphotosynthetic bacterium *Thiobacillus denitrificans*.

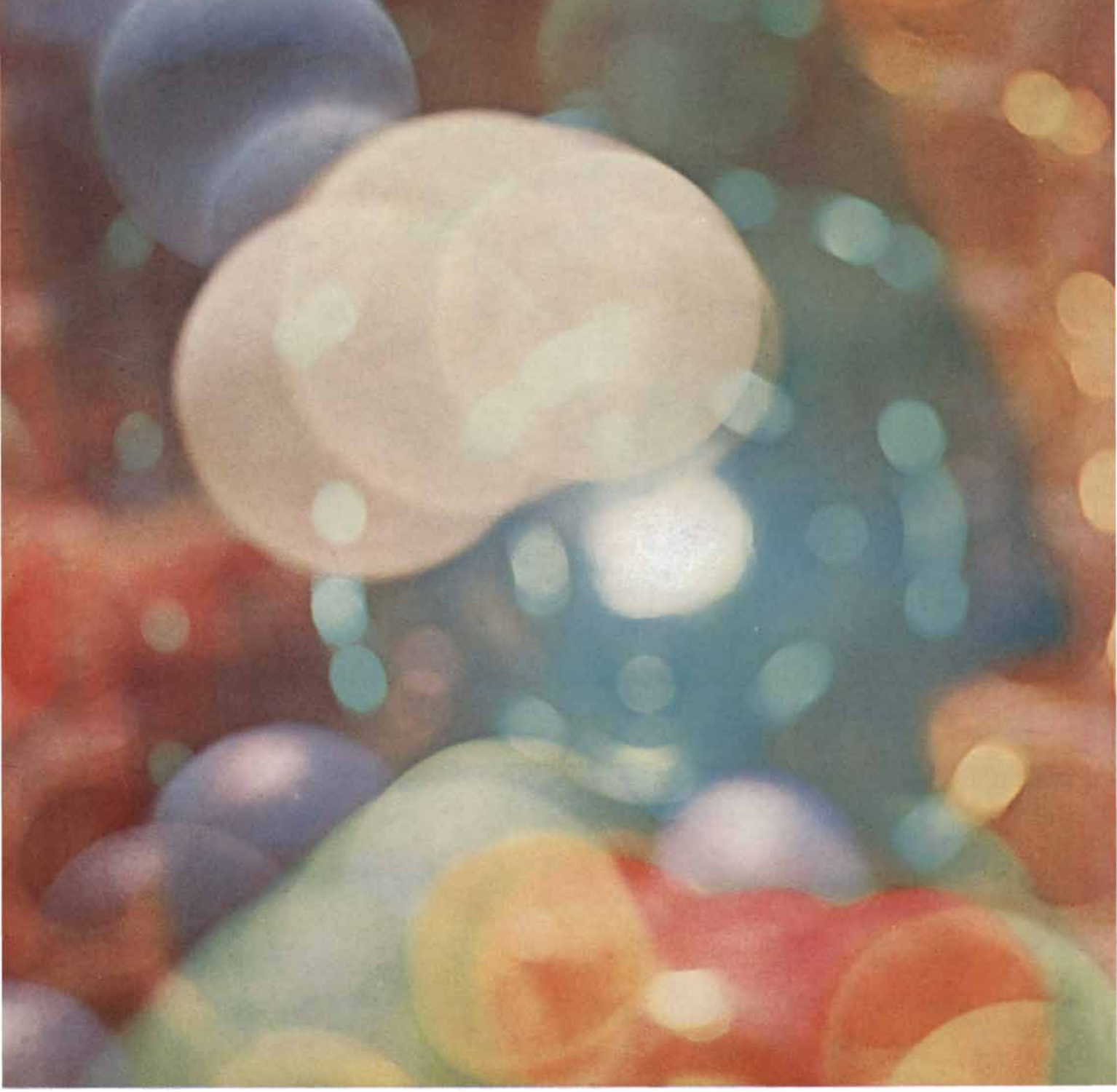
In all these dark reactions energy was provided by ATP and PNH_2. This implied that the function of light must be to manufacture ATP and PNH_2. Then in 1951 workers in three laboratories discovered that isolated chloroplasts do make PNH_2 in the light. The exact mechanism remained to be identified, but the whole problem of the role of



GREEN ALGA *Platymonas* is grown in bottles in the laboratory of the author of this article at the University of California. The bottles are illuminated from below by fluorescent lights. Lettering on the bottles indicates the composition of the nutrient medium.



RED BACTERIUM *Chromatium* is similarly grown. Bottles at left receive nitrogen gas; top two bottles contain molybdenum. Top bottle in center receives hydrogen gas. Middle bottle in center obtains hydrogen from malic acid; bottom bottle, from thiosulfate.



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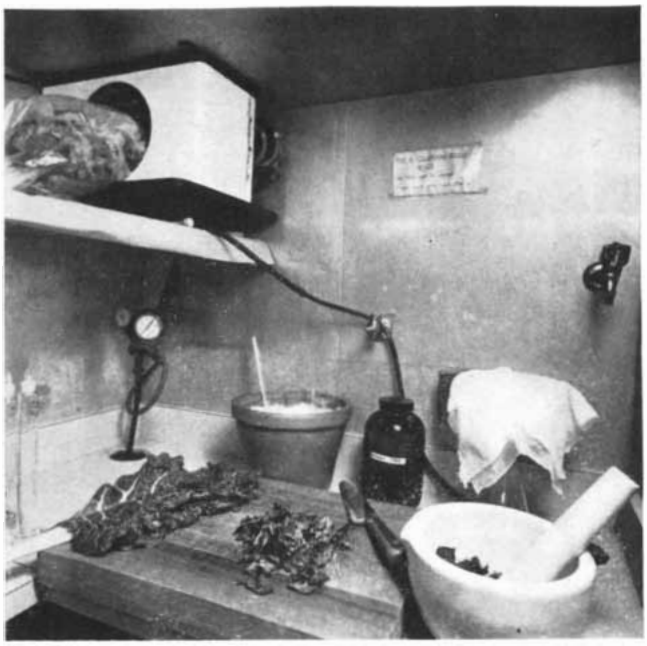


ISOLATION OF CHLOROPLASTS in laboratory of author is shown in sequence of photographs on this and following pages. Here spinach leaves are prepared for grinding with sand and water.

SLURRY IS POURED into filter after hand-grinding with mortar and pestle. The ice in the bowl is used to keep the flask cool to preserve the enzymes that will mediate the photosynthetic reactions.

light seemed very near solution. As has been mentioned, PNH_2 is used to make ATP by oxidative phosphorylation in mitochondria. Presumably the mitochondria in photosynthetic cells could obtain PNH_2 from chloroplasts and with it manufacture ATP. The model was reasonable, and widely accepted. At that time I almost abandoned further work on the role of light in photosynthesis in the belief that the problem was essentially solved.

But the model posed one major difficulty: The most specialized photosynthetic cells in leaves have very few mitochondria, being almost filled with chloroplasts. How could these few bodies produce enough ATP to support the vigorous photosynthetic activity of all the chloroplasts? Because this question seemed to have no satisfactory answer, I continued my attempts to find out if chloroplasts produced anything other than PNH_2.

In 1954 we found that chloroplasts alone carry out complete photosynthesis. Since they convert carbon dioxide into carbohydrates by a reversal of the breakdown reactions, they must be able to make ATP.

Isolated Chloroplasts

Our first task was to be sure that photosynthesis in our chloroplast preparation was really the same process that occurs in living cells. In the next few years we subdivided chloroplasts into various parts and identified in them, or isolated from them, the individual enzyme systems that catalyze the step-by-step transformation of carbon dioxide into carbohydrates. The products of assimilation—identified with radioactive tracers, chromatography and radioautography—proved to be the same as in photosynthesis by whole cells.

The experiments demonstrated that the assimilation of carbon dioxide in isolated chloroplasts is indeed a reversal of the carbohydrate breakdown reactions. Further, the energy for the process is provided jointly by ATP and PNH_2. When experimental conditions were arranged so that only one of the pair was formed in light, no carbohydrates were made.

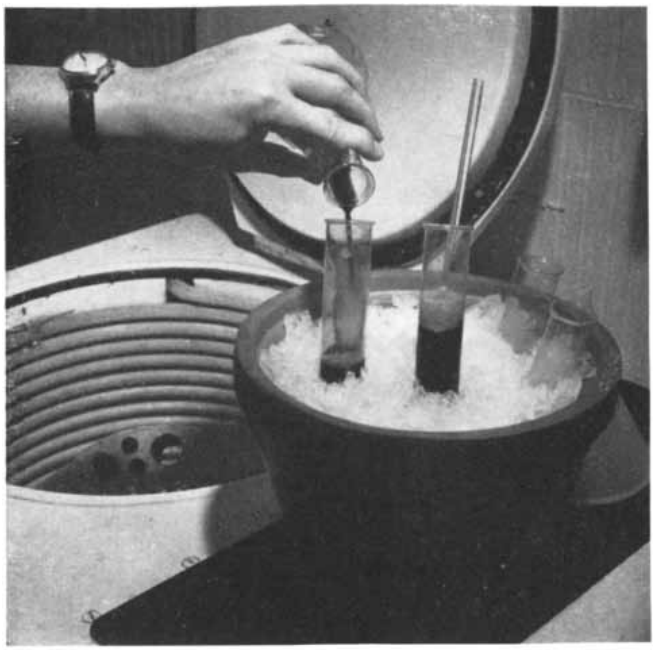
We were now virtually certain that the role of light in photosynthesis is to supply ATP and PNH_2. Final evidence was forthcoming when we separated the light and dark phases of photosynthesis in chloroplasts. We illuminated a chloroplast preparation, but did not supply any carbon dioxide, so there was no raw material for manufacturing carbohydrates. Instead, we supplied large amounts of ADP, inorganic phosphate and TPN (triphosphopyridine nucleotide). The result was the evolution of oxygen and an accumulation of ATP and $TPNH_2$.

Now we extracted the enzymes for carbon dioxide assimilation, discarding the green part of the chloroplasts and with it the light-absorbing chlorophyll. Using ATP and $TPNH_2$ made when the light was on, the enzymes proceeded to assimilate carbon dioxide in the dark and to produce the same carbohydrates that whole chloroplasts and intact green leaves manufacture. In a further experiment PNH_2 and ATP taken from animal cells were supplied to the enzymes in total darkness; again the extracts assimilated carbon dioxide and made the familiar compounds.

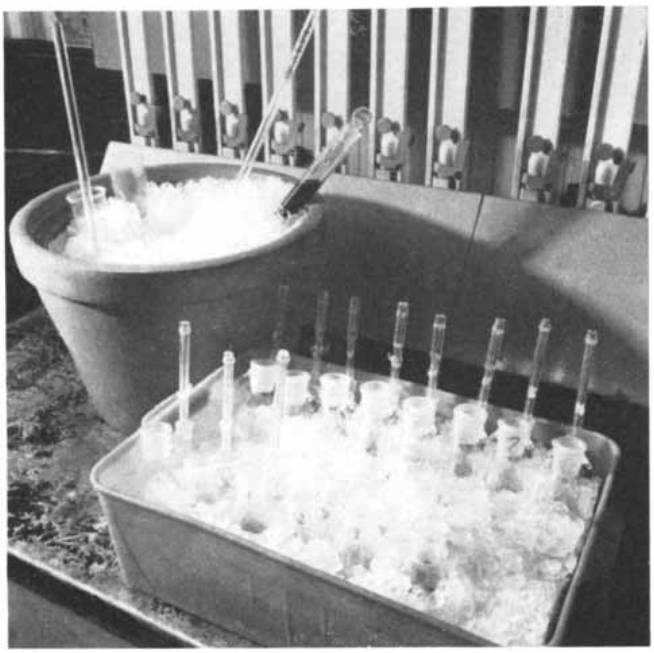
At this point the objectives of our research narrowed to the problem of identifying the reactions through which light energy forms ATP and PNH_2. At first we looked for a mechanism within the framework of Van Niel's water-splitting scheme, which had guided our research for many years. We tried to envisage a process by which the hypothetical (H), produced when light splits water, could form ATP and PNH_2. As time went on, however, new experimental facts showed that this approach was inadequate. We had to abandon it to look for different guideposts.

Photosynthetic Phosphorylation

Since the manufacture of PNH_2 by chloroplasts in light had been observed before, we decided to concentrate on the completely unknown process by which ATP is synthesized. Very early we established that isolated chloroplasts could apply absorbed light purely to the formation of ATP. We discovered this by depriving illuminated chloroplasts of carbon dioxide and pyridine nucleotide while giving them large amounts of ADP and inorganic phosphate. With no raw



FILTRATE IS POURED INTO TEST TUBES which will be placed in a refrigerated centrifuge. Spinning the material at high speed separates the chloroplasts from the other portions of the cells.



ISOLATED CHLOROPLASTS in stoppered cylinder in bowl at left are placed in vessels having long tubes (*foreground*) along with the reagents that contain radiocarbon or radiophosphorus.

material for making carbohydrate or even PNH_2, the chloroplasts used light energy to force the third phosphate group on ADP to form ATP, which accumulated in substantial quantities by the end of the experiment. We called this process photosynthetic phosphorylation—photophosphorylation for short—to distinguish it from the oxidative phosphorylation by mitochondria. To biochemists, imbued with the idea that the energy of ATP comes from burning carbohydrates, it was as if we had suddenly learned how to get electric power directly from coal or oil, without burning them in a generating plant.

In our early experiments photosynthetic phosphorylation showed a puzzling dependence on oxygen. Chloroplasts would manufacture ATP only in the presence of oxygen, although none of the gas was consumed. Apparently the oxygen acted as a catalyst. Further probing soon revealed two other catalysts in the process: vitamin K and flavin mononucleotide (FMN), a component of the vitamin B complex. Both are constituents of green leaves, and vitamin K had long ago been found to be localized in the chloroplasts. Because its location suggested a connection with photosynthesis, earlier workers had tried adding vitamin K in experiments on whole cells. Paradoxically, it inhibited photosynthesis. But when we added it to our isolated chloroplasts, it increased the rate of ATP production almost twentyfold. Adding FMN had the same result. And, when enough catalyst was added, the reaction no longer required the presence of oxygen. Thus oxygen is not essential to the process of photophosphorylation. The process is anaerobic.

Soon after we discovered photosynthetic phosphorylation in chloroplasts, Albert W. Frenkel, then at Harvard University, found that cell-free extracts of the photosynthetic bacterium *Rhodospirillum rubrum* also make ATP anaerobically, in the presence of light. (Bacteria do not have chloroplasts. Their chlorophyll is contained in structures called chromatophores, and it was these that Frenkel had extracted.) Subsequent investigations in various laboratories, on chloroplasts and chromatophores from several different plants and bacteria, have established anaerobic photophosphorylation as a general process, common to all photosynthetic organisms.

In trying to understand how photophosphorylation works, it was natural to compare it with the oxidative phosphorylation of respiration, about which so much had already been learned. In the respiratory process the energy required to force the third phosphate on ADP is obtained when an electron (attached to a hydrogen atom) drops from a higher to a lower energy-level while moving from an electron donor to an electron acceptor. The drop is accomplished in a series of steps that divides the total energy available in the electron into portions of the required size. Each chemical step may be thought of as a sort of water wheel that is turned by the falling electron and uses its power to attach phosphate to ADP (or to drive some other necessary reaction in the cycle). The original electron donor is sugar or starch; the ultimate acceptor is oxygen. When oxygen receives the electron (with its hydrogen ion), it is converted to water.

It seemed reasonable to suppose that "falling" electrons also power photosynthetic phosphorylation. The problem was to account for the electron donor and the electron acceptor. They cannot come from the outside; photophosphorylation consumes neither chemical fuel nor oxygen, only light.

About two years ago my associates and I constructed a theoretical model that seems to fit the experimental facts of photosynthetic phosphorylation. It was suggested by another photochemical reaction whose details were worked out in 1942 by Gilbert N. Lewis and David Lipkin of the University of California. We proposed that, in the primary photochemical act, a photon (quantum unit) of light strikes a chlorophyll molecule, exciting one of the electrons to an energy sufficient to remove it from the molecule. Having lost an electron, the molecule is now in a position to act as an electron acceptor. If it took back the electron directly, it would merely re-emit the light energy that had just been absorbed. (Under the proper conditions light does cause pure chlorophyll to fluoresce in just this way.) The reaction that makes phosphorylation possible is the capture of the excited electrons by a molecule such as vitamin K or FMN. Now the

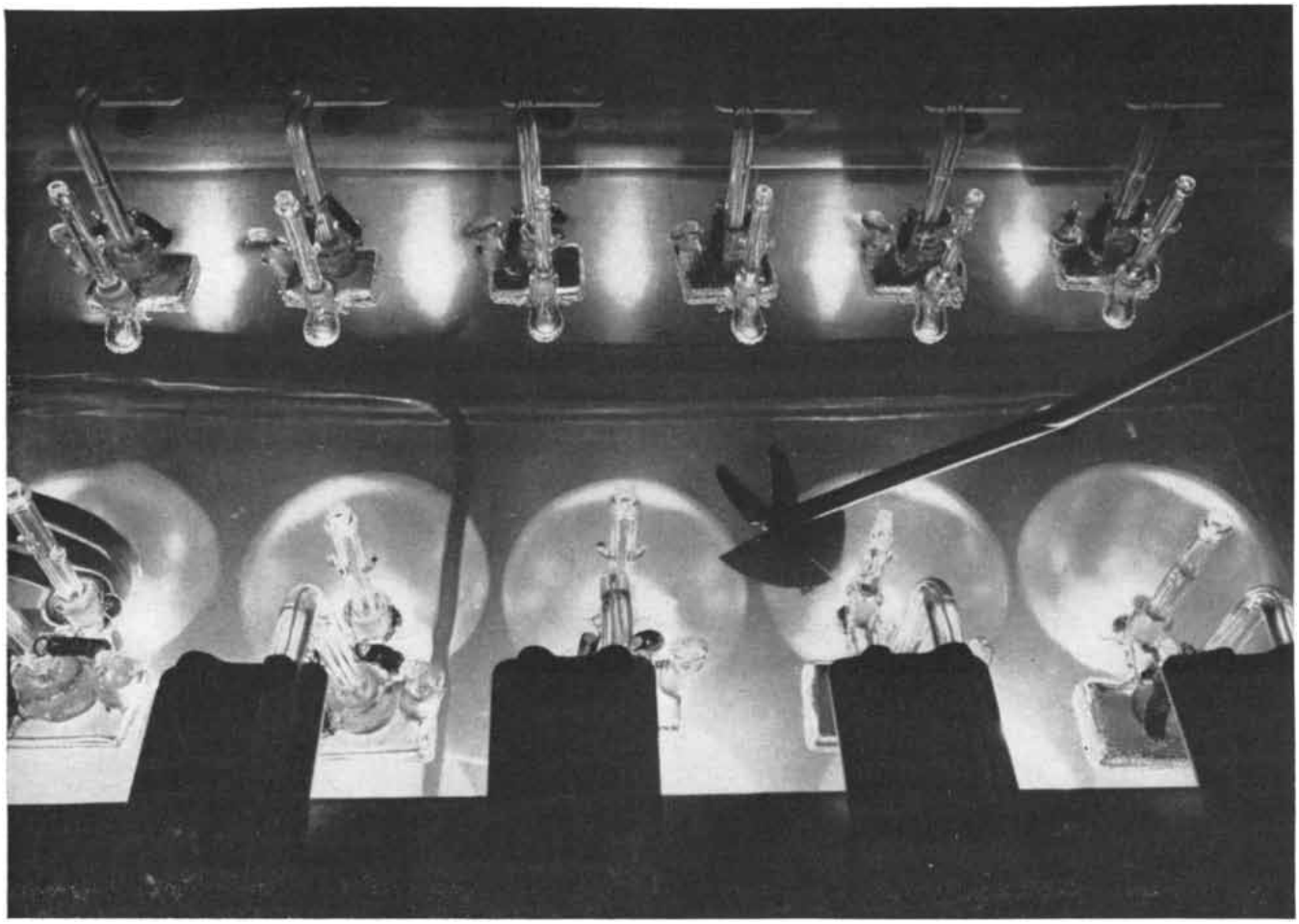
electrons are forced to return to chlorophyll in a series of graded steps, resembling those in respiration.

The downhill path we have traced takes electrons from vitamin K or FMN through a number of cytochromes—iron-containing pigments that catalyze many biological oxidations—and finally back to chlorophyll. The "water wheels" that drive the synthesis of ATP are thought to be linked with the cytochrome chain.

The electron transport and its coupled phosphorylation reactions are analogous to, and in some ways possibly identical with, their counterparts in oxidative phosphorylation. Only the light-induced production of a high-energy electron and its ultimate acceptor are peculiar to photosynthesis. Because the electron donor and acceptor are the same substance—chlorophyll—and because no outside donors are involved, we have named the process cyclic photophosphorylation.

There seems little doubt that photophosphorylation is a primary and critical reaction of photosynthesis. In most organisms, however, it is not the only one. Light energy is also required to make PNH_2, which furnishes the hydrogen to reduce carbon dioxide to carbohydrate. Yet the fact that chloroplasts do, under certain conditions, use light solely for the manufacture of ATP raises an interesting question: Are there any photosynthetic cells in which phosphorylation is really the only function of light, and which manufacture their reducing substance by a dark reaction? If so, they would exhibit the simplest, and therefore perhaps the most primitive, form of photosynthesis.

Recently we have found that the anaerobic red sulfur bacterium *Chromatium* is just such an organism. As has long been known Chromatium grows only in the light. The bacterium can use either carbon dioxide or acetate as the source of carbon for its cellular substance. To assimilate carbon dioxide it requires a supply of hydrogen gas, with which it can form the necessary PNH_2 in the dark. Acetate, however, is assimilated by a somewhat different chemical pathway, which does not require an external supply of hydrogen. When supplied with hydrogen gas and carbon dioxide, or with acetate, the only thing that Chromatium makes under the influence of light is ATP. Chromatium grows anaerobically and thus cannot make ATP by oxidative phosphorylation. To test whether ATP is indeed the sole product of the light reaction in the assimilation of CO_2 or acetate, we placed a cell-free preparation of Chromatium in the dark and added ATP. This preparation syn-



PHOTOSYNTHESIS TAKES PLACE in Warburg apparatus. The 11 small vessels seen in two rows contain the chloroplasts and the reagents. The vessels are in a constant-temperature water bath that is stirred by the propeller. Light for photosynthesis comes from reflector lamps under glass bottom of tank. Apparatus gently shakes the containers in order to facilitate the chemical reactions.

thesized organic carbon compounds in the dark just as Chromatium does in the light, when it is not supplied with ATP but has to make it from ADP and inorganic phosphate. Light and ATP were entirely equivalent!

Under certain circumstances higher plants may possibly act like Chromatium and go on making ATP even when carbon dioxide assimilation stops. In leaves, for example, the tiny pores that admit carbon dioxide are sometimes seen to close in the middle of the day. Usually they close when the leaves have accumulated an abundance of starch, and water is scant. It seems at least possible that the chloroplasts would continue to make ATP, which could be used to convert carbohydrate reserves into other compounds such as proteins and fat. Certainly plants conduct such reactions, and they need energy from ATP to do so.

This conjecture has recently received experimental support from the work of G. A. Maclachlan and Helen K. Porter at the University of London. They discovered that leaf tissue uses light energy to synthesize starch from glucose under conditions when carbon dioxide is excluded but photosynthetic phosphorylation can occur.

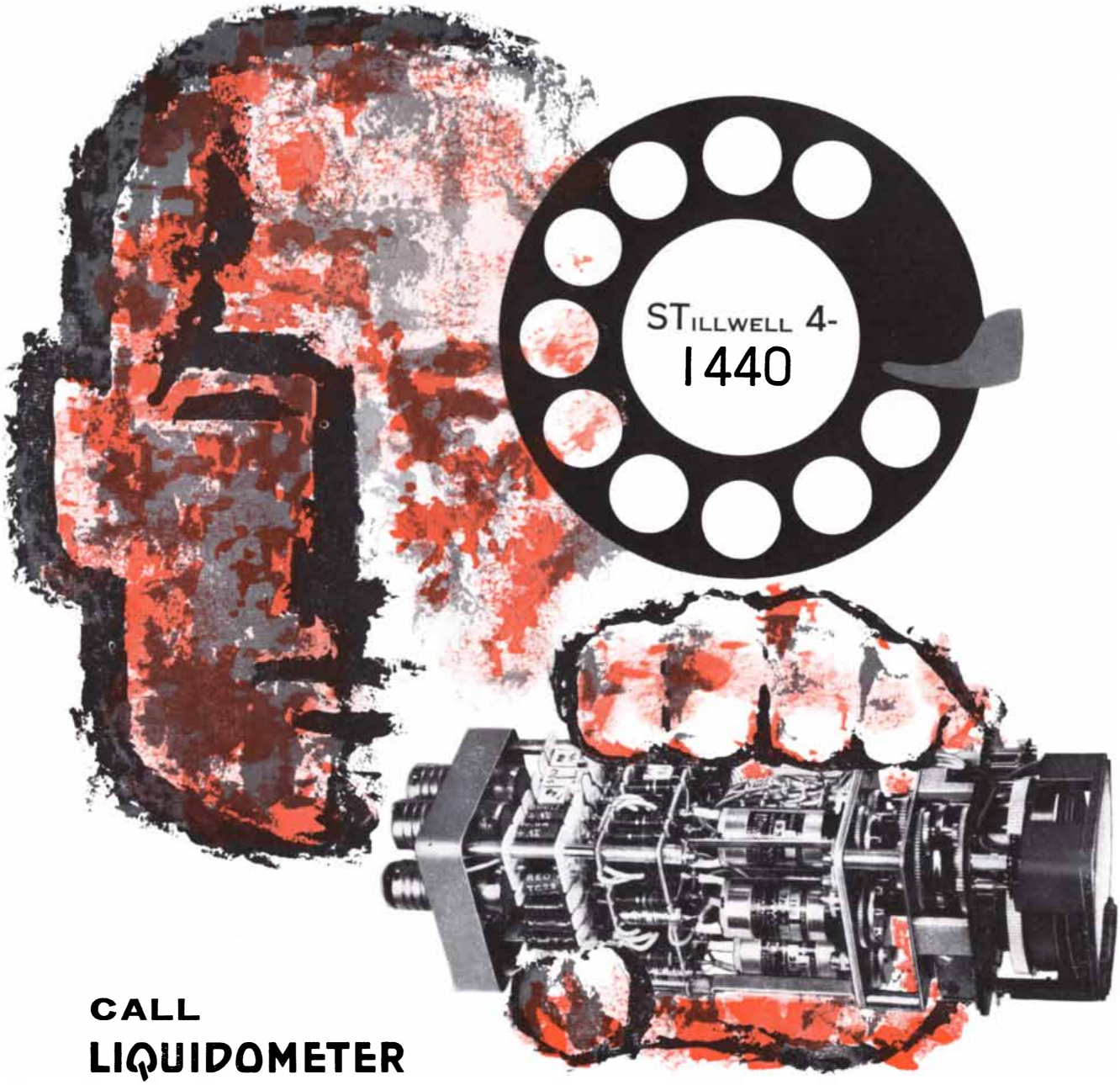
In any case, in Chromatium supplied either with hydrogen gas and CO_2 or with acetate, the role of light is limited to making ATP by cyclic photophosphorylation. As was mentioned in connection with Van Niel's work, however, photosynthetic bacteria can also make use of other hydrogen donors: inorganic materials such as thiosulfate and organic acids such as succinate. But the hydrogen in these substances does not have enough reducing capacity to convert PN to PNH_2 in the dark. Additional energy is required.

Noncyclic Photophosphorylation

In the photosynthetic mode of life of these bacteria, which grow without oxygen, the energy must come from light. How do they use light to reduce PN with thiosulfate or succinate? Recently we have found that our picture of electrons excited by light applies here too.

A number of investigators had shown that the cytochromes in photosynthetic cells become oxidized (that is, lose electrons) when the cells are illuminated. Our theory suggests that electrons are transferred from cytochrome to chlorophyll, replacing the ones expelled from chlorophyll by the action of light. Now we find that the oxidized cytochromes are in turn reduced by thiosulfate and succinate. The result is that electrons donated by thiosulfate and succinate are transferred via cytochromes to chlorophyll and are there raised at the expense of light energy to a reducing potential sufficient to make PNH_2.

The fate of these activated electrons is different, however, from that in the cyclic route. They do not return to chlorophyll but are eventually transferred to external acceptors. Three of these have now been identified: nitrogen gas, which is converted to ammonia (NH_3); PN, which is converted to PNH_2; and protons (hydrogen ions), which become hydrogen gas. Here light energy is being



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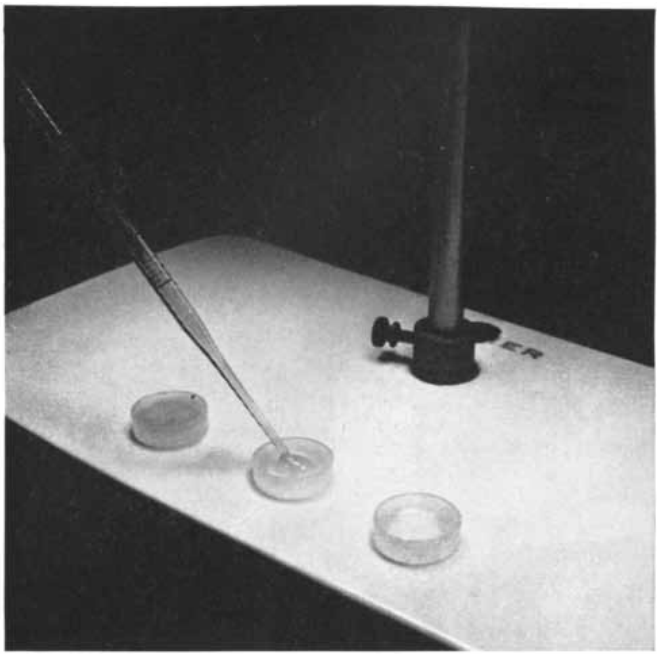

AFTER PHOTOSYNTHESIS a sample is taken in a pipette from each container and placed upon a planchet. There the material is allowed to dry preparatory to placing it into a radiation counter.

RADIOACTIVITY IS MEASURED by placing planchet in apparatus at left. Machine at right registers counts, showing the amount of radiocarbon or phosphorus absorbed in photosynthesis.

used either to produce PNH_2 or to fix atmospheric nitrogen. It further appears that, in traveling this noncyclic route, the electrons also give up some of their energy to the formation of ATP!

The complete picture of noncyclic electron flow has been uncovered very recently. It was foreshadowed, however, by earlier experiments in other laboratories. Howard Gest and Martin D. Kamen, then at Washington University in St. Louis, showed that in light photosynthetic bacteria fix nitrogen and evolve hydrogen gas. Frenkel, working at the University of Minnesota, and Leo P. Vernon of Brigham Young University demonstrated that the same organisms reduce PN with succinate in light. Hydrogen gas seems to be evolved when the reducing electrons donated by thiosulfate or succinate are a surplus because they are not consumed in metabolic reactions: fixing nitrogen or reducing PN.

Do green plants also have an open-ended route of electron transport for making PNH_2 as well as the closed path of cyclic phosphorylation? The answer turns out to be yes. The essential difference between their noncyclic electron-transport mechanism and that of bacteria resides in the fact that chloroplasts derive their external electron supply from water. The electrons from water have an even smaller reducing capacity than those from thiosulfate or succinate. Therefore green plants depend unconditionally on light for "raising" the electrons from water to a reducing potential sufficient to form PNH_2.

As we visualize the noncyclic process in plants, it involves a cytochrome-catalyzed reaction, thus far hypothetical, which is found in green plants but not in bacteria. The plant cytochrome is presumably so highly oxidized that it can take from hydroxyl ions (OH^-) the electrons to be fed to chlorophyll. There they are raised to the energy necessary for reducing pyridine nucleotide.

The special cytochrome reaction may possibly resemble a reaction, familiar to every high-school chemistry student, which takes place in the electrolysis of water. There the positive electrode, using energy supplied by a battery, takes electrons from hydroxyl ions. These then change to (OH) radicals, which combine to yield oxygen and water. This type of reaction would account for the evolution of oxygen by green plants. The whole sequence appears thermodynamically feasible, but it cannot be considered proved until the postulated cytochrome reaction is found. It is possible that the transfer of electrons from hydroxyl ions to cytochromes requires an additional input of energy.

In the course of our studies of PN reduction by chloroplasts we found that it is accompanied by the formation of ATP. We named this reaction noncyclic photophosphorylation. Compared with the "classical" type of oxidative phosphorylation it is a remarkable process indeed. It is accompanied by the evolution rather than the absorption of oxygen. And the formation of ATP results not in the ultimate oxidation, but in the reduction, of pyridine nucleotide. As with cyclic photophosphorylation, the noncyclic type has now been confirmed and elucidated in a number of laboratories.

The noncyclic mechanism, however, cannot by itself supply all the ATP needed for assimilating carbon dioxide in the manufacture of carbohydrates. Additional ATP must be supplied by cyclic photophosphorylation.

There remains one further phenomenon to account for in the chloroplast experiments: the catalytic role of oxygen in photophosphorylation when the concentration of vitamin K and FMN is low. We have worked out a scheme to accommodate oxygen in the general picture developed above. But the details need not be considered here.

Our theoretical model of photosynthesis is reasonably complete, although several features remain to be confirmed by experiment. The role of light in the primary photochemical act is simply to raise the energy of the electrons in chlorophyll. Thereafter cellular chemistry takes over, shunting the excited electrons into different downhill paths, where their energy is converted into chemical energy and is harnessed to drive several possible reactions. Thus the essence of photosynthesis is the conversion of light into chemical energy, which can be used by the cell in various ways. Most commonly, to be sure, it is applied to the assimilation of carbon dioxide, but this is by no means its only possible use.

In all photosyntheses, bacterial or

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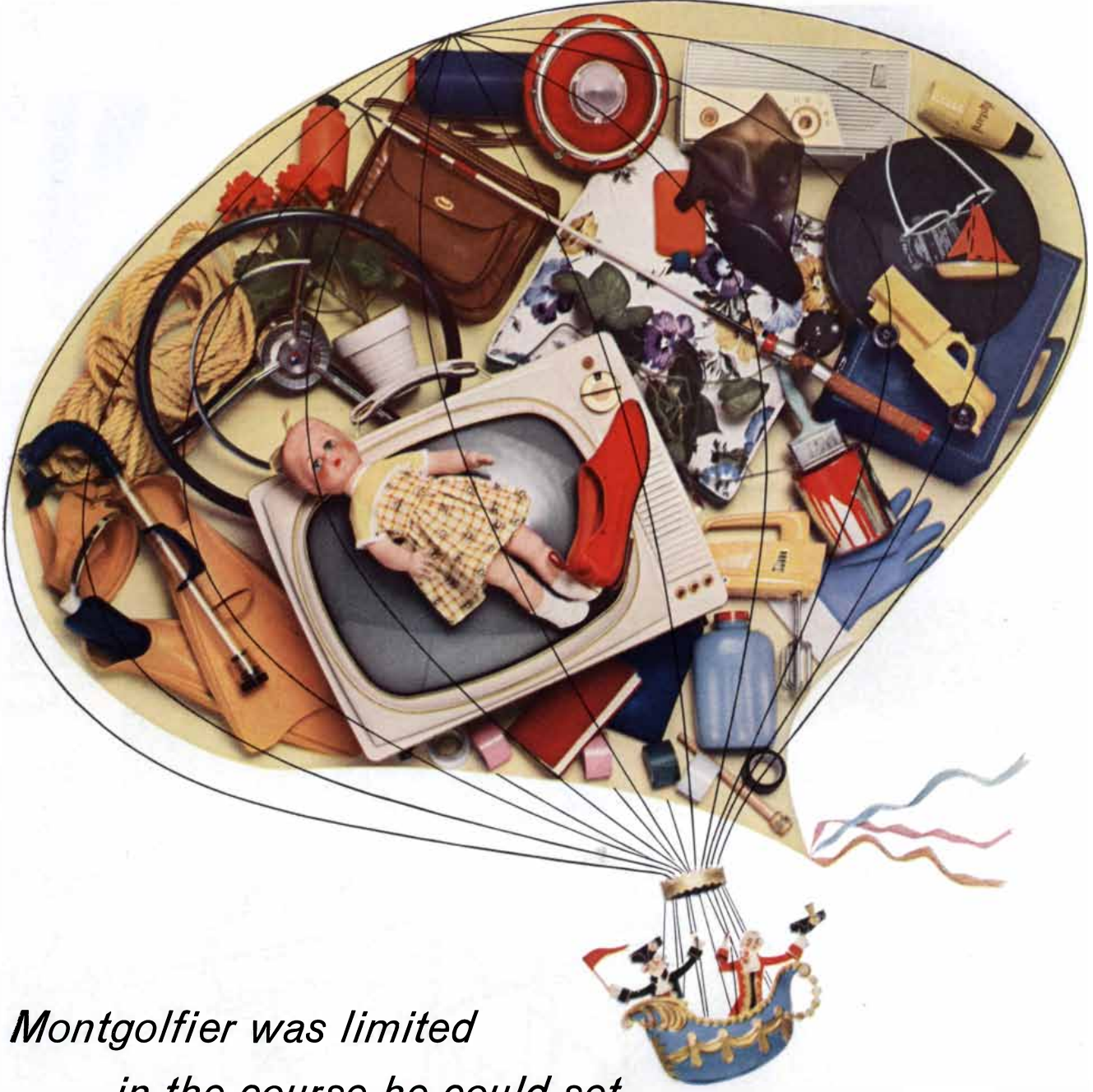
plant, the common denominator of the energy conversion process is cyclic photophosphorylation: the manufacture of the universal biological energy currency —ATP—at the expense of light energy alone, and with no consumption of material substances. All photosynthetic organisms, and only photosynthetic organisms, perform this feat. The assimilation of carbon dioxide and the evolution of oxygen are processes that the cell may, but need not, carry out while performing photosynthesis. Indeed, as our recent bacterial studies show, the list of processes that are driven by trapped light energy should be extended to include nitrogen fixation and the evolution of hydrogen gas.

Photosynthesis and Evolution

Finally it is worth noting that our model seems to fit nicely into present ideas about early biochemical evolution. There is a good deal of evidence that when life appeared on earth, the atmosphere contained little oxygen but did contain free hydrogen gas. It is reasonable to suppose that as soon as the chlorophyll molecule evolved, cells were able to harness the energy in the visible spectrum of sunlight for the production of ATP, by the same method still observed in Chromatium. This was a momentous event; it provided cells, living in an anaerobic environment, with a mechanism for making ATP that is much more efficient than fermentation, the only process they could have used earlier. It is particularly interesting from an evolutionary point of view that the aerobic plants of today have retained the ancient capacity for cyclic photophosphorylation even though they have acquired the ability to make ATP through respiration as well.

The next step up the ladder of evolution was probably the noncyclic process by which bacteria reduce pyridine nucleotide without molecular hydrogen, using electron donors such as thiosulfate and succinate. Finally, in the most advanced type of photosynthesis observed in green plants, water became the electron donor. By developing a mechanism for obtaining their reducing electrons from this ubiquitous substance, green plants were able to live virtually everywhere and were no longer restricted to areas where special electron donors could be found. At this point also, oxygen production became an inseparable part of photosynthesis. As plants spread over the surface of the earth, they released to the atmosphere the oxygen locked in the water molecule, opening the gateway to the biochemical evolution of higher organisms that depend on molecular oxygen.

RADIOAUTOGRAPH OF A CHROMATOGRAM is used to analyze products of photosynthesis by isolated chloroplasts. A sample of the reacting mixture is placed on moist chromatogram paper at spot in lower left corner. The various compounds then travel at characteristic rates along paper, thereby separating from each other. Dried paper is placed against photographic film. Radioactivity exposes the film, making spots seen here. Phosphorylated glucose and other compounds were identified in this chromatogram.



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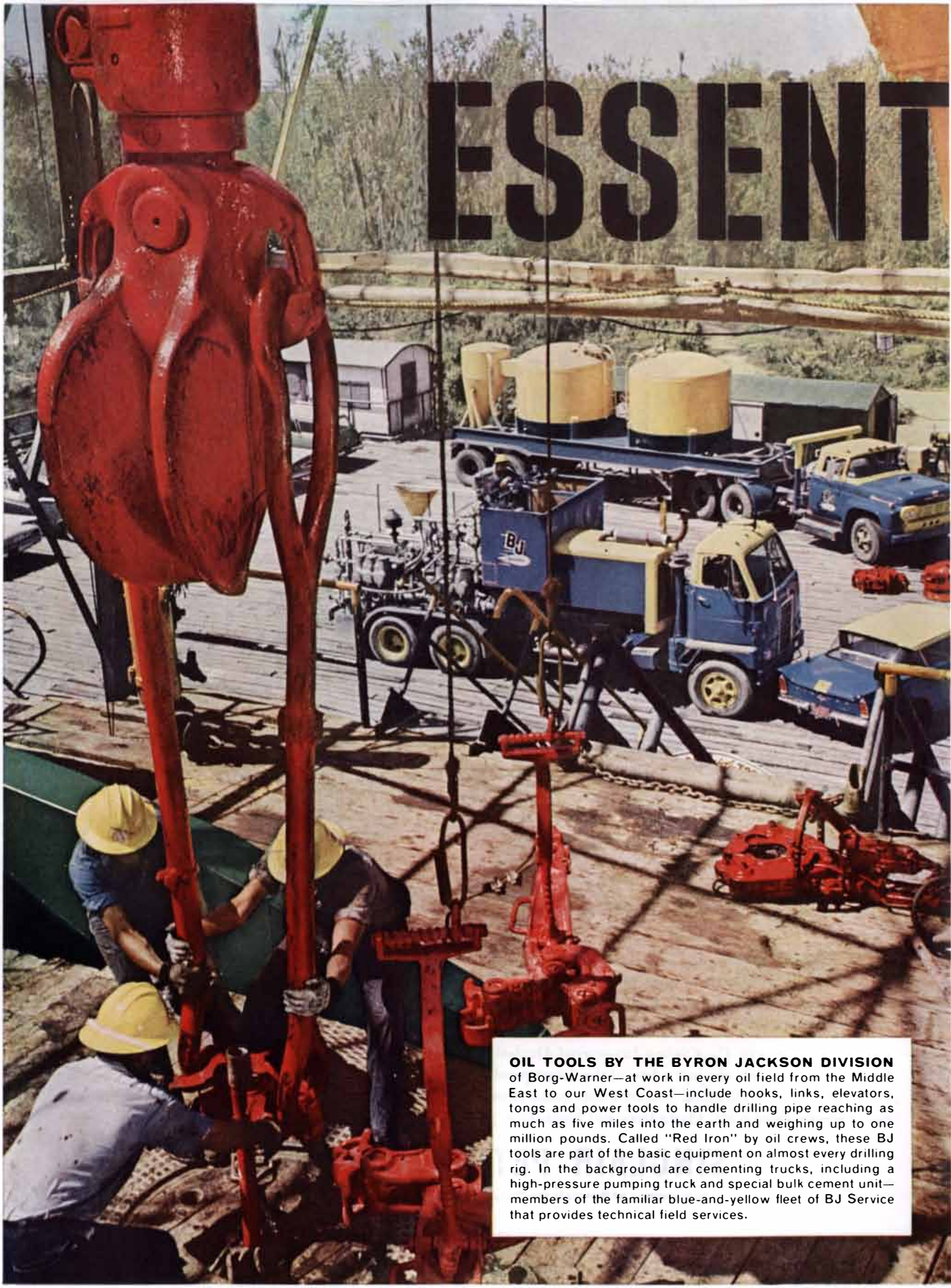

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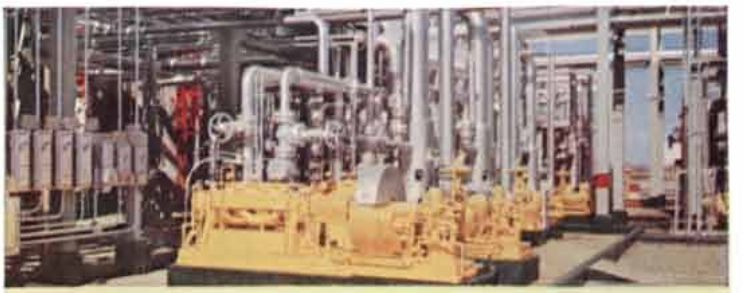

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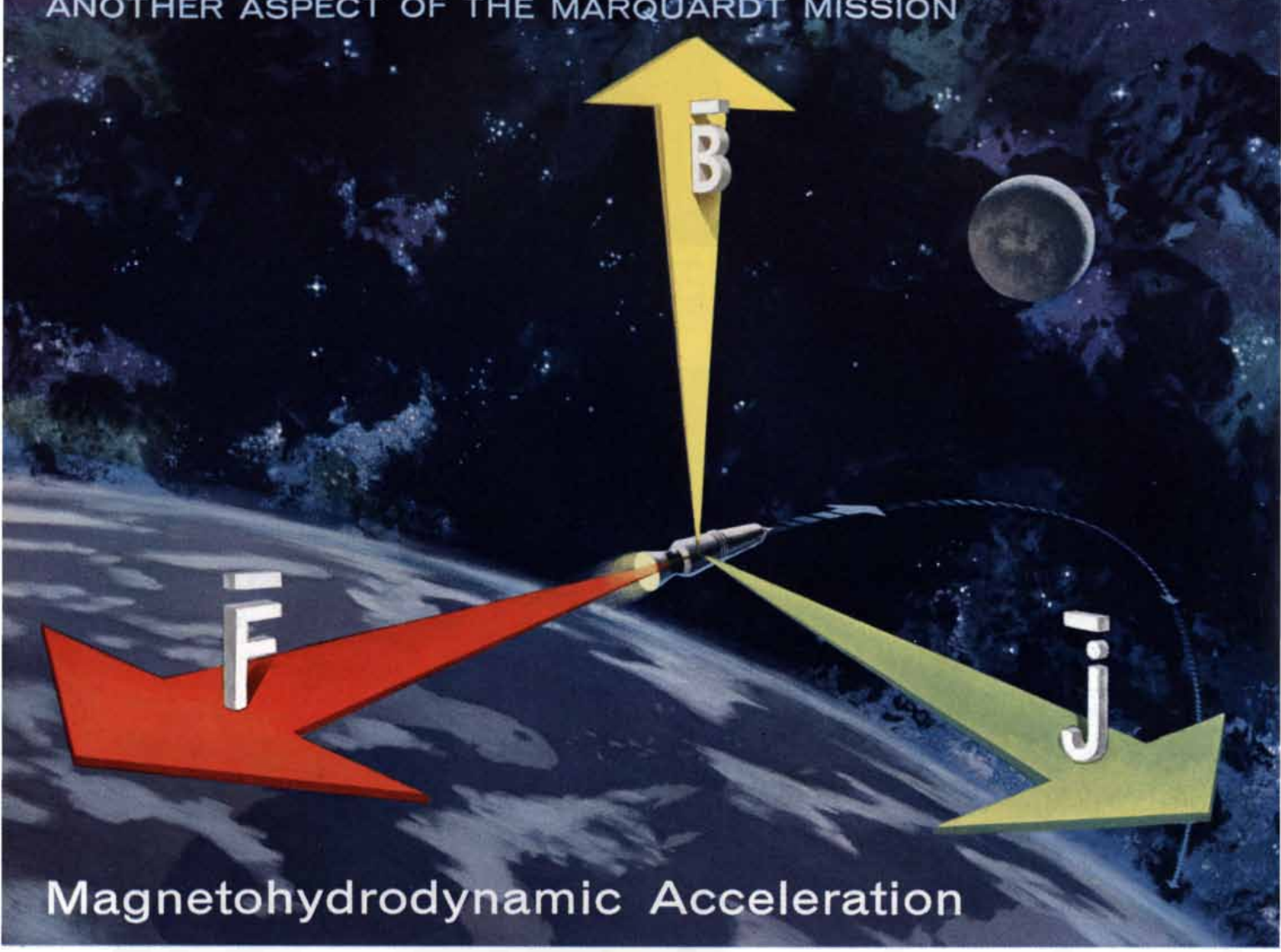

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Wildlife Husbandry in Africa

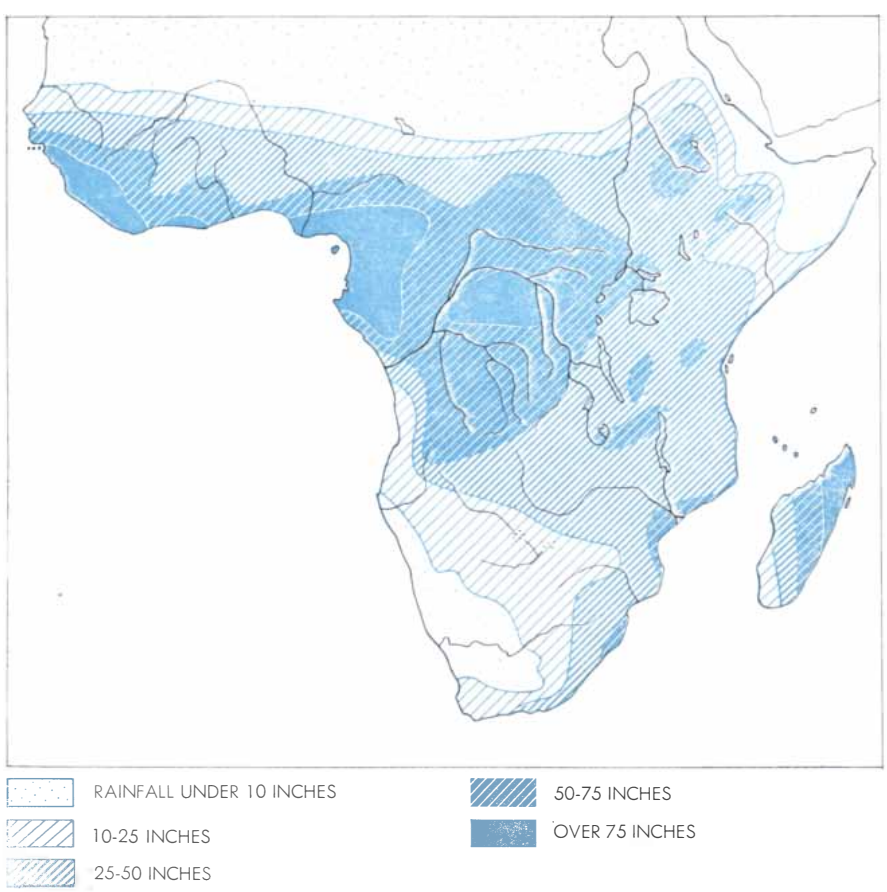
It is often assumed that vast areas of Africa can be farmed whenever man chooses. There is reason to believe, however, that the best use to which most of this land can be put is to crop its native animals

by F. Fraser Darling

Man has become the dominant species now in Africa as well as on the rest of the planet. This truism would scarcely need statement were it not a development of the last half-century, of the last quarter-century and even of the last decade. In Africa many races, nations and communities of men exist within the whole range from hunter and food gatherer to the urban dweller sealed off from nature by pavement, plumbing and prophylaxis. The rate of change is accelerating to such an extent that one cannot keep up to date with Africa. The African peoples have suddenly become aware of ways of life not their own and are fired with ebullient enthusiasm about they do not quite know what: nationalism, in a world that must overcome the jejune irrationality of nationalism, and a desire to copy the

TWO OF THE 20 TO 30 SPECIES of ungulate (hoofed animal) native to Africa appear in these photographs. In the picture at top is a herd of wildebeest on the Mara Plains of Kenya. At bottom is a herd of red lechwe on the Korfue Flats of Northern Rhodesia.

