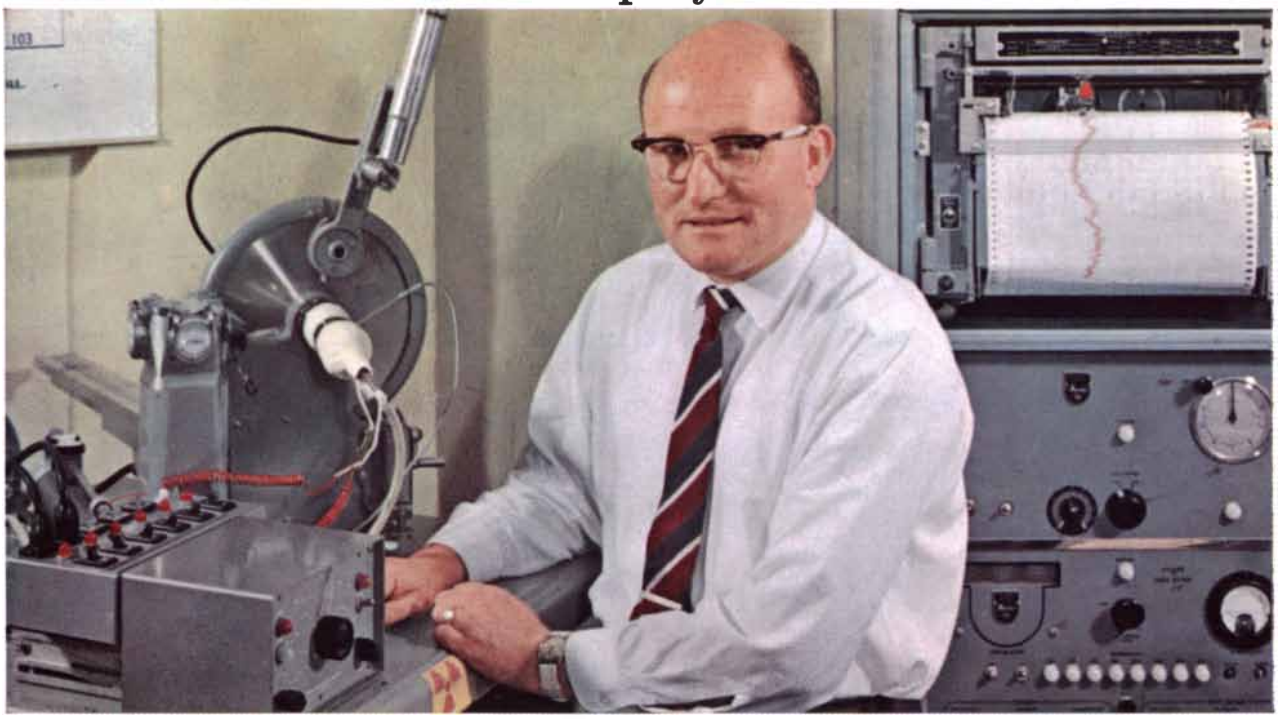
SCIENTIFIC AMERICAN

ANCIENT GLASS

FIFTY CENTS

November 1963

Basic Research at Sun Oil Company

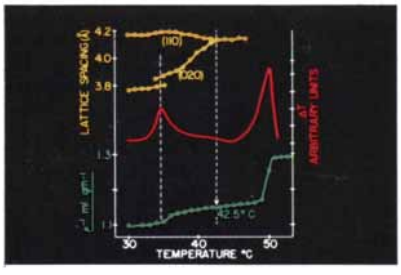


Discovery: The Transition Behavior of Waxes

The scientist shown above is Dr. David S. Barmby, Research Physicist at Sun's Marcus Hook Research Laboratory (B.Sc., Ph.D., Physics, University of Leeds, England; Associate of the British Institute of Physics; Member of the American Physical Society; and Member, Philadelphia Catalyst Club).

Dr. Barmby and his team of researchers are engaged in an extensive study of the physical behavior of paraffin waxes. The purpose of this study is to discover the true nature of wax solid-solid and solid-liquid phase transition processes and to determine the relationships that exist between fundamental and technological properties of waxes.

This basic research activity, which is essential to the Company's continuing development of new and improved wax products, involves a combination of techniques—X-ray diffraction, differential thermal analysis and volume dilatometric measurements. Progress to date has been significant, as reported in a recent paper.* Dr. Barmby's studies reveal that three different types of transition behavior are encountered.



Correlation between X-ray diffraction (top), differential thermal analysis (middle), and dilatometric data (bottom) for a paraffinic wax fraction.

Firstly, paraffin waxes melting below about 60°C exhibit two solid-solid transitions below their melting point. The lower transition is a lattice transition including both a volume and a latent heat change. The second transition, at a higher temperature, involves a gradual change from an orthorhombic to a hexagonal lattice structure with no discrete volume change and no observable latent heat. There is, however, a discontinuity in the thermal expansion coefficient at this second transition point.

The second type of transition behavior is encountered in waxes melting in the range 60-75°C. In these waxes, only a single transition occurs below the melting point and this transition always involves both a volume and a latent heat change. The third type behavior is found in the high melting point waxes where, as is well known, no solid-solid transitions are identified below the melting point.

In the first and second types of behavior, the endothermic transition occurs when the orthorhombic (110) and (020) lattice spacings reach critical values. In paraffinic waxes this criticallity appears as a constant specific volume at the transition point. Particularly significant to the wax technologist is the fact that these studies correlate, for the first time, the findings of the three techniques used, namely, X-ray diffraction, differential thermal analysis and volume dilatometric measurements.

Dr. Barmby's work has also resulted in a number of significant findings relative to wax crystallization, i. e., that the crystallization process is independent of both the melting point and the paraffinic hydrocarbon composition, that the process occurs by a two-dimensional growth mechanism involving secondary nucleation, and that the growth rate is diffusion controlled. Other studies have included investigations of the phenomena encountered in quenched wax films on paper substrates as well as the effect of polymer additives on the fundamental behavior of paraffin waxes.

The work of Dr. Barmby and his team is just one of many important major research programs currently under way at Sun. These programs, conducted at four separate research labs across the country, are led by other renowned scientists, are carried out by hundreds of R&D personnel and delve into such interesting and diverse subjects as: mechanisms of chemical reactions, microbial behavior in hydrocarbon media, synthesis of new organic compounds, and certain aspects of plasma physics.

SUN OIL COMPANY
1608 Walnut Street Philadelphia 3, Pa.

*Presented at the Sixth World Petroleum Congress, Frankfurt/Main, June 24, 1963.

SUNOCO

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This is silicon, the second most abundant element in the earth's crust. Its natural forms include quartz, rock crystal, amethyst, agate, flint, jasper and opal. These forms don't interest us, because we don't make jewelry.

But the silicon here is in a most-unnatural, pure, polycrystalline form. It does interest us, because from it we make more than four-hundred and twenty different silicon semiconductors. Many of them are PLANEX semiconductors, Raytheon's designation for planar epitaxial.

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Westinghouse assignment: Define a system to guide ships and planes everywhere

Westinghouse is defining for NASA a system of satellites and ground stations tailored specifically for the navigation and traffic needs of ships and planes.

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The traffic center will fix the craft's position by using a satellite as a navigational reference point. Then, the fix will be transmitted to the craft via the satellite. The complete operation will take only a fraction of a second.

Continuous monitors of appropriate agencies will scan worldwide traffic patterns and, again by satellite transmission, warn any craft in danger of collision. In the event of disaster, air and sea rescues will be able to get underway without delay.

Westinghouse is evaluating the problem so that such a system can be developed at minimum cost and with maximum benefit to civilian air and sea operations.

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Established 1845 **SCIENTIFIC AMERICAN** November 1963 Volume 209 Number 5

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THE COVER

The photograph on the cover shows an ancient Roman glass plaque, or tile (*see page 120*). Such plaques were formed by pairing two identical "slices" of a glass bar several inches long. The bar was built up by drawing and fusing together a number of separate design elements, each of which had been formed by combining variously colored glass rods. The cover picture was made by pairing two photographs of one plaque from the Corning Museum of Glass. The actual size is about the same as that in the picture above.

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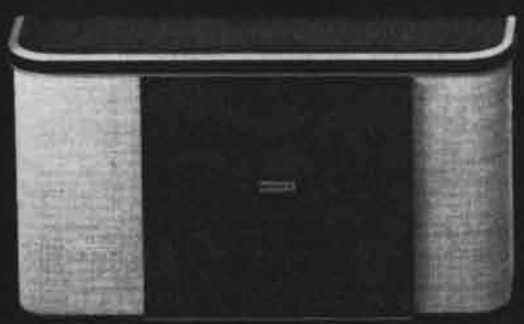

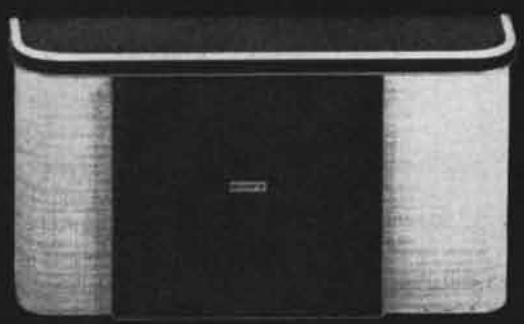

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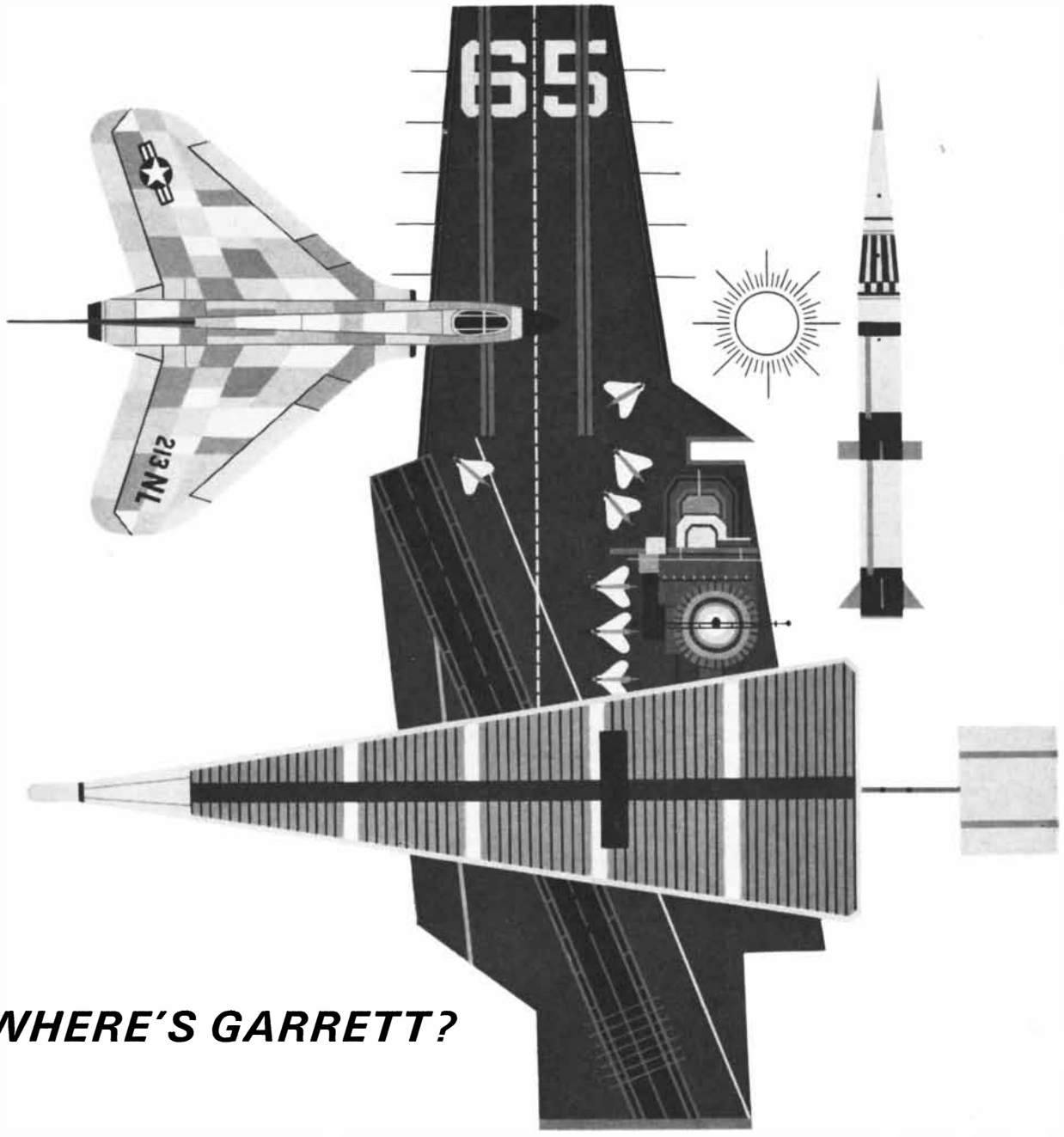

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EVERYWHERE! Here are a few of the ways U.S. defense and space progress are being helped by Garrett-AiResearch: ***IN SPACE***—Environmental control systems; auxiliary power systems; advanced space power systems; research in life sciences. ***IN THE AIR***—Pressurization and air conditioning for most of our aircraft; prime power for small aircraft; central air data systems; heat transfer equipment and hundreds of components. ***ON LAND***—Auxiliary power systems for ground support of aircraft and missiles; standard generator sets; cryogenic systems; ground support instrumentation and controls. ***ON THE SEA***—Auxiliary, pneumatic and electrical power for ships; auxiliary power systems and air conditioning for hydrofoil craft. ***UNDER THE SEA***—Environmental systems for submarines and deep diving research vehicles; pressurization systems, computers and control systems for submarines and underwater missiles.

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THE THREE BASICS

These are the three fundamental considerations behind every rack-and-panel connector application:

Geometry. The connector must fit the package. It must be small enough to serve unobtrusively in miniaturized equipment; large and rugged enough to handle the heavy duty jobs; and at the same time, accommodate the necessary number of interconnections.

Performance. Not only must a rack-and-panel connector mate perfectly. It also has to carry current with a minimum of resistance. And it must perform again and again in a wide range of environments.

Price. A truly great rack-and-panel connector should be a bargain. That is, the connector should deliver top value per purchase dollar.

LET'S TALK GEOMETRY

Blue Ribbons come in two series . . . small (26 series) and smaller (57 series . . . called Micro-Ribbons). Series 26 units pack 32 contacts into a $3\frac{1}{4}'' \times \frac{3}{4}''$ body with 8, 16, and 24 contact units available in proportionately smaller bodies. Micro-Ribbons come with 14, 24, 36, and 50 contacts and are, contact for contact, one-third the size of the 26 series. All are rated 5 amps.

Unlike pins and sockets, Blue Ribbon contacts join with a wedge-like mating action. Once united, resilient spring action binds male and female together.

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2. Remarkably low contact resistance because of large contact surfaces;
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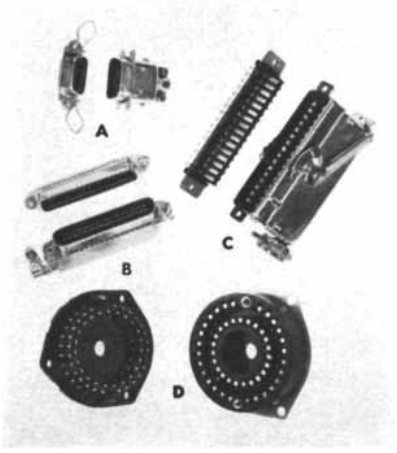
4. No pin bending or socket jamming.



Four Blue Ribbon connector types: (A) Micro-Ribbon 14-contact pair in cable-to-chassis housing; (B) Micro-Ribbon 50-contact pair with cable-to-chassis housing; (C) Blue Ribbon 36-contact pair in latch-type housing with end cable outlet; (D) Circular Blue Ribbon pair.

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Reliability? Over 5 billion contacts have been used by the maintenance-conscious telephone industry—without a single reported failure! (Confidentially, we think there must have been a failure someplace, but nobody told us about it.)

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Blue Ribbon prices are down, too. But for a different reason. Blue Ribbon prices have resulted directly from the acceptance that this unique connector has built up since its introduction nearly fifteen years ago.

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You can get Blue Ribbon (or Micro-Ribbon) connectors as fast as one of our sales offices or stocking distributors can arrange shipment.

If you'd like to know more about Blue Ribbon connectors, just write to: Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 S. 54th Avenue, Chicago 50, Illinois.

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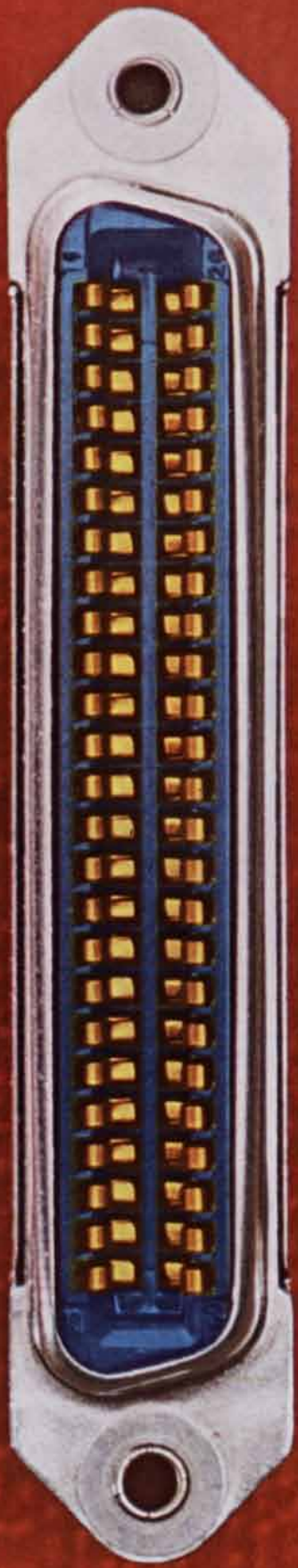

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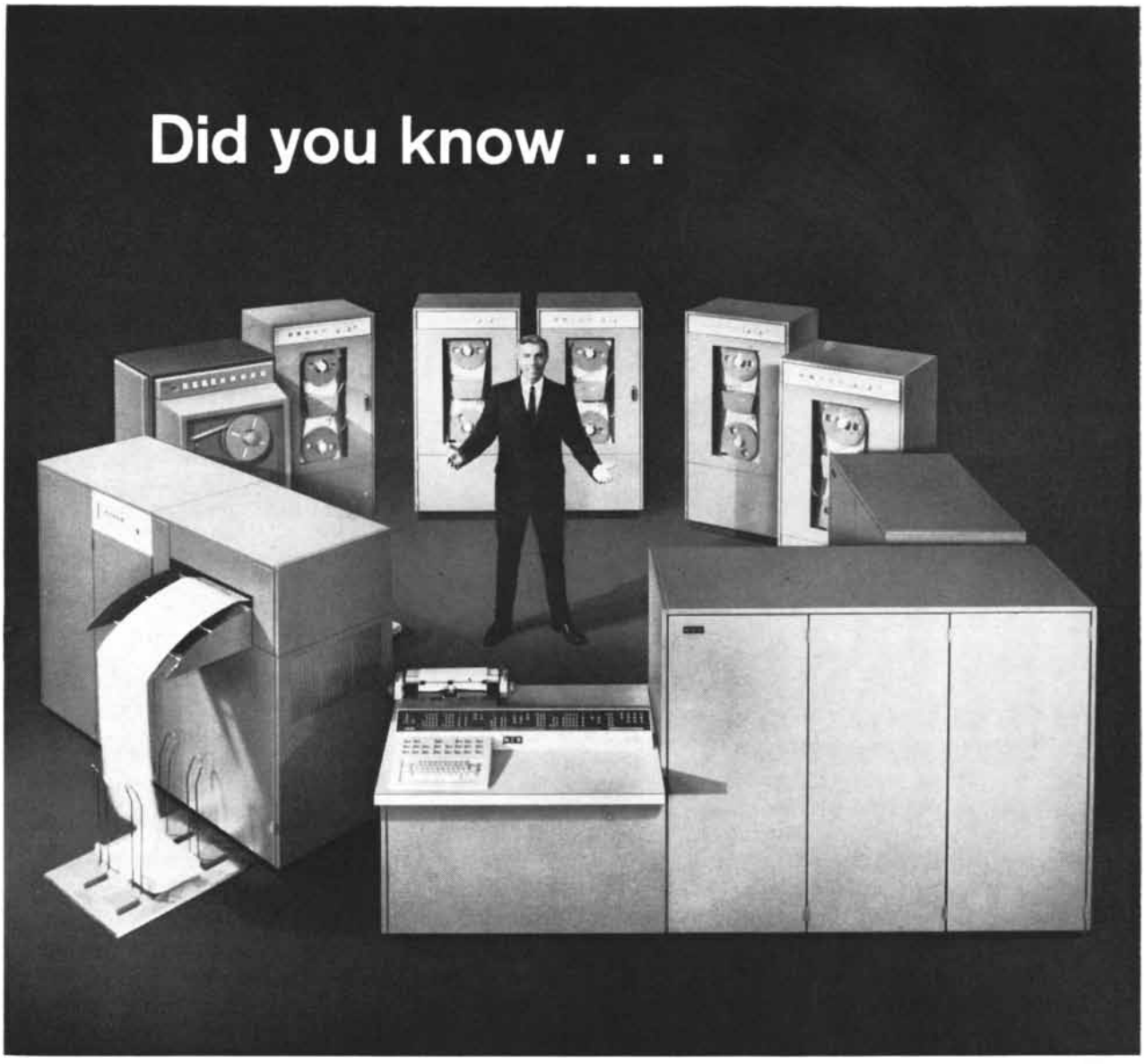

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LETTERS

Sirs:

Your September issue "Technology and Economic Development" was superb. I was particularly attracted by Nevin S. Scrimshaw's fine article, "Food." There were, however, two points in his paper for which I would suggest additional dimensions.

First, Scrimshaw states that the U.S. "produces a huge surplus of food." This may overstate the present situation. Actually not all crops are in "huge surplus"; rather, excess stocks (and production capacity) are found largely in wheat, feed grains and cotton. In the case of the grains, utilization in the past two years has exceeded production as growers have reduced acreage. And remaining stocks may not be considered huge by some when examined in terms of emergency reserves (at present we have approximately a 12-month reserve of wheat) or in terms of supplying food to underdeveloped nations, now and in the future. The nature of the present surplus, then, depends to some degree on how it is viewed.

I would also suggest another dimension to Scrimshaw's statement that "feeding fuel to a machine is cheaper than feeding a horse, and the machine needs less care and maintenance." In certain societies or at certain stages of devel-

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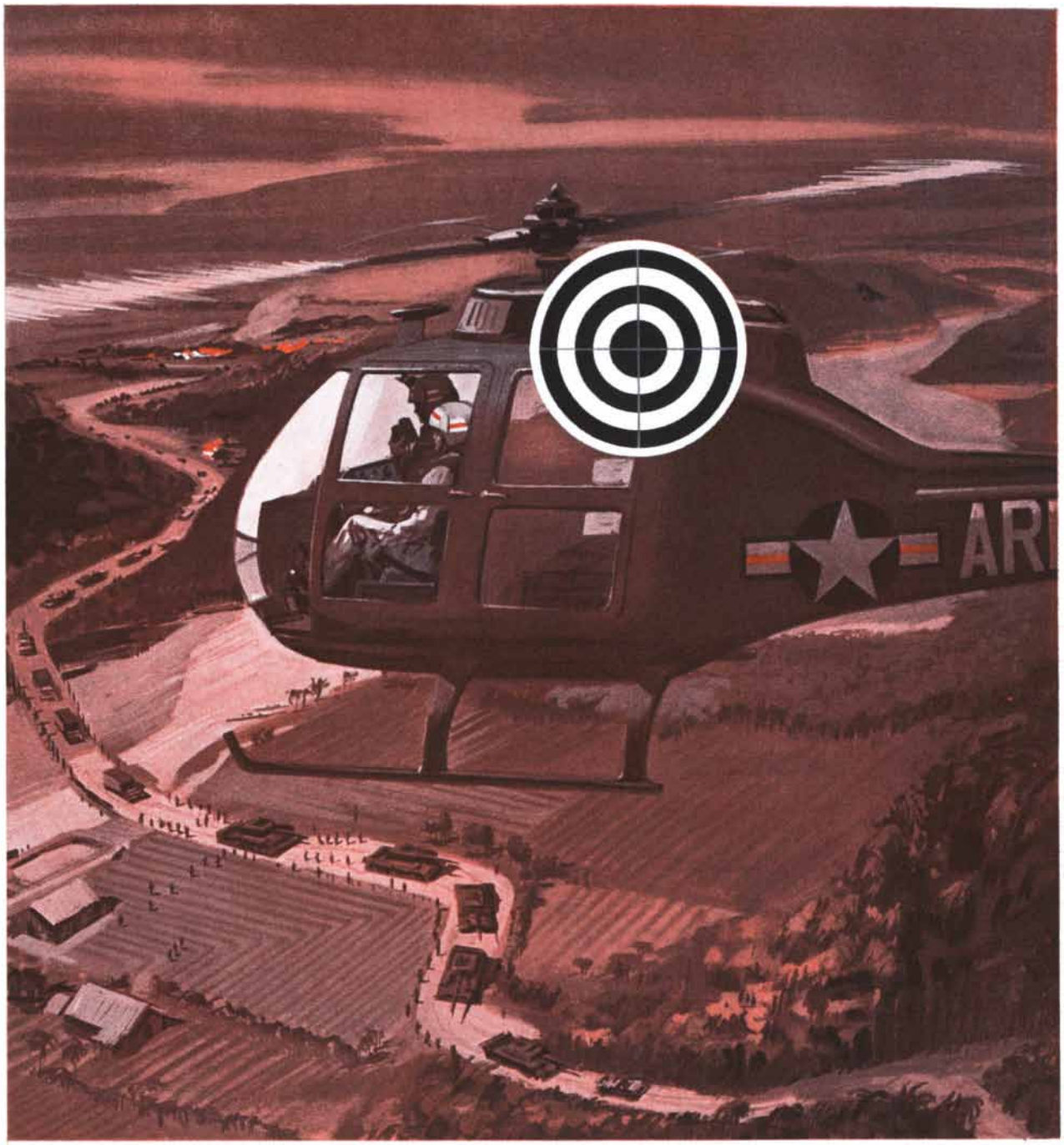

on target with turboshaft power for the LOH—the Light Observation Helicopter which will soon be helping the Army fulfill its mission. The only LOH engine to have both US Army approval and FAA certification, the Allison T63 was selected for the LOH because of its light weight, power, simplicity, compactness and ease of maintenance. Now proving its capabilities in airframe evaluation flight tests for the Army, the T63 has over 1,000 flight hours, hit every performance and delivery target set for it. That kind of bull's-eye performance is the big reason why our other aerospace and nuclear programs are also on target.

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opment this may not be true. Study of the introduction of the tractor to Soviet agriculture suggests that initially the machine may not have been more economical than the horse. It also appears that proper care and maintenance of the tractors was a severe problem. It still is today. Other developing nations could well face the same problems.

In general, however, I can only commend Scrimshaw for a fine paper and the editors for an excellent and well-balanced issue.

DANA G. DALRYMPLE

Federal Extension Service
United States Department of Agriculture
Washington, D.C.

Sirs:

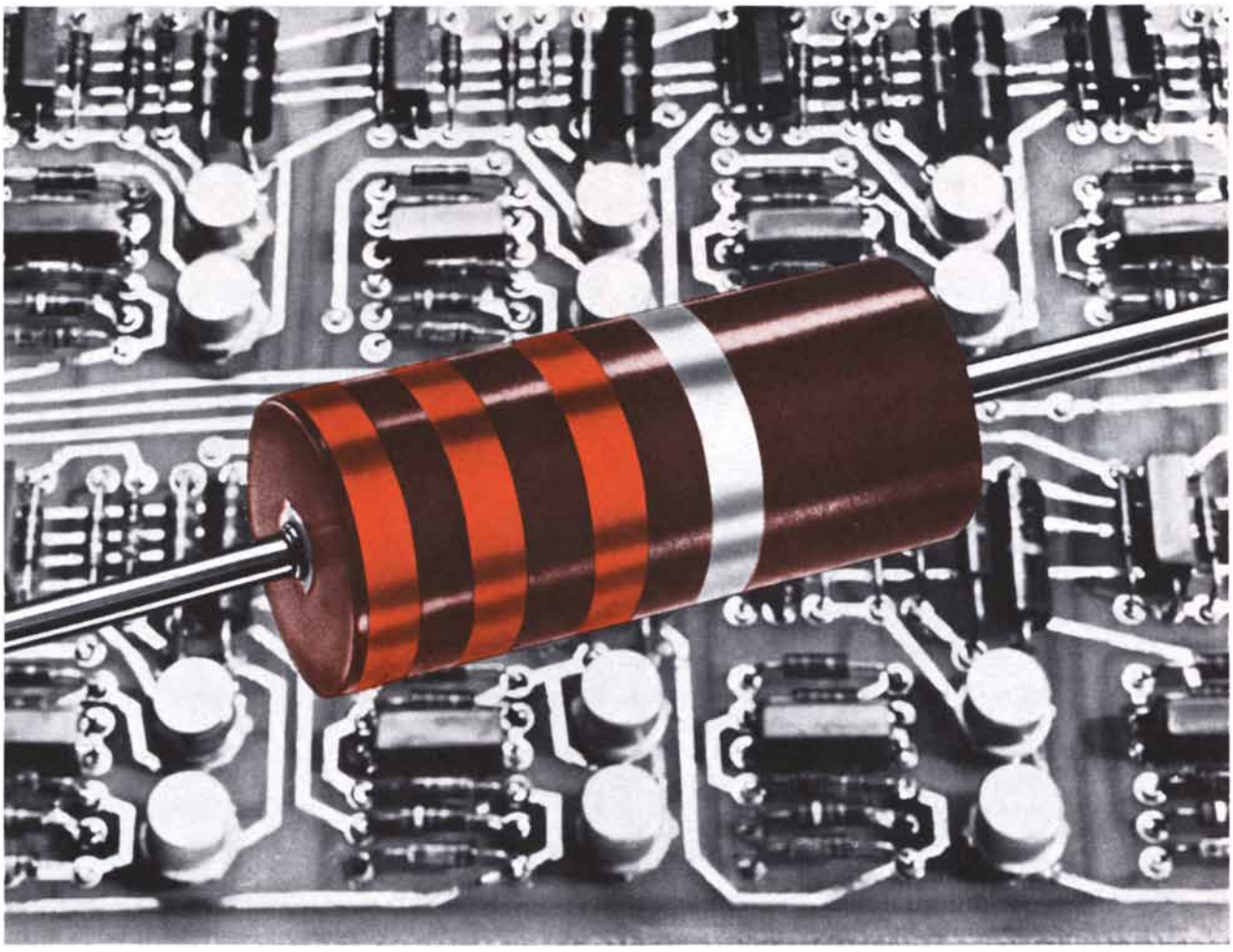
Whatever the meaning of the word "flourish," it is hardly fair to say, as A. Rupert Hall says in his review of Lewis S. Feuer's "The Scientific Intellectual" [SCIENTIFIC AMERICAN, August] that "the upper levels of Russian society from, say, 1800 to 1917 were not notably austere, ascetic or superstitious. Yet science did not flourish." During this period Russia produced some great scientists: the mathematicians Lobachevski, Liapunov and Markov, the chemist Mendeleev, the physiologists Pavlov and Metchnikoff, and Prince Golitsyn, one of the founders of modern seismology. There were many others of lesser rank. For a comparative newcomer to the field of science (Russian science began with the reforms of Peter the Great) and an industrially backward country this was a considerable achievement.

A. V. BUSHKOVITCH

Department of Physics
Saint Louis University
St. Louis, Mo.

ERRATUM

Pitambar Pant, author of the article "The Development of India" in the September issue of this magazine, has called attention to the fact that the maps of India illustrating his article do not plainly show the state of Jammu and Kashmir to be included within the international boundaries of India. For these maps and for the accompanying statistical charts the editors, who prepared them, assume exclusive responsibility.



Why Allen-Bradley hot molding is so important to resistor performance

First and foremost, Allen-Bradley's exclusive hot molding provides a uniformity that cannot be matched by any other resistors on the market—a fact with which hundreds of Allen-Bradley customers have become acquainted through their experience for over 30 years. Such history of uniformity in physical dimensions and electrical properties from one resistor to the next . . . from one order to the next . . . has been demonstrated in the production of more than *ten billion resistors.*

In addition, with their stable characteristics and conservative ratings providing an *extra* margin of safety, you can accurately predict long term resistor performance under various circuit conditions—and at all times be certain of *complete freedom from catastrophic failures.*

A unique manufacturing method is the key which makes all this possible. Allen-Bradley's hot molding technique is unlike anything in the industry, because both the process and the automatic machines—with built-in precision control—were developed and perfected by Allen-Bradley. Here, the resistance material, insulation material, and lead wires are hot molded into one solid integral structure that's mechanically strong—completely free of cracks which might admit moisture.

There are additional reasons why more and more leading electronic manufacturers are standardizing on Allen-Bradley hot molded resistors. Complete specifications are furnished in Technical Bulletin 5050. Please send for your copy, today: Allen-Bradley Co., 1204 S. Third Street, Milwaukee, Wis. 53204. In Canada: Allen-Bradley Canada Ltd., Galt, Ont.

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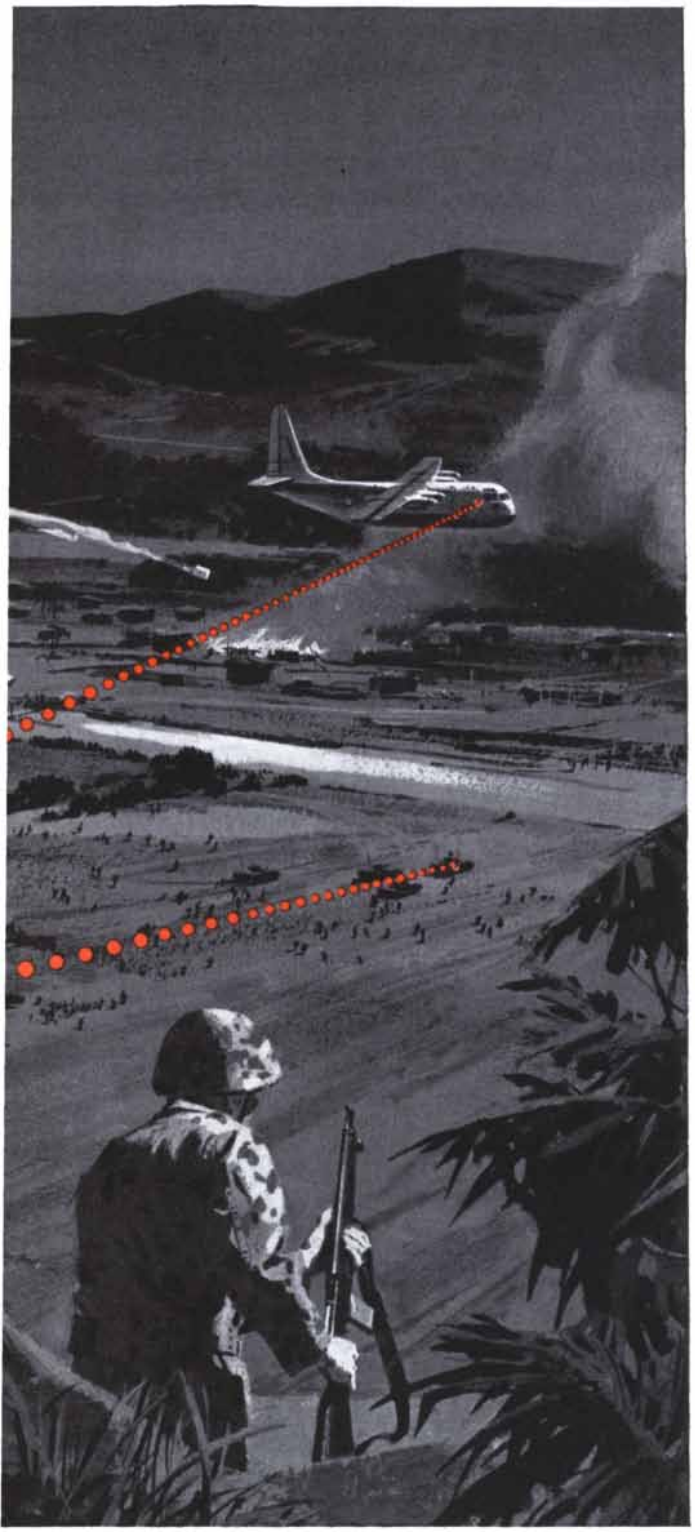

Finding new and better ways to improve vital military communications is a challenge we continually meet at General Telephone & Electronics.

Not long ago, our scientists and engineers developed, under the sponsorship of 1st CAG, Eglin Air Force Base, Florida, a modular pack of four command radio sets that permits tactical communications between anti-guerilla fighters in forward areas and friendly forces, base headquarters, field personnel, and aircraft pilots—all at the same time! With this communication package, one man can command and control all ground and air movements toward the objective.

A major advance in weight reduction, this 37-pound command pack can be carried by a single parachutist or dropped into a forward area to do the same job which formerly required approximately 300 pounds of equipment. It provides the full flexibility of 8 communication channels in the high frequency, very high frequency, and ultra-high frequency bands. With it, a forward observer or forward air controller can communicate with ground forces up to 25 miles, aircraft up to 100 miles and base stations up to 500 miles away. And each of the four transceiver units can be removed and operated independently as each has a self-contained rechargeable battery. Yet, in spite of the versatility of this command package, it was designed and produced in just 120 days.

Quick reaction to the military's urgent need for better communications is one of the many ways the scientists and engineers of General Telephone & Electronics serve the nation. The vast communications and electronics capabilities of GT&E, directed through Sylvania Electronic Systems, can research, design, produce, install and service complete electronic systems. These systems include detection and tracking, electronic warfare, intelligence and reconnaissance, communications, data processing and display.

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There are many reasons why the PI-3V portable TV recorder is by far the most widely used in closed-circuit television. Below are a few of the reasons; for others, send your name and address to get a copy of our new brochure. We'll also arrange, if you'd like, for a live demonstration in your office. Address us at 3170 Porter Drive, Palo Alto 12, California.

PRECISION INSTRUMENT

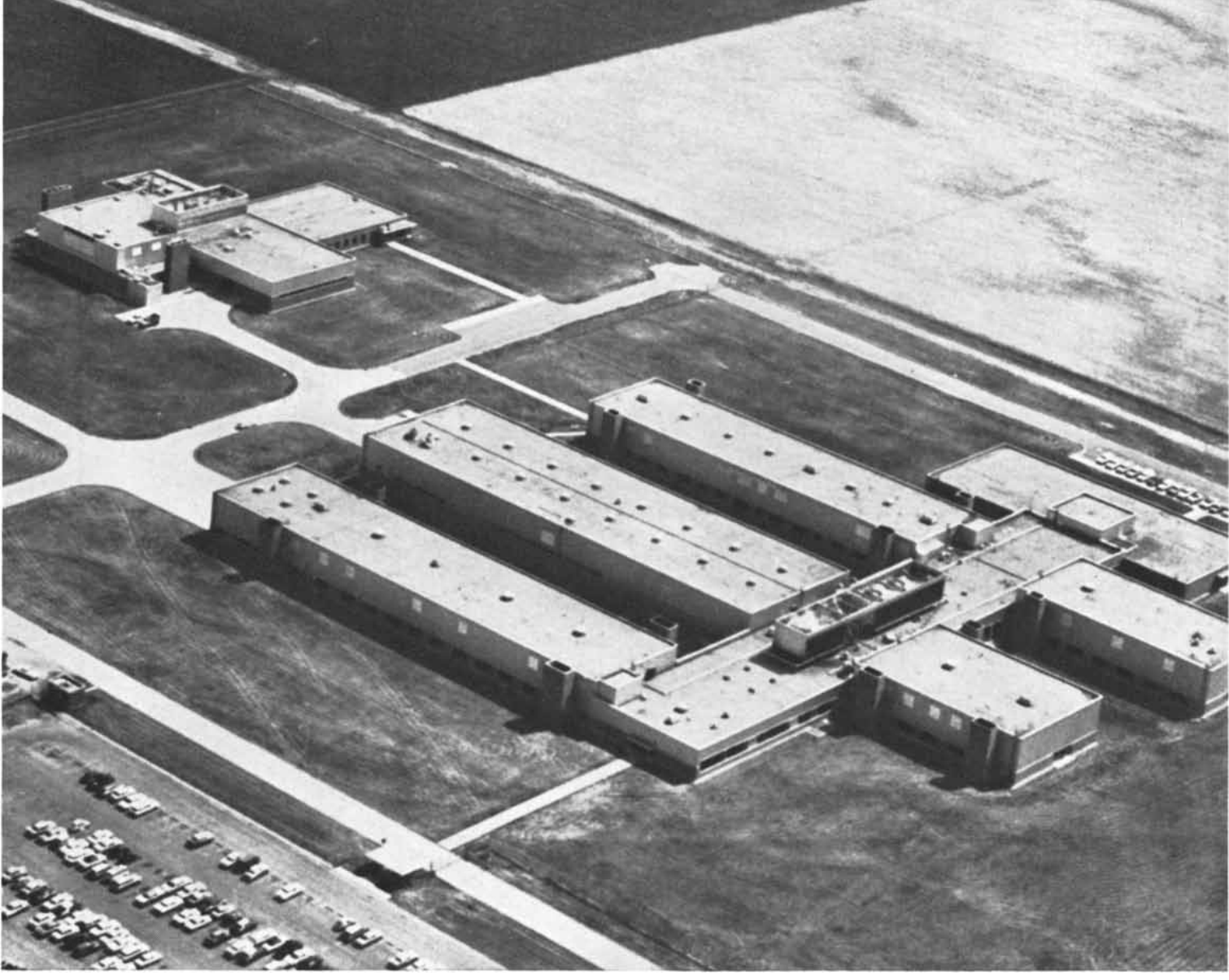
PI

"You can tell it's better engineered; there's more recorder in less package. It uses no vacuum tubes at all, fewer transistors, and is much simpler mechanically. And you can see the difference in the picture."

"If I can operate it, you know it's easy. Just plug in the camera and microphone, turn it on, and push the start button. It re-winds and plays back just like the audio recorders in our language department."

"Now that we've got the PI-3V, we tape everything that goes on in surgery, day and night. More students get exposed to it, with a better chance to study techniques close-at-hand. And it's small enough not to get in the way."

"On my lecture tours, I take the PI-3V right with me, even aboard planes. Only 75 pounds! And I can use it anywhere in the world, 50 or 60 cycle current; I've also run it from a gas-driven generator, and not a flicker on the picture."



Four years ago it was

Today—it's the site of Caterpillar's new Technical Center—facilities designed to provide additional space for Caterpillar's constantly expanding research and development programs.

Intensive research has always played a major role in helping Caterpillar to provide the right product at the right time for both the standard product line and specialized products for the defense program.

The new facilities already available at the Tech Center include the Engine Research and Development Lab, a Gas Turbine Lab, and a Research Administration Building. Three other buildings are planned—Engineering Sciences, Vehicle Component Research and Research Manufacturing.

What do these modern facilities mean to the performance of Caterpillar products?

Here's an example of the type of project constantly recurring these days.

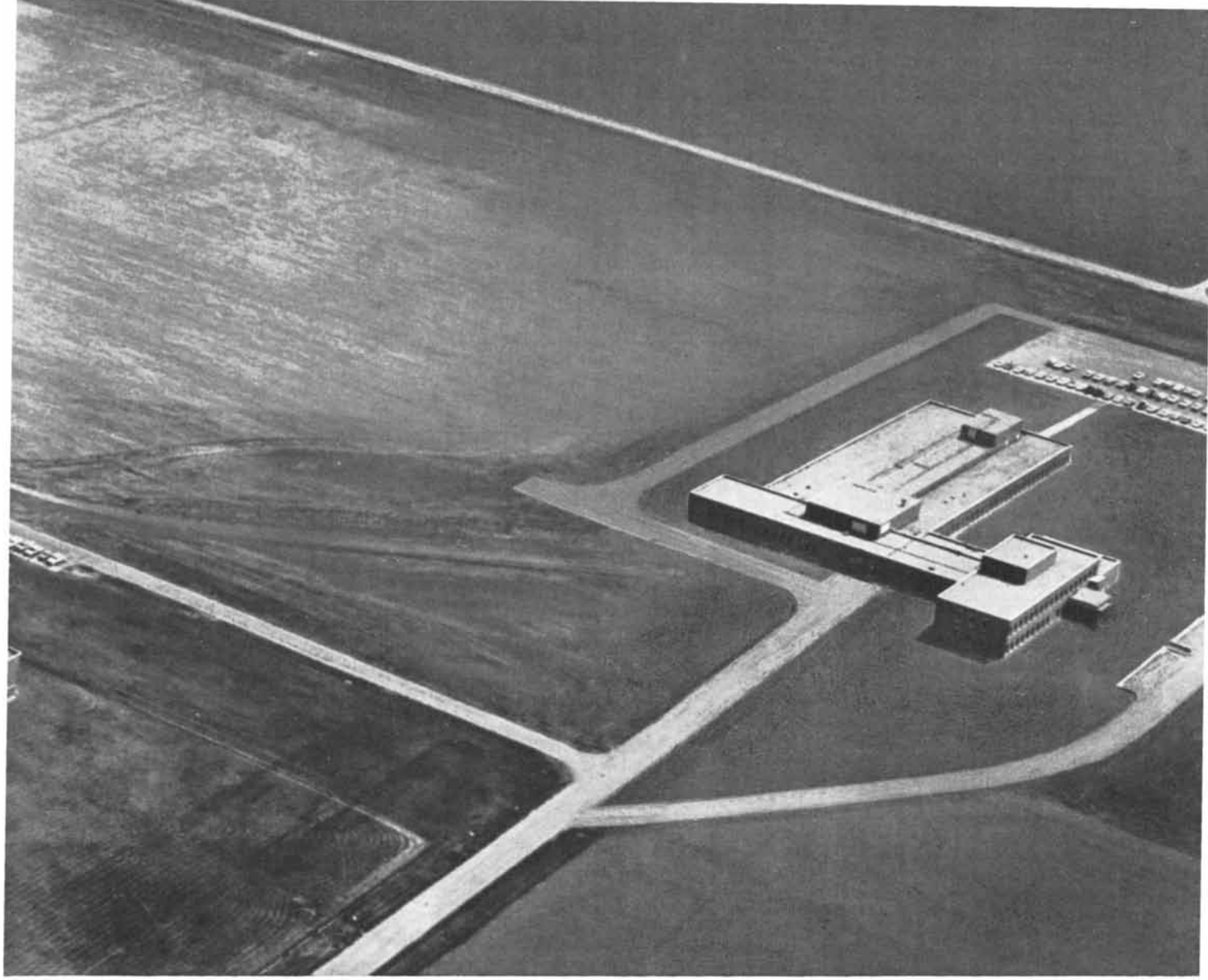
Frank Koch, supervising engineer in the Transmission Lab, recently asked Research Engineer Harry Wilson to evaluate new clutch disc material for a vehicle in development.

He wanted Harry to find out if the new clutch facing would engage smoothly. Would it withstand heat generated during slippage? What was its coefficient of friction? Would it lead to better clutch design? The list of questions was impressive.

A few days later Harry dropped a complete report on Frank's desk. Not many years ago—without easy access to sophisticated instrumentation and computers—the project could have taken several months.

Technical progress of this kind produces products with greater built-in reliability. And it means shorter development schedules, too.

At right are just a few examples of the modern facilities at Caterpillar's new Technical Center.



640 acres of Illinois farmland

Telemetering is a phase of modern test instrumentation regularly used at Caterpillar. Here a research engineer adjusts a new torque measuring coupling which can transmit signals to measuring equipment without mechanical connections.

Analog tape recorder plays back information during a vibration test. It records data from failures which occur in milliseconds during real time testing. It preserves data from tests which can't be duplicated easily. And it accurately records test variables which occur rapidly.

Oscillograph and analog computer are calibrated and adjusted before a dynamic strain simulation. Through this means the engineer can observe, monitor and record the effect of a wide range of loads on a system still in the design stage.

Infrared spectrograph determines changes in molecular structure of liquids and gases. Here a Caterpillar research engineer looks for indications of structural breakdown in an oil sample subjected to hard use.

Sheer physical dimension pays off in Caterpillar's accelerated research effort. In the Engine Laboratory a complex of 72 soundproofed test cells, similar to the one here, is available to subject engines to a wide variety of rigorous testing.

When completed the six buildings of the Technical Center will give Caterpillar Researchers the most modern facilities possible to carry out their long-range research.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER, 1913: "Prof. J. J. Thomson brought out the fact that corpuscles are emitted by alkaline metals under the action of light, and the effect feebly subsists in the dark. The question has been the object of research on the part of various scientists. L. Dunoger and E. Miller consider this effect to be due to obscure heat rays and not to radio-activity, and is a photo-electric action set up by the infra-red rays. Woodrow measured the potential and considers the action not a Volta effect but a spontaneous emission of corpuscles like that which radio-action produces. However, as H. Thirring claims it to be due to the Volta effect and that such cells act like galvanic cells, it will be seen that the question is far from being settled."

"Before a recent congress of German naturalists and physicians, Dr. W. Stempell described the utilization of ultra-violet rays in studying micro-organisms. By the aid of ultra-violet rays it is possible to discover objects which cannot be seen in an ordinary microscope because of their extreme smallness. With the aid of ultra-violet rays Dr. Stempell discovered the spore of the dreaded parasite that infests the silkworm—a feat which would have been utterly impossible with ordinary light. Dr. Stempell suggests that it may thus be possible to discover the microbes of infectious diseases of whose bacteriological origin little is known."

"The remarkable fact that two men at opposite ends of the earth had worked out, unknown to each other, an identical solution to the problem of the genesis of species has been so often told that it hardly needs to be repeated. Each of these two men, with a modesty that is rare even among scientists, constantly insisted that all honor for the great discovery was due to the other. For many years they lived in friendly communion—and nowhere is there the slightest indication of envy or jealousy. One of these men, Charles Darwin, died in April, 1882; the other, Alfred Russel Wallace, has just passed away."

"The world's fastest seagoing vessel has recently performed its trial runs. According to German press notices, the Russian torpedo-destroyer *Novik*, built in the shipyards of Vulcan-Werke, in connection with the official trial on the measured mile with her trial load, has reached a mean speed of 37 knots, the maximum speed being 37.3 knots per hour."

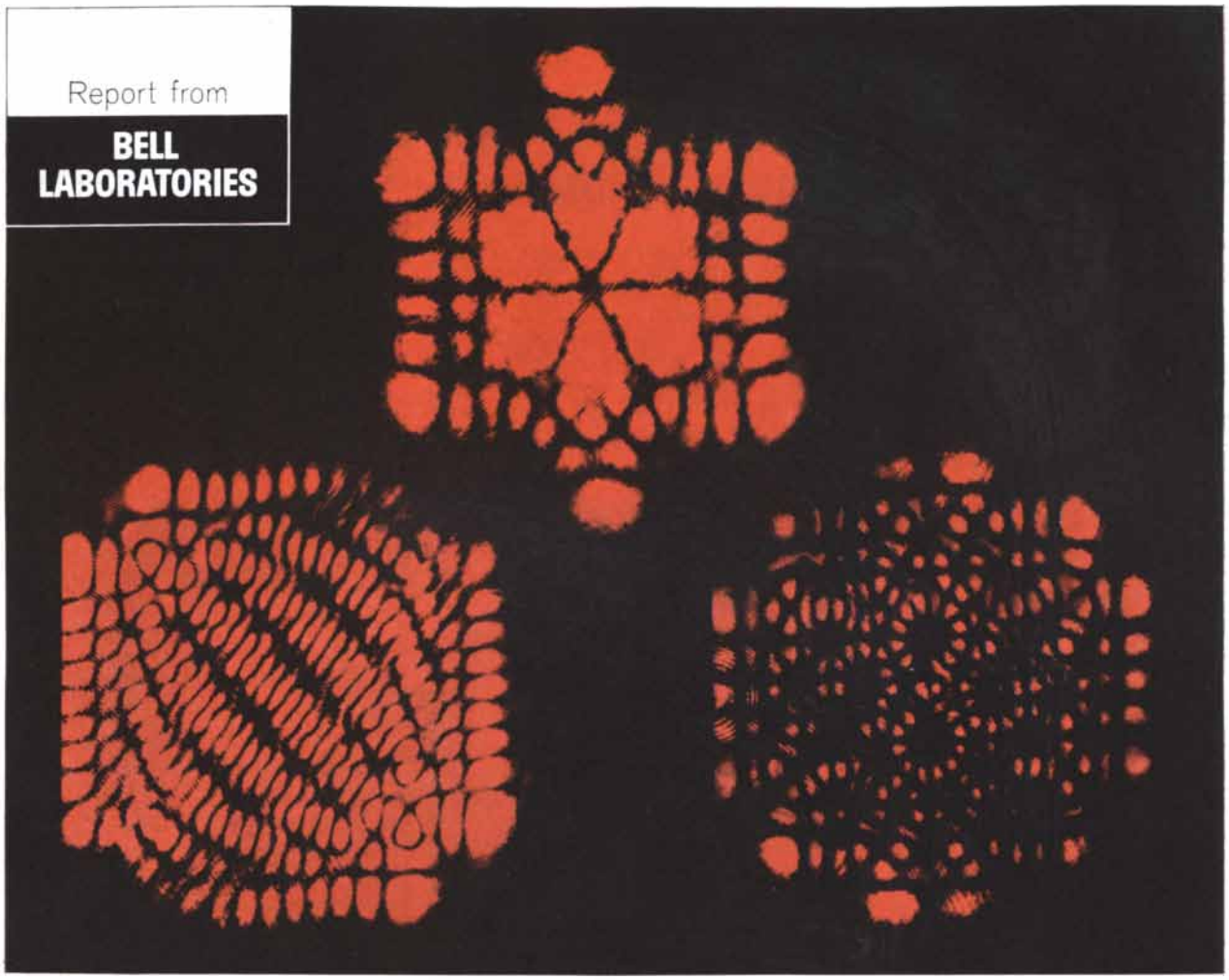
Scientific American.

NOVEMBER, 1863: "It appears quite evident to all who observe the signs of the times that Generals Grant and Meade are about to open a new campaign, which we trust will inaugurate glorious results. Not exactly following in the wake of these military chieftains, the Publishers of SCIENTIFIC AMERICAN propose to begin, on the first of January next, a new and brilliant campaign in the fields of popular science, and they hope to give renewed assurance that this journal is fully up to the stirring events of the day. After a flattering success of 18 years SCIENTIFIC AMERICAN will commence a new volume at the time mentioned, being the 'Tenth' of the 'New Series.' The Publishers promise untiring devotion to the interests of their patrons. No department of the journal will be allowed to fall behind preceding years, while it will still be their aim to excel in every respect."

"Several valuable prizes have recently been finally adjudicated, and the money will be ready for distribution in the course of a week or 10 days. Among them are the *Memphis,* the *Britannia* and the *Victory*. The former was captured by the United States steamer *Magnolia* and yielded the snug sum of $510,914.07, after paying the expenses of adjudication. Acting Volunteer Lieut. Wm. Budd is the happy man who takes as his share $38,318.55, his vessel not being attached to a squadron at the time of the capture and his share being three-twentieths of the half awarded to the captors. All the officers on this vessel belonged to the volunteer service, and their several shares amount to a handsome sum. The sailors too come into a small fortune for them, the seamen getting $1,736.86 to each, ordinary seamen $1,350.88 and the landsmen $1,157.91. The Navy is in

Report from

BELL LABORATORIES



To produce these mode patterns, the normal operation of a helium-neon optical maser is perturbed by placing a pair of wire cross hairs in the cavity. These wires interact with the mode structure of the unperturbed cavity, suppressing some modes and, in certain cases, coupling others together. By changing the angle between the cross hairs, this interaction can be altered and different mode patterns, as shown, can be produced.

A STEADILY GROWING FAMILY OF OPTICAL MASERS

Scientists at Bell Telephone Laboratories are continuing extensive research programs to gain increased knowledge about optical maser (laser) action. The immediate goal of these investigations is more complete understanding of the phenomenon itself. In the long run, however, this knowledge will help us to evaluate better the communications applications.

One aspect of optical maser research is the study of the mode structures in laser cavities. The modes excited in a particular experiment can be identified by mode patterns, shown above, produced by directing the emergent beam onto a photographic plate.

Optical maser research at Bell Laboratories has resulted in a broad new field of radiation science. For instance, discovery of gas lasers also provided the first continuously operating laser. The active medium in this device is a mixture of helium and neon; its operation depends on the excitation of neon atoms by collision with excited helium atoms. Originally, this system emitted infrared light, but recently it has been made to produce visible red and yellow light.

More recently, in another significant advance, our scientists have discovered two other new mechanisms for creating maser action in gases. One depends on the dissociation of oxygen molecules in mixtures of oxygen and neon or argon. The other takes place in pure noble gases—helium, neon, argon, krypton and xenon—and depends on a direct transfer of energy from accelerated free electrons to the gas atoms.

With these mechanisms and various gases or gas mixtures, we have achieved maser action at approximately 150 different wavelengths extending from 0.594 microns in the yellow region of the spectrum to 34.5 microns in the far infrared—and more are in prospect.

BELL TELEPHONE LABORATORIES

World center of communications research and development

immediate want of seamen, and with such chances for fortunes it is amazing that the want exists for a single day."

"The American *Journal of Photography* contains a very full report of Henry Draper's paper recently read before the American Photographical Society on his new telescope and the large photographs which he has taken of the moon. In the paper it is stated that in the autumn of 1858 Dr. Draper determined to make the largest reflecting telescope in America, the construction of which, with various improvements introduced, has occupied his time up to the present period—more than five years. This telescope is nearly 16 inches in aperture and 13 feet in focal length and was intended to be devoted to celestial photography; consequently it has many novelties fitting it for this purpose. It has the largest silver reflector of any instrument in the world, with the exception of the one in the Imperial Observatory in Paris. Celestial photography is as yet only in its infancy, but it is progressing rapidly."

"An ingenious mechanic, Mr. S. H. Roper of Roxbury, Mass., has invented and put in operation a new steam wagon or buggy for common roads. It is thus described:—An ordinary four-wheel carriage has a boiler of about 16 inches in diameter in the rear, with the lever regulating the steam and speed extending over the seat in front. Beneath this boiler is the furnace, and in the rear of the boiler is a small water tank. The steam gauge is on a level with the driver, and he can at a glance ascertain the amount of steam pressure. The whole machine is of two horse-power. Two persons take their seats in the carriage and off it starts, the driver guiding with one hand the front wheels by means of a crank, and with the other hand he can regulate the speed of the engine or stop the carriage in less time than a pair of horses can be brought to a halt. Coal sufficient for one day's running can be carried beneath the seat of the carriage, and although the speed attained is that of the fastest horse, the expense of running the carriage is estimated at one cent per mile while in operation, with the additional virtue of not costing anything in the way of feed and stabling when not in use. Lately, when the carriage was exhibited, the engine carried but 15 or 20 pounds of steam and yet it taxed the power of the horses present to keep pace with its speed. The carriage and engine do not weigh more than 700 pounds. No difficulty was experienced in turning sharp corners or in backing."

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Especially pure—color 1 max. to be exact. To get it, we got rid of troublesome high polymer fractions and left only the essentially pure diglycidyl ether of bisphenol A. But actually, all of our epoxies are strong on purity. It all starts back with quality control. We make all the ingredients for our epoxies. Even most of the ingredients that go into the ingredients. A fact alert inventors are sure to appreciate.

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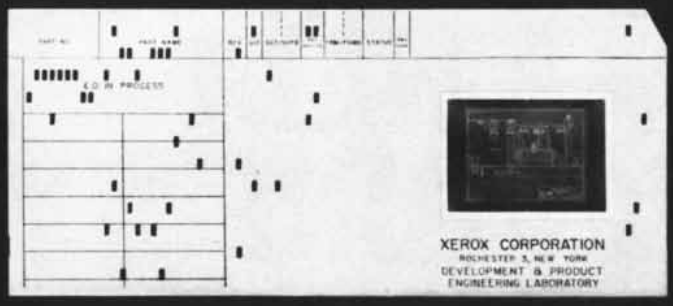

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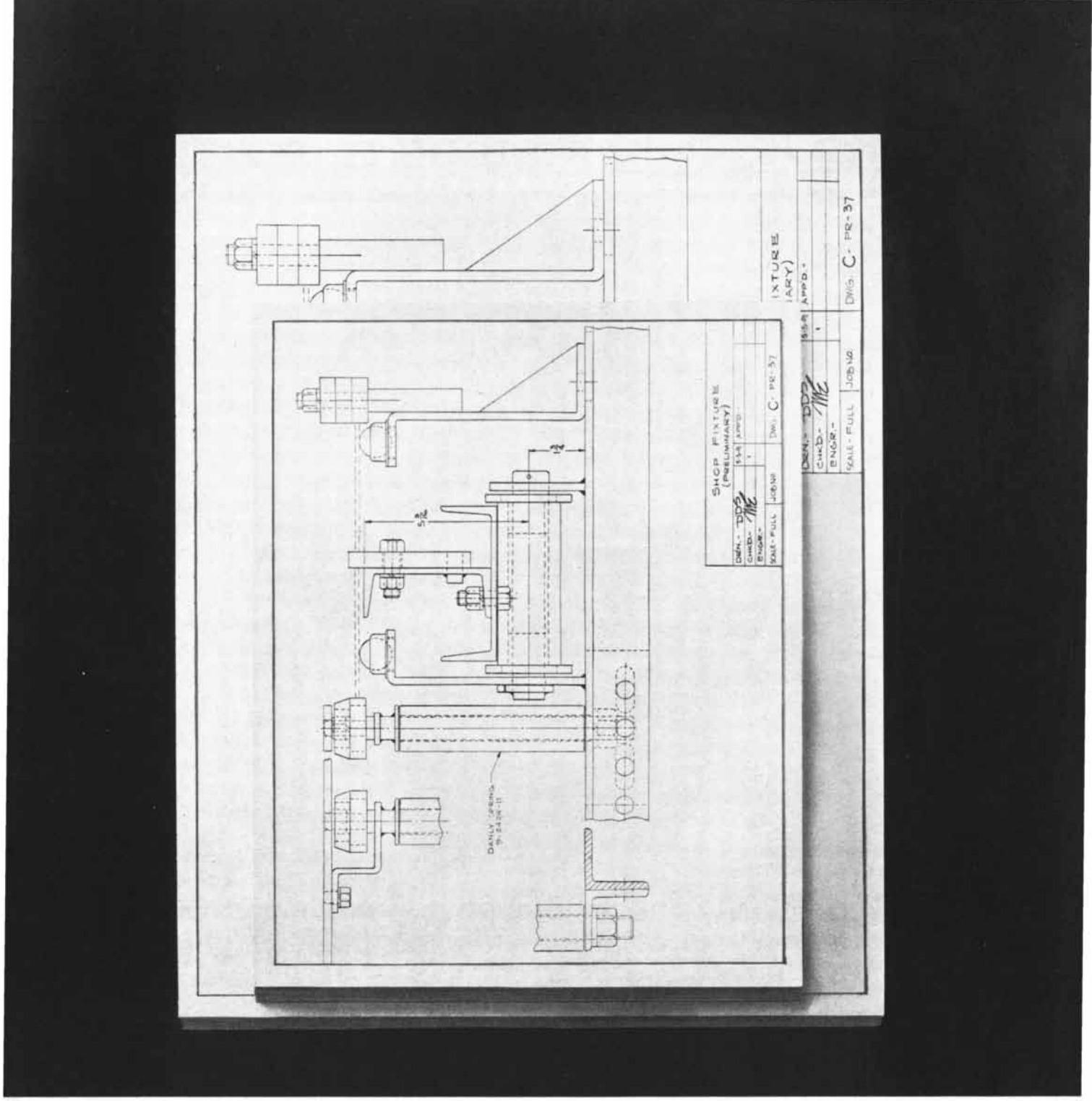

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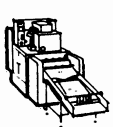

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Why you should wear ACCUTRON® instead of a watch

ONLY THE ACCUTRON TIMEPIECE is guaranteed 99.9977% accurate on your wrist (not just in a test laboratory).

ONLY THE ACCUTRON TIMEPIECE does away with the hairspring and balance wheel, the parts which limit the accuracy of all watches.

ONLY THE ACCUTRON TIMEPIECE—with just 12 moving parts—is so rugged, so trouble-free you can forget about usual watch maintenance and repair.

ONLY THE ACCUTRON TIMEPIECE keeps time by the constant vibrations of a tuning fork activated electronically. It doesn't tick. It hums.

THE ACCUTRON TIMEPIECE never, never needs winding—even off your wrist. Power cell lasts a full year. Second year's cell free. Additional cell only $1.50.

ACCUTRON has been selected as a timing device in U. S. space satellites and Telstar.

Above: Revolutionary electronic tuning fork mechanism of ACCUTRON seen through transparent dial of "Spaceview" model. 14-KT gold case. $200*

ACCUTRON is the only timepiece guaranteed 99.9977% accurate on your wrist. It makes the finest watches—even electric watches—obsolete.

The ACCUTRON timepiece keeps time by a revolutionary new principle. This miniature tuning fork, driven by a transistorized electronic circuit, vibrates at a constant 360 times a second. Result? ACCUTRON is the only timepiece that's guaranteed 99.9977% accurate on your wrist.

The ACCUTRON timepiece already has become the new world standard of accuracy. It was purchased by the U.S. Air Force for every X-15 pilot. It's approved for use by all major railroads. And it's the timepiece of leaders in science, industry and government.

See ACCUTRON—the most distinctive timepiece you can own, the most unique gift you can give. Your choice of many distinguished waterproof* and shock-protected styles, from $125 to $2500*.

For name of nearest ACCUTRON dealer and free booklet, write Bulova Watch Co., Inc., Dept. SA, 630 Fifth Avenue, New York 20, New York. Don't you owe it to yourself to wear ACCUTRON instead of a watch?

Read the ACCUTRON guarantee of accuracy! ACCUTRON is guaranteed by Bulova not to gain or lose more than one minute a month in actual daily use on your wrist. For one full year from date of purchase, the authorized jeweler from whom you purchased your ACCUTRON timepiece will adjust it to this tolerance, if necessary, without charge.

ACCUTRON comes in many distinguished styles. Above: ACCUTRON "214" Brilliant stainless steel case, raised dial markers. $125*

ACCUTRON BY BULOVA—*WORLD'S ONLY ELECTRONIC WRIST TIMEPIECE*

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Studies of Small Gap Semiconductors for Infrared Detection

The window in the atmosphere between 8 and 14 microns has stimulated work on devices that will detect longer wave lengths. New semiconductor materials may make practical the detection of longer wave lengths and therefore targets with far lower temperatures.

The atmosphere offers several windows for energy transmission in the infrared spectrum. One particularly good one occurs between 8 and 14 microns where energy is transmitted freely. However, radiation on either side of the window is blocked due to absorption by the molecules in the atmosphere.

All objects at temperatures above absolute zero give off radiations and the lower the temperature the longer the wave length. Therefore, if long wave lengths can be detected by a practical means, targets of much lower temperatures could be recognized.

Infrared detectors use either intrinsic or extrinsic semiconductors. Intrinsic detectors use electron transitions within the atoms that make up the semiconductor material itself. The extrinsic type utilizes electron transitions that occur due to the presence of impurity atoms introduced into the semiconductor material. (See Fig. A.)

While the extrinsic materials permit detection of infrared radiation beyond 6 microns, these materials require cooling to below 40°K. This calls for bulky, heavy apparatus undesirable for airborne applications and difficult to design into multi-element detectors.

Until now no one has been able to make an intrinsic conductor that will detect photons in the longer wave lengths. In an intrinsic detector the narrower the energy gap between the valence band and the conduction band the easier it is to excite an electron across the gap. This excitation occurs two ways: by photon excitation and by thermal excitation. The problem is to produce a material with a gap narrow enough to respond to long wave lengths (that is, low energy photons) but wide enough so that practical cooling temperatures will be sufficient to minimize thermal excitation.

Honeywell scientists have performed a theoretical analysis which shows the feasibility of making an 8 to 14 micron intrinsic detector capable of operating at liquid nitrogen temperature, 77°K. (−320°F.)

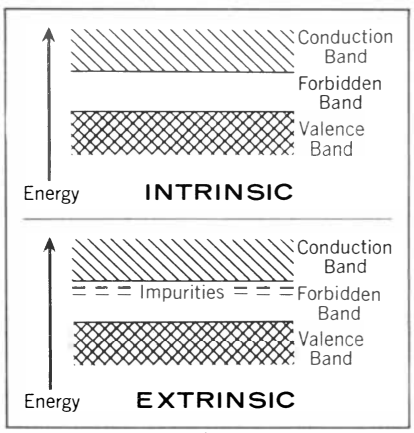

FIG. A

The analysis also shows that by the use of intrinsic material the detectors operating at 77°K could be made so sensitive that the only limitation is imposed by the randomness of the photons coming from the radiation background. Problems present themselves in selecting elements for the semiconductor. For example: while some narrow gap materials meet many of the requirements, their gap is so narrow that the required cooling is impractical. (This is the case with mercury telluride.)

Honeywell's contribution to the development of a suitable detector has been to prepare a compound semiconductor composed of different proportions of mercury, cadmium and tellurium and to develop a theory capable of explaining the behavior of this material.

The compound is difficult to synthesize. Mercury evaporates readily at room temperature yet the compound requires heating to 800°C. At this temperature the pressure of mercury within the capsule is very high.

A number of different compositions have been formulated. Most promising is a compound of approximately 80% mercury telluride and 20% cadmium telluride. With this compound Honeywell scientists, for the first time, have been able to demonstrate photon detection at wave lengths out to 14 microns. Previous workers had been able to demonstrate only thermal effects in these materials.

Further work is under way at Honeywell's Research Center on purification of the material and improvement of its crystal structure. At the same time additional theoretical work is under way to further understand the very complex band structure of small gap semiconductors. If the transitions in these materials can be explained, new insights in semiconductor theory will be attained. This research is partially supported by the Aeronautical Systems Division, Air Force Systems Command.

If you are engaged in scientific work involving small-gap semiconductors and would like to have copies of papers on the subject by Honeywell scientists, you are invited to correspond with Dr. Paul W. Kruse, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree, you are invited to write Dr. John Dempsey, Director of Research at this same address.

Honeywell
First in Control

THE AUTHORS

EDWARD J. SACHAR ("Behavioral Science and Criminal Law") is senior research psychiatrist and director of the Psychoendocrine Research Project at the Massachusetts Mental Health Center in Boston. He is also a member of the faculty of the Harvard Medical School. Sachar was graduated from Harvard College in 1952 and received an M.D. from the University of Pennsylvania School of Medicine in 1956. He studied clinical psychiatry at the Massachusetts Mental Health Center and also at Beth Israel Hospital in Boston. His major field of interest is psychoendocrinology—the study of psychological influences on the endocrine system; from 1959 to 1961 he did research in this area at the Walter Reed Army Institute of Research in Washington.

RAYMOND BOWERS ("Plasmas in Solids") is associate professor of physics at Cornell University. Bowers was born in London in 1927 and received his undergraduate degree from the University of London in 1948. Soon after obtaining a doctorate in physics from the University of Oxford in 1951 he came to this country to do research at the Institute for the Study of Metals of the University of Chicago. In 1953 he joined the Westinghouse Research Laboratories, where he investigated weakly magnetic solids, including luminescent materials, semiconductors and metals. He became a member of the Cornell faculty in 1960 and has since been engaged in research on the interactions of electrons and magnetic fields in highly conducting metals.

DAVID H. HUBEL ("The Visual Cortex of the Brain") is associate professor of neurophysiology and neuropharmacology at the Harvard Medical School. Born in Windsor, Ontario, in 1926, Hubel received a B.Sc. and an M.D. from McGill University in 1947 and 1951 respectively. He studied clinical neurology for three years at the Montreal Neurological Institute before coming to this country in 1954 to spend a year's residency in neurology at the Johns Hopkins Hospital. In 1955 he began neurophysiological research at the Walter Reed Army Institute of Research in Washington, and in 1960 he joined the Harvard faculty.

VERN O. KNUDSEN ("Architectural Acoustics") is professor of physics and chancellor emeritus of the University of California at Los Angeles. Knudsen was born in Provo, Utah, in 1893 and was graduated from Brigham Young University in 1915. He received a Ph.D. in physics from the University of Chicago in 1922 and joined the U.C.L.A. faculty the same year. From 1932 to 1938 he was chairman of the department of physics and from 1934 to 1958 dean of the graduate division of U.C.L.A. Adept in both physiological and architectural acoustics, Knudsen has invented instruments for measuring and correcting impaired hearing and has also served as acoustical consultant for several of the first sound stages in Hollywood and for numerous auditoriums, churches and music buildings throughout the U.S. In 1958 he received the Wallace C. Sabine medal for original contributions to architectural acoustics. He is a past president of the Acoustical Society of America and is currently president of the California Institute for Cancer Research and chairman of the board of the Hollywood Bowl. Knudsen recently moved his office into U.C.L.A.'s new physics building, which has been named in his honor Knudsen Hall.

H. O. J. COLLIER ("Aspirin") is director of pharmacological research at Parke, Davis & Company in Hounslow, England. Born of English parents in Brazil in 1912, Collier holds a B.A. and a Ph.D. in comparative physiology from the University of Cambridge. He taught physiology at the University of Manchester from 1937 to 1941, when he joined the staff of Imperial Chemical Industries. He spent the next four years at the School of Tropical Medicine in Liverpool, doing research on the treatment of spirochaetal diseases with penicillin. In 1945 he set up a pharmacology laboratory for Allen & Hanbury's, Limited, which he directed until 1958, when he joined Parke, Davis. Collier has participated in the development of several drugs, some of which are widely used as neuromuscular blocking and antimicrobial agents. In August of this year he took part in the international pharmacological meeting held in Prague. He is the author of the article "Kinins," which appeared in the August 1962 issue of SCIENTIFIC AMERICAN.

EARL FRIEDEN ("The Chemistry of Amphibian Metamorphosis") is professor of chemistry and chairman of the department at Florida State University. He received a B.A. in chemistry from the University of California at Los Angeles in 1943 and a Ph.D. in biochemistry

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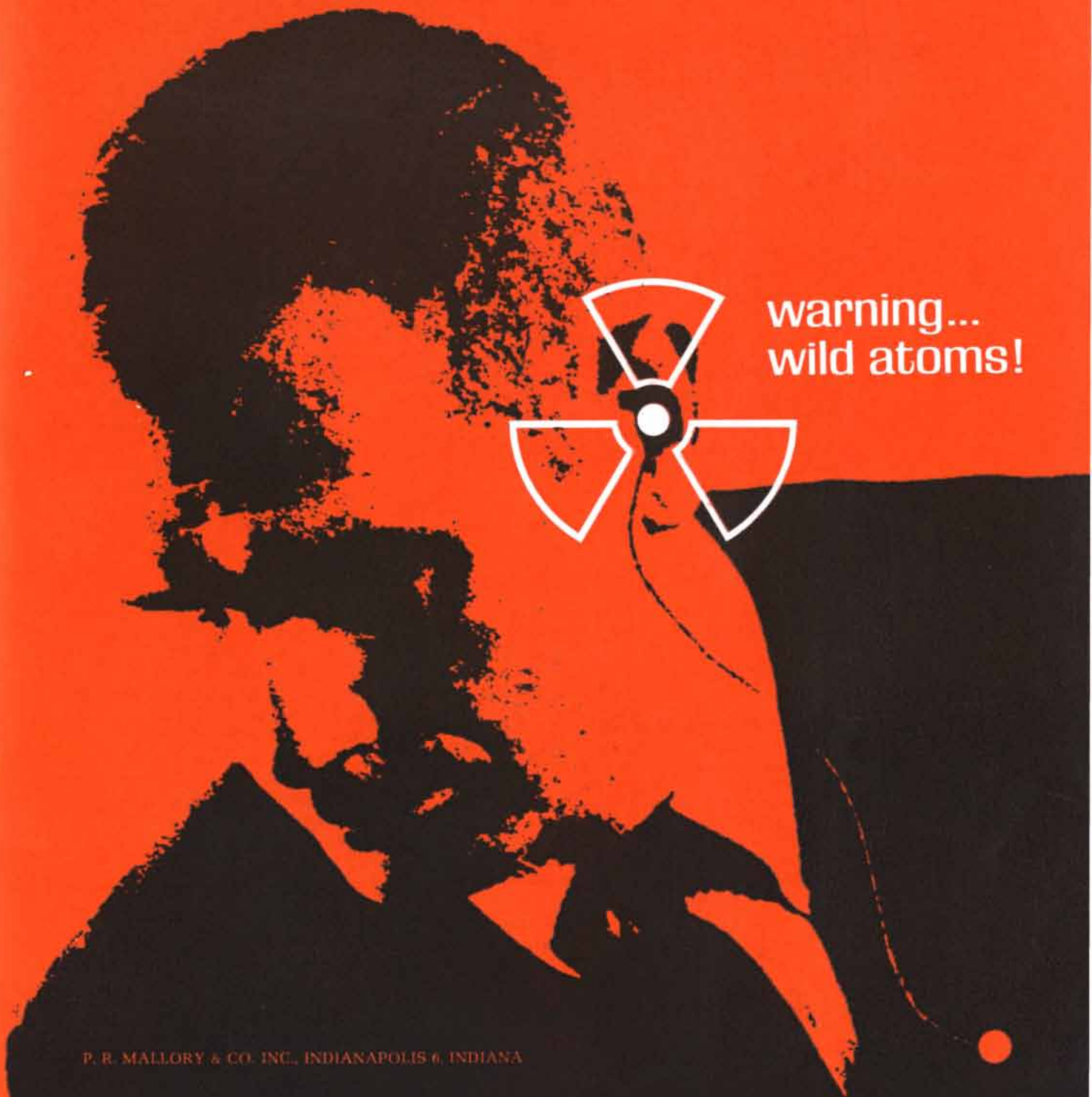

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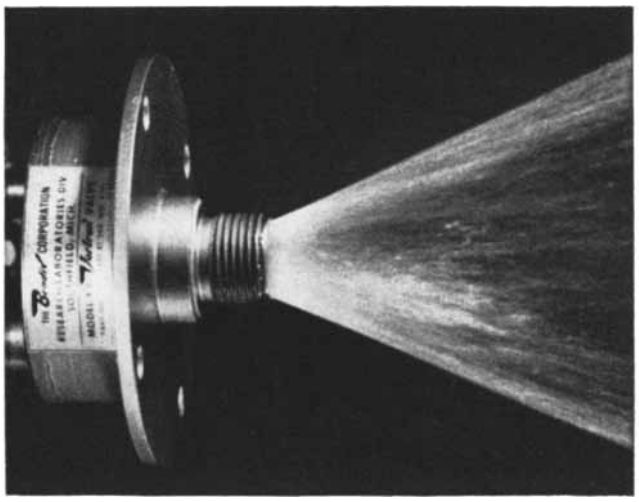
from the University of Southern California in 1949. He has been a member of the Florida State faculty since 1949. During 1955 Frieden did research at the Institute for Enzyme Research of the University of Wisconsin, and in 1957 he went to Denmark on a Public Health Fellowship to work at the Carlsberg Laboratories in Copenhagen. This is his second article for SCIENTIFIC AMERICAN; the first, "The Enzyme-Substrate Complex," appeared in August, 1959.

ROBERT H. BRILL ("Ancient Glass") is Administrator of Scientific Research at the Corning Museum of Glass. A graduate of Upsala College, Brill received a Ph.D. in physical chemistry from Rutgers University in 1954. He was assistant professor of chemistry at Upsala from 1954 to 1960, when he took up his present post. He wishes to acknowledge the valuable contributions to his work made by August Erickson, John Wosinski, Andrew Rasmussen and Alan Werner of the Research Laboratories of the Corning Glass Works.

PAUL F. KERR ("Quick Clay") is Newberry Professor of Mineralogy at Columbia University. A native of California, Kerr was graduated from Occidental College in 1919 and received a Ph.D. in mineralogy from Stanford University in 1923. He has been a member of the Columbia faculty since 1924, serving as chairman of the department of geology from 1942 to 1950. During the early 1920's he was one of the first to apply X-ray diffraction techniques to mineral identification. He has described eight new minerals and has worked at reorganizing the kaolin minerals for the U.S. Geological Survey. During World War II he served as a consultant to the Manhattan District on problems of uranium supply. He has since done research on the origin of uranium for the Atomic Energy Commission. At the first Atoms for Peace Conference in Geneva in 1955 he surveyed the natural occurrence of uranium for the United Nations. Primarily a specialist in clay minerals, Kerr became interested in quick clays in 1960 while serving as visiting professor at the University of Oslo under the auspices of the educational division of NATO.

GEORGE A. MILLER, who in this issue reviews C. D. Broad's *Lectures on Psychical Research*, is professor of psychology at Harvard University. He is at present on sabbatical leave from Harvard and working at the Institute for Experimental Psychology of the University of Oxford.



Vortex Valve for operation at 2000°F.

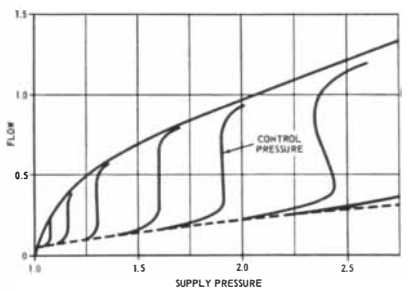
Fluid Phenomena:

New Technique For Sensing, Computing, And Control

Advances in all-fluid signal generation and amplification (the use of a flowing liquid or gas without moving parts) have opened a new field of research and development and have made available a new family of techniques for sensing, computing, and control. These methods offer many potential advantages in the extreme temperature, radiation, and acceleration environments of advanced aircraft, missile, and space applications, and in less exotic applications where rugged, inexpensive, and reliable equipment is required.

The all-fluid program at Bendix includes research in jet, boundary-layer, and vortex phenomena, and the application of these phenomena to both all-fluid devices and complete subsystems. Sensors, amplifiers, oscillators, logic elements, control valves, and regulators are among the components under development. Control systems for gas turbine engines, nuclear reactors, and flight vehicles are typical of the subsystems being studied.

The vortex valve is one of the most versatile of the all-fluid components. Fundamentally a flow control device, it varies flow rate through the action of a controlled vortex sheet on the main fluid stream. It can be used as a power amplifier and, with appropriate configurations, as an oscillator, or as a variety of sensors.



Normalized flow curves for vortex valve.

Because of the potential of the vortex valve, Bendix has undertaken fundamental studies of vortex phenomena related to this valving principle. A normalized analysis of the vortex valve has been established which can be used to predict the performance characteristics of the valve over a wide range of operating parameters. By appropriate design, vortex valves have been made to have extremely high gain. In fact, near mid-range they have been made to have negative resistance characteristics as shown in the curves. Negative resistance oscillators have been operated using vortex valves in conjunction with appropriate tuned flow networks.

Bendix Research embraces a wide range of technology including acoustics, nuclear, solid state physics, quantum electronics, mass spectrometry, photoelectronics, electron beam and tube technology, measurement science, applied mechanics, energy conversion systems, dynamic controls, systems analysis and computation, navigation and guidance, microwaves, digital techniques, data processing and control systems. Motivation: to develop new techniques and hardware for The Bendix Corporation to produce new and better products and complete, integrated, advanced systems for aerospace, defense, industrial, aviation, and automotive applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

Research Laboratories Division

THE Bendix CORPORATION

WHERE IDEAS UNLOCK THE FUTURE

"When you buy a microwave tube from us, you've got a right to expect it to perform in precise

conformance with the operating parameters set forth in our data sheets. And it *will.* One reason, if I may blow the Varian horn a moment, is the extensive system of quality controls we impose on the manufacture, testing, and shipping of our microwave tubes. This covers a lot of things, from the maintenance of ultra-clean assembly rooms to the compiling of a complete history on every tube at Varian. This report covers every tube in manufacture, in test, waiting shipping, in inventory, and so on. This kind of quality control costs us plenty, but we figure that you, as a customer, not only expect it, but deserve it. It's my job to see that you *get* it." *George Reyling, head of Quality Control at Varian's Palo Alto Tube Division.*

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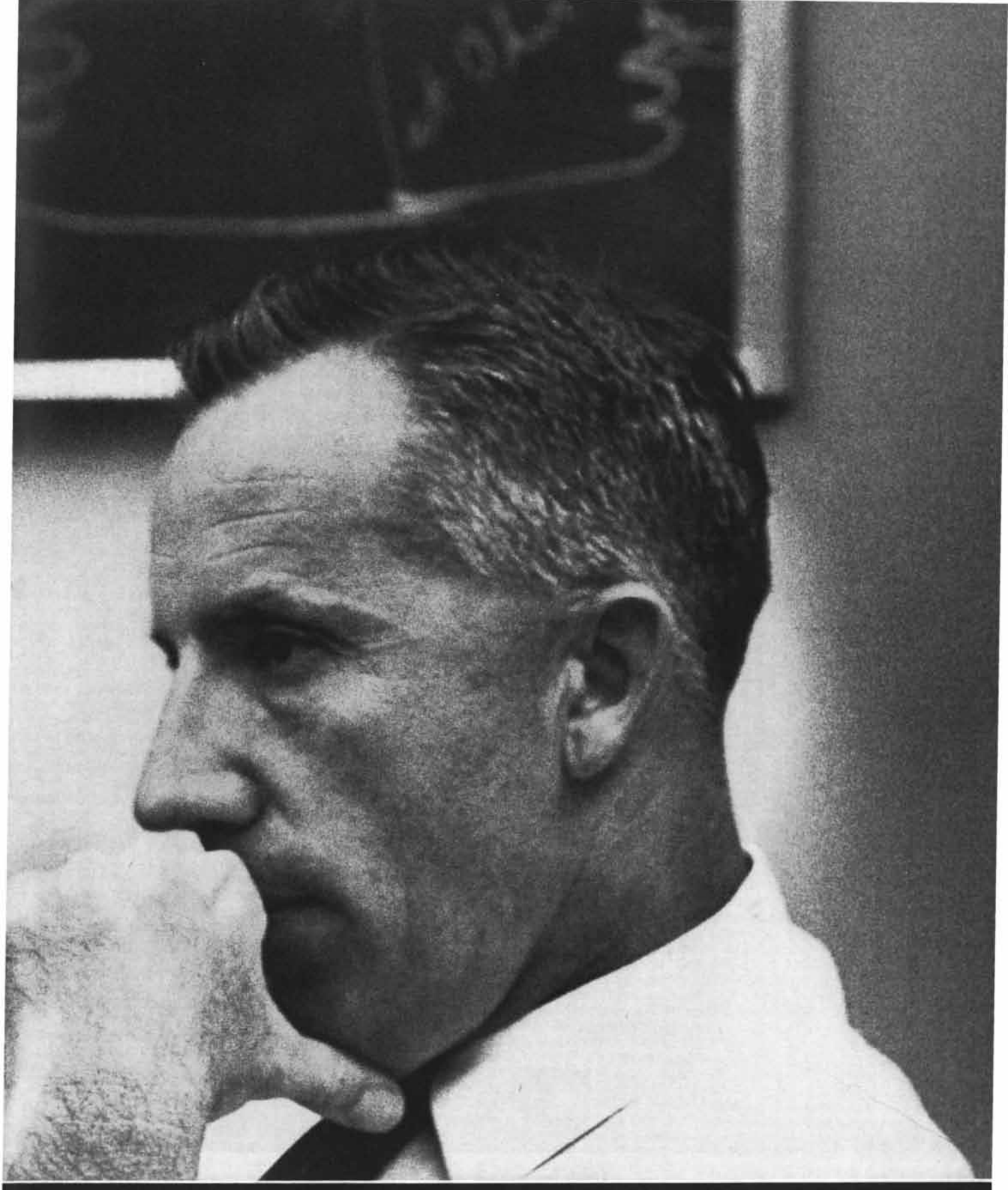
Write Tube Division, Palo Alto, for our descriptive brochure.



MICROWAVE TUBE GROUP

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FAR OUT FACT FINDING

...AND WHAT DOUGLAS IS DOING ABOUT IT

What will man's problems be in the vast emptiness of outer space? How will the materials and systems he will use stand up? Will his communications with earth work properly? □ At the new Douglas Space Systems Center in Huntington Beach, California, many of the required answers will be found. Part of the Center is an environmental laboratory where space "hardware" up to 30 feet wide can be tested at vacuum levels and temperatures which would be encountered 500 miles out. Other units can produce deeper space conditions down to a vacuum of 10^{-14} torr and with any required radiation and gravity situations. □ Such research facilities are basic for the development of manned and unmanned satellite systems, launching and space vehicles, earth to moon communication devices, lunar housing and vehicles, life support systems, and similar projects in which Douglas is involved.

Other research programs covering some 23 broad technological areas are under way in the major Douglas divisions located at Santa Monica and Long Beach, California; Tulsa, Oklahoma, and Charlotte, North Carolina.

DOUGLAS

WHAT'S IN THE AIR FOR ASTRONAUTS

Hundreds of contaminants, many toxic, can be present in a capsule's atmosphere. Even ordinary materials like plastics can produce dangerous out-gassing under extreme heat or shifts in barometric pressure. The vital job of continuous atmosphere monitoring on extended space flights is an application for gas chromatography, a versatile technique that can measure multi-components in the parts per million level quickly. Perkin-Elmer has pioneered the development and made important advances in chromatography for industrial and research use. It now is applying this capability, plus its understanding of space system packaging, to capsule atmosphere monitoring, planetary surface and atmosphere analysis and other sophisticated space science efforts. Gas chromatography is another example of Perkin-Elmer's dedication to the development of instrumentation for precise measurement in the interest of industry, science and defense. Perkin-Elmer Corporation, Norwalk, Connecticut.

PERKIN-ELMER

MELTING UNDER PRESSURE (at 100,000 atmospheres)

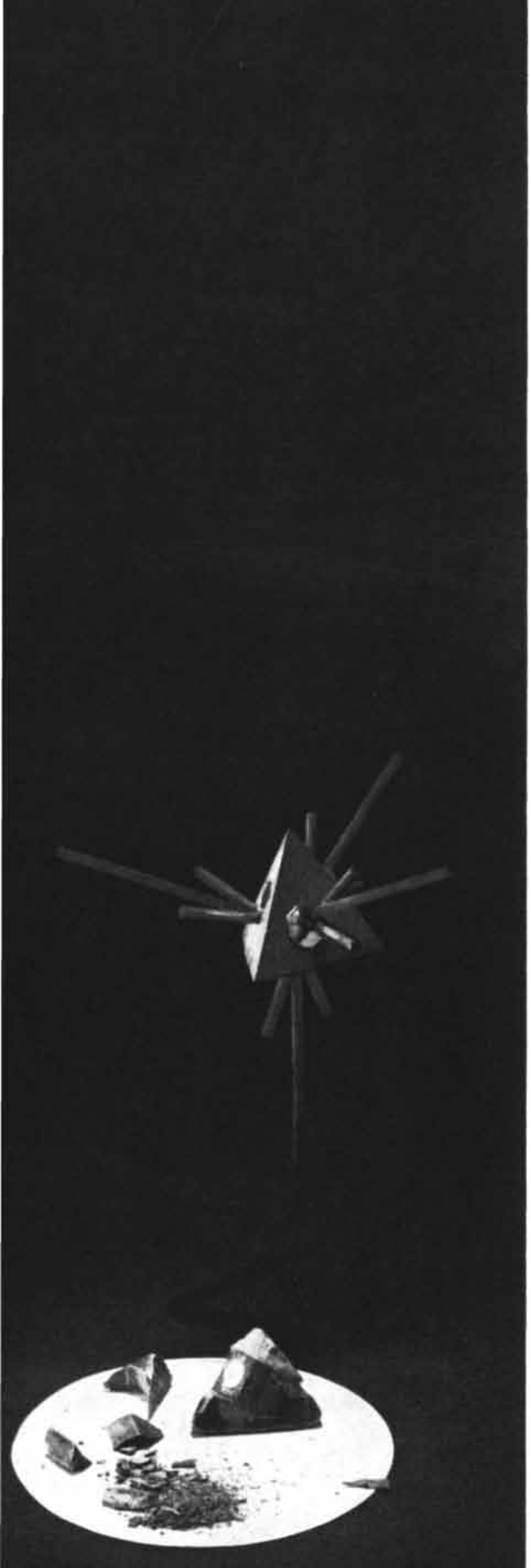
Most substances expand as they melt. A few—such as ice and bismuth—take up less volume as they become liquids. Employing pressures up to 100,000 atmospheres, scientists at the General Motors Research Laboratories have added three tellurium compounds to a small list of remarkable materials that seem to do both—expand as they melt at low pressures, become more dense in liquid form at high pressures.

The materials in this new group exhibit a maximum melting point—a puzzling deviation from normal melting curves. They challenge the theorist to interpret such macroscopic behavior in terms of microscopic structural changes. Perhaps one clue is the decrease in electrical resistance when they melt. But how then does the structure of the liquid differ from that of the solid? And do new solid structures produced at high pressures have unusual or useful properties that can be preserved at one atmosphere?

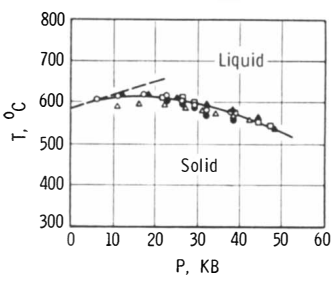
These and other intriguing aspects of solid-liquid interactions formed the starting points for discussion at a recent international symposium on the structure, properties, and theories of liquids. Sponsored by the Research Laboratories, this seventh in a series of annual world gatherings is another way General Motors is furthering the understanding of important, unresolved areas of science.

General Motors Research Laboratories

Warren, Michigan



Tetrahedrons are sample holders used in the Laboratories' 600-ton tetrahedral anvil apparatus. Force on four sides is transmitted to cylindrical specimen inside.



Melting point curve for Bi_2Te_3

Established 1845 SCIENTIFIC AMERICAN November 1963 Volume 209 Number 5

Behavioral Science and Criminal Law

Criminal law has traditionally been based on the concepts of moral condemnation and deterrence by punishment. Does the knowledge of the behavioral sciences dictate a modification of these concepts?

by Edward J. Sachar

In recent years lawyers and behavioral scientists have been talking about the prospective value and increasing need of collaboration between their disciplines in the task of dealing with crime and the criminal. The lawyer reasons that criminal law is concerned with human behavior and should therefore take advantage of understanding gained by scientific observation. The behavioral scientist senses an obligation as a citizen to understand and to serve in the operations of criminal law. These complementary impulses toward collaboration are reinforced by the incalculable toll of human suffering and human waste that is labeled the crime problem and by society's apparent failure to cope with it. The presence in the nation's prisons of about 220,000 felons—those convicted of the most serious crimes—suggests the magnitude of the problem. The fact that 70 per cent of these inmates have been in prison at least once before emphasizes the inadequacy of present methods of handling the criminal.

Desirable as the collaboration of criminal law and behavioral science may appear to be, efforts in this direction have not fulfilled expectations. In the first place, the goals of such collaboration have not always been clearly articulated. It turns out in retrospect that the would-be collaborators have not successfully reckoned with important differences between their disciplines—in aims, premises and working hypotheses. An old principle of psychiatry states that differences that are covert are likely to prove more disruptive in the long run than those that are clearly recognized and understood by both parties. This article will explore some of these fundamental differences in order to delineate more clearly the areas of potential collaboration between the lawyer and the behavioral scientist.

Here another caution is in order: It must not be supposed that criminal law and behavioral science are homogeneous entities with unitary points of view The two disciplines each have their more or less diverse schools of thought, and professionals in each are careful to distinguish between the teachings of theory and the issues that are involved in actual events in particular courtrooms and laboratories.

With these qualifications in mind, criminal law can be described as having two major goals. The first is that of the affirmation of the ethical absolutes of society; the approach to this end has been the moral condemnation and punishment of those who violate these absolutes. The second is that of the reduction of the number of criminal acts within society; the approach to this end has been primarily the penalty system of deterrence and correction.

Although these objectives overlap somewhat, the first is primarily concerned with traditional moral issues, the second with more practical matters of social utility. Almost every legal act in the framework of criminal law attempts to serve both aims simultaneously. As traditionally approached, however, these aims are not always compatible, and one must sometimes be served at the expense of the other. This tension inherent in criminal law has not always been recognized in legal "doctrine," particularly in earlier times. Currently the balance of emphasis given the two goals varies considerably in different legal circles. The leading contemporary theorists of criminal law, for example, are far more interested in the utilitarian goal than in the moral issue. In many courtrooms, on the other hand, the moral issue is held to be paramount.

The traditional moral aspect of the law has often been labeled the attitude of retributive justice. In recent times that attitude has acquired many ugly connotations (for instance, it has been associated with primitive tribal vengeance) that have tended to impede thoughtful analysis of its real aims, premises and methods. This is unfortunate, not only because the moral consideration has shaped to a considerable extent the terms of the law's approach to the criminal but also because the role of criminal law in upholding the moral code is a vital one for every society and cannot be dismissed as irrationalism.

The spirit of the unreconstructed moral aspect of criminal law is caught well in this passage from Thomas Carlyle: "Caitiff, we hate thee.... Not with a diabolic but with a divine hatred....

As a palpable deserter from the ranks where all men, at their eternal peril, are bound to be.... We...solemnly expel thee from our community; and will, in the name of God, not with joy and exultation, but with sorrow stern as thy own, hang thee on Wednesday next...."

Criminal law appears thus as an instrument for reinforcing and celebrating the moral principles of society. In its approach to its moral objective it casts out, condemns and punishes the offender.

The philosophy underlying this approach considers each man to be operating as if he had complete freedom of will. Since he can choose the path of moral right or moral wrong, his commission of a criminal act constitutes a free choice of evil, the expression of a criminal state of mind or intent: *mens rea*. The reprehensibility of the act and of the person committing it are indivisible; such a person is therefore held criminally responsible, that is, deserving of moral condemnation and punishment as a malefactor by the community, in proportion to the heinousness of the crime. When this has been accomplished, justice has been done.

Over the years exceptions and qualifications have been added around this central core of the doctrine of full criminal responsibility. The accused may have acted in self-defense or under duress, or he may be a juvenile. The most significant exception for the purpose of this discussion is that made by the M'Naghten Rule of 1843. A person who is judged to be suffering from a mental illness so severe as to render him incapable of knowing the nature and quality of his act, or of knowing that the act was wrong, is considered to be unable to entertain *mens rea* and is therefore deemed "insane" and "not responsible."

Even in this exception allowed under the M'Naghten Rule, however, it should be noted that the "insane" person's crime is assumed to be an act of free choice. He is exempted from responsibility because he lacks moral judgment, not because his choice is determined by pathology. Correspondingly, the law in its moral aspect rules out consideration of the possible role of social forces in the making of a criminal because such would be inconsistent with the postulate of free will.

The behavioral sciences proceed from premises diametrically opposed to the moral premises of the law as they are stated here. The goals of the behavioral sciences are the understanding and the manipulation of behavior. For these ends the concept of free will, whatever its value in constructing systems of morality (or, for that matter, its value in everyday personal decisions), is of no use. On the contrary, it is necessary to postulate that the behavior and the thought of men are determined in accordance with dis-

VERDICT IN MURDER TRIAL that took place in 1850 B.C. in the Sumerian city of Nippur is symbolic of eye-for-an-eye punishment. Three men were found guilty and executed. The victim's wife, who maintained she did not know of the murder until after it was committed but still did not report it, was acquitted of a charge of complicity because her husband had not supported her.

coverable laws. Only with this working premise can the determinants—social, psychological, physiological and cultural—be identified and their workings analyzed.

It may be that in many areas men have a largely free and "undetermined" choice, but the scientific exploration of behavior cannot begin unless that notion is excluded, just as in physics the notion of the "miraculous" is excluded. Knowledge of certain aspects of behavior may be "indeterminable," that is, unascertainable. The laws of behavior become then, like all scientific law, statements of probability. The ideal of order and lawfulness remains, however, the guiding faith of behavioral science.

Devised for quite different purposes and resting on different premises, the legal and the scientific views of behavior are able to exist in conceptual independence of each other. They do not come into conflict until they are brought into the ostensibly desirable collaboration that is urged by professionals on both sides.

Front of the cuneiform clay tablet is at left, back at right. It is in the University Museum of the University of Pennsylvania.

The clash of outlooks that now follows can perhaps be best viewed from the vantage of the psychiatrist, because he is the behavioral scientist most frequently summoned to the courtroom and the prison. The usual occasion for such a summons is the need for a determination, under the M'Naghten Rule, of whether or not the accused should be deemed "insane" and so exempted from responsibility and condemnation for the crime alleged. Since the psychiatrist, from a scientific point of view, must regard all behavior—criminal and law-abiding, healthy and sick—as determined, he finds the issue of moral condemnation of the individual to be inappropriate. Some criminal behavior appears to him to be symptomatic of mental illness, but in many other instances the model of mental illness does not seem to fit, or at least it does not appear to be useful in dealing with the behavior. In any case, to this way of thinking the offender's illness has nothing to do with the question of whether or not he is "free" or "responsible" in the traditional sense. Just as the functions of the sick body and the healthy body proceed in accordance with the laws of physiology, so sick and healthy minds function in accordance with the laws of psychology. The difference between sickness and health is measured not in degrees of freedom but in degrees of success or failure in meeting objectively defined standards of function or behavior.

In place of the moral-legal doctrine of responsibility the psychiatrist, as a scientist, asserts his own concept of responsibility. It is very different from the moral-legal one: to hold someone criminally responsible is to say that he must change. Thus in psychotherapy helping a patient "to recognize his responsibility" means helping him to see how he must change if he is to achieve his goal in therapy. Applied to criminal behavior, the finding that someone is criminally responsible means to the psychiatrist that the criminal must change his behavior before he can resume his position in society. This injunction is dictated not by morality but, so to speak, by reality. A burglar's present antisocial character and behavior may have been shaped by his slum environment, his domineering mother and alcoholic father, but he is still criminally responsible; his behavior must become law-abiding if he is to be tolerated in a society that is against burglary. Initially this behavior change will be accomplished by external controls, but the expectation is that the control will eventually be internalized. The psychiatrist attempts to understand the formative factors in a patient's life, not to excuse him but to help him to change.

The psychiatric and moral-legal views of criminal responsibility are similar in that both involve an imperative, a calling to account and an intervention in an ongoing pattern of living. They differ in that the strict moral-legal view is directed to the blame and punishment of the offender; the psychiatric view, to change in his behavior. From the psychiatrist's point of view no offender would be "responsible" in the legal sense but all would be responsible in the psychiatric sense, including psychotics, mental defectives and children, who are usually exempted from the legal doctrine.

In his approach to the criminal the psychiatrist discards the strict moral-legal concept of criminal responsibility; he does not, however, discard morality. Nor does he need to differ with the lawyer as to what constitutes a crime. The psychiatrist condemns the offense but not the offender. This constitutes another important departure from the moral-legal definition of responsibility, a departure the psychiatrist finds essential for his goal of effecting behavior change. There is a world of difference therapeutically between saying "You have done a terrible thing" and "You are a terrible person." Melitta Schmideberg of the Association for the Psychiatric Treatment of Offenders put the matter succinctly when she said that if you condemn the offender, you give up all hope of treating him, but if you condone his offense, you give up all hope of changing him.

The psychiatrist's way of thinking about criminal responsibility has a social as well as an individual aspect. He would argue, for example, that the slum is to the offender what the polluted well is to the typhoid case. In the fixing of criminal responsibility in the psychiatric sense—that is, in the determination of who and what must change—the slum as well as the individual offender must be incriminated. Here is still another important difference between the psychiatric and the moral-legal view of criminal responsibility. Whereas the moral-legal approach fixes responsibility exclusively on the offender, the psychiatrist may arraign society as well.

For whose sake does the psychiatrist attempt to change the criminal? For the criminal's sake or for society's? For the

SING SING PRISON, a New York State institution at Ossining, is an architectural expression of the concept of punishment as the basis for criminal law. This photograph shows a gate, guard tower and part of the high wall, typical of older prisons.

sake of both, he would argue, just as the physician, confronted with a case of smallpox, thinks immediately of saving the patient as well as protecting the health of the community. The psychiatrist acts in regard to the criminal as an agent of behavioral science and of the humanitarian movement of the 19th and 20th centuries that has placed high value on the inviolability of the individual. In the realm of criminal law that movement is reflected in a growing concern to protect not only the rights of the potentially innocent but also the rights of the unquestionably guilty.