POLITICAL MAP of Africa south of the Sahara shows larger nations and colonies as they are today. Author's studies have focused on Kenya, Tanganyika, Rhodesia and Nyasaland.



RAINFALL MAP depicts average annual precipitation, but does not indicate areas with wet and dry seasons. Rain forest (jungle) occurs in much of area with over 50 inches a year.

West in a continent which might better realize its own innate dignity.

In the intoxication with technology, Africa south of the Sahara is seen as an area of fabulous potential merely awaiting the magical touch of modern technology. What could be more inevitable than the vision of the bush bulldozed into agricultural production, of the grassy plains carrying huge herds of the familiar domesticated animals? Of course, out of deference to conservation, it is agreed that the extraordinary assemblage of wildlife that still occupies the open country may be preserved as something of the past in a few national parks.

But conservation has come to be a subject of more than purely sentimental or academic interest. As a realm of scientific investigation called ecology, it has assumed urgent importance in the maintenance of the human habitat. The vast number of species and races of plants and animals defined and named by earlier naturalists have been recognized by the ecologist as living in mutual interdependence in characteristic associations and communities. Man has been able to become a member of most terrestrial biological communities. As a hunter and food gatherer he was in the nature of an indigenous animal. Where he exists in such conditions today, limited in numbers and in the power to aggregate, he continues as a species that lives by virtue of and within the environment. The arts of agriculture and pastoralism bring about direct modification of the environment in time and space. Subsequent limited independence of the environment, with technical advance, allows human aggregations of a permanent nature and that increasing complexity of organization which we call civilization. It is at those times especially, when he emerges as the dominant species in an environment, that man must take care not to make demands upon the community that may destroy his habitat.

Time and again in recent years disastrous experience has shown that the habitats afforded by Africa are brittle and susceptible to ruin. The monumental failure of the earthnut (peanut) project in Tanganyika—a megalomaniac pipe-dream advanced in ignorance of the plainest facts about African soils—is well known. There have been other failures. Where the vegetation of the great African plateau is replaced by crop plants, many soils either set rock-hard or erode. Within a few years after pastoralism is attempted, it is found that the

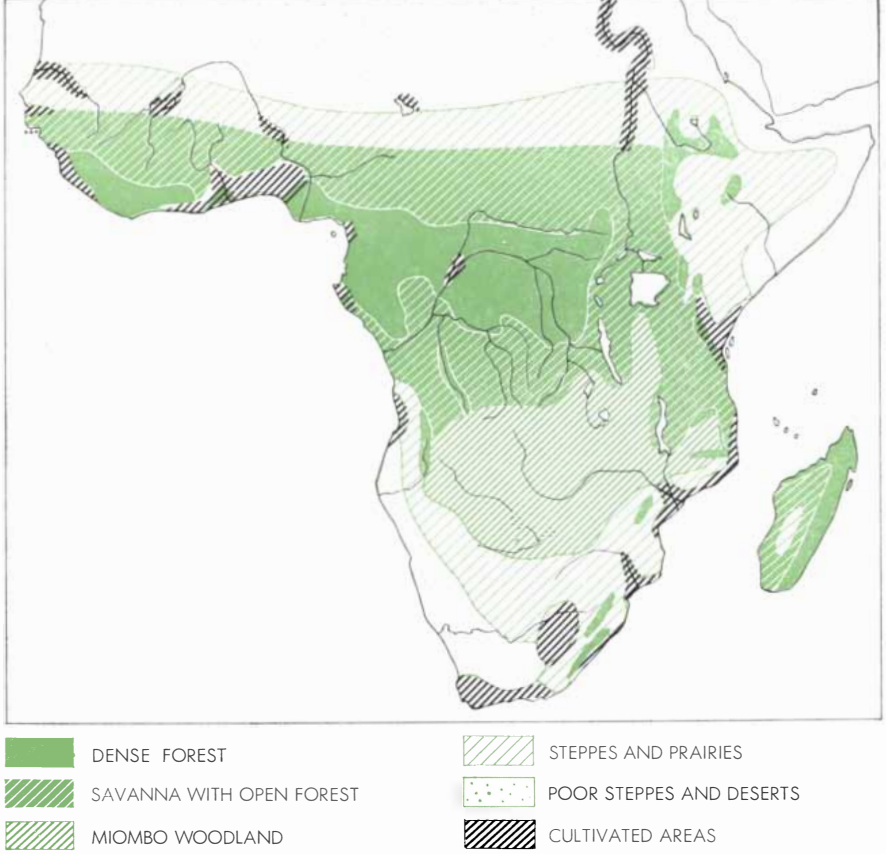
vegetation becomes degraded, erosion sets in and carrying capacity declines.

The record supports one radical conclusion to which many students of African ecology have now been persuaded. It is their opinion—and the thesis of this article—that only under the natural communities of game animals can a high biological capture and turnover of solar energy be maintained. This conclusion calls for the management and cropping of game to produce the protein element in the food supply. The techniques and the economics of this proposal remain to be developed. But even the little that is known about the natural history of Africa argues that to exchange the wide spectrum of 20 to 30 hoofed animals, living in delicate adjustment to their habitat, for the narrowed spectrum of three ungulates exotic to Africa—cattle, sheep and goats—is to throw away a bountiful resource and a marvelous ordering of nature.

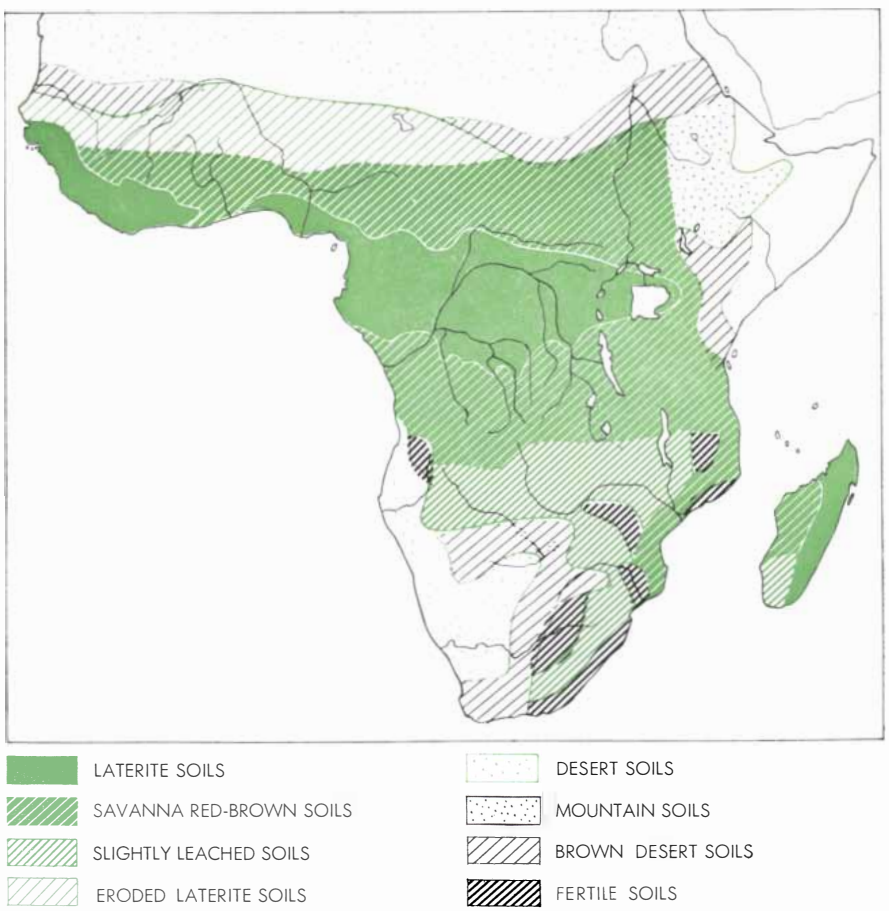
Africa is old. Many of the soils of the great plateau are senile. They have not had the remaking influences of fairly recent glaciation and sedimentation, followed by the biological colonization typical of many rich lands in more temperate zones. What remains is the residual product of rock decay: the red pseudo-lateritic soil which is rich in iron and aluminum and lacking in the bases potassium, calcium and sodium. The few young soils, the volcanic ones, are very porous and occur most often in arid and semi-arid regions. The existing vegetation is adapted to these senile or immature soils and to the sharp divisions of rainy and dry seasons.

The plateau supports tracts of relatively open *miombo* forests of mainly leguminous trees, deep-rooting and productive of protein-rich beans. The interspersed grassy drainage-areas of great extent are deficient in calcium, phosphorus and nitrogen, and this fact, coupled with the long dry season, results in grass markedly deficient in protein for 10 months of the year. Only where the soils show high basic content, partly as a result of a precipitation-evaporation ratio approaching unity, does the herbage synthesize protein adequately and cure on the stalk to provide nutritious feed in the dry season. Yet these two types of land are confused and considered of equal pastoral potential by the optimists.

The truly rich and profit-yielding soils occupy but a small part of the African continent. The few such expanses are the cocoa and earthnut zones of West Africa, the White Highlands and the



VEGETATION MAP indicates types characteristic of various areas, and shows that extent of cultivated areas is relatively small. Scale is too large to show *mopani* (valley) forest.



SOIL MAP indicates that most of the continent is covered by types that are not suitable for cultivation. "Fertile soils" refers to the types that are most suitable for cultivation.

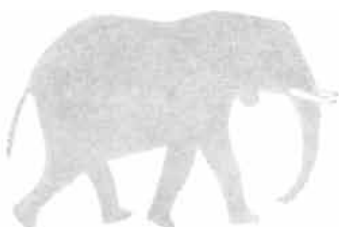
Kikuyu Reserve in Kenya, the coffee areas of Kenya and Tanganyika, the maize lands in parts of the Rhodesias, the alluvial sugar-cane soils of Mozambique and the cotton soils of the Sudan. Regions of great forests, showing an apparently immense wealth, are products of time and adaptation in a continent which has not known the catastrophes of glaciation. When the forests are felled, it is all too often found that the imagined wealth of soil is an illusion.

In their natural condition the several habitat types in Africa may be looked upon to some extent as a changing mosaic, with fire as the great changing factor. Wildfire has been natural in Africa for eons of time, not breaking into tropical rain forests but certainly into the forests of the plateaus and changing these secondary successional forests into grassland savannas. Fire diversified the environment. In the grasslands and open glades it was much gentler in action than the panic-inspiring conflagrations in northern coniferous forests. The many hoofed animals and their predators were well adapted to it and simply moved on to where their chosen conditions had arisen again. Thus in the vast expanse of Africa, never catastrophically changed, a wide variety of ungulate species evolved and survived. Pleistocene relics such as elephant, rhinoceros and hippopotamus are still thriving animals. The greatest threat to their existence has arisen only recently, with the shrinking of their habitat by man.

Fire has now ceased to be a natural diversifying, ameliorating factor and has become an attenuating one—man-made and far too frequent in incidence. This is apparent both in the grasslands and in the leguminous *miombo* forest of Tanganyika and the Rhodesias. I regard irresponsible man-made fire as one of the principal impoverishing agents in the decline of much African habitat.

It is evident that species evolve by differentiation in behavior and wants as well as in form. Differentiation implies varied demands on the environment or differing possibilities of exploiting it. A wide spectrum of hoofed animals means a widely differentiated usage of the vegetation, and to a remarkable extent this results in a mutual conservation of habitat. The environmental stratification of the ungulates is beautiful and fascinating to observe. Over and over again one sees evolution probing unoccupied niches or finding possible new niches. There is also the ecological axiom that two species in the same habitat do not occupy exactly the same niche. Man is the most adaptable of animals and succeeds by the variety of habitats he can occupy; the elephant comes next and is so successful in occupying different African habitats that he now comes bang up against an expanding human population.

The elephant is at one end of the spectrum of browsers and grazers. True desert and deep swamp are impassable for him. Of marshes he is definitely fond, and he occupies several kinds of forest: bamboo, dry bush types and savanna. His loss from the fauna would be irreparable, for he is primarily the great pathmaker, opening the country to penetration by other species. He is also the great plowman, a function which too many observers describe as destructive. But when he pulls over trees, exposing the soil at their roots, in a vast area of uninhabited *mopani* (valley) forest,



	GIRAFFE	ELEPHANT	HIPPOPOTAMUS
ENVIRONMENT	OPEN FOREST	OPEN FOREST, RAIN FOREST, MARSHES	ALL RIVERS AND LAKES
FEEDING HABITS	BROWSES TREETOPS, HIGH SHRUBBERY	BROWSES, BREAKS DOWN FOREST	EATS WATER PLANTS
ADAPTABILITY TO HARVESTING	GOOD	EXCELLENT	EXCELLENT
EQUIVALENT TO:	40 SHEEP	80 SHEEP	60 SHEEP

POSSIBILITY OF HUSBANDRY of six animals is outlined on this chart. More than 20 varieties of antelope fall under the one heading here. Animals best adapted to harvesting move in herds and can be driven. The rhinoceros is nonsocial, wide-ranging,

what does it matter? The dense clay soil is probably aerated by no other means. Though the rotation of plowing by this method may be centuries long, it is nevertheless significant, even as is ploughing by the action of hurricanes in northern forests every two centuries or so.

The elephant is a sure prospector and digger for water. Guinea fowl and doves come in flocks at first light to the funnel-like holes made by the elephants at night in dry sand rivers. The browse of trees and bushes is kept in condition for many species of antelope and for buffalo. Finally I would mention a small and pleasant observation made in the Mashi River on the southeastern Angola border; as I waded in the open lily-zone outside the reeds I noticed stickleback fish protecting nests in the cylindrical depressions that had been made in the river bed by the feet of elephants.

The wide spectrum of 20 to 30 ungulates in several African habitats goes down through eland, buffalo, wildebeest, zebra, impala and the rest to the tiny dik-dik antelope, scarcely bigger than a rabbit. All have their niche in the conversion of vegetation, with subtle and indirect effects arising from this varied use that challenge the perception of the ecologist. Not only are there the different levels and kinds of browsing and grazing, but mechanical effects such as pan-making, path-making, soil aeration, seed dispersal, keeping waters open, maintenance of drainage channels (the hippopotamus) and fertilization of waters (the hippopotamus, waterbuck and lechwe antelope). The varied fauna interweaves with the habitats. In the *miombo* forest, for example, the game animals make full use of the browse and the protein-rich beans and are therefore better able to graze the grassy *dambos*, where the grass loses its protein content so quickly.

The more complex the niche structure in a biological community the more efficient the conversion cycle. As stated in the axiom of the mathematical ecologist Alfred J. Lotka, the collective activities and effects of the organisms evolve in the direction of maximum energy intake from the sun and maximum output of free energy by the dissipative processes of life and of decay after death. In other words, evolution tends to bring the whole ecosystem to a higher metabolic rate. An ecological climax—as represented by the biological communities of Africa—embodies the maximum energy-flux possible in a given set of physical and climatic conditions. Maintenance of the energy flux is conservation; reduction of it is the opposite of conservation.

At this moment in world history we might think it important to determine the rate of energy flux in any habitat before we embark on radical changes in its character. Some changes seem to be irreversible. The all-too-general experience in tropical habitats is that change is towards deterioration or lessening of the energy flux.

When man breaks good ground for agriculture, he effects a deflection in the natural process of ecological succession. If he farms well he may be able to maintain the energy flux as he deflects it through his own species to a much greater degree than in the natural, pre-agricultural state. For example, with the introduction of clover into the English farming rotation, man was able to in-

BUFFALO	RHINOCEROS	ANTELOPE
OPEN FOREST, SAVANNA	OPEN FOREST, SAVANNA	OPEN FOREST, SAVANNA
GRAZES	GRAZES AND BROWSES	BROWSES AND GRAZES
DIFFICULT	POOR	EXCELLENT
15 SHEEP	60 SHEEP	3-12 SHEEP

slow to reproduce and dangerous to man. The buffalo lives in herds but is also dangerous. The weight of a domestic sheep is taken here to be 100 pounds. Information for this chart was supplied by Harold E. Anthony of American Museum of Natural History.

EROSION of plain near Lake Amboseli in Kenya is the result of overgrazing by domesticated cattle of the Masai tribe. All photographs in this article were made by the author.

BURNT-OVER LAND in Nyasaland, on the border of Northern Rhodesia, was once forest. This type of destruction has accompanied the advance of modern civilization into Africa.

MOPANI FOREST characterizes valleys. This forest is in the valley of the Luangwa River of Northern Rhodesia. Elephants often fell mopani trees, which here grow in clay soil.

crease the energy flux far above the level of the untouched ecosystem.

This desirable condition has even been achieved at times in Africa. It is a far more remarkable achievement than merely canalizing energy flow through the human species, as by bringing wild lands under pasture, regardless of a declining rate of flow through the ecosystem as a whole. The combing of wild lands with man's few domesticated animals is an exceedingly ancient land use. But it is a parasitic one and not constructive or additive to the habitats. Analysis of wild lands that have been thus exploited shows them to be more or less impoverished compared with their original state. Deterioration of habitat is seen in the reduction of the number of species of plants and animals and change in the array of dominant species. In other words, the delicately balanced niche structure is impaired. Fire and pastoralism, so often hand in hand, hasten the deterioration, causing bottlenecks in the conversion cycle which slow it down.

The tsetse fly still occupies two million square miles of Africa, barring such areas to pastoralism. But the tsetse fly is no longer the guardian that it was of pristine habitat and wild game; science is beating it gradually. Within the tsetse and game-rich areas there is much overhunting of the wild ungulate animals. Insofar as pastoralism is achieved, it is at the expense of the environment, bringing the fauna, flora and land into a state of progressive and sometimes irreversible deterioration.

In a perfect world pastoralism would never have been undertaken on wild lands without pilot projects and research to establish the limits of carrying capacity. We can forgive the past its mistakes if only for the truth they reveal. But in this present time there is no excuse whatsoever for bringing land under cultivation or pasture without knowing whether such use can be sustained. If it cannot, no argument of expedience can justify the despoliation of an adjusted ecosystem and the creation of a desert for posterity.

Immense areas of the plateau and volcanic soils of Africa south of the Sahara are quite unsuited to permanent agriculture. One aspect of the senility of these pseudo-lateritic soils is the meager rate at which they sustain the process of base-exchange, so essential to plant nutrition. Under the natural forest-cover the soils work up a fair store of organic matter with adequate capillarity; under cultivation they lose structure, organic matter and the power to conduct water.

These soils have been cultivated with

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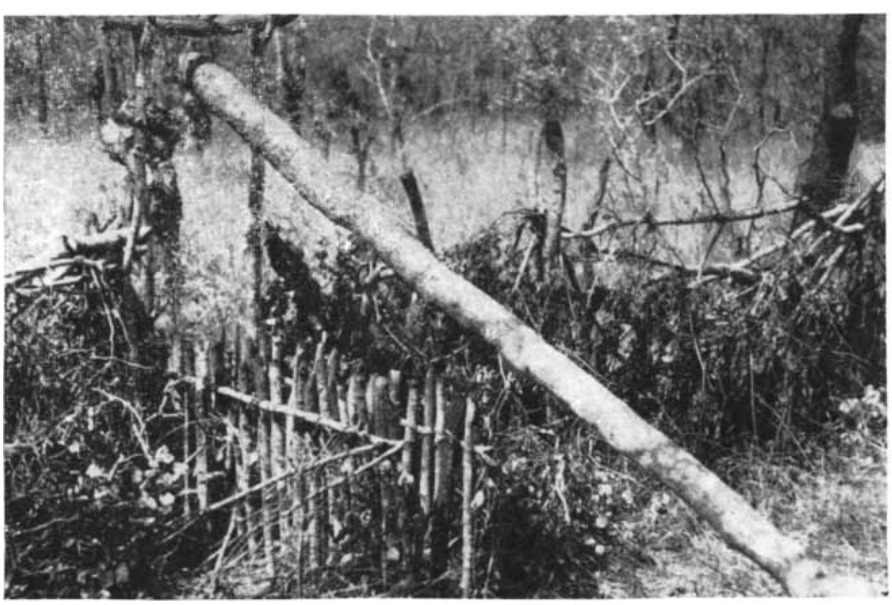
TWO POACHERS photographed in Tanganyika carry wire snares, a bow and poisoned arrows. Poachers customarily butcher the animals themselves and sell meat for high prices.

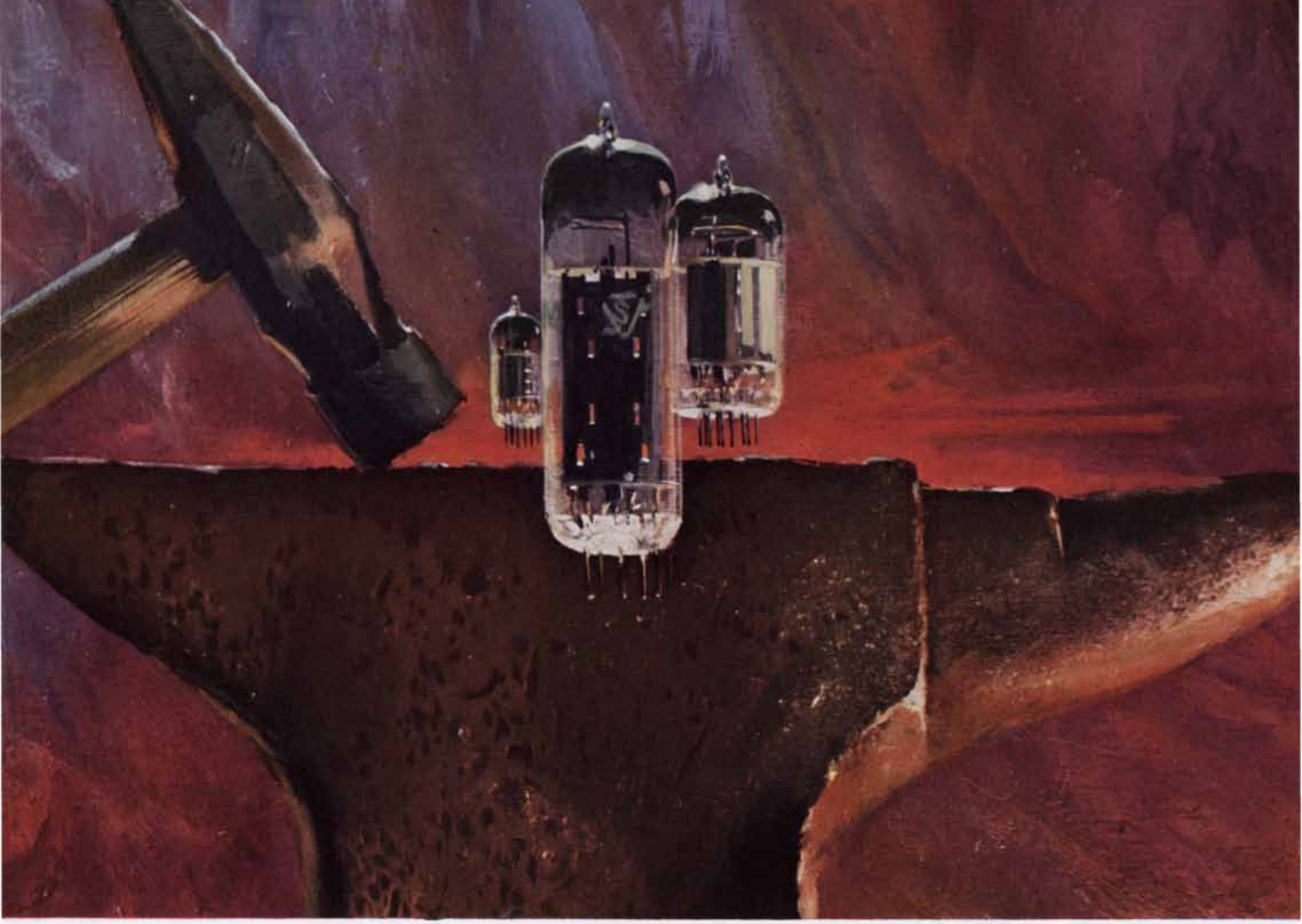


POLE TRAP in the Isoka district of Northern Rhodesia is designed to attract small animal to a position under the suspended log. Then the log falls and breaks animal's back.

success for generations by the primitive technique of the *chitemene* garden. In a circle of an acre or two the trees are lopped and burned, and the crop is planted in the ash. After three years the garden must be abandoned, and regeneration occurs in 25 to 40 years. With all our new and accumulated knowledge we know no surer way to work these soils. There is a tendency for Western man to be contemptuous of shifting cultivation. Such an attitude derives from an inelasticity of mind which takes for its criterion a home-loving population living on highly durable soils and growing food for both subsistence and export. The African, far from being wasteful in applying his traditional method, is practicing a measure of conservation in leaving the soil to recuperate under its natural cover. But *chitemene* gardening will maintain only a small population of human beings. Trouble has come with curtailment of the recuperative period in the effort to feed an increasing population.

It is on lands that will not withstand pastoralism or sustained agriculture that the wild game represents a natural resource of great value in providing the much-needed protein element in the African diet. Take the example of the great Luangwa Valley of Northern Rhodesia—15,000 to 20,000 square miles solidly under tsetse fly, carrying one permanent central river and one permanent transverse stream. The other watercourses fail in the dry season; in the rains the Luangwa widens to several miles, and there is water everywhere. The valley is still rich in game species which disperse over it in the rains and concentrate on the rivers in the dry season. There are elephants and buffalo by the thousands in the valley, zebra, eland, kudu, puku, roan, impala, waterbuck, rhinoceros, hippopotamus and many other species. For control purposes it is necessary to kill 300 elephants a year. Even though this slaughter is not designed for food production, every effort is made by the government to use the meat. The elephants killed represent more than half a pound of meat per week for every one of the 60,000 humans of the valley. This is but one species and takes no note of the licensed toll of game taken by Africans carrying muzzle-loading guns.

Understanding of the possibilities of wildlife management is in its infancy. Research must determine the niche structure of the many species of larger animals and must make assessments of energy flux in the several African ecosystems. In practical terms, the stock-



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carrying capacity of the habitats must be determined for game in comparison with that for the three domesticated animals, and cropping yields in terms of protein must be established in relation to maintenance of the habitat. There are no such figures as yet, but there is some hope that experimental game-management schemes now starting or being contemplated will yield the knowledge within a few years.

It may be argued that the cropping of wild animals in bush country is altogether impractical, and that normal pastoralism is more sound economically, even though less efficient biologically. Thinking purely in terms of Western man's fastidiousness in meat selection, this argument has point. But it is highly unlikely that Africa will be able to afford such fastidiousness for a long time. Moreover, the cattle that can be reared on African pastures cannot possibly compare in quality with the breeds from which Western man chooses his steak. Quality, in any case, may be a false standard, for game meat is very good indeed. The fault lies largely in the butchering and preparation.

Large quantities of game meat, poached by individuals and gangs and quite revolting in quality and preparation, are being sold at this moment in African villages and to the industrial compounds of the copper belt. The prices paid are high and prove the demand. With all the hurry and lack of care caused by furtiveness, the animals are butchered in the field and the meat is smoked on racks over wood fires. The nature of this traffic is indescribable. I have taken part in forays against the gangs and have seen the hiding places in dense bush where the butchering is done. And I have helped catch the purveyors of the meat, the bicycle men with sacks over the crossbar. Skin and guts are all there.

If game management schemes could be run properly under the native authorities, butchering and preparation could be taught and carried through carefully. Smoking can keep the meat from spoiling for a month or more, but experimentation with antibiotic sprays may provide alternative means of preservation. Fulbright scholars from the U. S. working on wildlife ecology in Africa have been foremost in demonstrating the practicality of cropping some of the hoofed animals for meat. Wendell G. Swank of the University of Arizona has worked out killing percentages (meat-offal ratios) of African ungulates in comparison with those of domesticated animals. Helmut K. Buechner and Irven O. Buss of Washington State University have worked on elephants; George A. Petrides of Michigan State University has studied population structure; William M. Longhurst of the University of California has shown the possibilities of herding wild game by small airplane. Longhurst also organized the shooting of 500 hippopotamuses in Queen Elizabeth National Park in Uganda. All the meat was utilized. (This last operation exposes the inadequacy of the notion that national parks should be absolute sanctuaries. The hippopotamus had so far increased as to endanger the

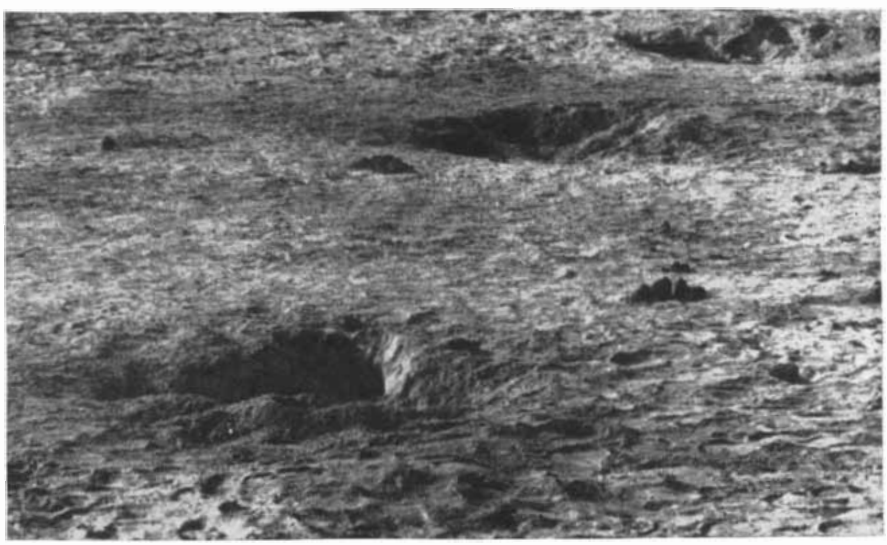
GRASS FIRE in the Rukwa Valley of Tanganyika produces tall cloud of smoke. Fire can play important role in diversifying the environment by turning forests into grasslands.

GROUP OF ELEPHANTS drink from the Tsavo River in Kenya. Elephants play an important ecological role by breaking paths through forest and aerating soil by uprooting trees.

persistence of grazing. National parks without game management can become problem areas.) Thane Riney and Ray Dasmann of the University of California are working on protein yield and the structure of the grazing community in Southern Rhodesia.

Much is expected from the newly established Waliangulu Game Management Scheme in southeastern Kenya. The area is arid during most of the year, but there is a fair head of game. The primitive Waliangulu tribe of 250 to 300 people had been badly exploited by illegal ivory agents in Mombasa, who paid them a pittance to poach the elephants. When the anti-poaching campaign broke up this traffic, the management scheme had to be instituted for the good of the tribe.

I have not mentioned the spiritual and cultural values of wildlife conservation and the scientific interest of the wonderful African fauna and flora, which are at present receiving the most unsympathetic treatment. We all believe in these values, and I personally feel the claim of the animals and the habitats to survive in their own right, irrespective of any value we reap. Most of the politicians, African and white alike, are townsmen who have little idea how their primitive fellow-men subsist, and they know little or nothing of the limitations of the African environment. Hopefully, a wider appreciation of the economic possibilities of game and habitat management may secure the conservation of the stocks of African wildlife and of the land itself.



WATER HOLES DUG BY ELEPHANTS in a dry sandy stream bed bring up water for other animals as well. These holes were found by the author in a tributary of the Tsavo River.

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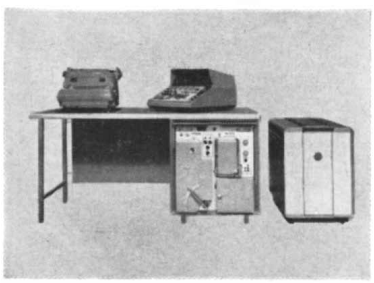

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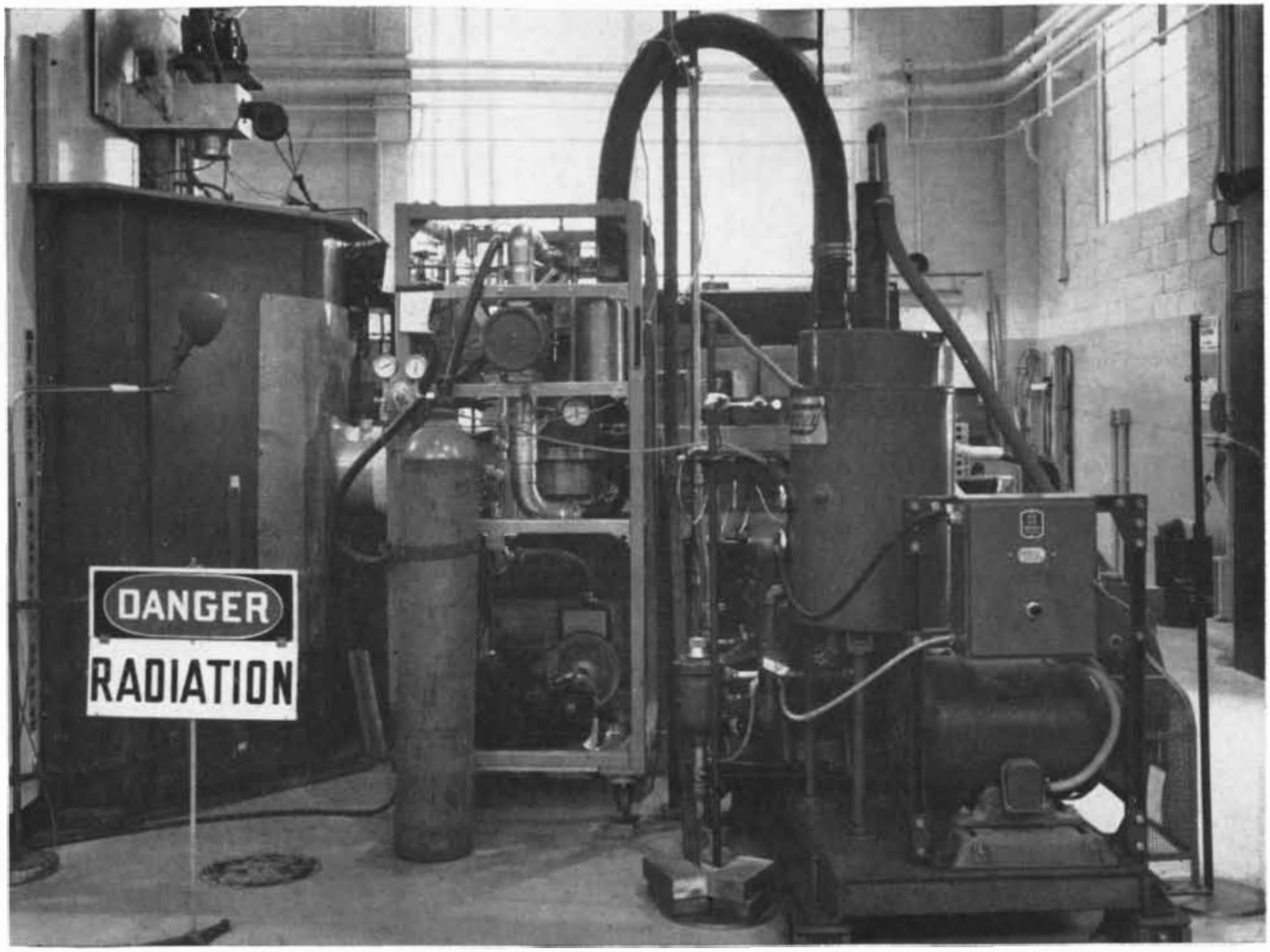
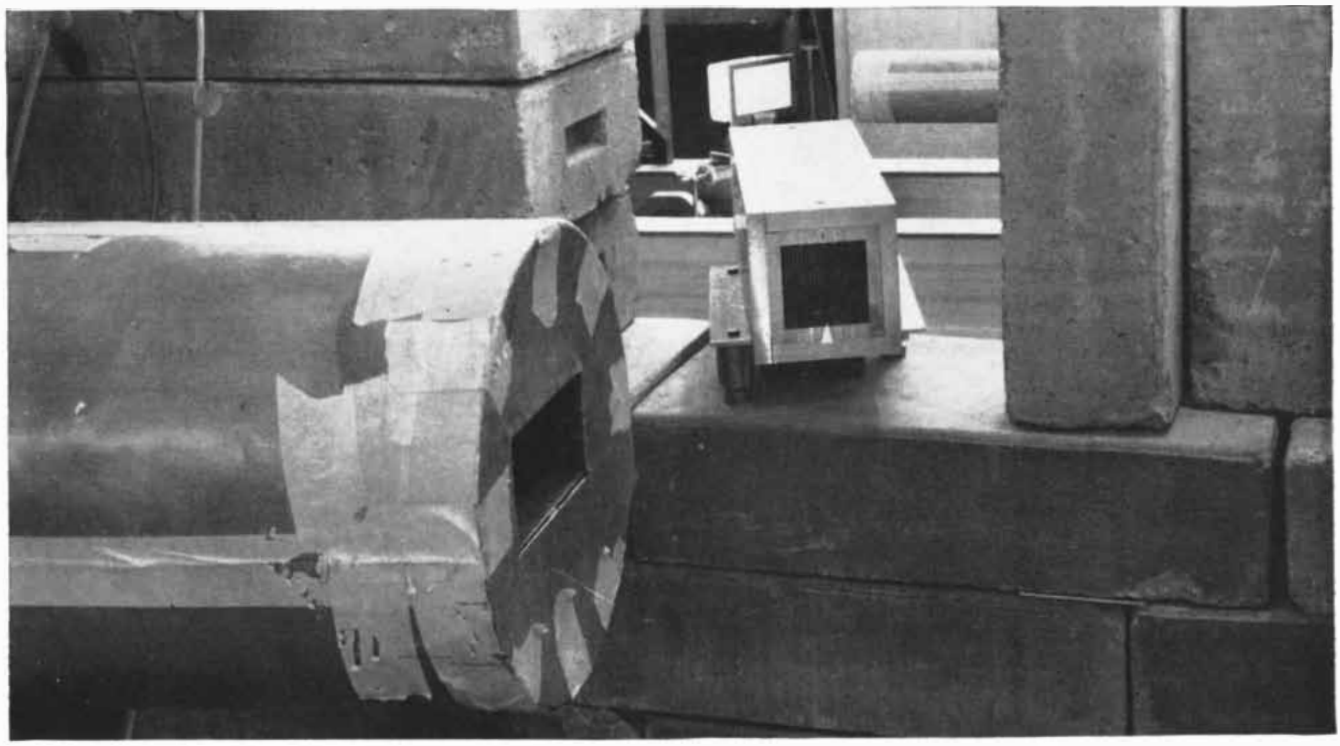


SCATTERING OF NEUTRONS by superfluid helium is measured in this apparatus at the Los Alamos Scientific Laboratory by John L. Yarnell. Neutron source is Omega West reactor at far left. Liquid helium is in small cylinder behind pipe-elbow at left center.



TARGET AREA is shown with helium target removed. Neutron beam enters through opening at left. Target (normally located at center) scatters neutrons toward collimator (*center*). Neutrons are detected by scintillation crystal (*top center*) and counters.

SUPERFLUIDITY AND "QUASI-PARTICLES"

The curious properties of liquid helium are explained by regarding it as a gas of hypothetical particles in a similarly hypothetical background fluid. Recent experiments strikingly confirm the model

by F. Reif

It is a cliché to say that theoretical physics has become hopelessly abstract and does not provide "models" that can be intuitively understood. That is why the story of liquid helium seems to me to have a special appeal. It provides a better glimpse than most into the way in which a few simple, abstract ideas can provide the key to a concrete but baffling problem.

Helium is a remarkable substance. Its properties were described in SCIENTIFIC AMERICAN not long ago by Eugene M. Lifshitz ["Superfluidity"; June, 1958]. Here I shall mention only a few: The temperature at which helium liquefies—4.2 degrees absolute (—269 degrees centigrade) at atmospheric pressure—is lower than that for any other gas. Unlike all other substances, helium does not freeze; it remains liquid down to absolute zero.

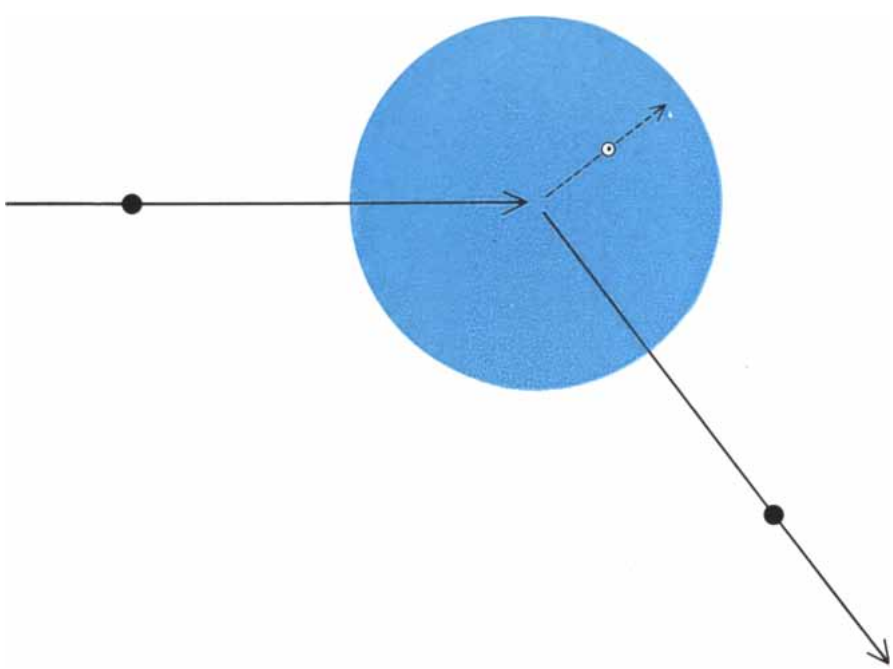
At temperatures not too far below 4.2 degrees absolute, helium behaves like an ordinary liquid. For example, when it is boiling, bubbles are formed in its interior. But below 2.18 degrees—the so-called lambda point—the bubbling suddenly ceases and the liquid becomes perfectly still. The transition is marked by abrupt changes in other properties of the substance; for example, in its heat capacity. Above the lambda point the liquid is called helium I; below it, helium II.

Helium II has an uncanny ability to pass through extremely small openings: it flows easily through a slit less than a hundred thousandth of an inch wide, which would be virtually impassable to water. Accordingly it is said to be "superfluid." The speed with which an ordinary liquid moves through a narrow tube or slit is inversely proportional to its viscosity; water flows faster than molasses. On this basis helium II is incomparably less viscous than any other liquid; in fact, its viscosity is less than a ten thousandth that of hydrogen gas.

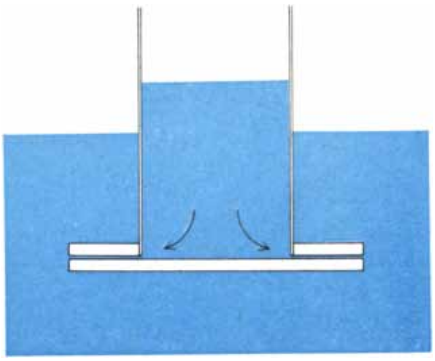
Another common method of determining viscosity is to enclose a fluid in a narrow gap between two concentric cylinders. When the outer cylinder is slowly rotated, the fluid transmits a force to the inner cylinder, tending to turn it in the same direction. This force is by definition a measure of the viscosity of the fluid. Measured in this way, the viscosity of helium II turns out to be appreciable; at some temperatures it is greater than that of "normal" helium I!

For the present I shall mention just one more feature of this strange liquid: the fact that local differences in temperature can produce pronounced mechanical effects. When a vessel with a very narrow neck is partially immersed, with its open end down, in a bath of helium II, this liquid, like any other, flows into the vessel until the level is the same inside and outside. But if the liquid in the vessel is heated, the flow starts again, and the level inside the container rises higher than that on the outside [*see illustration at bottom left on next page*]. If such a vessel also has an opening at the top, helium II can be made to spurt out the top like a fountain. This phenomenon is therefore known as the "fountain effect."

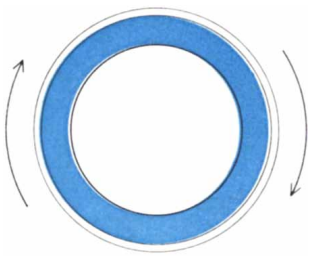
The list is not exhaustive, but it gives a fair idea of what the theoretical physicist was called on to explain. Before turning to theory, let us take a moment to consider what "explaining"



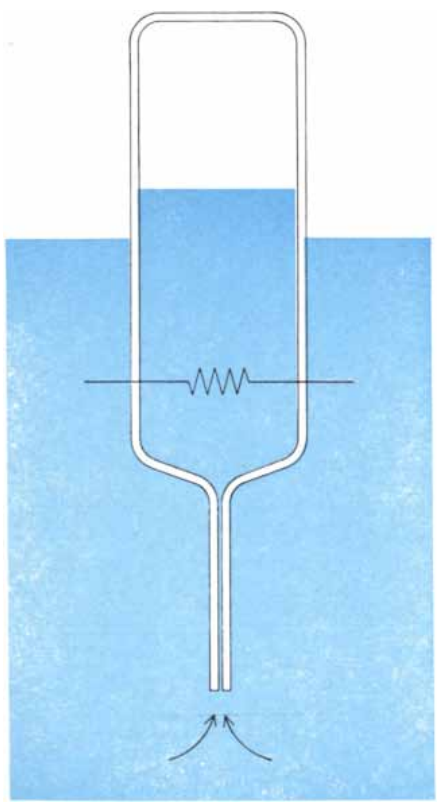
QUASI-PARTICLE (*top right*) is created when superfluid helium (*color*) scatters a neutron (*black ball*). Quasi-particle acquires the energy and momentum lost by neutron.



SUPERFLUIDITY of helium II (*color*) makes it possible for the liquid to flow freely through a very narrow channel formed by two polished glass plates. Such a channel is virtually impervious to the flow of water.



VISCOMETER consists of two concentric cylinders. When outer cylinder is rotated, the fluid (*color*) exerts a twisting force on the inner cylinder. The magnitude of the force depends on the viscosity of the fluid.