The psychiatrist's interest in the welfare of his patient as well as of society is the reason for his exercise of ethical restraint as to the methods he uses to effect change. Furthermore, the patient's awareness that the psychiatrist is concerned about him as an individual may be one of the most important tools the psychiatrist has for overcoming his resistance to change. Similarly, the psychiatrist's firm awareness of the strictures of society as part of the reality principle is a significant portion of what he has to impart to the patient.

Considering that for moral purposes criminal law regards most criminal behavior as a product of free will, requiring moral condemnation and punishment for the criminal primarily in the interests of society, it would appear that the grounds for psychiatric and legal collaboration in the fixing of criminal responsibility are sharply limited. Unless there is a revision of the basic doctrine of responsibility on one side or the other, the area of collaboration cannot be broader than it is now. The behavioral scientist presents his observations; the legal apparatus thereupon applies its own criteria to these data to make the determination of criminal responsibility. A more far-reaching collaboration would require a decision by judges and legislators that the imperative "You must change" can be as effective in upholding and solemnizing the moral code, and would be as consonant with the moral temper of the age, as the imperative "You must be morally condemned and punished."

In its second major aim criminal law strives toward the practical end of reducing the number of criminal acts within society. In its approach to this aim criminal law has sanctioned almost exclusively the penalty system of deterrence and correction. Here the goal of criminal law coincides with one of the major aims of behavioral science: the manipulation of behavior. This coincidence of goals must necessarily bring the differences between the two disciplines into sharper relief and conflict. On the other hand, in exposing the procedures of the law to criticism from behavioral science, it may also open the way to broader collaboration between the disciplines.

In the approach sanctioned by the law, a graded program of penalties is designed to accomplish three ends: the deterrence of those who might commit crimes if it were not for the fear of punishment; the correction of those who have committed crimes by creating pain-

HOSPITAL FOR NARCOTICS ADDICTS at Lexington, Ky., treats rather than punishes law violators. The hospital is operated by the U.S. Public Health Service. Some patients are convicts but most have entered the hospital and remain there voluntarily.

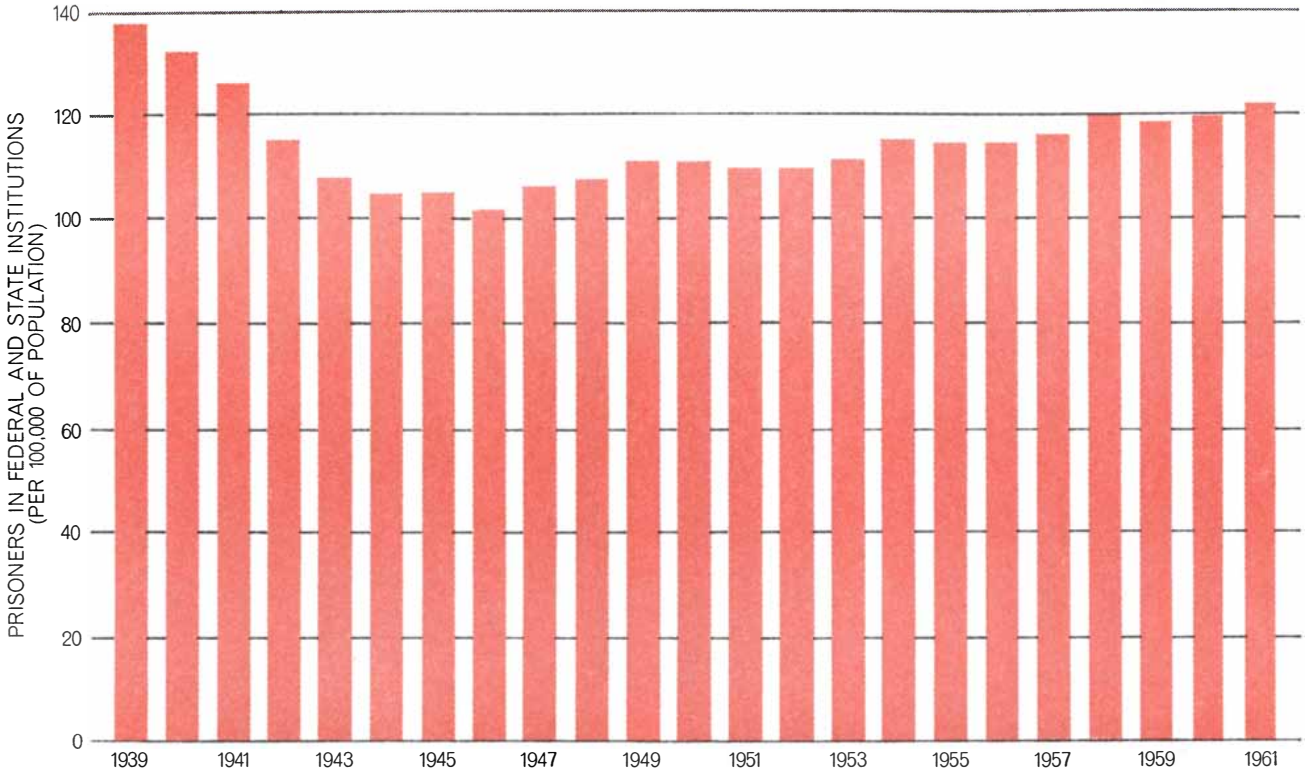
ful associations discouraging repetition of the offenses, and the isolation of the offender in order to reduce his danger to the community. Criticism from behavioral science has centered on the question of whether or not a penalty system alone is sufficient to serve the goals of deterrence and correction. In this utilitarian context the question is not whether the punishment is deserved but whether the penalty is effective.

Some years ago the universal validity of the penalty-reward system for behavior control was held to be proved by its effectiveness in the training of animals. Since the work of the Russian physiologist I. P. Pavlov and more recently the work of Howard S. Liddell of Cornell University, it is possible to point to animals that repetitiously follow certain behavior patterns in spite of invariably associated painful stimuli. These examples of "experimental neuroses" [see "Conditioning and Emotions," by Howard S. Liddell; SCIENTIFIC AMERICAN, January, 1954] cannot be ignored by those thinking about the problem of the habitual criminal. On this and other evidence the behavioral scientist would question exclusive commitment to the simple penalty-reward technique.

He would argue that such a technique is likely to prove most effective for people who are, ironically, perhaps the least likely to commit major crimes, and likely to prove least effective in the case of social deviants with a background of abnormal disciplinary experience who are perhaps the most likely to commit major crimes.

Crime statistics suggest that the penalty system works well as a technique of deterrence and correction in certain areas, such as the enforcement of traffic laws and in certain types of "white collar" crimes. For certain other serious criminal problems, however, such as crimes of violence and drug addiction, the technique seems to have relatively little effectiveness. No one knows with certainty, of course, how many people are deterred from crime by fear of punishment, but the high rate of recidivism indicates that such fear does not work in the case of those who seem to need deterrence most. In a study to be published next year Daniel Glaser of the University of Illinois estimates that 50 per cent of all felons discharged from prison have later trouble with the law and that 35 per cent are back in prison within three years. Among youthful offenders, who represent the major crime problem, the rate of recidivism is considerably higher. The relative ineffectiveness of the penalty system may be attributed to its failure to reach the psychological and social forces that are responsible for the behavior of many criminals. The flogging of psychotics in the 17th century proved to be of only limited effectiveness for the same reason.

The psychiatrist would further point out that the imposition of a penalty is a complex interpersonal transaction, and that the interpersonal "context" in which the penalty is delivered is at least as critical a factor in determining the outcome as the penalty itself. For instance, a penalty administered by a parent who



RATE OF IMPRISONMENT of felons in Federal and state institutions is not as high as before World War II, but it has been climbing slowly since the war. The rate of imprisonment is affected by such factors as changes in the law and in parole policies, as well as by the number of crimes. Data for this chart and that on the opposite page were collected by the Federal Bureau of Prisons.

enjoys inflicting pain, and who watches avidly to catch his child in an offense, is likely to produce very different behavioral effects from those produced by the same penalty imposed by a parent whom the child perceives to be firm but kind. Data from the studies of penologists tend to bear out the forebodings of the psychiatrist. Evidence is accumulating that the interpersonal milieu in many prisons is one that tends to brutalize the offender, to foster a sense of criminal identity and to reinforce criminal trends rather than discourage them.

For a basically crime-centered system, in which the penalty fits the crime, the psychiatrist would substitute an offender-centered system, in which the treatment would be designed to effect change in antisocial behavior. Most psychiatrists who have become concerned with penology agree that such treatment would call for a setting in which discipline is firmly established but in which something more would be provided. That would include greater attention to the interpersonal milieu of the disciplinary institution. Taking advantage of the insights gained from "milieu therapy" in mental hospitals, the prison staff in its interactions with the patient-prisoners would communicate qualities of iron firmness combined with sincere concern for the welfare of their charges, a clear conviction that behavior change is both possible and essential coupled with a genuine respect for their charges as human beings. There would also be provision for a rehabilitative program, in most cases the teaching of a useful trade and other skills essential to a successful adaptation to society (for example reading and writing).

Central to the therapeutic program would be the effort to provide the offender with more mature mechanisms for dealing with the psychological tensions and compulsions that presumably played a role in the production of his criminal behavior. Of course, psychotherapy does not mean an analyst and a couch per prisoner. There are less intensive methods that may suffice for the limited goal of helping to alter behavior. Considerable success is claimed in this regard for group psychotherapy; what is more, nonpsychiatrists can be trained to lead such groups. Finally, the same attitude and concern would follow the released prisoner in his relations with his parole officer and others during his readjustment in society, a period that is critical to the chances for recovery or recidivism. The same principles would apply to the management of those offenders who do best in an outpatient-probation setting.

This kind of reform has been carried out in a few progressive prisons. In the vast majority, however, therapeutic programs are only rudimentary, and efforts in this direction tend to encounter misunderstanding and resistance in the community. It is true that knowledge and skills in this underdeveloped area of psychiatry are still uncertain. Nevertheless, they can be expected to improve with experience, because a scientific approach to the change of behavior necessarily involves constant experimentation and testing of techniques. This is a fundamentally different approach from that of the system sanctioned by criminal law and committed with relative inflexibility to penalty as its technique.

The critical question at this juncture is not whether present psychiatrically based methods and understandings are good enough to be 100 per cent successful in the treatment of all offenders. It is whether or not the psychiatric approach can now be more effective than the traditional one. To put this question to the test of experiment would be difficult but not impossible. Offenders matched for age and criminal records might be sent to alternative corrective facilities,

one following the traditional approach, the other utilizing psychiatric principles. The institutions would have to be located in the same or matched communities, since community attitudes toward the ex-convict appear to have an important influence on his tendency to regress. Careful follow-up of both samples for 10 years after release would furnish information as to which approach is most effective in correcting criminal behavior.

It would be somewhat more difficult to compare the effectiveness of the two systems in deterring crime. In the view of the psychiatrist the cause of crime prevention is not well served by penalizing the offenders; slum clearance and the development of school counseling systems would be of more value in the long run than changes in the practice of penology. For these reasons the psychiatrist would not predict that his approach to the treatment of offenders would show greater deterrence value.

Critics of the psychiatric approach make even bleaker predictions. They say that a prison run along therapeutic lines would be known as a resort and that there would be no fear of punishment to restrain those with criminal tendencies.

To settle such doubts, the crime rates might be compared in communities matched as to population, slums, schools, nationalities and so on and differing in the handling of their criminals. Or crime rates might be compared in a single community before and after a shift to the therapeutic method of handling offenders. Keeping other significant variables constant in such social experiments would, of course, be next to impossible, and crime statistics are notoriously hard to gather. Yet even these uncertain experiments might suffice to rule out with confidence the hypothesis that a shift to a therapeutic approach would invite a dramatic rise in the crime rate.

What compromises can be suggested, then, that would allow the collaboration of two disciplines that are so divergent in theory and in practice? One proposal would confine the law to the moral drama of the courtroom and would give behavioral science a free hand in the prison. The demand for punitive treatment of the offender would be dropped; moral condemnation by the court would be deemed sufficient to celebrate and reinforce the moral values of the community. After this rite the offender would be sent to prison not for punishment but for treatment, guided by behavioral science.

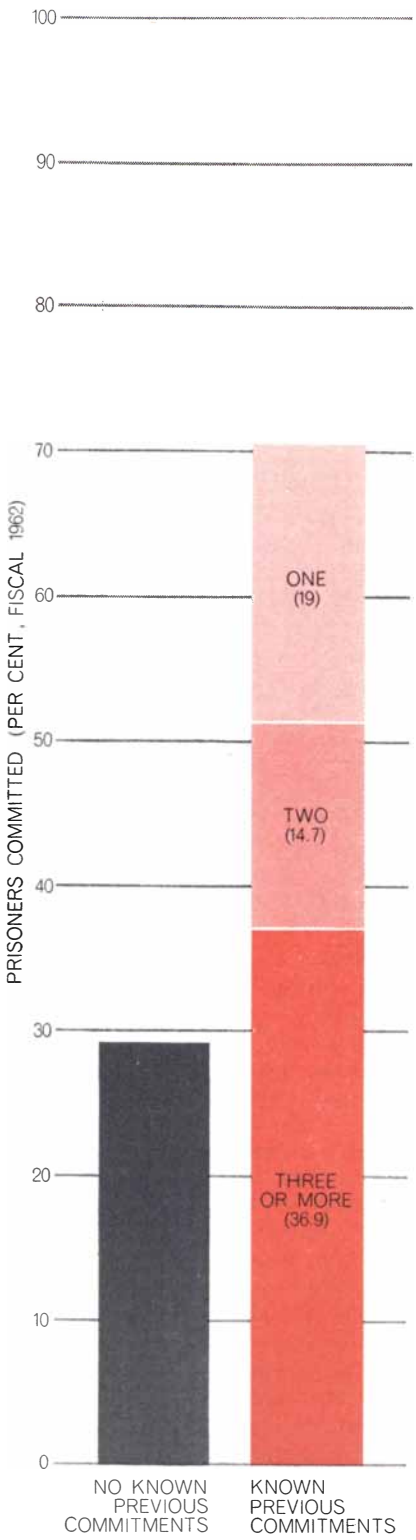
Critics of this compromise contend that moral condemnation, with the associated experience of being cast out by the community, cannot help but have psychological repercussions inimical to any subsequent effort to change the behavior of the offender. Reliable data bearing on this point are not available, and once again the techniques of behavioral science would have to be invoked to put the hypothesis to the test. Even if it were shown that moral condemnation in the courtroom had detrimental effects on subsequent corrective efforts, however, it could still be argued that the moral aim justified this "expense"—within limits.

An alternative compromise would require a change in the law's approach to its first goal: the upholding of the moral code. According to this scheme the law would substitute the imperative "You must change" for the imperative "You must be morally condemned and punished." In other words, the "psychiatric" definition of criminal responsibility would replace the present legal one. In this event there would be complete consonance between the moral and the practical aims of the law. This is in effect the trend in the legal system of certain Scandinavian countries.

Critics of this compromise argue that the traditional moral values of a society cannot be sustained under it and maintain that moral disintegration is a characteristic of those countries that have employed it. Conceivably this hypothesis could also be tested, but only if measurable criteria of a society's moral fiber could be devised.

The issue of testability has been labored here because this in itself is a realm where behavioral science can provide an important service to the law. Once the questions have been posed and the goals have been set on the basis of value judgments, the assistance of behavioral science can be useful in determining the most efficient ways of answering those questions and reaching those goals.

The theoretical nature of this discussion should not obscure the terribly concrete nature of the problem of crime, which is the subject of all collaborative efforts between behavioral science and criminal law. In the final analysis the success of these efforts will depend not on the theoretical points of contact and difference between science and the law but on the willingness of the individual behavioral scientists and lawyers to dedicate themselves to this work.



RECIDIVISM was high among felons committed to Federal institutions during fiscal 1962, a typical year. More than 70 per cent had been in prison before. This does not mean, of course, that 70 per cent of all those who have been in prison return to prison. That figure is in the range of 35 to 40 or 45 per cent, according to several follow-up surveys of released prisoners.

PLASMAS IN SOLIDS

Gaseous plasmas pervade the universe, but it is not easy to control their properties in the laboratory. The plasmas that exist in solids are friendlier and serve very well to test theoretical predictions

by Raymond Bowers

The experimenter is always looking for new ways to study complex phenomena. For example, he would like to find physical systems that exhibit in simpler form the complex phenomena to be found in a gaseous plasma. Such a system would be especially interesting if it exhibited some of the features of the plasma of outer space and acted as a simple model for the test of astrophysical theories. Therefore the demonstration that properties of plasma can be duplicated in metals and other solids not only has been a source of satisfaction to the experimenter but also has permitted a careful test of theories predicting plasma behavior.

A plasma is a collection of positively and negatively charged particles moving about so energetically that they do not readily combine. Plasmas are everywhere in the universe. They form the intensely hot gas under high pressure in the sun and the stars, as well as the rarefied gas in interstellar space and in the ionospheric envelope surrounding the earth. Plasmas also exist closer to hand. They are present in the flames of burning fuel and in gas-discharge devices such as neon signs. Plasmas exhibit such an enormous variety of physical effects that physicists have studied their properties for more than 130 years. Past research on plasmas, particularly on gas discharges, led to the discovery of the electron and to the elucidation of atomic structure.

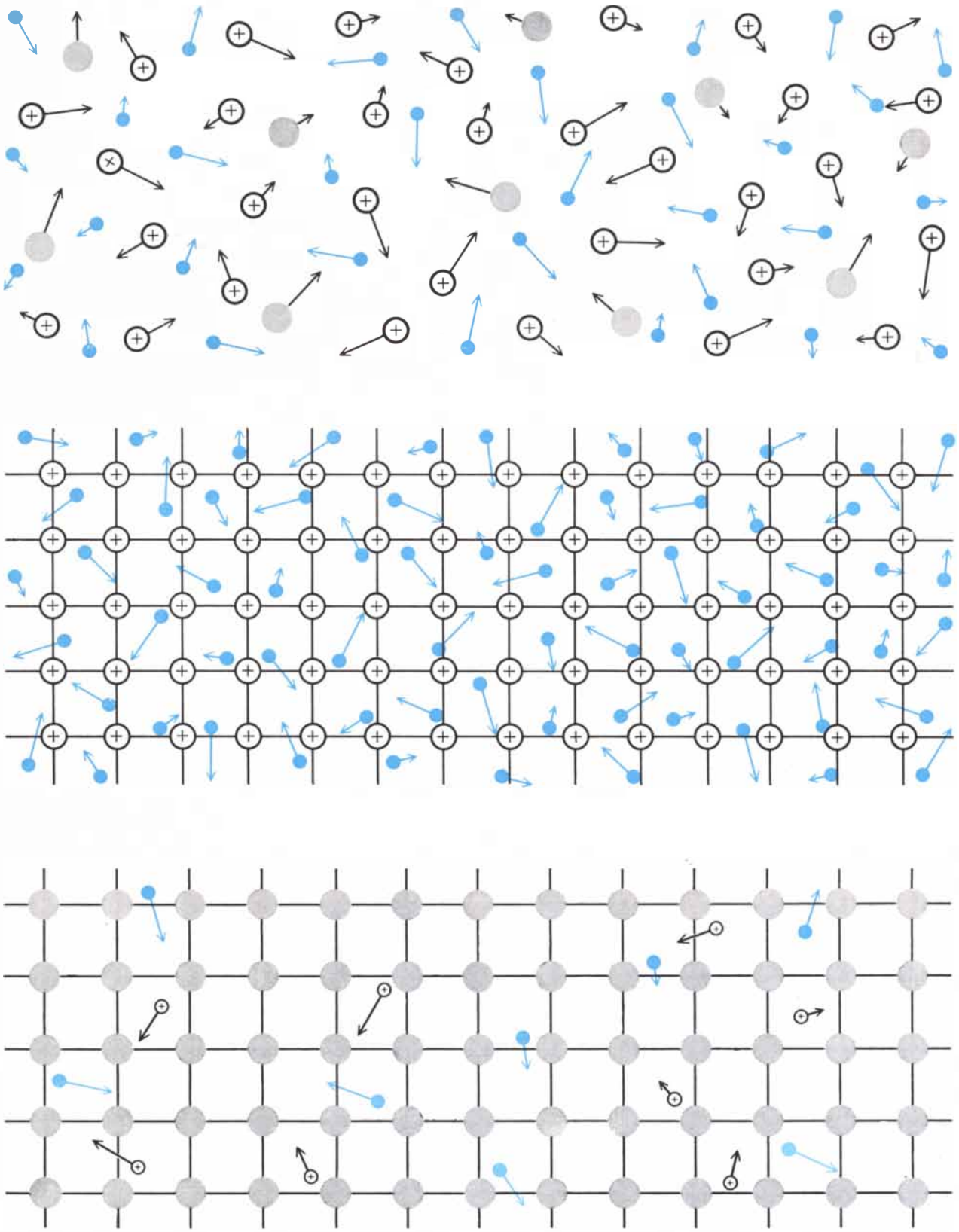
The current interest in plasmas reflects two principal motives. The first is technological. An understanding of plasma behavior is crucial to the controlled release of thermonuclear energy, the attempt to reproduce in a man-made plasma the kind of nuclear reaction found in the sun. Another technical goal is the design of magnetohydrodynamic generators, in which electric power is generated by jets of gas plasma traversing magnetic fields. The second broad motive for the study of plasmas is the importance of plasma phenomena in space and in astrophysics. When a plasma is subjected to electric and magnetic fields, the motion of the particles is no longer completely random. One important consequence of this imposed order is that a plasma containing a magnetic field can transmit certain kinds of waves that are related to electromagnetic waves but that have unique and curious properties. It has been recognized in the past 30 years or so that such magnetoplasma waves play a significant role in the large-scale energy-transport processes of the universe. Plasma waves are believed to be involved in sunspots and solar flares and may provide the mechanism for accelerating cosmic rays in space. In short, plasma waves can be expected wherever an ionized gas contains a magnetic field, and this is just about everywhere in the universe.

In view of this background, it is not surprising that most people associate the word "plasma" solely with phenomena taking place in gases. This article will describe some experiments involving plasma waves in solids and will show how they resemble similar waves in a gas plasma. In these experiments the plasma consists of the carriers of electricity to be found in any metal or other solid conductor. The carriers can have either negative or positive charge, and in certain semiconductors the two carriers can exist simultaneously, just as they do in a gas plasma.

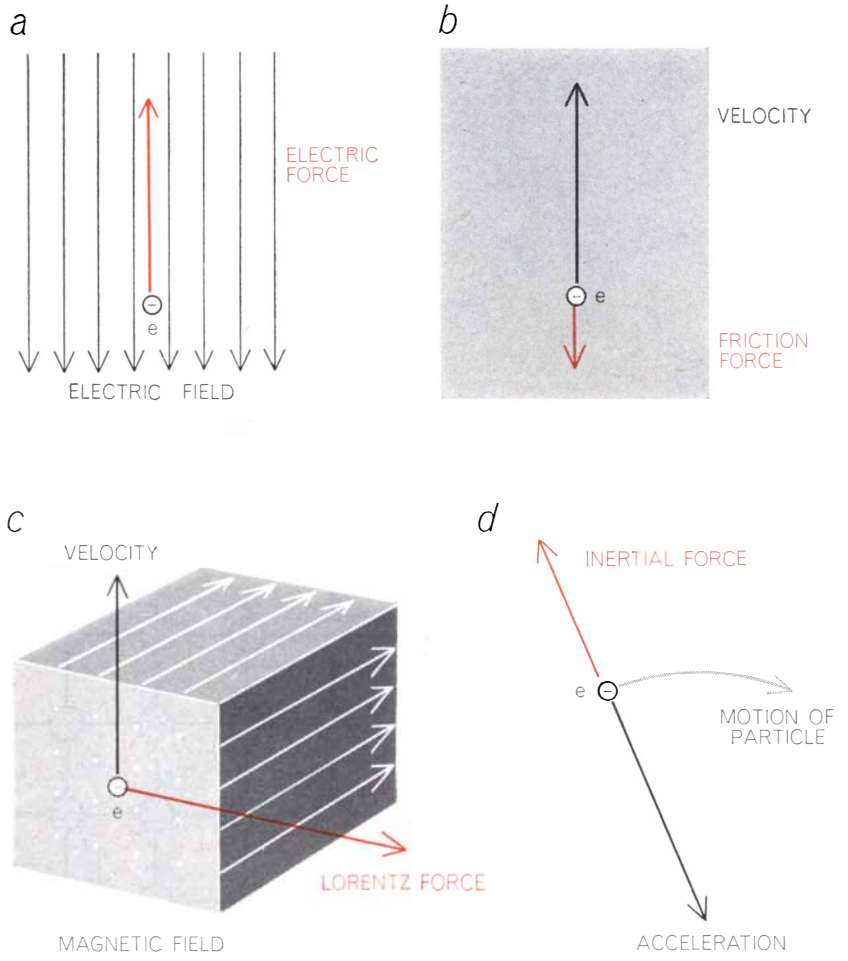
One might reasonably ask: What is the point of such experiments? No one can hope to create a thermonuclear reaction in the plasma of a solid, nor can one remotely approach the scale of phenomena that is the crucial element in astrophysical problems. This is quite true. Yet plasma experiments in solids offer a unique opportunity to observe plasma behavior under well-defined and accurately known conditions. In a solid, one can usually determine quite precisely the number of charge carriers, their masses, their random heat energy and the boundaries of the plasma. Such a degree of knowledge and control is rarely attainable in gas-plasma experiments, which often take place in transient discharges where conditions are subject to rapid change. Consequently certain aspects of plasma theory can be tested better in a solid than in a gas.

One can regard many phenomena in solids as manifestations of plasma effects. I shall limit my discussion, however, to two groups of experiments in which the plasma effects observed in solids had previously been associated only with gas plasmas. Both experiments involve waves generated in the presence of a magnetic field.

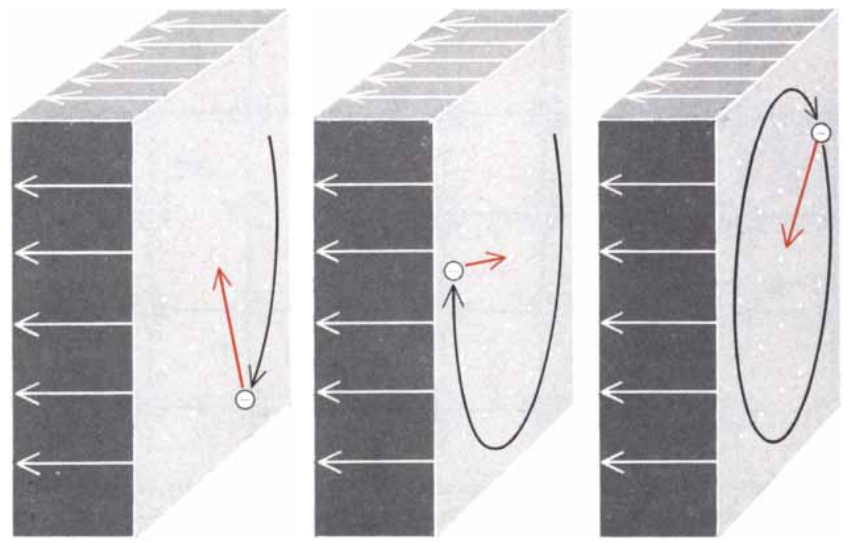
To follow the experiments one must understand the factors that influence the propagation of a wave in a plasma that contains a large magnetic field. Let us consider first the propagation of an ordinary electromagnetic wave, such as a light wave. When there is no plasma present, an electromagnetic wave travels with the velocity of light, and the application of a large magnetic field has no influence on the wave or its velocity. If, however, a plasma is placed in the magnetic field, the positive and negative charges of the plasma will interact with the electric field of the wave, and the propagation of the wave will be profoundly modified. In fact, the existence of the plasma sets tight restrictions on the type of wave



THREE KINDS OF PLASMA are represented schematically: a gaseous plasma (*top*), the plasma in a simple metal (*middle*) and the plasma in a semiconductor or semimetal (*bottom*). Plasmas contain negative and positive carriers under conditions in which they do not combine. In the diagrams a colored dot is an electron, or negative charge, a circle containing a plus sign is a positive charge and neutral atoms are shown gray. In a gas there are two kinds of charge carrier: electrons and positive ions (atoms lacking electrons). In a simple metal the only mobile carriers are electrons; positive ions are locked in the crystal lattice. A semiconductor has two kinds of mobile carrier: electrons and positive "holes," or missing electrons. All three plasmas can transmit waves.



FORCES ACTING ON ELECTRON in a plasma are four: electrical, frictional, magnetic and inertial. The electric force (*a*) is the product of the electric field and the electron's charge. The friction force (*b*), produced by collision with other particles, is proportional to velocity. The magnetic, or Lorentz, force (*c*) is perpendicular to the magnetic field and the velocity and is proportional to both. The inertial force (*d*), which acts in a direction opposite to the net acceleration, is proportional to acceleration and the electron's mass.



PATH OF ELECTRON in a magnetic field is governed by the Lorentz force (*colored arrows*), which acts in a direction perpendicular to the magnetic field and the velocity. In the absence of an electric field this obliges the electron to circle around the magnetic lines.

that can be propagated through it. These restrictions are basically determined by the motions of the charged carriers in the plasma; in a sense the wave must be "in tune" with these motions.

The motion of an electron (negative carrier) in a plasma can be influenced by four forces [*see illustration at left*]. First, it will be accelerated by an electric field. This field can be imposed from the outside or it can be the electric component of an electromagnetic wave propagated through the plasma. Second, the electron will be retarded by frictional forces such as might arise from collision with other particles. Third, the electron will be deflected by a magnetic field. This magnetic force, called the Lorentz force, acts at right angles to both the electron's velocity and the direction of the magnetic field. Regardless of the forces that act to accelerate an electron, the acceleration is resisted by a fourth force, which is the inertial force. The inertial force is proportional to the electron's mass and acceleration and acts in a direction opposite to that of the electron's net acceleration.

Of the four forces mentioned, the frictional force produces the same effect on all waves: it damps the motion of the plasma components and damps the wave being propagated. For the wave to be well defined the friction in the system must be small. One of the attractions of solids for plasma studies is that in some materials friction can be made negligible. Carriers of high mobility, largely undamped by friction, can be obtained in certain semiconductors and in some very pure metals by cooling them to low temperatures, which reduces the thermal vibration of the atoms in the crystal lattice of the material.

To make things simple let us consider a plasma in which friction is negligible and in which there are equal numbers of positive and negative charges. We will assume that the negative charges are electrons and that the positive charges are heavy positive ions, that is, atoms that lack one or more electrons. In such a plasma the mobility of the electrons is so much larger than the mobility of the heavy positive ions that we can regard the positive charges as stationary. Now one can ask: What kind of wave can propagate through this system when it is placed in a magnetic field?

One can imagine that the electric field associated with the wave will push on the electrons in the plasma. Assuming that friction can be neglected, the electric force on the electron will be

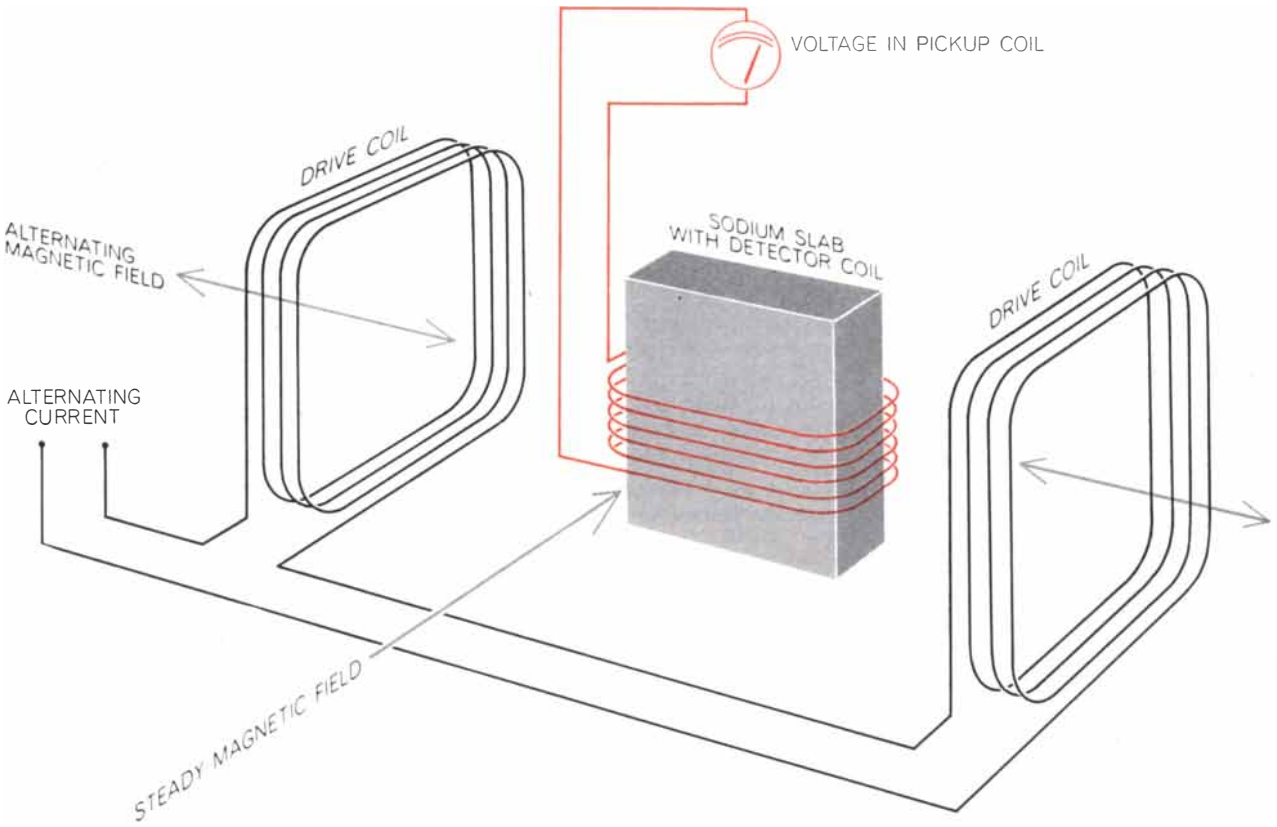
balanced by the sum of the Lorentz force and the inertial force. If one calculates the relative sizes of these forces for waves of moderate frequencies, one finds that for electrons the Lorentz force is far larger than the inertial force; hence the magnetic field dominates the electron's motion. Because the Lorentz force is always perpendicular to the magnetic field and to the direction of the electron's motion, the electron is obliged to rotate around the lines of force in the magnetic field.

It turns out that the only kind of wave that can impart to the electron a permissible type of motion, and therefore propagate, is a wave whose electric field and associated current direction rotate about the magnetic field at a certain frequency. This frequency is inversely proportional to the square of the wavelength and depends also on those factors that enter into the calculation of the Lorentz force, namely the magnetic-field strength and the number of electrons per unit volume. Not surprisingly, the wave will propagate only if its sense of rotation coincides with the sense of rotation that electrons wish to follow in a magnetic field.

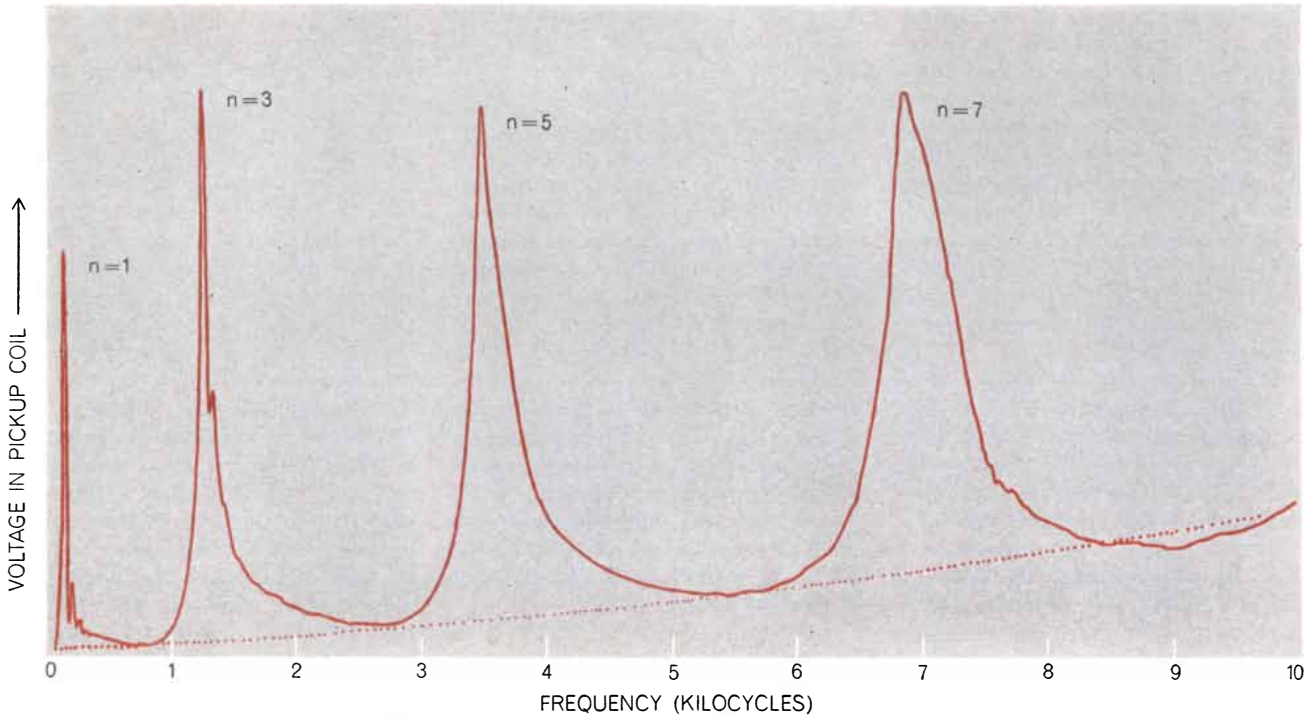
The fact that the frequency of this wave is inversely proportional to the square of its wavelength gives the wave an unusual property: its velocity increases as its frequency increases. This is because the velocity of any wave equals the frequency times the wavelength. In the case of light waves and sound waves any increase in frequency is accompanied by a proportional decrease in wavelength, so that the velocity remains constant. In the case of this particular plasma wave, as the frequency rises, the wavelength decreases only as the square root of the change in frequency. For example, if the frequency rises by a factor of 100, the wavelength drops by a factor of only 10, with the result that the velocity rises by a factor of 10.

A wave with just these properties, known as a whistler wave, is frequently propagated in the rarefied plasma of the earth's ionosphere [see "Whistlers," by L. R. O. Storey; SCIENTIFIC AMERICAN, January, 1956]. Whistlers are created by lightning flashes. The waves travel along the horseshoe-shaped lines of force in the earth's magnetic field, which have termini called conjugate points in the extreme Northern and Southern hemispheres. Whistlers can be detected by an antenna coupled to an audio-frequency amplifier. The whistle can result from a lightning flash at the conjugate point on the far side of the earth or it can be produced by a flash near the receiver that has sent a wave to the far conjugate point, where it is reflected and returns by the same path.

Why the whistle? The explanation is that the lightning flash initially excites waves with a wide band of frequencies. As described above, however, the high frequencies travel through the plasma faster than the low frequencies, with the result that the wave is dispersed. The arrival of successively lower frequencies at the receiver produces a whistle that descends in pitch. Because of uncertainty about the density



PLASMA WAVES IN METAL were demonstrated by the author and his associates at Cornell University with this experimental arrangement. The sodium slab is cooled to the temperature of liquid helium to reduce friction in the electron "gas" that forms the plasma, and the plasma is subjected to a strong, steady magnetic field. When an alternating current is passed through the drive coil, a plasma wave of the type known as a whistler is excited in the sodium slab. The whistler does not travel but appears as a standing wave in a "box" defined by the size of the slab. Frequencies of four standing waves are shown at the top of the next page.



STANDING WHISTLER WAVE is produced in a slab of sodium (*see illustration on preceding page*) when the dimension of the slab in the direction of the magnetic field is an integral number times half the whistler wavelength. The voltage peaks, indicating the existence of a standing wave, are shown for the odd integers 1, 3, 5 and 7. Voltage output for even-integer waves is canceled by the experimental circuitry. The broken colored line shows the output voltage when the magnetic field in the sodium slab is zero.

of free carriers in the ionosphere it is difficult to compare quantitatively the properties of whistler waves with those predicted by theory.

Our group at Cornell University has excited the same whistler wave in the electron "gas" of a metal and has carried out precise comparisons between theory and experiment. Certain metals are ideal subjects for this kind of study. The electrons are extremely mobile, whereas the positive ions are immobilized in the crystal lattice of the metal. This is just the simple condition described earlier. In order to have little friction in the electron gas, we wanted a metal with the highest possible conductivity. For this purpose we selected sodium, and we lowered its temperature to that of liquid helium. Thus chilled, its conductivity is 7,000 times greater than it is at room temperature. Under such conditions the effect of the Lorentz force compared with friction forces is very large indeed.

We did not produce a traveling whistler wave in our small sample of sodium; instead we produced a standing whistler wave in a "box." This is much like the standing wave that is produced when a violin string is plucked. The slab of sodium is placed in a strong, steady magnetic field [*see illustration on preceding page*]. Two small coils, mutually perpendicular and also perpendicular to the large magnetic field, are wound outside the sodium specimen. One of these coils, called the drive coil, carries an alternating current that is used to excite the whistler wave in the sodium. The second coil, called the detector coil, is used to detect whether or not a wave has actually been generated. In the experiment the voltage in the detector coil is recorded while the frequency of the drive current is varied.

The detector shows a voltage peak only at certain particular frequencies when the system resonates [*see illustration above*]. Resonance occurs when the length of the sample in the direction of the magnetic field is an integral number times half the whistler wavelength. This is merely another way of saying that only a half-wavelength, or multiples of a half-wavelength, will fit exactly in the sodium box. This relation describes the fundamental mode of oscillation and the higher harmonics of most vibrating systems. (The reader may note that the resonance peaks shown in the illustration above do not include modes of vibration for the even integers. The explanation is that our pickup coil envelops the whole specimen, and even modes have electric fields that add up to zero when they are summed over the full area of the pickup coil.)

The frequency at which the peaks occur can be calculated from the theory that describes the propagation of a whistler wave in a plasma. The frequency depends on the dimensions of the plasma, the strength of the magnetic field and the density of the carriers. The first two can be measured quite precisely in a solid; the number of carriers can be calculated on the assumption, based on theory and many experiments, that there is one conduction electron per atom of sodium. The frequencies of whistler peaks in our sodium system agree closely with those predicted by theory. The discrepancy, which amounts to only a few per cent, is probably connected with aspects of the solid not related to the general theory of waves in plasmas.

In the whistler experiment described above the whistler was kept resonating by continued excitation from the drive coil. This is equivalent to bowing a violin string to keep it resonating. But just as one can also pluck a violin string and obtain a sound that diminishes in time, one can "pluck" the whistler wave by applying a sharp electric pulse to the drive coil. When this was done, we ob-

tained the smoothly decaying "notes" shown in the oscillogram on this page.

Our group was the first to report whistler waves in metals. Our findings were published in 1961, and at the time we did the experiments we knew of no prior discussion indicating that such waves might be produced. Actually Pierre Aigrain of the University of Paris had in 1960 published a proposal to excite in a semiconductor placed in a magnetic field a wave motion he called a helicon. The name was chosen to indicate that as this wave traveled along the magnetic field, the electric field associated with it would trace out a helix. Aigrain proposed experiments to look for the existence of this wave at a frequency of about 10 billion cycles per second. Our own investigations produced waves with a frequency of 10 to 100 cycles per second. It did not occur to us at first that there could be any relation between our work and the experiments proposed by Aigrain.

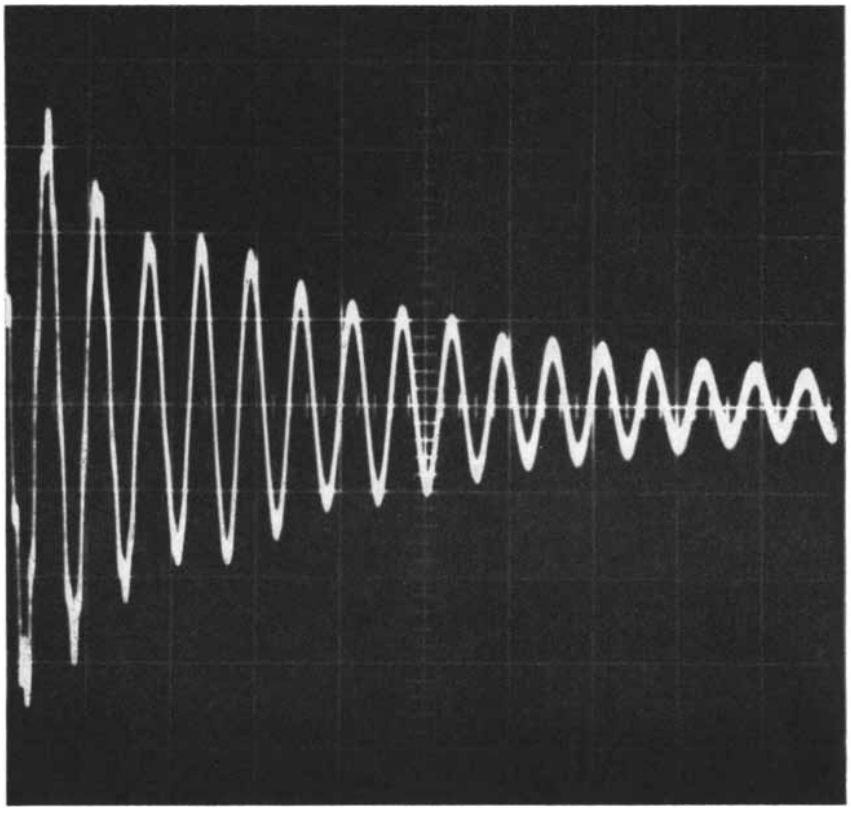
Once the theory of the experiments in metal had been worked out, however, it became clear that the helicon proposed by Aigrain and our own waves are identical. The enormous difference in frequency is due entirely to the difference in the number of electron carriers in metals and semiconductors. The former contain 10^{22} electrons per cubic centimeter; the latter, 10^{14}. The ratio of these numbers is just the ratio of the two frequencies. The helicon, the atmospheric whistler and the very-low-frequency plasma resonance observed in metals by our group are physically identical. It is a great satisfaction to see the manifestation of the same wave in such vastly differing environments. As far as I know Aigrain's publication was the first to propose that whistler waves could be transmitted through solids under reasonable experimental conditions, and his group has since confirmed their existence in semiconductors at the predicted frequencies.

The second type of magnetoplasma wave I wish to discuss has a character quite different from that of the whistler wave. It is the dominant wave mode in a plasma that has equal numbers of positive and negative charges, both of which are highly mobile. If both positive and negative charges are mobile, the electric currents that are the result of the electric field and the Lorentz force can balance out to zero; the current due to the mobile positive charges exactly cancels the one due to mobile negative charges. Even though there is no net flow of electric charge, there is nevertheless a flow of particles [*see top illustration on next page*].

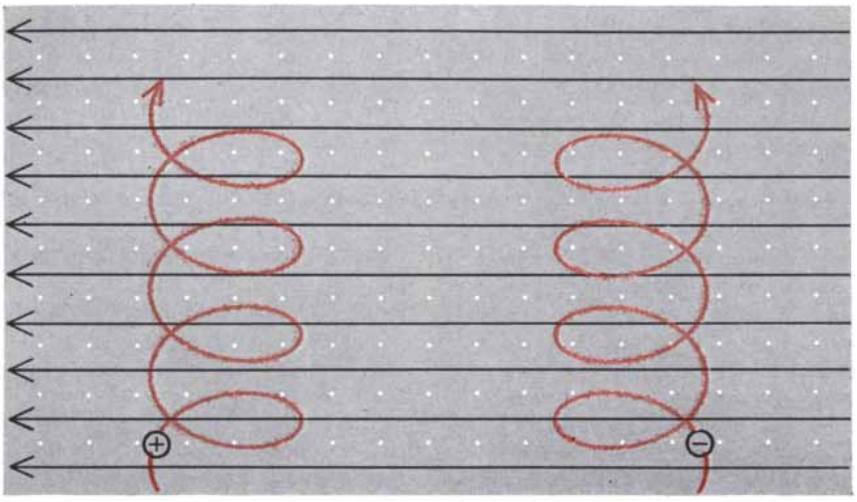
As a consequence certain waves can be excited in this system as a result of the interplay of magnetic and kinetic energies. Such a wave motion is called an Alfvén wave after Hannes Alfvén, who first predicted its existence [see "Electricity in Space," by Hannes Alfvén; SCIENTIFIC AMERICAN, May, 1952].

The Alfvén wave is perhaps harder to visualize than the whistler wave. The neutral plasma in which it propagates is an excellent conductor. When such a plasma is placed in a magnetic field, the particles of the plasma and the field become intimately attached to each other. If one tries to move a portion of the plasma, it resists any change in the number of magnetic-field lines passing through it; currents are induced that act to keep the magnetic flux constant. If a portion of the plasma is moved, the flux lines are stretched but stay trapped in that portion. This stretching is equivalent to increasing the magnetic energy of the system. If the outside force that moved the plasma is shut off, the magnetic lines tend to snap back into their original place and in so doing carry the plasma particles with them. In this way magnetic energy can be converted into kinetic energy carried by the motion of the plasma particles. The energy conversion is analogous to that which takes place when a pendulum is pulled to one side and released: the potential energy (gravitational in this case) is converted into kinetic energy and the system continues to oscillate about an equilibrium position until it is stopped by friction. In the same way the plasma will oscillate, and any wave motion that is in tune with this fundamental oscillation can propagate. When the factors that determine the frequency of an Alfvén wave are analyzed, it turns out that frequency is inversely proportional to wavelength, which means that the velocity of an Alfvén wave, unlike that of the whistler wave, is constant. Alfvén proposed that such waves could transmit vast energies in the thermonuclear plasmas of stars.

Alfvén waves have been produced in a laboratory gas plasma, but it is difficult to demonstrate precise agreement between the experimental waves and theory. There have also been attempts to create the Alfvén wave in a liquid metal such as mercury, which is, after all, a collection of very mobile positive and negative charges. Success has been limited, however, because the electrical re-



"PLUCKING" OF WHISTLER WAVE in a sodium slab produces a smoothly decaying signal. The whistler is plucked by applying a sharp electrical pulse to the drive coil.



LOOPING PATHS are traced by charged particles subjected simultaneously to an electric field (*horizontal arrows*) and a magnetic field (*dots*) perpendicular to both the electric field and the paths of the particles. Loops are produced because positive particles are accelerated when moving with the electric field and decelerated when moving against it. The converse is true for negative particles, but both drift in the same direction. The drift represents a net flow of matter but no flow of current because opposite electric charges cancel.

sistance of mercury is fairly high and the wave is quickly damped.

What about creating an Alfvén wave in a solid? Can one find suitable plasmas in a solid with much lower resistance and friction? The answer is yes. Pure bismuth, which is a semimetal with certain attributes of both metals and semiconductors, serves nicely. The carriers of electricity in bismuth behave as if there were an equal number of positive and negative charges both of which are highly mobile. The two types of carrier originate as follows. In a crystal of bismuth the bismuth atoms have fewer electrons in their local environment than is the case for isolated atoms of bismuth. The surplus electrons, which are not required in the bond structure of the solid, move about the crystal and are the negative carriers of electricity. Since the crystal is electrically neutral, the mobile electrons leave behind a "hole," which has an effective positive charge. This hole can move from one bismuth atom to the next, thereby acting as a positive carrier of electricity. Hence the positive carriers in bismuth are not ions but holes, or missing electrons. As electrons move in one direction under the influence of an electric field, holes move in the other.