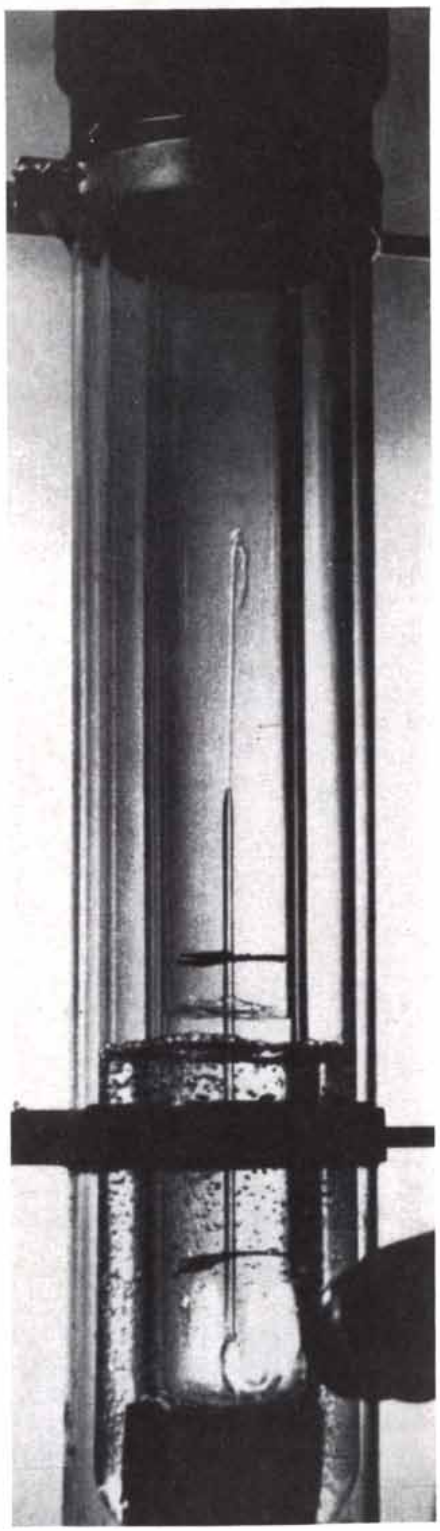
FOUNTAIN EFFECT causes level of helium II in vessel to rise when liquid in vessel is heated. Heater is shown at center.

means. The physicist seeks to account for the gross properties of matter in terms of the behavior of its constituent particles. The program has had its greatest success in dealing with dilute gases, where the individual molecules are so far apart that they spend most of their time moving as isolated bodies. When they do meet, they come together two at a time; the chance of a simultaneous collision of more than two molecules is negligible. Thus the theory of gases can be reduced to a tractable "two-body" problem. Liquids, even the ordinary well-behaved kind, pose a much more difficult problem. Their molecules are so densely packed that each one is always under the direct influence of about a dozen neighbors. Considering that even the celebrated three-body problem of mechanics still presents formidable difficulties, it is little wonder that the theory of liquids is far from satisfactory. Nevertheless, by making drastic simplifications and focusing attention on the motion of at most a few molecules at a time, it is possible to understand the behavior of ordinary liquids at least semiquantitatively.

At first glance liquid helium would seem to be particularly easy to deal with in this way. Its molecules are identical single atoms, and the force they exert on one another is both simple and weak. But we cannot isolate one atom of helium II, even in theory. Not only must we take its immediate neighbors into account, we must consider all the trillions of trillions of atoms in the entire sample simultaneously, as if they made up a single gigantic molecule.

The reason is to be found in the laws of quantum mechanics. As the reader is aware, these laws govern the behavior of small particles such as atoms or molecules. In dealing with matter on a larger scale quantum effects can usually be ignored, because they are obscured by the random heat motions of the particles. In helium II, however, the temperature is so low that heat motion can no longer mask quantum effects. Hence they manifest themselves on a macroscopic scale. One consequence of the quantum laws is that helium atoms must be considered as completely indistinguishable from one another. In mathematical terms all expressions describing the system must remain the same when atoms change places. This means that the motion of any one atom is not quite independent of the motion of any other atom anywhere in the liquid.

But if 12 molecules are too many to consider at a time, what can be done with 10^{23} particles? It turns out that, near absolute zero, they can be dealt with in a simple and useful way. If we consider the whole liquid as we would a molecule, then at absolute zero it would be in its "ground state" of lowest possible energy. (Quantum mechanics tells us that this energy is not zero. That



FOUNTAIN of helium II rises from the capillary tube within the double Dewar flask at center. Fountain is caused by the excitation of liquid helium by a light source.

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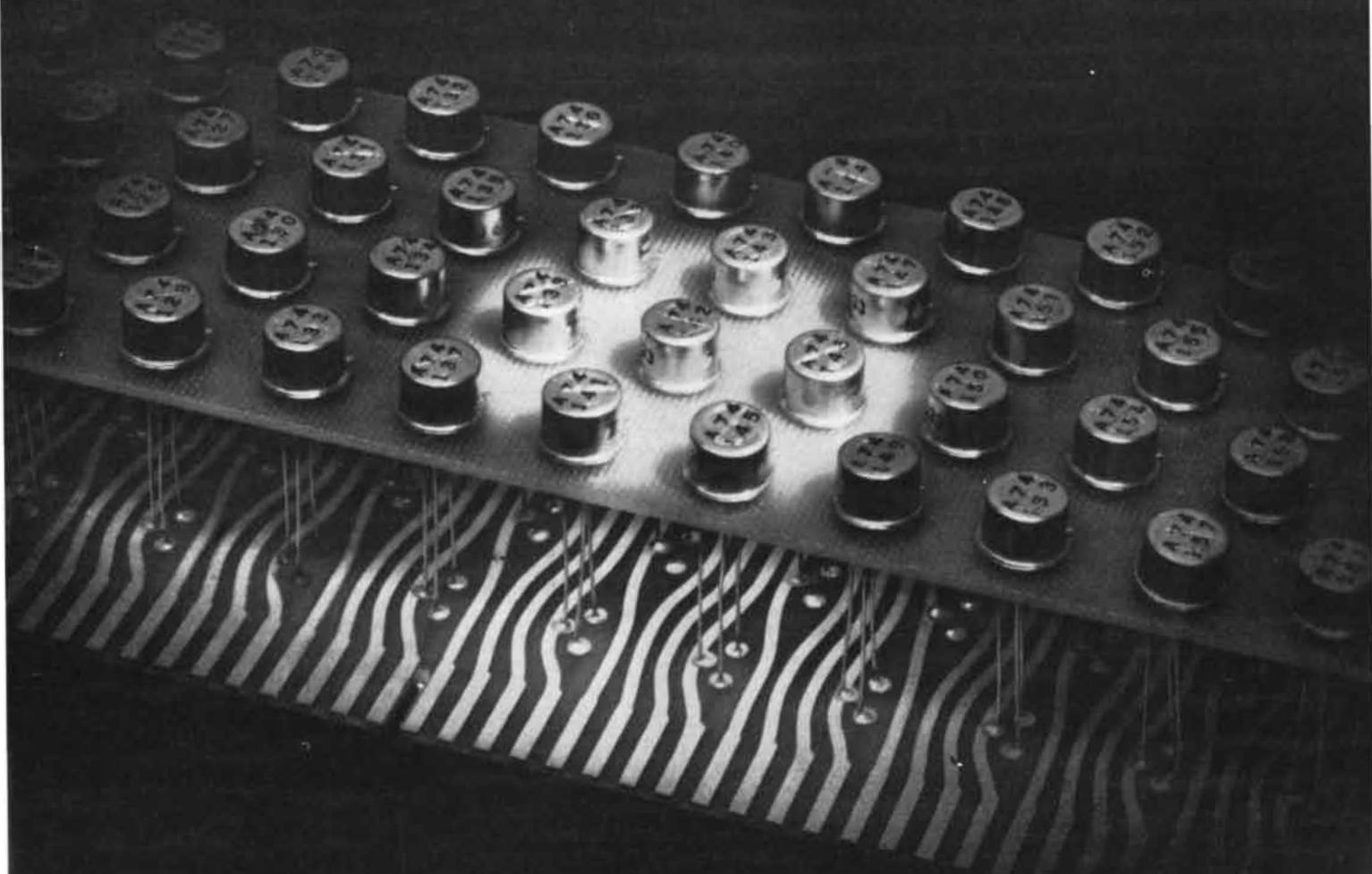
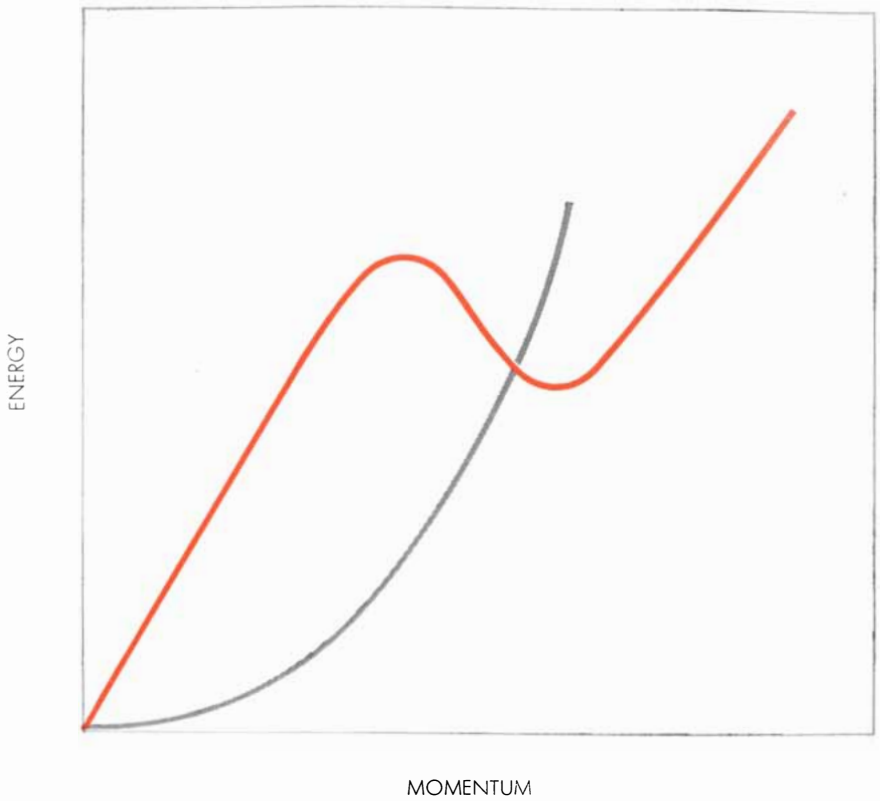
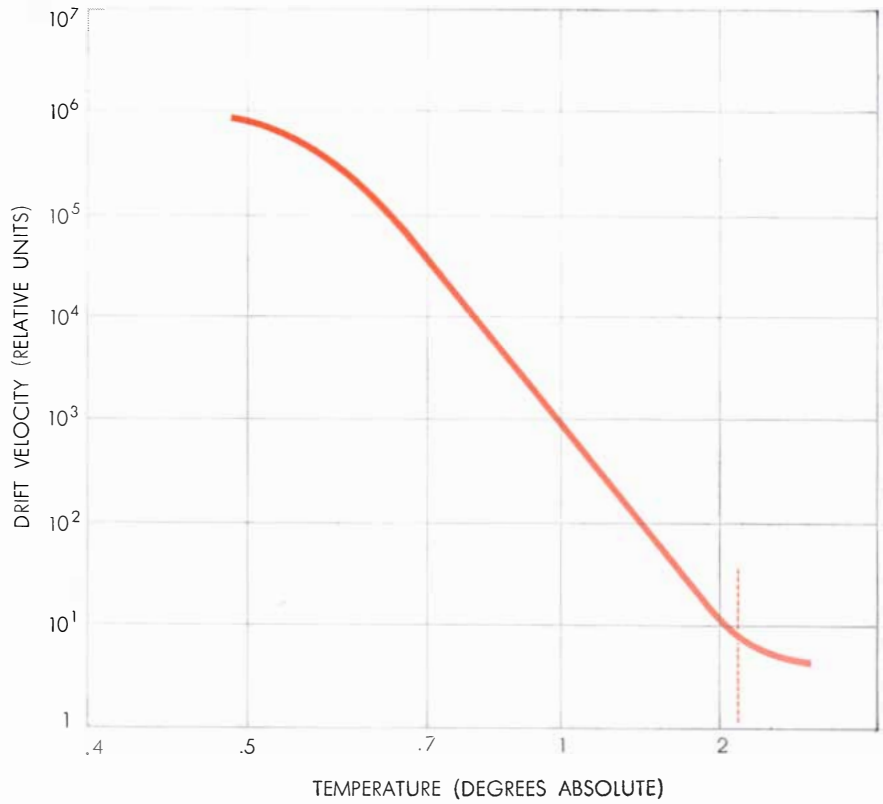


Carrier-matrix board designed by Autonetics tests groups of 100 Fairchild Transistors simultaneously



RATIO OF ENERGY TO MOMENTUM for real particles (*gray curve*) can have any value greater than zero. In contrast, the slope of the curve for quasi-particles (*color*) indicates that the ratio of energy to momentum can never be less than a certain minimum value.



DRIFT VELOCITY of a charged particle (ion) moving through helium II increases as the temperature decreases. Above lambda point (*broken line*) velocity is almost constant.

is why the liquid does not solidify.) At higher temperatures the liquid would be found in one of its "excited states" of somewhat higher energy. An excited state implies some sort of motion or vibration in the fluid. At temperatures not too far above absolute zero, the possible excited states are few in number and have low energy. Therefore only comparatively simple types of motion need be considered.

This method of attack was initiated by the Russian theoretical physicist L. D. Landau. He began by trying to find the simplest modes of motion of the liquid as a whole. For example, one such type of mode is a sound wave passing through the liquid. Each sound wave or other mode of motion carries with it a certain amount of energy and momentum. Landau's analysis showed that the energy and momentum of any low-lying excited state must be simple combinations of the values associated with the separate possible modes. Thus the formula for energy is just: $E = E_0 + n_1e_1 + n_2e_2 + n_3e_3 \ldots$ E_0 is the energy of the ground state (at absolute zero); the e's represent the energies of the successive modes of motion. The laws of quantum mechanics restrict the n's to whole numbers: 0, 1, 2, 3 and so on. Exactly the same relation holds for momentum (denoted by P): $P = P_0 + n_1p_1 + n_2p_2 + n_3p_3 \ldots$

A glance at these simple formulas suggests a concrete and useful interpretation of the abstract argument. Note that the expressions for the total energy and momentum of the liquid are the same *as if* it consisted of a "background fluid" of energy E_0 and momentum P_0, with a number of individual particles immersed in it. There would be n_1 particles of energy e_1 and momentum p_1, n_2 particles of energy e_2 and momentum p_2, and so on. Of course there really are no such particles; to underscore the fact, let us call them "quasi-particles." But all the pertinent equations can be interpreted as though they were actually there. What makes this view so fruitful is that, at low temperature, there are not too many modes of motion to deal with, and hence not too many quasi-particles. They can therefore be considered as making up a dilute gas. Thus the hopeless problem of dealing with the interdependent motions of almost countless numbers of helium atoms is overcome, and can now be treated by the well-understood theories of gases applied to quasi-particles.

It should be emphasized that a quasi-particle is a purely theoretical construct,

(PART 1)

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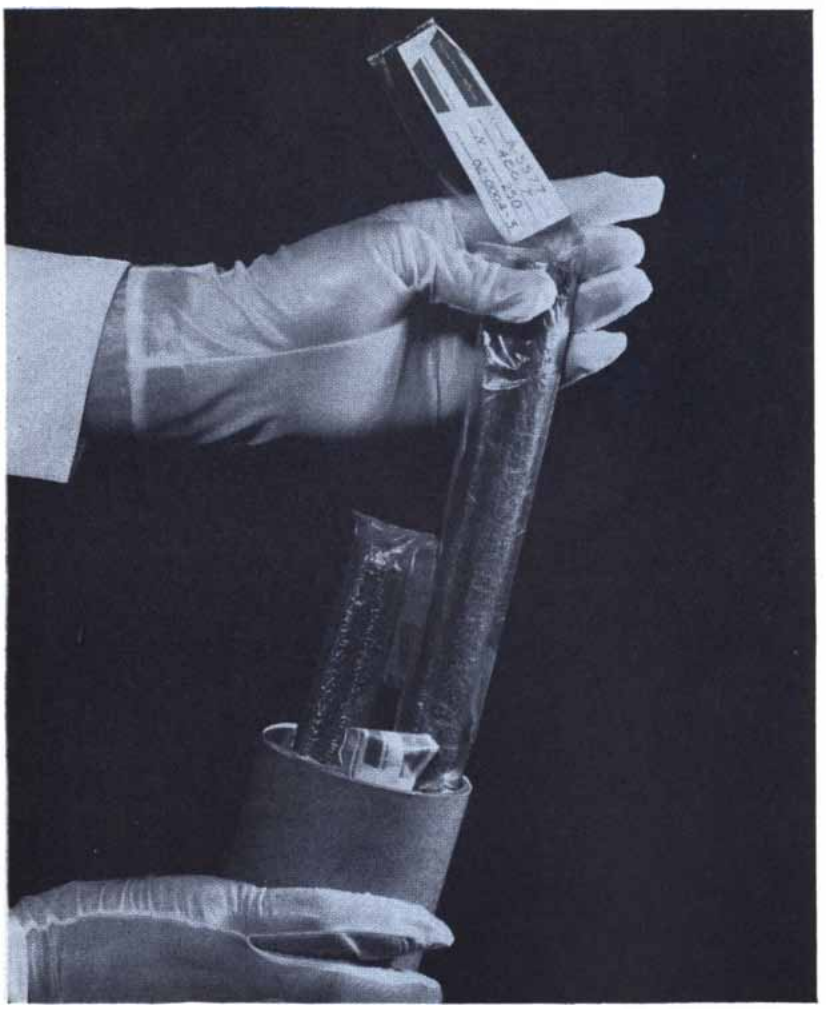

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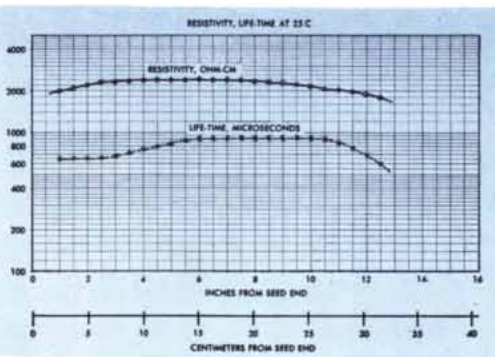

Typical Properties of Polycrystalline Silicon

Acceptor Impurity Content:	0.15 part/billion
Donor Impurity Content:	0.5 part/billion
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Rod Length:	up to 450 mm (17.7 in.)
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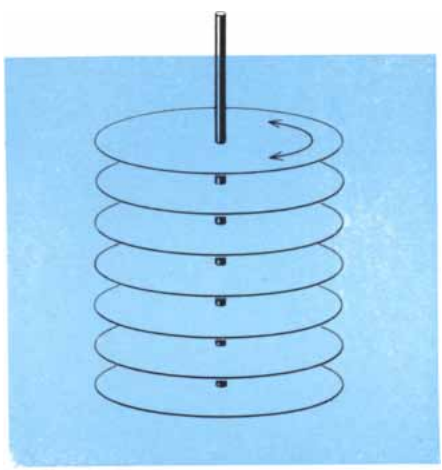
FILTER of finely packed emery powder (*dots*) separates quasi-particles from helium II. As helium flows out, concentration of quasi-particles increases, raising temperature of fluid in vessel. Electrical-resistance thermometer at center measures temperature.



STACK OF DISKS immersed in helium II oscillates like the balance wheel of a watch. As temperature rises, numbers of quasi-particles adhere to the stack, increasing its mass and hence its period of oscillation.

having to do not with an individual helium atom, but with motion of the liquid as a whole. Nevertheless, the behavior of a quasi-particle gas is remarkably like that of a real gas, with two important differences. The first of these concerns the relation between the energy and momentum of a quasi-particle. This relation reflects the properties of the modes of motion of the whole liquid and is quite unlike the corresponding relation for a real particle. The second difference concerns the number of particles in a given sample of material. In a real gas the number is fixed. In helium II it depends on the temperature, in a way that can be calculated once the energy-momentum relation for quasi-particles is known. At absolute zero there are no quasi-particles, and their number increases as the temperature, and hence the energy of the fluid, is raised.

The relation between the energy and momentum of a quasi-particle [*see top illustration on page 142*] is of fundamental importance. Landau originally inferred it by fitting his theory to empirical data. Later Richard P. Feynman of the California Institute of Technology succeeded in calculating it approximately from a detailed analysis of the modes of motion.

Since the simple S-shaped curve contains the clue to superfluidity, it is worth a moment's consideration. Note the contrast between it and the energy-momentum curve for real particles, shown in gray. The latter curve starts horizontally, becoming steeper as it moves to the right. This simply reflects the fact that, as the velocity of a particle increases, its energy (which depends on the square of the velocity) goes up faster than its momentum (which depends on the first power of the velocity). The important point here is that the ratio of energy to momentum can have any value from zero upward. By contrast, the curve for quasi-particles rises sharply, at an angle to the horizontal. Hence the ratio of energy to momentum can never be less than some minimum value.

To see how the theory accounts for superfluidity, consider the simplest situation at absolute zero; then there are no quasi-particles, only pure background fluid. Imagine an object, say a golf ball, moving through the liquid. In an ordinary fluid the ball would quickly slow down, transferring its energy to the molecules. In the case of helium II the absorption of energy would mean the creation of a quasi-particle in the background fluid. If the golf ball is to slow down, any energy it loses must be transferred to the quasi-particle. Now when the conservation of momentum is also taken into account, it is found that the ratio of the energy to the momentum acquired by the quasi-particle depends on the original speed of the ball. And if that speed is low enough, the ratio is less than the minimum possible value. Therefore a slow-moving ball cannot give up any energy to the fluid. By the same token, if the fluid is moving slowly, it cannot lose energy to the walls of the vessel. In short, it is superfluid.

Many other features of the strange behavior of helium II can be readily understood in terms of quasi-particles. Consider first the paradox of the two different viscosities. When helium II flows in a narrow channel, it is the background fluid (having the superfluid property of the liquid in its ground state) that gets through, while the quasi-particles do not. In the rotating cylinder viscometer, on the other hand, the gas of quasi-particles transmits a force from the outer to the inner cylinder even though the background fluid does not. The paradox is thus resolved because one is really dealing with two distinct entities: the background fluid, which is responsible for the flow through narrow openings; and the quasi-particles, which are responsible for the viscosity measured in the viscometer.

This idea of two interpenetrating fluids is strikingly supported by the following experiment. Helium II is placed in a container with an open bottom, which is then plugged with tightly packed emery powder [*see top illustration on this page*]. Background fluid can escape through the fine channels in the plug, but quasi-particles cannot. As the container empties, therefore, the concentration of quasi-particles in the remaining liquid is increased. But as we have said, the number of quasi-particles per unit volume is related to the temperature of the fluid. Hence the temperature of the liquid remaining in the container should also increase, and this is just what happens.

Since quasi-particles have momentum, they ought to produce observable mechanical effects. The Russian physicist Peter Kapitza demonstrated such an effect by heating helium II contained in an open bottle, which was in turn immersed in a bath of helium II. As the temperature rose, the number of quasi-particles in the bottle increased, thus "raising the pressure of the quasi-particle gas." As a result a jet of quasi-parti-

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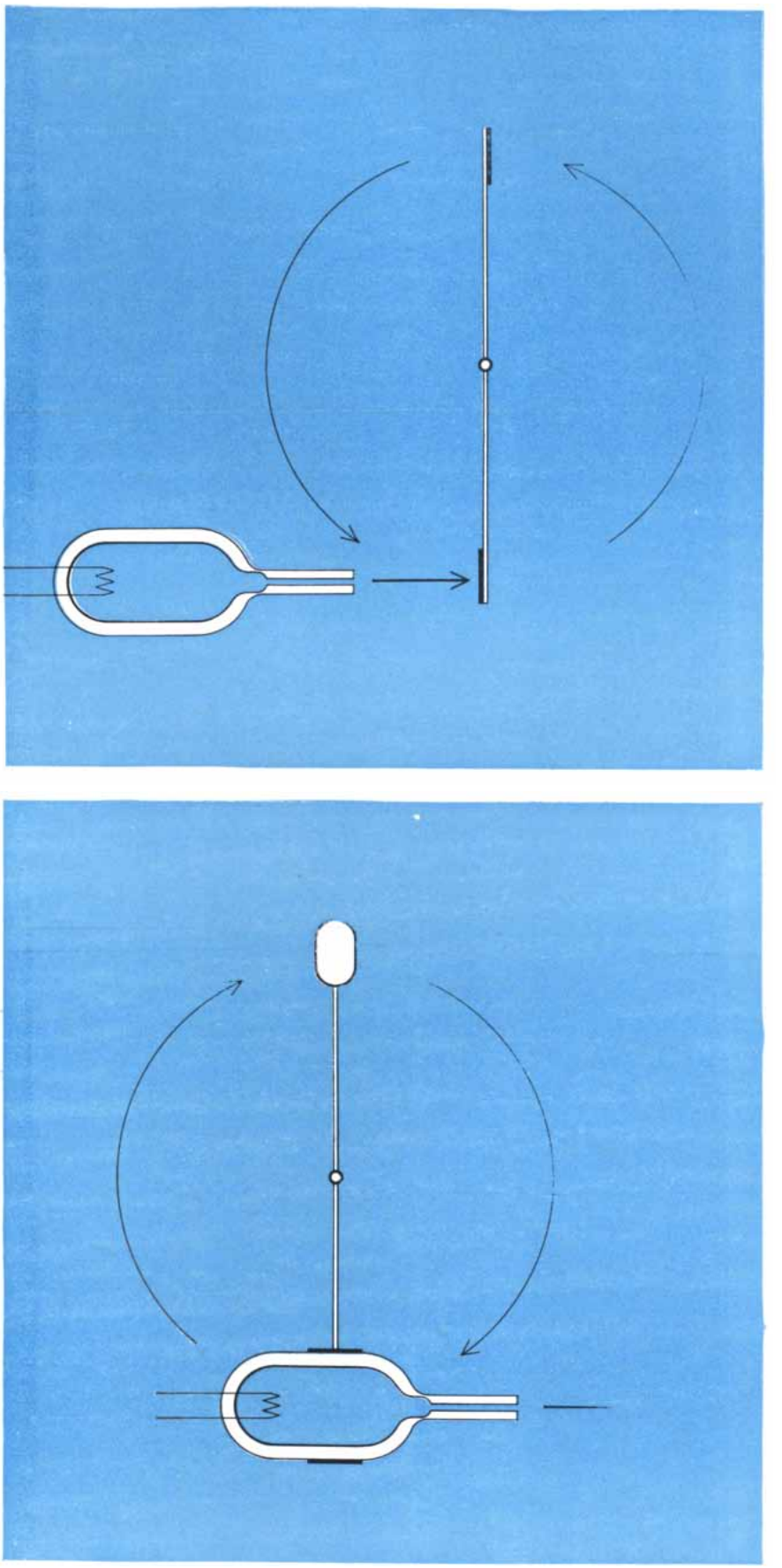
cles emerged from the bottle, deflecting a small vane placed in front of the mouth. When the bottle itself was suspended so that it was free to move, it recoiled when the heater was turned on.

A change in the setup of this experiment produces the fountain effect mentioned earlier. The bottle is partially immersed in the main helium II bath, and is open to it only through a very fine channel that passes background fluid but not quasi-particles. When the fluid in the bottle is heated, its level rises. As before, heating increases the pressure of the quasi-particle gas, but now it cannot escape. Instead it exerts a pressure on the background fluid which confines it and forces the level of liquid to rise in the bottle. In the process, background fluid passes from the main bath into the bottle.

The phenomenon is completely analogous to osmotic pressure in ordinary liquids. If a bottle partly filled with sugar solution is connected to a bath of pure water through a membrane that is permeable to water but not to sugar molecules, water flows into the bottle, raising the level of the solution above that of the bath. In this experiment real particles (sugar molecules) take the place of quasi-particles, but the basic mechanism is the same.

Another demonstration of the relation between quasi-particles and temperature was devised by Kapitza's co-worker E. L. Andronikashvili. He suspended a stack of very closely spaced circular disks from a fiber, so that the stack could execute circular oscillations like those of the balance wheel of a watch. When the disks were immersed in helium II, the period (the time required for each oscillation) decreased rapidly as the temperature was reduced from the lambda point toward absolute zero. The period of course depends on the mass of the stack; the greater the mass, the longer the time. In helium II the background fluid passes readily between the disks, but the quasi-particles become clogged in the narrow spaces and are carried back and forth with the disks. Therefore they increase the effective mass of the stack and lengthen its period of oscillation. As the temperature is reduced, there are fewer quasi-particles and so the oscillation speeds up. This experiment can therefore provide a quantitative measurement of the mass that is contributed by quasi-particles at any temperature.

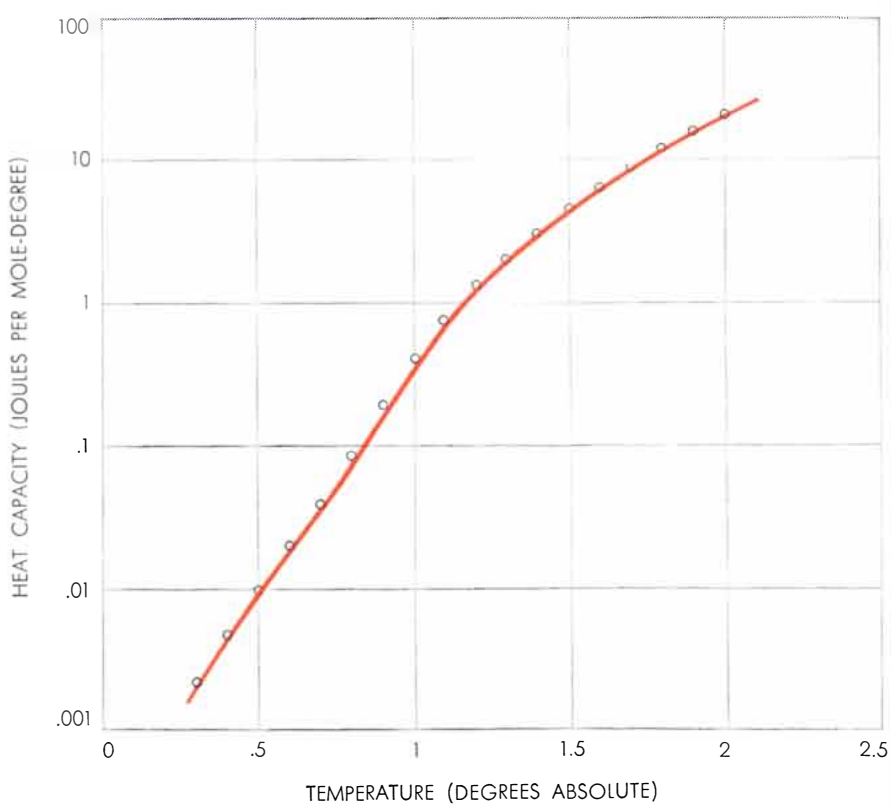
One of the most interesting features of the behavior of helium II was predicted by the quasi-particle theory before it was found in the laboratory. This



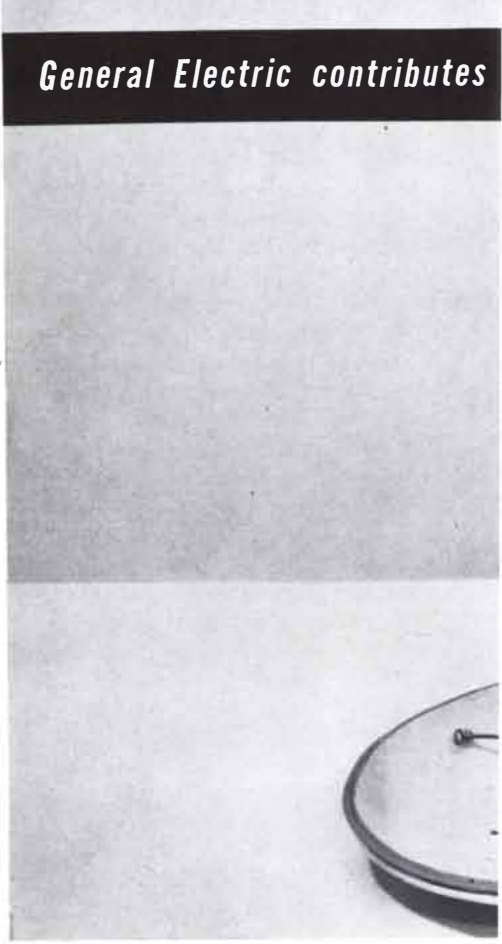
JET OF QUASI-PARTICLES emerges from a bottle of helium II when electric heater is turned on. Jet can be used to spin a small vane (*top*) or to make the bottle rotate (*bottom*).

is the phenomenon of temperature waves, or, as it is sometimes called, second sound. An ordinary sound wave is set up in a fluid when a moving body such as the diaphragm of a loudspeaker produces a local compression of the material. This compression travels through the fluid at a well-defined speed, and can be detected at a distance from the source by its effect on a second diaphragm—for example, the eardrum. Sound travels through helium II just as through an ordinary fluid. When the liquid is compressed, the background fluid and the quasi-particle gas both increase in density simultaneously. It is possible, however, to conceive of a local increase in density of the quasi-particle gas separately, the background fluid moving so as to keep the total density of the liquid constant. In that case the compression should travel through the quasi-particle gas with a definite speed, much as a sound wave moves through the air. But a local increase in the concentration of quasi-particles corresponds to a local increase in temperature of the liquid. Hence a local temperature increase in helium II should move through the liquid with all the properties of a wave motion. This wave motion has actually been set up by heating a sample of helium II in a localized region. The compression wave of quasi-particles can be detected some distance away with a thermometer.

All the foregoing experiments deal with macroscopic phenomena observed in helium II, and the theory of quasi-particles has certainly been very successful in accounting for the results. Very recently some experiments of a more microscopic kind have been carried out that subject the theory to a more detailed test. One was performed by L. Meyer and myself at the University of Chicago. We introduced a few electrically charged helium atoms (helium ions) into a sample of helium II and applied a voltage across the fluid. The ions move through the fluid under the influence of the electric force. We investigated the variation of the drift velocity with temperature, and found that the velocity increases very rapidly as the temperature is lowered below the lambda point. For example, at .6 degree absolute it is about 100,000 times greater than at the lambda point. Thus the superfluid character of helium II manifests itself also on an atomic scale. The ions are slowed by collisions with quasi-particles, and therefore speed up as the number of these quasi-particles decreases with temperature. Note that collisions with individual helium atoms are of no significance to the motion of the ions.



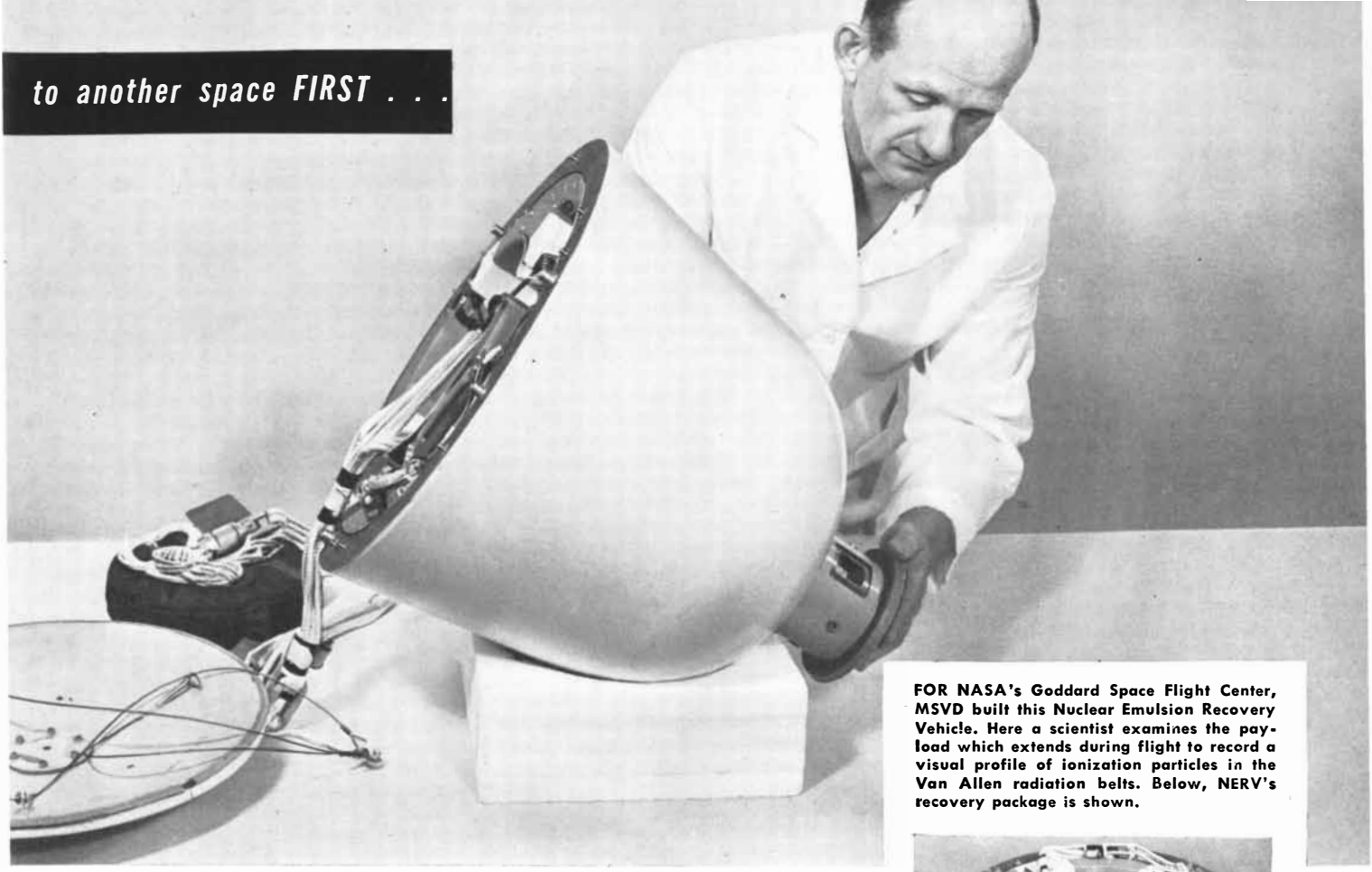
HEAT CAPACITY of helium II (*colored curve*) was calculated from results of neutron-scattering experiments. Curve agrees with direct measurements of heat capacity (*circles*).



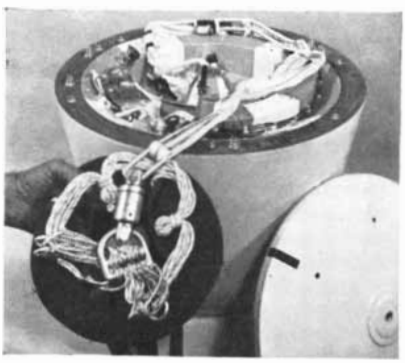
How NERV Space

NASA's Nuclear Emulsion Recovery Vehicle, developed by General Electric Missile and Space Vehicle Department, is highest space probe ever to be recovered.

Another major step in space exploration was achieved September 19 when NASA's first NERV—Nuclear Emulsion Recovery Vehicle—was successfully recovered after a 1200 nautical mile-high flight into the Van Allen space radiation



FOR NASA's Goddard Space Flight Center, MSVD built this Nuclear Emulsion Recovery Vehicle. Here a scientist examines the payload which extends during flight to record a visual profile of ionization particles in the Van Allen radiation belts. Below, NERV's recovery package is shown.



Returns Highest Radiation Measurements

belts. NERV brought back detailed measurements of the belts' radiation intensity.

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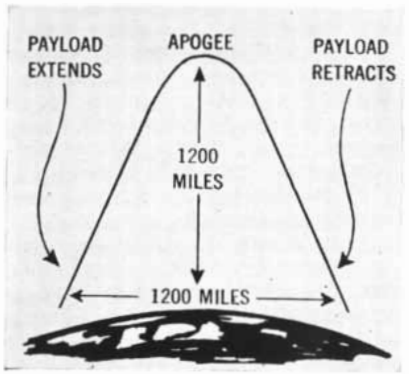
To learn more about NERV and other MSVD programs leading toward man's entry into space, write to Section 160, General Electric Missile and Space Vehicle Department, Philadelphia 1, Penna. 160-82A



MISSION PROFILE is illustrated above. After burnout of the rocket's four stages, a linear actuator extends the emulsion package. Payload is exposed through its apogee of approximately 1200 nautical miles and until the vehicle is within approximately 250 nautical miles of the earth upon return.

GENERAL ELECTRIC

MISSILE AND SPACE VEHICLE DEPARTMENT

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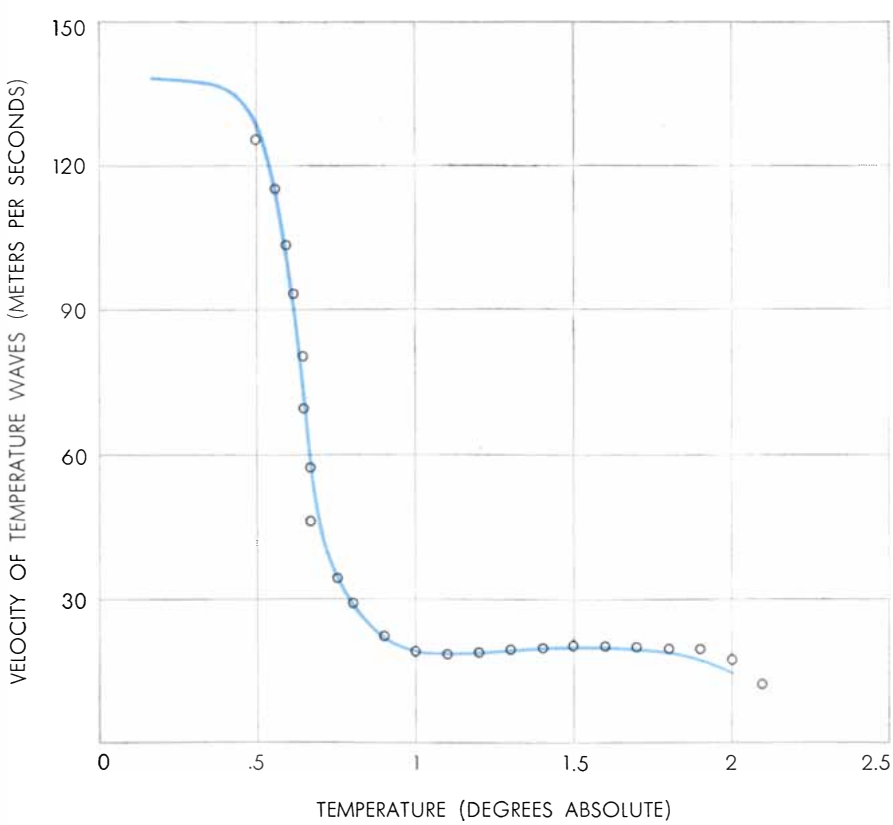
Indeed, in this experiment an ion can travel distances as great as 10,000 times the separation between atoms without being deflected by any of them. Again this is a typical quantum effect.

Finally let us turn to a very fundamental microscopic experiment, suggested by Feynman, in which a neutron beam is used to probe helium II. When neutrons are passed through any material, some of them are scattered in various directions by collisions with the atoms of the target. In the case of helium II at sufficiently low temperatures, neutrons of a suitable energy range are scattered by transferring some of their energy and momentum to the liquid as a whole. This means that a quasi-particle must be created having energy and momentum equal to that lost by each neutron. The latter values can be determined from the known energy of the incoming neutrons and the measured energy of the deflected neutrons.

This experiment provides a direct measure of the energy and momentum of individual quasi-particles. The experimental curve obtained by John L. Yarnell and his colleagues at the Los Alamos Scientific Laboratory has exactly the shape previously discussed and constitutes a striking confirmation of Landau's theory. Furthermore, the curve provides a precise, quantitative measure of the energy-momentum relation for quasi-particles. It can therefore be used to compute many of the properties of helium II, such as heat capacity and the velocity of temperature waves, and to determine how these quantities vary with temperature. The calculated values agree very closely with direct measurements of these quantities.

Outside the realm of nuclear and high-energy physics, all systems, even biological organisms, can be said to be understood "in principle." That is, their atoms obey well-known laws of quantum mechanics and interact through well-known electromagnetic forces. Understanding "in principle," however, is meaningless when the systems are so complex that their behavior cannot be predicted from these laws and forces. Nor is the problem of complexity likely to be overcome simply by resorting to bigger and better electronic computers. More often the basic problem is to find a particular theoretical framework—a set of concepts well adapted to the system—which can facilitate and guide our thinking. Ideally these concepts should be derived from fundamental principles. In the case of superfluid liquid helium, the quasi-particle concept achieves precisely these aims.



VELOCITY OF TEMPERATURE WAVES in helium II (*colored curve*) was also calculated from neutron-scattering experiments. Curve agrees with measured values (*circles*).