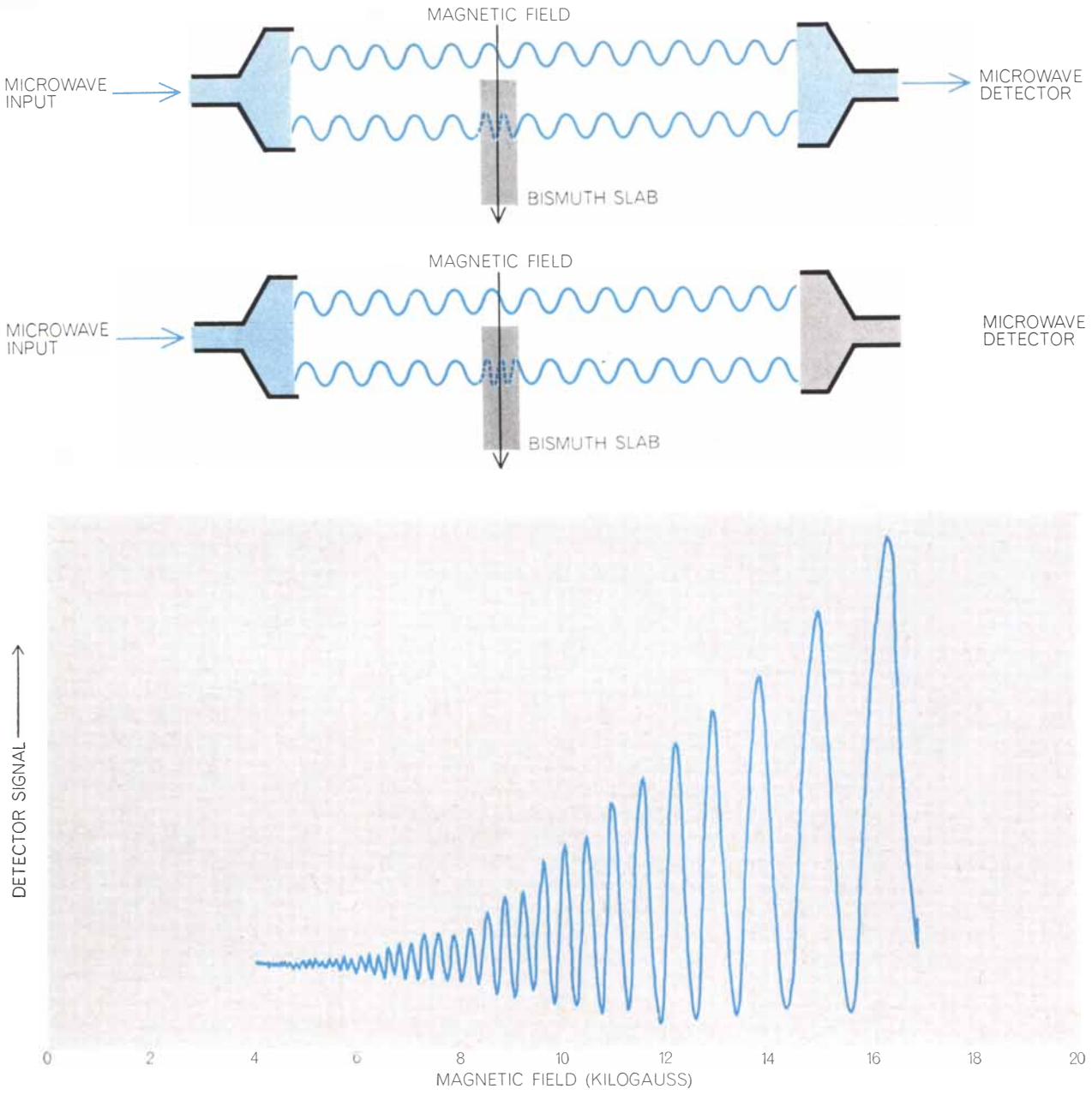
	IONOSPHERE	SEMICONDUCTOR	METAL
NUMBER OF CHARGED CARRIERS PER CUBIC CENTIMETER	10^3 TO 10^5	10^{14} TO 10^{16}	10^{22}
MAGNETIC FIELD (GAUSS)	.2	10,000	10,000
FREQUENCY (CYCLES PER SECOND)	5,000	10^{10}	1 TO 10,000
WAVELENGTH (CENTIMETERS)	400,000	.3	.5
VELOCITY (CENTIMETERS PER SECOND)	2×10^9	3×10^9	20

WHISTLERS IN DIFFERENT ENVIRONMENTS have frequencies, wavelengths and velocities that are dictated by the physical properties of the plasmas in which they travel. The table shows typical values for these properties and for those of the whistler transmitted. In a semiconductor a whistler travels more than 100 million times faster than in a metal.

Some elegant experiments have demonstrated the Alfvén wave in bismuth. The one I shall describe was first performed in 1962 by George A. Williams of the Bell Telephone Laboratories. Williams exploited two characteristics of the Alfvén wave: its velocity is much lower than that of an electromagnetic wave in free space and is proportional to the strength of the magnetic field.

Williams set up a microwave-transmitting and -receiving apparatus in which part of the microwave beam was intercepted by a slab of bismuth. The bismuth was placed in a magnetic field whose strength could be varied. Williams reasoned that the part of the microwave beam striking the bismuth would be transmitted through the slab as an Alfvén wave of lower velocity than that of the unimpeded part of the beam. To see if this were so he arranged for the rays emerging from the bismuth to interfere with the unobstructed rays. If the former were retarded by one complete wavelength, they would reinforce the direct rays and the signal at the detector would be strong. If they were retarded by half a wavelength, the two groups of rays would tend to cancel and the signal at the detector would be much reduced. Williams found that he could indeed retard the rays passing through the bismuth by multiples of whole or half wavelengths, depending on the strength of the magnetic field he applied to the bismuth.

I do not wish to leave the impression that these are the only plasma experiments in solids; there have been many others. For example, Maurice Glicksman, M. C. Steele and their co-workers at the David Sarnoff Research Center of the RCA Laboratories have demonstrated the existence of the "pinch" effect in the electron-hole plasma of a semiconductor. The effect arises when a strong current is passed through the plasma. The current creates its own magnetic field in the form of circular field lines around the current. Because the current carriers are moving in this magnetic field, they experience a Lorentz force, which



ALFVÉN PLASMA WAVES, which have properties very different from those of a whistler, can also be generated in solids. George A. Williams of Bell Telephone Laboratories has demonstrated that, in passing through a plasma in bismuth, microwaves travel as Alfvén waves and are slowed down. If the rays emerging from bismuth are in phase with the unobstructed rays (*top*), a strong signal is received at the microwave detector. If the emerging rays are out of phase (*middle*), the signals tend to cancel. The speed of Alfvén waves is proportional to the strength of the magnetic field. The curve at bottom shows the results of varying the magnetic field.

pinches them into a thin stream. The phenomenon has been much investigated as a possible means for containing a gas plasma in the effort to achieve a controlled thermonuclear reaction.

Glicksman and Steele have proposed that some curious features they had observed in the electrical resistance of indium antimonide at very high current flows could be explained by assuming that a pinch had occurred in the plasma carriers. Subsequently B. P. Osipov and A. N. Khvoschev of the U.S.S.R. showed directly by optical means that a pinch indeed occurs. Within the past few months Betsy Ancker-Johnson and James E. Drummond of the Boeing Scientific Research Laboratories have published photographs demonstrating that the plasma in the pinch becomes hot enough to melt the solid locally, leaving a channel in its path. In addition to these specific experiments, a number of theoretical investigations (particularly those of David Pines of the University of Illinois) have examined plasma phenomena in solids.

The concept of using solids to study plasma behavior is quite young, and one can reasonably expect new findings at least as interesting as any yet observed. There seems little doubt that experiments in solids will make important contributions to understanding the most ubiquitous stuff in the universe: the gas plasma.

The Visual Cortex of the Brain

A start toward understanding how it analyzes images on the retina can be made through studies of the responses that individual cells in the visual system of the cat give to varying patterns of light

by David H. Hubel

An image of the outside world striking the retina of the eye activates a most intricate process that results in vision: the transformation of the retinal image into a perception. The transformation occurs partly in the retina but mostly in the brain, and it is, as one can recognize instantly by considering how modest in comparison is the achievement of a camera, a task of impressive magnitude.

The process begins with the responses of some 130 million light-sensitive receptor cells in each retina. From these cells messages are transmitted to other retinal cells and then sent on to the brain, where they must be analyzed and interpreted. To get an idea of the magnitude of the task, think what is involved in watching a moving animal, such as a horse. At a glance one takes in its size, form, color and rate of movement. From tiny differences in the two retinal images there results a three-dimensional picture. Somehow the brain manages to compare this picture with previous impressions; recognition occurs and then any appropriate action can be taken.

The organization of the visual system—a large, intricately connected population of nerve cells in the retina and brain—is still poorly understood. In recent years, however, various studies have begun to reveal something of the arrangement and function of these cells. A decade ago Stephen W. Kuffler, working with cats at the Johns Hopkins Hospital, discovered that some analysis of visual patterns takes place outside the brain, in the nerve cells of the retina. My colleague Torsten N. Wiesel and I at the Harvard Medical School, exploring the first stages of the processing that occurs in the brain of the cat, have mapped the visual pathway a little further: to what appears to be the sixth step from the retina to the cortex of the cerebrum. This kind of work falls far short of providing a full understanding of vision, but it does convey some idea of the mechanisms and circuitry of the visual system.

In broad outline the visual pathway is clearly defined [*see bottom illustration on opposite page*]. From the retina of each eye visual messages travel along the optic nerve, which consists of about a million nerve fibers. At the junction known as the chiasm about half of the nerves cross over into opposite hemispheres of the brain, the other nerves remaining on the same side. The optic nerve fibers lead to the first way stations in the brain: a pair of cell clusters called the lateral geniculate bodies. From here new fibers course back through the brain to the visual area of the cerebral cortex. It is convenient, although admittedly a gross oversimplification, to think of the pathway from retina to cortex as consisting of six types of nerve cells, of which three are in the retina, one is in the geniculate body and two are in the cortex.

Nerve cells, or neurons, transmit messages in the form of brief electrochemical impulses. These travel along the outer membrane of the cell, notably along the membrane of its long principal fiber, the axon. It is possible to obtain an electrical record of impulses of a single nerve cell by placing a fine electrode near the cell body or one of its fibers. Such measurements have shown that impulses travel along the nerves at velocities of between half a meter and 100 meters per second. The impulses in a given fiber all have about the same amplitude; the strength of the stimuli that give rise to them is reflected not in amplitude but in frequency.

At its terminus the fiber of a nerve cell makes contact with another nerve cell (or with a muscle cell or gland cell), forming the junction called the synapse. At most synapses an impulse on reaching the end of a fiber causes the release of a small amount of a specific substance, which diffuses outward to the membrane of the next cell. There the substance either excites the cell or inhibits it. In excitation the substance acts to bring the cell into a state in which it is more likely to "fire"; in inhibition the substance acts to prevent firing. For most synapses the substances that act as transmitters are unknown. Moreover, there is no sure way to determine from microscopic appearances alone whether a synapse is excitatory or inhibitory.

It is at the synapses that the modification and analysis of nerve messages take place. The kind of analysis depends partly on the nature of the synapse: on how many nerve fibers converge on a single cell and on how the excitatory and inhibitory endings distribute themselves. In most parts of the nervous system the anatomy is too intricate to reveal much about function. One way to circumvent this difficulty is to record impulses with microelectrodes in anesthetized animals, first from the fibers coming into a structure of neurons and then from the neurons themselves or from the fibers they send onward. Comparison of the behavior of incoming and outgoing fibers provides a basis for learning what the structure does. Through such exploration of the different parts of the brain concerned with vision one can hope to build up some idea of how the entire visual system works.

That is what Wiesel and I have undertaken, mainly through studies of the visual system of the cat. In our experiments the anesthetized animal faces a wide screen 1.5 meters away, and we shine various patterns of white light on the screen with a projector. Simultane-

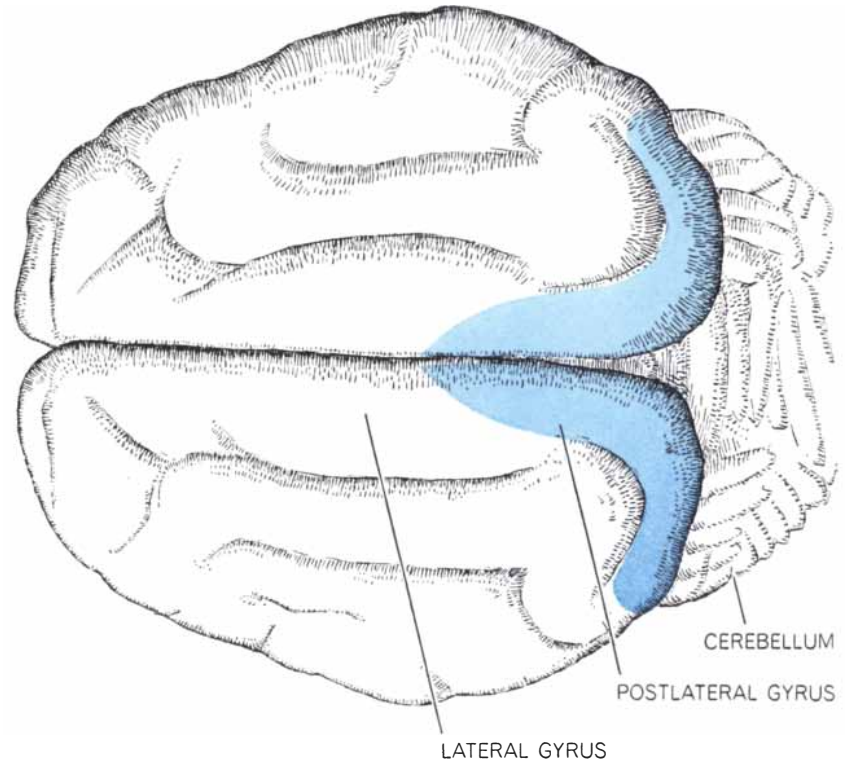
ously we penetrate the visual portion of the cortex with microelectrodes. In that way we can record the responses of individual cells to the light patterns. Sometimes it takes many hours to find the region of the retina with which a particular visual cell is linked and to work out the optimum stimuli for that cell. The reader should bear in mind the relation between each visual cell—no matter how far along the visual pathway it may be—and the retina. It requires an image on the retina to evoke a meaningful response in any visual cell, however indirect and complex the linkage may be.

The retina is a complicated structure, in both its anatomy and its physiology, and the description I shall give is highly simplified. Light coming through the lens of the eye falls on the mosaic of receptor cells in the retina. The receptor cells do not send impulses directly through the optic nerve but instead connect with a set of retinal cells called bipolar cells. These in turn connect with retinal ganglion cells, and it is the latter set of cells, the third in the visual pathway, that sends its fibers—the optic nerve fibers—to the brain.

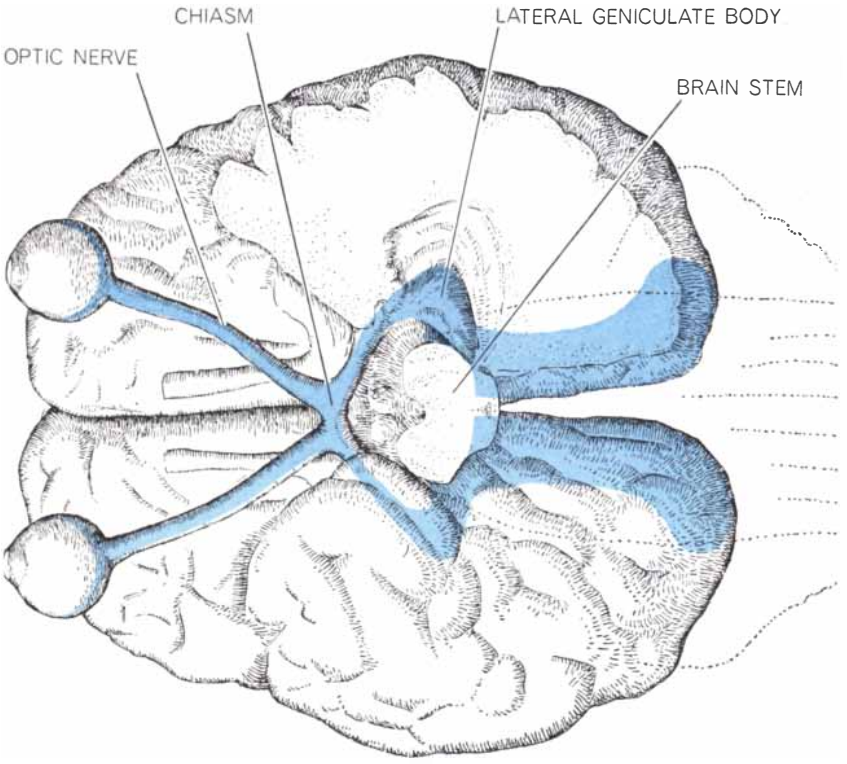
This series of cells and synapses is no simple bucket brigade for impulses: a receptor may send nerve endings to more than one bipolar cell, and several receptors may converge on one bipolar cell. The same holds for the synapses between the bipolar cells and the retinal ganglion cells. Stimulating a single receptor by light might therefore be expected to have an influence on many bipolar or ganglion cells; conversely, it should be possible to influence one bipolar or retinal ganglion cell from a number of receptors and hence from a substantial area of the retina.

The area of receptor mosaic in the retina feeding into a single visual cell is called the receptive field of the cell. This term is applied to any cell in the visual system to refer to the area of retina with which the cell is connected—the retinal area that on stimulation produces a response from the cell.

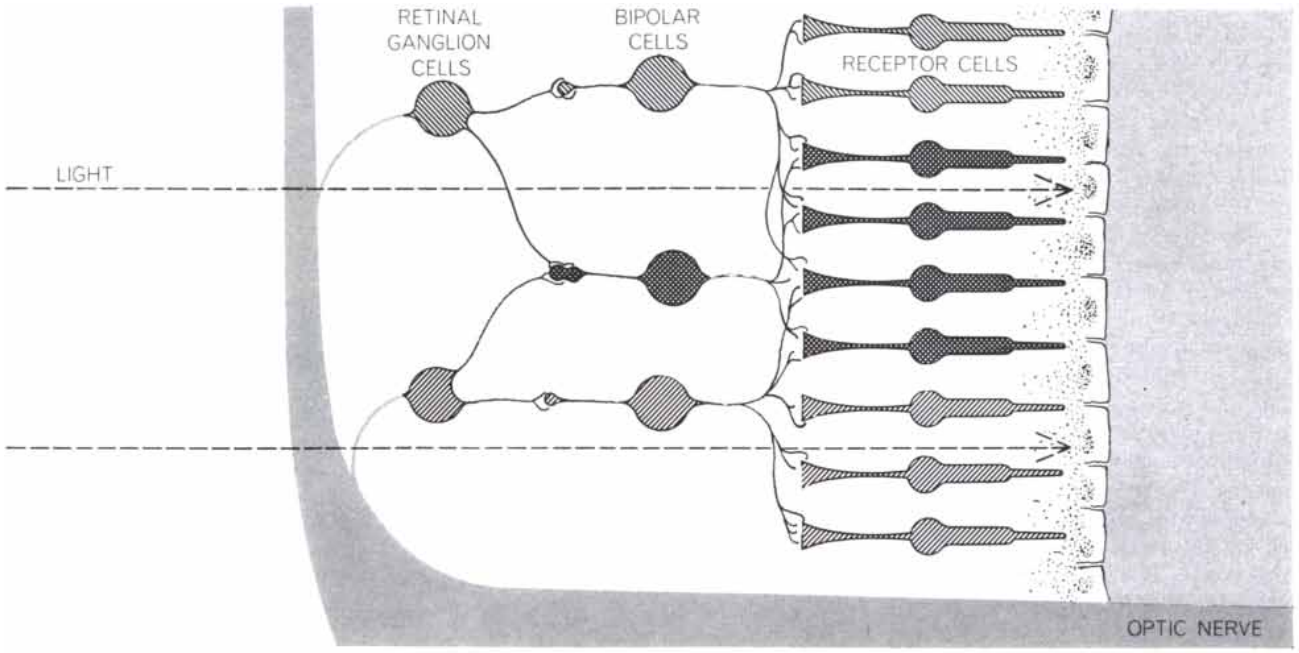
Any of the synapses with a particular cell may be excitatory or inhibitory, so that stimulation of a particular point on the retina may either increase or decrease the cell's firing rate. Moreover, a single cell may receive several excitatory and inhibitory impulses at once, with the result that it will respond according to the net effect of these inputs. In considering the behavior of a single cell an observer should remember that it *is* just one of a huge population of cells: a stimulus that excites one cell will undoubtedly excite many others, mean-



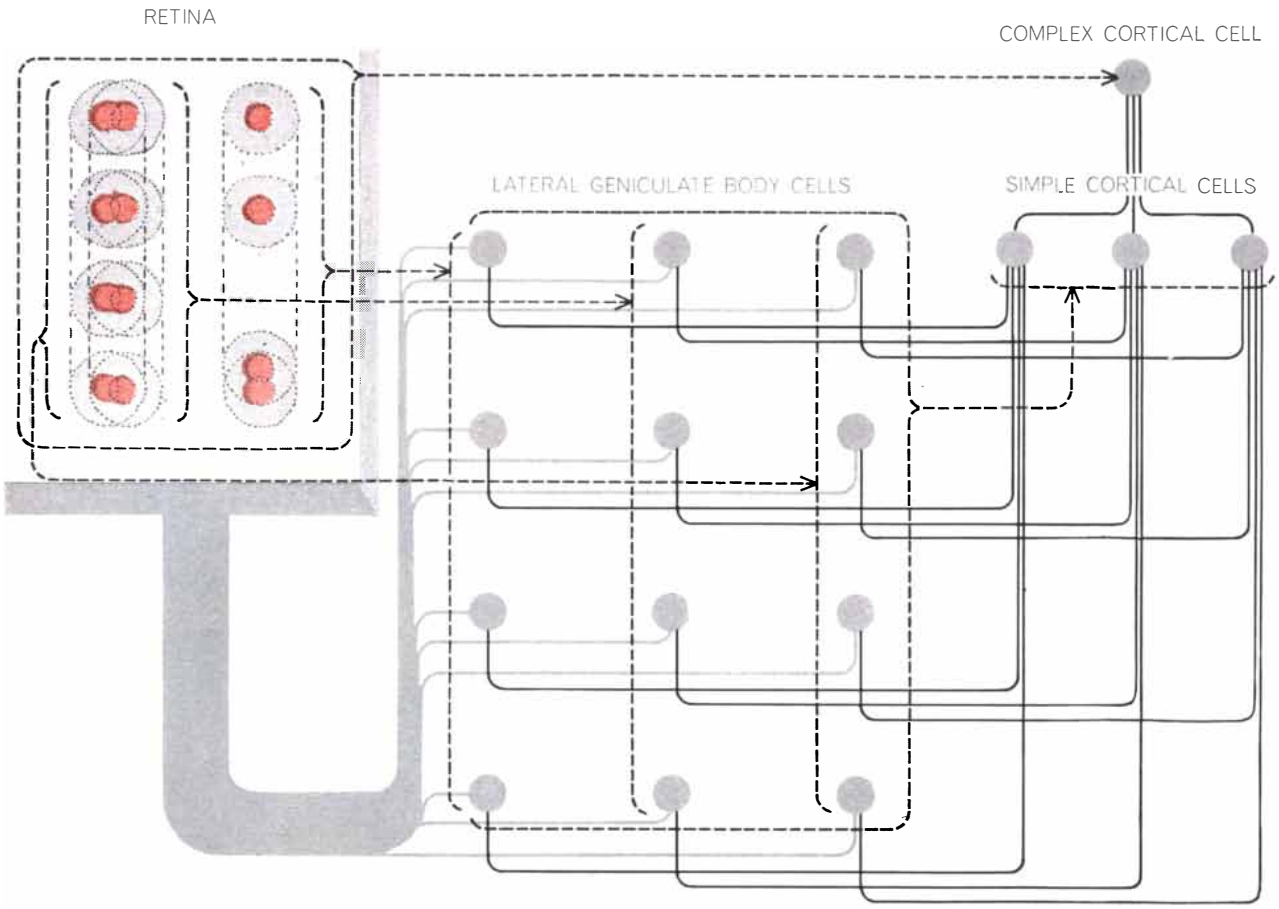
CORTEX OF CAT'S BRAIN is depicted as it would be seen from the top. The colored region indicates the cortical area that deals at least in a preliminary way with vision.



VISUAL SYSTEM appears in this representation of the human brain as viewed from below. Visual pathway from retinas to cortex via the lateral geniculate body is shown in color.



STRUCTURE OF RETINA is depicted schematically. Images fall on the receptor cells, of which there are about 130 million in each retina. Some analysis of an image occurs as the receptors transmit messages to the retinal ganglion cells via the bipolar cells. A group of receptors funnels into a particular ganglion cell, as indicated by the shading; that group forms the ganglion cell's receptive field. Inasmuch as the fields of several ganglion cells overlap one receptor may send messages to several ganglion cells.



VISUAL PROCESSING BY BRAIN begins in the lateral geniculate body, which continues the analysis made by retinal cells. In the cortex "simple" cells respond strongly to line stimuli, provided that the position and orientation of the line are suitable for a particular cell. "Complex" cells respond well to line stimuli, but the position of the line is not critical and the cell continues to respond even if a properly oriented stimulus is moved, as long as it remains in the cell's receptive field. Broken lines indicate how receptive fields of all these cells overlap on the retina; solid lines, how several cells at one stage affect a single cell at the next stage.

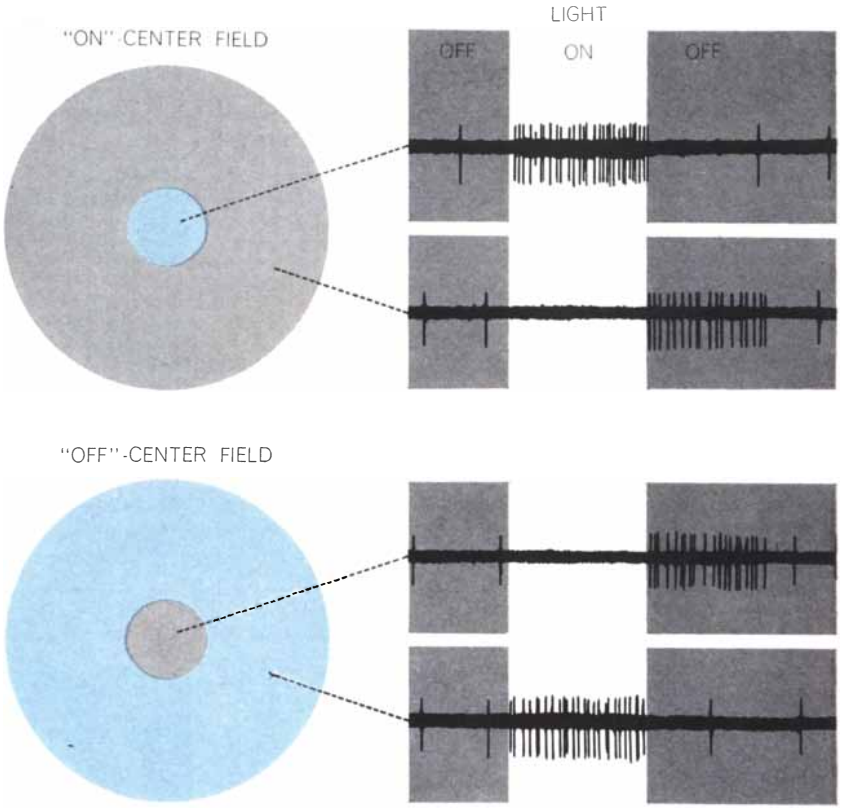
while inhibiting yet another array of cells and leaving others entirely unaffected.

For many years it has been known that retinal ganglion cells fire at a fairly steady rate even in the absence of any stimulation. Kuffler was the first to observe how the retinal ganglion cells of mammals are influenced by small spots of light. He found that the resting discharges of a cell were intensified or diminished by light in a small and more or less circular region of the retina. That region was of course the cell's receptive field. Depending on where in the field a spot of light fell, either of two responses could be produced. One was an "on" response, in which the cell's firing rate increased under the stimulus of light. The other was an "off" response, in which the stimulus of light decreased the cell's firing rate. Moreover, turning the light off usually evoked a burst of impulses from the cell. Kuffler called the retinal regions from which these responses could be evoked "on" regions and "off" regions.

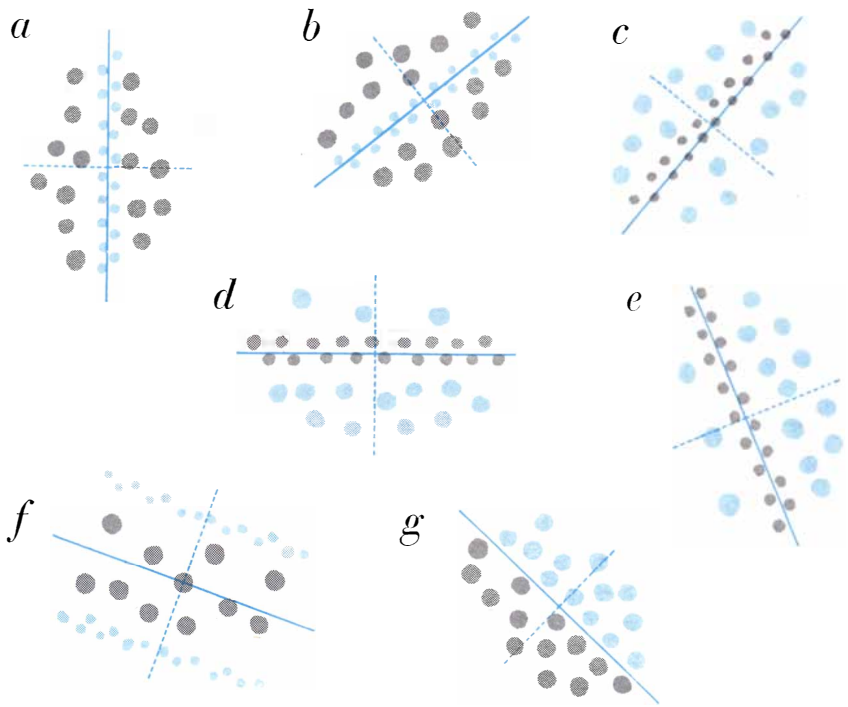
On mapping the receptive fields of a large number of retinal ganglion cells into "on" and "off" regions, Kuffler discovered that there were two distinct cell types. In one the receptive field consisted of a small circular "on" area and a surrounding zone that gave "off" responses. Kuffler termed this an "on"-center cell. The second type, which he called "off"-center, had just the reverse form of field—an "off" center and an "on" periphery [*see top illustration on this page*]. For a given cell the effects of light varied markedly according to the place in which the light struck the receptive field. Two spots of light that were shone on separate parts of an "on" area produced a more vigorous "on" response than either spot alone, whereas if one spot was shone on an "on" area and the other on an "off" area, the two effects tended to neutralize each other, resulting in a very weak "on" or "off" response. In an "on"-center cell, illuminating the entire central "on" region evoked a maximum response; a smaller or larger spot of light was less effective.

Lighting up the whole retina diffusely, even though it may affect every receptor in the retina, does not affect a retinal ganglion cell nearly so strongly as a small circular spot of exactly the right size placed so as to cover precisely the receptive-field center. The main concern of these cells seems to be the contrast in illumination between one retinal region and surrounding regions.

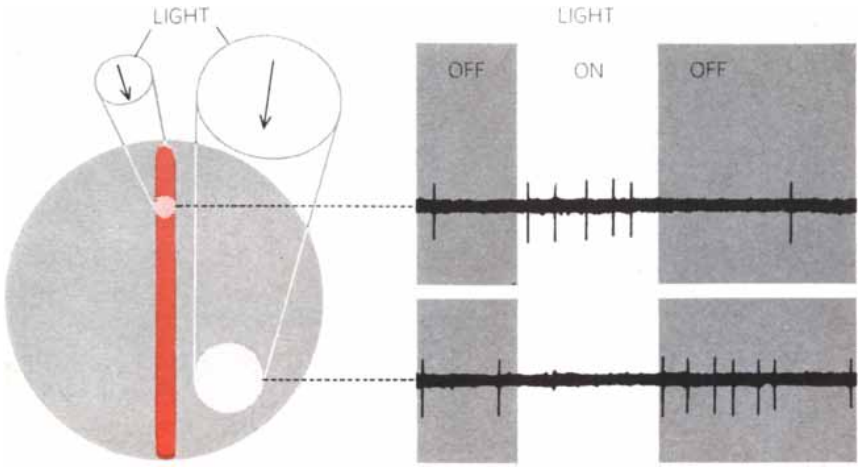
Retinal ganglion cells differ greatly in the size of their receptive-field centers.



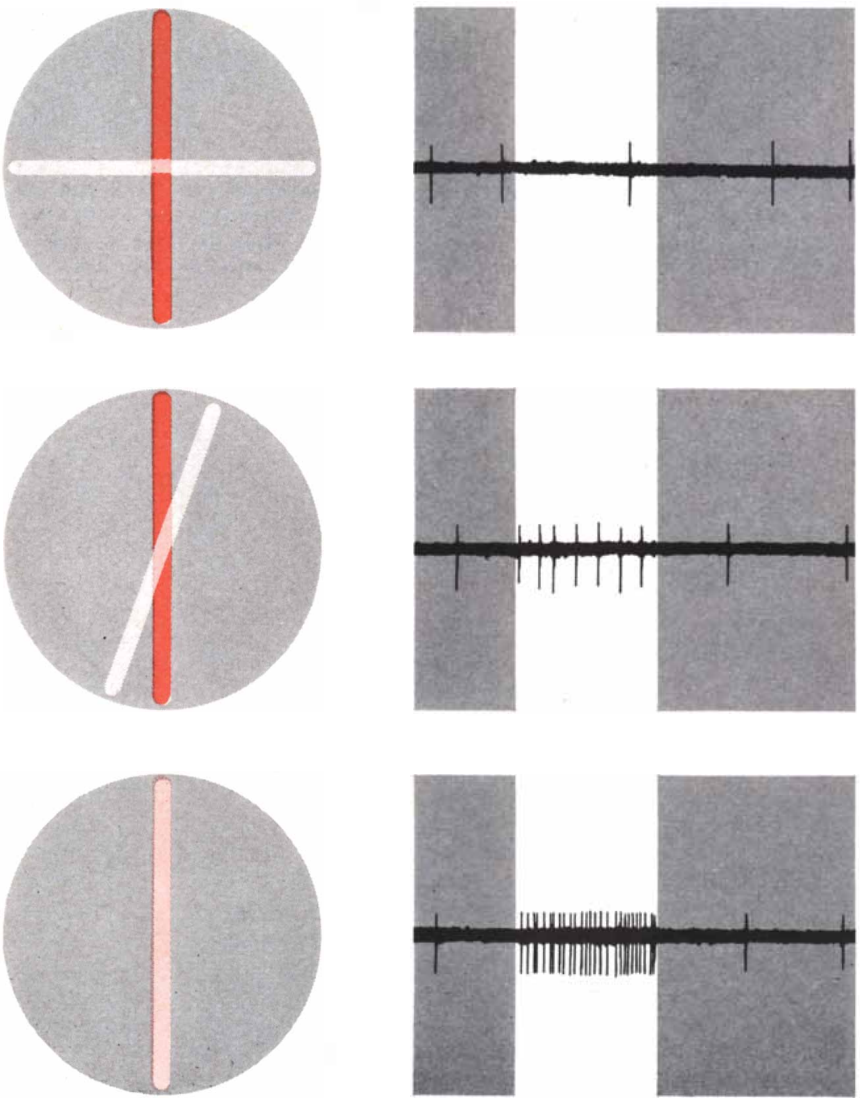
CONCENTRIC FIELDS are characteristic of retinal ganglion cells and of geniculate cells. At top an oscilloscope recording shows strong firing by an "on"-center type of cell when a spot of light strikes the field center; if the spot hits an "off" area, the firing is suppressed until the light goes off. At bottom are responses of another cell of the "off"-center type.



SIMPLE CORTICAL CELLS have receptive fields of various types. In all of them the "on" and "off" areas, represented by colored and gray dots respectively, are separated by straight boundaries. Orientations vary, as indicated particularly at *a* and *b*. In the cat's visual system such fields are generally one millimeter or less in diameter.



RESPONSE IS WEAK when a circular spot of light is shone on the receptive field of a simple cortical cell. Such spots get a vigorous response from retinal and geniculate cells. This cell has a receptive field of type shown at *a* in bottom illustration on preceding page.



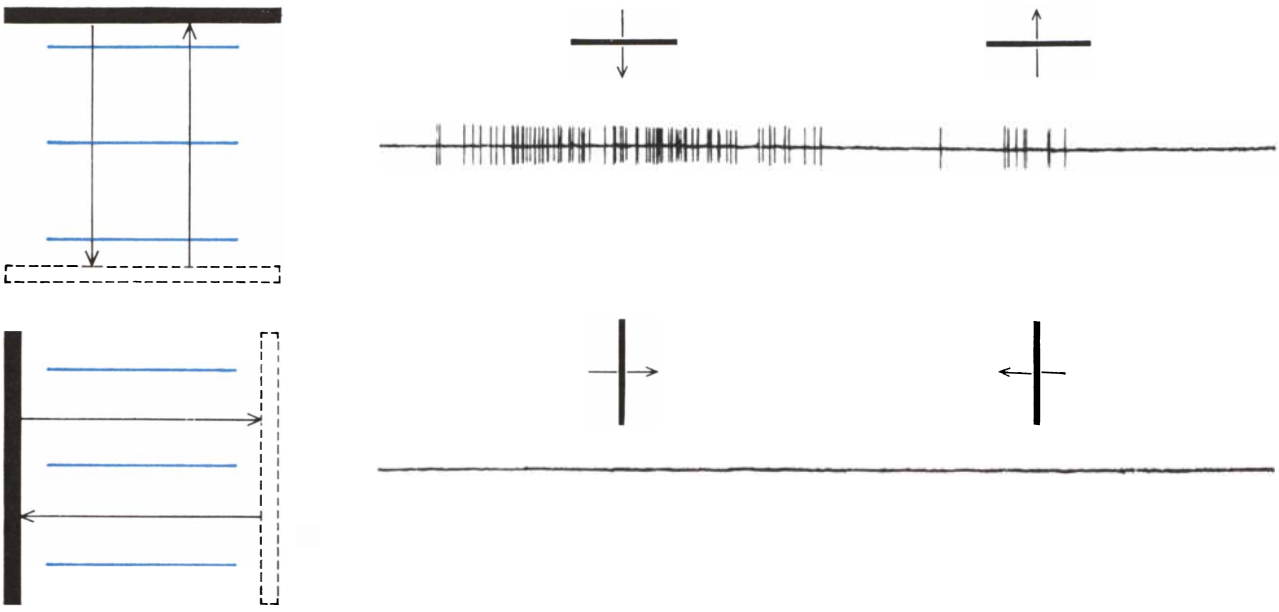
IMPORTANCE OF ORIENTATION to simple cortical cells is indicated by varying responses to a slit of light from a cell preferring a vertical orientation. Horizontal slit (*top*) produces no response, slight tilt a weak response, vertical slit a vigorous response.

Cells near the fovea (the part of the retina serving the center of gaze) are specialized for precise discrimination; in the monkey the field centers of these cells may be about the same size as a single cone—an area subtending a few minutes of arc at the cornea. On the other hand, some cells far out in the retinal periphery have field centers up to a millimeter or so in diameter. (In man one millimeter of retina corresponds to an arc of about three degrees in the 180-degree visual field.) Cells with such large receptive-field centers are probably specialized for work in very dim light, since they can sum up messages from a large number of receptors.

Given this knowledge of the kind of visual information brought to the brain by the optic nerve, our first problem was to learn how the messages were handled at the first central way station, the lateral geniculate body. Compared with the retina, the geniculate body is a relatively simple structure. In a sense there is only one synapse involved, since the incoming optic nerve fibers end in cells that send their fibers directly to the visual cortex. Yet in the cat many optic nerve fibers converge on each geniculate cell, and it is reasonable to expect some change in the visual messages from the optic nerve to the geniculate cells.

When we came to study the geniculate body, we found that the cells have many of the characteristics Kuffler described for retinal ganglion cells. Each geniculate cell is driven from a circumscribed retinal region (the receptive field) and has either an "on" center or an "off" center, with an opposing periphery. There are, however, differences between geniculate cells and retinal ganglion cells, the most important of which is the greatly enhanced capacity of the periphery of a geniculate cell's receptive field to cancel the effects of the center. This means that the lateral geniculate cells must be even more specialized than retinal ganglion cells in responding to spatial differences in retinal illumination rather than to the illumination itself. The lateral geniculate body, in short, has the function of increasing the disparity—already present in retinal ganglion cells—between responses to a small, centered spot and to diffuse light.

In contrast to the comparatively simple lateral geniculate body, the cerebral cortex is a structure of stupendous complexity. The cells of this great plate of gray matter—a structure that would be about 20 square feet in area and a tenth of an inch thick if flattened out—are arranged in a number of more or less dis-



COMPLEX CORTICAL CELL responded vigorously to slow downward movement of a dark, horizontal bar. Upward movement of the bar produced a weak response and horizontal movement of a vertical bar produced no response. For other shapes, orientations and movements there are other complex cells showing maximum response. Such cells may figure in perception of form and movement.

tinct layers. The millions of fibers that come in from the lateral geniculate body connect with cortical cells in the layer that is fourth from the top. From here the information is sooner or later disseminated to all layers of the cortex by rich interconnections between them. Many of the cells, particularly those of the third and fifth layers, send their fibers out of the cortex, projecting to centers deep in the brain or passing over to nearby cortical areas for further processing of the visual messages. Our problem was to learn how the information the visual cortex sends out differs from what it takes in.

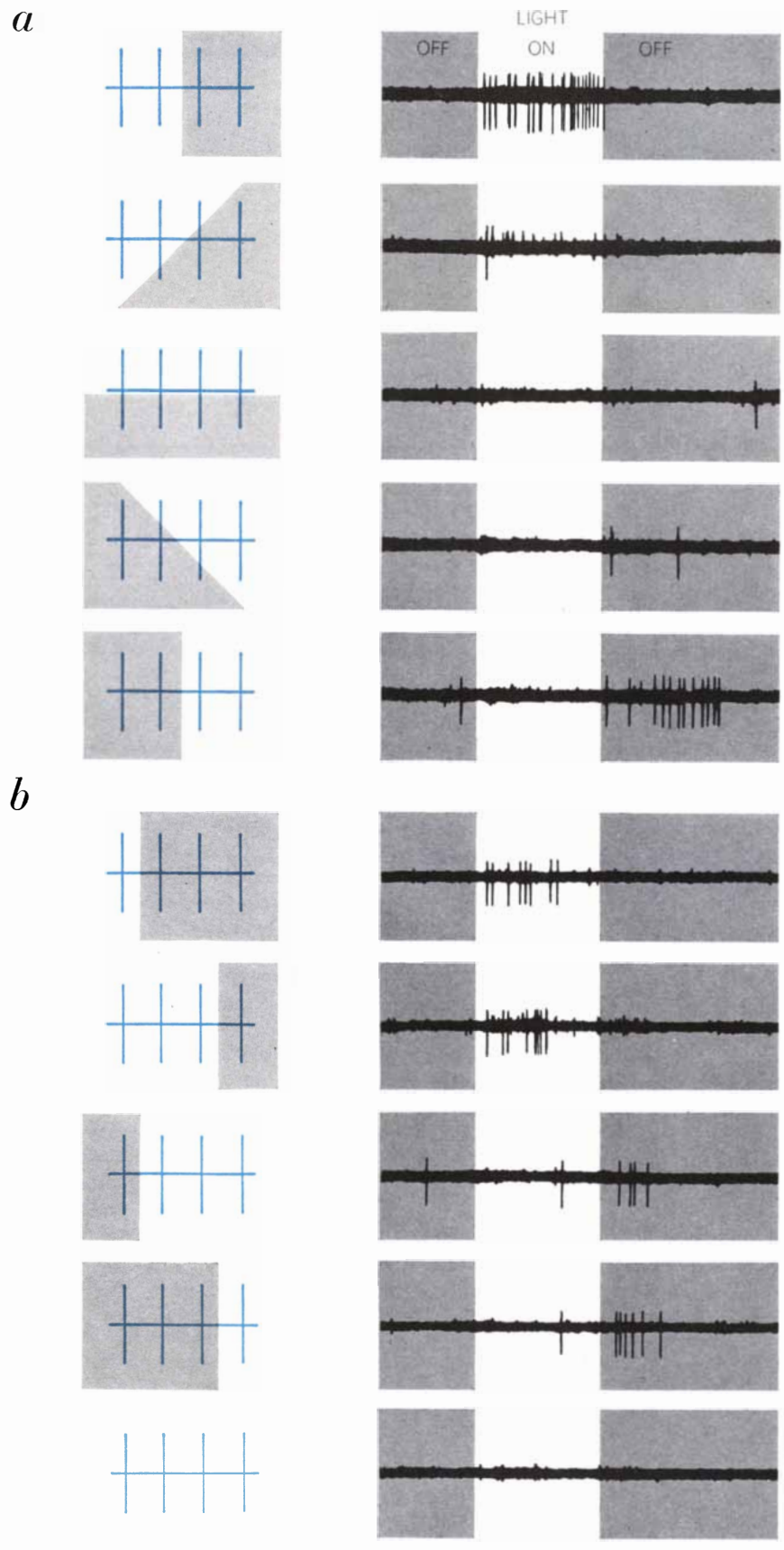
Most connections between cortical cells are in a direction perpendicular to the surface; side-to-side connections are generally quite short. One might therefore predict that impulses arriving at a particular area of the cortex would exert their effects quite locally. Moreover, the retinas project to the visual cortex (via the lateral geniculate body) in a systematic topologic manner; that is, a given area of cortex gets its input ultimately from a circumscribed area of retina. These two observations suggest that a given cortical cell should have a small receptive field; it should be influenced from a circumscribed retinal region only, just as a geniculate or retinal ganglion cell is. Beyond this the anatomy provides no hint of what the cortex does with the information it receives.

In the face of the anatomical complexity of the cortex, it would have been surprising if the cells had proved to have the concentric receptive fields characteristic of cells in the retina and the lateral geniculate body. Indeed, in the cat we have observed no cortical cells with concentric receptive fields; instead there are many different cell types, with fields markedly different from anything seen in the retinal and geniculate cells.

The many varieties of cortical cells may, however, be classified by function into two large groups. One we have called "simple"; the function of these cells is to respond to line stimuli—such shapes as slits, which we define as light lines on a dark background; dark bars (dark lines on a light background), and edges (straight-line boundaries between light and dark regions). Whether or not a given cell responds depends on the orientation of the shape and its position on the cell's receptive field. A bar shone vertically on the screen may activate a given cell, whereas the same cell will fail to respond (but others will respond) if the bar is displaced to one side or moved appreciably out of the vertical. The second group of cortical cells we have called "complex"; they too respond best to bars, slits or edges, provided that, as with simple cells, the shape is suitably oriented for the particular cell under observation. Complex cells, however, are not so discriminating as to the exact position of the stimulus, provided that it is properly oriented. Moreover, unlike simple cells, they respond with sustained firing to moving lines.

From the preference of simple and complex cells for specific orientation of light stimuli, it follows that there must be a multiplicity of cell types to handle the great number of possible positions and orientations. Wiesel and I have found a large variety of cortical cell responses, even though the number of individual cells we have studied runs only into the hundreds compared with the millions that exist. Among simple cells, the retinal region over which a cell can be influenced—the receptive field—is, like the fields of retinal and geniculate cells, divided into "on" and "off" areas. In simple cells, however, these areas are far from being circularly symmetrical. In a typical example the receptive field consists of a very long and narrow "on" area, which is adjoined on each side by larger "off" regions. The magnitude of an "on" response depends, as with retinal and geniculate cells, on how much either type of region is covered by the stimulating light. A long, narrow slit that just fills the elongated "on" region produces a powerful "on" response. Stimulation with the slit in a different orientation produces a much weaker effect, because the slit is now no longer illuminating all the "on" region but instead includes some of the antagonistic "off" region. A slit at right angles to the optimum orientation is usually completely ineffective.

In the simple cortical cells the process of pitting these two antagonistic parts of a receptive field against each other is carried still further than it is in the lateral geniculate body. As a rule a large spot



SINGLE COMPLEX CELL showed varying responses to an edge projected on the cell's receptive field in the retina. In group *a* the stimulus was presented in differing orientations. In group *b* all the edges were vertical and all but the last evoked responses regardless of where in the receptive field the light struck. When a large rectangle of light covered the entire receptive field, however, as shown at bottom, the cell failed to respond.

of light—or what amounts to the same thing, diffuse light covering the whole retina—evokes no response at all in simple cortical cells. Here the "on" and "off" effects apparently balance out with great precision.

Some other common types of simple receptive fields include an "on" center with a large "off" area to one side and a small one to the other; an "on" and an "off" area side by side; a narrow "off" center with "on" sides; a wide "on" center with narrow "off" sides. All these fields have in common that the border or borders separating "on" and "off" regions are straight and parallel rather than circular [*see bottom illustration on page 57*]. The most efficient stimuli—slits, edges or dark bars—all involve straight lines. Each cell responds best to a particular orientation of line; other orientations produce less vigorous responses, and usually the orientation perpendicular to the optimum evokes no response at all. A particular cell's optimum, which we term the receptive-field orientation, is thus a property built into the cell by its connections. In general the receptive-field orientation differs from one cell to the next, and it may be vertical, horizontal or oblique. We have no evidence that any one orientation, such as vertical or horizontal, is more common than any other.

How can one explain this specificity of simple cortical cells? We are inclined to think they receive their input directly from the incoming lateral geniculate fibers. We suppose a typical simple cell has for its input a large number of lateral geniculate cells whose "on" centers are arranged along a straight line; a spot of light shone anywhere along that line will activate some of the geniculate cells and lead to activation of the cortical cell. A light shone over the entire area will activate all the geniculate cells and have a tremendous final impact on the cortical cell [*see bottom illustration on page 56*].

One can now begin to grasp the significance of the great number of cells in the visual cortex. Each cell seems to have its own specific duties; it takes care of one restricted part of the retina, responds best to one particular shape of stimulus and to one particular orientation. To look at the problem from the opposite direction, for each stimulus—each area of the retina stimulated, each type of line (edge, slit or bar) and each orientation of stimulus—there is a particular set of simple cortical cells that will respond; changing any of the stimulus arrangements will cause a whole new popula-

tion of cells to respond. The number of populations responding successively as the eye watches a slowly rotating propeller is scarcely imaginable.

Such a profound rearrangement and analysis of the incoming messages might seem enough of a task for a single structure, but it turns out to be only part of what happens in the cortex. The next major transformation involves the cortical cells that occupy what is probably the sixth step in the visual pathway: the complex cells, which are also present in this cortical region and to some extent intermixed with the simple cells.

Complex cells are like simple ones in several ways. A cell responds to a stimulus only within a restricted region of retina: the receptive field. It responds best to the line stimuli (slits, edges or dark bars) and the stimulus must be oriented to suit the cell. But complex fields, unlike the simple ones, cannot be mapped into antagonistic "on" and "off" regions.

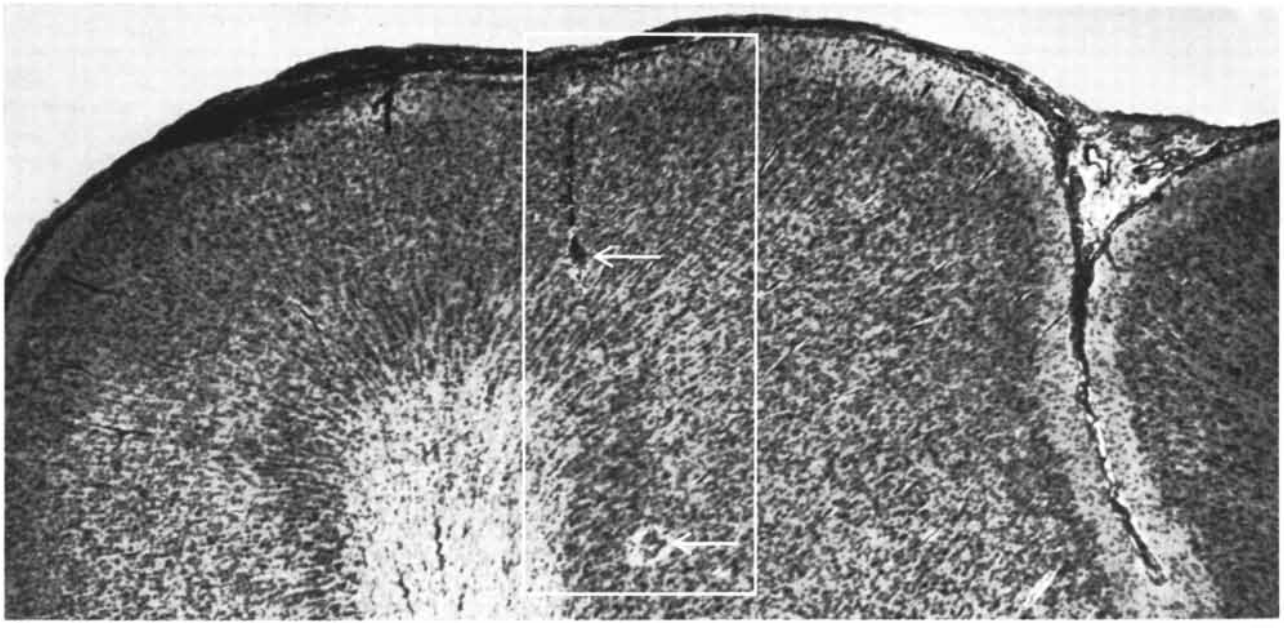
A typical complex cell we studied happened to fire to a vertical edge, and it gave "on" or "off" responses depending on whether light was to the left or to the right. Other orientations were almost completely without effect [*see illustration on opposite page*]. These responses are just what could be expected from a simple cell with a receptive field consisting of an excitatory area separated from an inhibitory one by a vertical boundary. In this case, however, the cell had an additional property that could not be explained by such an arrangement. A vertical edge evoked responses anywhere within the receptive field, "on" responses with light to the left, "off" responses with light to the right. Such behavior cannot be understood in terms of antagonistic "on" and "off" subdivisions of the receptive field, and when we explored the field with small spots we found no such regions. Instead the spot either produced responses at both "on" and "off" or evoked no responses at all.