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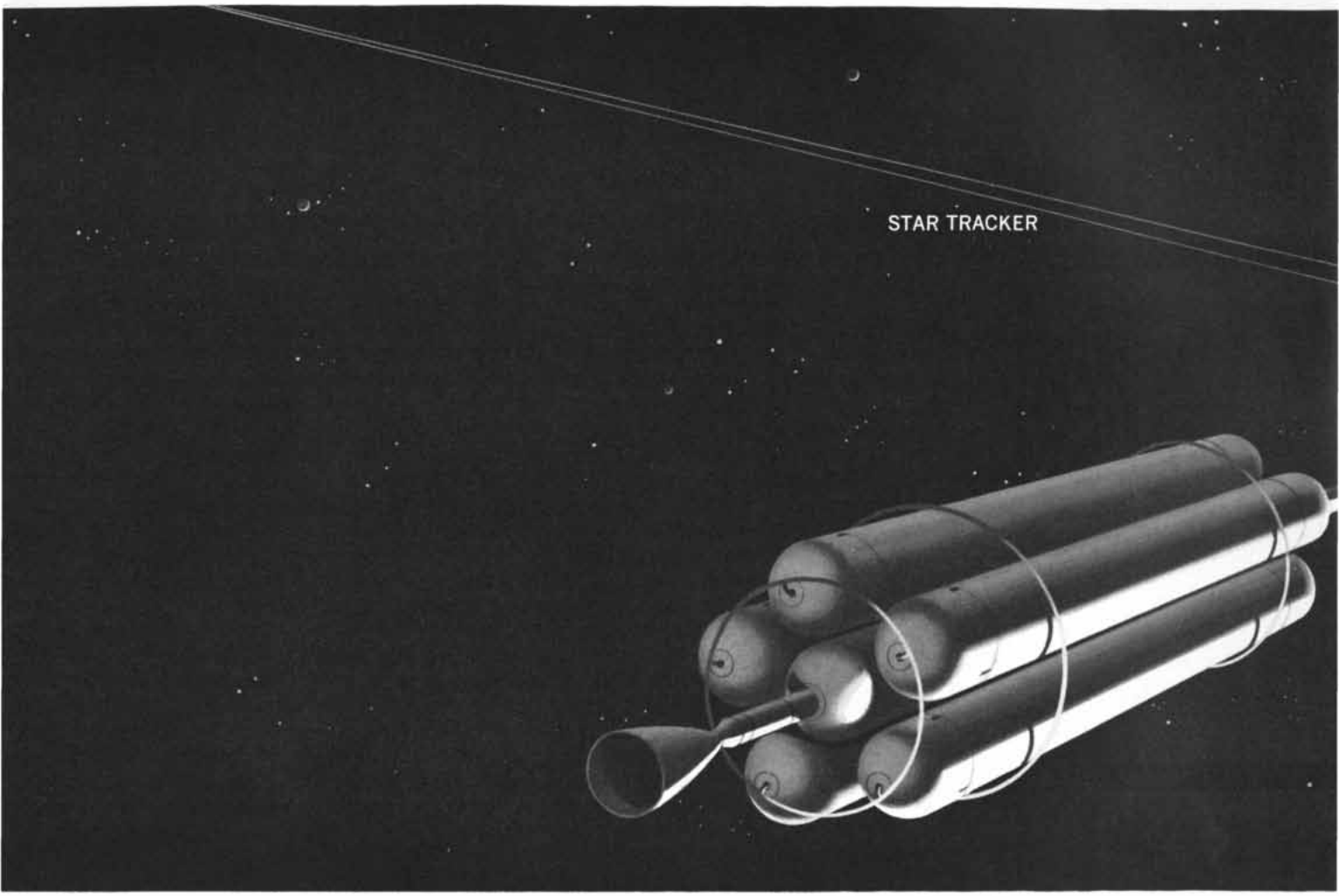

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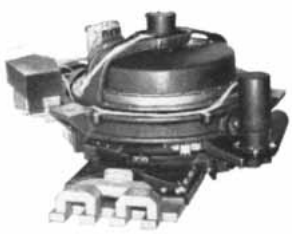

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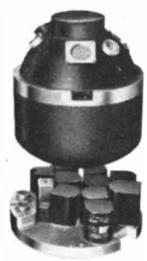

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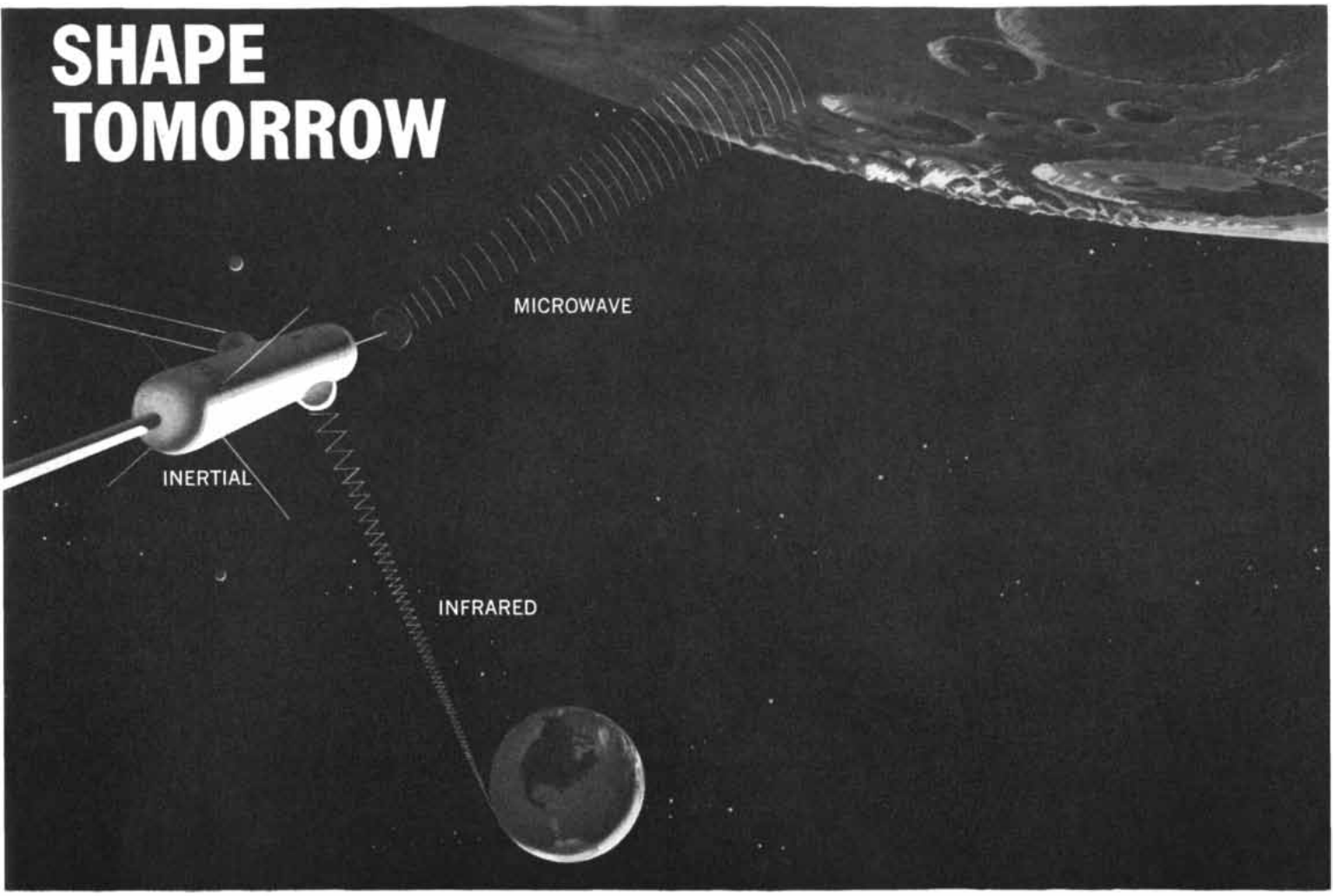

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THE TREASURE OF ST. NINIAN'S

On this tiny island in the Shetland group archeologists recently discovered a hoard of silver objects. The discovery reveals that Christians inhabited the island before the end of the eighth century

by R. L. S. Bruce-Mitford

St. Ninian's Isle is one of the tinier islands in the Shetland group off the northern tip of Scotland. There on July 4, 1958, archeologists from the University of Aberdeen were digging in the floor of a ninth-century church which they had found underneath the ruins of a 12th-century church. They had uncovered in the nave area a cracked stone slab with a cross lightly incised in its surface. On the instruction of A. C. O'Dell, who was directing the work, a 16-year-old Shetland schoolboy named Douglas Coutts lifted away the stone slab. Beneath lay a tightly packed and entangled assemblage of greenish objects, all apparently of bronze. It was the first day of Douglas Coutts's first excavation, and it is sad to think (as the archeologist Jacquetta Hawkes remarked in *The Sunday Times*) that the

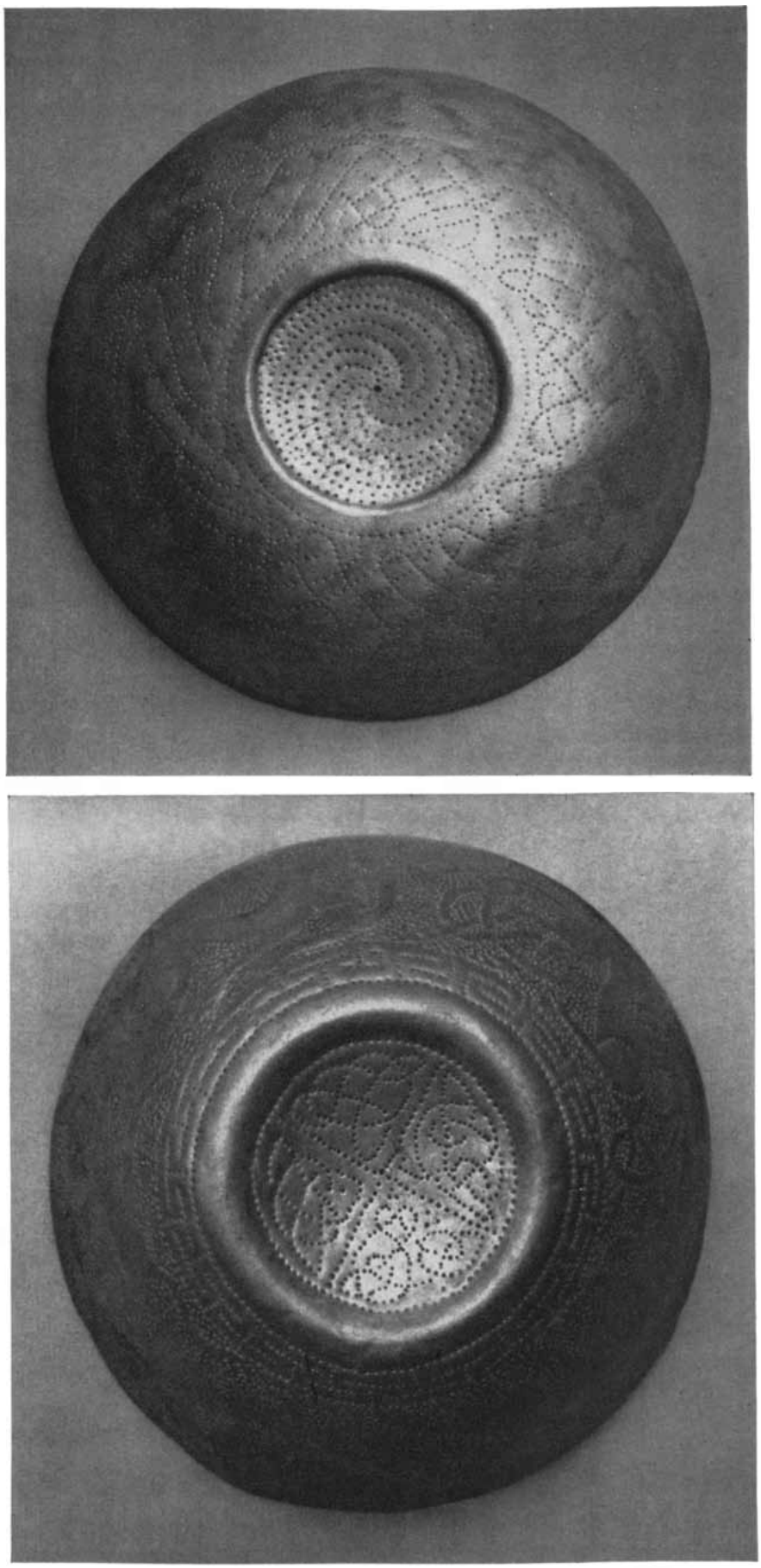
ST. NINIAN'S ISLE (*center*) **is about a mile long and about half a mile wide. It is one of the tinier islands of the Shetland group, located about 100 miles from the northern tip of Scotland. Coastline of the largest of the islands lies in foreground.**

rest of his archeological career is bound to be one long anticlimax. For this assemblage of objects, now known as the St. Ninian's Isle treasure, has proved to be the most important single discovery in the annals of Scottish archeology—a group of artifacts that yields intriguing insight into an obscure century and into a region that was historically an almost total blank before.

Around the opening of the ninth century the Shetland Islands were colonized from Norway. It has been generally believed that this was a peaceful settlement of uninhabited islands that served as steppingstones for the subsequent Norse invasion of the Scottish mainland and Ireland. But were the Shetlands really uninhabited when the Norse arrived? Or did the Norsemen find communities there, outposts of the Christian civilization of Britain, that fought for their lives and their land? The St. Ninian's Isle treasure and the church in which it was found reveal for the first time that the islands were the home of a civilized Christian people when the invasion from Norway began. The valuables of the church and the community were hidden under the church floor—hastily hidden, as the evidence shows. But there was no effective hiding place for the people. No one came back to reclaim the treasure, the Norse never discovered it, and there it stayed until it once again saw daylight a whole millennium later.

The 12th-century church on St. Ninian's Isle, which was destroyed around 1750, was known to have been dedicated to St. Ninian. This fourth-century saint, a native of Strathclyde in southwestern Scotland, went to Rome to be trained and came back to lead a mission to the Picts in the north. A whole string of churches dedicated in his name marks the spread of his activity and influence northward from Whithorn on the Firth of Solway. It was the dedication in his name of a 12th-century church on the tiny islet in the Shetlands that suggested this church might stand on the site of an earlier, pre-Norse Christian church.

The exact location of even the later church had been lost when the Aberdeen archeologists came to the island; gales had borne sand from a spit offshore and had completely buried the area by 1850. The site was located in 1955, and interest quickened with the discovery of a small walled enclosure: the so-called Founder's Tomb. This contained seven carved stone pillars which could be dated to about A.D. 800, five



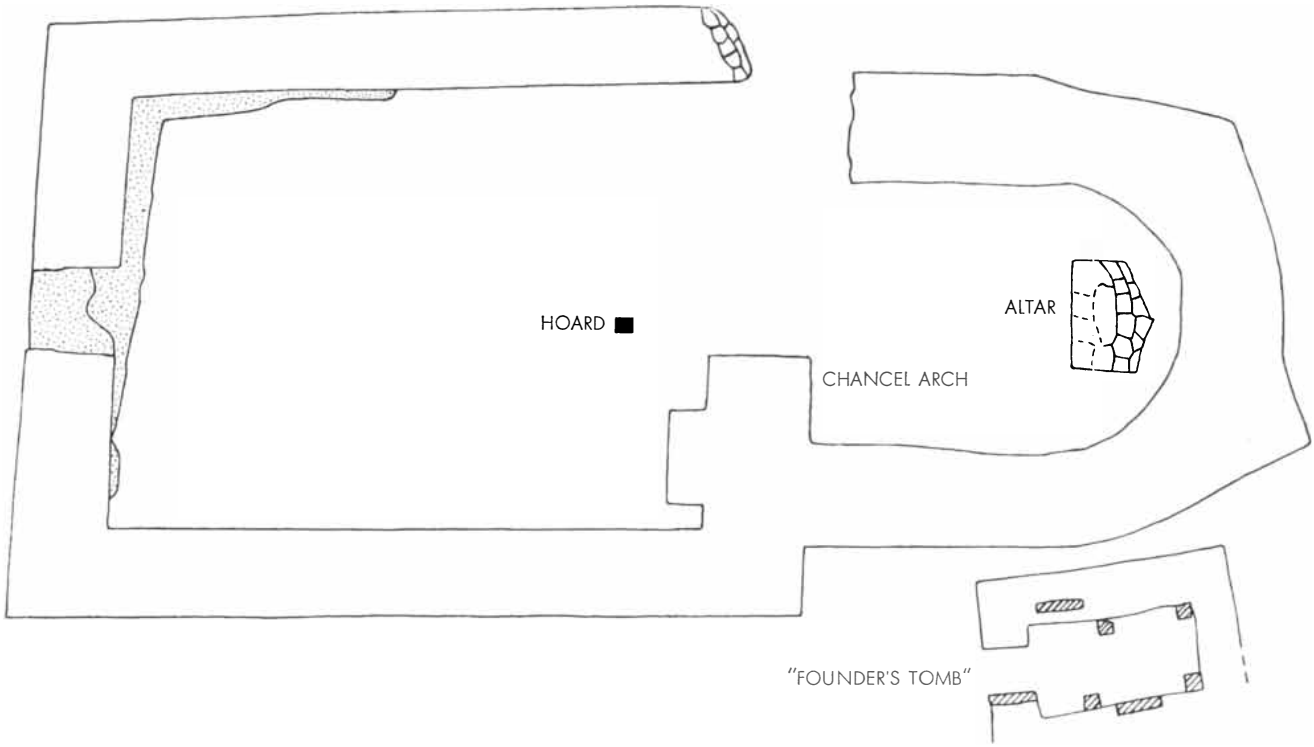
SILVER BOWLS are decorated with patterns of punched dots. Seven of the bowls were found, some in very poor state of preservation. This photograph shows the undersides of two bowls. Bowls range from 5 to 5.8 inches in diameter and from 1.25 to 2.25 inches deep.

of them being carved with Pictish symbols. Excavation was carried below the level of the footings of the 12th-century walls, and the slab with the incised cross was uncovered.

A dark stain was almost all that remained of the box in which the treasure had been buried; a few splinters which survived because of their impregnation with salts from the metal showed that the box had been made of larch wood. Within the circumference of this stain was the heterogeneous collection of objects; bowls lay nested in one another upside down and ornaments were tangled together, in witness to the haste with which the box was buried (upside down). The whole appeared as a clotted mass of poisonous-looking green metal, in fragments of all shapes and sizes. But much of it, as might be seen at a glance, was of a quite unprecedented nature. From the circumstances of its burial, it was plain that the hoard represented the wealth of the established church, or of the community, and not just a pirate's loot which might have been gathered from anywhere.

Professor O'Dell wisely lifted the entire complex intact and brought it straight down to the British Museum Research Laboratory in London. As H. J. Plenderleith and his experienced staff began to disentangle and clean the confused and often highly brittle mass, they made a rewarding discovery. The true nature of the metal, concealed by the greenish earthy coating of copper compounds, was shown by the spectrograph to be a silver alloy containing copper as a minor constituent. The treasure as a whole proved to consist of 29 objects: seven small shallow bowls, one hanging bowl, a spoon, a forklike implement with one prong, a sword pommel, three heavily decorated cones of uncertain function, two horseshoe-shaped objects that appear to be chapes, or fittings for a scabbard (one with an important, though short, inscription), 12 brooches, and the jawbone of a porpoise (without a trace of decoration or

THREE MAPS at left show the position of St. Ninian's Isle in North Sea region (*top*) and in Shetland group (*bottom left*); close-up map at bottom right indicates location of church where treasure was found and of the sand bar (*stippling*) that covered it.

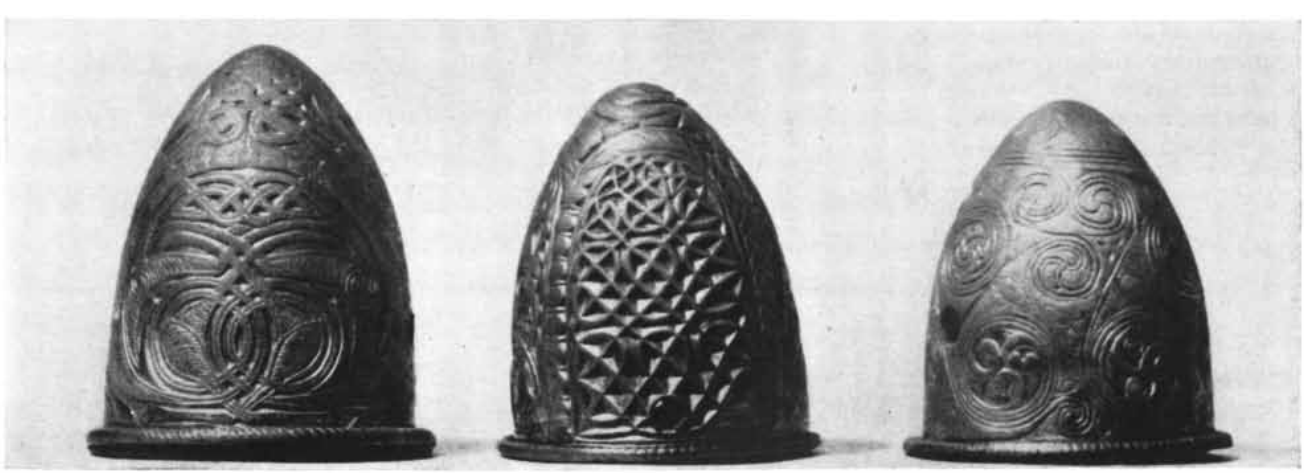


PLAN OF ANCIENT CHURCH shows the exact location of the treasure. Church measured about 50 feet long and 25 feet wide. The so-called Founder's Tomb contained seven carved stone pillars that dated from about A.D. 800. The hatching indicates their position.

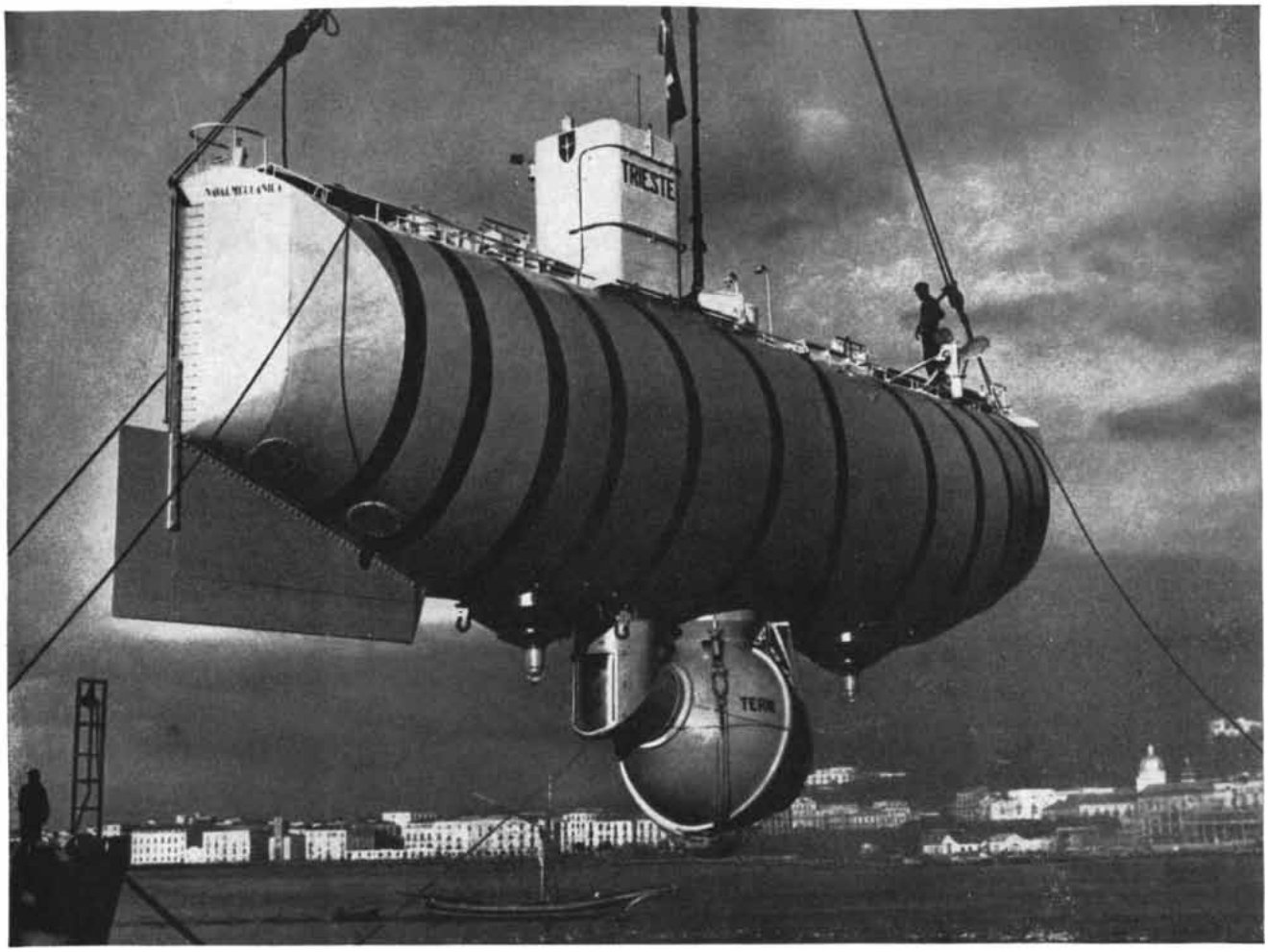
manipulation, but deliberately buried with the silver). Some of the pieces showed traces of gilt.

The majority of the silver bowls, presently on display in the University Natural History Museum at Aberdeen, appear to be quite robust, watertight vessels. In most of them, however, so much of the copper constituent of the silver alloy had leached out that they were structurally nothing but a frail network of silver. It was necessary to clean off the corroded copper surface not only to reveal the design, but also to strengthen and stabilize the remaining metal. Upon cleaning in a bath of dilute acid, the metal was impregnated and coated with a synthetic lacquer. Some bowls needed more elaborate restoration: a rim was remade, a fractured edge was reinforced with ribbons of silver, and a part that had wholly disintegrated was replaced by a fibrous gap-filling plastic, colored to match the old silver. It was impossible to restore several of the bowls to anything like their original shape and condition; to remove the decayed and swollen surface metal was to remove the design it had borne. After cleaning and strengthening, it was necessary to prevent further corrosion. Because it was not possible to eliminate the copper chloride, the principal agent of corrosion, the objects were enclosed in portable transparent cases together with a dessicating agent to trap moisture and thereby inhibit the corrosion process.

The seven small bowls are all of roughly the same shape and size, between 5 and 5.8 inches in diameter and from 1.25 to 2.25 inches in depth. As



SILVER CONES may have adorned a sword belt. Decoration on cone at left consists of a highly stylized rendering of an animal. Cone at center has interlaced geometric design. A different artistic tradition is represented by the Celtic design on cone at right.



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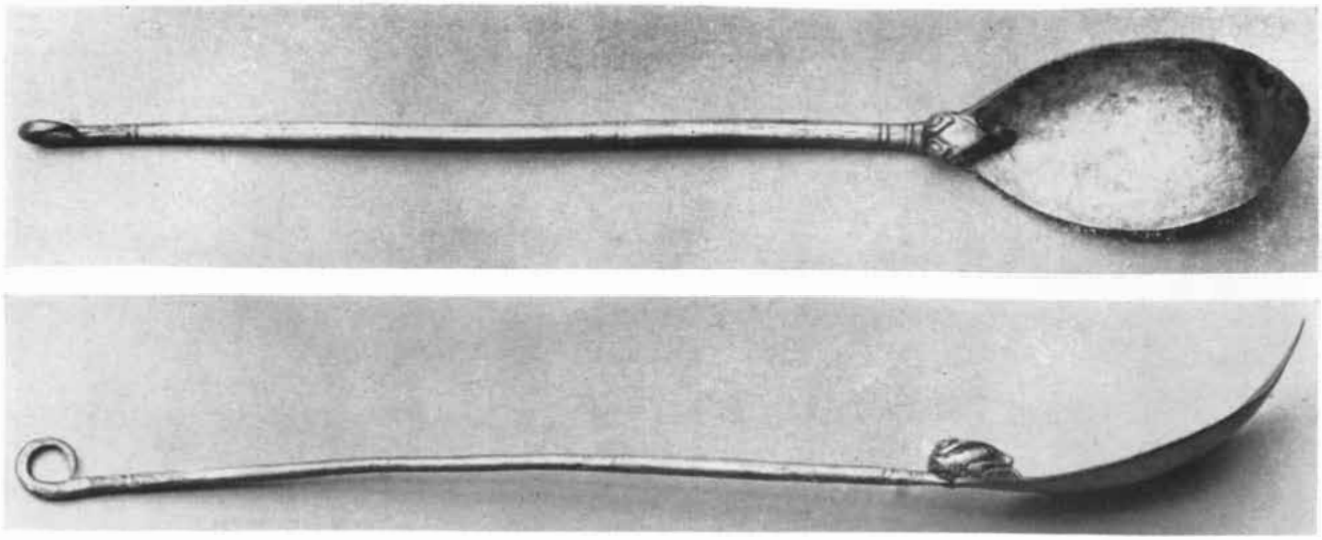


SPOON (*shown in two views*) **is made of a strip of silver flattened at one end. The point where the bowl and the handle meet is decorated with a small dog's head; the tongue of the dog licks inside of the bowl. The spoon is too delicate for rough domestic use.**

finally revealed, each has its individual pattern, including some very interesting animal processions, interlaces and geometrical designs. They are the first bowls of their era and kind to be found in Scotland, either on the mainland or in the outer isles. Moreover, only one other silver bowl of this era is known in the whole of the British Isles: the Ormside Bowl now in the Museum at York. This object also dates back to the eighth century, but it is very different in construction and decoration.

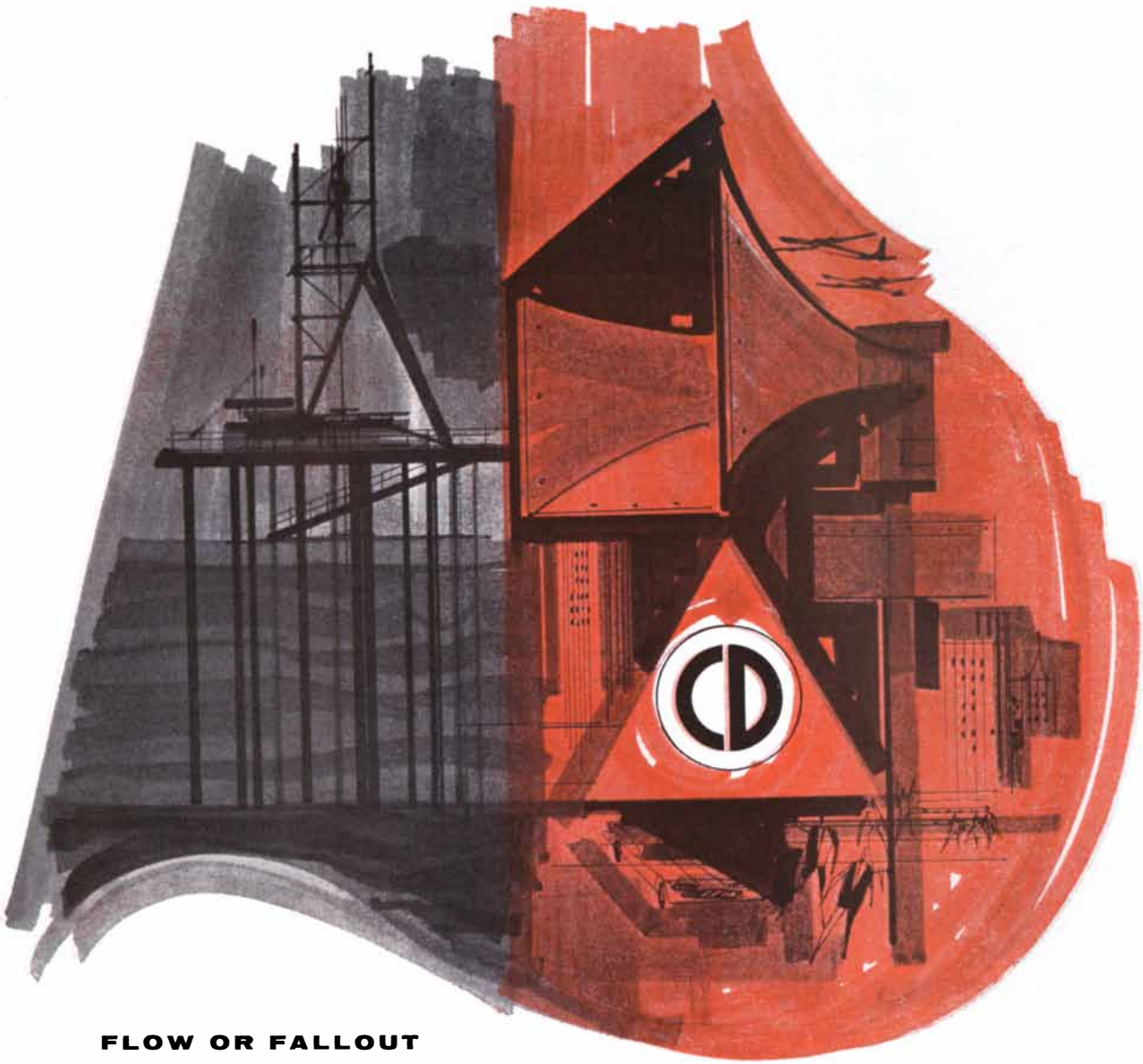
The fact that the hoard was found under the floor of a church does not necessarily mean that the silver was all ecclesiastical in character. Indeed, only four items in the hoard seem to have had a religious use: the spoon, the one-pronged implement, the porpoise bone and the hanging bowl.

The spoon is made of a strip of silver, flattened at one end to form the bowl and curled back at the other end to form a loop by which the spoon could be hung. A small green nodule of metal, retrieved from among the rest of the find, proved upon cleaning to be a small dog's head that fits neatly into a small hole at the point where the bowl and the handle meet. The dog's blue glass eyes gaze straight ahead, and his tongue licks the inside of the bowl. The spoon is much too delicate for rough domestic usage; the bowl is not strong enough for its edges to be used for cutting and is too shallow to carry much liquid.

One might suppose that the forklike, one-pronged implement went with the spoon. They may well have been used together, since they were found together, and both were furnished with rings for suspension. But they were manufactured by different processes—one wrought, the other cast—and they must have had separate origins. The interesting thing about the pronged implement is a small spur that projects below the prong and ends in a small cutting edge. The prong overhangs in such a way, however, that it is difficult to see how the cutting edge could have been brought to bear. Someone has suggested that the thing was a lobster pick, but the projecting blade would be useless for this purpose and would get in the way as one attempted to poke the prong into a lobster claw. The blade can only have been applied by means of pressure directed vertically downward. Clearly the implement must have had a highly specialized use. At the back of the Stowe Missal, an eighth-century manuscript in the library of the Royal Irish Academy in Dublin, is a short treatise, in the Old Irish tongue, on the celebration of the Mass. This describes a ritual division of the mystical seven pieces of the Communion Host into 65 pieces. The pronged implement from St. Ninian's Isle would seem ideally adapted for such a purpose. The small blade would have served to break up the Host into particles, and each might then have been picked up on the prong. The spoon, the bowl of which was too flat to contain much liquid, could also have been used for carrying pieces of the Host. It is not unlikely that both implements were used in ritual.

The hanging bowl is one of an interesting class of bowls made in the Celtic parts of the British Isles and found scattered from Ireland to Norway, especially in the early Saxon graves of southeastern England. They were de-

FORKLIKE IMPLEMENT of cast silver was found with spoon (*above*) **and might have been used with it during the Mass, the forklike implement to divide Communion Host and spoon to pick it up. Spoon could also have been used to carry pieces of the Host.**



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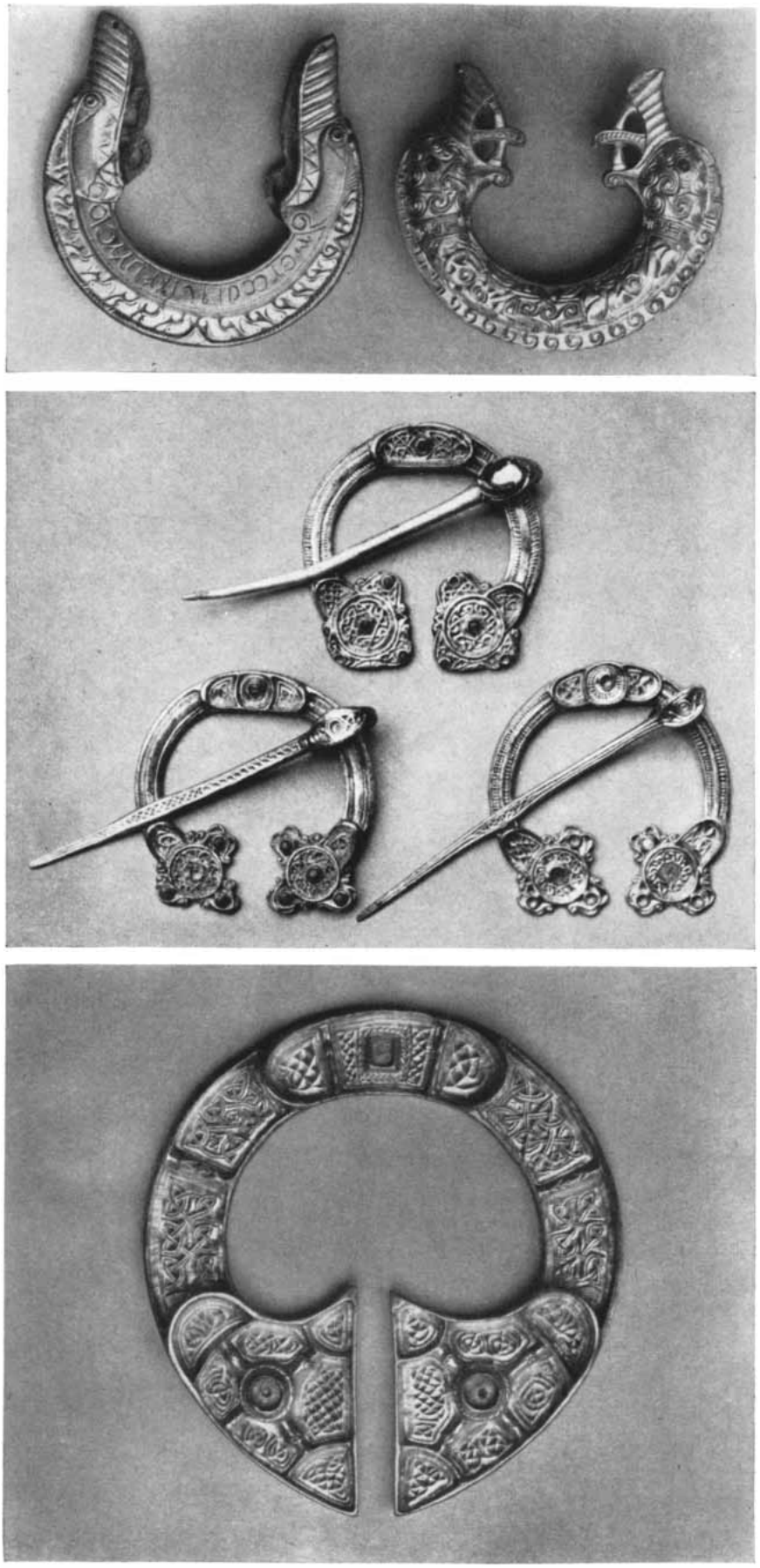

SECULAR OBJECTS of silver include two chapes (*top*) and 12 brooches. Three of the brooches are shown at center; the largest and finest appears at bottom. The design pattern of largest brooch is well preserved. Brooches were part of the dress of wealthier inhabitants.

signed for suspension from rings held by three hooks spaced equally around the rim. The hanging bowls have interesting enameled or cast decoration (seen as soldered-on disks and appliqués), which gives them a very special importance in the early art history of the British Isles; they range in date from the fourth to the ninth centuries. The St. Ninian's Isle bowl is the only silver one to survive; all the others (some 130 are known) are bronze. They are thought to be associated with the Celtic church and to have served as holy-water stoups or as basins for the ritual washing of hands.

As for the porpoise bone, it is difficult to see why a bone should be deliberately concealed in the box with the silver, unless it was regarded as a relic. Many early saints were especially associated in legend with animals: St. Jerome with his lion; St. Cuthbert of Northumbria with the sea otter; St. Malo of Brittany with the sow he restored to life out of compassion for its litter (and for the poor swineherd who had a heavy stake in both); St. Colman of Kilmacduagh in Ireland, who is associated with the pet mouse that infallibly woke him when it was time for his devotions and with the fly that used to mark his place in a book by sitting at the end of the last sentence until he returned to his reading. The porpoise bone in the St. Ninian's treasure might have commemorated some special association of this kind between a local saint and the porpoise, a beast that is often seen plunging in the sea around the Shetlands.

The plainly secular pieces in the hoard—the sword pommel, the three mysterious cones and the two chapes—are all elaborately and luxuriantly carved. It is difficult to make head or tail of the patterns on these objects, except for a panel on one of the cones that carries a fairly regular interlace. Head or tail is indeed what one has to make of them, for they consist chiefly of fantastically contorted animals whose necks, bodies and tails are drawn out into long ribbons that wander over the decorated area, coiling and interlacing. A different artistic tradition is reflected in the smallest of the cones, which bears an over-all design of interconnected spirals—a purely Celtic theme.

The exposed surfaces of the three cones, which may have adorned a baldric (sword belt), are heavily worn, and they must have been quite old, say 50 years old, when they were buried around A.D. 800. The carving and design of the sword pommel is particularly accomplished. It is the detail of this dec-

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SWORD POMMEL, like the chapes at the top of page 162, is decorated with coiled and interlaced bodies of animals. The two objects on this page are not reproduced to the same scale.

oration and that of the bowls that has helped to date the hoard, relating the St. Ninian's Isle objects to dated manuscripts and other works of art, such as sculptured stones. The style of adornment also holds still-unraveled clues to the question of where the objects were made; there are links to the border regions between Scotland and England far to the south.

The chapes, if that is what they are, are particularly provocative pieces. They are hollow, with a thin opening along the inner edge. The one that carries an inscription shows considerable wear and seems to have been fitted onto the tip of the scabbard of the sword to which the pommel belonged. The other, with more elaborate carving, is in mint condition, freshly carved and not yet gilded. It must be the latest piece in the hoard, still unfinished when buried. This

HANGING BOWL was designed to be suspended from rings held by hooks on the rim. Such bowls were made in Celtic parts of British Isles and are found from Ireland to Norway.

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suggests the rather surprising possibility that fine-quality silversmith's work may have been carried on even in the remote Shetlands.

The inscriptions on the older of the two chapes have great interest because few inscriptions come down from this period and because they indicate literacy in Latin on the part of the owner or the maker. On one face the inscription reads RESADFILISPUSSCIO, meaning "(the property of) Resad, son of Spusscio." Neither name has been recorded before. But a distinguished Celtic scholar, Kenneth Jackson of Edinburgh, who has provided this interpretation, observes that Pictish nomenclature contains many exceedingly queer names, such as Canutulachama, Bliesblituth, Usconbuts, Uipoignamet, Uumpopual and Dorornauch Nerales, which are no less odd than Spusscio, and a good deal odder than Resad. The inscription on the other face reads INNOMINEDS, that is, *in nomine Dei summi*, "in the name of God the highest." If the object is indeed a chape, this inscription would have no especially ecclesiastical connotation. As Jackson has remarked, it would merely mean that Resad, son of Spusscio, "drew his sword in the Lord's name, like thousands of his compatriots after him."

The brooches are all of a design which archeologists call penannular, a ring which does not make a full circle, the ring being broken at one point to allow for the passage of a long pin. The penannular brooch is the common Celtic type, and brooches like this, often copies of early examples, are still worn. Only 18 penannular brooches of the seventh and eighth centuries were known from Scotland before the St. Ninian's Isle hoard came to light and almost doubled the number at a stroke. Most of the St. Ninian's brooches show rather heavy wear, and so must have been of some age when buried. The finest is the largest. Because the panels of ornament are countersunk below the level of the raised flanges on which the ring of the pin moved, the design pattern is particularly sharp and well preserved. The brooches are not ecclesiastical in any way, but were part of the dress of the relatively well-to-do.

The secular character of these ornaments supports the deduction that the treasure trove represented the capital assets of St. Ninian's church. These various items were perhaps received as valuable gifts over the century or so before a sudden danger compelled their hasty burial and consequent preservation as a major "document" of the early history of the British Isles.

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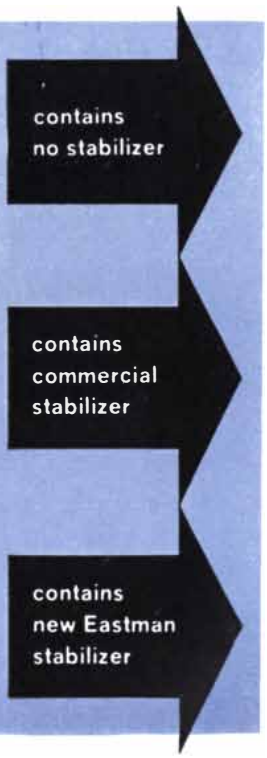

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New, specially stabilized Tenite Polyethylene formulations for extrusion into thin, transparent, weather-resistant film are now available from Eastman. Incorporated in the resins is a new non-pigment ultraviolet inhibitor developed by Eastman chemists.

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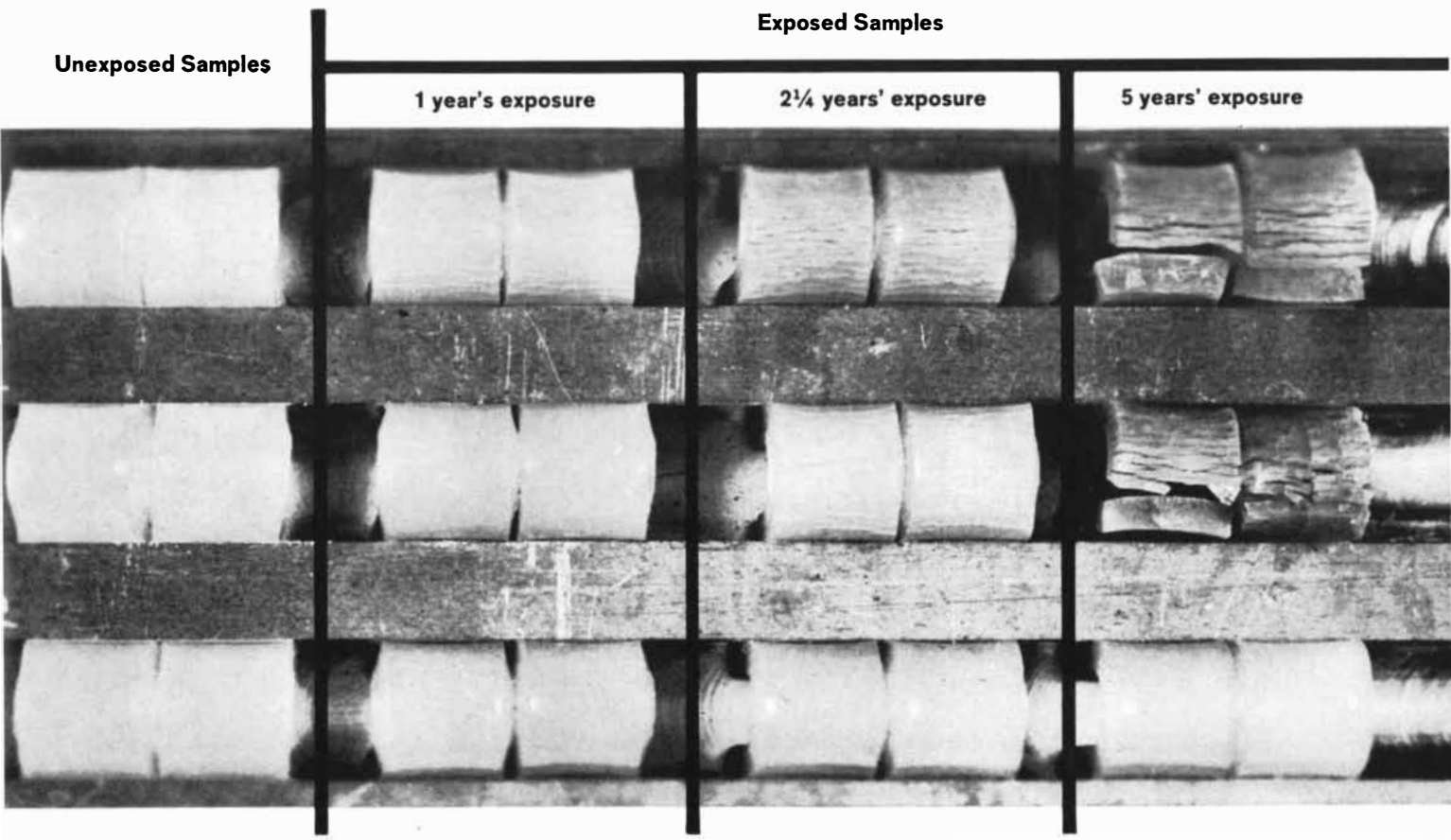

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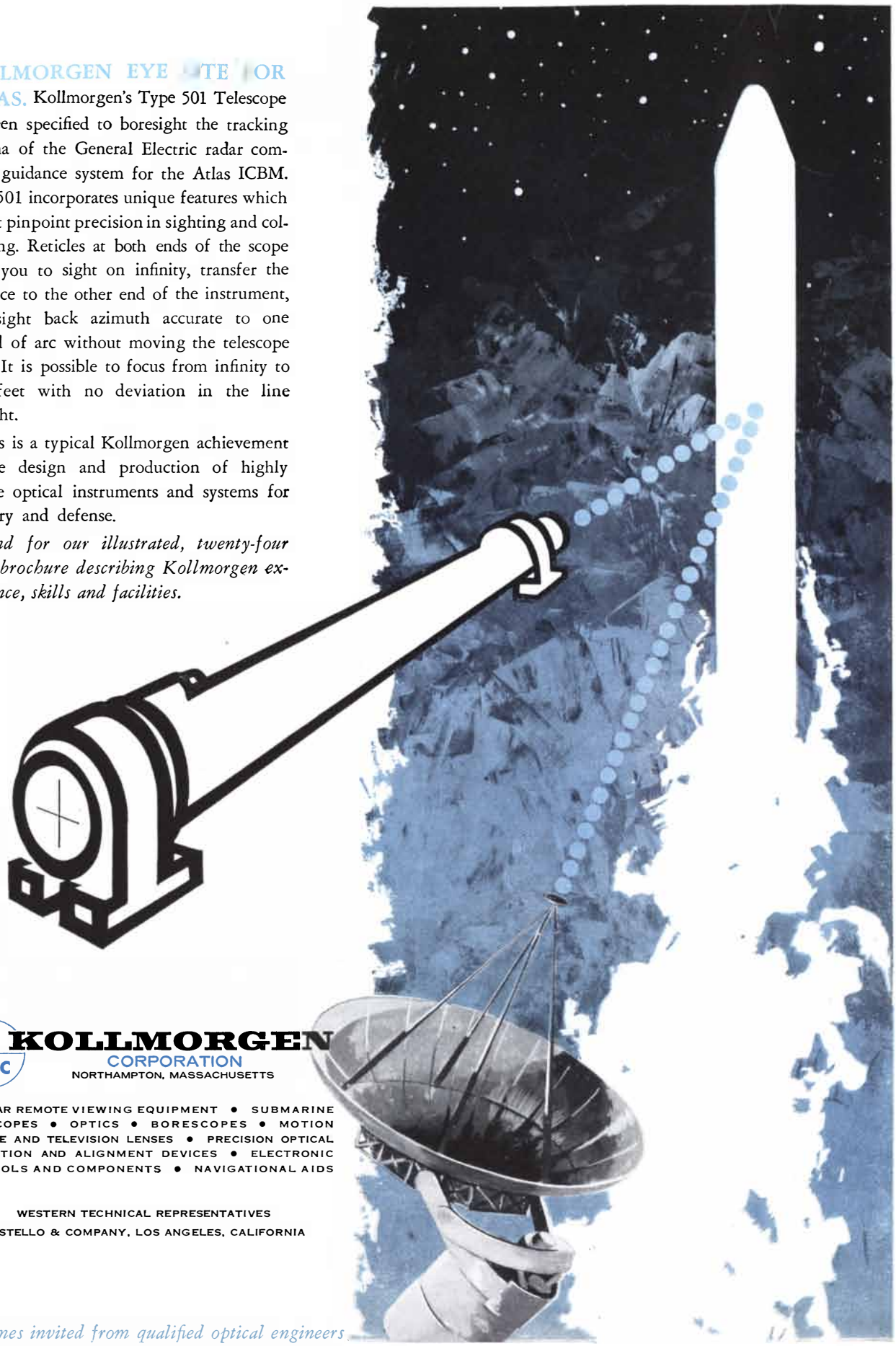

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The Age of the Elements in the Solar System

Studies of the inert gases found in meteorites have confirmed estimates that the earth is 4.6 billion years old and provide evidence that the elements in the solar system are not much older

by John H. Reynolds

How old is the solar system? The question is a big one, and it suggests research tools of commensurate size—large telescopes on mountaintops and rockets roaring into space. On the contrary, the answer is coming from the analysis of minute bits of matter by quite modest instruments mounted on the laboratory bench. It is true that the bits of matter come from meteorites: those samples of interplanetary rubble that are swept up by the earth's gravitational field. But the passage of cosmic time is measured by counting the few atoms of the "noble" gases—helium, argon, neon, krypton and xenon—that are trapped in the crystal lattices of meteoritic stone and iron.

Certain isotopes (atoms of the same element that have slightly different masses) of the noble gases represent clocks that have stopped. They are dead ends to which nuclear transformations have carried other atoms higher up in the table of elements. The transformation of some atoms proceeds spontaneously by radioactive decay. Since the rate of decay is immutable and is known, time can be measured by comparing the relative abundance of the parent elements and their noble-gas daughters present in a sample of matter. Some nuclear transformations in nature are induced by the impact of the highly energetic particles called cosmic rays. The rate at which these latter transformations occur can be estimated within reasonable ranges of error to yield another sort of time-scale.

As investigators have mastered these ways to tell time, they have found in the noble gases an independent check on the ticking of the classic uranium clock in the rocks of the earth. As a result it now appears that the cold planetary bodies of the solar system all crystallized at about the same time: some 4.5 or 4.6 billion years ago. The noble

RICHARDTON STONE METEORITE discussed in the text fell in North Dakota in 1918. Specimen shown here, part of 200 pounds of material collected, weighs about 1.4 pounds. Bright area at lower right is iron inclusion. Smaller sample of the Richardton stone was used by the author in his research on age of elements in the solar system. Photograph was made at the Smithsonian Institution.

gas technique also dates the more recent breakup of some of these massive bodies into meteorites and provides clues to the life histories of the fragments. And one noble-gas clock that ran down and stopped at the very dawn of time has made it possible to reach into the twilight of cosmology and measure the full age of the solar system, from the epoch in which the elements that compose it were formed.

The uranium clock was one of the first fruits of the discovery of radioactivity. As early as 1907 workers in the Cavendish Laboratory of the University of Cambridge recognized that the decay of uranium to helium offered a way to measure the age of rocks. Natural uranium consists of two different isotopes that decay to helium at different rates. The helium-to-uranium ratio in a rock yields, therefore, a measurement of time, although the ratio must be qualified by the realization that the helium tends to leak away. Fortunately the decay of each uranium isotope also yields a different isotope of lead. These lead-to-uranium and lead-to-lead ratios lie behind most of the readings of the uranium clock.

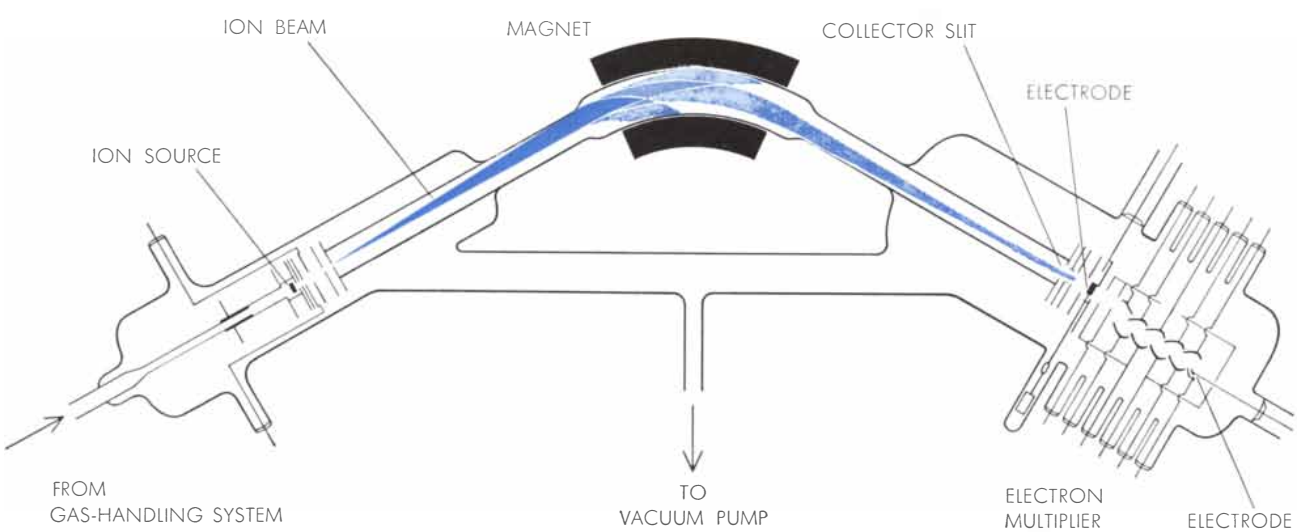
The interest of investigators in helium was renewed about a decade ago, when measurement of the helium-to-uranium ratio in meteorites produced a startling result. In studying the ages of a number of iron meteorites, F. A. Paneth of the University of Durham arrived at values ranging from about one million years to 7.6 billion years. The upper figure raised a paradox; it was more than twice the then estimated age of the solar system [see "The Origin of Meteorites," by S. Fred Singer; SCIENTIFIC AMERICAN, November, 1954]. Since there was too much helium in the meteorites with respect to the uranium, it was suggested that some of the helium might have evolved from the breakdown of iron atoms under cosmic ray bombardment as the meteorite traveled on its orbit around the sun. If this were the case, the excess helium would turn out to be partly helium 3 rather than only the helium 4 which terminates the decay of uranium.

However, measuring the relative abundance of isotopes of the elements calls for procedures quite different from those that distinguish one element from another. Since isotopes differ primarily in mass, they must be discriminated by the tools of physics rather than of chemistry. With the help of the mass spectrometer, an instrument that sorts out atoms according to their masses [*see illustration on this page*], investigators soon established that helium 3 accounted for the paradoxical "age" of the meteorites. This work also had the larger consequence of stimulating studies of the other noble gases that occur in meteorites.

The radioactive isotopes that are produced by cosmic ray bombardment—for example, the carbon 14 in the earth's atmosphere—are easily detected. They proclaim their presence to sensitive radiation counters of various kinds. But when such isotopes are stable, it is normally all but impossible to detect a change in their relative abundance. The change is so small that even over geologic time it lies within the range of error of the best mass spectrometers. Happily the stable isotopes of helium and the other noble gases in meteorites represent an exception. They are so scarce to begin with that any change in their abundance ratios looms quite large. What is more, the chemical inertness that gives them their patent of nobility makes it possible to isolate the tiny quantities that occur in meteorites, without significant contamination by noble gases of terrestrial origin.

The chemical segregation of chemically active elements by conventional procedures necessarily involves great contamination. Suppose that an element of atomic weight 40 is to be isolated from a sample weighing one gram. The first step is to dissolve the sample in some way, for example by using hydrofluoric acid. The next step will involve distillation, precipitation or passing the sample through an ion-exchange column. In any case the sample will be mixed with as much as 100 grams of liquid, including a number of extraneous atoms of atomic weight 40. Assuming that a purity (with respect to that atomic weight) of a few parts in a billion can be achieved, the procedure will still introduce about two billionths of 100 grams, or .0000002 gram, of contaminating material. This corresponds to about three million billion (3×10^{15}) atoms of an element of atomic weight 40.

In noble gas "chemistry" the procedure is quite different. To start with,



MASS SPECTROMETER analyzes small samples of noble gases by distinguishing among gas isotopes according to their weight, or mass. After a virtually permanent vacuum is achieved by pumping and baking, vacuum valve is closed and sample is admitted from gas-handling system. The gas atoms are ionized by a stream of electrons at ion source and accelerated by a series of electrodes, emerging in a diverging stream (*ion beam*). Ions of a particular isotopic weight are deflected by magnetic field to the collector slit. Focusing action is result of wedge shape of field. Lighter and heavier isotopes are deflected to a greater and lesser degree. Slow variation in the strength of the field causes other isotopes to reach the collector slit in succession, and a mass spectrum is recorded. The ion currents are recorded either at the first electrode or, after intensification by an electron multiplier, at the second electrode.

the sample of meteorite is melted in a vacuum. Exposure of the released gas to hot copper oxide, to a trap cooled with liquid air and to a few milligrams of hot calcium or titanium accomplishes the required purification. All but the noble-gas elements either freeze out in the liquid-air trap or combine with the calcium or titanium, leaving a phase of almost pure noble gas ready for study in the mass spectrometer. Under typical conditions the background pressure in the purification system is about one billionth of an atmosphere. The volume of the system is typically one liter; at this pressure there is about one millionth of a cubic centimeter of extraneous gas. Assuming that the gas has the composition of air, 1 per cent of it will be argon, mostly argon 40. The contamination level at atomic weight 40 is then one hundred-millionth of a standard cubic centimeter, or 300 billion (3×10^{11}) atoms; that is, one ten-thousandth of the contamination in conventional chemistry. For the less abundant noble gases the number of contaminating atoms is correspondingly less. For neon, krypton and xenon the approximate levels of contamination are respectively 500 million, 30 million and two million atoms. Helium is rather a special case because it diffuses so readily in hot solids; special precautions must be taken if helium contamination from the atmosphere is to be kept at a minimum. The last step, measuring the isotopic abundances in the tiny noble gas samples, is accomplished with mass spectrometers especially designed for this task.

Dramatic proof of cosmic-ray production of helium 3 in meteorites came in 1952, when K. I. Mayne of the University of Oxford and Paneth and P. Reasbeck at Durham announced that they had found a helium-3 to helium-4 ratio of about one to three in a number of meteorites. In the earth's atmosphere, by contrast, the ratio is one to a million. Two years later Mayne and Reasbeck found that the ratios among the neon isotopes in meteorites also differ markedly from those in the atmosphere. The neon isotopes of mass 20, 21 and 22 appear in the atmosphere in the ratios of 350 to 1 to 34. In meteorites these three isotopes occur in roughly equal abundance. At about the same time W. Gentner and Josef Zähringer in Germany discovered similar variations in meteoritic argon.

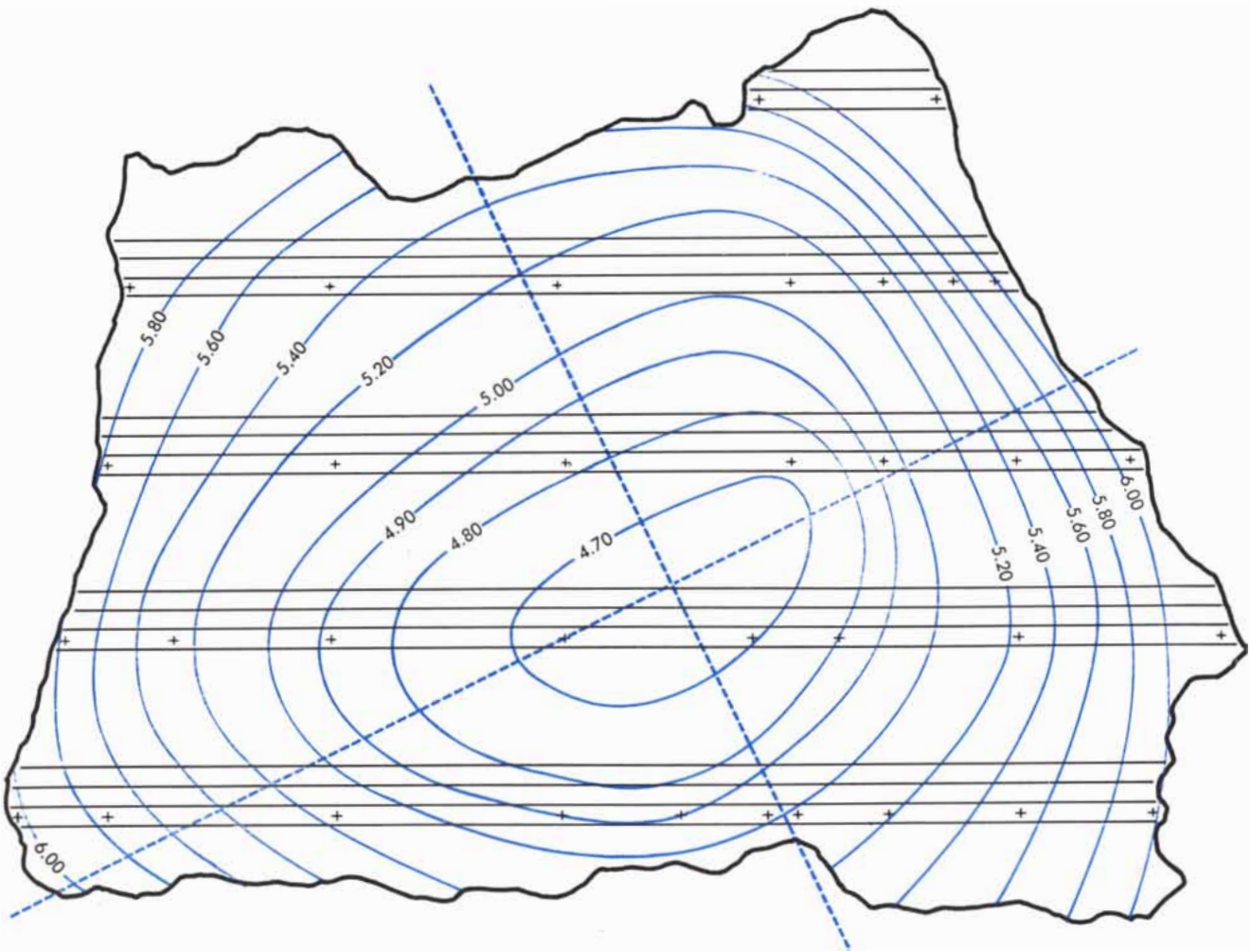
These findings not only brought the ages of meteorites into line with the age of the earth's crust as measured by the uranium clock; they also opened up

the history of the meteorites to study. It became possible to determine with considerable accuracy how long a meteorite had been exposed to cosmic radiation before it reached the earth. This involves measuring the amount of helium 3 in a meteoritic sample and dividing this figure by a calculated cosmic-ray production rate. The exposure ages of meteorites vary considerably. In most common stone meteorites it is a few tens of millions of years, with individual ages ranging all the way from four million to 90 million years. The average exposure age of iron meteorites is considerably longer—about 600 million years, with individual ages ranging up to 1.7 billion years.

Though these extreme variations present some difficulties, it is generally agreed that the exposure ages represent breakup ages, that is, the time since a given fragment was last detached from a larger parent body. In a planet or planetoid, the main mass of the material is shielded from cosmic radiation. When such a body breaks up in collisions with other sizable objects, its various fragments are exposed to cosmic rays and, with each successive breakup, still smaller fragments become exposed to bombardment. The systematic difference in the breakup ages of stone and iron meteorites is explained by the deduction that the latter do not break up as easily.

These studies have also told something about the individual life histories of meteorites. By analyzing the distribution of helium 3 in thin cross-sectional slabs of metal cut from two iron meteorites—the Grant meteorite and the Carbo meteorite—investigators were able to determine the distribution of helium 3 in the body of a meteorite. "Contour maps" prepared by J. H. Hoffman and Alfred O. C. Nier at the University of Minnesota show that the helium-3 content falls off toward the center of the bodies, as would be expected. The contours also show that the Grant meteorite reached the earth in something like its original shape, though it lost about half of its original mass to erosion by friction in the earth's atmosphere. In the case of Carbo the helium-3 contours indicate that most of one half was eroded away. Edward L. Fireman of Harvard University has measured the helium-3 content in Carbo with essentially the same results.

Helium 3 thus yields clues to the age and biography of the meteorite as a fragment of some larger parent body. But it does not reflect the age of the stone or iron that constitutes the meteorite. This is a more general and significant question because it bears upon the age of the solar system as a whole. If all the cold bodies in the solar system cooled down and crystallized at about



CONTOURS OF HELIUM-3 CONTENT (*solid colored lines*) **in a slab cut from center of Grant iron meteorite show that present shape is not greatly different from original one. Contours, roughly lines of constant depth in original body, are based on mass-spectroscopic measurements of helium-3 content at points** (*crosses*) **in bars cut from slab. J. H. Hoffman and Alfred O. C. Nier of the University of Minnesota made measurements. Figures give content in millionths of a cubic centimeter per gram. Reduction of content with increased depth is result of increased shielding from cosmic rays that originally produced helium 3 in meteorite.**

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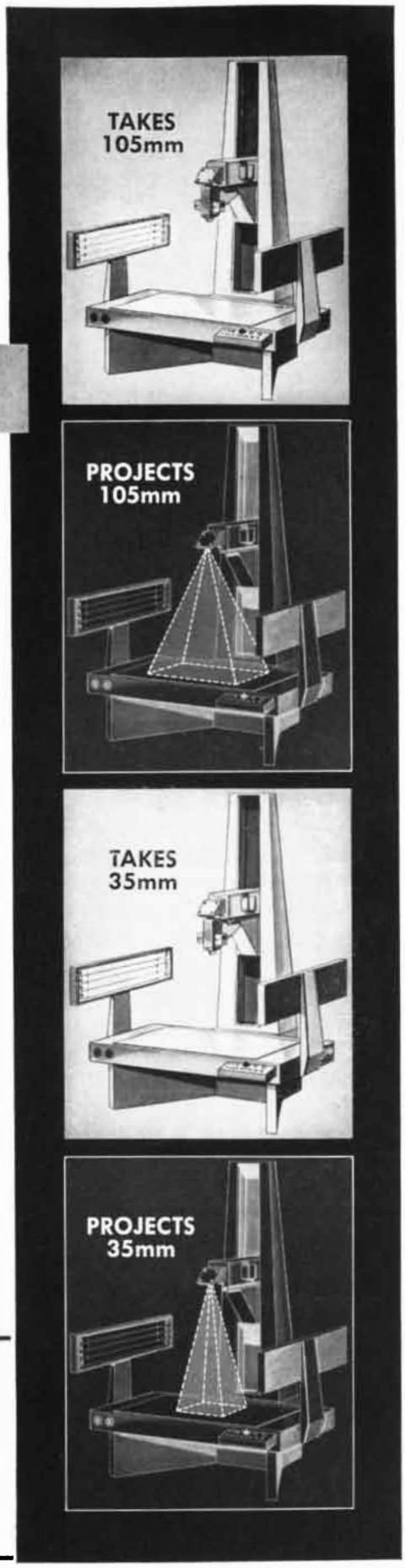

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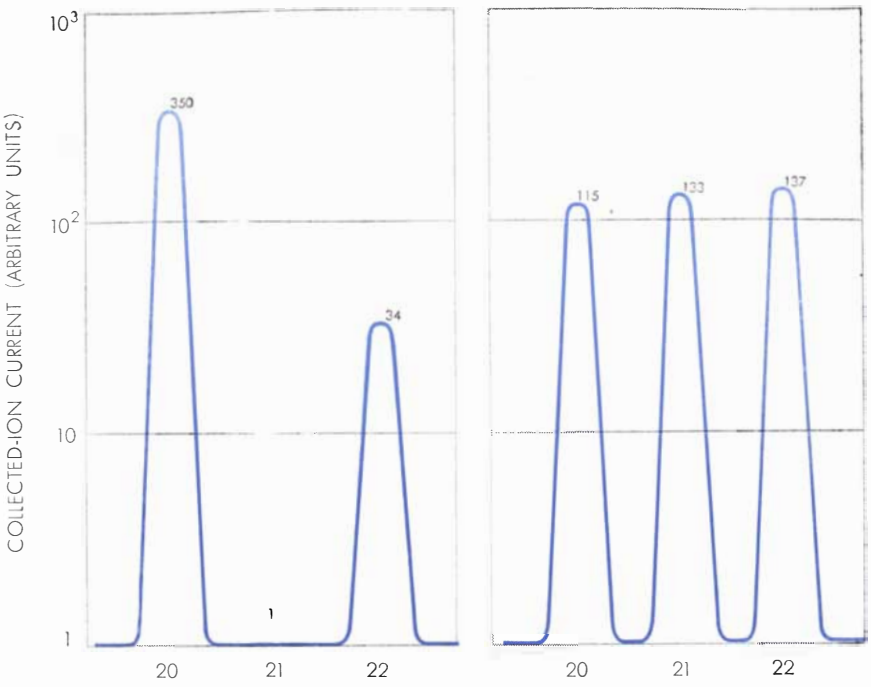
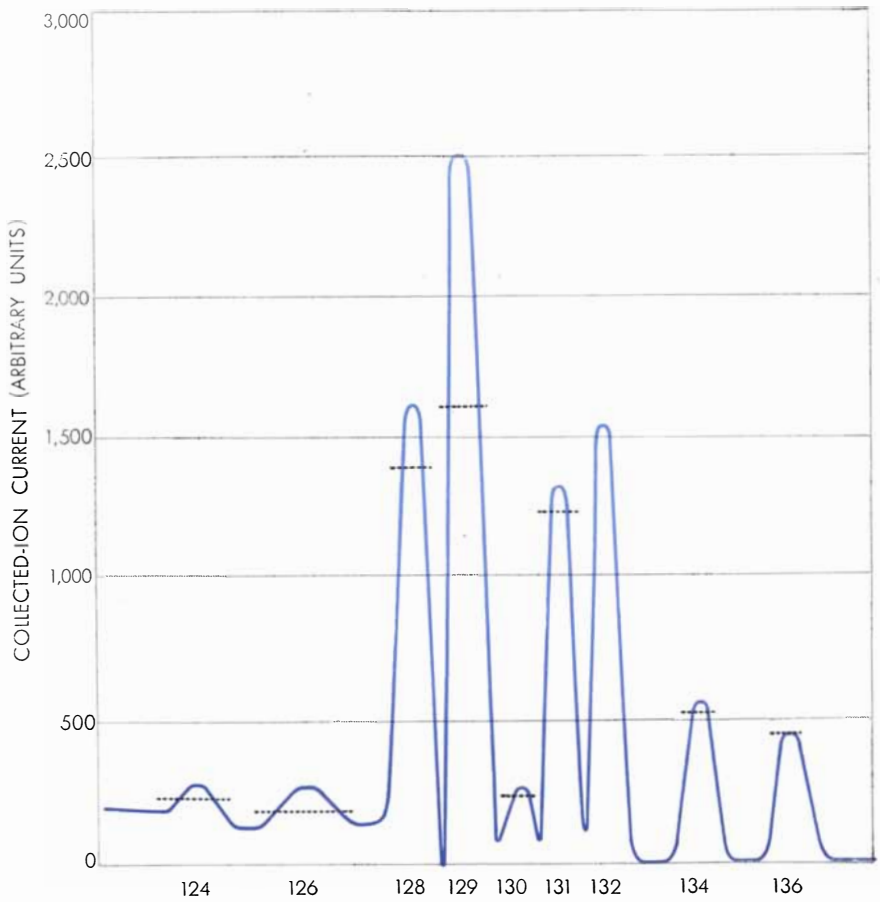


MASS SPECTRUM OF NEON in stone meteorite (*right*) reveals cosmic-ray production of neon isotopes (*numbers at bottom*) in nearly equal abundance. On logarithmic scale used here, neon 21 does not appear in spectrum of equivalent neon sample from earth's atmosphere (*left*).



EXCESS XENON 129 was first found in Richardton meteorite. Here scale of mass spectrum is linear. Xenon 124, 126 and 128 (*numbers at bottom*) are recorded at sensitivity 10 times that for others. Standard was xenon 132. In normal sample peaks would be at dotted lines.

the same time, as other considerations suggest, then a meteorite is as good a sample for this determination as a terrestrial rock which dates its crystallization from the most primitive era of our planet. Many meteorites have accordingly been subjected to the standard uranium-clock measurements. But stone meteorites also contain argon, which provides an independent check on the uranium clock.

Argon is the daughter of potassium 40, the relatively rare radioactive isotope of this common mineral element. The half-life of potassium 40 is 1.3 billion years, that is, half of the atoms of the isotope present in the rock disintegrate spontaneously in that period. The reaction yields two daughter elements: 89 per cent of the potassium 40 turns into calcium 40; the other 11 per cent turns into argon 40. As a consequence any mineral containing potassium gradually accumulates argon 40 in its lattice. So long as the system is undisturbed, the rate of argon accumulation is definite and immutable, governed only by the potassium content and by the rate of decay. By measuring both the potassium-40 and the argon-40 content in such an undisturbed sample it is possible to compute how long the system has been accumulating argon or, in other words, to calculate the date at which the sample crystallized.

This method was first applied to meteorites in 1951 by E. K. Gerling and his coworkers in the U.S.S.R. Since then investigators at various laboratories have dated many stone meteorites. A consistent pattern has emerged from the results: the potassium-argon ages of the most common stone meteorites tend to clump in the range of 4 to 4.5 billion years. Some of the ages fall below this clump, but none are higher. These findings are consistent with the age of 4.6 billion years indicated by the lead-to-uranium ratios and the parallel decay of rubidium to strontium. That the potassium-argon age is somewhat "younger" is taken to reflect the fact that the parent body of the meteorites was hot early in its history; some of the argon would thus have been lost before the body cooled to a temperature at which it began to retain argon. The still younger ages found for some meteorites indicate either that the potassium occurred in minerals unfavorable for argon retention or that some argon may have boiled out of the meteorite on an unusually close passage around the sun.

An age of 4.6 billion years is now generally accepted for both meteorites and the crust of the earth. All evidence

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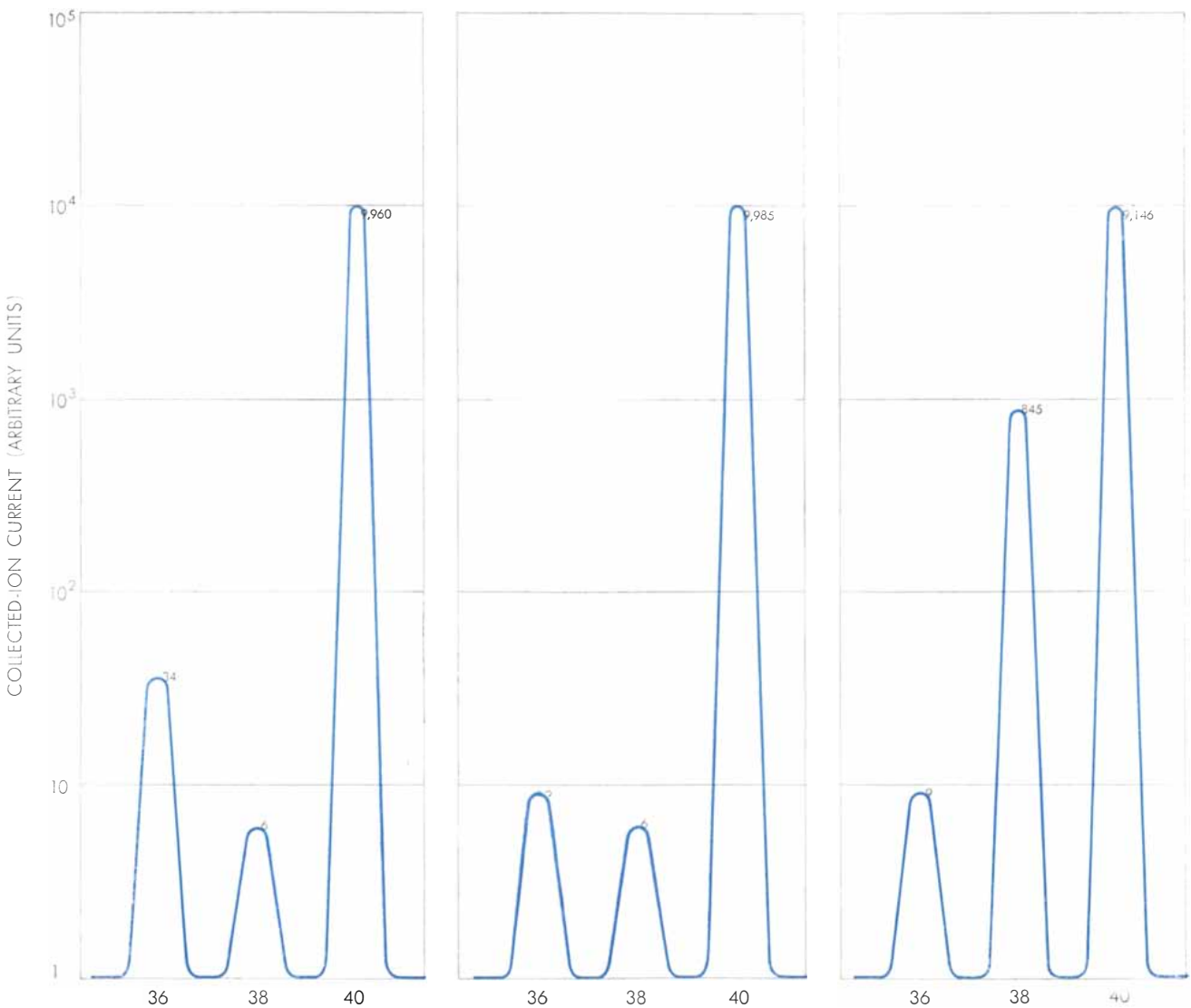
indicates that the stable, cold objects in the solar system took their present form at about that time.

Before the advent of the noble-gas technique for measuring time, it was quite difficult to go back further into the past with anything like certainty. The success of the technique in recent years encouraged investigators to apply it to the task of dating the origin of the elements themselves. With that ultimate starting point established, it might be possible to learn more about events in the period during which the solar system took shape from primordial matter. Inquiry into the age of the elements, however, takes one almost immediately into the thick of the controversy that divides cosmologists into two camps: the proponents of the "evolutionary" cosmology, who hold that the heavier elements were formed (along with hydrogen) all at once; and the "steady state" theorists, who contend that the formation of elements (including hydrogen) has been going on all along.

The simpler choice is to assume that the heavier elements were all created at once, or in a very brief period. One can then ask: When were they formed? Or, speaking of meteorites specifically, what was the time interval between the formation of the elements they contain and the time at which they crystallized?

One of the most important keys to the answer is the abundance ratio of the two long-lived radioactive isotopes of uranium—uranium 235 and uranium 238. Of the two, uranium 235 is much shorter lived, having a half-life of 700 million years, compared to 4.5 billion years for uranium 238. The relative abundance of these two isotopes is about 1 to 137. Going back in time, it is apparent that the ratio has doubled about every 850 million years. If the original ratio was unity, as seems reasonable to assume, then these isotopes were formed no more than approximately 6.6 billion years ago. The very existence now of uranium 235, with its shorter half-life, places an upper limit on the age of the elements in the solar system.

The difficulty is that the original abundance ratio is not known. For each



DETERMINING AGE OF METEORITE by one method involves measuring the amount of argon 40 it contains. Argon isotopes in three mass spectra depicted here are identified by mass number at bottom. Two lighter isotopes in spectrum of argon from atmosphere (*left*) are primordial (formed along with other elements). Most of the argon 40, however, has accumulated from radioactive decay of potassium 40. In spectrum of equivalent amount of argon from a stone meteorite (*middle*) the two lighter isotopes are partially produced by cosmic-ray bombardment of calcium, accounting for the difference in their ratio from that in the first spectrum. In the spectrum at right a known quantity of argon 38 has been added to provide a yardstick for measuring the argon-40 content. The age of the meteorite is calculated from the ratio of this isotope to the potassium-40 content of the meteorite.

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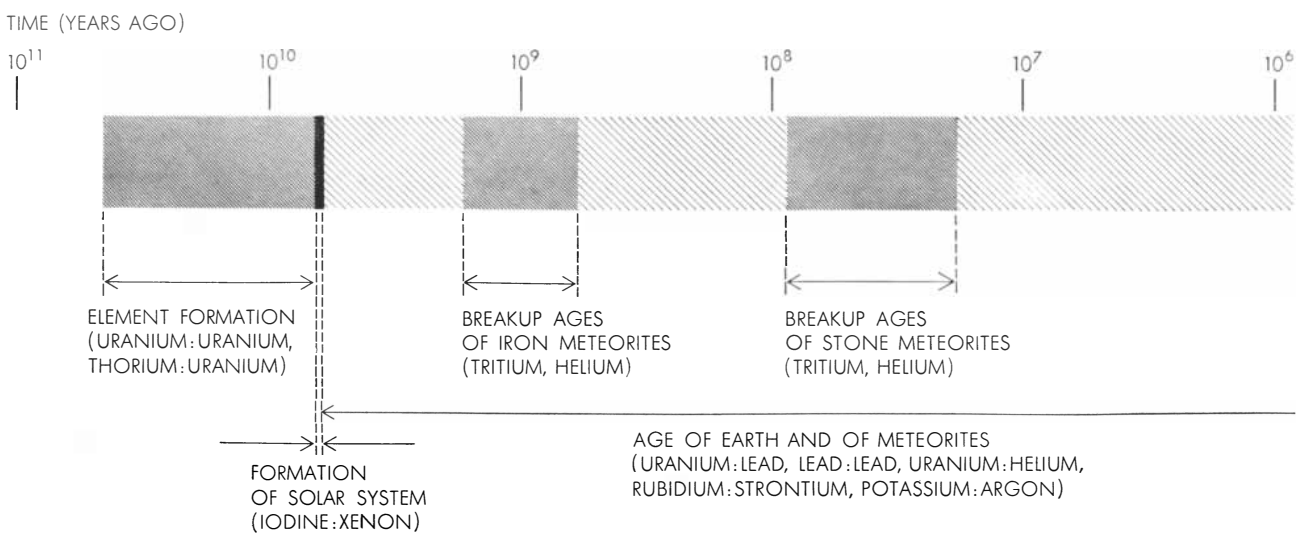
uncertainty of two, that is, with each doubling of the ratio, there is a corresponding uncertainty of about 850 million years in the time interval between element formation and the crystallization of the planetary bodies. The problem may be illustrated by a simple analogy. Suppose a clock is provided with a counter to indicate the number of times it has struck 12. The reading on the counter then tells how long the clock has run. But the reading has an inherent 12-hour error, because one does not know the hour at which the clock was set when it was wound. Under such circumstances another clock, wound at the same time but running, say, 40 times faster, would be highly useful. If the counter of the first clock were to read 1, the counter of the second would show something like 40. The original setting of the first clock could then be calculated with an error of only 18 minutes (one 40th of 12 hours).

Harrison Brown, now at the California Institute of Technology, suggested in 1947 that one of the shorter-lived radioactive elements might be used in just this way—as a faster-running clock to calibrate the original setting of the uranium clock. The original element would now be extinct, having disappeared from the solar system long ago by virtue of its relatively rapid decay; the clock would have by now completely run down. But it might still have been running at the time the meteorites were formed. In this case some atoms of the element would have been incorporated in the meteorites, and, under favorable conditions, they would have left a detectable "fossil" there. This fossil would be the daughter isotope to which all the radioactive material would have eventually decayed.

Following Brown's suggestion, the table of elements was searched for possible parent-daughter pairs. Since the parent isotope was necessarily extinct, it had to be found among the "artificially" radioactive products of the nuclear reactor or the high-energy accelerator. The most likely pair proved to be iodine 129 and its daughter xenon 129. A fairly common fission-product, iodine 129 was almost certainly formed in nature along with ordinary stable iodine 127, and in approximately equal abundance. Because it has a half-life of only 17 million years, it has completely disappeared. This half-life seemed to be in just the right range—long enough so that some of the isotope might have been incorporated in meteorites, but short enough to provide a clock that runs down about 40 times faster than the uranium clock. The daughter, xenon 129, also seemed ideal for the purpose. It is a noble gas, and that portion of it which arose from the decay of iodine 129 would show up in meteorites as an excess over the average ratio of xenon 129 to xenon 132. But when the first attempts in 1955 and 1956 failed to reveal such excess xenon 129, the prospects for finding extinct radioactivity seemed poor indeed.

Then in November of last year a small piece of very crumbly stone that fell in Richardton, N.D., in 1918 yielded the looked-for excess in our laboratory at the University of California. The mass spectrometer showed clearly that several of the isotopes, when compared to the reference isotope xenon 132, were in anomalous abundance in the Richardton meteorite, but the most striking excess was that of xenon 129 [*see bottom illustration on page 176*]. This effect has since been confirmed in samples of Richardton studied at the University of Minnesota and at Heidelberg University, and in other meteorites studied at the University of California. In the black stone Indarch, which fell in 1891 in Transcaucasia, the xenon-129 peak is 3.4 times higher than the xenon-132 peak, a reading that is five times as striking as that in Richardton.

Quantitative studies of Richardton samples have already yielded preliminary figures. The amount of excess xenon 129 and the amount of stable iodine 127—which serves as an indication of the amount of iodine 129 originally formed—have been measured. The ratio of these two quantities is .000010. Calculating from the 17-million-year



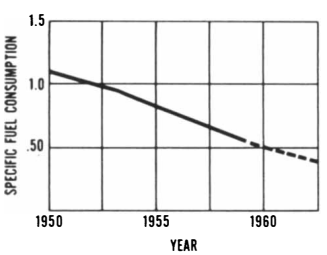
HISTORY OF THE SOLAR SYSTEM as calculated from element ratios shown in parentheses is plotted logarithmically. On theory that formation of heavier elements took 10 billion years, interval (*formation of solar system*) from end of element formation to crystallization of earth's crust is 120 million years. On theory that the elements were created at about the same time some five billion years ago, the interval is 290 million years. Age of earth and of meteorites is 4.6 billion years. Breakup ages of meteorites represent time since parent bodies of which they are fragments last broke up. Lowest value shown for iron meteorites (600 million years) is average breakup age; highest age is 1.7 billion years. Corresponding values for stone meteorites are 20 million and 90 million years. Ages are computed from the content of helium 3 in a meteorite and its rate of production (calculated from tritium decay-rate).

Small gas turbines soon to surpass piston engines for competitive applications

by Herbert Kunzel, President
Solar Aircraft Company
A Subsidiary of International Harvester Company

The gas turbine engine has made news this year as it has expanded into new and broader applications in the prime mover field. Behind this advance is continuing improvement in design and production. Even more advanced gas turbines will be developed in the next few years. In the small engine class (under 1000 hp) gas turbines will soon surpass overall piston engine performance and cost for competitive applications. They will also retain the inherent advantages of the gas turbine over the reciprocating engine.

One of the major reasons for this prediction is an impressive improvement in gas turbine economy. Previously, fuel consumption and high initial cost have kept the turbine out of all but selected power assignments. Industry and the military both thought the engines too expensive for most applications.



Through constant improvement, however, Solar has been steadily bringing simple cycle, small turbine specific fuel consumption down to an area competitive with piston engines. The fuel consumption of Solar's early 50 hp engines in 1948, for instance, was about 2.25 lb/hp-hr. The 1100 hp Saturn engine, which went into production this year, has the excellent simple-cycle fuel consumption of only .63 lb/hp-hr. Solar's experienced engineers improve life, "producibility," and performance characteristics with each new engine. At the same time, production costs are lowering rapidly.

Another significant advance in Solar turbine development has been the evolution of a unique design philosophy. Most gas turbines fall into one of two extreme categories: 1) Lightweight, high horsepower aircraft turbines, built to be as light as possible (about ¼ to ½ lb/hp), and 2) conventional industrial engines designed along the lines of steam turbines with a ratio of about 10 lb/hp. Both have inherent disadvantages. The aircraft turbines are relatively delicate with consequent problems of frequent overhaul and short life. Massive engine design, on the other hand, involves unnecessary bulk and difficulties with thermal lag and distortion. In either case, inherent advantages of the gas turbine engine are diminished and initial cost is adversely affected.

Solar's approach has been to develop a family of gas turbines that have both long life and light weight. The Saturn engine, with a weight-to-power ratio of 1.1 lb/hp, is heavier and more rugged than aircraft engines but much lighter than the usual industrial gas turbine. Although it is designed for long life, it has no more materials than are necessary to satisfy structural and thermal requirements.

Promising even further improvements in the turbine engine is the combination of Solar with International Harvester Company this year. IH saw the advantage of more power per pound several years ago. Their research and development has stressed performance and much work has been done by them on regenerative cycle turbines to reduce fuel consumption.

To basic research, they have added their many years of experience and leadership in high performance and low cost through efficient production of many thousands of IH engines for trucks, construction equipment and farm machinery.

Solar's successful Saturn engine development team and the combined research and resources of the two firms are now focused on further engine development in the area below 1100 hp. Preliminary design for a turbine in this range indicates that the following standards are feasible:

1. A life cycle equal to or better than conventional diesel engines—with considerably less maintenance.
2. Fuel consumption in the .4 to .5 lb/hr range.
3. Cost competitive to conventional reciprocating engines.
4. Inherent ease of starting and operation in a wide variety of climatic conditions.
5. Small size and light weight.

Developments like these are certain to continue the increase in turbine applications and use.

For additional information write to Dept. H-300, Solar Aircraft Company, San Diego 12, California.

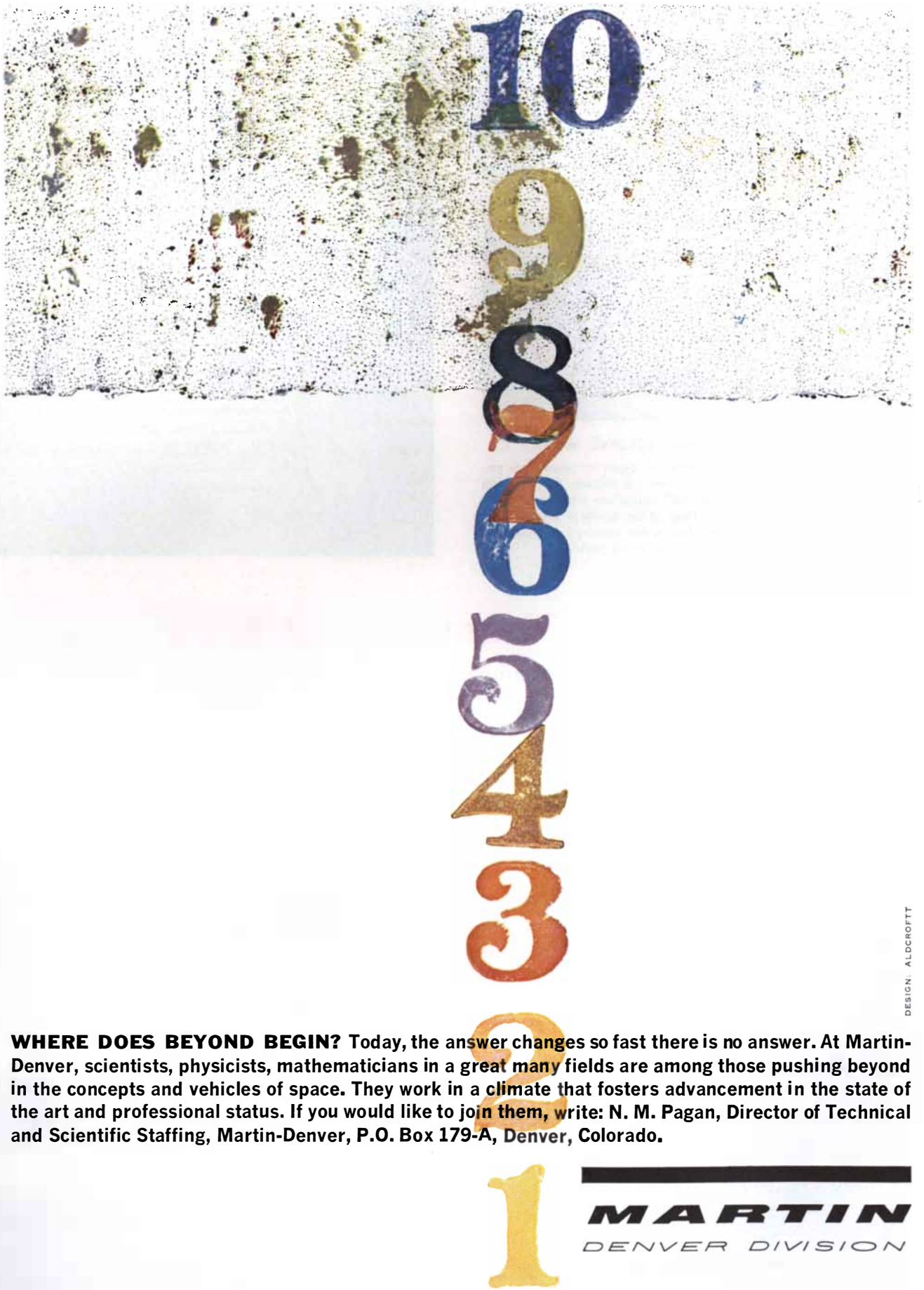
Saturn engine powering oil well fracturing unit

half-life, the time required for the iodine-129 to iodine-127 ratio to fall from 1, or thereabouts, to .000010 proves to be 290 million years.

This interval is not greatly affected when it is recalculated on the assumption (which accords with steady-state cosmology) that the heavier elements were built up over billions of years. William A. Fowler and Fred Hoyle at the California Institute of Technology and A. G. W. Cameron of the Chalk River Laboratory in Canada think it likely that a long succession of exploding stars have gradually built up the present inventory of these elements. Their estimates of this buildup period, based on theoretical production rates of the two uranium isotopes and of thorium, run close to 10 billion years. In this case the ratio of iodine 129 to iodine 127 at the conclusion of element formation in the vicinity of the solar system would not be 1 but .0025. Steady decay of iodine 129 over the long buildup period accounts for the large decline in the ratio. The time required thereafter to bring the ratio down from .0025 to .000010—that is, the time from the formation of the elements to the incorporation of the elements in the solid bodies of the solar system—would be 137 million years. If iodine production was not uniform over the 10 billion years of element formation, but declined throughout this interval as some astrophysicists believe, another small correction must be applied—giving 120 million years instead of 137.

In terms of cosmological time the difference between 120 million years and 290 million years is not great. In either case it can be stated that there has been element-building which contributed to the solar system within the last 4.9 billion years.

The iodine-xenon clock is not yet fully calibrated. Past experience with other important radioactive clocks has shown that the clock becomes more reliable as experimental techniques improve. The iodine-xenon clock should ultimately provide a reliable time-scale for events which took place at about the time the solar system was formed. It is clear, however, that the time interval between element formation and the formation of the minerals in the meteorites is relatively short. Otherwise the iodine clock would have completely run down before the minerals were formed. The possibility that billions of years intervened between the formation of the elements of the solar system and the time its planetary bodies were formed is now conclusively ruled out.



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WHERE DOES BEYOND BEGIN? Today, the answer changes so fast there is no answer. At Martin-Denver, scientists, physicists, mathematicians in a great many fields are among those pushing beyond in the concepts and vehicles of space. They work in a climate that fosters advancement in the state of the art and professional status. If you would like to join them, write: N. M. Pagan, Director of Technical and Scientific Staffing, Martin-Denver, P.O. Box 179-A, Denver, Colorado.

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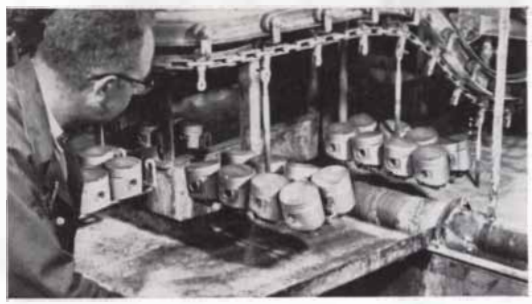
Steel bracing, angles, solid rods 7½ inches thick—all welded—rise 1676 feet at Cape Girardeau, Mo., to become the world's tallest structure. Designed and fabricated by Dresser-Ideco, this TV tower is a tribute to modern welding, which leans on science as well as the weldor's skill. The chemical composition of the electrode must be compatible with the structural metal. Electrodes are coated with metals and chemicals to promote weld integrity. M&T not only satisfies engineering requirements with "Murex" electrodes —but also mines titanium mineral used in many electrodes.



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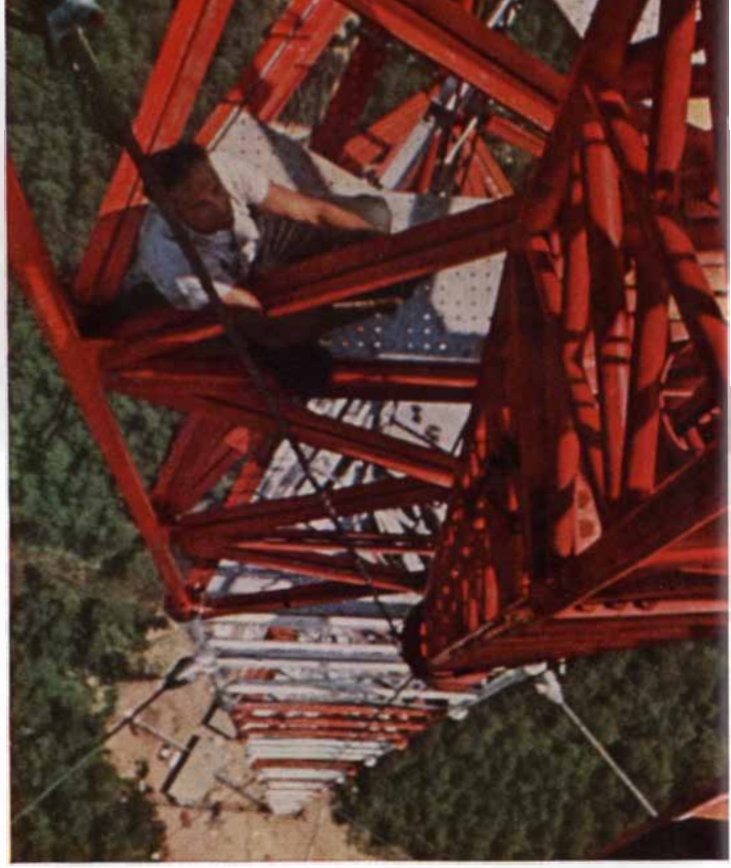

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M&T has formulated a vinyl plastisol so tough it's used as a lining in dishwashers. Tested unmercifully, the coating was steamed, stretched, gouged, scratched, "guillotined," abraded . . . subjected to chemicals, heat, stains, detergents. It proved it could last the life of the machine. Developing chemical-resisting organic coatings for metals has been an M&T specialty for over 20 years.

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Just a few millionths of an inch of chromium—and automotive brightwork stays beautiful. Plating it a little thicker (over a nickel base) greatly increases corrosion resistance. In developing SRHS® Chromium, a self-regulating high speed process, M&T simplified plating this thicker chromium. M&T's Crack-Free Chromium Process increased corrosion resistance still more. Today, combining both (M&T "Duplex Chromium Process"), dramatically increases durability.

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MATHEMATICAL GAMES

More about the shapes that can be made with complex dominoes

by Martin Gardner

Polyominoes—the intriguing shapes that cover connected squares on a checkerboard—were introduced to the mathematical world in 1954 by Solomon W. Golomb, now a research supervisor at the California Institute of Technology's Jet Propulsion Laboratory. They were first discussed in this department in 1957. Since then they have become an enormously popular mathematical recreation, and hundreds of new polyomino puzzles and unusual configurations have come to light. The following communication from Golomb discusses some of these recent discoveries.