Complex cells, then, respond like simple cells to one particular aspect of the stimulus, namely its orientation. But when the stimulus is moved, without changing the orientation, a complex cell differs from its simple counterpart chiefly in responding with sustained firing. The firing continues as the stimulus is moved over a substantial retinal area, usually the entire receptive field of the cell, whereas a simple cell will respond to movement only as the stimulus crosses a very narrow boundary separating "on" and "off" regions.

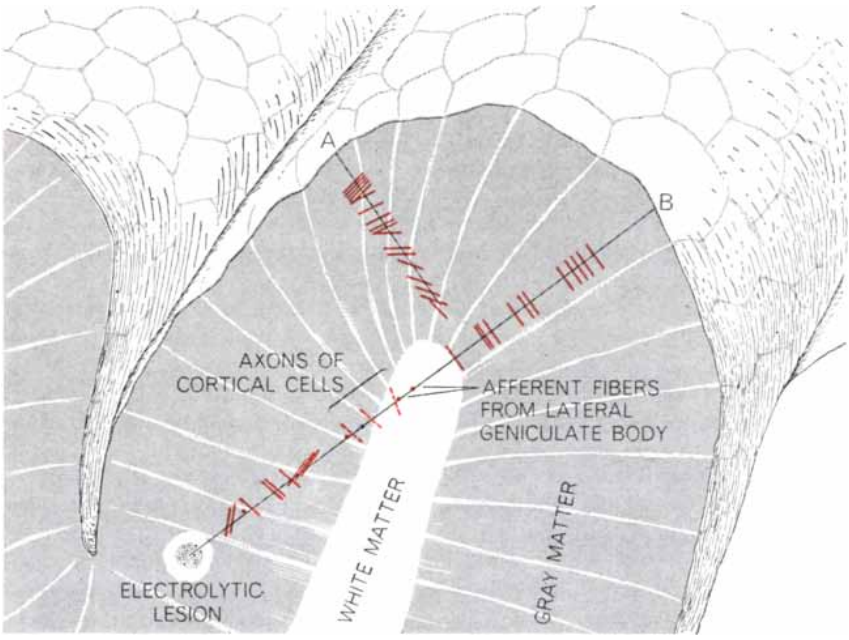
It is difficult to explain this behavior by any scheme in which geniculate cells project directly to complex cells. On the other hand, the findings can be explained fairly well by the supposition that a complex cell receives its input from a large number of simple cells. This supposition requires only that the simple cells have the same field orientation and be all of the same general type. A complex cell responding to vertical edges, for example, would thus receive fibers from simple cells that have vertically oriented receptive fields. All such a scheme needs to have added is the requirement that the retinal positions of these simple fields be arranged throughout the area occupied by the complex field.

The main difficulty with such a scheme is that it presupposes an enormous degree of cortical organization. What a vast network of connections must be needed if a single complex cell is to receive fibers from just the right simple cells, all with the appropriate field arrangements, tilts and positions! Yet there is unexpected and compelling evidence that such a system of connections exists. It comes from a study of what can be called the functional architecture of the cortex. By penetrating with a microelectrode through the cortex in many directions, perhaps many times in a single tiny region of the brain, we learned that the cells are arranged not in a haphazard manner but with a high degree of order. The physiological results show that functionally the cortex is subdivided like a beehive into tiny columns, or segments [*see illustration on next page*], each of which extends from the surface to the white matter lower in the brain.

A column is defined not by any anatomically obvious wall—no columns are visible under the microscope—but by the fact that the thousands of cells it contains all have the same receptive-field orientation. The evidence for this is that in a typical microelectrode penetration through the cortex the cells—recorded in sequence as the electrode is pushed



SECTION OF CAT'S VISUAL CORTEX shows track of microelectrode penetration and, at arrows, two points along the track where lesions were made so that it would be possible to ascertain later where the tip of the electrode was at certain times. This section of cortex is from a single gyrus, or fold of the brain; it was six millimeters wide and is shown here enlarged 30 diameters.



FUNCTIONAL ARRANGEMENT of cells in the visual cortex resembled columns, although columnar structure is not apparent under a microscope. Lines *A* and *B* show paths of two microelectrode penetrations; colored lines show receptive-field orientations encountered. Cells in a single column had same orientation; change of orientation showed new column.

ahead—all have the same field orientation, provided that the penetration is made in a direction perpendicular to the surface of the cortical segment. If the penetration is oblique, as we pass from column to column we record several cells with one field orientation, then a new sequence of cells with a new orientation and then still another.

The columns are irregular in cross-sectional shape, and on the average they are about half a millimeter across. In respects other than receptive-field orientation the cells in a particular column tend to differ; some are simple, others complex; some respond to slits, others prefer dark bars or edges. We were particularly interested to find that although the receptive fields of cells in one column are in the same general region of retina, they vary in an apparently random way in their exact retinal positions. The small random variation in receptive-field positions turns out to be of the same order of magnitude as the width of the field of an average complex cell in the same column.

Returning to the proposed scheme for explaining the properties of complex cells, one sees that gathered together in a single column are the very cells one should expect to be interconnected: cells whose fields have the same orientation and the same general retinal position, although not the same position. Furthermore, it is known from the anatomy that there are rich interconnections between neighboring cells, and the preponderance of these connections in a vertical direction fits well with the long, narrow, more or less cylindrical shape of the columns. This means that a column may be looked on as an independent functional unit of cortex, in which simple cells receive connections from lateral geniculate cells and send projections to complex cells.

It is possible to get an inkling of the part these different cell types play in vision by considering what must be happening in the brain when one looks at a form, such as, to take a relatively simple example, a black square on a white background. Suppose the eyes fix on some arbitrary point to the left of the square. On the reasonably safe assumption that the human visual cortex works something like the cat's and the monkey's, it can be predicted that the near edge of the square will activate a particular group of simple cells, namely cells that prefer edges with light to the left and dark to the right and whose fields are oriented vertically and are so placed on the retina that the boundary between "on" and "off" regions falls exactly along the image of the near edge of the square. Other populations of cells will obviously be called into action by the other three edges of the square. All the cell populations will change if the eye strays from the point fixed on, or if the square is moved while the eye remains stationary, or if the square is rotated.

In the same way each edge will activate a population of complex cells, again cells that prefer edges in a specific orientation. But a given complex cell, unlike a simple cell, will continue to be activated when the eye moves or when the form moves, if the movement is not so large that the edge passes entirely outside the receptive field of the cell, and if there is no rotation. This means that the populations of complex cells affected by the whole square will be to some extent independent of the exact position of the image of the square on the retina.

Each of the cortical columns contains thousands of cells, some with simple fields and some with complex. Evidently the visual cortex analyzes an enormous amount of information, with each small region of visual field represented over and over again in column after column, first for one receptive-field orientation and then for another.

In sum, the visual cortex appears to have a rich assortment of functions. It rearranges the input from the lateral geniculate body in a way that makes lines and contours the most important stimuli. What appears to be a first step in perceptual generalization results from the response of cortical cells to the orientation of a stimulus, apart from its exact retinal position. Movement is also an important stimulus factor; its rate and direction must both be specified if a cell is to be effectively driven.

One cannot expect to "explain" vision, however, from a knowledge of the behavior of a single set of cells, geniculate or cortical, any more than one could understand a wood-pulp mill from an examination of the machine that cuts the logs into chips. We are now studying how still "higher" structures build on the information they receive from these cortical cells, rearranging it to produce an even greater complexity of response.

In all of this work we have been particularly encouraged to find that the areas we study can be understood in terms of comparatively simple concepts such as the nerve impulse, convergence of many nerves on a single cell, excitation and inhibition. Moreover, if the connections suggested by these studies are remotely close to reality, one can conclude that at least some parts of the brain can be followed relatively easily, without necessarily requiring higher mathematics, computers or a knowledge of network theories.

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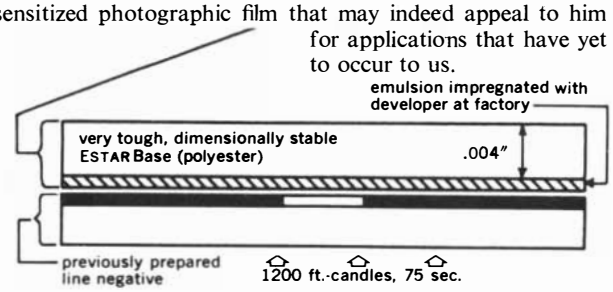

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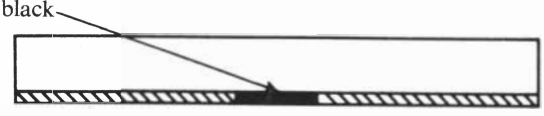

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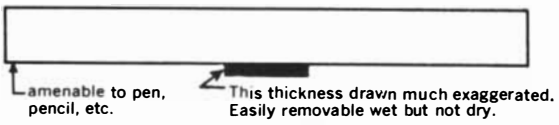

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A new chemical Chicago

Diketene (CH_2COCH_2CO) is terrible stuff. It brings tears to the eyes even in small whiffs, smells awful, once killed a shaved guinea pig bathed with it, and may polymerize violently when catalyzed by casual contamination. For carelessness with it, one ought to go to jail.

To keep it out of inexpert hands and for other more or less obvious reasons, we sell no less than 39,000 pounds at a crack and are proud of our achievement in bringing it to market. It comes in its own stainless steel tank truck, insulated heavily enough to stay safely near the −7.5°C freezing point for up to 72 hours. Obviously anybody willing to have this truck pull up to the gate with the driver complaining of unseasonable heat on the road the past 2½ days and asking where to connect up to the refrigerated storage tanks will have given the matter considerable thought in advance. Very likely, despite the touchy nature of *Diketene* and because it works directly without troublesome by-products, he will have chosen it as a replacement for methyl or ethyl acetoacetate.

To explain to a liberal-arts wife the now threatened role of these acetoacetates in civilization offers difficulty. To point out that in $CH_3COCH_2COOC_2H_5$ the methylene group with an acetyl group on one side and a carbethoxy group on the other is highly activated for conversion to mono- and dialkyl C-substitution products and that these and the parent compounds with their two different carbonyl-containing groups joined to the methylene group can undergo hydrolytic cleavage—all this begs the question and plants in her mind a little seed of doubt as to whether you are really as dependable as everybody says you are. Instead, you might sum up that ethyl acetoacetate has been a sort of chemical Chicago, from which one can go in any of many directions. For historical perspective, you might point out that ethyl acetoacetate has had to be made by an expensive sodium-ethyl acetate route, now to be by-passed as rising standards of safety and materials-handling sophistication make *Diketene* a practical commodity.

On the other hand, that's a lot of pointing out and summing up to do. Perhaps it is enough to say that *Diketene* is used to make drugs, dyes, and agricultural chemicals (which is probably true, even if you have nothing specific in mind). When she asks whether they really need all those agricultural chemicals, gently turn her attention to the problem of what to get the kids for Christmas.

We have spent as much as $500 moving a 2-gallon free sample of Diketene *1500 miles from Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company) and can't afford too much of* that, *but this is the place with which to establish mutual earnestness of purpose.*

5 ml of homogeneity

For around $30 per vial, we take pride in offering 5 ml under N_2 of

EASTMAN G50 Butyl Alcohol
EASTMAN G943 sec.-Butyl Alcohol
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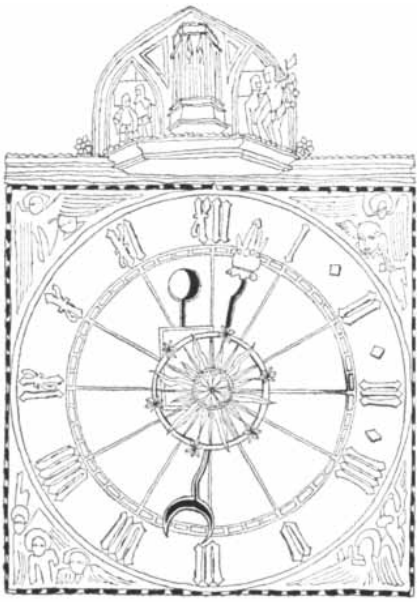
EASTMAN G945 iso-Butyl iso-Butyrate
EASTMAN G6104 1-Chloroheptane
EASTMAN G1481 Cumene
EASTMAN G702 Cyclohexane
EASTMAN G972 Cyclohexanone
EASTMAN G2543 Cyclopentanone
EASTMAN G2405 Decane
EASTMAN G2144 p-Dioxane
EASTMAN G1697 2-Ethoxyethanol
EASTMAN G719 Ethylbenzene
EASTMAN G413 Ethyl Hexanoate
EASTMAN G5890 2-Ethylhexyl Acetate
EASTMAN G125 Ethyl Propionate
EASTMAN G2793 Fluorobenzene
EASTMAN G2215 Heptane
EASTMAN G5082 Hexyl Acetate
EASTMAN G467 Methanol
EASTMAN G2381 2-Methoxyethanol
EASTMAN G946 Methylcyclohexane
EASTMAN G1263 4-Methylcyclohexene
EASTMAN G1107 Octane
EASTMAN G568 Pentyl Alcohol
EASTMAN G848 Propyl Alcohol
EASTMAN G212 iso-Propyl Alcohol
EASTMAN G325 Toluene
EASTMAN G2396 2,2,4-Trimethylpentane

The "G" stands for gas chromatography, the means of final purification that gives us strong confidence that these are the purest of all liquid EASTMAN Organic Chemicals and a strong suspicion that they are the purest liquids available from a commercial house. Sure, with nothing better to do for a few months and nobody asking questions about outlays for equipment, a good physical chemist could work up a sneer at that word "commercial." He could possibly also work up 5 ml of any of these compounds constituted of molecules more homogeneous in some respect or other than are ours. Ours carry a green label. They are intended as standards. You may conceive of less static uses. We expect that each transaction will involve individual correspondence and explanation of the g.c. curve for the particular batch, a document we shall furnish with the vial. It's knowing precisely what you are getting in the vial that has to be worth the price. Neither the liquid nor the information is worth much without the other.

The list of "G" liquids can be expected to grow. Ask for our latest list of them. Inquiries should be addressed to Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company). The cost to us of any discussion that does not result in an order is on the house, alas.

SCIENCE AND



Beyond the Test Ban

As the partial ban on nuclear testing went into effect last month two modest "second steps" were taken toward international control of the atom. One limited the means of delivery of nuclear weapons and the other marked the first vote by the U.S.S.R. in favor of international supervision of nuclear installations.

After a series of talks in New York, the U.S. and the U.S.S.R. joined in sponsoring a UN resolution calling on all nations not to place in orbit or otherwise station in space "any objects carrying nuclear weapons or other weapons of mass destruction." This agreement by the great powers was not considered a major advance in arms control because apparently neither nation had been attracted to satellites as a means of delivering nuclear warheads; missiles can presumably do the job more efficiently. But a nation might achieve a devastating psychological advantage by placing in a hovering orbit a huge nuclear device subject to detonation at any moment. This eerie specter, at least, was banished by the agreement, which was generally welcomed as an indication that the big powers were anxious to maintain the atmosphere established by the test-ban treaty.

The Soviet vote on nuclear installations came at a meeting in Vienna of the International Atomic Energy Agency. The delegates voted, 57 to four, to extend the agency's safeguards system to large nuclear reactors that produce significant amounts of plutonium. All the Soviet-bloc nations except Albania voted with the majority. The safeguards procedures, which require strict accountability for plutonium production, are designed to prevent the diversion to weapons purposes of nuclear equipment or materials supplied through the agency or placed under its jurisdiction. These procedures had previously applied only to small research and training reactors of less than 100,000 kilowatts of thermal output.

As for the test-ban treaty itself, in which the signatories undertook not to conduct nuclear tests except underground, the U.S. Senate approved it on September 24 by a vote of 80 to 19. It went into effect on October 10, having been signed by more than 100 countries.

Children's Treaty

It has become increasingly clear that the principal beneficiaries of the test-ban treaty are the world's present and future generations of children. Provided that nonsignatories such as China and France do not conduct extensive tests in the atmosphere, the treaty can be expected to bring virtually to an end the fallout of strontium 90 and iodine 131, the two products of nuclear explosions that are a particular hazard to infants and children.

Strontium 90 finds its way into food, particularly milk, and from food into bone, where its radioactivity (half life, 28 years) can give rise to bone cancer and leukemia. Since children drink more milk than adults and form new bone at a faster rate, they accumulate far more strontium 90 than adults do. Both the volume of fallout and the concentration of strontium 90 in milk will decrease. The latter will decline more slowly, however, because the concentration of strontium 90 in milk at any one time is a reflection of current fallout rates plus the accumulation of strontium 90 in the ground from previous fallout. John M. Fowler, a physicist at Washington University in St. Louis, believes that next summer the level of strontium 90 in milk will be higher than the record average, as measured in 62 U.S. cities and communities, of this past June: 31 picocuries per liter. (A picocurie is a millionth of a millionth of a curie; at 31 picocuries per liter a quart of milk contains nearly a sixth of

THE CITIZEN

the long-term daily dose permitted by Federal radiation standards.) Thereafter, Fowler said, the strontium 90 level in milk will decrease.

Iodine 131 similarly finds its way into milk, and it is selectively absorbed by the thyroid gland. At a recent congressional hearing Eric Reiss, associate professor of medicine at Washington University and spokesman for the St. Louis Citizens Committee for Nuclear Information, charged that tests in Nevada have several times exposed children in Nevada and Utah to doses of iodine far in excess of the levels permitted by Government standards. Barring accidents and testing by nonsignatory nations, however, the main danger of iodine 131 fallout has passed: the isotope has a half life of only 8.1 days.

The chief remaining fallout problem is carbon 14 generated by the bombardment of atmospheric nitrogen by neutrons released in thermonuclear explosions. This hazard was first pointed out by Linus Pauling of the California Institute of Technology, who last month was awarded the Nobel prize for peace. Because of its 5,600-year half life the carbon 14 produced by past bomb tests will remain a hazard for a long time to come.

Antarctic Inspection

During the Antarctic "summer season" starting this month the U.S. will begin formal inspections of the Antarctic bases of other countries. The Antarctic Treaty, signed by 12 nations late in 1959, states that "Antarctica shall be used for peaceful purposes only" and that the signatories may conduct such inspections as they wish. The U.S. is the first of the nations to exercise this privilege.

The plan to inspect the bases of the U.S.S.R. and six other countries, as yet unnamed, was announced during the Senate debate on the nuclear-test-ban treaty. *The New York Times* later reported that the President had made the decision after objections by a number of Government scientists, who were said to fear that inspections would harm their friendly relations with their colleagues from the other nations. The scientists reportedly argued that U.S. and other Western investigators normally

spend weeks or months and sometimes as much as a year as guests of the Russians in the Antarctic and that visits between the bases of various nations are frequent; thus formal inspections, which would involve only short visits, are unnecessary.

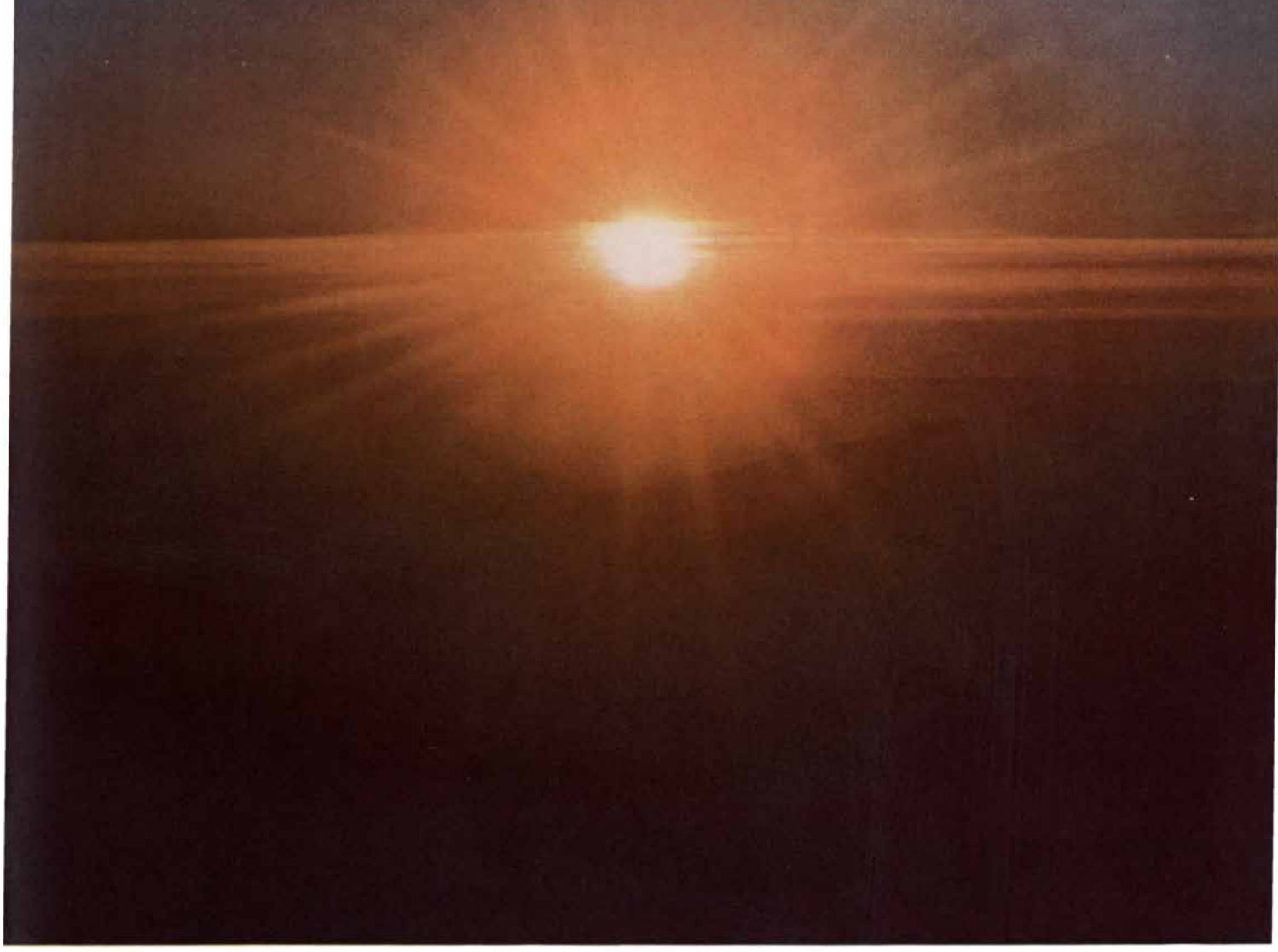
In announcing the inspections the Department of State said that no treaty violations are suspected or anticipated and that the U.S. simply wants to exercise the right of inspection in order to establish a precedent. The inspection teams, now being trained, will keep their activities separate from those of U.S. scientific investigators in Antarctica.

"Thresher" Post-Mortem

The sinking of the nuclear submarine *Thresher* on April 10 with 129 men aboard may have been caused in part by a severe storm that passed over the Gulf of Maine several days before the fatal test dive. The Navy, which suspended its five-month search for the submarine early in September, has officially attributed the disaster to a mechanical failure in the ballast-pumping system. However, Columbus O'D. Iselin of the Woods Hole Oceanographic Institution concludes from a study of prevailing currents in the area of the dive that two delayed subsurface effects of the storm could have forced the submarine out of control before mechanical failure became the critical factor.

Writing in *Oceanus*, a journal of the Oceanographic Institution, Iselin reconstructs the events leading up to the loss of the *Thresher*. On April 8 a large storm moved northeastward across the Gulf of Maine from the Cape Cod area toward Nova Scotia, causing a marked reduction in barometric pressure over the Gulf and heavy southeasterly gales over Georges Bank and Browns Bank at the entrance to the Gulf. As a result the sea level in the entire area rose considerably.

After the storm center had passed, barometric pressure rose and the wind shifted to the west and northwest. The excess water in the Gulf was forced out through the deep, narrow Eastern Channel between Georges Bank and Browns Bank. Meeting the prevailing southwesterly current at the mouth of the channel, this unusually strong outflow set up a large subsurface eddy moving in a counterclockwise direction. The Coriolis effect caused by the earth's rotation would tend to tighten the eddy, increasing the water pressure toward its center. As a result the eddy would assume the form of a wide, dome-shaped subsurface whirlpool of high-density water. It was



This is an incandescent ball of gases, plasmas, magnetic fields, thermonuclear reactions and mysteries.

But NASA has started to throw some light on it.

After all, the sun does sustain life on earth. It disrupts our communications, pours deadly radiation into space and makes our weather do tricks.

So we need to learn the how and why and when of the sun's phenomena. And in the process pick up some basic facts about the whole universe.

So far the trouble has been that our atmosphere acts as a barrier. It makes optical and photographic and spectrographic images shimmer and scatter. In fact it completely *stops* most of the sun's radiation spectrum.

Now . . . if we could only put our instruments *outside* the earth's atmosphere . . . in a new and extremely sophisticated satellite . . . pointed precisely at the sun . . . .

Today, development work for that satellite—the Advanced Orbiting Solar Observatory—is being performed at Republic, under a prime contract to NASA/Goddard.

The AOSO will orbit 300 miles above the earth. In sunlight uninterrupted for months on end. Carrying about 250 pounds of instruments to collect, store and transmit data on the sun's gamma-ray, x-ray and ultraviolet activity.

It will be aimed at the sun with an accuracy of five seconds of arc. That's like shooting at a dime one-half mile away. And hitting it.

NASA's Advanced Orbiting Solar Observatory will look something like the model below. Nobody expects it to find *all* the answers that solar physicists and astronomers have sought for 350 years. But after it has studied that incandescent ball for a while, we'll be a lot less in the dark.

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Electrically activated by sea water, Sonobuoys can pick up underwater sounds from miles distant . . . distinguish between significant sounds and random noise . . . then radio the information they receive to nearby ships or aircraft.

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RCA nuvistors—shown actual size—power the FM radio transmitter in a typical submarine-detecting Sonobuoy.

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directly into the top of this dome—estimated by Iselin to be some 60 miles in diameter—that the *Thresher* would have dived on April 10.

Regardless of the direction of the *Thresher*'s dive, Iselin points out, the submarine would soon come to the perimeter of the eddy and enter water of a much lower density. Its angle of dive would suddenly and, as far as the crew was concerned, inexplicably increase. Nonetheless Iselin believes that recovery from this predicament was not beyond the capabilities of the *Thresher*.

Here, however, a second environmental factor may have come into play. The same storm that disrupted normal flow through the Eastern Channel was now off the entrance of the Gulf of St. Lawrence and generating large subsurface waves in all directions. Iselin estimates that these waves, whose amplitude is largest at the interface between high- and low-density water strata, may have been as high as 300 feet at the *Thresher*'s diving depth. If a submarine were heading into such a wave at five or six knots, the wave's normal period of about eight minutes would be roughly halved. In other words, the submarine would be forced to descend the 300 feet from crest to trough in only two or three minutes. Assuming that the submarine encountered an exceptionally high wave just as it reached the perimeter of the eddy, these two forces would combine to accelerate its descent.

At this point, Iselin concludes, a mechanical failure in the ballast-pumping system could have prevented the *Thresher* from pulling out of its drastically steepened dive before it reached its maximum diving limit, or collapse depth.

Troublesome Fault

Local anomalies in the earth's magnetic field along the Atlantic coast have revealed a deeply buried fault in the earth's crust beginning at least 400 miles out in the Atlantic and extending across New Jersey to central Pennsylvania. The fault, which has a length of 600 miles or more, suggests considerable movement of segments of the earth's crust, but at the wrong time and in the wrong direction to fit into recently advanced theories of continental drift.

The fault was uncovered by Charles L. Drake, James Heirtzler and Jules Hirshman of the Lamont Geological Observatory of Columbia University. During a study of magnetic data collected by Government agencies, by Lamont and by a number of oil companies, a curious

feature was noticed in records for areas around the 40th parallel. The pattern of anomalies was repeated on both sides of a line running approximately along the 40th parallel; to the north of the line, however, it was shifted 100 miles to the east. Since local anomalies in the earth's magnetic field reflect differences in the magnetization of nearby crustal rocks and thus differences in the rocks themselves [see "The Magnetism of the Ocean Floor," by Arthur D. Raff; SCIENTIFIC AMERICAN, October, 1961], the pattern displacement was interpreted as evidence of a buried fracture in the ocean floor. Simultaneously Herbert P. Woodward of Rutgers University found, in a study of the distribution of Paleozoic sediments in New Jersey and Pennsylvania, that the fault extended into Pennsylvania.

Writing in the *Journal of Geophysical Research,* Drake and his associates note that the fault—the first ocean-bottom fracture known to continue onto the shore—provides new evidence of sizable crustal movements. However, the newly discovered fault appears to date back some 200 million years and to have been quiescent since. This is difficult to reconcile with other recent studies suggesting a considerable change in the position of the continents in the past 200 million years. In addition, the direction of displacement is opposite that of several fractures in the floor of the Pacific. Some Pacific fractures show shifts in the same direction as the Atlantic fault. But the largest, the Mendocino fault, shows a shift of no less than 750 miles to the west instead of the east in the ocean floor north of the fault. Regarded together, such displacements would appear to tear continents apart rather than move them as a whole.

Mosaic Females

Women, it seems, are genetic mosaics: organisms in which some body cells have one set of genes and other body cells have a somewhat different set. Recent studies of a sex-linked enzyme defect indicate that one of the two X chromosomes of the human female (the male has only one) is active in some of her somatic cells and the other X chromosome is active in the rest. The finding lends credence to a hypothesis first advanced two years ago: that the sex chromatin—a distinctive body found in the nuclei of female somatic cells—is a displaced X chromosome and that in each female somatic cell only one X chromosome is fully active.

Since its discovery in 1949 the sex

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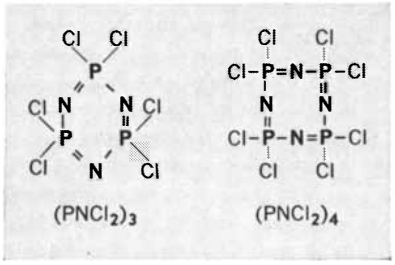
- **Phenylneopentyl phosphite**



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The photo shows two plastic strips—the right one is burning and dripping. The left one doesn't drip when a flame plays on it—stops burning when you take the flame away. A new, stable, chlorine-rich chemical added to the polymer provides fire retardance without affecting electrical properties.

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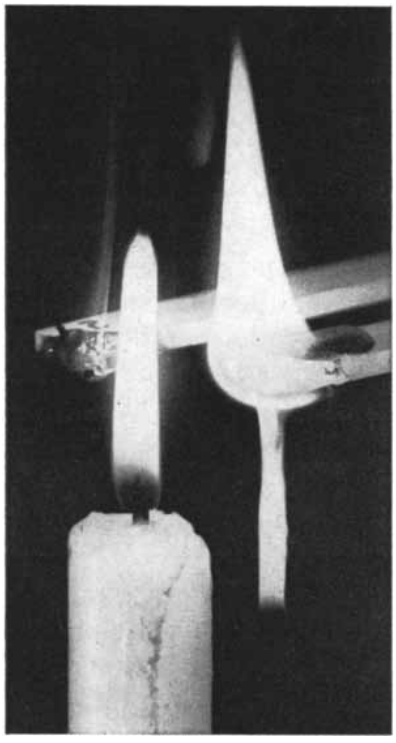
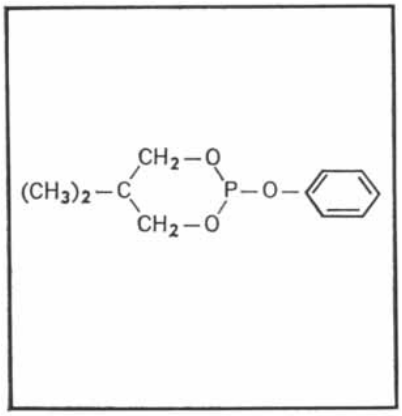


Dechlorane is currently available in semicommercial quantities. For information on physical properties, solubility and other data, please check and mail the coupon.



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chromatin has been widely utilized to determine the genetic sex of individuals suffering from abnormalities of sexual development. In the course of such studies it was noted that only one X chromosome could be seen in most somatic cells, regardless of the individual's X-chromosome complement, and that individuals with extra X chromosomes had extra sex-chromatin bodies. This led to the identification of the sex chromatin as an X chromosome that condenses into chromatin at about the third week of embryonic life—presumably after the two X chromosomes have fixed development of the embryo as a female.

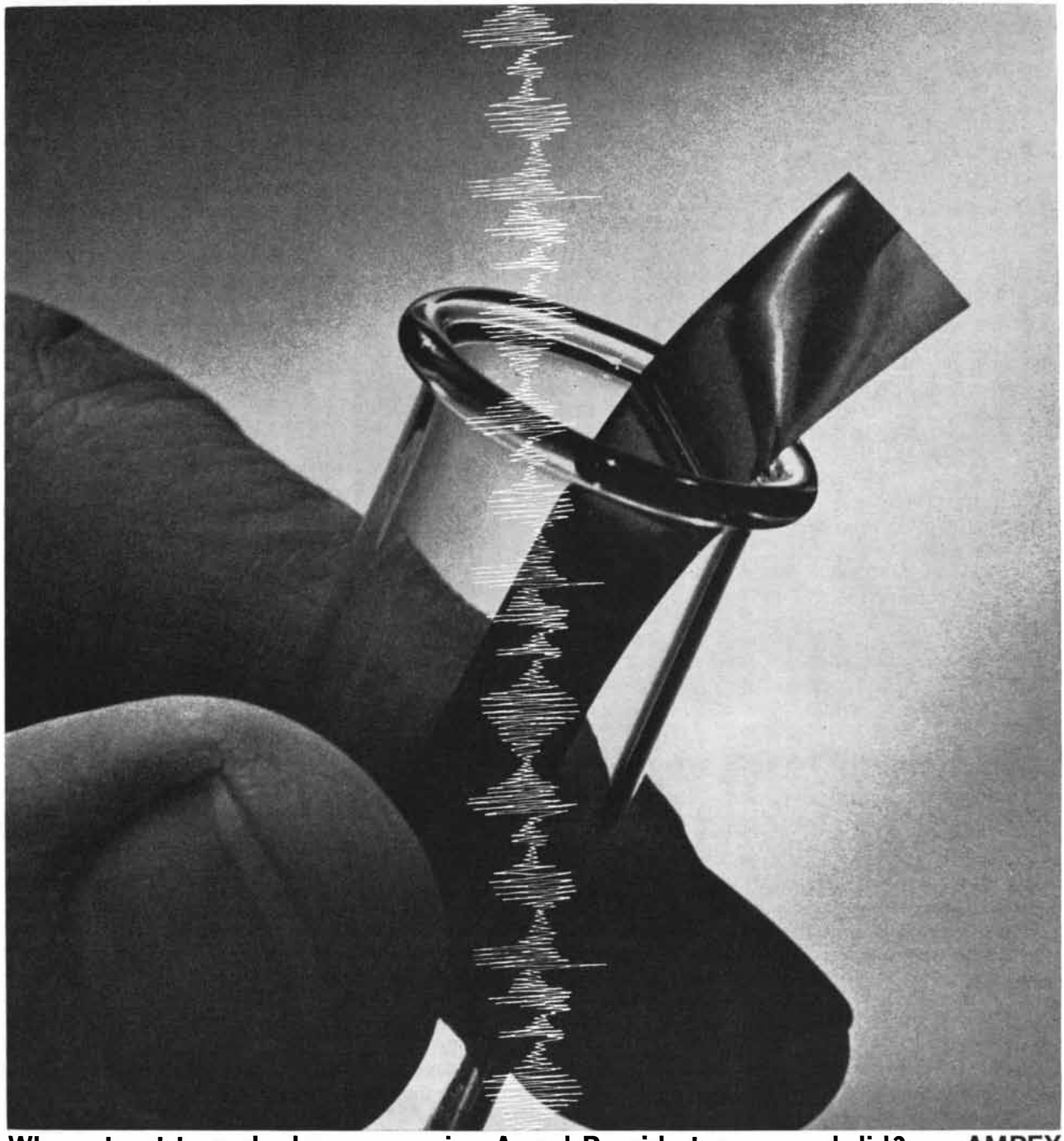
In 1961 Mary Lyon of the British Atomic Energy Establishment at Harwell and Liane B. Russell of the Oak Ridge National Laboratory independently suggested that in mammals one X chromosome is inactivated in some embryonic cells and their descendants, that the other is inactivated in the rest and that mammalian females are consequently X-chromosome mosaics. Their conclusion was based on the behavior of coat-color genes located on the X chromosomes of rats and mice.

In man a comparable X-chromosome gene governs the formation of glucose-6-phosphate dehydrogenase, an enzyme involved in the utilization of glucose. The gene has at least two forms; one gives rise to an "A" species of the enzyme and the other to a "B" species. In addition, a third form of the gene (possibly a missing gene) results in a deficiency of the enzyme. The A and B genes occur in Negroes, the B gene and the gene for deficiency in Caucasians.

Studies of the production of the enzyme in skin cells taken from Negro women with genes for both A and B enzymes and in white women with genes for the B enzyme and enzyme deficiency have in both cases revealed the existence of two distinct populations of cells. In each of six Negro women Ronald G. Davidson, Harold M. Nitowsky and Barton Childs of Sinai Hospital in Baltimore and the Johns Hopkins School of Medicine found that some cells produced the A enzyme and some the B enzyme; none produced both. In two white women some cells produced the B enzyme and some were deficient in it. The work was reported in *Proceedings of the National Academy of Sciences.*

The Information Explosion

The total number of different "things" (books, pamphlets, journals, maps, photographs and so on) in the world's libraries is estimated to be somewhere



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For today's instrumentation applications, a demand exists for increasingly longer-wearing tapes. Ampex decided to meet the demand. Result? Two totally new instrumentation tapes formulated to meet A and B oxide MIL-SPEC and to provide longer wear characteristics. Not only do these new tapes offer far longer wear but also far superior performance. For example: Both new tapes are conductive and antistatic. They have less tendency to attract foreign particles. This makes for clean operation as well as longer life. Due to the uniformity of the new formulation, the occurence of dropouts is minimized. The new Ampex A and B oxide tapes provide higher resolution and improved general output characteristics. And each is application engineered. All this adds up to excellent performance, outstanding reliability. It has to add up to that. That's what Ampex set out to do. For more information write to Ampex Corporation, Redwood City, California. Sales and service offices throughout the world.

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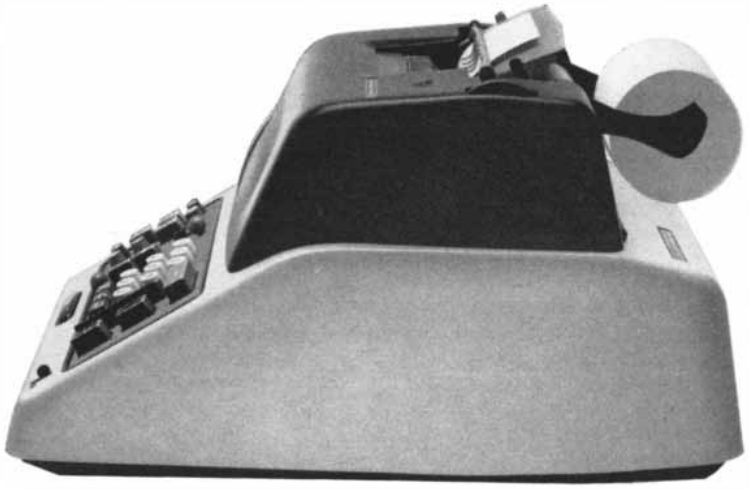
between 7.5 million and 770 million and to be growing at the rate of about 3.1 per cent per year. The total number of "bits" of information represented by all these items is roughly 2×10^{15} (two quadrillion), and it is increasing at the rate of two million bits per second. These estimates, recently published in *Science*, were made by John W. Senders of the firm of Bolt Beranek and Newman.

The objective of Senders' study was to estimate the size of the storage problem that may face libraries, or their successors, in the next century. Senders obtained his totals by analyzing figures from various sources. These include the estimate that in 1958 the Library of Congress contained 11 million volumes, that the total number of items of all sorts in the library is 3.5 times the number of volumes and that it is adding 350,000 "volumes and pamphlets" a year. Senders also evaluated the UNESCO estimate that the world's libraries contain about three billion volumes and concluded that the net number of different titles is only about 75 million. This is actually the basis for the lowest of Senders' various estimates.

To convert items into bits of information, Senders treats all stored items as equivalent to books containing 100,000 five-letter words per book. The items are of course written in many different languages and different alphabets. For simplicity Senders assumes 50 alphabets and 50 characters (including numerals and other symbols) to an alphabet, yielding a total of 2,500 characters. To translate this many characters into a binary code, using a different sequence of zeros and ones to represent each character, would require 12 digits, or bits, per character. Each bit of this sort is considered a bit of information. The information stored in one "book" of the world's literature is therefore six million bits. And the information in all the world's stored literature lies somewhere between 4.6×10^{14} and 4.6×10^{15} bits.

Using Senders' estimates, it is possible to compare the "information explosion" with the "population explosion" in order to see how man's ability to produce recordable literary works compares with his ability to produce readers. So far readers, or potential readers, outnumber books and other library items by at least four to one. Moreover, the population is increasing at the rate of about two humans per second, compared with one new library item every three seconds. Nevertheless, the gap is closing; the population is growing at a rate of only about 2 per cent per year compared with about 3 per cent for recordable items.



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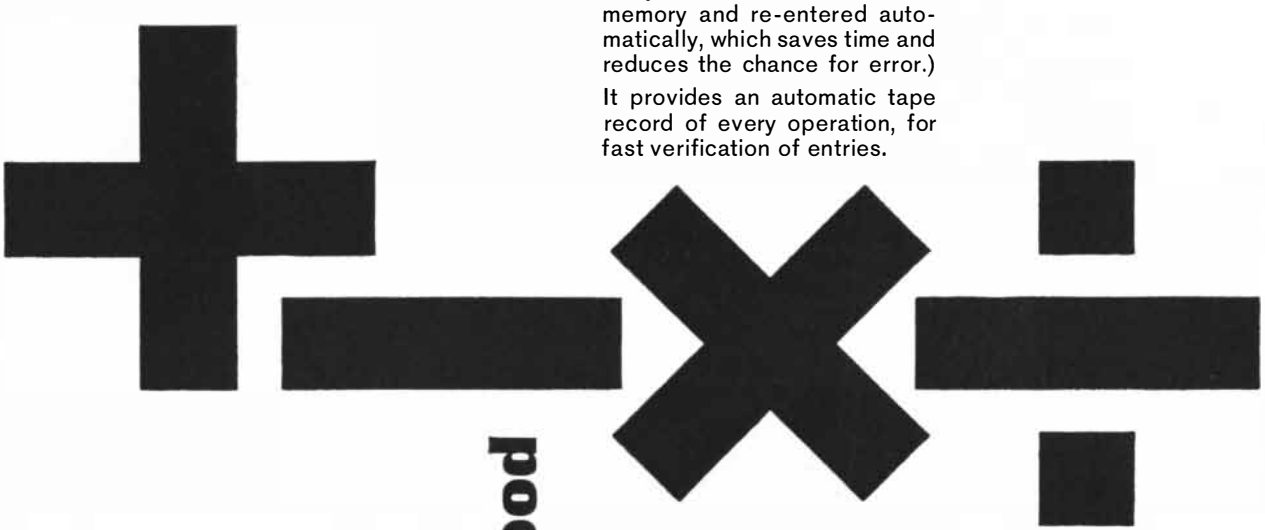

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ARCHITECTURAL ACOUSTICS

Sound is as much a part of man's man-made environment as heat or light. It can now be effectively managed, notably in rooms where music is heard, by applying the principles of acoustical physics

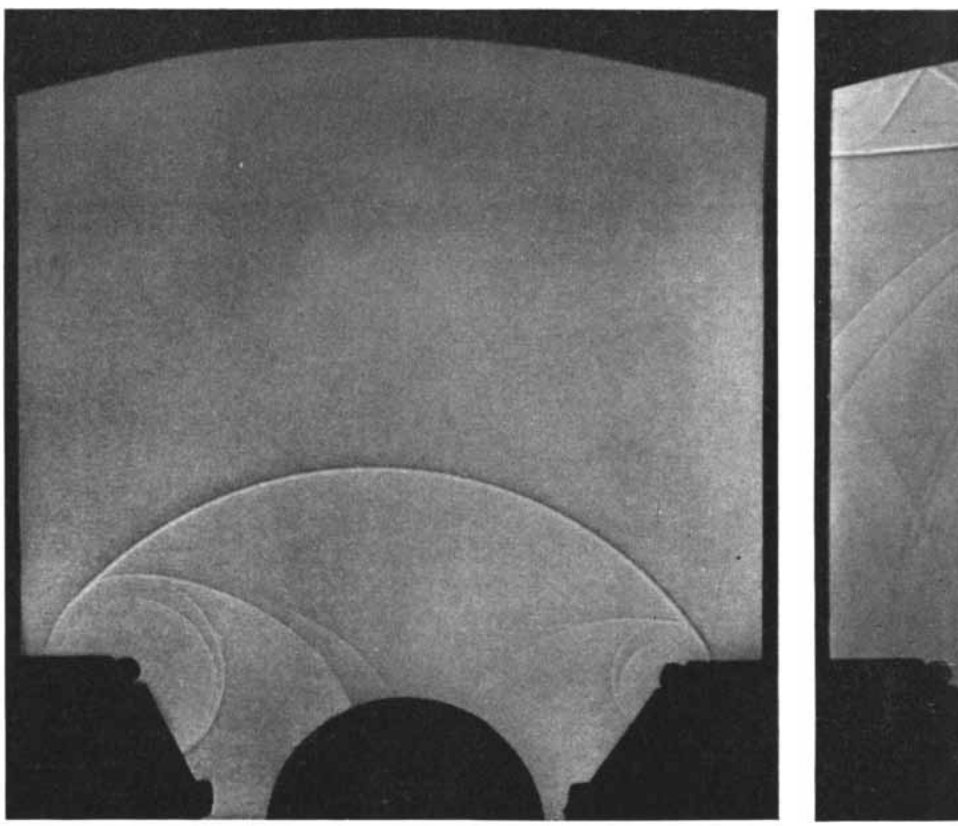
by Vern O. Knudsen

The opening of a large concert hall these days is almost inevitably followed by a spate of reports, reviews, criticisms and opinions about its acoustical qualities. Amateurs and competent critics alike try to compare the music heard in the new hall with their recollection of the same or similar music heard in concert halls of acknowledged acoustical excellence. This exercise in auditory memory is not easy, and it gives rise to many pretentious statements. Yet the fact remains that, as in winetasting, the subjective evaluation of experts is the court of last appeal. For this reason architectural acoustics is an art as well as a science. If a new concert hall shows palpable deficiencies, as sometimes happens even today, the impression is strengthened that the science of acoustics has failed, or at least has been found wanting. Such a judgment is much too harsh. What usually happens in such cases is that the available knowledge, for a whole complex of reasons, has not been adequately applied. For example, critics reported serious deficiencies in the acoustics of Philharmonic Hall in New York, which opened a year ago. The original acoustical engineers and an independent team of consultants have now established these deficiencies by objective methods, and a number of changes have been made in the auditorium's design. The results of these changes, however, are still subject to critical evaluation, and it would be premature to discuss them here.

The purpose of this article is to describe the objective acoustical elements that have led to the design of many fine music halls and auditoriums. The application of acoustical knowledge to architecture dates back barely 60 years. Until about 1900 the design of a successful music room was almost entirely a matter of luck. Today the design can be based on well-established principles of physics and engineering.

Acoustics is one of the oldest branches of physics. It originated in the study of music, which probably began with Pythagoras more than 2,500 years ago. By means of a single stretched string he showed that consonant intervals in music can be expressed by ratios of simple whole numbers. Acoustics has come a long way since then, both as an independent branch of physics (physical acoustics) and in association with other sciences and arts. In the second category are psychoacoustics and physiological acoustics, which deal broadly with the nature of speech and hearing; communication acoustics, which deals with the auditory aspects of telephony, radio and sound reproduction; musical acoustics, which deals with the acoustics of the human voice and musical instruments, and architectural acoustics.

Acoustics first became associated with



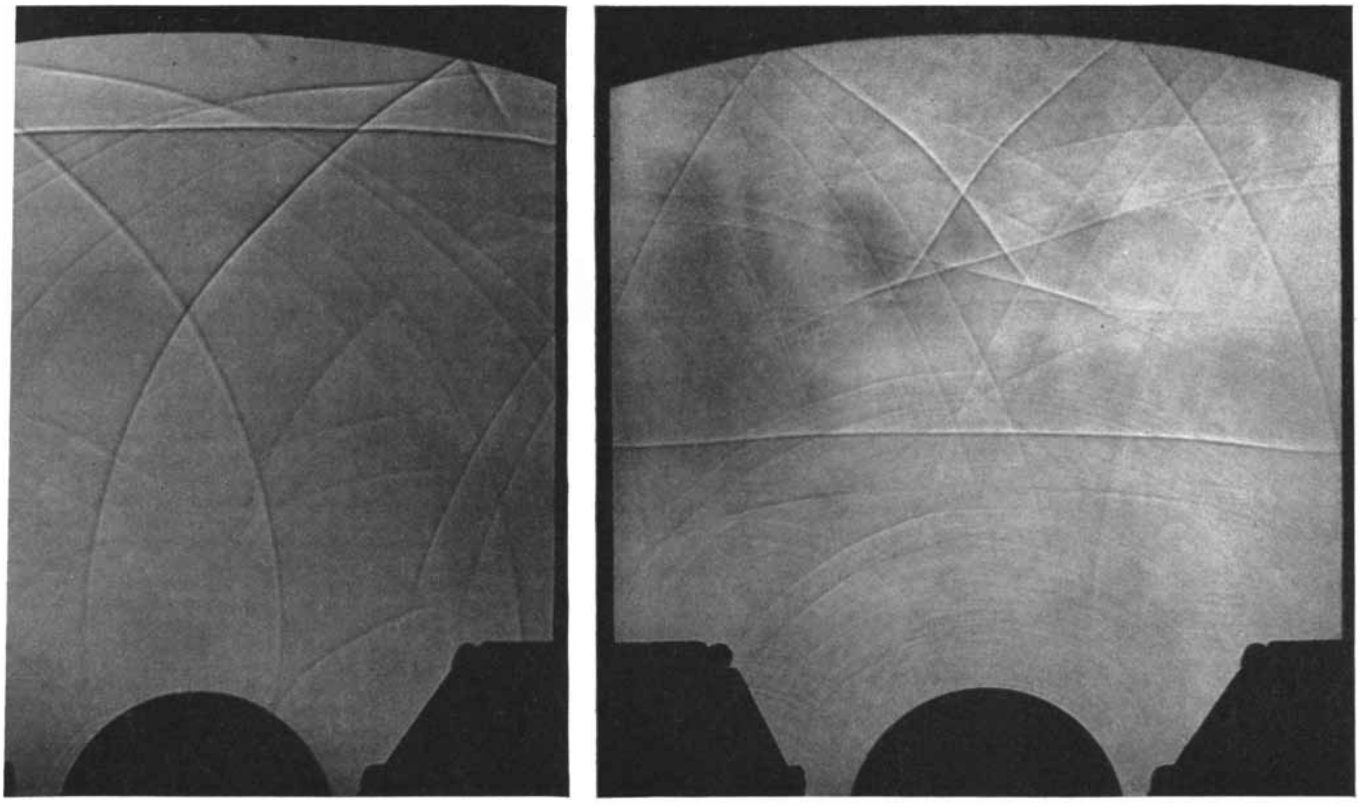
REFLECTION AND DIFFRACTION of sound waves can be studied by photographing the wave patterns created by an electric spark. This sequence shows the waves generated by a spark in a model of Royce Auditorium at the University of California at Los Angeles. The spark wave originates from a point on the stage and travels to the rear of the auditorium,

architecture when men began to assemble in groups to hear speeches, listen to music and see and hear plays. To create a favorable setting for such activities the Greek and Roman open-air theaters and forums evolved, and many of them have survived to this day. The typical open-air amphitheater consists of steeply banked benches arranged in a semicircle in front of a platform. With the passage of time the platform evolved into a stage with massive rear and side walls of masonry (and sometimes a ceiling) that served the acoustical purpose of reflecting, directing and thereby reinforcing the sound intended for the audience. Vitruvius, the first-century Roman architect and engineer, wrote that large vases tuned as resonators were often located in the seating area to reinforce certain sounds. Whether or not such vases were actually used is uncertain, but in any case they could only have absorbed sound, not reinforced it.