"The shapes that cover five connected squares," Golomb writes, "are called pentominoes. There are 12 such shapes. If they are arranged as shown in Figure 1 they resemble letters of the alphabet, and these letters provide convenient names for the pieces. For mnemonic purposes, one has only to remember the end of the alphabet (TUVWXYZ) and the word FILiPiNo.

"In previous articles it was shown that the 12 pentominoes, which have a total of 60 squares, can form such patterns as a 3×20 rectangle, a 4×15 rectangle, a 5×12 rectangle and a 6×10 rectangle. They can all be fitted onto the 8×8 checkerboard, with the four excess squares of the board forming a 2×2 square at any specified location on the board. Given any pentomino, nine of the others can be used to triplicate it, that is, to form a scale model three times as long and three times as high as the selected pentomino. It is also possible to arrange the 12 pentominoes into *two* rectangles, each 5×6.

[This last configuration is known as

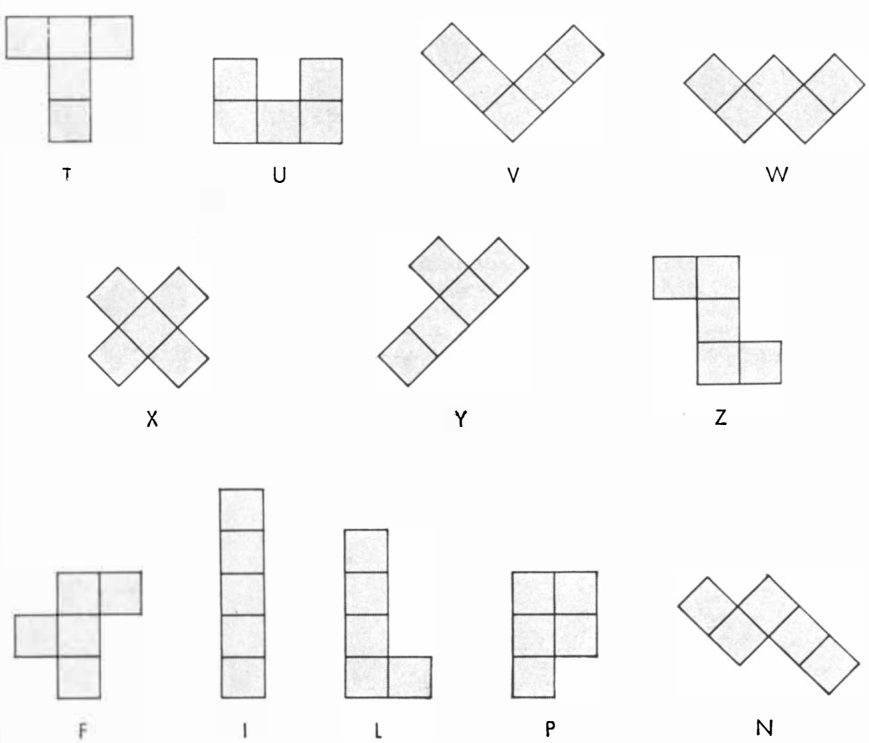
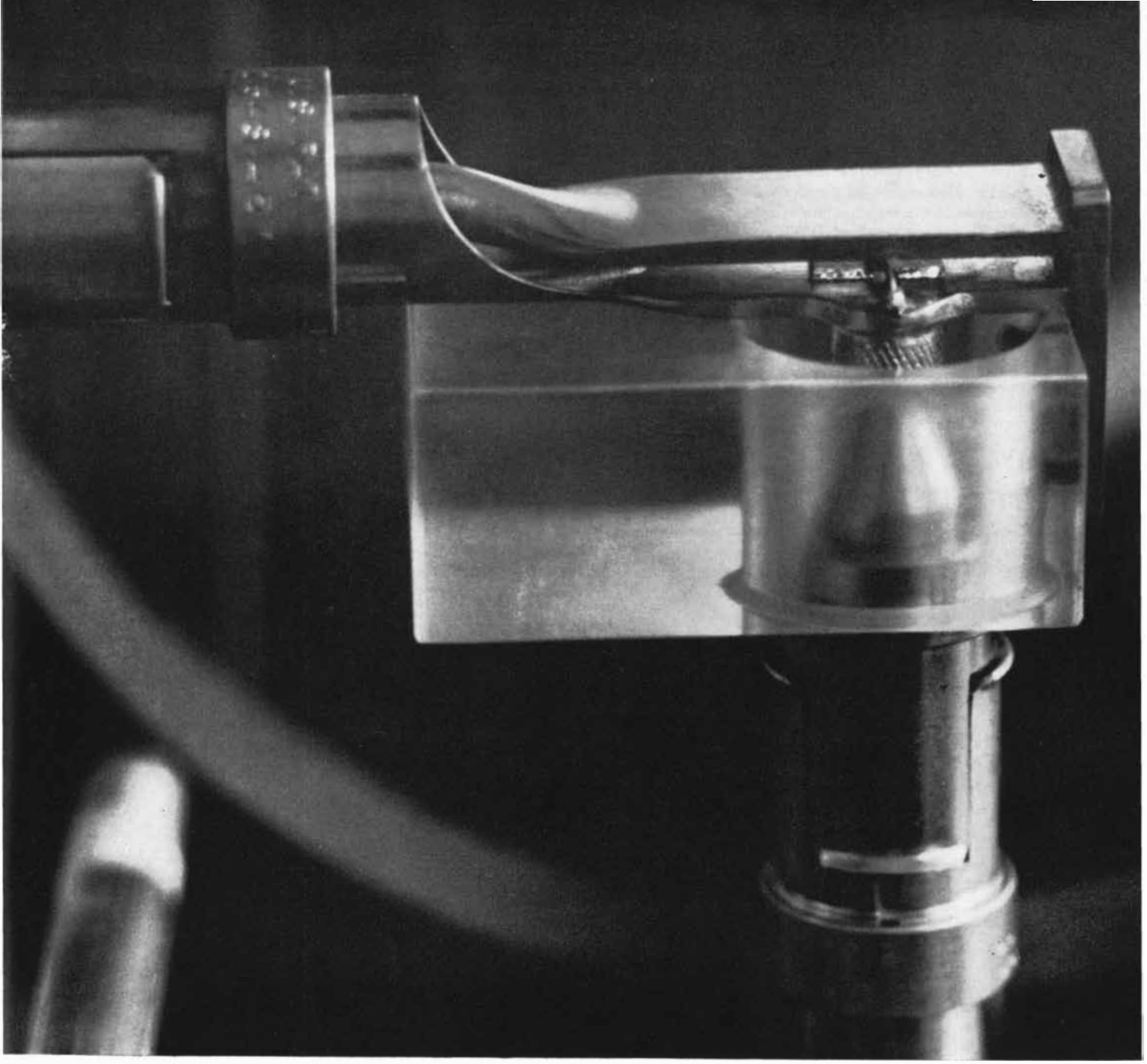


Figure 1



Special high-speed pulse equipment sets up a magnetic field in a fraction of one nanosecond to measure switching times in thin magnetic films.

Nanosecond switching in thin magnetic films

Switching in thin magnetic films takes place in the nanosecond range—10^{-9} seconds. Because of this, thin magnetic films —some just 100 atom-layers thick—promise many advantages over conventional magnetic elements in storage and switching applications.

The physical behavior of these thin films is now under investigation by a group of scientists at the IBM Research Laboratory in Zurich, Switzerland. A study is being conducted to determine how fast thin magnetic films can switch, and how this speed is related to fundamental magnetics.

To observe changes in magnetization, special high-speed pulse equipment had to be designed. The sample holder above is a part of the equipment which sets up a magnetic field in the film's plane in a fraction of a nanosecond. In addition, a pulse sampling oscilloscope, capable of a time resolution of 0.35 nanoseconds, was built to detect the switching.

Experiments using this equipment bring nanosecond switching one step closer to application in memory and logic units. This will help make possible greater speed and versatility in tomorrow's computers.

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a superposition problem, because it involves shapes that can be superposed. Golomb reports on five new superposition problems, here published for the first time. If the reader has not yet discovered the fascination of playing with pentominoes, he is urged to make a set of them from cardboard and try his skill on some of the puzzles that follow. In all such puzzles, pieces may be placed with either side up.]

"1. Divide the 12 pentominoes into three groups of four each. Find a 20-square shape that each of the three groups will cover. The solution is depicted in Figure 2. No other solutions have yet been discovered.

"2. Divide the 12 pentominoes into three groups of four each. Subdivide each group into two pairs of shapes. For each group find a 10-square region that each of the two pairs will cover. The solution is shown in Figure 3. It would be interesting to find other solutions, especially one that would eliminate all holes from the shapes.

"3. Divide the 12 pentominoes into three groups of four each. To each group add a monomino (a single square), and form a 3×7 rectangle. Figure 4 shows the solution. It is known to be unique except that in the first rectangle the monomino and Y pentomino can be rearranged and can still occupy the same region.

"The uniqueness proof follows a suggestion by C. S. Lorens. To begin with, in the pattern shown in Figure 5, the X pentomino can be used only in conjunction with the U pentomino. Next, neither the F nor the W pentomino can be used to complete this rectangle. Also, with the U pentomino needed to support the X, it is impossible to use F and W in the *same* 3×7 rectangle. Hence, of the three 3×7 rectangles, one will contain X and U, another will contain W (but not U) and the third will contain F (but not U). When all possible completions of these three rectangles are listed and compared (a very time-consuming enterprise), it is found that the solution shown is the only possible one.

"4. Divide the 12 pentominoes into four groups of three each. Find a 15-square region which each of the four groups will cover. No solution to this problem is known; on the other hand, the problem has not been proved impossible.

"5. Find the smallest region on the checkerboard onto which each of the 12 pentominoes, taken one at a time, will fit. The minimum area for such a region is nine squares. There are only two examples of such a region (Figure 6).

"The adequacy of each region is proved by observing that each pentomino in turn will fit on it. The impossibility of fewer than nine squares is proved as follows: If it were possible to use a region with fewer than nine squares, then in particular the I, X and V pentominoes would fit on a region of no more than eight squares. The I and X pentominoes will then have three squares in common. (Otherwise either nine squares are needed, or else the longest straight line has six squares, a needless extravagance.) This can happen in only two distinct ways (Figure 7). In either case, however, the fitting of the U pentomino would require a ninth square. Thus eight squares are not enough, whereas nine squares have been shown by example to be sufficient.

"Recently the resources of modern

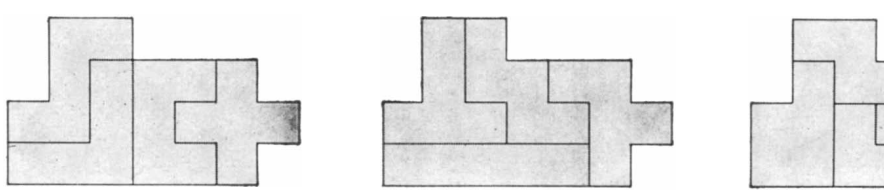

Figure 2

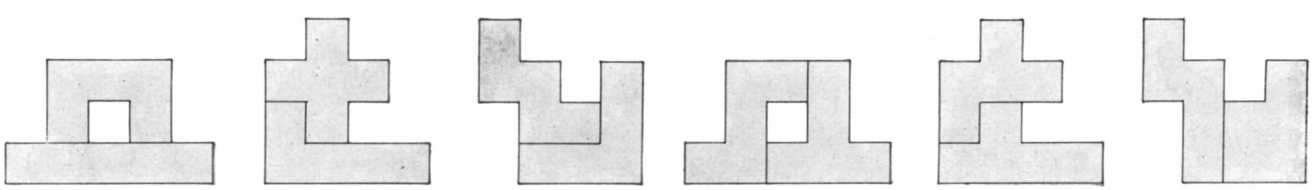

Figure 3

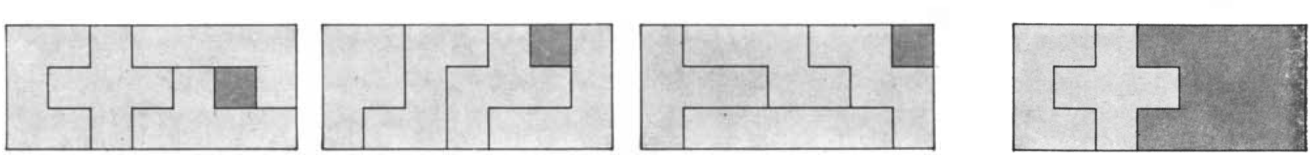

Figure 4

Figure 5

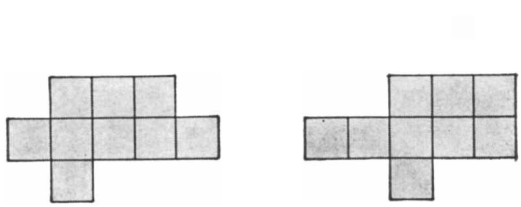

Figure 6

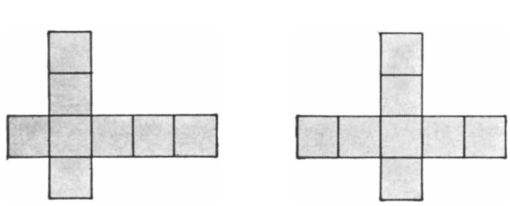

Figure 7

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PROBLEM: $$I = \frac{E}{\sqrt{R^2 + (6.2832\,FL - 1/6.2832\,FC)^2}}$$

(For values of R, F & L as specified. For values of E ranging from 100 to 300 in increments of 50. For values of C ranging from .00002 to .000021 in increments of .0000001)

COMPLETE ALGO PROGRAM:

```
BEGIN Ⓢ
R = 10 Ⓢ
F = 60 Ⓢ
L = ₀2 Ⓢ
FOR E = 100(50)300 BEGIN Ⓢ
FOR C = ₀00002(₀0000001)₀000021 BEGIN Ⓢ
I = E/SQRT(R ↑ 2 + (6₀2832 * F * L — (1/(6₀2832 * F * C))) ↑ 2) Ⓢ
PRINT (FL) = E Ⓢ
PRINT (FL) = C Ⓢ
PRINT (FL) = I Ⓢ
```

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electronic computing have been turned loose on various pentomino problems. The chapter on polyominoes in *The Scientific American Book of Mathematical Puzzles and Diversions* contains a brief account of how Dana S. Scott programmed the MANIAC computer at Princeton University for determining all the ways that 12 pentominoes can be fitted onto the 8 × 8 checkerboard, leaving a 2 × 2 hole in the center. It was discovered that there are 65 basically different solutions in the sense that two solutions differing only by rotation or reflection are not regarded as distinct.

More recently, C. B. Haselgrove, an astronomer at the University of Manchester, programmed a computer to find all possible ways to form a 6 × 10 rectangle with the 12 pentominoes. Excluding rotations and reflections, he found 2,339 basically different solutions! He also verified Scott's program for the 8 × 8 checkerboard problem.

"Several special pentomino configurations make excellent puzzles. Figure 8 shows a 64-square pyramid that can be formed with the 12 pentominoes and the 2 × 2 square tetromino. [A solution will be given in this space next month.] The cross in Figure 9 requires only the 12 pentominoes, and is unusually difficult. [This also will be answered next month.] Still unsolved (neither constructed nor proved impossible) is the pattern shown in Figure 10. Even if the monomino hole is moved to another location, no solution has been found. The closest approximation yet known is pictured in Figure 11. Also believed impossible is Scott Taylor's configuration, shown in Figure 12, though no one has yet found an impossibility proof.

"Fortunately not all such problems are undecided. The pattern shown in

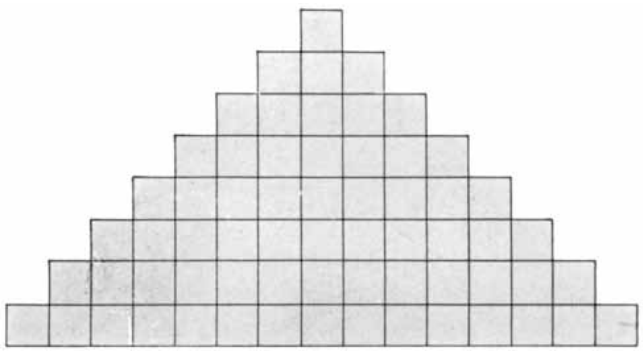

Figure 8

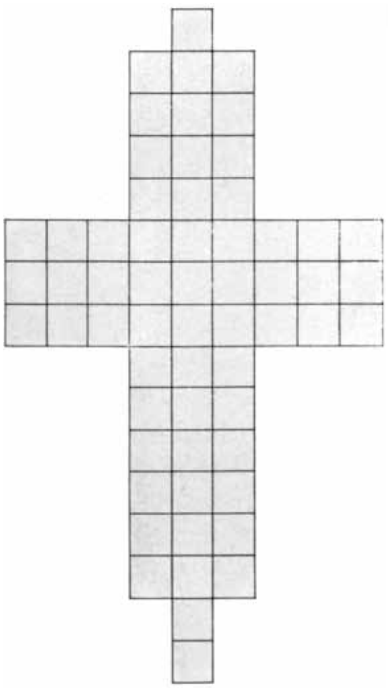

Figure 9

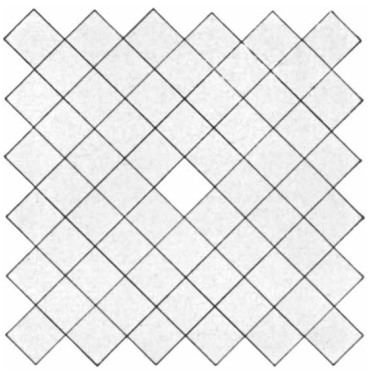

Figure 10

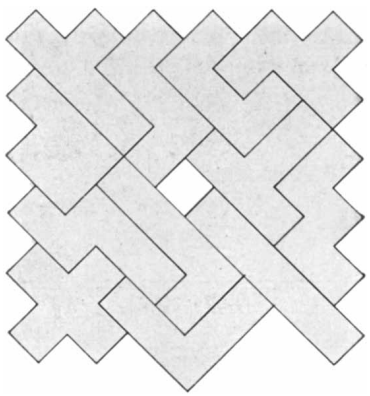

Figure 11

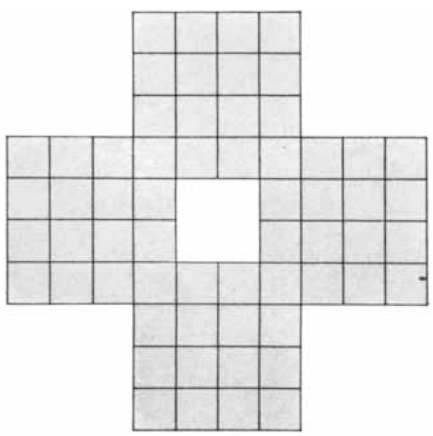

Figure 12

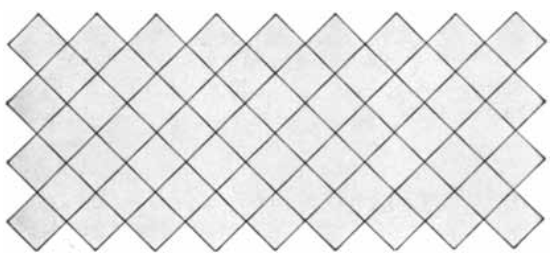

Figure 13

NO. 4 OF A SERIES . . . BOMAC LOOKS AT RADAR THROUGH THE AGES

Have Trunks, Will Travel

It was a cold day in the Alps. But Hannibal, the great general on his way to conquer Rome, was very, very hot under the collar of his Punic tunic.

"How did you camel herders ever get those elephants stuck up there?" he bellowed, hanging precariously onto a ledge he shared with a mountain goat.

"I guess you could blame it on faulty radar," one of the men said. "The elephants lost their way."

"Well, I'll just have to leave you there!" Hannibal roared. "I have a date in Rome. Serves you right for forgetting that radar just can't work in the Alps without Bomac tubes!" (The general must have been talking about Bomac's peak performance. But his watch was fast — by about 2165 years.)*

So Hannibal went down in history — but his radar stayed up in the Alps. As the History Book writes:

"In search of sundry Roman scalps,
Mighty Hannibal crossed the Alps.
But he lost his radar on the way —
The Alps crossed Hannibal, you might say."

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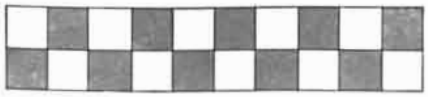

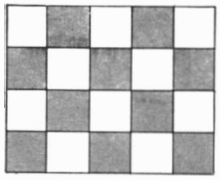

Figure 14

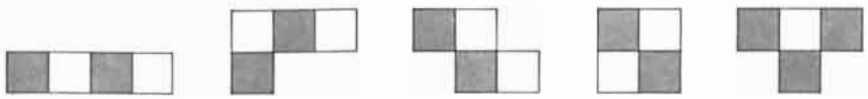

Figure 15

Figure 13, for example, was proved by R. M. Robinson, a mathematician at the University of California, to be incapable of formation by the 12 pentominoes. It has 22 edge squares that form its border. If the pentominoes are examined separately, and the maximum number of edge squares that each could contribute to the pattern are listed, the total proves to be 21, just one short of the required number. This type of reasoning is used in working jigsaw puzzles. It is common practice to separate the edge pieces from the interior pieces so that the picture's border can be made first.

"Polyominoes that cover four squares of the checkerboard are called tetrominoes. Unlike the pentominoes, the five distinct tetrominoes will not form a rectangle. To prove this, color the squares of a 4×5 rectangle and a 2×10 rectangle (the only two rectangles with a 20-square area) in checkerboard fashion (Figure 14). Four of the five tetrominoes (Figure 15) will always cover two dark and two light squares, but the T-shaped tetromino always covers three squares of one color and one square of the other color. Altogether, therefore, the five shapes will cover an odd number of dark squares and an odd number of light squares. However, the two rectangles in question have 10 squares of each color, and 10 is an even number.

"On the other hand, any of several different pentominoes can be combined with the five tetrominoes to form a 5×5 square. Two examples are shown in Figure 16. This raises an interesting question: How many different pentominoes can be used in this manner?

"Robert I. Jewett, a graduate student in mathematics at the University of Oregon, has proposed a problem involving dominoes (two-square polyominoes) that is quite different from any of the problems just discussed. Is it possible to form a rectangle with dominoes in such a way that there is no straight line, vertical or horizontal, that joins opposite sides of the rectangle? For example, in Figure 17 there is a vertical line in the center that extends all the way from top to bottom. If dominoes are thought of as bricks, such a line represents a structural weakness. Jewett's problem is thus one of finding rectangular masonry patterns without 'fault lines.' Many people who try this problem soon give up, convinced that there are no solutions. Actually, there are infinitely many."

The reader is invited to make or obtain a set of dominoes—the standard set of 28 dominoes is more than sufficient—and see if he can determine the

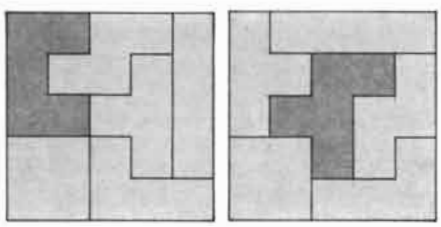

Figure 16

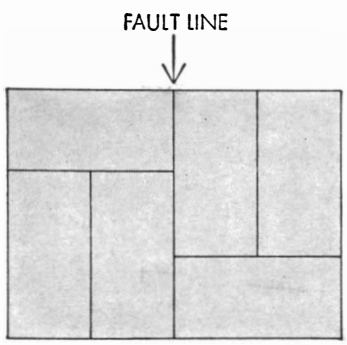

Figure 17

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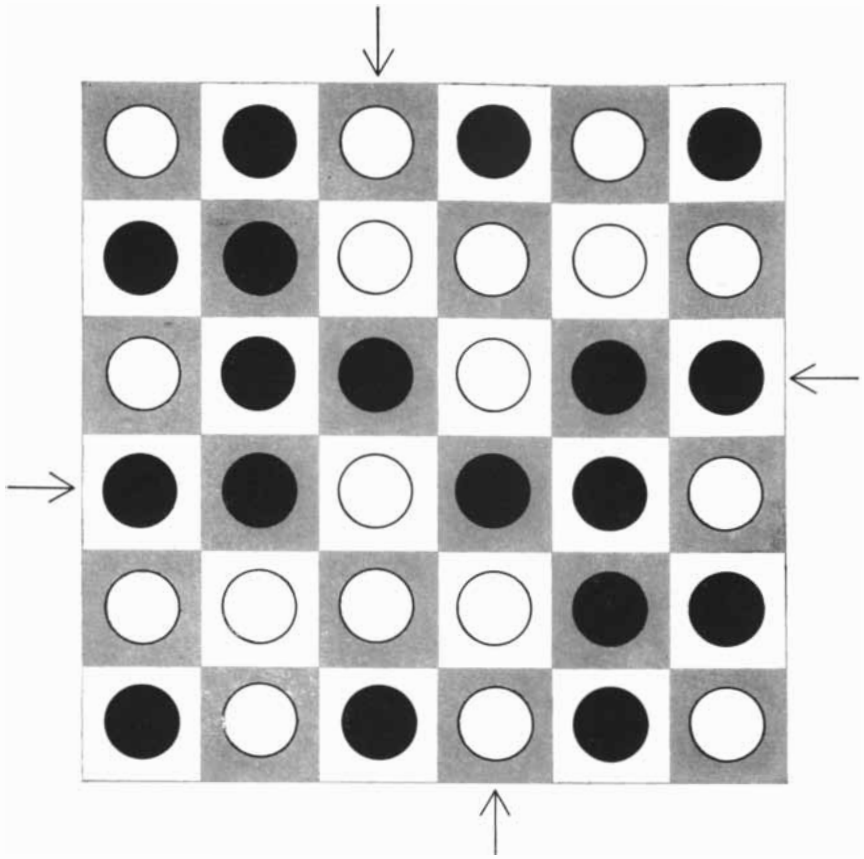


Answer to the problem of the drawn game of hip

smallest possible "fault free" rectangle that can be made with them. The solution to this beautiful problem will be published next month, together with a remarkable proof, devised by Golomb, that there are no fault-free 6×6 squares.

Here are the answers to last month's "brain-teasers":

1.

The top illustration on this page shows the finish of a drawn game of hip; a solution discovered by C. M. McLaury, a mathematics student at the University of Oklahoma. I cannot promise to answer all letters, but I would be pleased to hear from anyone who obtains a solution essentially different from this one. (Note that each of the four border cells marked with arrows can be of either color, provided all four are not the same color.)

2.

The locomotive can switch the positions of cars A and B, and return to its former spot, in 16 operations:

1. Locomotive moves right, hooks to car A.
2. Pulls A to bottom.
3. Pushes A to left, unhooks.
4. Moves right.
5. Makes a clockwise circle through tunnel.
6. Pushes B to left. All three are hooked.
7. Pulls A and B to right.
8. Pushes A and B to top. A is unhooked from B.
9. Pulls B to bottom.
10. Pushes B to left, unhooks.
11. Circles counterclockwise through tunnel.
12. Pushes A to bottom.
13. Moves left, hooks to B.
14. Pulls B to right.
15. Pushes B to top, unhooks.
16. Moves left to original position.

This procedure will do the job even when the locomotive is not permitted to pull with its front end, provided that at the start the locomotive is placed with its back toward the cars.

3.

The curious thing about the problem of the Flatz beer signs is that it is not necessary to know the car's speed to determine the spacing of the signs. Let x be the number of signs passed in one minute. In an hour the car will pass $60x$ signs. The speed of the car, we are told, is $10x$ miles per hour. In $10x$ miles it will pass $60x$ signs, so in one mile it will pass $60x/10x$, or 6, signs. The signs therefore are 1/6 mile, or 880 feet, apart.

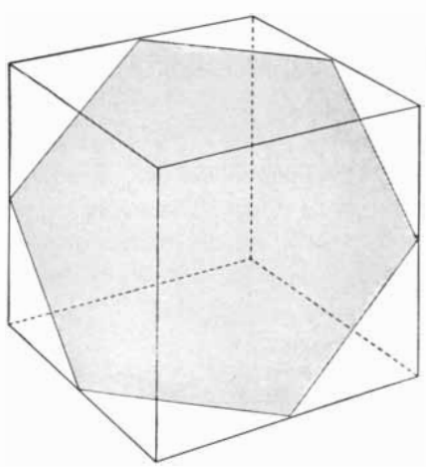
4.

A cube, cut in half by a plane that passes through the midpoints of six sides as shown in the bottom illustration on this page, produces a cross section that is a regular hexagon. If the cube is half an inch on the side, the side of the hexagon is $\sqrt{2}/4$ inch. (This hexagon, by the way, furnishes the solution to an interesting puzzle by Lewis Carroll, cited by Warren Weaver in his article "The Mathematical Manuscripts of Lewis Carroll," *Proceedings of the American Philosophical Society*, October 15, 1954. Can a billiard ball travel inside a cube in such a way that it touches all six sides and continues forever on the same path, all portions of the path being equal? The solution is a path joining the midpoints of the sides of the hexagon.)

To cut a torus so that the cross section consists of two intersecting circles, the plane must pass through the center and be tangent to the torus above and below, as shown in the illustration on page 196. If the torus and hole have diameters of three inches and one inch, each circle of the section will clearly have a diameter of two inches.

5.

The bottom illustration on page 198 shows how to construct a straight line that bisects both the Yin and the Yang, the dark and light regions of the monad. A simple proof is obtained by drawing



Answer to the cube-slicing problem

THIS IS GLASS

A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING

YES, WE HAVE NO GASKETS

Gaskets cause countless problems in sight glasses, people told us.

Get rid of the gaskets, we replied.

Show us how, they retorted.

So, we did.

Two ways.

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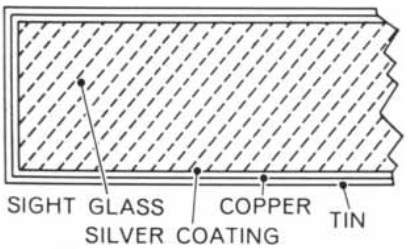

Two. When it makes sense, we can and do metallize a glass with a base coat of silver, electroplate it with copper, and face it with a coat of tin which accepts soldering to a bezel, which we also can and do do. The finished window is rated to take 15 psi inside or out.

Since we are as versatile as the material we work with, we can pull such tricks as pressing configurations into the windows. We've already done things like bull's-eyes and indentations.

We had another job where we pressed an optical lens into a glass. The focal length of the lens is such that you get a reflection of light back to your eye, except when the unit is full of liquid, in which case you focus on the liquid itself.

Look into our windows whenever you find a gasket a nuisance, whether from temperature or pressure or corrosive environment or any of the many other conditions which tend to make gaskets a nuisance.

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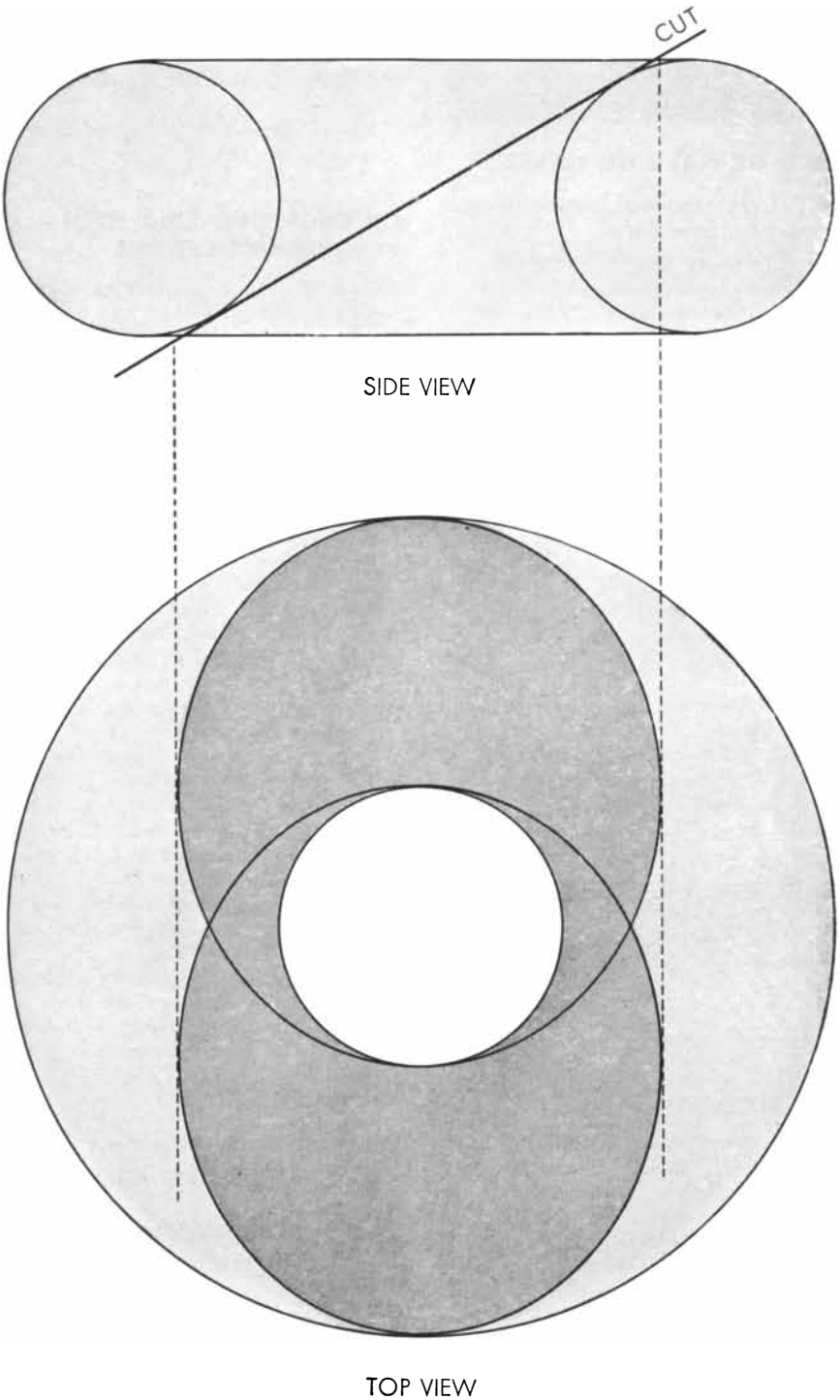
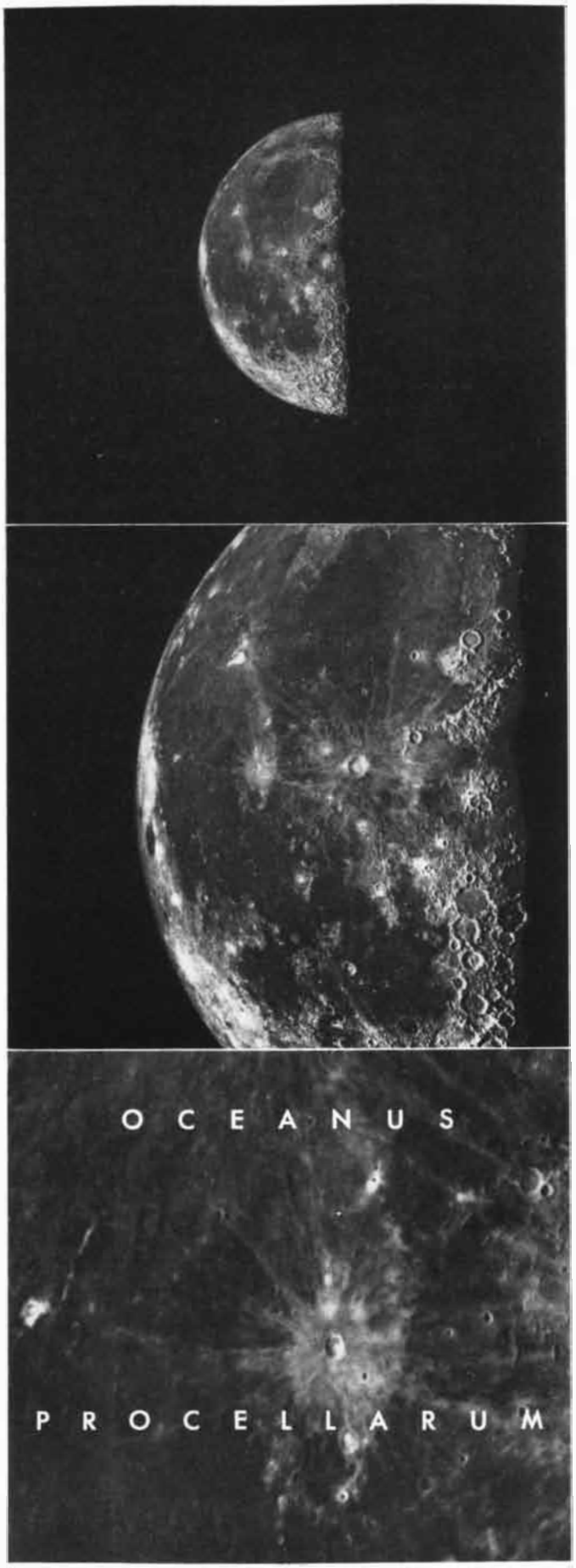
the two broken semicircles. Circle K's diameter is half that of the monad; therefore its area is one fourth that of the monad. Take region G from this circle, add H, and the resulting region is also one fourth the monad's area. It follows that area G equals area H, and of course half of G must equal half of H. The bisecting line takes half of G away from circle K, but restores the same area (half of H) to the circle, so the black area below the bisecting line must have the same area as circle K. The circle's area is one fourth the monad's area, therefore the Yin is bisected. The same argument applies to the Yang.

6.

There are probably three blue-eyed Jones sisters and four sisters altogether. If there are n girls, of which b are blue-



Answer to the doughnut-slicing problem



SPRINGBOARD FOR SPACE: LUNA

The moon is a ready-made space station for interplanetary exploration; space vehicles could be built, fueled, and launched there; lunar elements could be used to give man independence from earth. To help make this concept a reality, NAA's Missile Division has integrated the ideas of scientists in many fields and is studying how to reach the moon... how to live in its alien climate... how to process lunar matter. One example: a study of processes to obtain water from materials likely to be found on the moon.

THE MISSILE DIVISION OF

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eyed, the probability that two chosen at random are blue-eyed is:

$$\frac{b(b-1)}{b(n-1)}$$

We are told that this probability is 1/2, so the problem is one of finding integral values for b and n that will give the above expression a value of 1/2. The smallest such values are $n = 4$, $b = 3$. The next highest values are $n = 21$, $b = 15$, but it is extremely unlikely that there would be as many as 21 sisters, so four sisters, three of them blue-eyed, is the best guess.

7.

The rose-red city's age is seven billion years. Let x be the city's present age; y, the present age of Time. A billion years ago the city would have been $x - 1$ billion years old and a billion years from now Time's age will be $y + 1$. The data in the problem permit two simple equations:

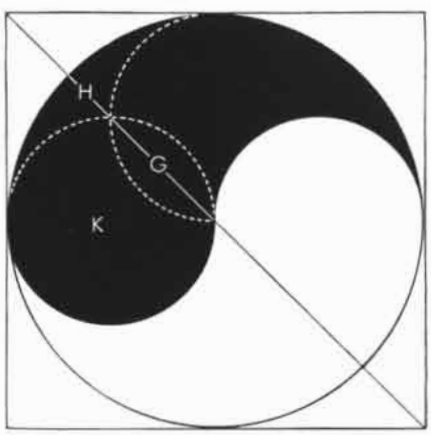
$$2x = y$$

$$x - 1 = 2/5\ (y + 1)$$

These equations give x, the city's present age, a value of seven billion years; and y, Time's present age, a value of 14 billion years.

8.

There is space only to suggest the procedure by which it can be shown that Washington High won the high jump event in the track meet involving three schools. Three different positive integers provide points for first, second and third place in each event. The integer for first place must be at least 3. We know there



Answer to the monad problem

EVENTS	1	2	3	4	5	SCORE
WASHINGTON	2	5	5	5	5	22
LINCOLN	5	1	1	1	1	9
ROOSEVELT	1	2	2	2	2	9

Answer to the track-meet problem

are at least two events in the track meet, and that Lincoln High (which won the shot-put) had a final score of 9, so the integer for first place cannot be more than 8. Can it be 8? No, because then only two events could take place and there is no way that Washington High could build up a total of 22 points. It cannot be 7 because this permits no more than three events, and three are still not sufficient to enable Washington High to reach a score of 22. Slightly more involved arguments eliminate 6, 4 and 3 as the integer for first place. Only 5 remains as a possib lity.

If 5 is the value for first place, there must be at least five events in the meet. (Fewer events are not sufficient to give Washington a total of 22, and more than five would raise Lincoln's total to more than 9.) Lincoln scored 5 for the shot-put, so its four other scores must be 1. Washington can now reach 22 in only two ways: 4, 5, 5, 5, 3 or 2, 5, 5, 5, 5. The first is eliminated because it gives Roosevelt a score of 17, and we know that this score is 9. The remaining possibility gives Roosevelt a correct final tally, so we have the unique reconstruction of the scoring shown in the table above.

Washington High won all events except the shot-put, consequently it must have won the high jump.

9.

It is not possible for the termite to pass once through the 26 outside cubes and end its journey in the center one. This is easily demonstrated by imagining that the cubes alternate in color like the cells of a three-dimensional checkerboard. The large cube will then consist of 13 cubes of one color and 14 of the other color. The termite's path is always through cubes that alternate in color along the way; therefore if the path is to include all 27 cubes, it must begin and end with a cube belonging to the set of 14. The central cube, however, belongs to the 13 set; hence the desired path is impossible.

BUT, SIR ISAAC, WE'RE NOT GUIDING APPLES!

Until a ballistic missile is in free fall, our inertial guidance systems must be able to account for both rocket thrust and gravity. Making them this smart is a tough job, but we hit the mark so well on Thor that all of this country's long range missiles will soon be guided inertially. If you would like to help us keep pioneering new guidance systems, and have a BS, MS or PhD in Physics or Math, or an ME or EE, please contact Mr. B. E. Allen, Director of Scientific and Professional Employment, 7929 S. Howell Ave., Milwaukee 1, Wisconsin.

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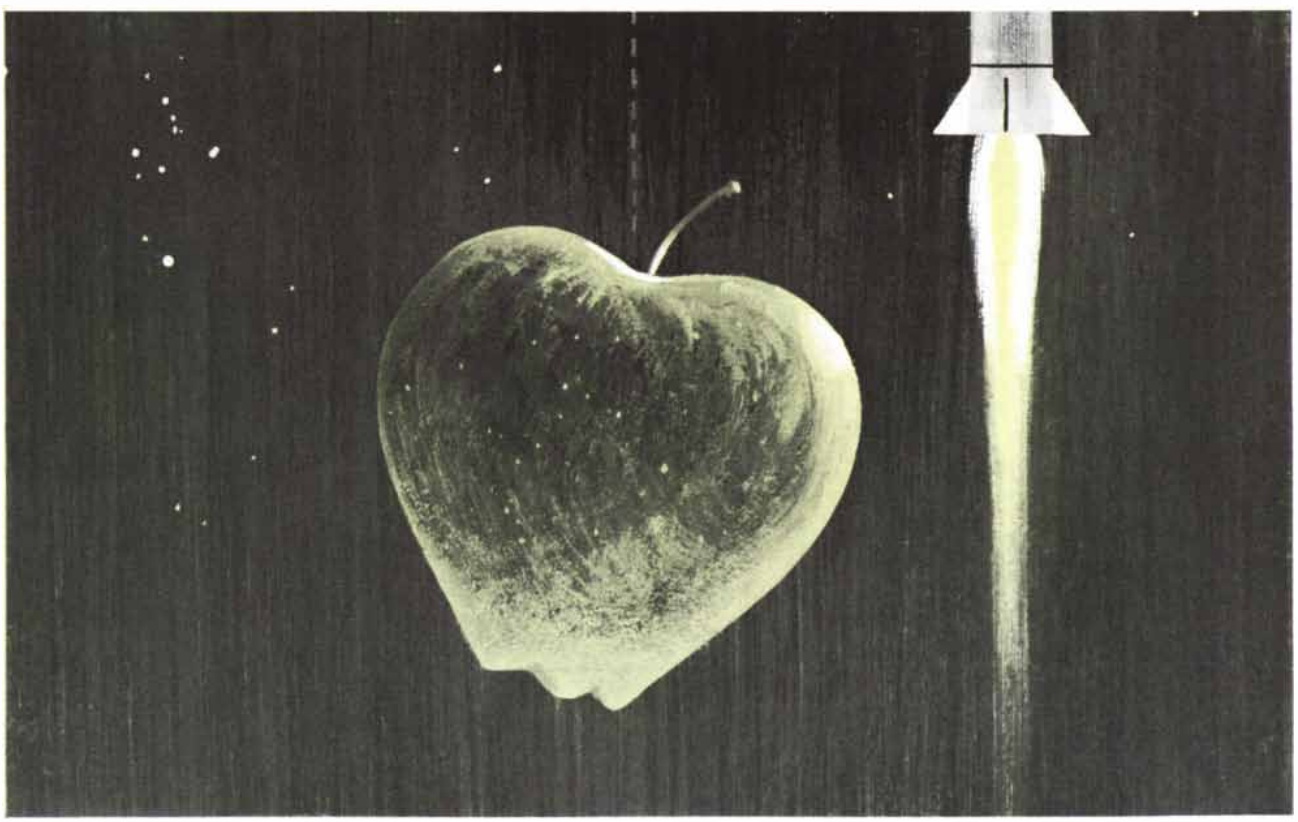

SQUIRREL-CAGE GRIDS FOR HIGH-FREQUENCY ELECTRON TUBES
For high-frequency vacuum-tube grids manufactured by General Electric Company, only a Platinum-clad wire, such as produced by Engelhard Industries, was able to provide the properties to assure efficient grid and tube operation.

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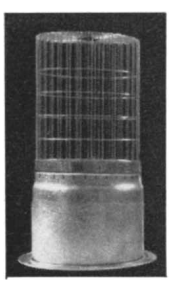

This cage is used by General Electric Company to tame electrons in a vacuum tube. It's called a squirrel-cage grid, and is used to control the electrons flowing from the hot cathode to the plate, or anode.

Some grids become contaminated by material from the hot cathode and then may *emit* electrons, which upset normal behavior of the tube and may even cause its destruction. This occurs when the work function of the grid becomes too low—when it is too easy to boil off electrons.

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This is why vacuum tube designers at General Electric's Power Tube Department in Schenectady specified platinum-clad wire for both the control and screen grids in two highly sensitive electron tubes . . . the G1-6251 and the G1-6942 . . . ceramic tetrodes for VHF television and UHF bands. The electronic properties of platinum, with the high temperature strength of tungsten, are combined in platinum-clad tungsten wire as the answer to the problem.

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Specialists are prepared to work 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.

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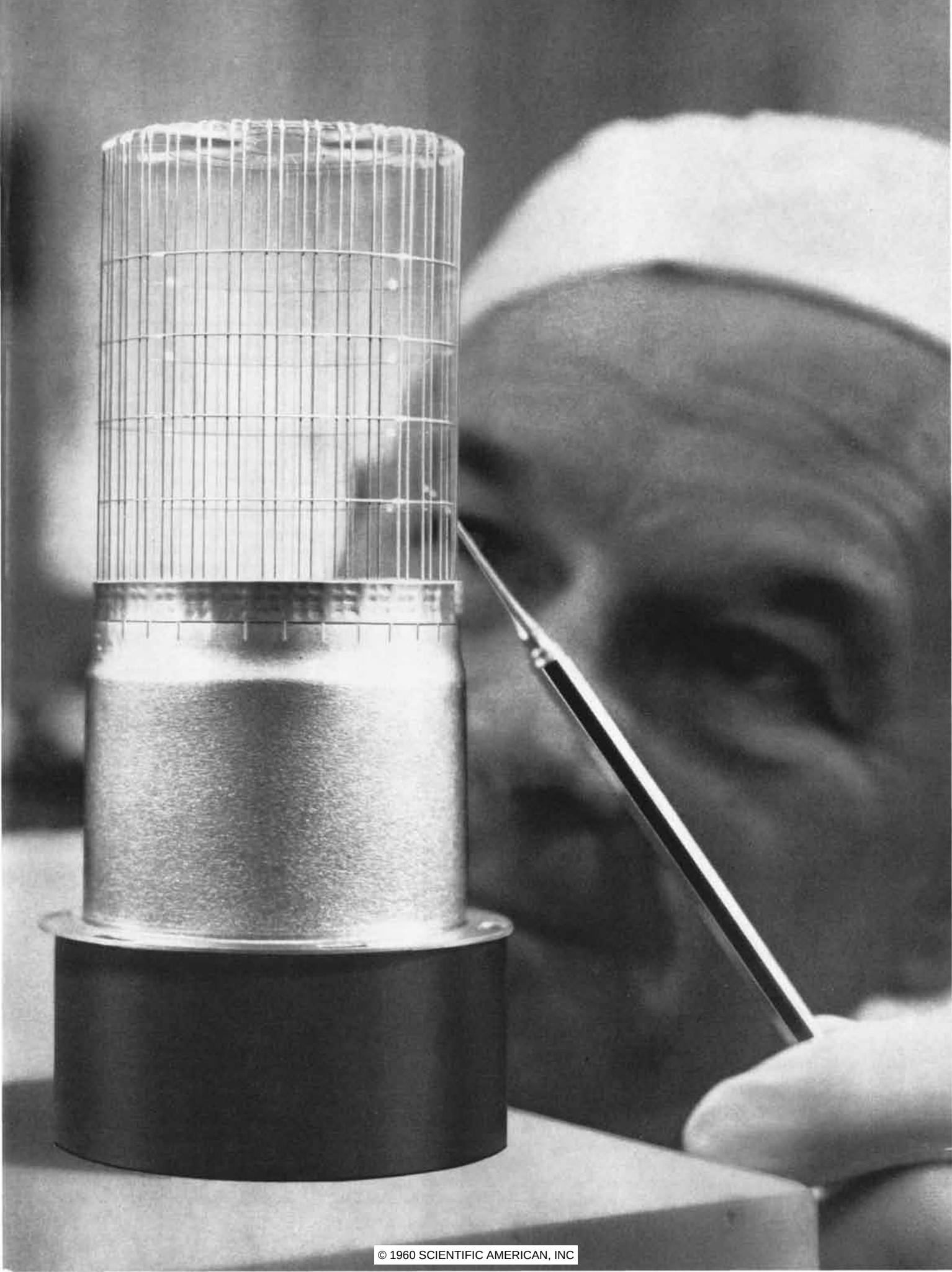


THE AMATEUR SCIENTIST

How to make an electret: the device that permanently maintains an electric charge

Conducted by C. L. Stong

The history of science is a treasure house for the amateur experimenter. For example, many devices invented by early workers in electricity and magnetism attract little attention today because they have no practical application, yet these devices remain fascinating in themselves. Consider the so-called electret. This device is a small cake of specially prepared wax that has the property of permanently maintaining an electric field; it is the electrical analogue of a permanent magnet. No one knows in precise detail how an electret works, nor does it presently have a significant task to perform. George O. Smith, an electronics specialist of Rumson, N.J., points out, however, that this is no obstacle to the enjoyment of the electret by the amateur. Moreover, the amateur with access to a source of high-voltage current can make an electret at virtually no cost.

"For more than 2,000 years," writes Smith, "it was suspected that the magnetic attraction of the lodestone and the electrostatic attraction of the electrophorus were different manifestations of the same phenomenon. This suspicion persisted from the time of Thales of Miletus (600 B.C.) to that of William Gilbert (A.D. 1600). After the publication of Gilbert's treatise *De Magnete*, the suspicion graduated into a theory that was supported by many experiments conducted to show that for every magnetic effect there was an electric analogue, and vice versa.

"In 1839 Michael Faraday suggested that it should be possible to polarize a dielectric material so as to produce 'a Dielectric Body which retains an electric moment after the externally-applied electric field has been reduced to zero.' In Faraday's time, however, other workers were so busy with such ideas as the telegraph and the arc light that they paid little attention to his device. An exception was Oliver Heaviside, who discusses it in his *Electrical Papers*. Finding Faraday's 19-word description a bit cumbersome, Heaviside coined the word 'electret,' by analogy to 'magnet.' Adorned with this name, the electret remained no more than a scientific concept until 1922, when the first electrets were produced by Mototaro Eguchi, professor of physics at the Higher Naval College of Tokyo.

"The analogy between the magnet and the electret is striking, and this includes the way in which they are fabricated. For example, a magnet can be made 'cold,' but the strength and permanence of its magnetism is enhanced if the material is placed in a magnetic field while it is in the liquid state and is then allowed to cool while the field is maintained. The same is true of the electret, though of course the effect and the field are electrical.

"One form of electret is made by melting a mixture of waxes and permitting the batch to cool slowly between a pair of electrodes charged to a direct-current potential of several thousand volts. When the wax has cooled to room temperature and is removed from the field, it will retain a charge. The strength of the charge depends on a number of factors, including the composition of the wax and the rate of cooling. However, even crudely made electrets can maintain a charge of several hundred volts. Just as some magnetic materials have a higher permeability than others, certain waxes make better electrets. One of the more efficient formulas for electret material is: carnauba wax, 45 per cent; water-white rosin, 45 per cent; white beeswax, 10 per cent.

"In the present state of the art this formula is subject to imponderables of the sort that make horse-racing popular: It is more a matter of opinion than of certainty. Some experimenters advocate the substitution of 'halowax' for the water-white rosin. Others who agree go on to point out that if halowax is substituted for the rosin, the beeswax may be omitted. The beeswax is added only to reduce the brittleness of the final electret, and equal parts of halowax and carnauba wax do a fine job. The carnauba-halowax mixture gives the finished product a creamy, ivory texture with a nicely polished surface, and it shrinks sufficiently upon cooling to come easily out of the mold. On the other hand, halowax is somewhat hygroscopic, and electrets containing it must be protected against humidity.

"Some experimenters claim that good electrets cannot be made unless the mixture contains at least a trace of carnauba wax. Others insist that any wax that cools to a fairly hard, shiny surface will accept the electric charge and develop an external electric field. One explanation in support of the carnauba-wax view suggests that the relatively large shrinkage of carnauba wax places an additional stress on the finished electret, which adds a piezoelectric effect to the over-all static charge. In recent years, however, this view has been refuted. When the ceramics industry undertook the development of dielectrics, a whole special class of materials was created. Starting with ceramic capacitors, piezoelectric ceramics were developed for hydrophones, microphones and phonograph pickups. Ceramic magnetic materials appeared, and finally ceramic electrets. A ceramic electret made of barium titanate contradicts the notion that electrets do not work without carnauba wax.

"A major problem in the manufacture of electrets stems from the cussedness of wax dielectrics in general. The insulating property of waxes decreases as the temperature increases. This is a smooth and well-established relationship. When the wax enters the liquid phase, however, the insulation resistance begins to drop sharply. This effect can expose the experimenter to hazard. If a high-voltage supply with low internal impedance is used to provide the polarizing electric field, it is possible that the supply will deliver enough current through the melted dielectric wax to add to the temperature of the mass. Because the internal resistance drops with increasing temperature, the process becomes explosive.

Ultimately enough current follows along one channel to provide a flash-arc path that can splatter flaming wax in a dangerous manner.

"On the other hand, a 'safe' high-voltage power supply (one that includes an internal resistance on the order of 50 megohms, say) will deliver only a fraction of its available voltage to the electret-forming terminals, because its ratio of internal impedance to external impedance acts to divide the voltage. The external load resistance also goes up as the electret cools and the strength of the polarizing electric field increases.

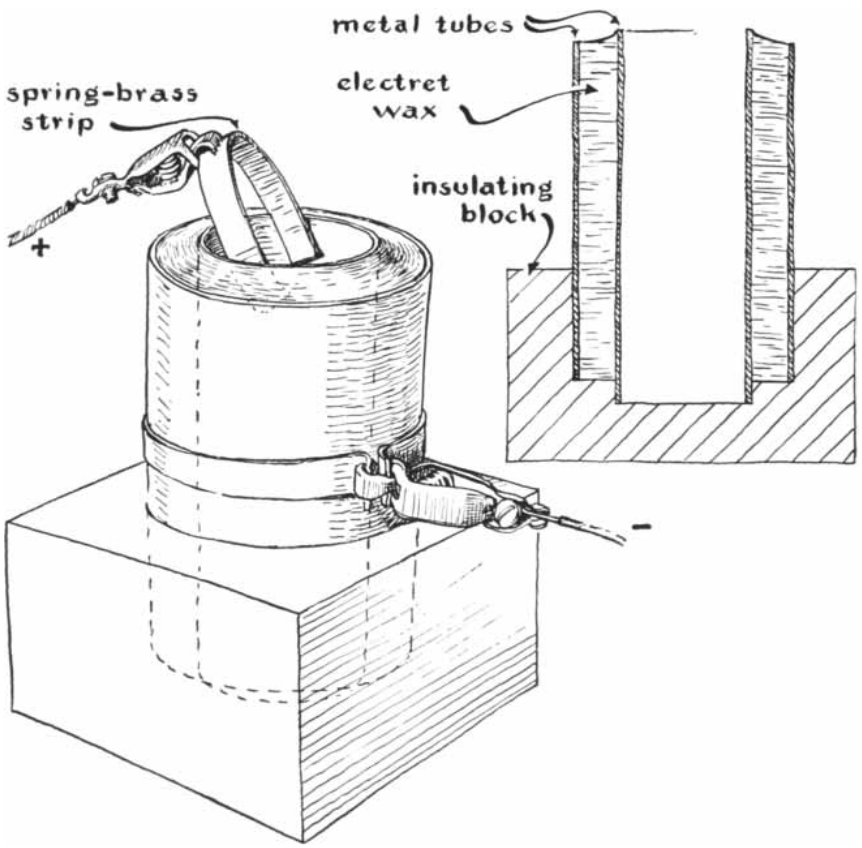
"The reason that the electret acquires a charge is fairly obvious. The molecules of the wax are electrically polarized, and they align themselves with the electric field just as the 'domains' of a magnetic material line up with a magnetic field. As the wax cools and solidifies, this alignment is maintained. Unlike metallic substances, however, waxes have no sharp melting point. Even when the wax is highly purified there is a span of many degrees between the solid state and the state in which the wax flows as a liquid. A mixture of waxes usually exhibits an even wider range of temperatures between the semiplastic and semifluid states.

"The current-carrying mechanism in waxes consists of a migration of polar molecules from one electrode to the other, of the delivery of electrons from cathode to anode by true physical movement. The positive end of a polar molecule picks up an electron from the cathode; this causes a local neutralization of the positive end, but destroys the neutrality of the molecule, making it act as if it were a negative ion (anion). Conversely, the negative end of the polar molecule can lose an electron to the anode, causing a local neutralization of the negative end and a loss of over-all molecular neutrality. This molecule now behaves as if it were a positive ion (cation). Both processes can occur in a single molecule, resulting in a restoration of molecular neutrality but the loss of dipolar features. The partially neutralized dipoles exhibit only half as much tendency to align themselves with the electric field, and the neutralized molecules none at all. Add these conditions to the lowered electric-field intensity caused by the current, and to the molecular vibrations caused by the temperature of the material, and it is not hard to understand why electrets that are cooled quickly during manufacture exhibit fields of lower intensity than those that are cooled slowly. Slow, deliberate cooling enables the vibrating molecules in the electret to come to rest in alignments that result in the maximum subsequent field strength.

"A simple form of the electret was devised some years ago by Edwin P. Adams of Princeton University. It consists of concentric metal cylinders sealed at the bottom by an insulating base and containing a cylinder of wax, as shown in the accompanying illustration [*below*]. In 1939 W. M. Good and J. D. Stranathan of the University of Kansas devised the improved version depicted in the second illustration [*next page*]. The large oil bath shown in this illustration provides a mass to retard the rate of cooling. Good and Stranathan also added electric heaters and an automatic temperature-control to lower the temperature gradually through the semiplastic state over a period of many days. This refinement is scarcely needed unless you embark on a program of meticulous research. When the oil bath is heated to the temperature that will cause a true fluidity of the electret material in the mold, it will cool slowly enough to give rise to an effective electret.

"Any high-voltage supply can be used; if the one at hand chances to be capable of delivering more than a milliampere, it can be rendered safe by adding resistors in series between the supply-terminals and the electret plates. This can best be accomplished by connecting the necessary number of two-, three- or five-megohm resistors in series for a total of 50 megohms. The resistors should preferably be of the two-watt size; they should not be smaller than the one-watt size. I concede that 1,000 volts across a five-megohm resistor dissipates only .2 watt. We are not concerned with the wattage, but rather with the voltage gradient across the resistor itself. The physical size of the larger resistors eliminates the high voltage-gradient and attendant internal electrostatic effects that cause fusing of the carbon granules. This process can cause a major change in the resistance value of small carbon resistors. The use of a string of two-, three- or five-megohm resistors also enables you to make a rough adjustment of the output voltage by coupling the output leads to intermediate points in the string.

"Sparking across the surface of the wax can be reduced or eliminated by increasing the series resistance. A meter of some sort should be connected in the load circuit so that you can observe the process. A zero-to-one milliammeter will prove far more informative than a volt-



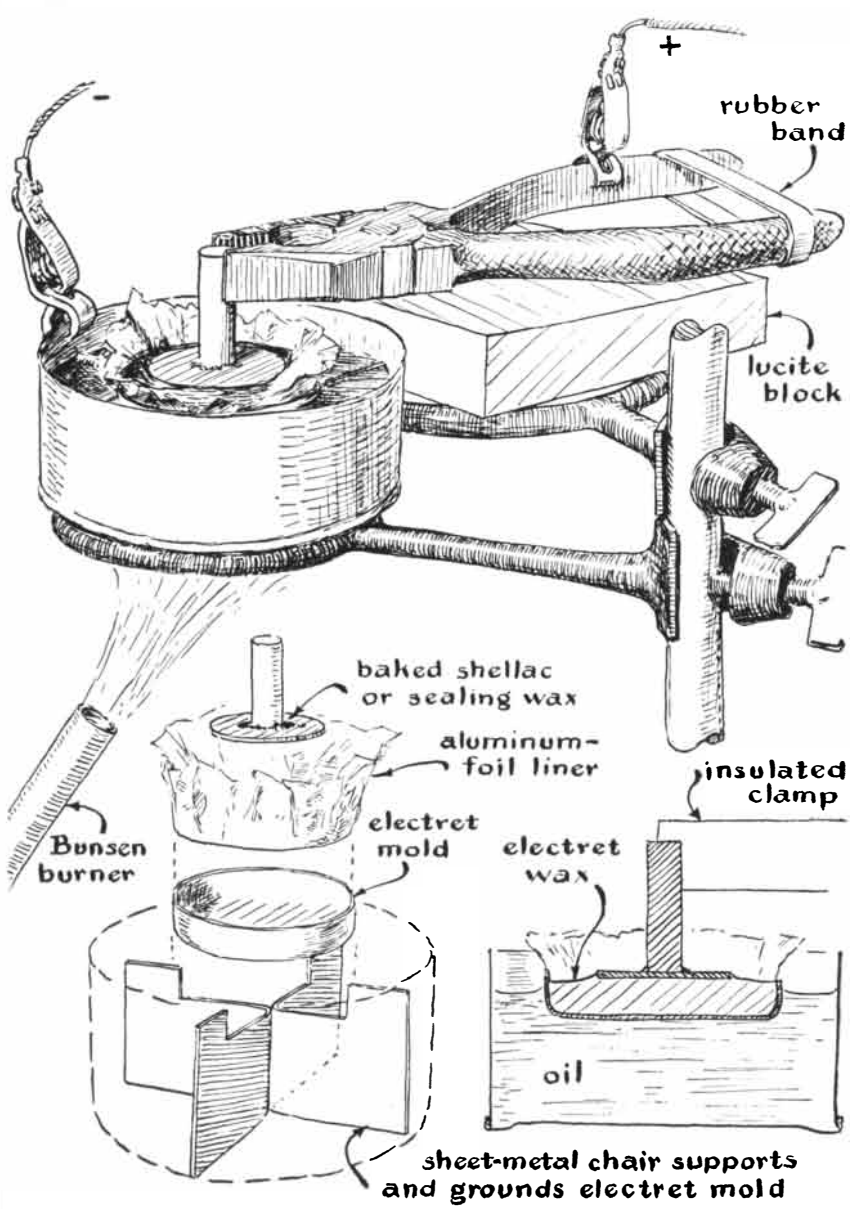
An electret devised by E. P. Adams of Princeton University

meter that merely indicates the total polarizing field.

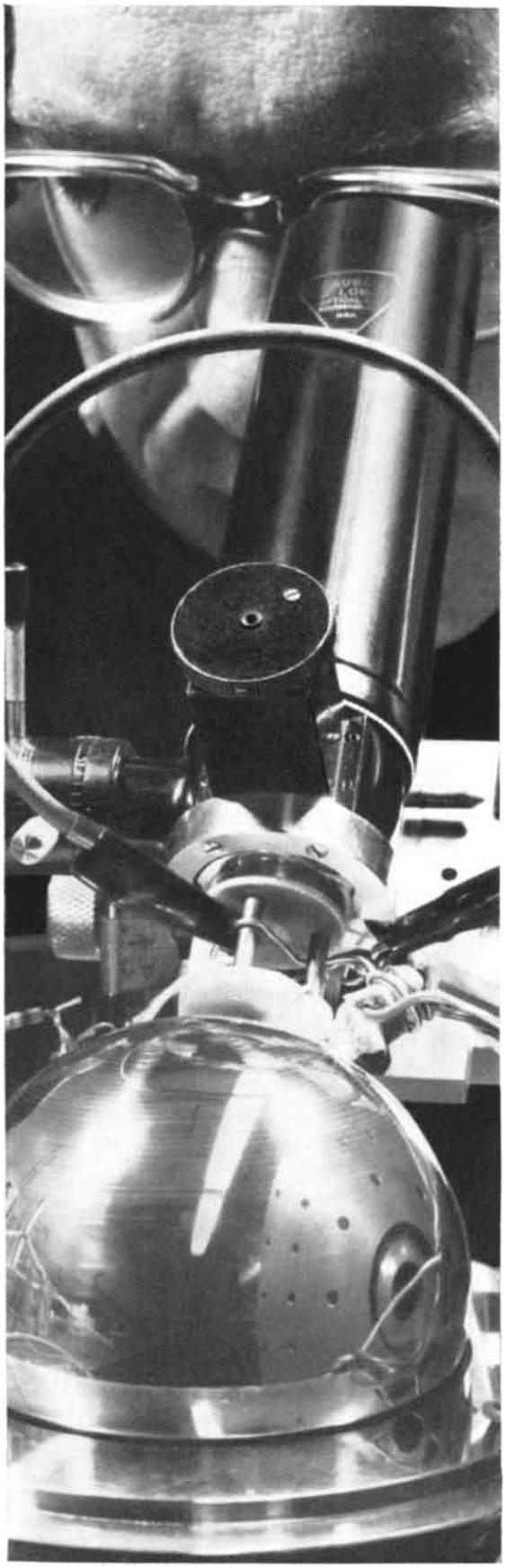
"The polarizing field should be maintained at a maximum. The current flowing through the melted electret wax should never be permitted to rise above .5 milliampere. At the dielectric material's most conductive phase the series resistance should be adjusted to limit the current to about .1 milliampere. It will not be necessary to readjust the resistance as the wax cools, because the internal resistance will rise to a safe limiting value. Simultaneously the polarizing voltage across the wax will increase to the maximum value.

"In computing the output voltage of your power supply, such as the one illustrated in the accompanying circuit diagram [*top of page 206*], remember that the voltage shown on the nameplate of the transformer must be multiplied by 1.414. This is because in this application the load current is so low that the delivered voltage practically reaches the peak value, and the rated output of the transformer is always given as the root mean square value.

"In processing electrets the oil bath should be raised to operating temperature first, or at least started so that it will be at operating temperature by the time the electret formula is mixed. Melt and mix the waxes in a separate pan, stirring frequently to drive out air bubbles and moisture. Keep the electret-mix temperature well above the boiling point of water for at least half an hour. Be



An electret devised by W. M. Good and J. D. Stranathan of the University of Kansas



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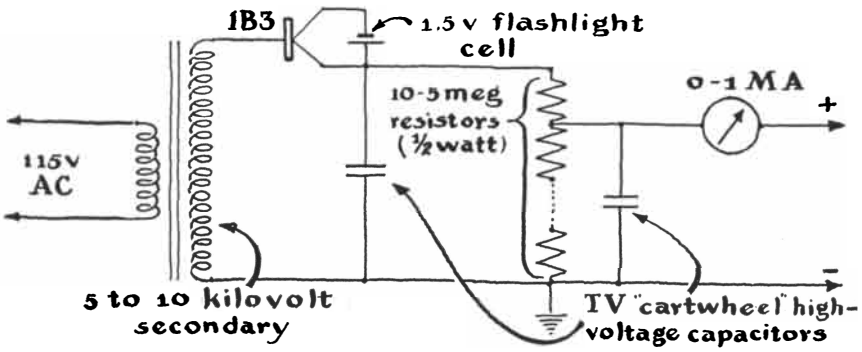


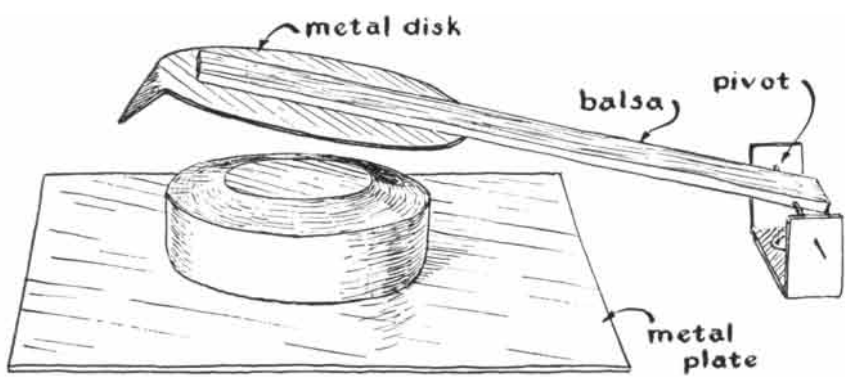
Circuit diagram of a power supply to polarize and charge an electret

wary of touching tiny bubbles that cling to the walls of the container. These may be water droplets. Touching them with a stirring rod breaks the surface tension that has prevented the water from boiling into steam. When the tension is broken, the water explodes into steam with sufficient violence to splatter the hot wax.

"In the meantime line the mold with aluminum foil and smooth it out to remove as many of the wrinkles as possible. Tapering the mold slightly will facilitate the subsequent removal of the foil-encased wax. Next pour the melted mix into the mold. (The size of the finished electret is optional. A disk two or three inches in diameter and about half an inch thick is convenient.) The top plate should just touch the top surface of the electret material. This plate should be heated, too, by the way. When the wax wets the top plate, the high-voltage supply can be turned on. The electrostatic stress should cause an abrupt jump in the annular meniscus of the wax surface between the center plate and the mold walls. If sparks appear on the molten wax, turn off the power and connect the output leads for lower voltage. Then reapply power, turn off the oil-bath heater and permit the assembly to cool to room temperature. Observe the temperature with a thermometer, not by feel. *Stay away from any part of the apparatus when the high-voltage supply is in operation!*

"When the oil reaches room temperature, turn off the power supply and remove the electret. Immediately fold the aluminum foil forward over the surface in contact with the top plate, short-circuiting the electret. The foil acts as a 'keeper' and is analogous to the soft-iron bar placed across the open jaws of a horseshoe magnet to preserve the magnetic flux. Electrets properly short-circuited have kept for longer than five years without noticeable loss of charge.

"Now comes the puzzler that stumps the experts. If the electret's polarity is measured directly after its manufacture, its charge will be just what theory predicts it should be. The negative surface of the electret will be that which made contact with the positively charged polarizing electrode, and vice versa. This agrees with the north-south polarity of a bar of steel magnetized by contact with a permanent magnet. In contrast with the behavior of a magnet, however, the charge on the electret begins to diminish immediately, and in about a week it will have fallen to zero. The charge then begins to build up *in opposite polarity* to a final value that may be several times



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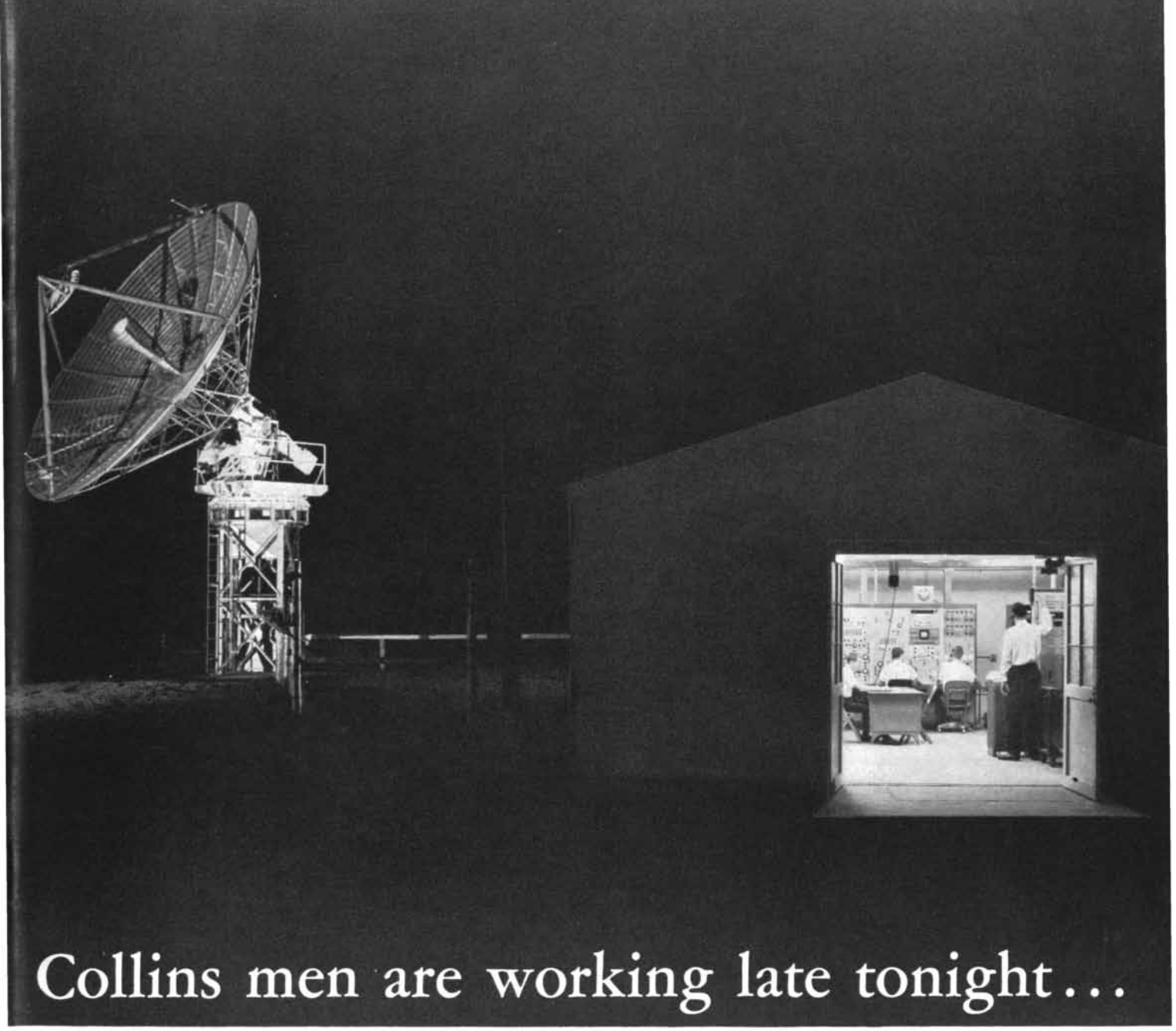
as large as the original charge. This may take as long as three months. The negative surface of the stabilized electret will be the face that made contact with the negatively charged polarizing electrode. In other words, the charge will correspond in sign to the polarity of the high-voltage field. Just why this reversal takes place has never been satisfactorily explained.

"Measurement of the electrostatic field that surrounds an electret requires a sensitive electrostatic meter, an instrument actuated by electrostatic attraction or repulsion rather than by the passage of current. The magnitude of the surface charge may be measured by passing a metal plate of known area at a known rate into the field until contact is made with the electret surface, the plate being connected to an electrostatic voltmeter. A voltmeter of this type can be made inexpensively by using an electrometer tube (essentially a vacuum tube designed for service in vacuum-tube voltmeters). The instrument will absorb substantially no power and can be calibrated by using a conventional voltmeter as a reference.

"For simple checks a gold-leaf electroscope will do an admirable job of measuring polarity. The polarity of the electret can be determined by charging the gold-leaf electroscope with a current of known polarity and observing whether the electret's approach adds to the charge (by causing the gold-leaf vanes to separate more) or subtract from the charge (by permitting them to fall closer together).

"Finally, at least one simple but spectacular test can be made. A metal disk with a point at the rim is cut just large enough to cover the electret. The disk is fastened to an insulating arm that is hinged to a metal base-plate as shown in the accompanying illustration [*bottom of page 206*]. The metal point should be bent so that when the disk rests on the electret, a sheet of writing paper (.003 to .005 inch thick) will just drag a bit when passed between the point and the metal base-plate. The insulating arm may be made of lucite, or of dry wood (such as a length of model-airplane balsa) that has been boiled in paraffin or impregnated in oil until a fresh-cut surface will repel water. The arm is pivoted at the end to allow the plate to fall through the electrostatic field of the electret. If your hand is steady and your aim unerring, you can omit the lever assembly and merely drop the plate onto the electret surface! The falling plate picks up a charge from the field, and the charge is dissipated in a small but brilliant spark discharge between the point



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The Echo project is being coordinated with the National Aeronautics and Space Administration. Data collected by Collins is being submitted to NASA to be used in the evaluation of this communications technique.

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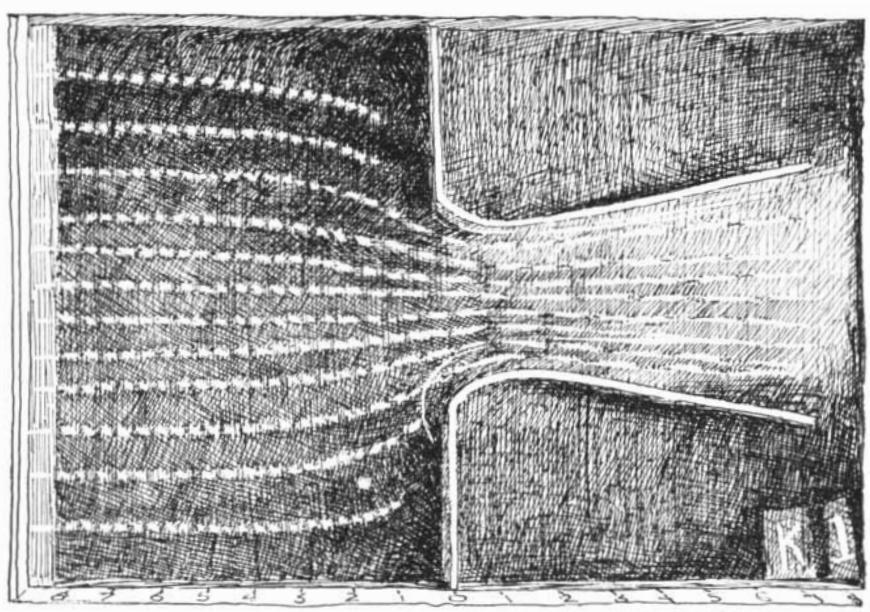
and the bottom plate. Try this with both surfaces of the electret. For some reason electrets are not symmetrical. One surface will deliver more energy than the other.

"The electret has not been entirely without practical application. It has been used to replace the high-voltage polarizing network employed for energizing some types of condenser microphones. The growth of radio broadcasting in the early 1920's, with its need for a microphone that worked on some principle other than the compression of carbon particles, seems to have spurred the original investigation of the electret. For some reason the condenser microphone grew up and passed into obsolescence without ever meeting an electret. But in 1935 Andrew Germant made an electret condenser-microphone for the engineering laboratory of the University of Oxford. Subsequently condenser microphones employing electrets were taken into the field by the Japanese army.

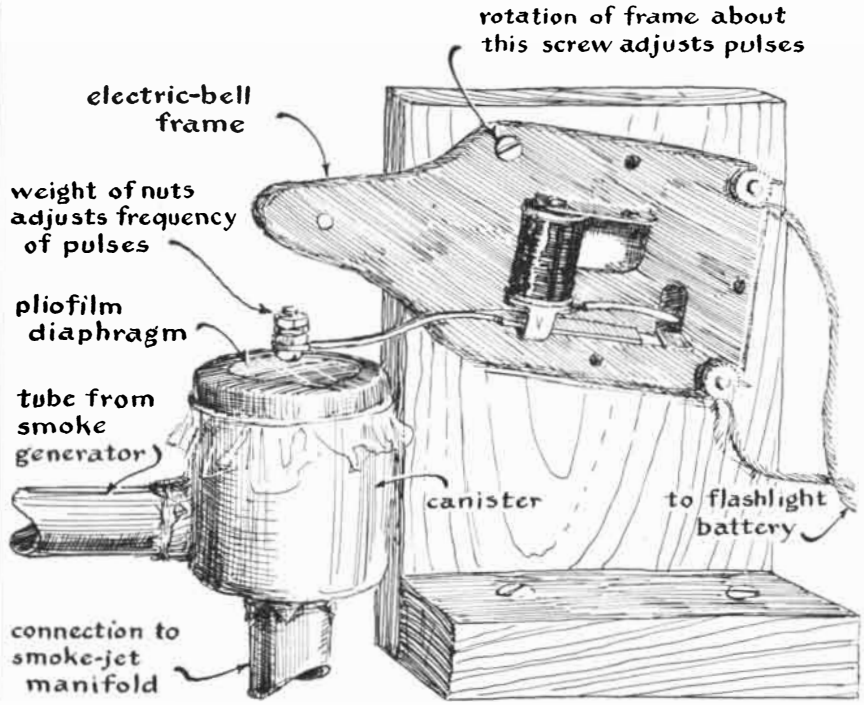
"The electret found another application a few years ago when the television industry was seeking a simple method for focusing picture tubes. Early picture tubes were focused by a magnetic coil that was adjusted by means of a costly power-potentiometer. Eventually the arrangement was replaced by a permanent-magnet focusing device adjusted by changing the magnetic gap. During one brief period, however, the picture tubes were made with an electrostatic lens, the focal length of which was adjusted by a potentiometer. At this point someone remembered the electret and reasoned that, if the electromagnetic focusing-coil could be replaced by a permanent magnet shunted by a mechanically adjusted gap, perhaps the permanent electret could similarly be put to work. Before the idea could be exploited, the development of the self-focusing electron gun solved the focusing problem and once again reduced the permanent electret to the status of a scientific waif."

Dillard Jacobs, associate professor of mechanical engineering at Vanderbilt University, has developed a novel accessory for extending the usefulness of aerodynamic smoke tunnels of the type described in this department [see SCIENTIFIC AMERICAN, May, 1955]. The pattern of air flow in such apparatus is made visible by a grating of smoke streamers admitted to the tunnel through a "rake" of small tubes near the inlet. The lines of smoke bend around test objects placed downstream, and enable the experimenter to approximate the distribution of forces acting on the object.

"Following your description of the smoke tunnel," writes Jacobs, "I promptly built one and can attest to the suitability of its design. The tunnel has been used extensively to produce photographs of fluid-flow phenomena for use in my classes. Some months ago I added a gadget to the tunnel which considerably broadens its utility as a scientific tool. This consists simply of an electric doorbell (with the gong removed) and a chamber with a diaphragm inserted in the smoke circuit just ahead of the 'rake.' When properly adjusted, the doorbell-and-diaphragm assembly acts as a



Pattern of smoke pulses passing through a nozzle in a homemade smoke tunnel



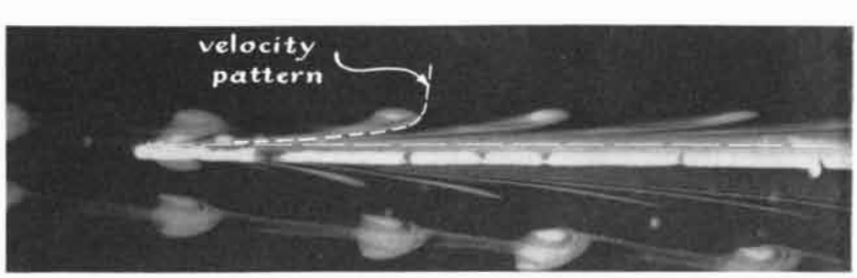
A simple device for pulsing the streams of smoke in a smoke tunnel

chopper to send the smoke out into the tunnel in small puffs or pulses instead of in a continuous stream. I was able to measure the frequency of these pulses (780 per minute). With the pulse frequency known, one has only to measure the distance between puffs on test photographs to calculate velocities precisely. When an obstruction such as a divergent nozzle is placed in the tunnel, the increase in velocity through various regions of the constriction show clearly [*see illustration on page 210*].

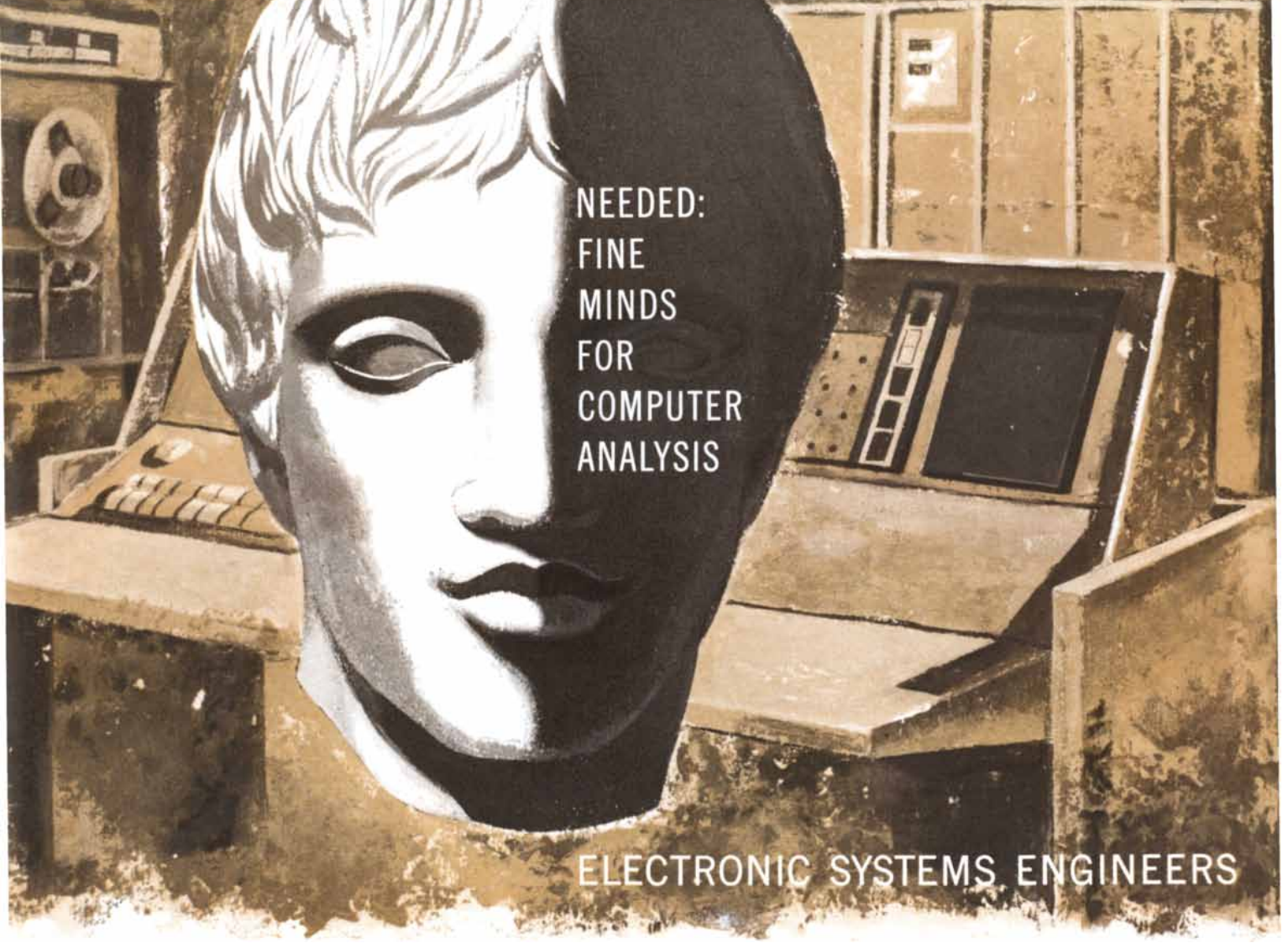
"The modified doorbell is supported by a wooden bracket as shown in the accompanying illustration [*above*]. This provides an adjustment for altering the impact of the clapper on the pliofilm diaphragm, thereby controlling the amplitude of the smoke puffs. If the diaphragm action is too strong, the smoke pulses become smoke rings, an interesting but unsatisfactory effect. Although the bell was originally designed to operate from a six-volt battery, in this device it works best on a volt and a half.

"I used an electronic stroboscope for timing the frequency of the pulses. This consists of a variable oscillator that triggers a high-speed gas-discharge lamp. The speed of the flashing lamp is varied until the smoke puffs appear to stand still. The flash rate is then read from a calibrated scale on the oscillator. If an experimenter does not have access to such apparatus, a motor-driven stopcock designed to operate at a known speed could be inserted in the smoke line.

"Among the interesting phenomena opened to investigation by the pulsed smoke tunnel is the shearing action in the boundary layer between the fluid and a solid surface, as shown in the accompanying photograph [*below*]. Both the thickness of the boundary layer and the velocity distribution through it can be determined with fair precision. In this case the smoke velocity beyond the boundary layer is .79 foot per second. The transverse Reynolds number is 960."



How pulsed smoke streams were used to investigate shearing in the boundary layer



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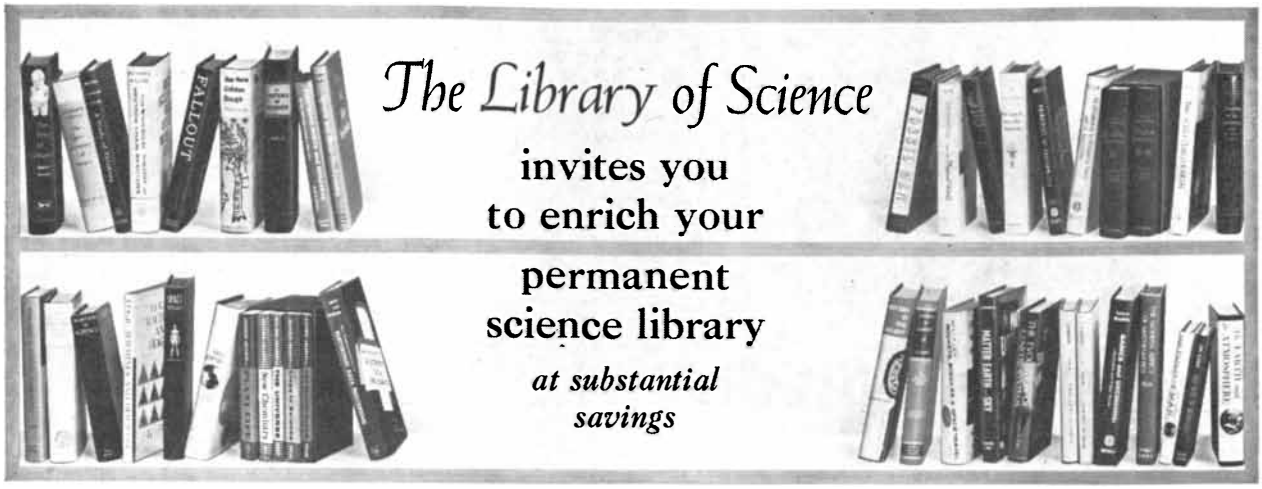

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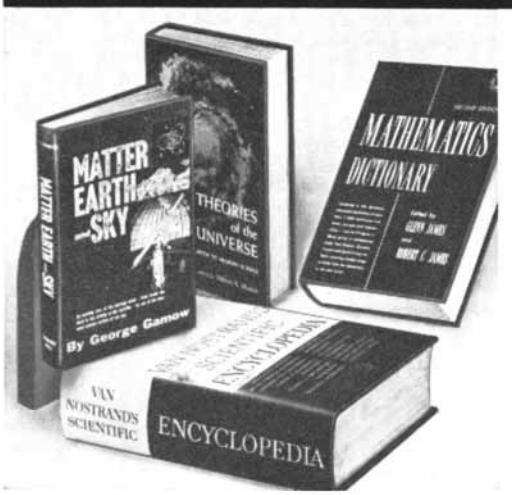

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BOOKS

Concerning the diverse lands and peoples of the world's largest desert: the Sahara

by James R. Newman

TRIBES OF THE SAHARA, by Lloyd Cabot Briggs. Harvard University Press ($6).

The Sahara is an immensely varied landscape, not the desolate rolling sea of sand that has lodged itself in popular imagination. The Arabic word—properly *sahra*—means "wilderness" or "emptiness." So much is true, for it is a vast empty quarter, by far the biggest desert in the world, stretching some 2,500 miles from the Red Sea to the Atlantic Ocean along the Tropic of Cancer and varying in breadth between 800 and 1,200 miles from north to south. Covering more than three million square miles, it is larger than the continental U. S. and twice as big as all of Europe west of the Russian border. Scattered over this huge plateau are less than 2.5 million persons, compared with some 385 million in the European area mentioned.

Empty it is, but not monotonous. Roughly a fifth of the Sahara, it is true, consists of sandy wastes. Two thirds of this surface is sandy plains, with minor groups of dunes; the remaining third is the feared Great Erg, characterized by the spectacular dune formations which, ornamented by a lone rider or by mysterious bands of Arabs astride their "ships of the desert," fill the mind's eye when the Sahara is mentioned.

Yet the Great Erg is barely a 15th of the whole. Gravelly plains and rock-ribbed plateaus cover much of the desert's surface. There are closed depressions of all shapes and sizes; steep-walled valleys, such as the Mzab and the Metlili, which lie deep enough so that the tops of the minarets in the valleys do not quite reach up to the level of the surrounding plain; low buttes with flat tops, all that remains of a still older plain; and huge mountain chains in the middle of the desert, the volcanic massifs of the Tibesti and the Ahaggar, with tremendously high cliffs (over 2,500 feet) and occasional peaks, such as the Emi Koussi, towering up well over two miles. The mountains are the putative parents of the desert. Once it was thought that the Sahara was the bed of an ancient ocean, but the prevailing geological view is that the volcanic mountains were worn down by heat, cold, wind, fierce rain and sand storms, which crumbled the rock and laid down the blanket of sand over the plains. In its complex of features the landscape of the Sahara appears to illustrate the effects of "major erosion cycles and the various transitional phases connecting them, all neatly laid out as though modeled after a diagram in a geology textbook."

No less varied than the landscape is the climate. Winter and summer means of air temperature in the shade are in the neighborhood of 52 and 98 degrees Fahrenheit; extremes run from 20 degrees to 130. The thermometer may fall 50 degrees at sunset. In the northern desert the relative humidity is sometimes higher than at Paris, but in midsummer it may drop to as low as 2.3 per cent. The annual evaporation rate (60 to 140 inches) is three to four times that along the Mediterranean coast, so that in the summer no one can safely go for more than 24 hours without water. The Sahara is not noted for its rainfall—as a whole it gets less than two inches annually, as against Phoenix, Ariz., say, which gets seven inches—but the variations from year to year and even from place to place are enormous. Parts of Fezzan have as much as four to six inches a year. Tamanrasset and In Salah have known periods of four to five years during which no rain fell. It is this irregularity of rainfall that accounts for the small amount of cultivated land. Prolonged droughts, which increase in duration as one moves from north to south, rather than total rainfall over long periods, determine the fertility of the land. The contrasting ratios of cultivated to uncultivated land are striking: 1 to 270 in the Annex of El Oued, 1 to 3,500 in El Goléa, 1 to 75,000 in the Ahaggar. Occasionally when it rains it pours: incidents are known of almost two inches of rain falling in a couple of hours. When this happens, powder-dry gullies are suddenly filled with roaring bores of water several feet high. For this reason nomadic camps are very rarely pitched close to the dry bed of a stream.

Sandstorms are more frequent than rain. They occur in winter and early spring, often brought on by a low-pressure area over the Atlantic moving toward the African coast, causing a shift of the prevailing winds from north to south and a rise in temperature and humidity. In his standard text *Le Sahara Français* the French writer Robert Capot-Rey describes the scene: "Suddenly the wind shifts to the southwest, growing in force from minute to minute; the sun is covered over and a distant wall of sand blots out the horizon. The wind begins to assume the proportions of a gale and streaming wisps of sand like trembling nets race over the ground. . . . This is the moment for action when shelter must be found as quickly as possible." Crops, domestic animals, human life—all are adversely affected by sandstorms. Sometimes the damage is catastrophic, although it is doubtful that the stories are true of entire caravans being swallowed up and buried.

It is a land that is more thirsty than empty: thirst is the burden of the Sahara, the key to its history, the taskmaster of its people. Where water is and where it is not determines the sites of cities, the routes of caravans, the products of the land, the occupations and dress and diet and ways of life of the inhabitants. The few favored spots are those with ample natural springs; there one may find oases, ponds, groves of trees. Other sources of water are hand-dug artesian wells varying in depth from 20 to more than 200 feet and just wide enough for a well-digger to stand inside and swing a short-handled pick. Many of these require constant attention because they are likely to cave in, get choked or even obliterated by sandstorms. The desert well that is reached after a long and bitter march, only to turn out to have run dry, is a familiar dramatic device. It has some basis in fact; more often the well is not

dry but the water is so unpleasant to the taste and so powerfully cathartic that, while the traveler drinks so as not to perish, he knows that drinking will make him violently ill. Another important water-gathering device is the *foggara*, already known in Persia during the time of Darius. This is a system for drawing water off the top of a sloping water table by means of a long tunnel and a line of vertical shafts, 20 to 50 feet apart, stretching for eight to 10 miles. The water flows by gravity from a water-soaked area to vegetable gardens or other places under cultivation. In a single region—the Touat, for example—there are 950 miles of such galleries, and even a small oasis may have 20 miles. By these means of irrigation date palms, the most important cultivated fruit-producing tree of the Sahara, are raised. (Dates, according to a popular saying, are to the people of the Sahara what wheat is to the French and rice to the Chinese.) The oases also yield fruits, cereals, vegetables and tobacco. The desert has great deposits of carbonate of soda that have been worked since the sixth century, and rich deposits of iron, oil and uranium, whose profitable exploitation has scarcely begun.