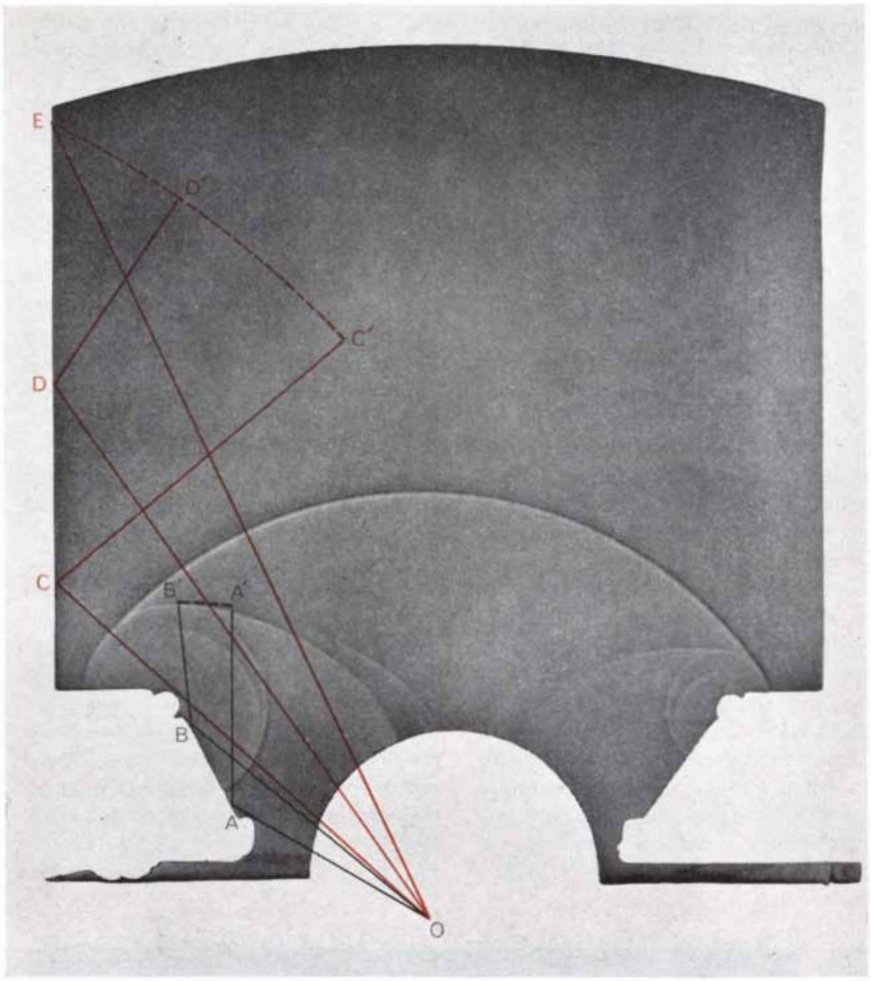
The Greeks did, however, develop one acoustical device of considerable value: the masks worn by actors. In addition to providing exaggerated facial expressions appropriate to the various roles, the masks served as megaphones that improved the mechanical coupling between the voice-generating mechanism and the surrounding air. A megaphone does not amplify the voice, but it does enable more of the available vocal energy to emerge in the form of sound waves than would emerge without the aid of the megaphone.

The principal defect of the Greek and Roman theaters is that the semicircular tiers of seats act as reflectors that tend to focus sounds from the stage back to a point on or near the stage. Moreover, the echoes from concentric tiers are reinforced at certain frequencies and diminished at others. The reason is that the vertical risers, which form the backs of the benches, create an echelon of uniformly spaced reflecting surfaces. The reflected waves are in phase and reinforce each other when the distance between risers is equal to one, two, three or any other whole number of half-wavelengths. When the distance between risers is one, three, five or any other odd number of *quarter*-wavelengths, the reflected waves meet in contrary phase and thus tend to cancel each other [*see illustration on page 82*]. For example, risers that have a spacing of 2.5 feet will constructively reinforce a series of sounds that have wavelengths in feet of 5, 2.5, 1.67, 1.25, 1 and so on, corresponding to tones that have frequencies in cycles per second of 225, 450, 675, 900, 1,125 and so forth. These frequencies constitute a harmonic series. The same riser spacing of 2.5 feet leads to wave cancellation in a series of odd-numbered harmonics with frequencies of 112.5, 337.5, 562.5, 787.5 and so on.

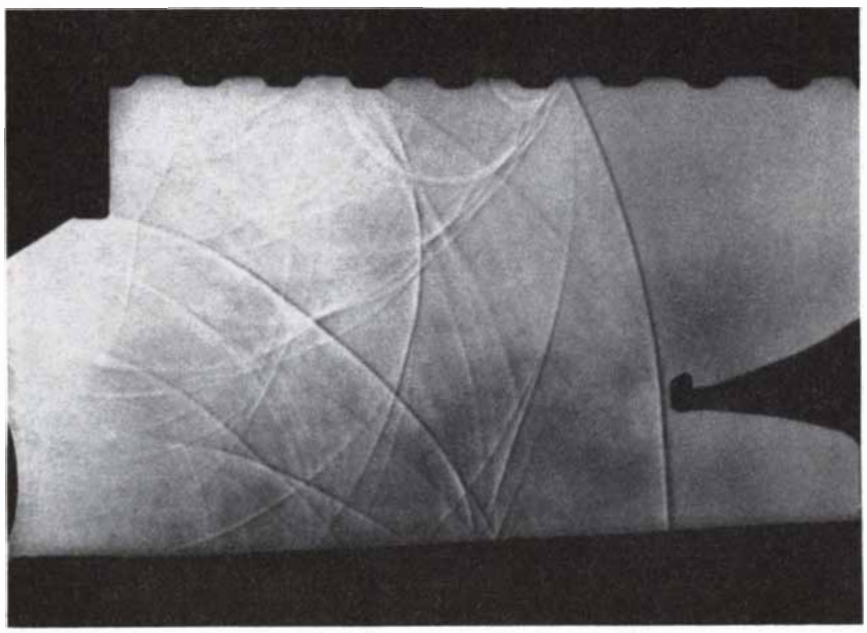
The effect of such wave reinforcement and cancellation can readily be demonstrated by speaking, singing or clapping hands on the stage of a typical Greek or Roman open-air theater. The sound reflected from the tiers of benches produces a sustained echo whose characteristic pitch is determined by the distance separating adjacent risers. As a result, when speech or music is heard in an open-air theater—or in a room or auditorium in which there are parallel and uniformly placed reflecting surfaces—the reflected sound may suffer a serious distortion in frequency. Fortunately in an open-air theater these frequency-dependent reflections generally pass over the heads of the audience, but since the reflections come to a focus on the stage they can be extremely disturbing to performers rehearsing in an empty theater. The problem largely disappears, how-



shown in plan view. (The black semicircle is not part of the plan but a mask to keep the bright spark from fogging the film.) The wave front begins as a simple arc (*left*) and becomes almost straight as it is reflected from the concave rear wall (*middle and right*). This produces an echo on the stage and in the front rows of seats. The echo was reduced by treating the rear wall with absorptive material. Note the complex patterns created by the proscenium. The photographs are by L. P. Delsasso and the author.



SIMPLE PLOTTING OF WAVE REFLECTIONS, called ray acoustics, has only limited value for predicting the acoustics of an auditorium. Several rays are shown superimposed on a spark photograph of Royce Auditorium. Note that rays *A* and *B* on reflection (*A'*, *B'*) fail to predict the complex diffraction patterns from the proscenium at left of stage. Rays *C* and *D*, however, represent reasonably well the reflections from a straight wall.



MODEL OF LONGITUDINAL SECTION of Royce Auditorium produced this complex wave pattern in a spark photograph. Diffusive reflections from the coffered ceiling cannot be predicted by ray acoustics. Analysis of such patterns is the objective of wave acoustics.

ever, when a capacity audience provides a sound-absorbing covering on the tiers of benches.

New acoustical problems arose when civilization and culture spread northward and it became necessary to provide enclosed buildings for theaters, churches and other auditoriums. In these buildings sound echoed from walls and ceilings, and when the enclosed space was finished with hard and sound-reflecting materials such as marble, stone and concrete, the architect encountered a vexing problem: excessive reverberation. This phenomenon is merely sustained echoing, and for the most part it was accepted as an inevitable result of building large enclosures of durable materials. Indeed, much of the majesty of a cathedral derives from the sonorous reverberations it imparts to voices and musical sounds. Although such reverberations may be acceptable, and even desirable, for church music and services, they must be held to strict limits in designing a lecture room, an auditorium, a concert hall or an opera house.

Acoustics of Closed Spaces

In order to handle the acoustical problems of enclosed spaces architects, and more recently acoustical engineers, have developed two basic procedures. The earliest and simplest utilizes ray, or geometrical, acoustics; the more recent and comprehensive procedure requires a detailed analysis of how waves of different frequencies actually interact with reflecting and absorbing surfaces of various shapes and dimensions.

Ray acoustics assumes that sound waves travel in straight lines and that when they encounter a new medium, such as the wall of a room or any substance whose density or elasticity differs from that in which the sound originated, the waves are reflected, refracted and transmitted in a fashion that is uniform for all wavelengths. It is assumed, for example, that sound waves are reflected from surfaces in the same way a billiard ball without spin rebounds from a cushion; in other words, that the angle of reflection equals the angle of incidence. In employing ray acoustics architects superimpose on their two-dimensional plans and sections families of straight lines that represent incident and reflected sound waves. This simple technique is useful for uncovering gross acoustical faults such as focusing effects from concave surfaces and for determining the shape of enclosures that will give optimum distribution of sound.

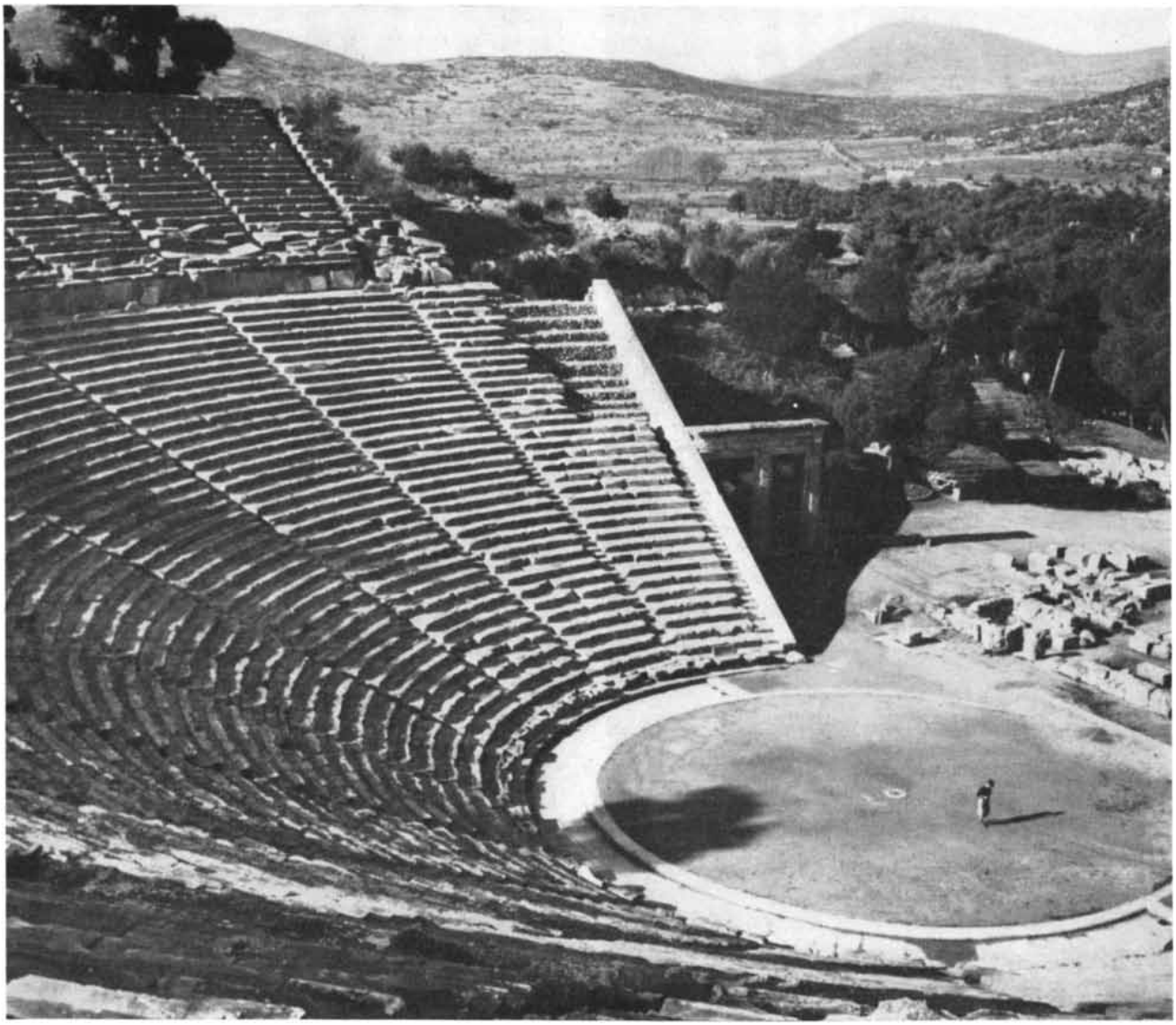
Ray acoustics is valid, however, only

for wavelengths that are small compared with the dimensions of the reflecting surfaces. The wavelength of a sound wave that has a frequency of 1,000 cycles per second is about 1.1 feet. For such a sound wave to be reflected in the simple manner predicted by ray acoustics, the dimensions of the reflecting surface must be at least two or three times the wavelength, or two or three feet. For wavelengths that are not short compared with the dimensions of the reflecting surfaces, ray acoustics fails. Thus sound that has a frequency of 100 cycles per second and a wavelength of 11.25 feet will not be reflected in a simple manner from a surface that measures two or three feet across. The limitations of ray acoustics become apparent when one considers that the wavelength of audible sound varies from about 56 feet at the low-pitch end of the range to less than an inch at the high-pitch end. Virtually every architectural detail in an auditorium or music room will be large compared with the shortest wavelengths and small compared with the longest.

In order to overcome the limitation of ray acoustics one must employ wave, or physical, acoustics, which is based on the physical theory of waves. Only wave theory can cope with the real behavior of sound in rooms. The preceding discussion of reinforcement and cancellation in sound waves reflected from the tiers of benches in an open-air theater gives an example of wave acoustics. An analysis of an open-air theater by means of ray acoustics would show only that sound reflected from the curved tiers of benches would come to a focus at the stage. Such acoustical phenomena as room resonance, reverberation at low frequencies, interference, diffraction and the reflection and transmission characteristics of openings in a room or of systems of suspended panels can be understood and subjected to control only by the rigorous application of wave acoustics.

Singing in the Shower

Perhaps the most familiar example of room resonance is that produced by someone singing in a tiled shower. The singer, who may be impressed by his vocal power, is not hearing his true singing voice; he is primarily exciting, or activating, the resonance, or natural, frequencies of a highly resonant chamber. The resonance frequencies for a shower stall, or any rectangular room, are determined by its dimensions and those of its occupant. For simplicity in calculating the resonance frequencies I shall assume that a glass door completely



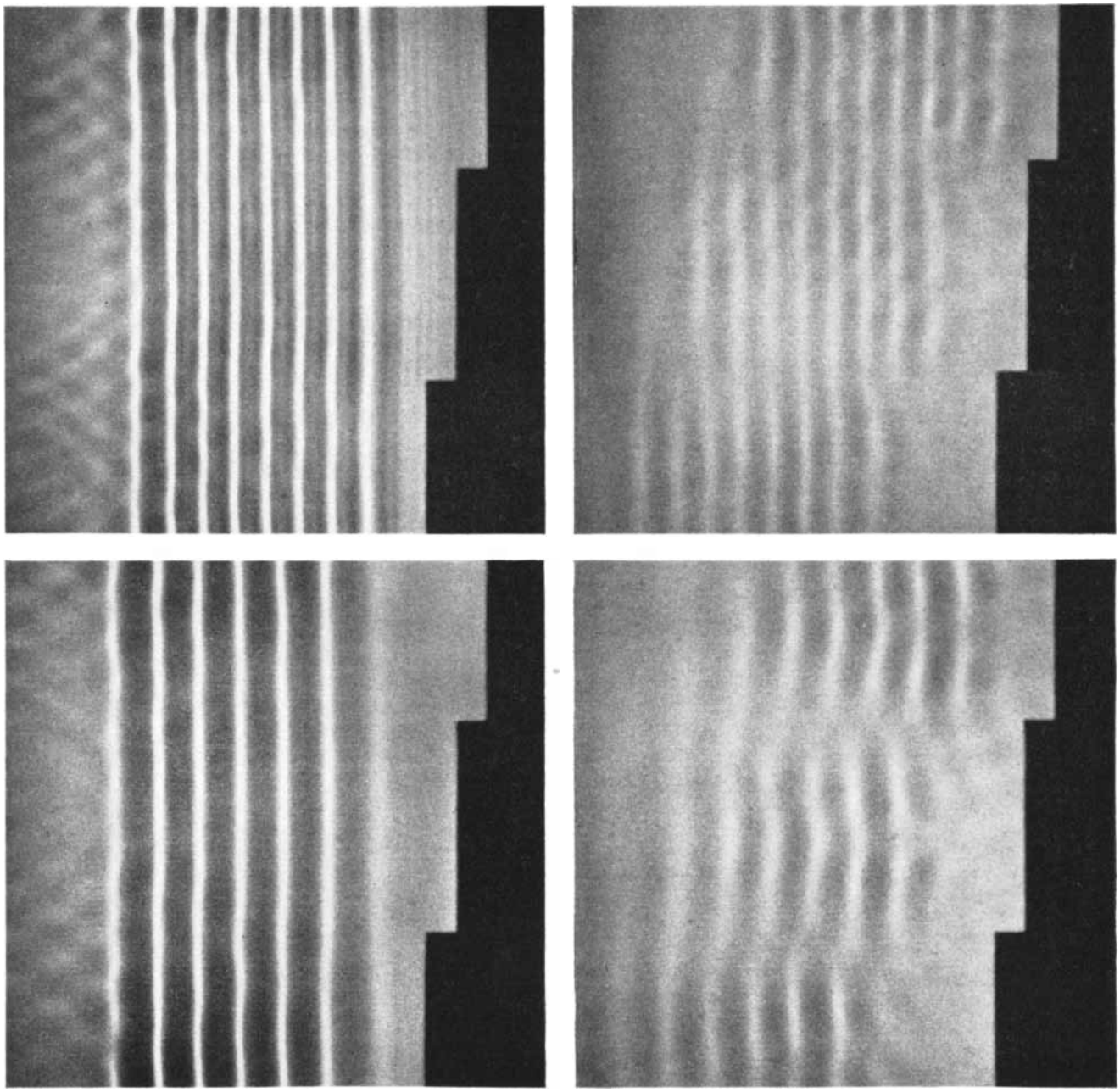
THEATER AT EPIDAURUS is widely regarded as the most beautiful in Greece. Although the stage no longer exists, nearly every seat is intact. The regular spacing of the risers behind the seats creates unusual sound reflections as illustrated on the next page.

closes the entrance to the shower and ignore the presence of the occupant.

My shower is three feet square and eight feet high, and I have demonstrated to my own satisfaction that my presence in it does not appreciably alter the low-frequency resonances. One can regard the enclosure as a kind of organ pipe, eight feet long and closed at both ends. The fundamental tone, or lowest frequency of vibration, of such an organ pipe is a tone whose wavelength is twice the length of the pipe, or 16 feet. To find the frequency of a sound of this wavelength one divides 1,125 feet (the speed of sound in air at 68 degrees Fahrenheit) by 16 feet, which yields almost exactly 70 cycles per second. As every music student knows, such an eight-foot organ pipe also generates a whole series of harmonic overtones that have frequencies of two, three, four, five and so on times the fundamental frequency, corresponding to 140, 210, 280, 350 and so forth cycles per second.

These are not, however, the only resonance frequencies in a three-dimensional shower; there are also transverse modes of vibration with their appropriate resonances and harmonics. It turns out that there is a triply infinite series of resonance frequencies. They are determined by the dimensions of the shower, the velocity of sound and the appropriate assignment of integral numbers in groups of three, corresponding to the three dimensions of the shower. The first seven members of the triplet series are 0, 0, 1; 0, 0, 2; 1, 1, 0; 0, 2, 0; 2, 0, 0; 1, 1, 1 and 1, 1, 2. The three digits in each triplet are integers, two of which may be zero, and each of the three may increase (theoretically) to infinity.

The first four resonance frequencies for my shower, calculated by the appropriate formulas, are 70, 140, 187 and 264 cycles per second. These are only the first four of the triply infinite



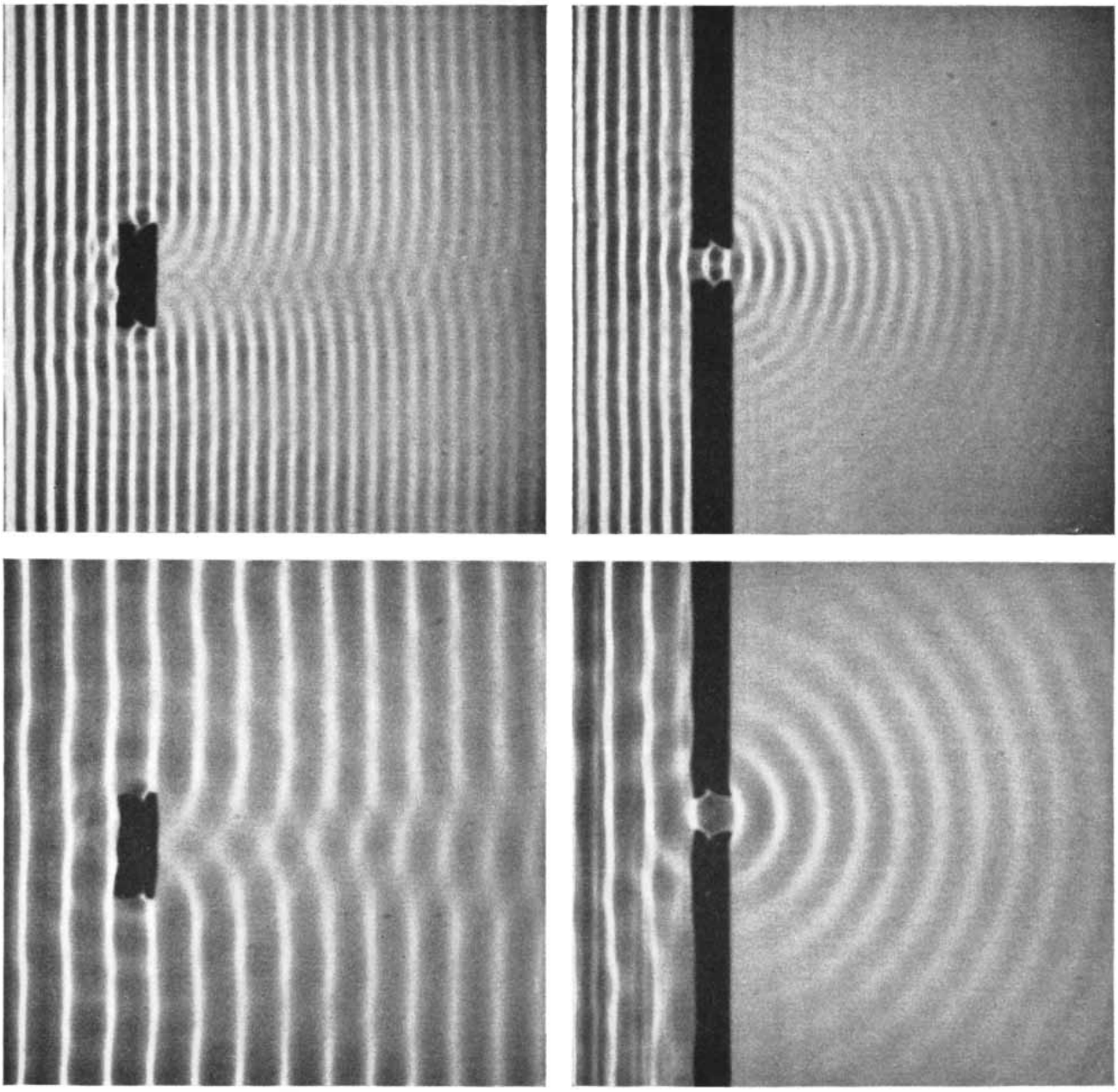
WAVE REFLECTION from regularly spaced risers, as in Greek open-air theaters, can be demonstrated with water waves in a ripple tank. When setback of risers is equal to integral multiples of a half-wavelength (*top pair of photographs*), the reflected waves are in phase. When the setback is equal to odd multiples of a quarter-wavelength (*bottom*), the reflected waves are out of phase.

series of resonance frequencies for this simple enclosure. At higher frequencies the separate modes of the resonant vibrations come closer and closer together and ultimately can no longer be resolved either by ear or by instrument. Therefore at sufficiently high frequencies this enclosure (or any rectangular room) has a frequency response that is essentially "flat," which means that it responds to all frequencies alike.

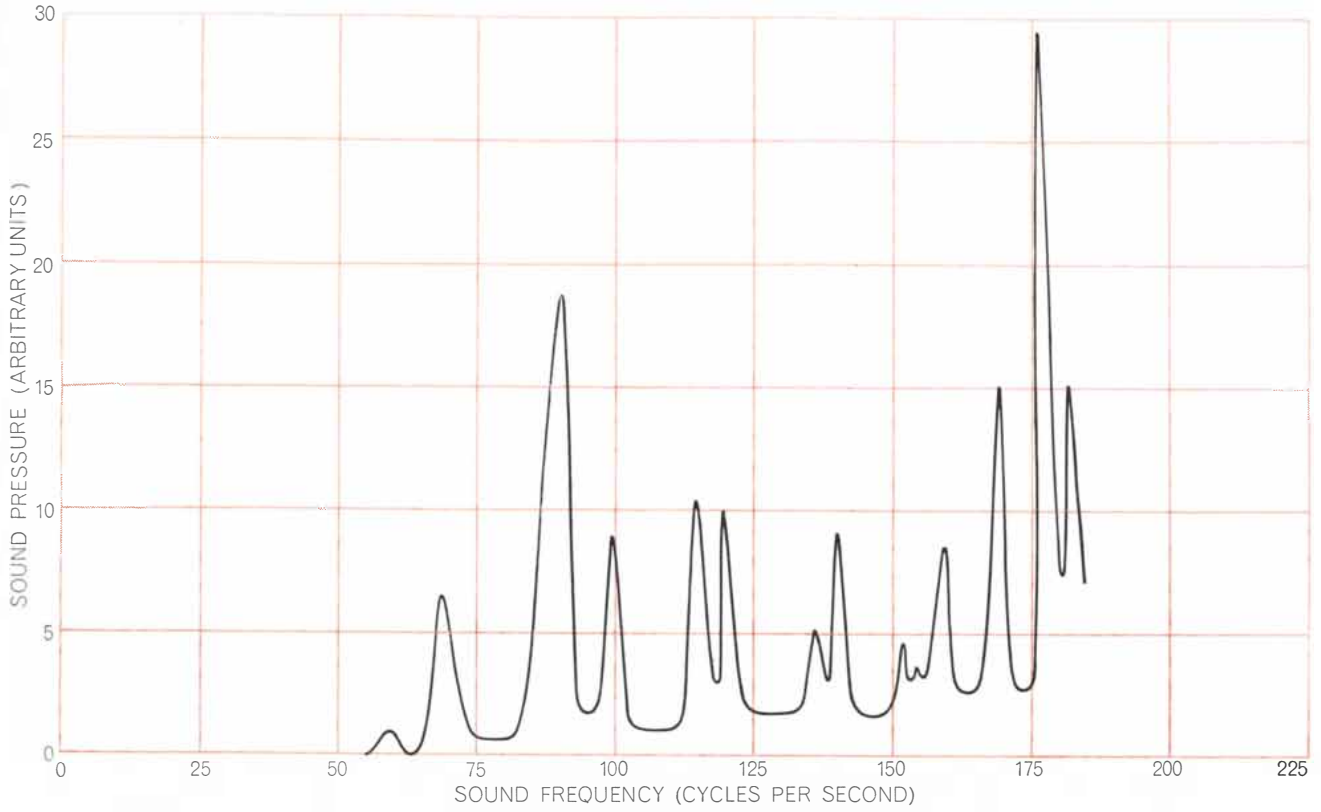
The prominence of resonance frequencies in a room is dependent on the reflective properties of its walls. Bathroom tile, for instance, reflects about 98 per cent of the sound energy that strikes it. Consequently the resonance frequencies in a tiled shower are very prominent; moreover, the small dimensions of the shower give rise to resonances that have frequencies well within the audible range. In contrast, the prominent resonances in large rooms occur at frequencies that are usually below that range. Resonance frequencies can readily be suppressed by placing sound-absorptive materials on the wall surfaces of a resonant room. With nothing more than three large terry-cloth towels one can reduce the resonances in a tiled shower to the point where they are barely noticeable. This is done by placing one towel on the floor and centering the other two on adjacent walls.

More than 30 years ago I investigated the resonances in a special experimental room eight feet square and 9.5 feet high. The room had concrete walls 10 inches thick and contained only one opening, which was sealed by a steel door. The first four resonance frequencies for this room, calculated for a temperature of 70 degrees F., were 59.2, 70.3, 92.9 and 99.7 cycles per second. These calculated values agreed with the experimentally determined frequencies quite precisely.

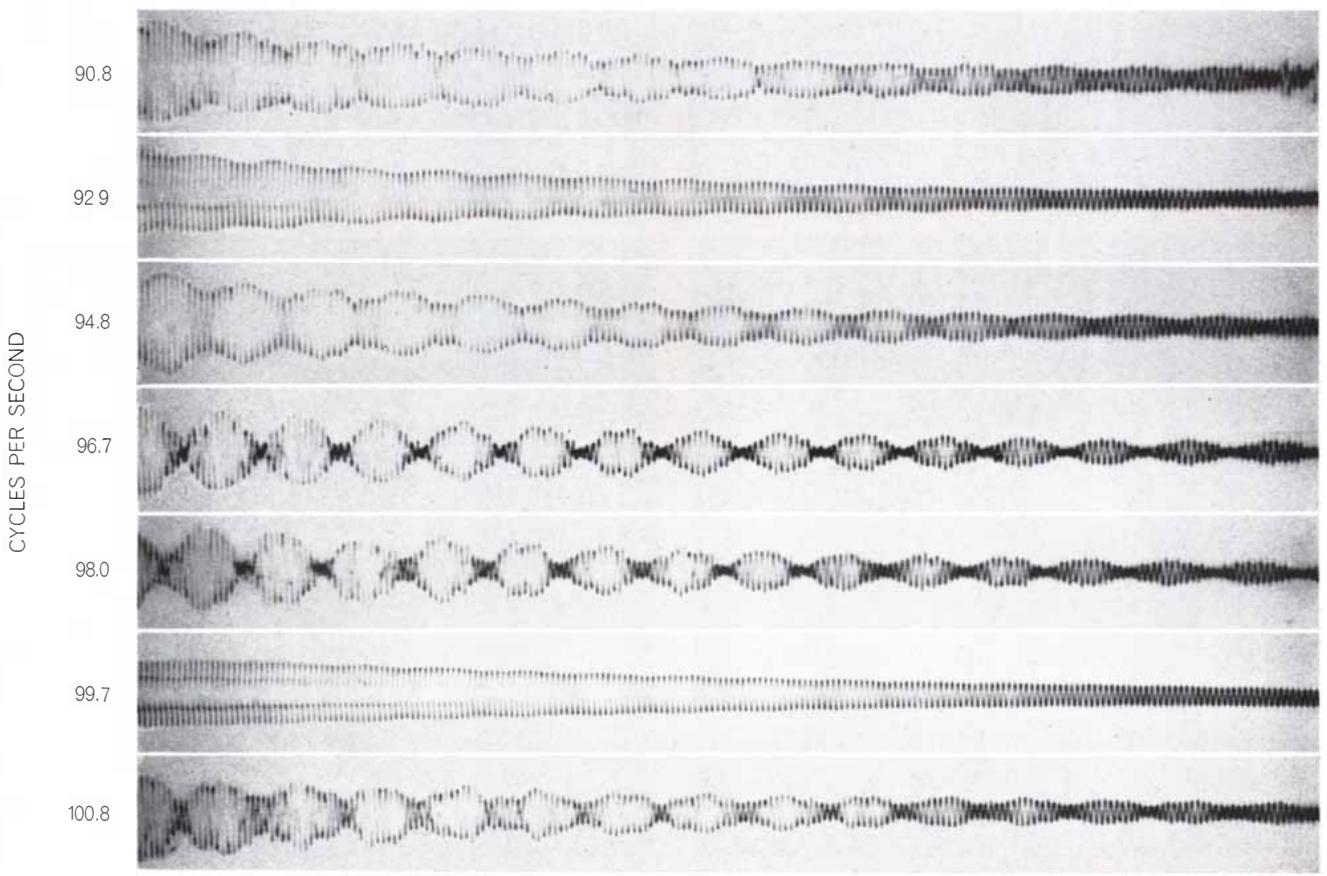
The top illustration on the next page shows how this room responds to sounds



WAVE DIFFRACTION occurs when waves pass around an object or through an opening. When the wavelength is small compared with the size of the object or hole, the object tends to create a fairly sharp "shadow" (*top left*) and the waves tend to emerge from the hole in a "beam" (*top right*). As the wavelength is increased (*bottom*), the waves tend to spread more in both cases.



RESONANCE PEAKS were determined by the author for a massive concrete room eight feet square and 9.5 feet high. The curve shows how the room responds to sounds that have a frequency range between 50 and 185 cycles per second. The resonance peaks agree with those calculated. The peaks are proportional to the linear deflection of an oscillograph, therefore indicate sound pressure.

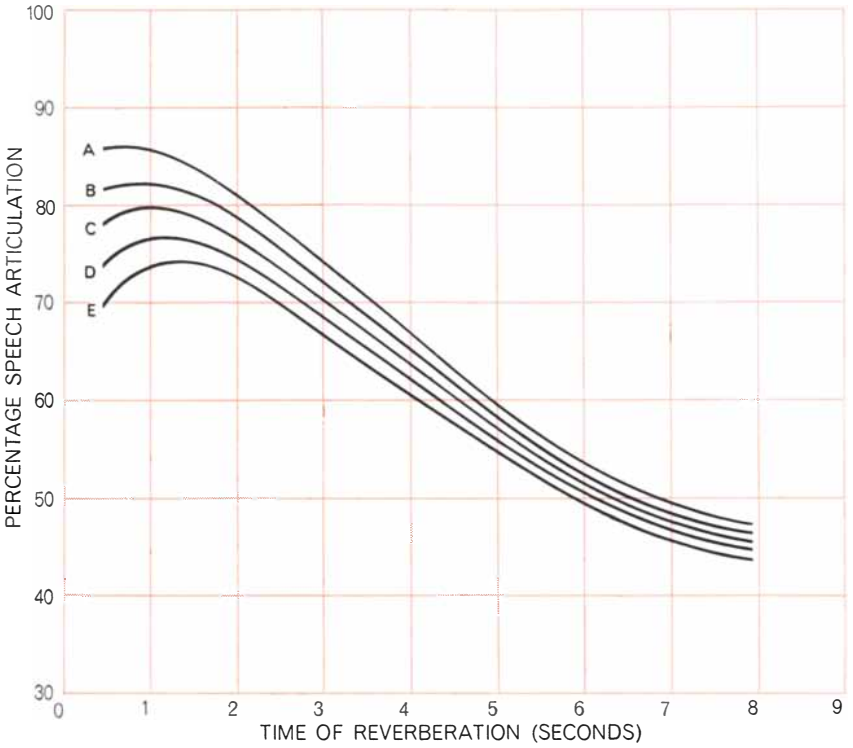


DECAY OF TONES in the room described above is shown in these oscillograms. Sounds of 92.9 and 99.7 cycles per second, which coincide with room resonance frequencies, decay smoothly. Tones of other frequencies do not. When the room is stimulated with a tone not a resonance frequency, the tone stimulates two or more resonance frequencies, which decay together and give rise to beats.

that have a frequency range between 50 and 185 cycles per second. It shows resonance peaks not only at the four frequencies listed above but also at nine higher frequencies, all of which agree with calculated values. The amplitudes of the peaks are proportional to the linear deflection of an oscillograph; hence they are more prominent than they would be if they were converted to decibels, which are based on a logarithmic scale. (On the decibel scale each interval of 10 units corresponds to a tenfold variation in sound energy. Thus a 100-decibel sound contains a million times more energy than a 40-decibel sound. To the ear, which hears a 10-decibel increase as an approximate doubling in strength, the 100-decibel sound is about 2^6, or 64, times louder than the 40-decibel sound.)

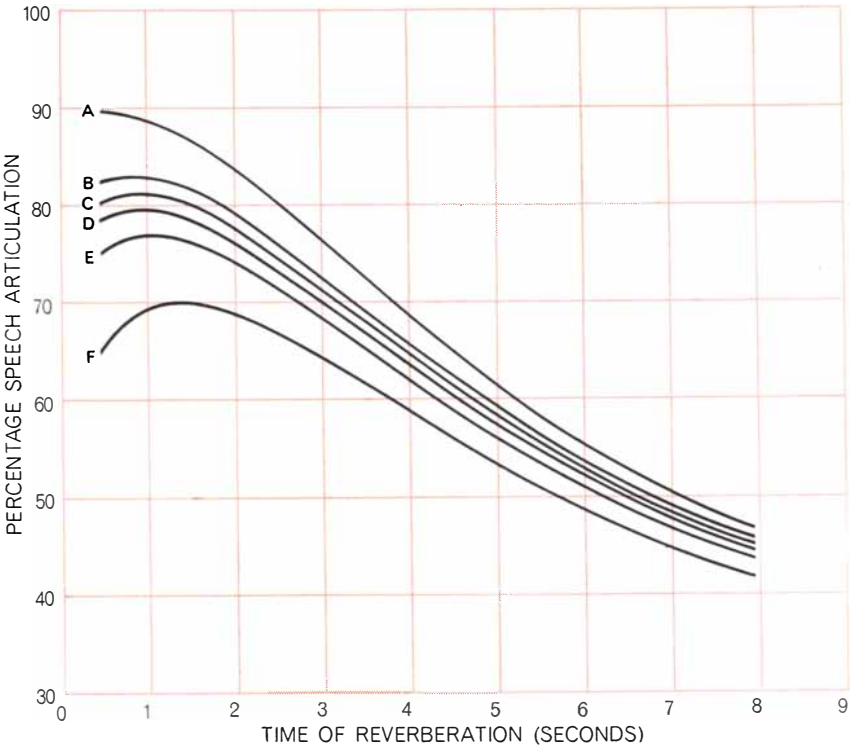
The bottom illustration on the opposite page shows how pure tones in the frequency range between 90 and 100 cycles per second die away in the same experimental room. In this range there are two prominent room resonances, at 92.9 and 99.7 cycles per second. Inspection of the seven oscillograms shows that sounds of these two frequencies decay smoothly, whereas sounds that do not coincide with resonance frequencies decay irregularly. Analysis of the five irregular decay oscillograms reveals that all are made up of two or more of the resonance frequencies of the room. For example, the fourth oscillogram consists of the decay of the two resonance frequencies of 92.9 and 99.7 cycles per second. It is apparent that when the room is stimulated with a tone that has a frequency about halfway between these two resonance frequencies, both frequencies are stimulated and decay together. In the process they give rise to "beats" with a frequency of 6.8 beats per second, which is precisely the frequency difference between the two resonance frequencies ($99.7 - 92.9 = 6.8$).

These tone-decay oscillograms demonstrate convincingly that room reverberation is made up of the free decay of the room's resonance frequencies, or natural modes of vibration. Such a phenomenon is readily understood in terms of wave acoustics but is wholly unpredictable by ray methods. For lack of understanding of wave acoustics many architects believe that optimum reverberatory properties of a room can be obtained by treating one surface of the room, usually the ceiling, with an absorptive acoustical material ("acoustic tile"). Although such a treatment is usually beneficial in large public rooms such as restaurants and offices, where the prime objective is to reduce the general noise level, it is often



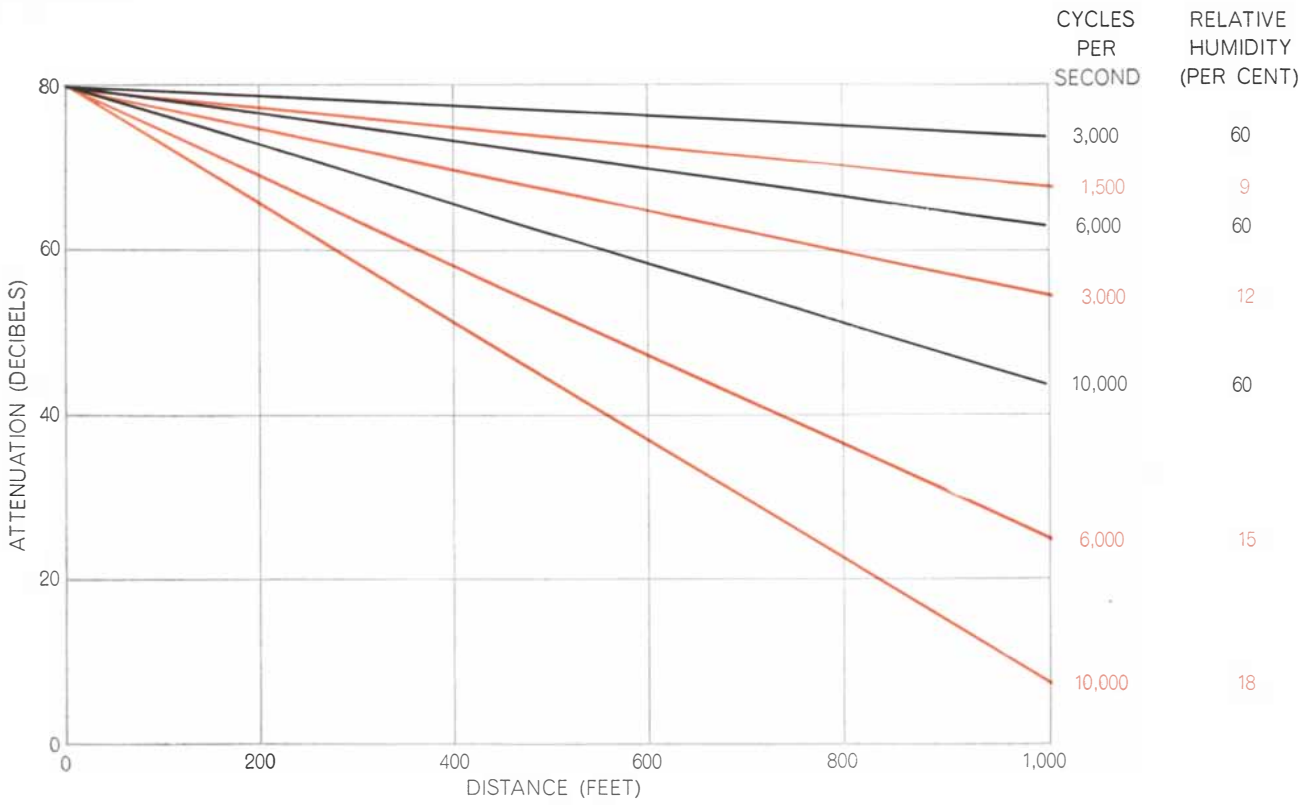
ROOM VOLUME (CUBIC FEET)
A 25,000
B 100,000
C 400,000
D 800,000
E 1,600,000

AUDIBILITY OF SPEECH in a quiet room depends primarily on reverberation time and size of room. Audibility is expressed as Percentage Speech Articulation (PA), the per cent of unamplified speech sounds that a panel of listeners identifies correctly. Curves show the difficulty of achieving a PA above 75 per cent, the minimum acceptable value.

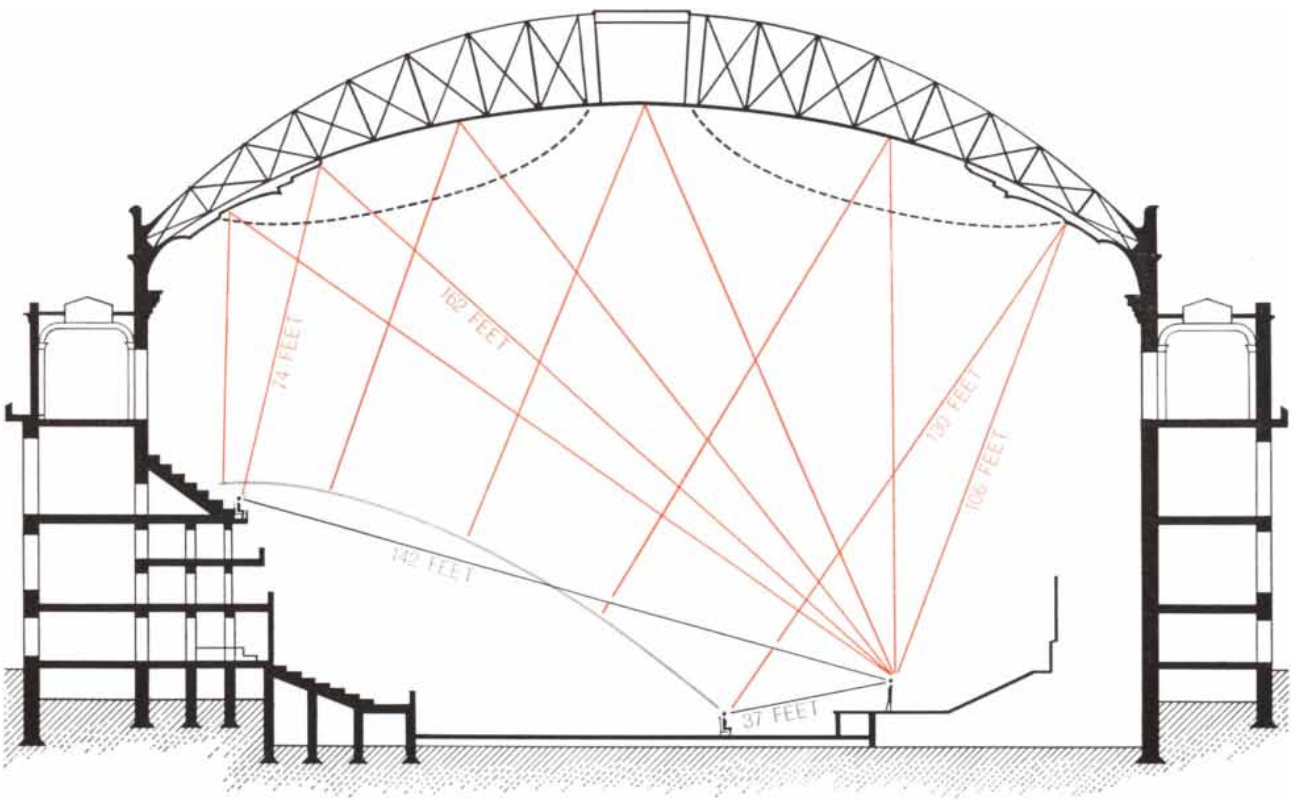


A SPEECH AMPLIFIED
B LOUDEST SPEAKER
C MODERATELY LOUD
D AVERAGE
E MODERATELY WEAK
F WEAKEST SPEAKER

AUDIBILITY OF SPEAKERS depends on their vocal strength and reverberation time. The curves show the Percentage Speech Articulation for amplified and unamplified speech in an auditorium of 400,000 cubic feet. Both sets of curves are by the author.



SOUND ABSORPTION IN AIR varies with frequency, humidity and temperature. Black curves show sound attenuation at typical concert-hall humidity, 60 per cent, and at 70 degrees Fahrenheit. Colored curves show attenuation at humidities for which sound absorption is highest, at 70 degrees F. Each 20-decibel drop represents a decrease by a factor of 100 in sound energy. Thus music heard outdoors on a very dry, warm night will sound deficient in high frequencies, particularly at distances over a few hundred feet.



ROYAL ALBERT HALL, opened in 1871, was originally plagued by echoes reflected from the great dome. The colored lines show reflections of equal travel time. A listener in the front of the auditorium would hear an echo nearly a fifth of a second behind the direct sound. Echoes and reverberation were much reduced by installation of a velarium, or heavy fabric awning (*broken lines*).

harmful in music rooms, and it is almost never a sufficient measure for obtaining good acoustical performance.

Interference and Diffraction

We have seen in the discussion of open-air theaters how regularly spaced reflecting surfaces can lead to deleterious reinforcement and cancellation of harmonic series of sound frequencies. Similar but usually less serious interference effects also take place indoors when sound waves encounter the boundaries of a room. The interference between the direct and reflected waves is aggravated if the room has prominent modes of resonant vibration. To minimize such difficulties the architect must avoid large, smooth reflecting surfaces and either judiciously introduce irregularities in the boundary contours of the room (for instance window frames, pilasters and niches for art objects) or install randomly placed panels of sound-absorptive materials on the large reflecting surfaces. The purpose is to attain a high degree of diffusion of the reflected sound so that everywhere in the room there will be a multitude of reflected sound waves coming from all directions and meeting in random phases.

Even more subtle than the effects produced by interference are those produced by diffraction of sound waves. Everyone has noticed how sound waves bend around corners. An automobile concealed by a building can be heard even when it cannot be seen. To shut out noise from a room one must close a door or window completely. The closing of the last half-inch often excludes more noise than was excluded by the entire closure up to that point.