But the mineral and vegetable resources of the Sahara, important though they are, are so unevenly distributed that they could not support the sedentary population were it not that they can be transported and extensively used in trade. The hero of this activity is of course the camel.

The camel is a strange, marvelous and, on the whole, unpleasant beast. It is stubborn, unfriendly and both remarkably rugged and remarkably frail. Tender loving care has its place in camel education as in ours. When its masters are brutal, as are the Arabs, it is less tractable than when they are patient, as are the Tuareg; yet in either case it is sufficiently cantankerous so that "few who know camels well ever ride one when there is any other way of getting where they want to go." Riding camels are graceful and imposing: taller, finer boned, more sensitive and delicate than their "servile and less pampered cousins," the camels of the caravans and baggage trains. The riding camel dies suddenly of exhaustion on the march (often in its sleep, shortly before dawn); the baggage camel is more likely to work out its last decrepit years pulling on a well-rope. A good mount can cover extraordinary distances at high speed: cases are known of picked animals traveling 400 miles in six days and nights. Baggage camels usually do 15 to 20 miles a day under loads of 400 to 500 pounds. Camels can be eaten and sometimes are, but they are a capital investment and are no more likely to be slaughtered for meat than a lifeboat is to be chopped up for firewood. (Within the past 20 years, however, certain nomad tribes have begun to raise camels for sale to butchers in neighboring commercial centers.) Camels also give milk, which is a prized luxury throughout the desert.

The camel makes nomadic life possible, but it is not the only important domestic animal of the Sahara. Sheep are raised in the northern region, some woolly and white, some hairy and brown; they are good exchange merchandise for dates and textiles. Long-coated and short-coated goats are domesticated; humpbacked cattle (zebus) are also raised, as are horses. Dogs, cats and chickens are kept for various purposes.

Much is known, as is indicated even by this sprinkling of facts, about the landscape and natural resources; and the more one learns the more one realizes what a fascinating region it is, how different from the widely accepted notion of it. Of its peoples much less is known. The literature—not only the older geographies and histories but even the modern studies based on the direct observations of explorers—presents at worst a wildly misleading, at best a superficial or narrowly limited picture. The book I am reviewing (which I have already plundered to describe the land and its resources) is by far the best work of its kind: engrossing in itself, an education, a corrective to confusion and error. Lloyd Cabot Briggs is Research Fellow in North African Anthropology at Harvard University. Now living in Algiers, he devoted 12 years to preparing a technical monograph, *The Living Races of the Sahara Desert*, and the present, more general summary. Part of this time was spent in living among the desert tribes, part in studying the huge Saharan literature. "More pure balderdash," he says, "has been written and repeated about the tribes of the Sahara than about almost any other peoples of the world."

After an excellent chapter on the physical geography of the Sahara, Briggs sketches the history of the desert. It has never been, one learns, the "land of impenetrable mystery, the vast, unknown, and culturally stagnant wilderness that so many seem to have believed." Since prehistoric times it has had its settlements, its tribes of nomadic hunters and herdsmen. Commercial traffic has criss-crossed it for hundreds of years. Explorers and travelers penetrated to its heart in the 19th century. Long before

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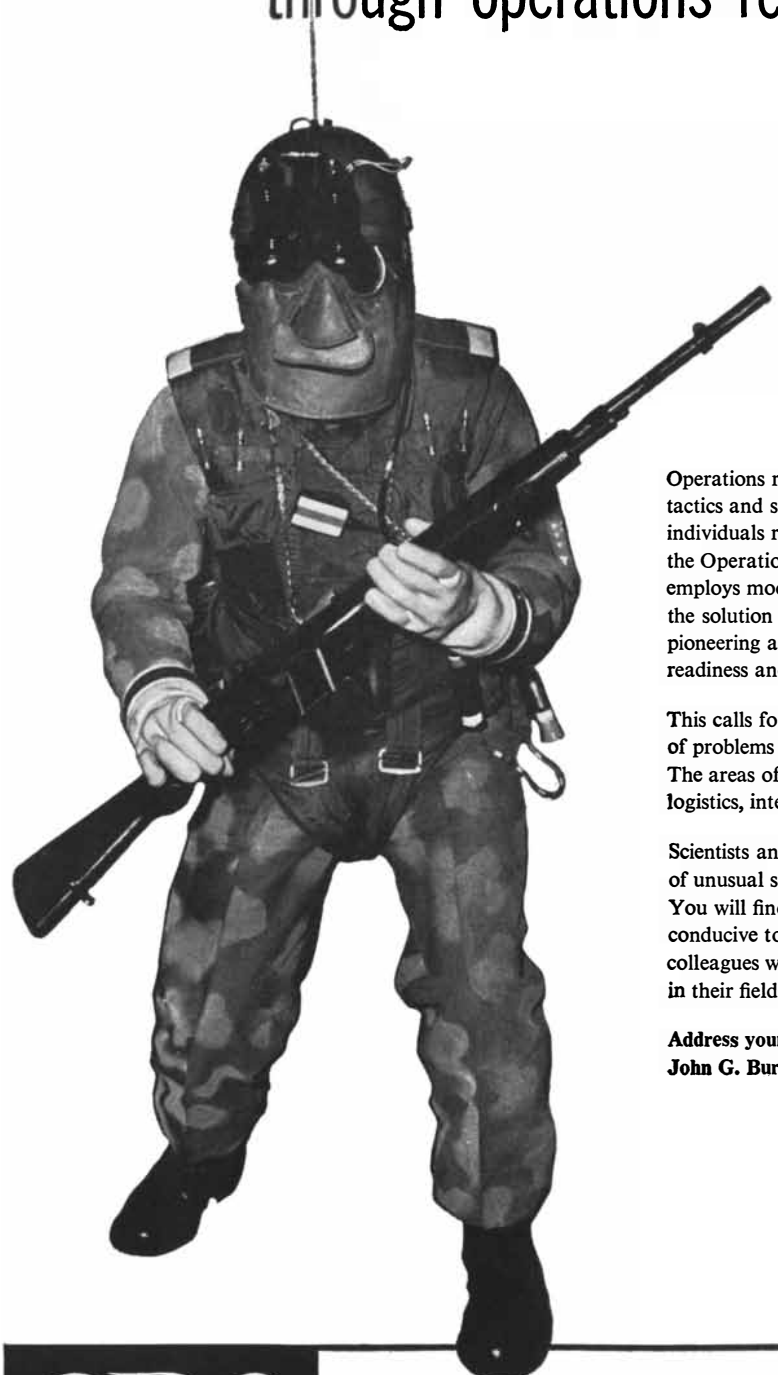

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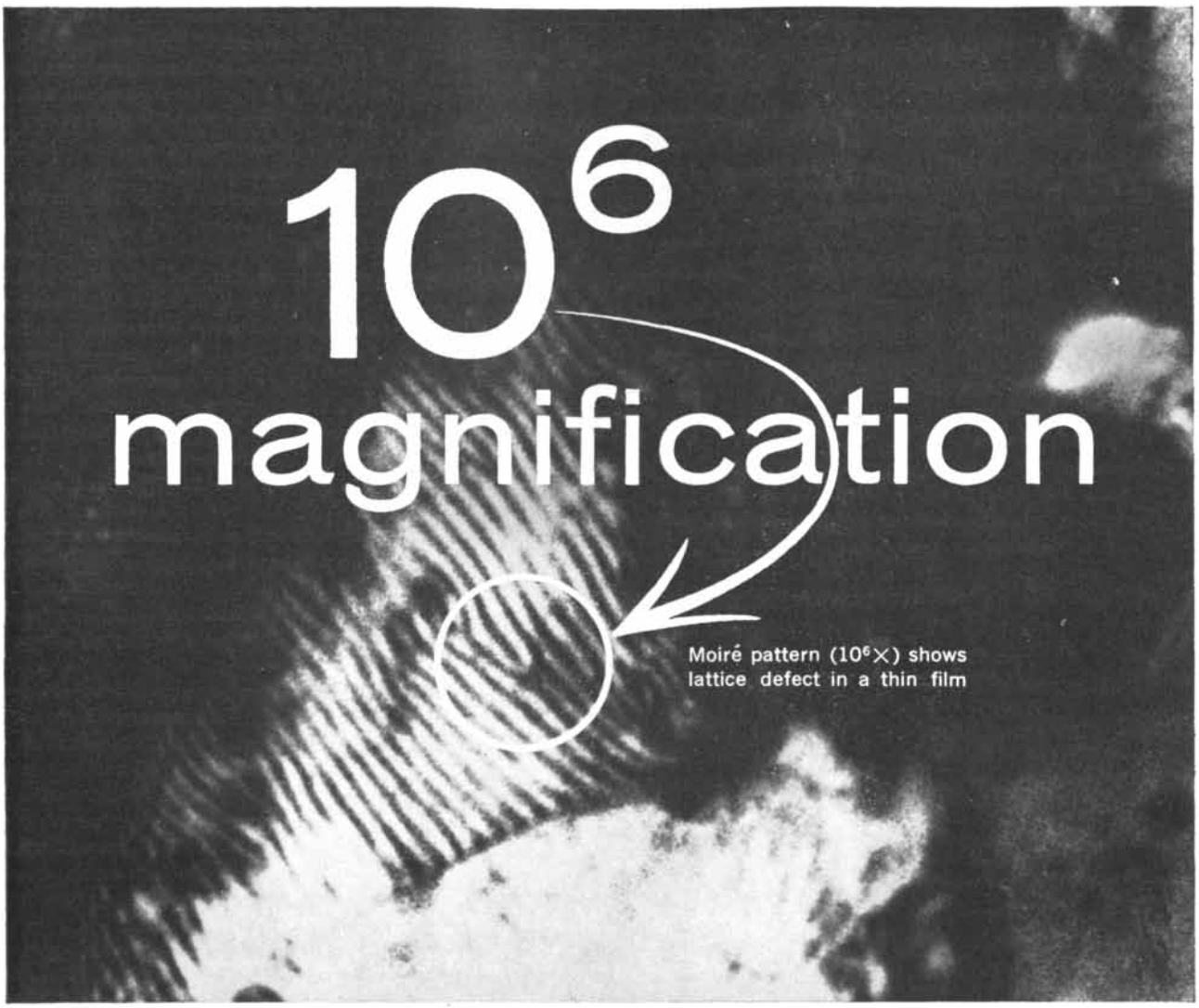
that whole armies traversed the land in marches of conquest. The Persians and the Romans once controlled the eastern portion; there were great Arab invasions in the 11th century; the Portuguese under Prince Henry the Navigator established commercial outposts and built up a flourishing slave trade; the Turks ruled loosely in the eastern Sahara in the 19th century, followed by the Italians; the French, once they got a foothold, gradually extended their sphere of influence southward across the western desert.

In short, not since pre-Roman times have the peoples of the Sahara been cut off from either their neighbors or the outside world. They have continued to live essentially as they lived then, "as links in a network of chains of communication, some strictly local, some regional or interregional, and others reaching far beyond the continent of Africa." But now this pattern is beginning to disintegrate under the pressure of mechanized transport and economic boom. Towns are springing up around oil wells; desert tribesmen are flocking to them to sleep in air-conditioned huts with running water and to eat European food prepared under the direction of professional dietitians. Jeeps and special desert trucks (equipped with refrigerator and deep-freeze units) are making tracks in areas where no vehicle has been seen since the days of the chariot. And the people themselves are changing: Briggs speaks of an aristocratic young desert warrior of the Ahaggar Tuareg recently boarding a northbound plane at Tamanrasset, dressed in a soft felt hat, a black leather jacket and blue jeans.

The Sahara has many cities, and they are as diverse as the landscape. Oases, watering points, small agricultural centers stud the southern half. They are peopled mainly by Negroid folk, known by the general term Haratin. The emergence of this group from a neolithic nucleus of Negroid Sudanese and white Mediterraneans, later mixed with Berber refugees, bush Negro slaves and others, is a story too complex to untangle; but the mixture of the strains is thought to be one reason why the Haratin seldom have a language of their own but speak that of the white group with which they are in contact. They work their little gardens as sharecroppers, the landlords being whites and often warlike nomads. Haratin homes are dugouts, patched-up tents or *zeribas*, which are huts made of grass or palm fronds attached to a framework of sticks; the more prosperous live in one-story adobe houses with two or three windowless rooms. A Haratin center has a few tiny shops that offer cloth, salt, sugar, tea and tobacco, and sometimes simple hardware, cheap perfume and manufactured leather goods. The town, if such it may be called, usually has a couple of bakers, a tailor, a butcher or two. It is also likely to include two or three families of smiths, a special class of people identifiable by their economic function and social position, and found scattered clear across the Moslem world. They make iron, copper and brassware; they are jewelers, tinkers, tanners; they are also regarded with superstitious awe as makers of amulets and charms, "brewers of insidious concoctions and casters of powerful spells." Like a witch doctor or an alchemist—or shall we say a scientist?—a smith is despised and feared; he lives apart, comes and goes as he pleases, and is unmolested. The history of smiths is uniformly obscure, but there is reason to believe, says Briggs, that some of them may have enjoyed an unexpected degree of importance in the past.

Among the many strange people of the desert are the Dauada, a tiny tribe of the eastern Sahara. Like the Haratin they are sedentary food gatherers, but they are not servile sharecroppers. Some few hundred souls in all (together with a handful of assimilated refugees from neighboring nomadic tribes) live in tiny clusters of *zeribas* on the shores of three small, very salty lakes in the Erg Oubari. From these lakes they gather a primitive kind of shrimp, an eighth of an inch long, which flourishes in such abundance that at times the water actually looks pink. This shrimp, *Artemia salina*, is their most important economic resource; it is known as *dood*, an Arabic word for "worms," and has given its name to the Dauada, which means literally "wormers." Briggs characterizes the Dauada as "one of those humble, colorless and rather unattractive little groups which pass almost unnoticed in the presence of relatively spectacular and interesting neighbors, in this case warlike pastoral nomads and rich merchants of the caravan trade." It seems altogether amazing that such little tribes should survive, stubbornly holding on to their land and their ways.

In the central zone of the Sahara there are fewer pure agricultural centers and more trading places. The gardens are larger and furnish food not only for the towns themselves and the sedentary and nomadic landlords, but for merchants and traders. As one moves northward, this trend is accelerated. Larger urban centers are transfer points on caravan routes and market places which, in Briggs's apt phrase, act as "pumping stations" on pipelines of trade, and thus, incidentally, stimulate the flow of "cul-



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tural currents across and beyond the limits of the desert."

Fairly typical of this category are the five little walled cities of the Mzab, with Ghardaia, founded in 1053, as their capital. The dwellings of such fortress towns are often crowded together on a rocky outcrop; the gardens and palm groves lie in the bottom land. A town house is a cubical affair, 30 to 40 feet on a side, two or three stories high, with thick walls of stone or adobe brick finished with a coat of clay. Ground-floor rooms are eight to 10 feet high, the bedrooms windowless. Heavy housework is done downstairs; above is a formal parlor where honored guests are entertained. On the roof terrace rugs, bedding and laundry are put out to air and dry, along with a dog and perhaps a goat, and here the women sit and sun themselves while the children play.

The political organization of the urban centers is worth noting. Almost universally, says Briggs, the community is divided into two parties, loosely referred to as *sofs*. These are political factions, usually of the more conservative and the more progressive citizens. As in all things there is a yin and a yang, Democrats and Republicans, so "pairs of *sof*-like parties" are common among Moslem communities in many lands. What is important is the division and opposition rather than its cause. Sometimes the major parties consist of those who live in different halves of an oasis—the right and wrong sides of the track, so to speak. Sometimes the dichotomy is expressed in the fact of two mosques, representing an old and forgotten dispute over religious doctrine (*e.g.*, whether Aisha, the young wife of the prophet Mohammed, was faithful or a cheating hussy); sometimes the cleavage is ethnic. Whatever its other merits, the Saharan two-party system seems to have at least one strong point: since the factions are pretty evenly balanced, the danger is small of a basically republican form of government turning into a dictatorship, either by the disproportionate weakening of one party or by splintering into groups so small and numerous as to be incapable of resisting despotic encroachment.

Socially debased groups, it should be pointed out, do not affiliate with the major factions. Even so, among certain minorities, the dual pattern is reproduced in miniature. Thus, for example, the Jews of Ghardaia, of whom there are only about 1,200, are bitterly split into two parties which disagree violently on nearly all questions of general policy. They stand together against Moslems and Christians, but on all other issues,

social or economic, they are implacably antagonistic, even though members of opposing factions often live in adjoining houses.

The Mzabite form of government is a "theocratic autocracy." Each community is ruled "with a rod of iron" by two councils of elders chosen mainly on the basis of age and religious learning. A theocratic council, the *halga*, has supreme legislative and judicial power, while the *djemaa*, a lay council, has the executive function. So absolute is the power of the councils, and so great the fear they inspire, that in Algiers Mzabites have been secretly tried, condemned and even executed without the knowledge of the French authorities.

The preferred form of marriage among Mzabites is between children of brothers. Boys marry when they are 17 or 18, girls when they are 12 to 14, and although a French law forbids the marriage of girls under 14, the Mzabites are exempted from its provisions. When a Mzabite man goes off to set up a grocery shop in one of the cities of northern Algeria, which is not uncommon, and leaves his wife behind, any child she bears within two years of his departure is by Mzabite legal theory held legitimate. Since it is the practice for the departing father to hang up a pair of his trousers in the bedroom (either, Briggs suggests, as a proxy "endowed with power of magical procreation" or "as a concrete symbol of his spiritual presence"), the Mzabites, though perfectly prepared to grant legitimacy to the child, permit themselves the term "child of the trousers" for a baby born more than nine months after the husband's departure.

Briggs's chapter on the sedentary tribes contains an immense amount of information on the many different peoples in the urban centers: Arabs, Berbers, Jews, Negroes; people who have their own cherished ways, their own (often unchangeable) social and economic status, their own religious beliefs and practices, and who, despite profound differences, manage to live side by side in peace. The material makes an admirable monograph in itself, yet it is no more than the forerunner of a series of excellent chapters devoted to the main groups of Saharan tribes, which are nomadic.

He describes the Tuareg, numbering some 140,000 persons, who are divided into three confederations, of which the Ahaggar branch, with whom he has lived, receive his main attention. In Henri Duveyrier's words, the Tuareg "are all thin, dry and sinewy; their muscles are like springs of steel." They

are among the tallest people in the world (averaging only half an inch under the average male American), white-skinned (when not sunburnt), thin-nosed, dark-haired, dark-eyed. But since men are known to stray and nature enjoys its little jokes, red-haired Tuareg with blue eyes and freckles are not unknown; there are also many who are visibly Negroid, in both the noble and vassal classes. The Tuareg live in leather tents, preferably made of goatskin. Among their household goods are sheepskins, rugs, leather bags for food, saddles, bridles, weapons, wooden bowls, funnels, spoons and a quern of neolithic or Roman type for grinding corn. The spoons, by the way, are an interesting item, because until very recently all Saharan peoples other than the Tuareg ate with their fingers. Camps are pitched in an inconspicuous spot on high ground and are kept very tidy and clean. Leather shirts used to be worn, reaching below the knee; 2,500 years ago Herodotus described Libyan women as wearing fringed garments of red leather, and some Tuareg women still do, but the costume is getting rare. The men today wear loose baggy trousers of dark blue or black cotton cloth, held in place with a braided leather cord. The seat is baggy, the ends of the legs are sewed up to fit snugly around the ankles, there are no pockets and no fly. A huge rectangle of white cotton cloth, eight feet wide by 10 feet long, called a *gandoura*, folded over on itself with a V-shaped opening for the head and neck and sewed so as to leave the bottom and most of both sides open, is worn next to the skin, and usually a blue gandoura is worn over it. In cold weather an Arab burnous, a long hooded cloak made of wool or of camel's hair mixed with wool, serves as an outer garment. Standard footgear is a thin-soled sandal, shaped like a big figure eight and held in place by leather thongs. Among the armaments carried before the introduction of modern firearms were swords (imported from Italy, Germany and Spain), arm daggers, seven-foot iron spears, javelins, and shields made of antelope hide. Arm rings made of a soft greenish stone, boiled in fat to turn them black and give them a lustrous finish, are worn by Tuareg men as jewelry; their original purpose was to protect the blood vessels and tendons of the sword arm.

The most distinctive article of male clothing is the "mysterious *teguelmoust*," a 10-foot veil and turban made of lightweight cotton cloth, which is wound round and round the head, leaving exposed only the eyes and a small patch at the back of the scalp. Tuareg men

think it "shockingly indecent" to let the mouth be seen by anyone to whom one owes formal respect. While eating and drinking, the left hand is slipped under the veil to hold it away from the chin and mouth and to continue to conceal them during the process. How one arranges the veil is intended to reflect changes in mood and attitude, social status, clan affiliations and the like. (Among some of the American Plains Indians, buffalo robes are disposed in various ways about the neck and shoulders for the same purpose.)

The ancestry of the *teguelmoust*, the custom of veiling men instead of women, the practical uses of the veil as a protection against the sun and a conserver of moisture are considered in detail, as are the dress and cosmetic practices of Tuareg women, the disinclination of the people to bathe ("a dirty-looking, bluish skin is admired as a symbol of prestige"), diet (mainly milk and milk products), food consumption (which is barely above the starvation level) and their taboos (*e.g.*, they don't eat hen's eggs because hens live on unclean refuse, and they don't eat certain large lizards because they are "maternal uncles" of the Tuareg).

The range of the Ahaggar is about the size of New York, Pennsylvania, Virginia and Maryland put together (*i.e.*, 146,000 square miles) and supports a native population of about 12,000—half as many persons, Briggs observes, as work in the Pentagon. Of this number about 4,500 are Tuareg, 4,000 are Negro slaves and 3,500 are sedentary Haratin. The Ahaggar Tuareg are further divided into tribes, each headed by a noble clan which has satellite vassal clans. The premier noble clan provides a chief, selected by a clan council made up of the male heads of households; he must be confirmed by a council of representatives of all the clans of the entire tribe, for the nice practical reason that his tenure depends on the willingness of the tribe as a whole to pay him tribute.

Rank and privilege are inherited through the mother, property from both parents. Boys are circumcised between the ages of five and seven. Young ladies remain virgins until wed, though marriage usually comes late: 20 to 25 for women, 30 for men. Monogamy is the rule, divorce is disapproved, adultery is neither more nor less prevalent than in most cities where husbands often go off on their business for months. A cuckolded husband has the legal right to kill his wife and her lover, but as a rule he is less violent and merely shucks her off; or he may decide to keep her, in which case

he sees to it that the corespondent is fined. A betrayed wife either goes back to her people or follows the universal custom of pretending to be ignorant of the whole affair.

After explaining fully the high place of women in the Ahaggar, and the concept of "courtly love" which permeates their whole system of intersexual relations, Briggs describes their daily way of life. Like all Saharan nomads, the Tuareg live primarily off their livestock; and since livestock in turn lives off pasturage, which is sparse, the clans break up into small, mobile groups which move frequently and over long distances, but always within the tribe's territorial limits. The Tuareg have a class system that is rooted in their environment and reflected in their activities. The nobles, together with the headmen of the vassal clans, ride out in search of new pastures and also act as military scouts on the lookout for enemy raiders or victims. The vassals manage the flocks and herds and constitute an armed reserve that can be called up for large raids. The slaves—Negro captives from the Sudan or their descendants—do domestic service and household chores, while their sons serve as shepherds. (All slaves, it should be noted, are now theoretically free, but in practice they are still chattels who can be bought, sold and inherited.) Superficially it may seem that this is a feudal order like that of medieval Europe, but the comparison is false. On the one hand, Briggs observes, the pastoral community can only survive nomadically, and "no community of nomads can survive without a rigidly formalized division of labor and firm authority based on established rank"; on the other hand, it is the vassals who are really in control "for they can make and at least in theory break the mightiest of all the nobles, the Amenokal himself, and they can do so by peaceful means, again at least in theory." Their government is in fact "a kind of republic" (as opposed to a democracy) and not an absolute monarchy or military aristocratic autocracy.

The Tuareg breed camels, goats, sheep, donkeys, cattle; they collect garden rent; they engage in foreign trade, salt being the chief article of export; they used to receive revenues from the control of caravan trade routes over a very wide area—a kind of protection racket. European domination, however, has drastically shaken the structure of their economy. Raiding is a thing of the past, as is the protection business. Foreign trade has dwindled, and even pastoralism is not what it was. Socially, economically, politically, in their pursuits

and material culture, the Tuareg had adapted themselves successfully to an extremely harsh desert environment. But the forces of European civilization, though striving for reform and material betterment, have so undermined the Tuareg economic base, and the Tuareg have shown themselves so stubbornly resistant to change, that their name must be added to the "ever lengthening list of vanishing peoples."

Succeeding chapters deal with the fiercely individualistic Teda of the southeastern central Sahara, numbering about 200,000 some 40 years ago (among whom the high position of women is illustrated by an admirable ritual: when, on rare occasions, a man insults his wife in public, she promptly strips off all her clothes, flings them on the ground and stalks haughtily away through the assembled bystanders to her tent); with the Arab nomads, consisting of many different groups; with the proud and warlike Moors.

The peoples of the Sahara have never been united, nor have they even considered uniting in any common cause. Indeed, "only by bitter competition" have they been able to survive at all. Unity under an Arab dictatorship, says Briggs, is most unlikely, if for no other reason than that the concept of nationalism is foreign to Islamic thought regardless of the propaganda use of the term by contemporary Moslem leaders. The prospect of a stable democratic confederation, under paternal European domination, is no more likely. Politically and economically the tribal organizations are breaking down. The foundations of nomadic life have been eroded; commerce and industrial employment are drawing the gardeners and artisans as well as the warriors. The social structure cannot withstand these pulls and pressures.

Briggs is a little nostalgic about the gradual disappearance of nomadism. Its grand days, as he says, are over. Without sentimentalizing the people, he has come to admire and even love them; and he has made it quite clear that whatever blessings Western civilization may yet bring to the tribes of the Sahara, they are now worse off than a century ago. This is a masterly book, and though it is a picture of a vanishing scene, an understanding of that scene is the only real hope for rational policies in the future.

Short Reviews

THE FIRMAMENT OF TIME, by Loren Eiseley. Atheneum ($3.50). "God seldom alters or perverts, but like an Excellent Artist, hath so contrived his

work, that with the self-same instrument, without a new creation, he may effect his obscurest designs." These words uttered by Sir Thomas Browne in 1635 were a prophecy, though unknowing, of discoveries to come: the clockwork universe of Newton and Laplace; the grand scheme of Hutton, by which time, rain and the wind continually fashion and refashion, waste and repair the face of the earth; the evolutionary hypothesis of Darwin; even the unsettling ideas of modern physics and cosmology which have undermined the notion of a mechanical universe rolling on securely into the limitless future. How man has changed his view of the world and of his own place in it, how he has fathomed the obscurest designs effected by the "self-same instrument," is the subject of this book, which consists of six lectures Eiseley gave in 1959 as visiting professor of the philosophy of science at the University of Cincinnati. The word "natural" is the key to the progression he describes for us. The achievement of science is to expel the miraculous—the repeated Divine interventions —from the model, and to make it work by itself: rational and understandable, obedient to law. Thus all becomes "natural": the changes in the earth, the appearance of life, the origin and extinction of species, the evolution of man himself. And yet the explanation, brilliant, courageous and immensely fruitful though it is, does not fully explain, for the question still to be answered is how natural is "natural." The very triumphs of science and technology have made us take the natural for granted, to forget our origins and the chain of being. And the danger grows that in our arrogance and confusion we may, until it is too late, spurn the opportunity to pass through a doorway "which widening out, will take man beyond the nature that he knows." This is a sensitive and a stirring book. It is sometimes too eloquent, the argument is obscured in a lyrical mist, the lucid exposition interrupted by poignant episodes of intimate self-revelation. But Eiseley is a poet as well as a scientist, a man who is not ashamed both to feel and to impart his feelings, and no one who reads these lectures will fail to take their meaning, to be disturbed, enlightened and refreshed.

EVOLUTION AFTER DARWIN. VOL. I, THE EVOLUTION OF LIFE: ITS ORIGIN, HISTORY AND FUTURE; VOL. II, THE EVOLUTION OF MAN: MIND, CULTURE AND SOCIETY; edited by Sol Tax. University of Chicago Press ($10 each). The University of Chicago commemo-

rated the 100th anniversary of the *Origin of Species* by a scholarly celebration in November, 1959, to which were invited a large number of scientists and scholars who were asked to contribute papers dealing with their special interests in evolution, and later to participate in panel discussions. The literary fruit of this resplendent undertaking consists of three volumes, of which the two noted here have been published; a third, containing a small group of papers on the relationship between "science and spiritual values" and reports of the panel discussions, is to appear in the near future. So numerous are the essays, so rich and varied, that even a long review could do no more than describe briefly some of the contents; and an over-all critical appraisal of a work made by so many specialists is beyond the competence of any single reviewer. It is nevertheless safe to say that this survey is by far the most comprehensive and illuminating stock-taking at the mid-century of the departments of scientific knowledge which have grown out of the evolutionary hypothesis. In the first volume Sir Julian Huxley considers the emergence of Darwinism; Harlow Shapley, the evidences of inorganic evolution; Hans Gaffron, the origin of life; George Gaylord Simpson, the history of life as revealed by the fossil record. E. B. Ford's "Evolution in Progress" takes up the industrial melanism of moths ("the most striking instance of evolution ever actually witnessed in any organism, animal or plant"); G. Ledyard Stebbins, Jr., examines the comparative evolution of genetic systems; Daniel I. Axelrod devotes 80 pages to the evolution of flowering plants; Ernst Mayr treats of the "emergence of evolutionary novelties." C. H. Waddington raises some sharp questions about natural selection in his "Evolutionary Adaptation," as does Everett C. Olson in "Morphology, Paleontology and Evolution," which makes the point that the variety of phenomena "and the opposing features of many of them" that have to be explained by the selective process "appear to require manipulations of the available mechanisms to degrees that seem almost incredible." Also excellent are Theodosius Dobzhansky's "Evolution and Environment"; Sewall Wright's "Physiological Genetics, Ecology of Populations and Natural Selection"; N. Tinbergen's "Behavior, Systematics and Natural Selection"; and G. F. Gause's "Darwinism, Microbiology and Cancer," which suggests that since all living things are related through origin from common ancestors, a promising approach in cancer research is to look for

"possible equivalents of cancer cells among microorganisms." The essays of the second volume wander over even broader territory, and while the connection with Darwin's biological idea is, as one would expect, sometimes more metaphoric and analogical than real, the interest is maintained, and one never doubts the solid merit of this part of the program. Cultural evolution (which, as one reviewer has nicely said, is " Lamarckian," compared with biological evolution, which is selective and genetic) is the central theme, with papers by Alfred L. Kroeber ("Evolution, History and Culture"), S. L. Washburn and F. Clark Howell ("Human Evolution and Culture"), François Bordes ("Evolution in the Paleolithic Cultures"), Gordon R. Willey ("Historical Patterns and Evolution in Native New World Cultures"), Robert M. Adams ("The Evolutionary Process in Early Civilizations"). Other contributors are Cesare Emiliani on Pleistocene dating; H. W. Magoun on evolutionary concepts of brain function; Henry W. Brosin on psychiatry and evolutionary theory; Ernest R. Hilgard on psychology after Darwin; C. G. Darwin on population control; A. Irving Hallowell on behavioral evolution and the interplay between psychological "restructuralization," biological change, socialization, transmission of group habits, tool-using and communication; Hermann J. Muller on the possibilities of guiding human evolution by deliberate planned genetic tampering (recognizing the distinction between raising better corn or cattle and less bloodthirsty men). These books are in themselves an admirable course in contemporary thought, and Darwin would be overwhelmed if he could see them and realize what he started.

ART AND ILLUSION, by E. H. Gombrich. Pantheon Books ($10). A lady who visited the studio of Matisse looked at one of his paintings and was emboldened to observe "But surely, the arm of this woman is much too long." "Madame," he replied, "you are mistaken. This is not a woman, this is a picture." The anecdote might be said in a sense to summarize the main theme of this engrossing book, subtitled "A Study in the Psychology of Pictorial Representation," which is based on a series of lectures by the author, now director of the Warburg Institute of the University of London, at the National Gallery of Art in Washington in 1956. In his well-known *The Story of Art* Gombrich had sketched the development of representation from the conceptual methods of

the primitives and the Egyptians, "who relied on 'what they knew,' to the achievements of the impressionists, who succeeded in recording 'what they saw.' " Painting what one "knows" and painting what one "sees" are traditionally held to be quite distinct and different methods of expression, as if the light of the first came from inside and that of the second from outside. But the distinction, like similar distinctions in the theory of knowledge or the philosophy of science, is obviously too simple. It may be granted that there are artists who strive for meticulous imitation and reproduction of nature, and others who seem to shun, as if they were carriers of plague, any shapes and shades that might be thought to suggest the forms of common experience; but the most skillful imitators cannot hope to be cameras and those who make a fetish of creating entirely from within cannot hope to be pure incense pots. At the end of his earlier book Gombrich had asserted that no artist can "paint what he sees"; and in this study he strengthens and expands the theme, drawing upon other fields outside art itself, to demonstrate how the visible world is interpreted and coded by the artist, how contemporary conventions and stereotypes shape the style of a given period, how beliefs about the function of art affect its methods, and how the psychology of vision plays its part. Nor may one overlook, as he emphasizes, the "beholder's share," for art is a dialogue between the one who creates and the one who responds, each having a task of interpretation in the course of which they must find an area of agreement—which is what they "see." "Even if we drew one of these Indians with white chalk," said Apollonius of Tyana to his companion Damis, commenting on some metal reliefs which they found on their travels in India, "he would seem black, for there would be his flat nose and stiff curly locks and prominent jaw . . . to make the picture black for all who can use their eyes. And for this reason I should say that those who look at works of painting and drawing must have the imitative faculty and that no one could understand the painted horse or bull unless he knew what such creatures are like." The tradition of the time, says Gombrich, limits the artist as severely as the materials and techniques at his disposal and his knowledge of perspective and optics. He has a range of choice, to be sure, but it is narrower than is commonly supposed. Yet the tradition disciplines and strengthens as well as hampers, for if there were no stereotypes there would

be no landmarks, and the visual world might be for the artist what it is said to be for the newborn baby—all blooming, buzzing confusion. Gombrich's book is not always convincing in its analysis of the style of a period, in explaining just how the environment of ideas conditions the artist, or in making clear the circumstances which favor the mixtures and mutations that have brought about the changes in pictorial representation from cave painting to impressionism and abstract art. He is not much better at telling us how artists innovate than others have been in telling us how scientists invent. Yet one admires this essay for its richness and breadth of example, and for its remarkably apt illustrations of the same scenes and objects portrayed in different times, each according to prevailing preconceptions. Altogether a most interesting survey, which enlarges the understanding of art, removes its development from a closed and esoteric domain, and shows its links with other branches of human effort.

IMAGES OF MAN: THE CLASSIC TRADITION IN SOCIOLOGICAL THINKING, edited by C. Wright Mills. George Braziller, Inc. ($7.50). Never one to run with the pack, Mills has made this collection of 19th-century and early 20th-century sociological writings reflect his own tastes and critical judgment. This makes for a book of character, an illuminating book well above the usual level of social science anthologies. The ideas of the "classic" sociologists are "attempts to state the general historical trend, the main drift, of modern society." The classic sociologist, says Mills, is not a nervous pedant, worried about crossing academic boundaries and pathetically eager to ape the model of the physical sciences. As here represented he has a vision of society as a whole and a bold theory which he uses to interpret this vision. The theory will share the fate of all theories: in time, as more evidence accumulates, as analysis becomes sharper, it will be overthrown or at the very least substantially modified. But its accuracy is not in the long run the measure of its value; what is important is that it defines a position which can be tested, that it stimulates social reflection and inquiry. If, as is quite understandable, you have to struggle to keep awake reading most modern sociologists, you have an agreeable experience in store in these pages. The very first selection, "The World Outside and the Pictures in Our Heads," from Walter Lippman's best book, *Public Opinion*, sets a lively pace; there follow excellent pieces by Herbert

Spencer, Karl Mannheim, Karl Marx, Max Weber, Joseph Schumpeter, Emile Durkheim, Georg Simmel and others who had something to say and knew how to say it.

ADVANCES IN COMPUTERS, VOL. I, edited by Franz L. Alt. Academic Press, Inc. ($10). A collection of papers on computer methods, systems and applications. Included are articles on numerical weather prediction, the present status of automatic translation of languages, programming computers to play games, machine recognition of spoken words. Several of the monographs are unusually interesting not only for their theoretical and descriptive content but also for their salutary deflation of the extravagant claims which are so often made about what computers can do and have already accomplished. Yehoshua Bar-Hillel, for example, in his article on language translation (a critical survey based on a 1958 visit to almost all U. S. research centers) points out that fully automatic, high-quality translation "is not a reasonable goal, not even for scientific texts"; and the best to hope for, though it is far from having been attained, is fully automatic low-quality translation or partly automatic high-quality translation. Machine translation has a useful future, but it will not prompt the appearance of poems in praise of IBM artistry such as Chapman's *Homer* evoked from Keats. Arthur Samuels's essay on game-playing computers raises similar doubts. The best chess automaton yet devised or even theoretically conceived is a dull duffer. This is partly because chess is a hard game, partly because those who design machines to play it are mostly second-rate chess players without a very clear idea of what they are after, and partly because the first-rate players are themselves quite incapable of advising on just what it is that makes them as good as they are. It is doubtful, after all, that Newton could have told anyone how to be a discoverer, Mozart how to write great music, or Monet how to paint a masterpiece. There is too much hubris in the computer business.

Notes

AN INTRODUCTION TO KANSAS ARCHEOLOGY, by Waldo R. Wedel. U. S. Government Printing Office ($3). A comprehensive report, based on field work conducted between 1937 and 1940, and a review of a considerable body of ancillary information about the available ethnohistorical, archeological and geographical data bearing on the ab-

original occupancy of Kansas. Fully illustrated by sketches, maps and plates.

THE DECIPHERMENT OF LINEAR B, by John Chadwick. Random House (95 cents). A Modern Library paperback reprint of Chadwick's account of the brilliant work of Michael Ventris in deciphering the Minoan-Mycenaen Linear B script, thus affording a clue to the culture of Crete and Mycenae. A postscript carries the story told in the original edition (1958) up to July, 1959.

THE COPERNICAN REVOLUTION, by Thomas S. Kuhn. Random House ($1.25). An inexpensive soft-cover reprint of Kuhn's able monograph on planetary astronomy in the development of Western thought.

MARINE ALGAE OF THE EASTERN TROPICAL AND SUBTROPICAL COASTS OF THE AMERICAS, by William Randolph Taylor. University of Michigan Press ($19.50). A comprehensive manual, 30 years in preparation, of the marine algae of the tropics: historical survey, geographical distribution, descriptive catalogue. Extensive bibliography and 80 plates.

PROGRESS IN AUTOMATION, VOL. I, edited by Andrew D. Booth. Academic Press, Inc. ($8.50). The first of a series, this volume contains papers on a number of devices in the field of automation in Great Britain.

THE REAL PROJECTIVE PLANE, by H. S. M. Coxeter. Cambridge University Press ($3.75). Paperback reprint of an attractive introduction to projective geometry, which can be understood by anyone familiar with high-school geometry and algebra.

PSYCHOANALYSIS AND THE FAMILY NEUROSIS, by Martin Grotjahn. W. W. Norton & Company, Inc. ($5.95). Deals with psychoanalytic therapy addressed to the problems of the neurotic marriage and the neurotic family.

THE STRUCTURE AND DYNAMICS OF THE PSYCHE, by C. G. Jung. Pantheon Books ($6). Volume VIII of the *Collected Works of Jung* contains essays, ranging over four decades of his career, which illustrate the development of his conceptual models from the time he broke away from Freud up to formulation of his theory of synchronicity, proposing the concept of "meaningful coincidence" as a dimension of understanding "over and above causality."

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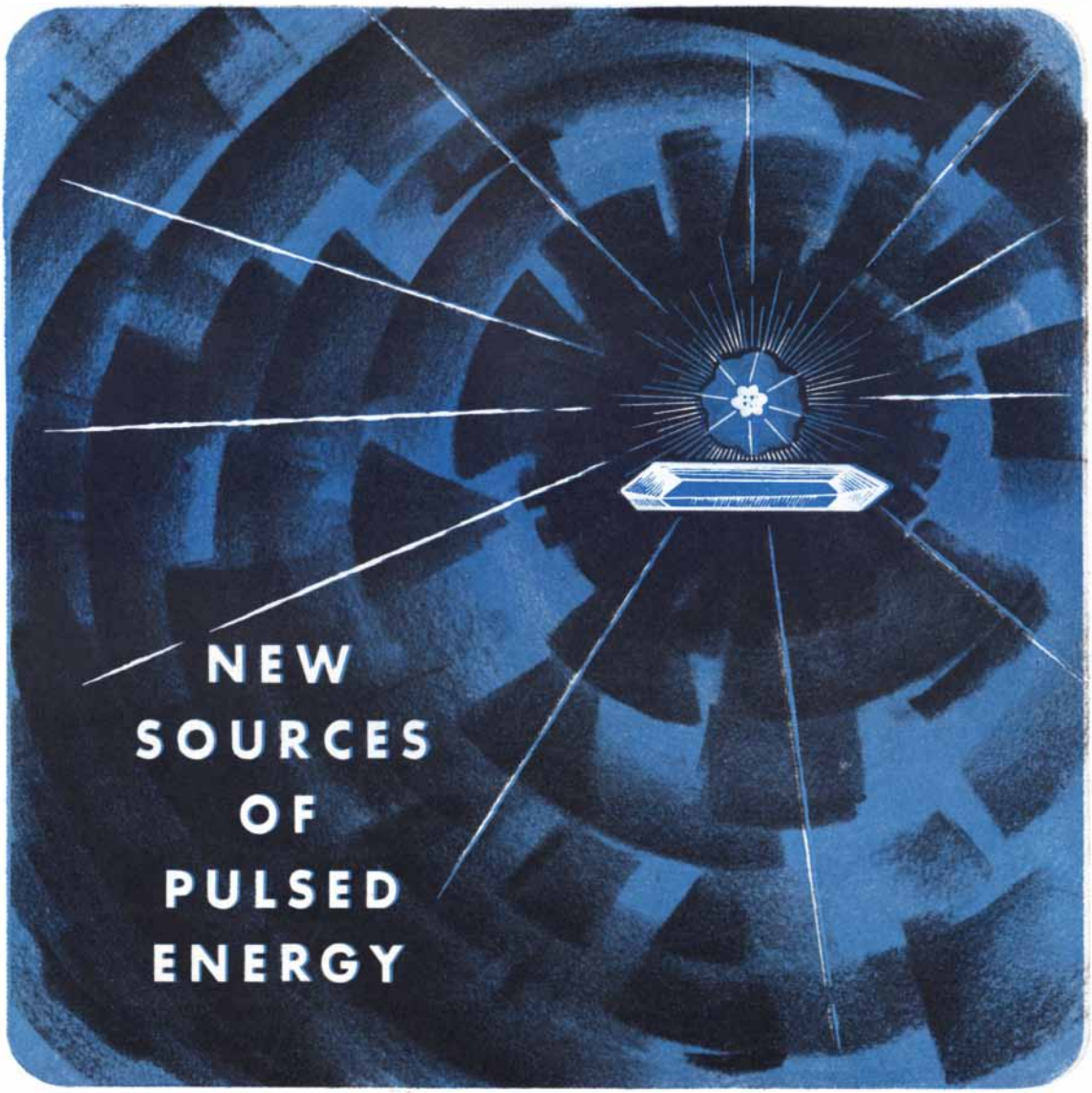

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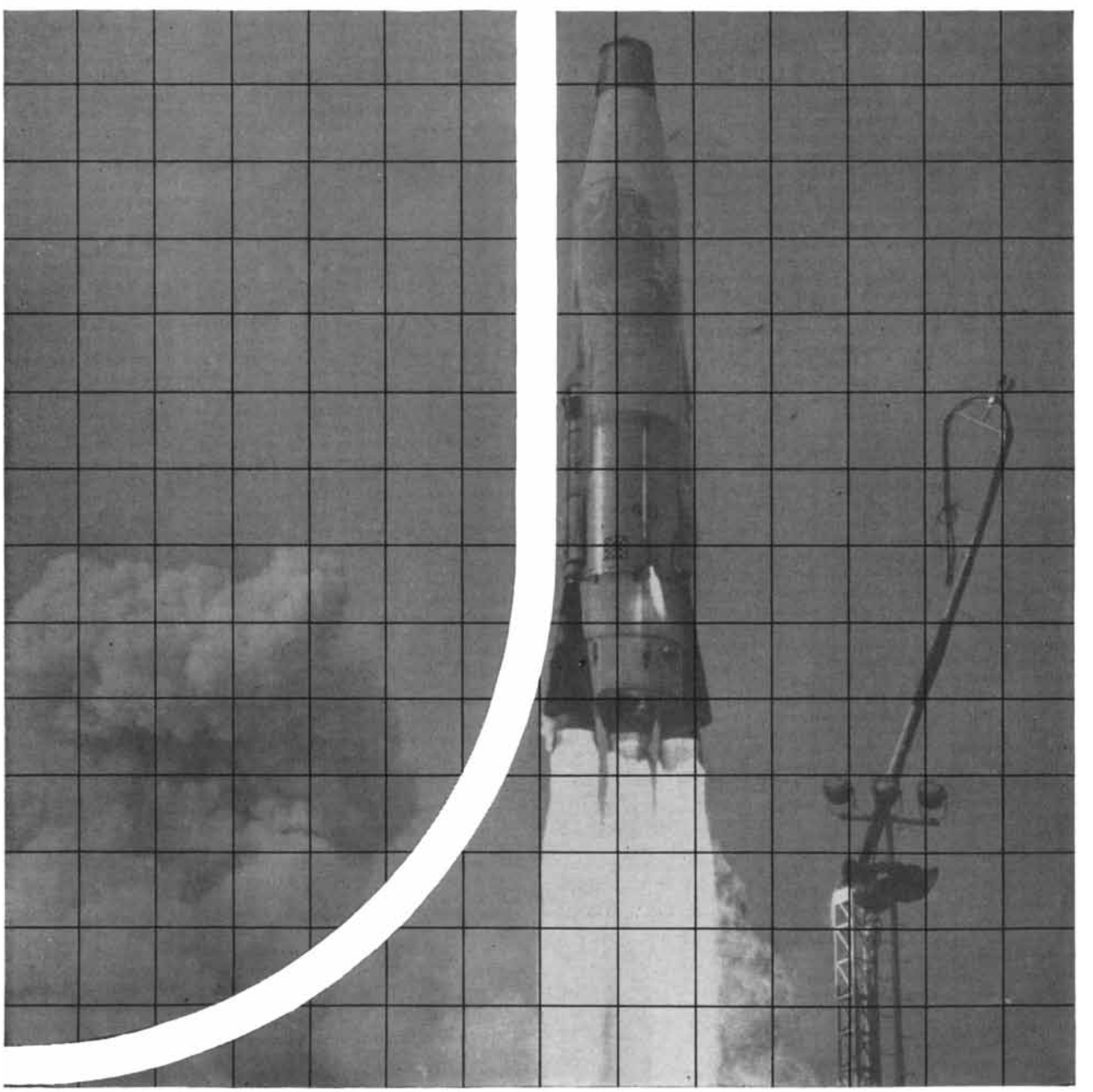

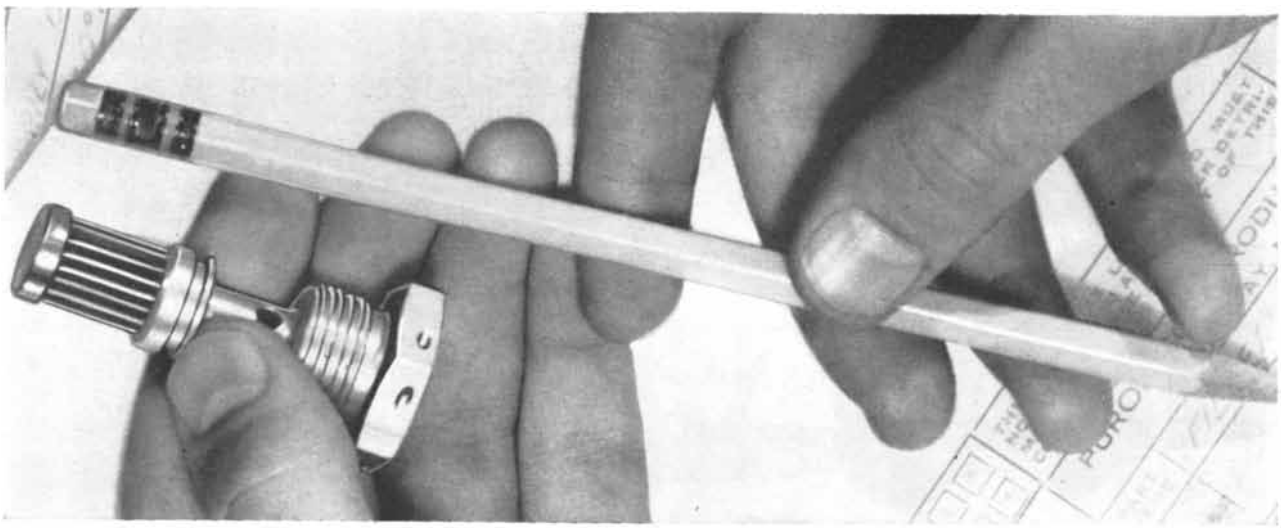

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