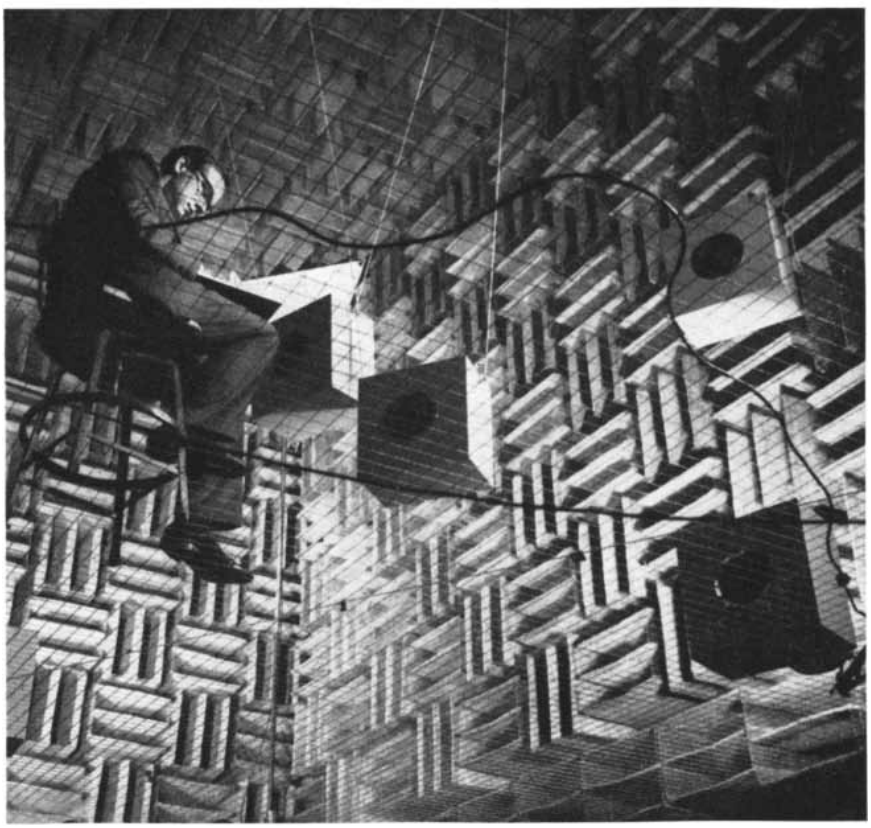
Sound waves, like light waves, bend or spread around an obstacle when the dimensions of the obstacle are comparable to the wavelength. The waves pass around the obstacle and unite in various combinations of phases, yielding the familiar diffraction patterns. The same kinds of patterns arise when waves pass through a small hole. The sound energy emerging through such a hole is often much more than would be indicated by multiplying the incident sound energy per unit area (a wavelength or more in front of the hole) by the area of the hole.

Because audible sound waves cover such a broad spectrum in size, the diffraction patterns produced by a given obstacle (or hole) can be exceedingly complex. Moreover, a hard (reflective) obstacle that is, say, two feet across will almost totally reflect high-frequency sounds, which have wavelengths measured in inches, and, if it is adjacent to an opening of comparable size, the obstacle and opening (acting together) will be almost totally transparent to low-frequency sounds, which have wavelengths measured in tens of feet.

One of the architect's problems is that in trying to correct one kind of acoustical defect he may introduce others. This is particularly true of the use of suspended ceiling panels, which are useful for overcoming such acoustical defects as echoes and long-delayed reflections. Suspended panels have been used to good advantage in several important concert halls and auditoriums, among them the Stockholm Concert Hall and the Tanglewood Music Shed in Lenox, Mass. There have also been less successful examples. The difficulty is that sounds of short wavelength are almost completely reflected by the panels, whereas sounds of long wavelength pass almost completely around the panels, to be reflected later by the ceiling above. For most arrays of panels the transmission, reflection, diffraction and scattering effects are greatly dependent on the wavelength of the sound. Precise calculation of these effects by the methods of wave acoustics is possible only for regularly spaced circular or rectangular panels, and even such simple arrays require formidable calculations. Where such calculations cannot be made it is imperative that the acoustical effects be studied in three-dimensional models using sound waves whose wavelengths are in the same ratio to the model as actual sound waves are to the full-sized room. Thus if the model is one twenty-fourth actual size, the experimental sound waves must be reduced in length correspondingly. In such a model one would use sound waves with a frequency of 24,000 cycles per second to simulate the effect of 1,000-cycle-per-second waves in a full-sized room.

The behavior of these high-frequency waves, which are inaudible, can be studied in a number of ways. One method is to photograph the waves produced by an electric spark [*see illustration on pages 78 and 79*]. Another method, recently developed in Germany, is to record in the model the high-frequency sounds on magnetic tape and play them back at reduced speed so that they can be heard as they would sound in a full-sized version of the room.

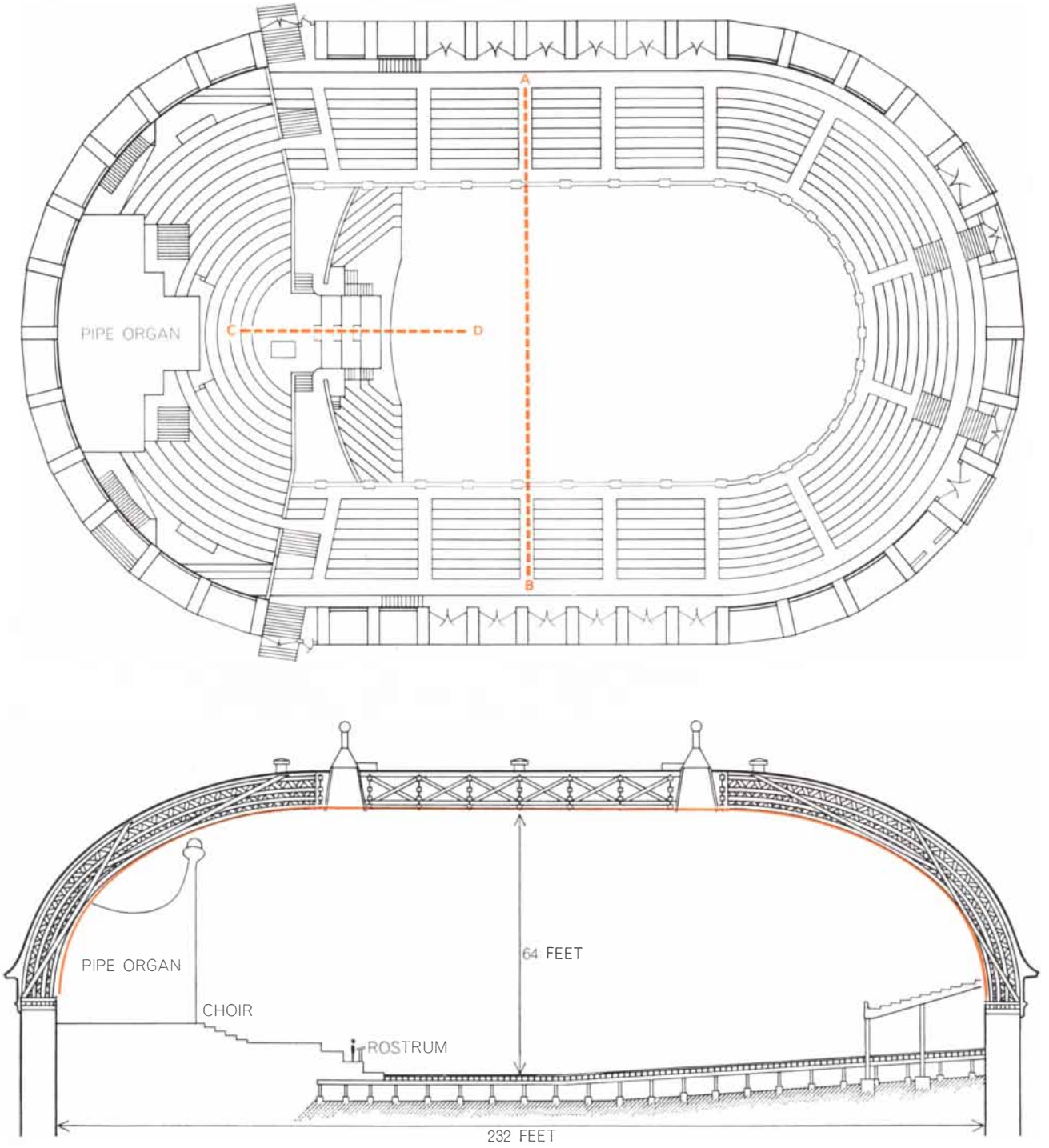
Manfred R. Schroeder of the Bell Telephone Laboratories has developed a promising method of using an elec-



ANECHOIC CHAMBER is employed by Manfred R. Schroeder of Bell Telephone Laboratories to evaluate stereophonic playback of a sound recording that has been modified by a computer to simulate the acoustics of a newly designed music room or concert hall.

tronic computer to simulate the acoustics of planned music rooms. He has devised computer programs that will modify a tape recording of music so that the music sounds as if it were being played in the room under study. For appraisal the tape is played back through multiple loudspeakers in a special anechoic, or echoless, chamber [*see illustration on preceding page*]. Whatever method one uses, it is essential that the performance of suspended panels and all other acoustical innovations be fully explored in advance of installation.

When the architect faces the job of designing a new concert hall or other music room, he must pay primary attention to three things: the shape of the total enclosure, the design of the stage and music shell and the reverberation time. A felicitous shape is a requirement of the highest priority. Unfortunately many architects believe that faulty shapes can be corrected by covering the offending surfaces with highly absorptive materials and by adjusting the reverberation time. Thus deluded, they adopt a fash-



MORMON TABERNACLE, built in Salt Lake City about 100 years ago, has generally fine acoustics, particularly when the audience is about 2,500, a number that provides optimum reverberation time. In the plan view *A* and *B* show the locations of the pistol and microphone used to make the upper decay curve on the opposite page. *C* and *D* show pistol and microphone locations used in making the lower decay curve. The colored line in the sectional view (*bottom*) indicates where the builders used plaster containing cattle hair.

ionable construction method, such as the concrete shell, and produce a building that is an acoustical perversion. A bad shape is a permanent liability.

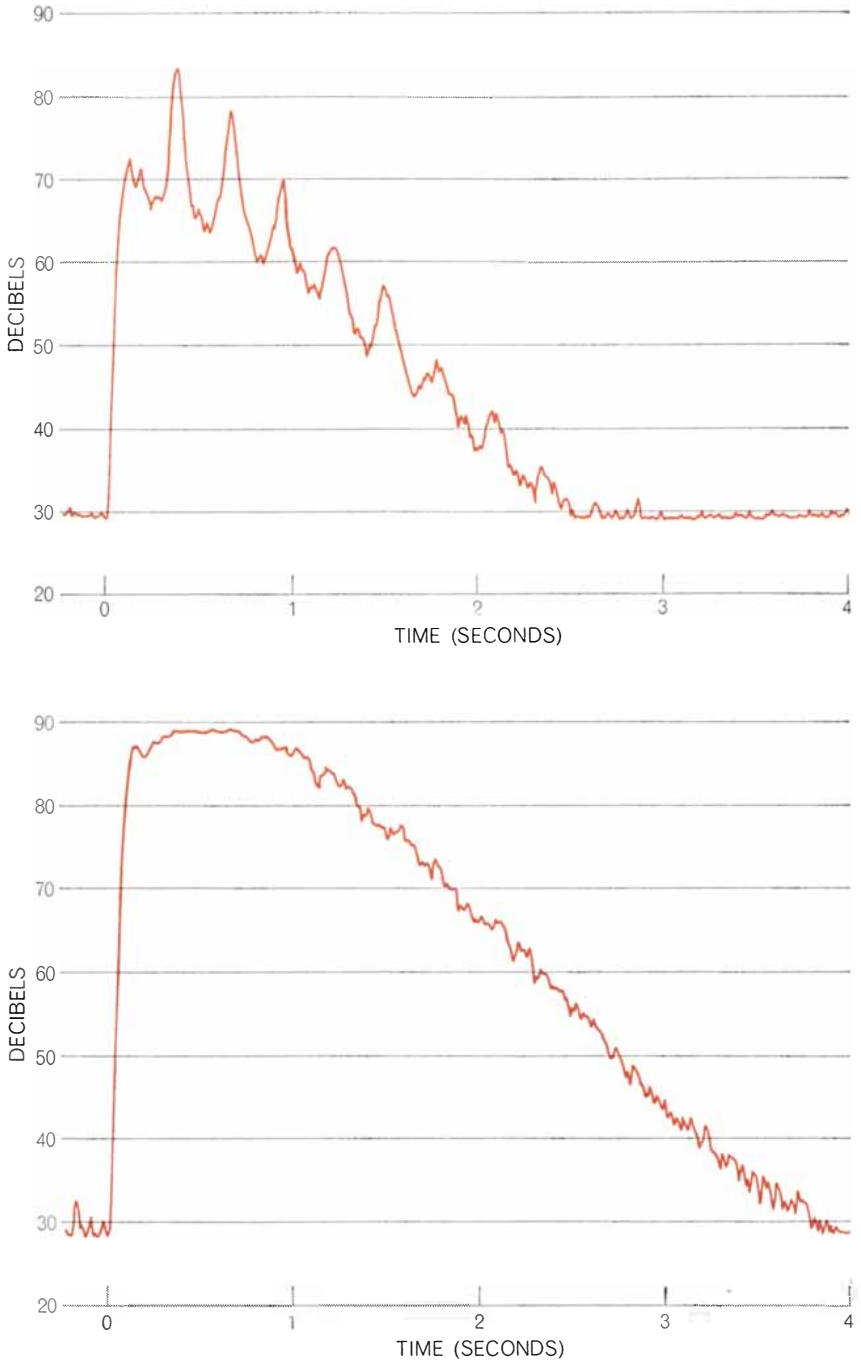
It is not difficult to arrive at acoustically satisfactory shapes using the methods of ray and wave acoustics. Experience and ratings by competent listeners indicate that for generally rectangular rooms that have volumes between 15,000 and 500,000 cubic feet a favorable ratio of length to width is about four to three, and a good ceiling height is about .6 times the cube root of the volume. Therefore for a chamber-music room seating about 200 people the favorable dimensions would be about 52 by 40 by 20 feet. It is usually desirable to make the side walls diverge slightly and to incline the floor so that it is not parallel to the ceiling. The reason is that parallel surfaces have a tendency to produce flutter echoes. If opposing surfaces must be kept parallel for some reason, flutter echoes can be suppressed by the use of diffusive or absorptive panels. Whenever possible, particularly in large music rooms, the design should be subjected to a thorough wave-acoustics analysis to ensure that the room will not be impaired by ill effects of resonance, interference and diffraction.

Reflection and Reverberation

An important consideration in music rooms is the time delays in the successive reflections reaching listeners seated in various parts of the room. For rooms that have volumes between 150,000 and 400,000 cubic feet the first reflections should be delayed not more than about 30 to 35 milliseconds beyond the arrival of the direct sound, and these first reflections should be followed by a succession of reflections, coming from all directions, that will "envelop" the listeners with a relatively smooth but slightly undulating reverberation (much like a vibrato) of the optimum duration and frequency characteristic. For larger rooms the first reflections should be delayed not more than about 45 milliseconds; the reflections should be diffuse and should come in good proportions from the side walls, the rear wall and the ceiling.

The acoustical design of the stage enclosure must meet two general requirements. First, the reverberation characteristic of the stage space, with its normal hangings and equipment, should not differ appreciably from that of the audience space. Second, there must be a properly designed music shell that will enable all the members of an orchestra to hear each other clearly and distinctly, blend and unify the sound of the entire ensemble and reflect a large portion of this enhanced sound to the audience.

The subject of reverberation time, the third major aspect of music-room design, has been given extensive study by acousticians, beginning more than 60 years ago with the pioneer work of Wallace C. Sabine of Harvard University. As we have seen, reverberation in a room is the persistence of the natural modes of vibration, or resonance frequencies, after the source of sound in the room has been stopped. For acoustical purposes reverberation is defined as the time required for the persistent sound to decay, or diminish, by 60



ECHOES IN MORMON TABERNACLE, recorded by Harvey Fletcher, William L. Woolf and the author, were produced by pistol shots at two different locations. The top curve shows the flutter echo when the pistol is fired in one balcony and recorded in an opposite balcony (*see upper illustration on opposite page*). A smoothly decaying reverberation (*bottom*) results when a pistol is fired on the rostrum and recorded part-way back in the Tabernacle.

decibels, which is an energy factor of a million.

Experience has shown that the optimum reverberation times for sound of 1,000 cycles per second are as follows: .5 second for small practice rooms (volume about 500 cubic feet); .8 to one second for rehearsal rooms (volumes up to 15,000 cubic feet); 1.1 to 1.4 seconds for chamber-music rooms (volumes between 35,000 and 75,000 cubic feet); 1.7 to two seconds for large concert halls (volumes between 350,000 and 700,000 cubic feet), and about two to 2.2 seconds in very large halls used for organ music and choral works. In Europe habit and experience give preference to reverberation times about 10 per cent longer than these.

Acousticians have also given much thought to the problem of how the reverberation time should vary with frequency. Should it be the same for all frequencies? Should it be based on the frequency distribution of sound energy in music, so that on the average all components will die away to inaudibility in the same length of time? Or should it be such that the rate of growth or decay of loudness level will be the same for all frequency components? Fortunately the last two criteria lead to about the same reverberation characteristics for frequencies below 1,000 cycles per second: a gently rising one in which the reverberation time is about 50 per cent longer at 62 cycles per second than it is at 1,000 cycles. Thus if the optimum reverberation time for 1,000 cycles is two seconds, that for 62 cycles is three seconds.

In order to obtain the desired reverberation times the designer of a music room has available a wide selection of building and decorative materials: stone, brick, wood, plaster, natural and synthetic fabrics and a great variety of acoustic tiles and composition panels. Their sound-absorption coefficients have been determined by careful measurements in reverberation chambers. By constructing the interior surfaces of a music room with judicious combinations of materials it is possible to obtain optimum reverberation times for all important frequencies throughout the audible range. Two recent examples of music rooms designed to meet these criteria are Hertz Hall on the Berkeley campus of the University of California and the Seattle Opera House.

Two Older Music Halls

I shall mention briefly two famous structures that were designed before acoustical knowledge was applied to architectural design: the Royal Albert Hall in London and the Mormon Tabernacle in Salt Lake City. The former, opened in 1871, is interesting because it exhibits nearly all the acoustical defects that should be avoided in the design of concert halls. The bottom illustration on page 86 shows several of the long-delayed echoes that result from the high, domed ceiling. Sound reflected from the ceiling can be delayed nearly a fifth of a second behind the direct sound and, because of the focusing effect of the ceiling, it can be nearly as loud. These extremely disturbing echoes have been greatly reduced by suspending a convex velarium, or canopy, below the ceiling, which also helps to reduce another defect of the hall: excessive reverberation.

In contrast, the Mormon Tabernacle,

HERTZ HALL of the University of California at Berkeley is an example of an auditorium that meets high acoustical standards. The forward stage can be elevated to take an entire symphony orchestra. Absorptive panels on side walls provide good diffusion and proper reverberation. The architect was Gardner A. Dailey and Associates. The acoustical consultants were Delsasso and the author.

completed in 1867, is famous for its good acoustics. Its virtues are somewhat surprising considering that its floor plan is approximately elliptical and the high, domed ceiling is elliptical in its transverse section [*see illustration on page 88*]. Fortunately the convergent reflections from the ceiling are disturbing at only a few locations. For the most part the concave surfaces around and above the organ and choir area sustain and blend the instrumental and vocal sounds and project them most effectively throughout the auditorium.

A recent study I have made in association with Harvey Fletcher and William L. Woolf has shown that the elliptical ceiling gives rise to a very prominent flutter echo when a sharp sound is made along the upper side balconies. The echo, set off by a pistol shot, is shown in the illustration on page 89. Fortunately this flutter echo is not activated appreciably by sounds originating in the organ and choir area.

Except for the floors, which are wood, the interior surfaces of the Tabernacle are mostly lime plaster on wood lath. Today such construction would produce an excessively long reverberation time, but at the time the Tabernacle was built it was the custom to mix large amounts of cattle hair with the plaster. This made the plaster considerably more absorptive than it would have been otherwise. Even so, when there is no audience, the reverberation time is about four seconds at 1,000 cycles per second. The optimum time for the Tabernacle, when music is being played, would be about 2.2 seconds.

It happens that the optimum reverberation time is obtained almost exactly when there is an audience of some 2,500. With an audience of about 6,500 the reverberation time drops to slightly below 1.5 seconds at 1,000 cycles per second. The Tabernacle management and radio station KSL frequently get letters of praise for the quality of music broadcast when the Tabernacle contains an audience of approximately 2,500. Complaints about the acoustics are often received, however, when the audience numbers 6,000 or more.

Compared with designing a music room, the job of designing a room used primarily for speech (for example lecture rooms and legislative rooms) is relatively simple. Like a music room, a speech room should be free from external sources of noise, from resonances and from echoes and sound-focusing effects. The reverberation time should be about a second (slightly less for small rooms and slightly more for large rooms). Finally, speech must be clearly heard throughout the room. This means that unless the room is small an amplifying system must be provided.

The general need for amplification can be demonstrated by using speech-articulation tests of the type developed by telephone engineers to determine the intelligibility of transmitted speech. The results are expressed in terms of Percentage Speech Articulation (PA). The PA is determined by having typical speakers call out speech sounds that occur in English words and having a panel of listeners record what they think they hear. If they hear correctly 75 per cent of the speech sounds, the PA is 75 per cent, which is the minimum value acceptable for satisfactory hearing.

The illustration at the top of page 85 shows in a family of curves how the

SEATTLE OPERA HOUSE has many acoustical features. Rear walls at all levels are inclined forward to prevent echoes and reflect sound beneficially. Wood panels on side walls can be opened to expose absorptive chambers that change reverberation time. The architects were B. Marcus Priteca and James J. Chiarelli. The acoustical consultants were Paul S. Veneklasen and the author.

hearing of the unamplified speech of the average speaker depends on the time of reverberation and room size. It will be seen that except for the smallest rooms with ideal reverberation times the PA values are below 75 per cent. The conclusion is that amplification is almost always necessary.

The illustration at the bottom of page 85 shows the PA for 14 speakers of widely different vocal strengths in an auditorium of 400,000 cubic feet. The curves indicate clearly why some speakers are heard much better than others and why some are not heard at all, and they demonstrate once again why it is generally advantageous to amplify speech.

The Acoustics of Homes

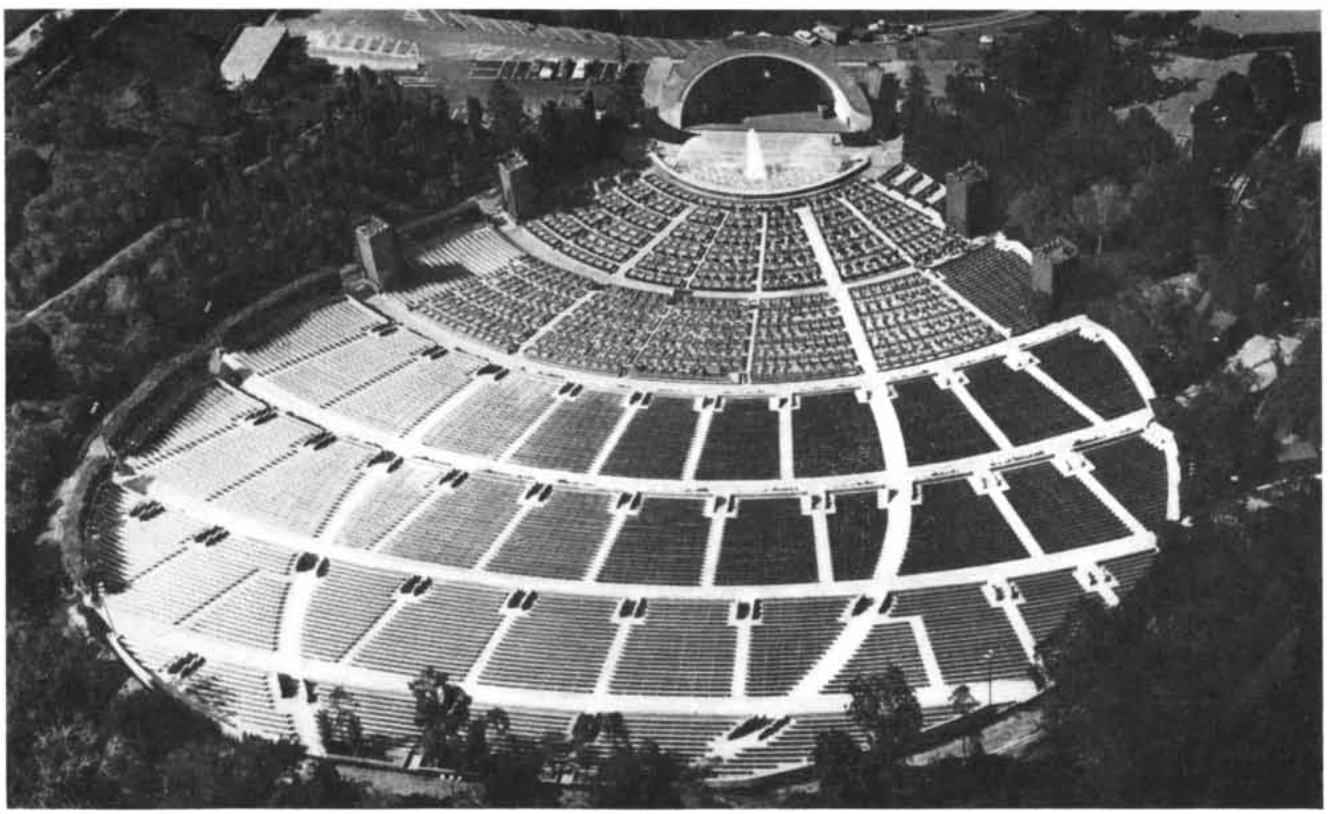
Perhaps the biggest failure of U.S. architects (and acousticians) is in not doing something constructive about the acoustical environment of the home, particularly the apartment dwellings that have been built in the past 20 years. An easily attained objective would be to shorten the reverberation time of small rooms to about .5 second and that of large living rooms used for music as well as speech to no more than one second. Typical values in U.S. homes with conventional plaster walls and ceiling, and with scant carpeting, are from 50 to 100 per cent higher. The more urgent and difficult problem is to screen out unwanted noise, whether it is of external or internal origin. (The flushing of a toilet makes a racket that often carries through every room of the house.)

U.S. cities should adopt as construction standards the many commendable and necessary acoustical features that are to be found in virtually all new apartments in both eastern and western Europe. Apartments are carefully planned so that rooms in which the loudest noises are likely to originate are the farthest from those in which the most quiet is desired. There is, for example, maximum separation between the bedroom of one apartment and the living room of the adjacent one. There is a heavy wall between adjacent bathrooms; the entrance hall is used as a sound lock between the living room and the bedroom; entrance doors are of solid-panel construction, well fitted in their frames so that threshold cracks are eliminated. Floors above ground level are usually floating concrete slabs, so that impact sounds as well as air-borne ones are thoroughly insulated.

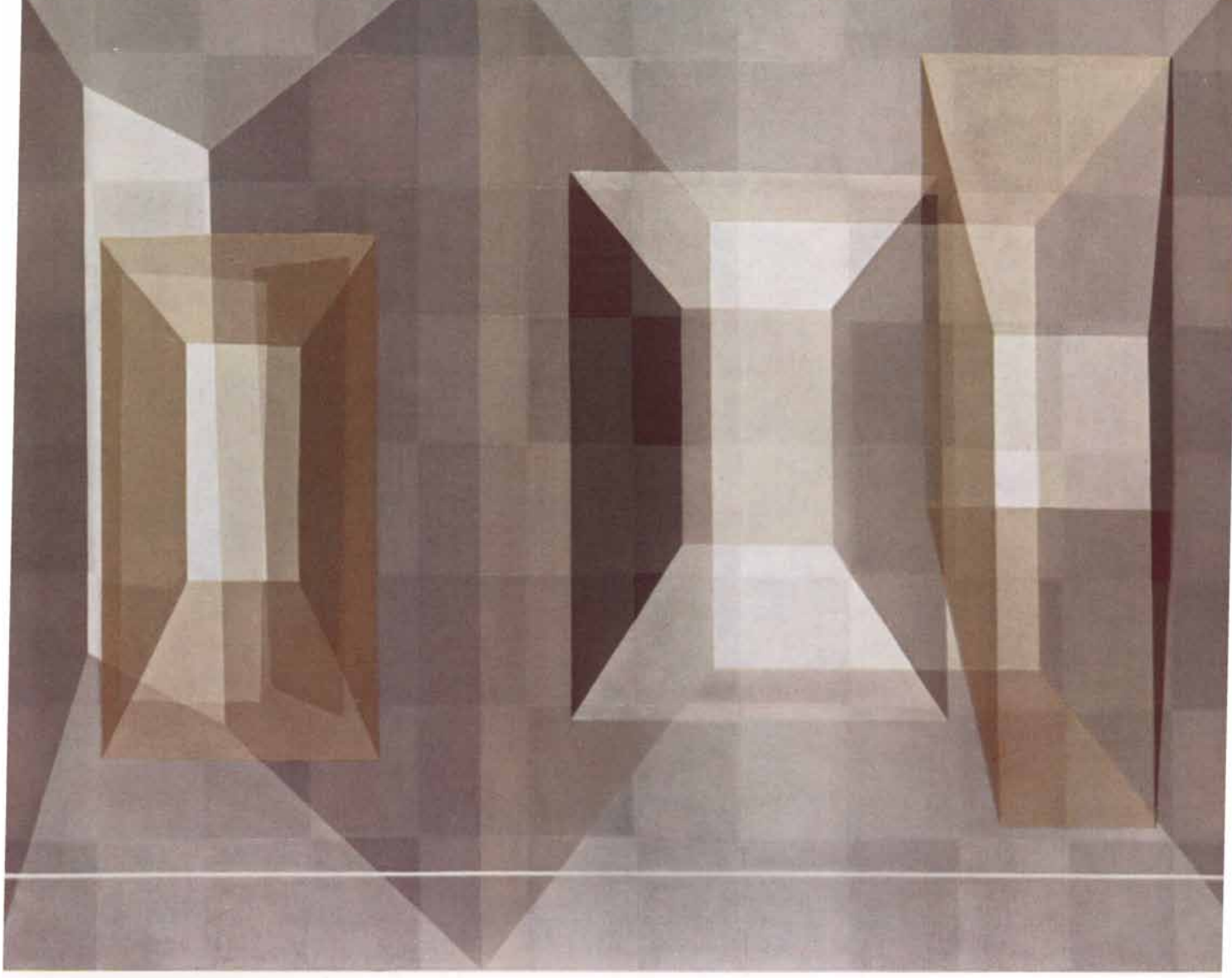
The effective control of noise in these modern European buildings is no accident. It is required by the high standards of building codes. Sweden, for instance, requires that there be enough sound insulation between rooms in residential buildings to reduce air-borne sounds by 48 decibels. Even higher standards are required in hospitals and certain other buildings. In the U.S., in contrast, sound insulation is completely ignored by practically all building codes. (It is a hopeful sign that a new code being considered for New York City may include noise-level specifications for the first time.)

The provision of quiet buildings, particularly those in which people live, learn and recover from illness, is an essential objective of good community planning. A nation that prides itself on its high technology and high standard of living should be willing to pay the additional 5 or 10 per cent that would be entailed in creating buildings with satisfactory acoustics.

I am sure it can be demonstrated that good acoustics is good business, but far more important, the providing of quiet buildings is indispensable for good health and the growth of culture. Home should be our refuge from a noisy world, where taut nerves may find rest from and refreshment for the strains of high-pressure living.



HOLLYWOOD BOWL, noted for its acoustics, was opened in 1922. The shell over the stage was an architectural and acoustical innovation, since much copied. The architect was Lloyd Wright, son of Frank Lloyd Wright. The author was acoustical consultant.



Perspective

The painting above was based on research in optical phenomena. The more you study it, the more the masses seem to change, the forms to advance and recede in space.

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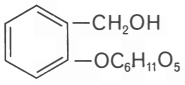
For more information, write today to Polaroid Corporation, Technical Sales Department, Cambridge 39, Massachusetts.

BARK OF WILLOW
(SALIX)
(EFFECT ON MALARIA; 1763, STONE)

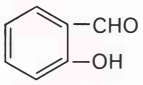
EXTRACTION;
1826–1829, BRUGNATELLI, FONTANA; LEROUX



SALICIN
(EFFECT ON RHEUMATIC FEVER;
1874–1876, MACLAGAN)

MEADOWSWEET FLOWER
(SPIRAEA)

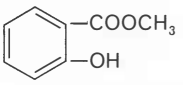
DISTILLATION;
1831, PAGENSTECHER



SALICYLALDEHYDE

OIL OF WINTERGREEN
(GAULTHERIA)

EXTRACTION;
1843, PROCTER; CAHOURS



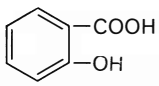
METHYL SALICYLATE

HYDROLYSIS AND OXIDATION;
1838, PIRIA

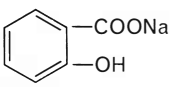
OXIDATION;
1835, LÖWIG

HYDROLYSIS;
1843, CAHOURS

SYNTHESIS;
1852, GERLAND;
1860, KOLBE, LAUTEMANN

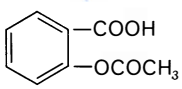


SALICYLIC ACID ("SPIRSÄURE")
(EFFECT ON RHEUMATIC FEVER;
1876, RIESS, STRICKER)

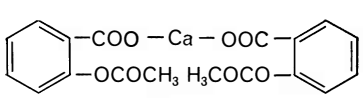


SODIUM SALICYLATE
(EFFECT ON GOUT, ARTHRITIS,
NEURALGIA; 1877, SÉE)

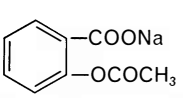
ACETYLATION;
1853, GERHARDT; 1893, HOFMANN



ACETYLSALICYLIC ACID (ASPIRIN)
(EFFECT ON RHEUMATIC FEVER
1899, WITTHAUER, WOHLGEMUT
ON PAIN; 1900, WITTHAUER)



CALCIUM ACETYLSALICYLATE



SODIUM ACETYLSALICYLATE

ASPIRIN

The most widely consumed drug owes its dramatic effectiveness in reducing pain and fever to a broader function: moderating the varied defensive responses evoked in the body by disease

by H. O. J. Collier

The most widely used drug in the world—if we accept one medical dictionary's definition of a drug as "any substance employed as a medicine in the treatment of disease" and consider disease to imply all the minor aches, pains and chills that flesh is heir to—is aspirin. Even if we expand the definition of a drug to include the active principles of alcoholic drinks, coffee, tea and tobacco, aspirin would follow grain alcohol, caffeine, nicotine and possibly other substances consumed as chemical comforts rather than medicaments in the number of effective doses taken. In 1962 the production of aspirin in the U.S. alone was 27.2 million pounds. The consumption of aspirin tablets was 15 billion, plus a somewhat larger number containing aspirin mixed with caffeine, codeine or other substances. In spite of this massive acceptance of aspirin as an analgesic, or mitigator of pain, its exact mode of action within the body remains obscure. Evidently it works not by blocking some agent of disease but by moderating such aspects of the body's defensive response as fever, pain and inflammation.

CHEMICAL ANCESTRY of acetylsalicylic acid, the chemical now known as aspirin, is traced on opposite page to plants in which salicylates were found. Formulas for the chemical relatives of salicylic acid are given below, with techniques used in isolating it, the chemists who performed the steps and physicians who reported medical uses of the drug. A method of acetylating salicylic acid to weaken its acidity was devised as early as 1853, but only in the last decade of the century was the process refined to make possible large-scale manufacture. The salts of aspirin (*bottom*) are more soluble, are more quickly absorbed into the bloodstream and are less injurious to the digestive tract.

The chemical component of aspirin is acetylsalicylic acid; this compound and its various salts appear under 56 proprietary names in the current *Pharmacological and Chemical Synonyms*. One of these is "Aspirin," the name under which the compound was introduced for medicinal purposes by the German firm of Bayer in 1899. Since that time wars and widespread usage have negated the effect of trade-mark laws in some countries and have deprived the name of its proprietary exclusiveness. In Germany, however, "Aspirin" remains the valuable trade-mark of the original manufacturer.

The name itself, a roundabout contraction of acetylsalicylic acid, represents one of the first exercises in the peculiar art of applied etymology that the merchandising specialists of the pharmaceutical industry have brought to such a high point of elaboration today. The prefix "a-" stands for the acetyl group that Charles Frédéric Gerhardt of Strasbourg first added to salicylic acid in 1853. The root, "spir," stands for *spirsäure*, the name given by Karl Jakob Löwig of Germany to the acid he prepared in 1835 from an aldehyde that Johann S. F. Pagenstecher, a Swiss pharmacist, had distilled several years earlier from the flowers of the meadowsweet (*Spiraea ulmaria*). Löwig's *spirsäure* is salicylic acid, a substance occurring in the form of esters in several plants. The diversity of natural sources of the acid resulted in more than one line of descent in the pharmacopoeia [*see illustration on opposite page*].

On June 2, 1763, a paper entitled "An Account of the Success of the Bark of the Willow in the Cure of Agues" was read to the Royal Society of London. The authorship of this first description of the effects of salicylic acid was recorded inaccurately. At the head of the paper, as printed in the *Philosophical Transactions of the Royal Society of London*, the author is named Edmund Stone; at the foot he has become Edward Stone [*see illustration on next page*]. The original manuscript bears the abbreviated signature of either "Edwd" or Edmd." An Edmund Stone was elected to the Royal Society in 1725 and was still a fellow in 1763, but he was a mathematician. A protégé of the Duke of Argyll, on whose estate he had been a gardener, Edmund's gifts came to light accidentally when the duke found that his gardener possessed a copy of Newton's *Principia* and was conversant with its contents. It is probable, however, that the author of the "Account of the Success of the Bark of the Willow" was one Edward Stone, a clergyman of Chipping Norton in Oxfordshire. The printer of the *Philosophical Transactions* apparently confused him with the better-known Edmund.

Edward Stone recommended a decoction of the bark of the white willow for treating "aguish and intermitting disorders," a description of malaria. Two coincidences bolstered Stone's proposal to try willow bark against malaria. First, the bark tasted extraordinarily bitter, as does cinchona, the Peruvian bark that was then acknowledged to be the sovereign remedy for malaria. Second, the willow grows in damp and marshy places, which in Stone's day were often malarial and where, in accordance with the contemporary medical "doctrine of signatures," he would have expected to find a cure for the disease.

Stone's decoction did indeed relieve the feverish symptoms of malaria because, as chemists later learned, it contains salicylic acid, an antipyretic com-

pound. It did not cure the disease, however, because willow bark does not contain quinine, the ingredient in cinchona bark that acts directly against the malarial parasite. Stone's recommendation of willow bark unfortunately led to the adulteration of cinchona bark with a less curative (and less expensive) material.

In 1829 a French pharmacist named H. Leroux isolated from a willow-bark extract salicin, a compound of glucose and salicyl alcohol. Salicylic acid itself was derived from this compound in 1838 by Raffaele Piria of Naples three years after Löwig had extracted the same acid from meadowsweet flowers. In 1842 William Procter of the U.S. and Auguste Cahours of France obtained methyl salicylate from oil of wintergreen; Cahours later carried the isolation a step further to salicylic acid. Since then the chemical relatives of salicylic acid have turned up in many plants. A salicylate has also been found in the secretion of the beaver's prepuce that is known as castoreum; the substance is perhaps derived from the bark of trees on which beavers subsist.

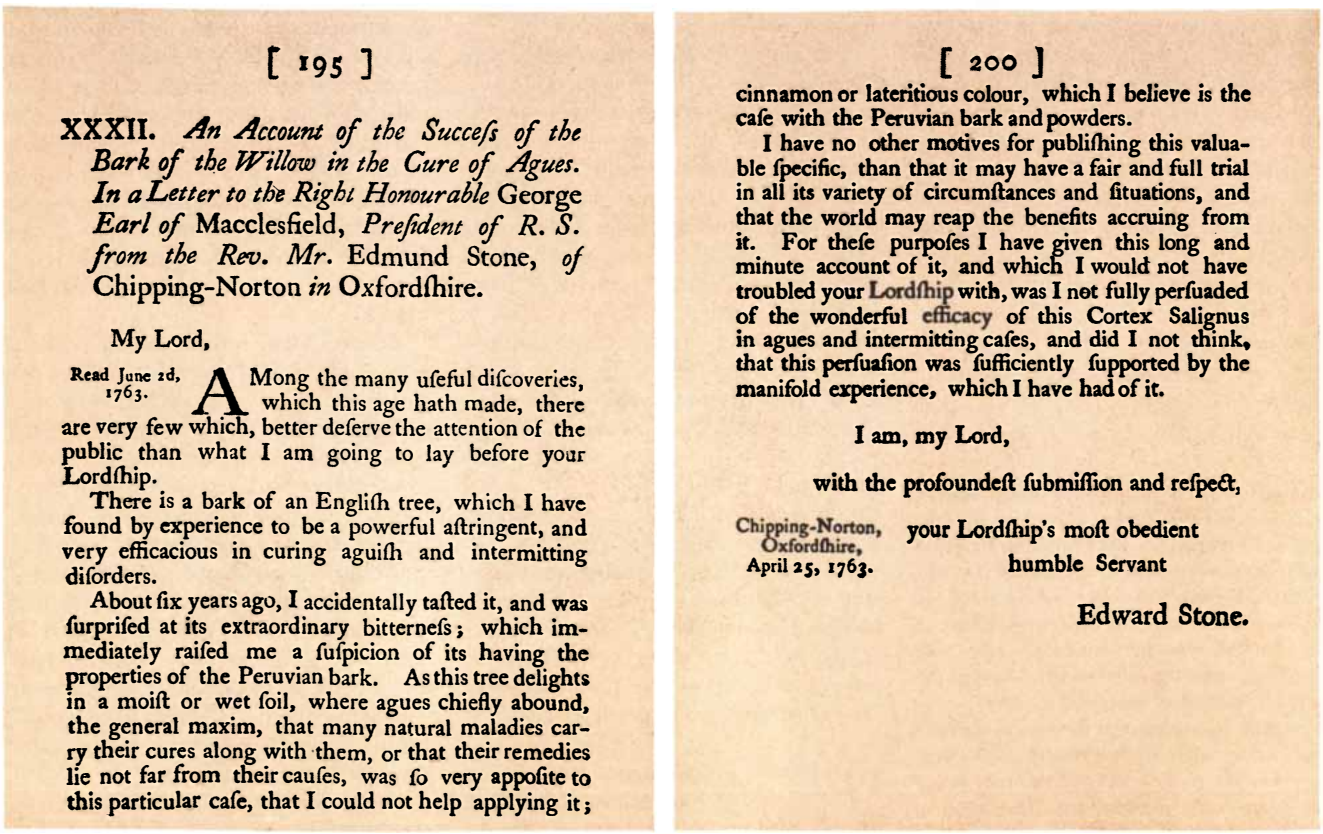
The purification and identification of salicylates occurring in nature facilitated their synthesis in the laboratory. In 1852 H. Gerland synthesized salicylic acid, and by the end of the decade Hermann Kolbe and E. Lautemann had developed a practical method of preparing it in sufficient quantity for therapeutic use. As chemists had been encouraged to synthesize salicylates by reports of medical interest, physicians were now aided in their research by the availability of salicylic acid and its purified esters.

In 1874, more than a century after Edward Stone's communication to the Royal Society, a Scottish physician named T. J. MacLagan echoed Stone's original proposal. He wrote: "Nature seeming to produce the remedy under climatic conditions similar to those which give rise to the disease... among the Salicaceae... I determined to search for a remedy for acute rheumatism. The bark of many species of willow contains a bitter principle called salicin. This principle was exactly what I wanted."

MacLagan did not, however, have to make his own decoction from the willow bark. With salicin available in pure form, he proceeded to a historic experiment: "I had at the time under my care a well-marked case of the disease which was being treated by alkalies but was not improving. I determined to give him salicin; but before doing so, took myself first five, then ten, and then thirty grains without experiencing the least inconvenience or discomfort. Satisfied as to the safety of its administration, I gave to the patient referred to twelve grains every three hours. The results exceeded my most sanguine expectations."

History was repeating itself, not only in the invocation of the doctrine of signatures that gave rise to the discovery but also in the way the remedy worked, because salicin and its derivatives no more destroy the infecting bacteria that initiate the immunological process culminating in rheumatic fever (as acute rheumatism is now often called) than they kill the malaria parasite that caused Stone's agues. Salicylates act by lessening the fever and painful inflammation that form part of the body's immunological response to some substance produced by the infecting bacteria.

MacLagan was the first physician to treat rheumatic fever successfully with salicylates, but a few months before his paper on salicin appeared in *The Lancet* of March 4, 1876, L. Riess and S. Stricker had separately reported in Berlin that



[195]

XXXII. *An Account of the Succeſs of the Bark of the Willow in the Cure of Agues. In a Letter to the Right Honourable* George *Earl of* Macclesfield, *Preſident of R. S. from the Rev. Mr.* Edmund Stone, *of* Chipping-Norton *in* Oxfordſhire.

My Lord,

Read June 2d, 1763. AMong the many uſeful diſcoveries, which this age hath made, there are very few which, better deſerve the attention of the public than what I am going to lay before your Lordſhip.

There is a bark of an Engliſh tree, which I have found by experience to be a powerful aſtringent, and very efficacious in curing aguiſh and intermitting diſorders.

About ſix years ago, I accidentally taſted it, and was ſurpriſed at its extraordinary bitterneſs; which immediately raiſed me a ſuſpicion of its having the properties of the Peruvian bark. As this tree delights in a moiſt or wet ſoil, where agues chiefly abound, the general maxim, that many natural maladies carry their cures along with them, or that their remedies lie not far from their cauſes, was ſo very appoſite to this particular caſe, that I could not help applying it;

[200]

cinnamon or lateritious colour, which I believe is the caſe with the Peruvian bark and powders.

I have no other motives for publiſhing this valuable ſpecific, than that it may have a fair and full trial in all its variety of circumſtances and ſituations, and that the world may reap the benefits accruing from it. For theſe purpoſes I have given this long and minute account of it, and which I would not have troubled your Lordſhip with, was I not fully perſuaded of the wonderful efficacy of this Cortex Salignus in agues and intermitting caſes, and did I not think, that this perſuaſion was ſufficiently ſupported by the manifold experience, which I have had of it.

I am, my Lord,

with the profoundeſt ſubmiſſion and reſpect,

Chipping-Norton, Oxfordſhire, April 25, 1763.

your Lordſhip's moſt obedient humble Servant

Edward Stone.

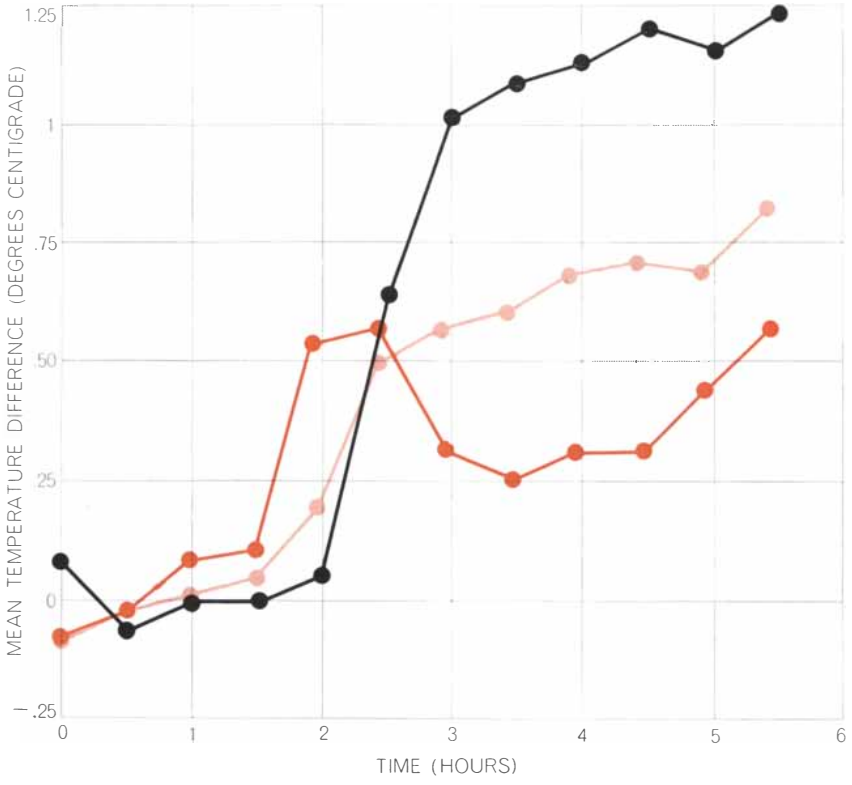
UNCERTAIN AUTHORSHIP of first paper to describe medicinal effects of willow-bark extract can be traced to a printer's error in the *Philosophical Transactions* of 1763. At top of paper (*left*) the author is named Edmund Stone. At bottom (*right*) the name is Edward. "Doctrine of signatures" is synopsized in the proposition that "many natural maladies carry their cures along with them...."

salicylic acid was effective in treating the disease. In the following year Germain Sée announced in Paris that salicylates also relieved chronic rheumatoid arthritis and gout. By this time several physicians had noted that salicylates detectably but not dramatically lessened certain nonrheumatic pains such as neuralgia and headache.

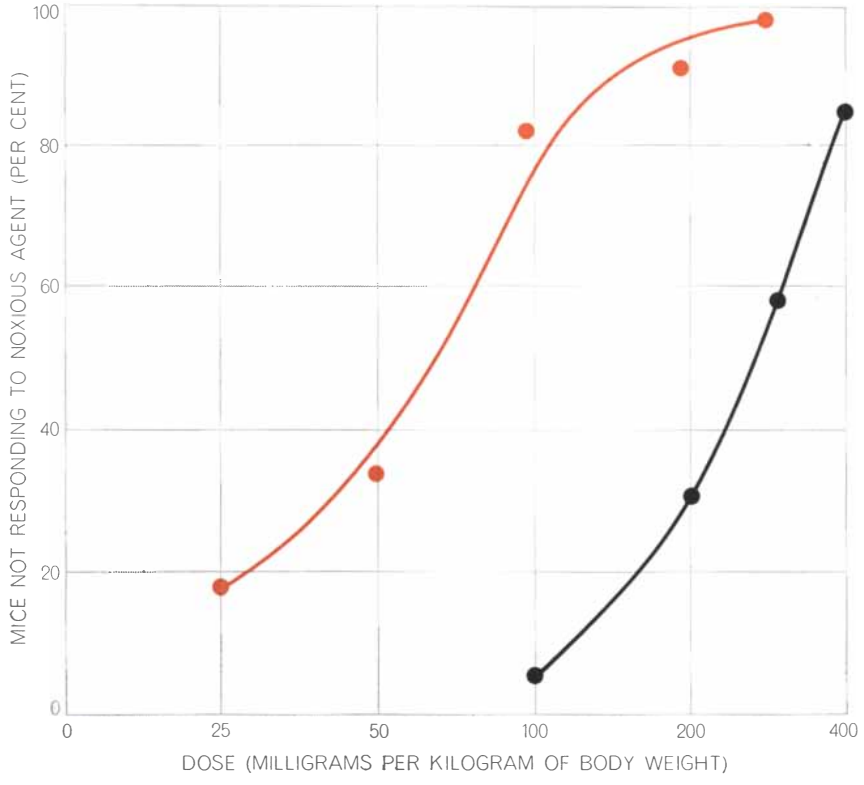
Although salicylic acid was probably the wonder drug of its day, its success was diminished by the irritation and damage it caused to the moist membranes lining the mouth, gullet and stomach. The molecule of the acid contains a hydroxyl group (OH) and a carboxyl group (COOH) extending from the six-carbon-atom benzene ring. The carboxyl group can dissociate on contact with the moist lining of the stomach wall to yield a hydrogen ion. The resulting acidity can be neutralized by replacing the hydrogen atom of the carboxyl group with an atom of a metal such as sodium. This salt, sodium salicylate, was less irritating than the acid and was prescribed by physicians, but it had to be administered in a solution that many people found to have an "obnoxious sweetish taste." Thus although the great potential of salicylic acid had been demonstrated as early as 1876, many of those to whom it was administered were distressed by its damaging effect on the lining of the digestive tract or by the unpleasant taste of the sodium salt.

Ironically the key step in successfully improving the drug's palatability had been demonstrated in 1853 by Gerhardt. He had replaced the hydrogen atom of the hydroxyl group with an acetyl group ($COCH_3$), but his method was cumbersome enough to discourage further investigation for some time. It was 40 years before Felix Hofmann, a Bayer chemist, found a simpler way to make the acetyl compound of salicylic acid. Hofmann had a personal interest in the task because his father was one of those sufferers from rheumatism who could not stomach sodium salicylate. After Hofmann's successful acetylation, his colleague Heinrich Dreser conducted an impressive exploration of the properties of acetylsalicylic acid.

"It is self-evident," he wrote, "that only a salicylate compound which is split as soon as possible in the blood with liberation of salicylic acid has medicinal value." Dreser performed several experiments on the breakdown of acetylsalicylic acid in the body, including some on himself. He swallowed a solution containing one gram of sodium acetylsalicylate, a salt in which the hydrogen

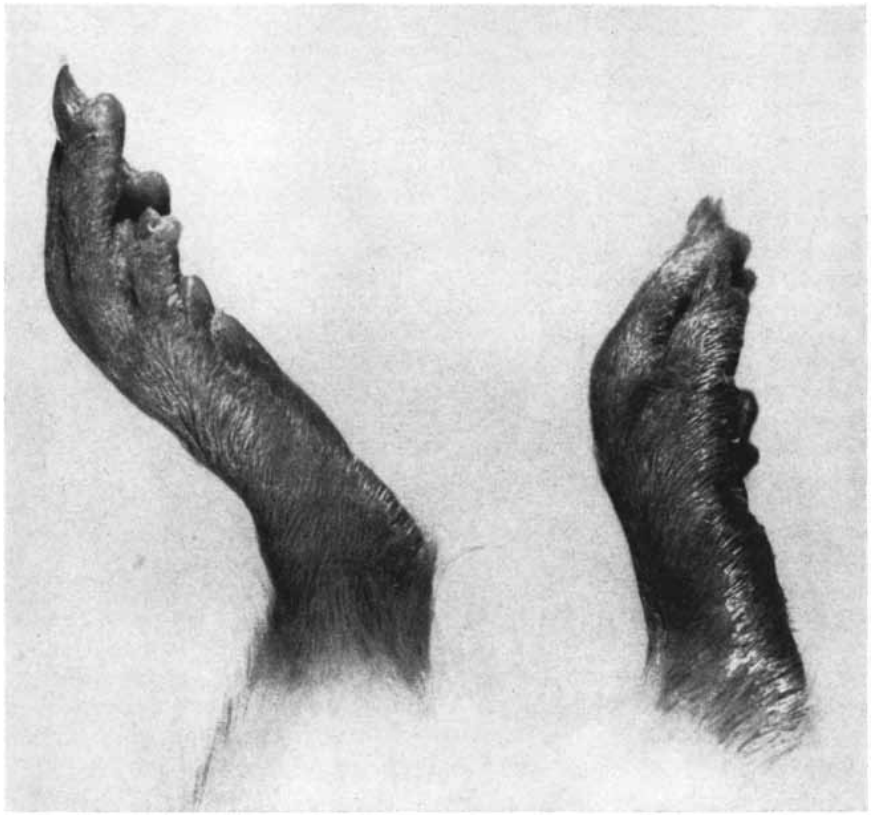


ANTIPYRETIC EFFECT of aspirin is graphed by plotting against time the rise in fever (*vertical axis*) of rabbits treated with pyrogen and aspirin. Dark-colored curve shows fever of rabbits receiving 66.7 milligrams of aspirin per kilogram of body weight. Light-colored curve depicts 22.2 milligrams per kilogram dose. Control animals (*black curve*) got no aspirin.



ANALGESIC EFFECT of aspirin (*colored curve*) is shown to exceed that of free salicylate. On horizontal axis is dosage of each drug given to mice before injection of phenylquinone, a noxious chemical. Vertical axis shows per cent that did not manifest any pain thereafter. Experiment was performed by L. C. Hendershot and J. A. Forsaith at Dow Chemical Company.

ARTHRITIC INFLAMMATION in hind feet of a rat that had received an injection of dead tubercle bacilli 13 days earlier is shown in this photograph. Precise nature of the swelling and response of arthritic rats to drugs provide a "model" of human rheumatoid arthritis.



ANTIRHEUMATIC EFFECT of aspirin is evident in this photograph of hind feet of a rat that had received daily doses of aspirin starting one day before the injection of tubercle bacilli. Photographs were made by B. B. Newbould of Imperial Chemical Industries.

atom of the carboxyl group has been replaced by a sodium atom and the hydroxyl group by an acetyl group. After 22 minutes the chemist tested a sample of his own urine for the presence of acetylsalicylate and free salicylate. The latter was present, but the urine gave no reaction for the acetyl compound. Over the next 12 hours the urine gave the same reactions, and Dreser concluded that acetylsalicylates readily decomposed in the body, liberating the therapeutically active salicylate. Observing that acetylsalicylic acid had "a pleasant sharp taste" instead of the sweet, nauseating flavor of sodium salicylate, and that it "acted more gently on the walls of the stomach," Dreser recommended it as a pharmaceutical preparation.

The first physicians to describe the medicinal uses of aspirin were Kurt Witthauer and Julius Wohlgemut of Germany. Their 1899 papers did not suggest that aspirin, either as a solid or as a liquid, had therapeutic effects greater than those of earlier salicin derivatives. Instead they emphasized the pharmaceutical advantages cited by Dreser, such as acceptable taste and decreased irritation of the stomach lining.

Only a year later—following the production of aspirin tablets "so cheap that no obstacle stands in the way of their use" and a small explosion of papers on aspirin in the medical journals—Witthauer wrote a second paper in which he described the unexpected potency of aspirin as a relief for pain in such varied conditions as migraine, persistent headache and inoperable carcinoma. Patients and their physicians had discovered in aspirin an analgesic so effective that its success misled them into extravagant optimism.

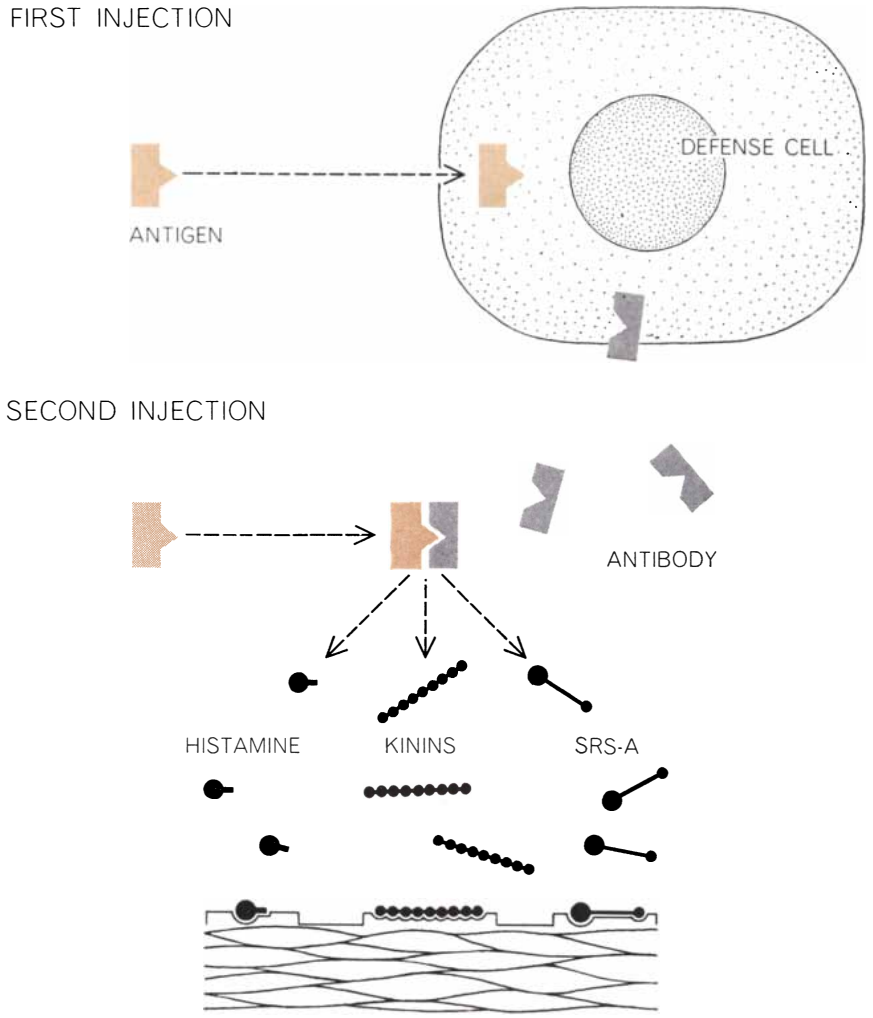
Witthauer himself warned that tablets "should not be swallowed whole but allowed to disintegrate first in a little sugar water flavored with 2 drops of lemon juice." Many ignored his advice and swallowed crude tablets of aspirin, which, disintegrating slowly and unevenly in the stomach, brought lumps of acetylsalicylic acid into contact with the stomach wall, with damaging results. Most modern aspirin tablets are designed to promote quick dissolution and so reduce the time in which an acidic lump can touch the stomach wall. Some tablets form the soluble calcium salt of acetylsalicylic acid as they dissolve in the stomach juices, whereas others yield a solution of the sodium salt in a glass of water prior to administration. Some capsules enclose the drug in a coat that

resists the acid of the stomach and dissolves in the alkaline juice of the small intestine. Although each of these is less likely to injure the stomach than the plain aspirin tablet, a real risk remains, as is indicated by the gastrointestinal bleeding that in some individuals can follow the taking of aspirin and by the fact that acetylsalicylic acid and its chemical relatives can produce stomach ulcers in rats, even when these drugs are injected under the skin rather than swallowed.

In some people aspirin induces an allergic hypersensitivity; thereafter a small dose has been known to provoke a fatal reaction. Because aspirin is incorporated in many medicaments, the occasional sufferer of the allergic reaction must be wary of this hazard. An interesting footnote to the "dangers" of aspirin is the listing in a chemical index of four of its helpful effects ("analgesic, antipyretic, antirheumatic, uricosuric") and 31 hazardous effects.

It has always been easier to catalogue the wide application of aspirin to man's commonest ills than to explain its mode of action. As an analgesic it relieves pain rapidly, inexpensively and effectively. Unlike morphine, it does not give rise to physiological dependence and may therefore be used freely for everyday aches, pains and malaises: headache, dysmenorrhea, hangover and so on. As an antipyretic, aspirin brings fever down by increasing sweating and the flow of blood through the skin. As an antirheumatic, it reduces the inflammation and pain in the joints and permits increased mobility. As a treatment for gout, it has both these effects and induces the excretion of uric acid, thus lessening the deposits of urate that form in the joints. There is no doubt about the usefulness of the drug. If the precise nature of its biochemical action remains a mystery, it is because so little is known about the biochemistry of the defensive responses, such as pain, fever and inflammation, evoked in the body by disease.

Early clinical studies indicated that the dose of aspirin for effective treatment of rheumatic fever, rheumatoid arthritis or gout virtually equaled that of sodium salicylate. This supported Dreser's view that aspirin acts by liberating salicylate within the body. When it came to the relief of pain, however, the situation soon appeared to be different: smaller doses of aspirin sufficed for effective treatment. Some investigators began to wonder what role



A MODE OF ACTION FOR ASPIRIN is suggested at bottom of this generalized view of bronchospasm in guinea pigs. An injection of antigen (*top*) signals antibody production. After a second injection the antigens react with antibodies to form histamine, kinins and the substance designated SRS-A, all of which induce a constriction of the bronchioles. This bronchospasm can be stopped if animal is treated with antihistamine, shown at bottom to block the action of histamine, and aspirin, which in this case antagonizes kinins and SRS-A.

the liberation of salicylate could play if aspirin itself was the more potent of the two substances.

The problem assumed clearer shape when in 1946 David Lester, Giorgio Lolli and Leon A. Greenberg of Yale University reported the results of their examination of the substances present in the blood plasma of volunteers who had taken a single oral dose of aspirin. As much as a quarter of the total dose, with the acetyl group still attached to the compound, could be detected in the blood for one to two hours after ingestion. The period during which aspirin was present intact in the blood corresponded with the duration of its analgesic action; hence the Yale workers argued that aspirin had an analgesic action independent of the salicylate it might release on decomposing.

In order to bring these findings back into line with Dreser's view it was suggested that some special characteristics of the distribution of aspirin to the tissues enabled it to liberate salicylate at sites of action that this substance alone could not reach. Doubt has been cast on this explanation by the discovery of other situations in which the potency of aspirin greatly exceeds that of the salicylate. One of these, which will serve as an example, involves thurfyl nicotinate, a substance that is sometimes applied to the skin as a counterirritant in muscular pain, sciatica and neuralgia.

When a cream that contains thurfyl nicotinate is rubbed into the skin, it evokes reddening and wealing. This is probably a local expression of the generalized skin flush that follows the swallowing of a tablet of nicotinic acid. In 1952 J. R. Nassim and H. Banner reported that the usual skin reaction to thurfyl nicotinate was not observed in patients with rheumatoid arthritis. For some years this was taken to be a sign of the disease. In 1959 L. H. Truelove and J. J. R. Duthie of the Northern General Hospital in Edinburgh showed that the effect was caused not by arthritis but by the aspirin with which the patients were regularly treated. In normal volunteers a single 10-grain (650 milligram) dose of aspirin delayed the reddening and abolished the swelling after thurfyl nicotinate was rubbed into the skin.

At the Salicylate Symposium in London in 1962 S. S. Adams and R. Cobb of the Boots Pure Drug Company described how they had tested the ability of several antirheumatic drugs to modify

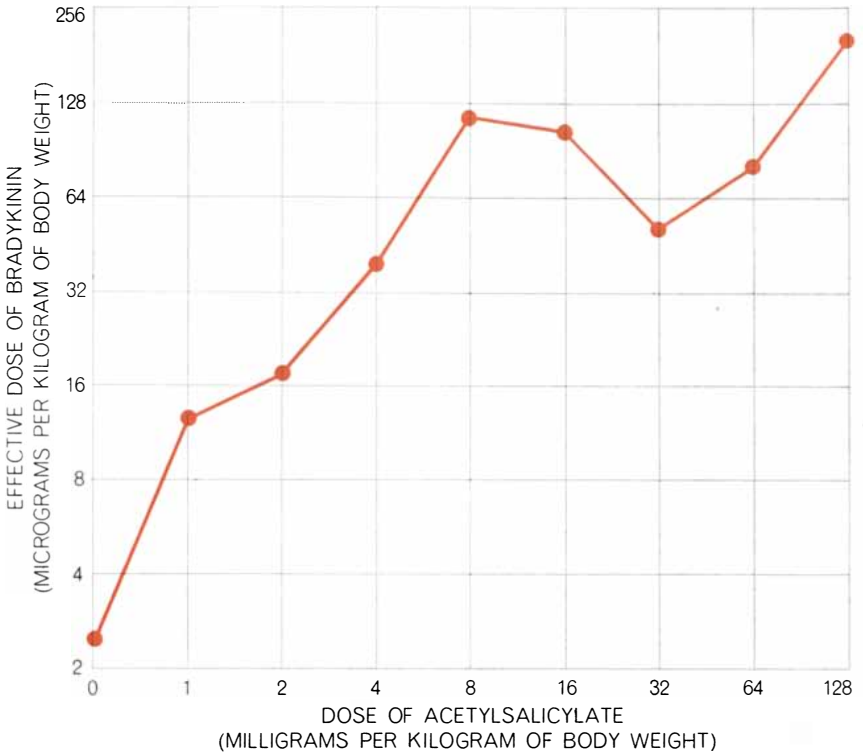
the skin response to thurfyl nicotinate. They found aspirin to be surprisingly potent: a single dose of 3.5 grains (225 milligrams) by mouth was detectably effective, and a 10-grain dose inhibited the skin response for several days. Neither sodium salicylate nor phenylbutazone, both useful antirheumatic drugs, was active at the dosage tested; taking into account the fact that decomposition in the bloodstream will allow no more than a quarter of the aspirin to reach the skin as the acetyl compound, it can be estimated that acetylsalicylic acid is at least 12 times more potent than sodium salicylate against thurfyl nicotinate.

This experiment indicates that acetylsalicylate has a medicinal effect in its own right, without having to be broken down first to salicylate as Dreser supposed. It does not show that the actions of the two drugs are qualitatively different, since a still larger dose of sodium salicylate might have shown activity.

A powerful stimulus to the study of how aspirin exerts its effects has been the desire of pharmaceutical manufacturers to find new drugs that have the therapeutic virtues of aspirin without its disadvantages. Here laboratory models of disease, or the body's various responses to disease, play a fundamental role. These models are set up in animals or in isolated living tissue. To be valid they must not only resemble the human disease and its symptoms but also react comparably to drugs.

Fever, rheumatoid arthritis and pain can be fairly well approximated in experimental animals. Of these, fever has proved the simplest to reproduce. Fevers in man usually arise during microbial infections, in which the invaders liberate minute quantities of substances called pyrogens. Pyrogens can be extracted from bacterial cultures, and they produce fevers when injected into laboratory animals. For example, the injection of half a microgram (half a millionth of a gram) of pyrogen extracted from cultures of *Bacillus proteus* will raise the rectal temperature of a rabbit by one to two degrees centigrade within an hour or two. This fever can be prevented by a relatively small dose of aspirin.

The main manifestation of rheumatoid arthritis is an inflammation of the joints, more simply "arthritis." An apparently close approximation of this condition can be induced in rats. In 1954 H. C. Stoerk, T. C. Bielinski and T. Budzilovich of the Merck In-



ANTAGONISM of bradykinin inducing bronchospasm in the guinea pig is graphed by plotting the dosage of acetylsalicylate injected (*horizontal axis*) against the quantity of bradykinin needed to cause constriction of the bronchioles (*vertical axis*). Experiment was performed by the author and Patricia G. Shorley at Parke, Davis & Company in England.

stitute observed that rats developed a chronic arthritis when they were injected with emulsions of spleen cells suspended in an adjuvant consisting of dead tubercle bacilli in liquid paraffin, commonly used by pathologists to intensify the action of injected cells or bacteria. A few weeks after the injection swelling appeared in some of the joints of about half of the animals treated. Tails as well as limb joints were affected, and the swellings lasted, with occasional temporary lessening, for many months [*see illustrations on page 100*]. Under the microscope the swelling was seen to be caused by inflammation like that in human rheumatoid arthritis.

Stoerk and his colleagues attributed this chronic arthritis to the spleen cells injected into their rats. In 1956, however, Carl M. Pearson of the University of California School of Medicine in Los Angeles showed that the adjuvant alone, without any spleen cells suspended in it, would produce the same effect. Later Pearson and Fae D. Wood found that dead bacteria of other species of the genus *Mycobacterium*, to which the human tubercle bacillus belongs, were also effective, although bacteria of other genera were not. Even chemical extracts of tubercle bacilli can elicit this chronic arthritis in rats. The disease seems therefore to be an ultimate immunological response of the animal to a foreign chemical derived from a particular kind of bacterium. Conceivably rheumatoid arthritis arises from similar causes in man.

In the treatment of arthritis the hormones of the adrenal cortex and other steroid hormones have proved to be most effective in both human beings and rats. Recently B. B. Newbould of the Imperial Chemical Industries has found that acetylsalicylic acid, sodium salicylate, phenylbutazone, aminopyrine and flufenamic acid, the most effective types of nonsteroidal agents in the treatment of human rheumatoid arthritis, show corresponding potencies when administered to rats. Newbould's research indicates that among drugs known to be effective against the human disease only the quinoline antimalarials are ineffective against the rat arthritis. His experiments thus affirm the similarity between the laboratory model of arthritis and the human disease and demonstrate the powerful anti-inflammatory action of aspirin and related drugs.

It has proved difficult to develop equally persuasive laboratory models of pain and the objective measurement of the analgesic effect that motivates most use of aspirin. In a few animal experiments aspirin could be shown to raise the intensity of noxious stimulation needed to elicit a protective response, but the magnitude of the effect was small and the dose required correspondingly large. In 1956, however, Christine Vander Welde and Sol Margolin of the Schering Corporation described a model pain situation in which the injection of a noxious chemical solution into the abdominal cavity of rats or mice produces a characteristic constriction of the abdominal wall followed by extension of the hind legs. The response, which has been termed "stretching" or "writhing," was usually repeated several times after the injection. The inference that this response signifies pain is supported by the actions of drugs. Local anesthetics suppress the response when they are injected at the site, and analgesics suppress it when they are administered by any route. In a mouse a dose of about 20 micrograms of morphine effectively reduces writhing, and a dose of about one milligram of aspirin is correspondingly active. For this model situation, then, it can be said that aspirin has about a fiftieth of the analgesic effect of morphine. This corresponds with human experience; on the subjective testimony of patients it is said that 300 to 1,000 milligrams of aspirin relieves pain about as well as 10 to 30 of morphine.

The suggestion has been made that aspirin acts in mice and men by antagonizing natural pain substances such as the peptides called kinins, which are released locally in the blood and tissues at the site of injury [see "Kinins," by H. O. J. Collier; SCIENTIFIC AMERICAN, August, 1962]. Robert K. S. Lim and his co-workers at the Miles Laboratories have performed ingenious experiments in dogs showing that aspirin blocks the action of one of these kinins (bradykinin) and suppresses its excitation of the nerve endings in the viscera that promote pain sensation. Bradykinin also evokes the writhing response when it is injected into the abdominal cavity of mice, and this too is blocked by aspirin. It has not been established that aspirin blocks the pain evoked by bradykinin more effectively than it blocks pain signaled by other substances; nor has aspirin been found to block all the types of pain caused by bradykinin. For example, bradykinin injected into the skin of guinea pigs elicits scratching and licking at the site of the injection; aspirin does not prevent these responses, although morphine does.

In the most illustrative experiments

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exploring aspirin's mode of action on the molecular level, the disease duplicated in the laboratory was bronchial asthma. Significantly, a disease can be described in terms of various elements, such as the invading agent (for example the influenza virus), the body's response (rheumatic fever) or the ultimate damage inflicted (infantile paralysis). Human bronchial asthma, which fits the second descriptive category, is the reaction of the bronchioles to the inhalation of a small amount of a specific antigen, usually a foreign protein present in a pollen or in the dander of an animal. Like fever, pain or arthritic inflammation, then, asthma represents the type of unwarranted or excessive bodily response to an invading agent that aspirin seems able to mitigate.

A crude example of asthma in the guinea pig has been observed for half a century. If a single dose of foreign protein such as egg white or horse serum is injected, it does little harm to the guinea pig. But a second dose a few weeks later causes an intense reaction in which the muscular walls of the bronchioles contract violently. The resulting constriction of the bronchioles, or bronchospasm, usually hinders breathing so drastically as to be fatal. This is one of the more familiar and extreme forms of the distorted immunological response known as anaphylactic shock. In response to the first injection of antigen, defense cells produce an antibody tailored to fit the substance [see "The Mechanism of Immunity," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, January, 1961]. When the antigen is injected a second time, it reacts with the antibody to produce anaphylactic shock [*see illustration on page 102*].

Human bronchial asthma is a much milder reaction of the bronchioles to inhalation of a dust containing a small amount of antigen to which the sufferer has become sensitized. A precise equivalent of human asthma in the guinea pig was set up in 1952 by Herbert Herxheimer, then at the University College Hospital Medical School in London, who caused animals previously sensitized to egg albumen to inhale a solution of it in a fine mist.

As long ago as 1910, at the Wellcome Physiological Research Laboratories in England, Sir Henry Dale and Sir Patrick P. Laidlaw had observed that the injection of histamine, a substance released by injured tissues, produces a bronchospasm like that of anaphylactic shock. Histamine had not long been synthesized at that time and was still known under its chemical name of beta-imidazolylethylamine. After comparing many responses of various animals to histamine and to anaphylactic shock, Dale and Laidlaw wrote: "We content ourselves with recording, as a point of interest and possible significance, the fact that the immediate symptoms with which an animal responds to an injection of a normally inert protein, to which it has been sensitized, are to a large extent these of poisoning by beta-imidazolylethylamine."

This comment had a powerful influence on later investigations. In 1932 several teams of workers in different parts of the world showed that histamine is released during anaphylactic shock in the guinea pig. Then in 1937 Daniel Bovet and A.-M. Staub, working at the Pasteur Institute in Paris, described the first antihistamine drug, 929F. This drug not only protected guinea pigs against constriction of the bronchioles caused by inhaling histamine solution in a fine mist but also protected them to some extent against anaphylactic shock. Many other antihistamines followed 929F; all of them lessened anaphylactic bronchospasm but none abolished it altogether. This confirmed that the histamine released in anaphylactic shock played a part in constricting the bronchioles, but it also implied that some other factor was involved.

A search for other substances that are released during anaphylactic shock and might play a part in constricting the bronchioles in the guinea pig has so far implicated two. In 1940 C. H. Kellaway and E. R. Trethewie found a substance that has not yet been purified and chemically identified and is known by the awkward name of Slow Reacting Substance in Anaphylaxis, or SRS-A. The other substance is the family group of kinins, as W. E. Brocklehurst and S. C. Lahiri of the University of Edinburgh demonstrated in 1961.

Previously John A. Holgate, Mel Schachter, Patricia G. Shorley and I, working at the laboratories of Parke, Davis & Company in England and at University College London, had shown that intravenous injection of kinin into normal guinea pigs causes constriction of the bronchioles, and in 1962 P. A. Berry, Holgate and I showed that SRS-A acts in a similar way. We also found that the bronchospasm induced by either kinins or SRS-A can be completely prevented by the administration of a small dose of aspirin a few minutes before the injection.

Although aspirin has no such effect

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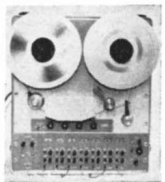

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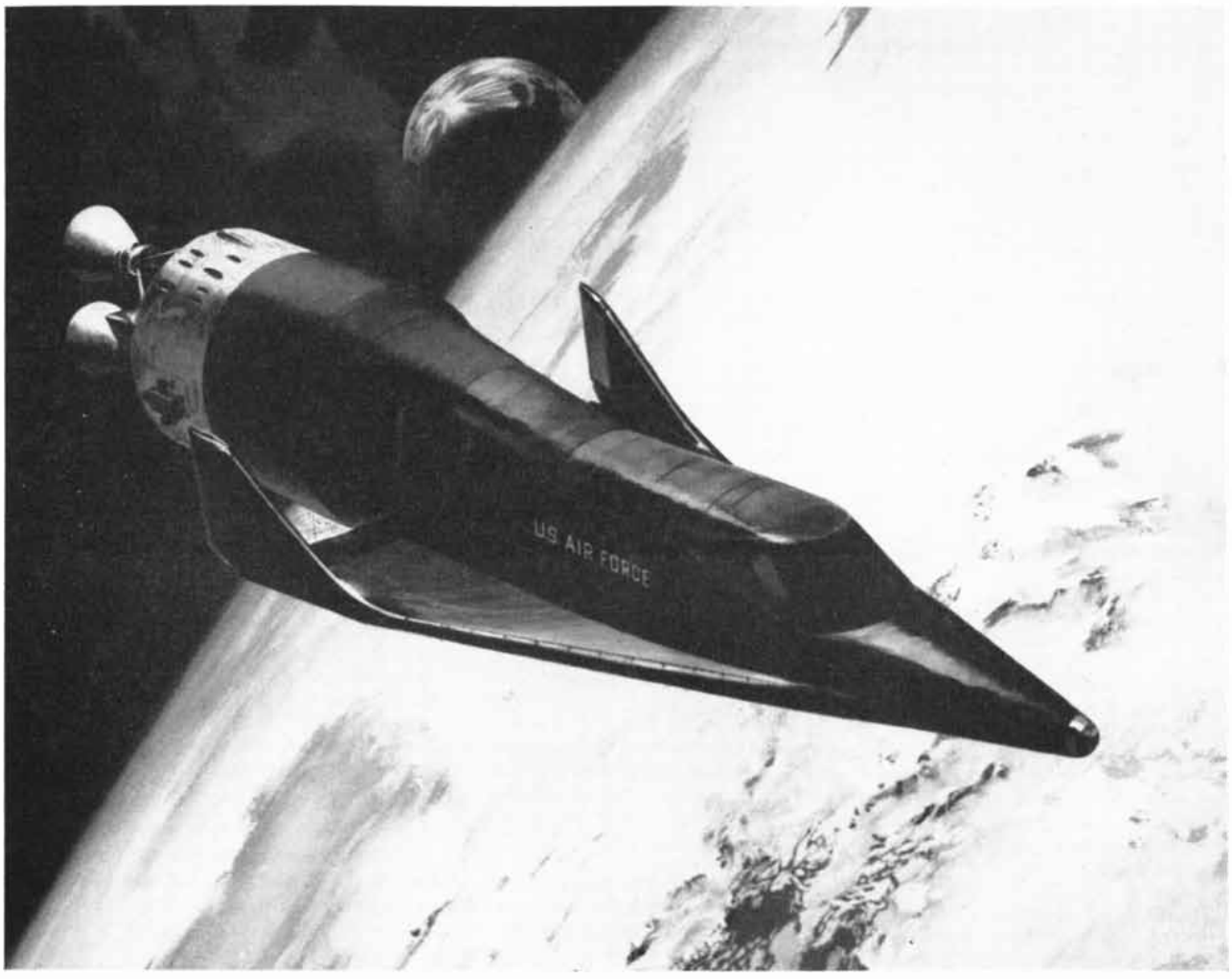
on the action of histamine, it appears to act as a specific chemical antagonist of kinins and SRS-A, just as antihistamines antagonize histamine. If the three substances are jointly responsible for the bronchospasm, one might expect that treatment with both aspirin and antihistamine would prevent it and that either drug alone would be partly effective. Within the past year Alexander R. Hammond, Barbara Whiteley and I have found strong evidence in support of this prediction. In this particular model of asthma, at least, it appears that aspirin acts as a pharmacological antagonist of kinins and SRS-A. This effect is probably achieved by the molecules of aspirin blocking a reaction between the molecules of kinin, SRS-A and the bronchial muscle they stimulate.

The question of how closely the guinea pig model of asthma resembles the human counterpart has occupied more than a generation of research workers. In 1951 H. O. Schild, Denis F. Hawkins, Jack L. Mongar and Herxheimer, working at University College London, showed that a piece of human bronchial muscle, removed from an asthma sufferer during a surgical operation and suspended in a suitable saline medium, released histamine when it was exposed to the pollen to which the patient was hypersensitive. In 1955 Brocklehurst, then working at the National Institute for Medical Research in London, found that contact with the appropriate antigen also released SRS-A from isolated fragments of a human asthmatic lung. Recently Herxheimer and E. Stresemann, working at the Free University of West Berlin, have demonstrated that when volunteers susceptible to asthma inhale a solution of either bradykinin or SRS-A in a fine mist, an asthmatic attack follows. From clinical experience it is known that aspirin and antihistamines, when taken separately, ameliorate asthma slightly in human patients. But it is not yet established that the two drugs, taken together, would have a stronger effect, or that aspirin acts as a pharmacological antagonist of kinins or SRS-A in the human lung.

Whether aspirin, in its vast consumption, is taken as an antipyretic, analgesic or antirheumatic, its general function seems to be the moderation of the defensive reactions to various forms of disease. It would appear that the human body has an unwieldy defense establishment that aspirin fortunately can help to control.

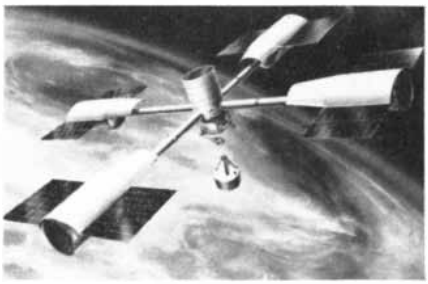


X-20 DYNA-SOAR. U.S. Air Force's X-20 spacecraft shown in drawing above as it will look in orbit before pilot begins controlled re-entry into atmosphere for landing at airfield of his choice. Designed to explore problems of re-entry from orbit and to develop technology of manned maneuverable re-entry from space, Dyna-Soar will combine speed of ballistic missile in space with controlled and accurate flight of an airplane in the atmosphere. From this and other studies, new space-mission concepts may evolve. Boeing, as X-20 system contractor, will build the spacecraft and integrate the vehicle with its booster.

Capability has many faces at Boeing

BOEING 727, America's first short-range jetliner, is pictured above with Boeing-Vertol 107 helicopter. Airlines have ordered 137 Boeing 727s. They enter service soon.

NATION'S LARGEST hydrofoil, U.S. Navy's anti-submarine vessel, High Point, is shown "flying" on underwater "wings". Length is 115 feet, speed over 40 knots. Built by Boeing, High Point is undergoing operational tests by U.S. Navy.



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The Chemistry of Amphibian Metamorphosis

The evolutionary transition from fish to land animal is paralleled by the transformation of an aquatic tadpole into a frog. Essential biochemical changes accompany and implement this conquest of land

by Earl Frieden

It seems likely that toward the end of the Devonian period some 280 million years ago a strange fish with footlike fins and a rudimentary lung flopped out of a nearly dry fresh-water pond and survived to wriggle to another pond. After millions of years in the water the vertebrates could thus have begun the slow colonization of the land. With the passage of time species evolved that could spend most of their lives out of the water: the amphibians. And the amphibians were the ancestors of all the other terrestrial vertebrates: reptiles, birds and mammals.

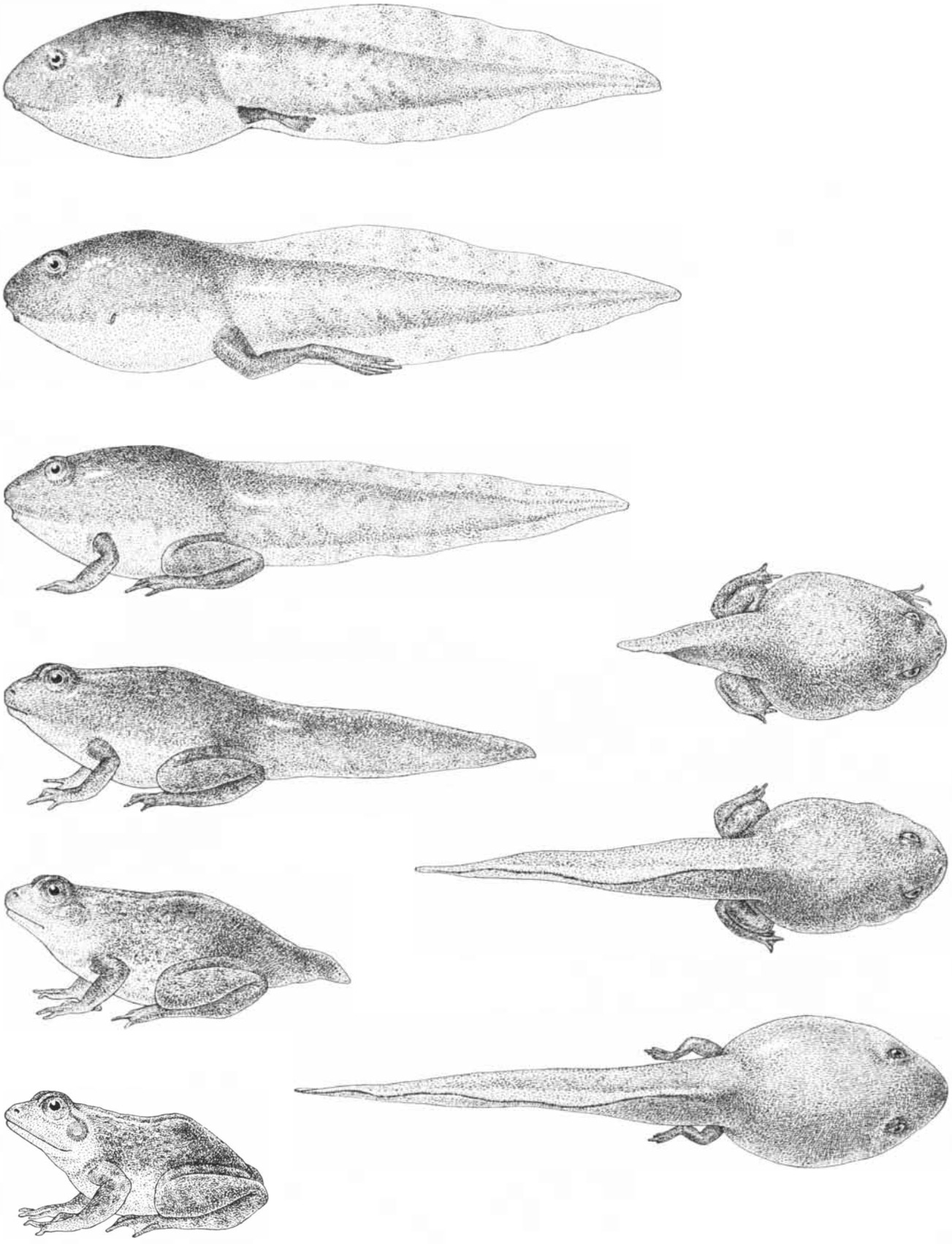
The transition from fish to amphibian took millions of years and proceeded in slow stages. In present-day amphibians—the frog, for example—a similar transition takes place within a stage in the life cycle of the animal; it is called metamorphosis. Evolution involves a series of adaptations to the environment by successive generations of an organism that takes advantage of genetic mutations; metamorphosis is a directed adaptation, a developmental transition from a larval form specialized for one environment to an adult form adapted to a completely different kind of existence. The frog tadpole is essentially a fish, with a streamlined body and tail, gills, lidless eyes, thin skin and a mouth suited to nibbling aquatic plants. Within a period of months it changes to a young frog, a versatile land animal without tail or gills and with lungs, eyelids, thick skin, large limbs with powerful muscles, and a mouth and tongue suitable for capturing insects.

What makes these changes come about? What triggers the process and controls its progress? In 1912 Frederick G. Gudernatsch of the University of Munich investigated the effects of various biological substances on amphibian metamorphosis. One of the things he did was to feed young animals of metamorphosing species fresh tissues from other animals. To his astonishment he found that when tadpoles were fed tissue from the thyroid gland, they underwent precocious and rapid metamorphosis. Later other workers traced the initiation of metamorphosis to thyroxine, the iodine-containing amino acid that is the principal hormone of the thyroid and that is necessary for growth and maturation and the control of oxidative metabolism in man. Bennett M. Allen of the University of California at Los Angeles subsequently established that the secretion of thyroxine is prompted by a thyroid-stimulating hormone (TSH) produced by the pituitary gland. Recently William Etkin of the Albert Einstein College of Medicine and the Soviet investigator A. Voitkevitch showed that the pituitary activity is in turn dependent on signals from the hypothalamus in the brain. If any of these tissues—thyroid, pituitary or hypothalamus—is removed from a tadpole, metamorphosis is forestalled or arrested. Metamorphosis is now routinely induced by treatment with thyroid hormones, either thyroxine or the related triiodothyronine. The hormones can even induce transformation in amphibian species that do not normally metamorphose, such as a salamander, the Mexican axolotl, that ordinarily retains its larval form into adult life.

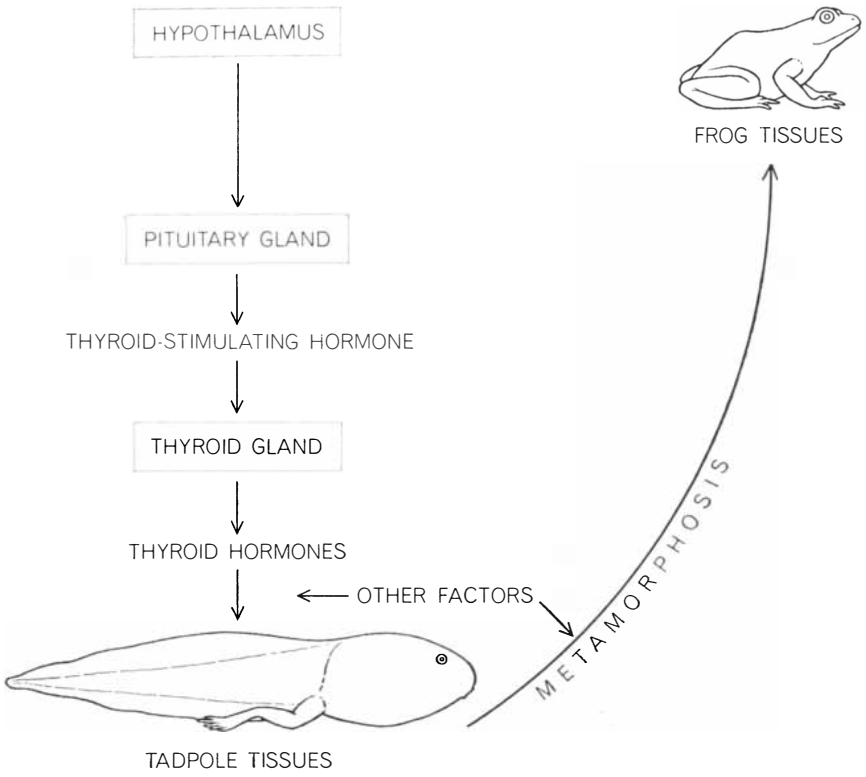
Classical biology was built on careful observations of animal structures and tissues. On this morphological level the dramatic changes in frog metamorphosis were long ago catalogued and appreciated. In the past 20 years research in the expanding field of comparative biochemistry has made it clear that spectacular chemical changes are associated with the morphological events of metamorphosis. A number of these biochemical alterations have now been described and measured. Some of them are obviously of immediate survival value. Others apparently serve as the basis for structural changes. Still others seem to have no discernible adaptive function—but even these may turn out to be essential adaptations when metamorphosis is better understood.

The conservation of water is a major problem for any animal that does not live in an aquatic environment. Maintenance of the proper fluid balance in the body requires, first of all, a skin tough enough to resist too rapid evaporation. The tadpole's skin is thin and delicate, and a tadpole is quickly dehydrated on exposure to air. During metamorphosis the skin thickens and an insoluble protein, keratin, develops in its outer layers. The skin becomes less sensitive to evaporation and to mechanical injury.

A more subtle adaptation to nonaquatic life takes place in the chemistry of the frog's excretory system. It involves a shift in the form in which nitrogenous waste products are excreted, and it follows a rule laid down in the 1930's by Joseph Needham and Ernest Baldwin of the University of Cambridge. They pointed out that the conversion of ammonia, the simplest end product of nitrogen metabolism, to other substances is an indispensable adaptation to a limitation on the availability of water in the animal's environment. This is because in metabolic quantities ammonia is quite toxic. Aquatic animals can dilute the ammonia in their bodies at will—there is plenty of water available—and they can excrete urine that contains ammonia as quickly as the ammonia forms. Land animals cannot afford to be so profligate with water; they could not dispose of ammonia fast enough to avoid its toxic



METAMORPHOSIS transforms an aquatic larval form, the tadpole, into a terrestrial adult form, the frog. The later stages of spontaneous metamorphosis, which can take up to 15 months in all, are shown from top to bottom at left. The animal is the Southern bullfrog *Rana grylio*, which the author used in many of his experiments. Precocious metamorphosis induced by treating a tadpole with thyroid hormone is seen at right. The drawings show a Florida swamp frog tadpole, *Rana heckscheri* (*bottom*), and similar tadpoles five days after injection with minute amounts of the hormones thyroxine (*middle*) and faster acting triiodothyronine (*top*).



CONTROL MECHANISM for amphibian metamorphosis is diagramed. Signals from the hypothalamus in the brain stimulate the pituitary gland to secrete thyroid-stimulating hormone (TSH), which in turn causes the thyroid gland to secrete thyroxine and the other hormones that initiate the events of metamorphosis. Other factors as yet unidentified probably interact with the thyroid hormones and with tissues undergoing metamorphosis.

effects. Over the years the evolving land animals solved this problem with a chemical reaction considered a classic adaptation in comparative biochemistry: they convert the ammonia into another product. In nearly all mammals and most other vertebrates, including salt-water fishes, this is urea, which is formed from ammonia in the liver and is no more toxic than table salt; birds and some reptiles excrete nitrogen in the form of uric acid. The fresh-water fishes remain "ammonotelic": most of their nitrogenous waste is excreted as ammonia.

As the fishlike tadpole changes to a terrestrial frog, its nitrogen-excretion pattern makes a predictable shift. A. F. Munro of the University of Aberdeen found some years ago that more than 90 per cent of the tadpole's waste nitrogen is excreted as ammonia. As metamorphosis gets under way there is a steady decrease in ammonia and a compensating rise in urea; eventually the pattern is 10 per cent nitrogen and 90 per cent urea. The intensely adaptive nature of this biochemical change is elegantly illustrated by what occurs in the South African clawed frog *Xenopus laevis*. This animal undergoes metamorphosis, but instead of leaving the water it remains completely aquatic. Baldwin and E. E. Underhay discovered that *X. laevis* makes a halfhearted gesture toward becoming ureotelic in the course of metamorphosis but returns to ammonotelism by the time it is a young frog. If an adult frog of this species is taken out of the water and subjected to a dry atmosphere, however, it does undergo a change in the direction of urea excretion.

Since preparatory changes in enzymes usually precede major metabolic shifts in plants and animals, it seemed likely that the switch from ammonia excretion to urea excretion would be reflected in the tadpole's enzyme complement. The chemical reactions involved had been identified by Hans A. Krebs and K. Henseleit of the University of Oxford, who worked out the ammonia-urea cycle in 1932 [*see top illustration on opposite page*]. The immediate antecedent of urea is the amino acid arginine, and the enzyme that catalyzes its hydrolysis to form urea is arginase. In 1955 John Dolphin and I, working at Florida State University, compared the arginase activity in the liver of several species of tadpoles. It increased as much as 10 times during spontaneous or induced metamorphosis. Arginine, in turn, is produced from ammonia by a process that involves at least three different enzymes. In 1959 Philip P. Cohen, G. W. Brown, Jr., and W. Brown of the University of Wisconsin showed that all these arginine-synthesizing enzymes increase in activity during the metamorphosis of a bullfrog tadpole —one of them as much as 50 times. The mobilization of the enzymatic machinery on behalf of urea synthesis is clearly an essential preparation for life on land.

Internal water, then, is conserved in the frog by modifications of the skin and the excretory system. But merely to retain water within the body is not enough; it must be conserved specifically within the blood vessels. The reason is that a land animal's more complex circulatory system calls for the maintenance of a proper balance between the blood and the fluid in the tissue spaces. To this end the osmotic pressure of the blood must be maintained at a satisfactory level, and this is accomplished primarily by certain large molecules, the serum proteins, of which albumin is the most efficient because it carries the largest electric charge. Albumin also serves to "bind" and transport in the blood smaller organic molecules and salts required by metabolizing tissue.

Several years ago Albert E. Herner and I studied the serum proteins of tadpoles to find out if their composition changed in the course of metamorphosis. We used the technique of paper electrophoresis, in which the various proteins in a sample of blood placed on a piece of paper and subjected to an electric field migrate different distances toward the positive electrode because they differ in negative charge.

When we electrophorized serum from several tadpole species, we found little or no serum albumin; virtually all the proteins present were globulins, which carry a smaller charge. The electropherograms of serum proteins from animals at successive stages of metamorphosis revealed a striking difference. In every species we studied there was a steady increase in the proportion of a rapidly migrating protein—albumin—as metamorphosis proceeded. In the fully transformed froglet the albumin fraction constituted about half of the total serum protein content [*see illustration on page 114*]. In addition we found that in several species there was a considerable increase in the total amount of these proteins. William E. Hahn of Texas Technological College has recently found similar serum protein changes in certain

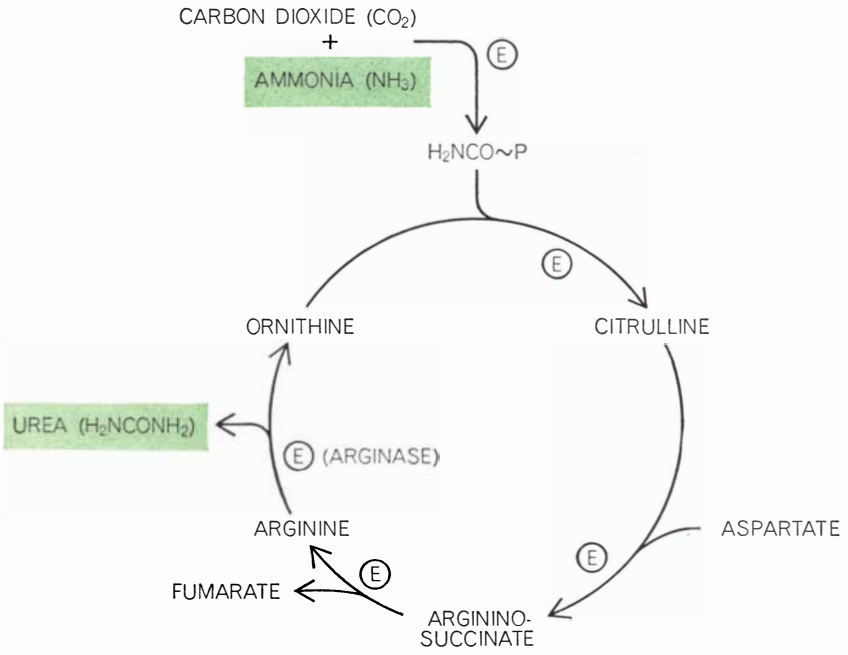
salamanders during metamorphosis. The remarkable increase in serum proteins, specifically in albumin, is a major molecular adaptation to conserve circulatory fluids.

The development of lungs is perhaps the most obvious of all the structural modifications that enable a frog to live on land. Equally significant is an adaptive change at the molecular level, in the oxygen-carrying pigment of the red blood cells—hemoglobin.

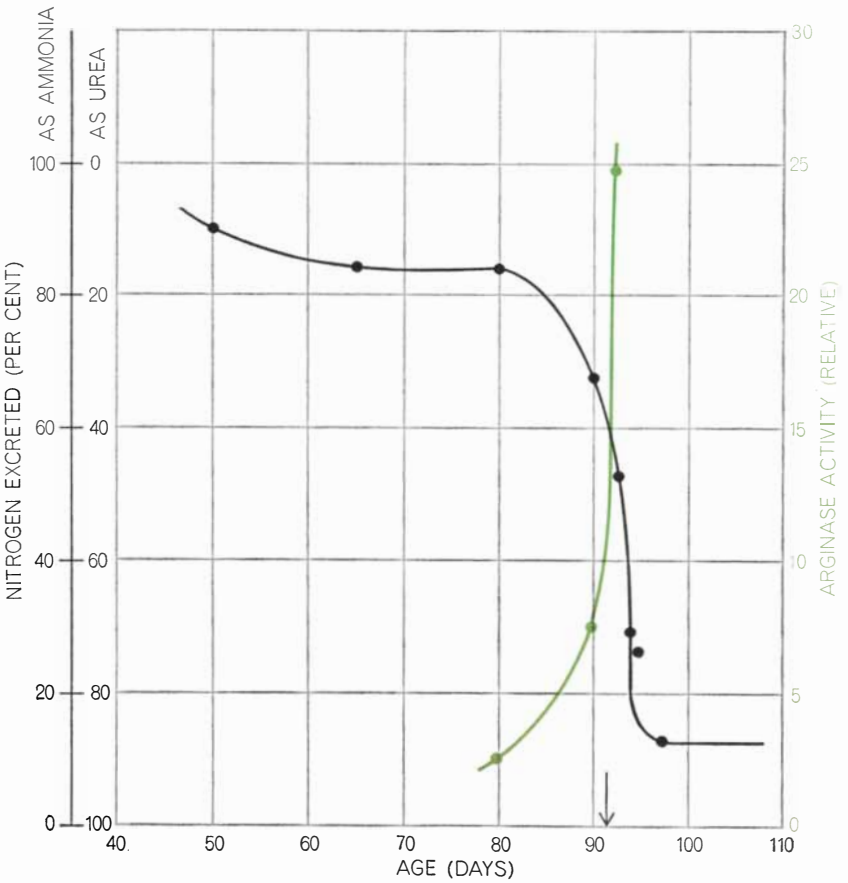
One of the variable characteristics of hemoglobin is its degree of affinity for oxygen: the extent to which it binds or releases oxygen as the pressure of the gas varies. F. H. McCutcheon of Duke University noted in 1936 that hemoglobin isolated from a frog's red cells binds oxygen less readily—which is to say that it releases it more readily—than tadpole hemoglobin does. In other words, tadpole hemoglobin has a large "oxygen loading" capacity, whereas frog hemoglobin has more "unloading" capacity. The adaptive nature of this difference seems clear. An aquatic tadpole depends on the rather small amount of oxygen dissolved in water, and its blood must load as much as possible. The frog, however, has plenty of oxygen available in the air and does not need to bind it as efficiently. What the frog does need is a sensitive unloading mechanism to supply oxygen for its active metabolism.

In 1951 Austen F. Riggs of Harvard University discovered another interesting adaptation in frog hemoglobin: the sensitivity of its oxygen-carrying ability to acidity. This property of hemoglobin is found in many higher animals and is known as the Bohr effect after its discoverer, Christian Bohr of Denmark. Riggs found that as the acidity of a hemoglobin solution increases there is a greater release of oxygen from frog hemoglobin but not from tadpole hemoglobin. In other words, the frog's hemoglobin shows the Bohr effect. This would seem to be an adaptation leading to particularly rapid release of oxygen where and when it is most needed: in regions where there is the build-up of acidity and carbon dioxide associated with intense metabolism, as in the muscles of a jumping frog's legs.

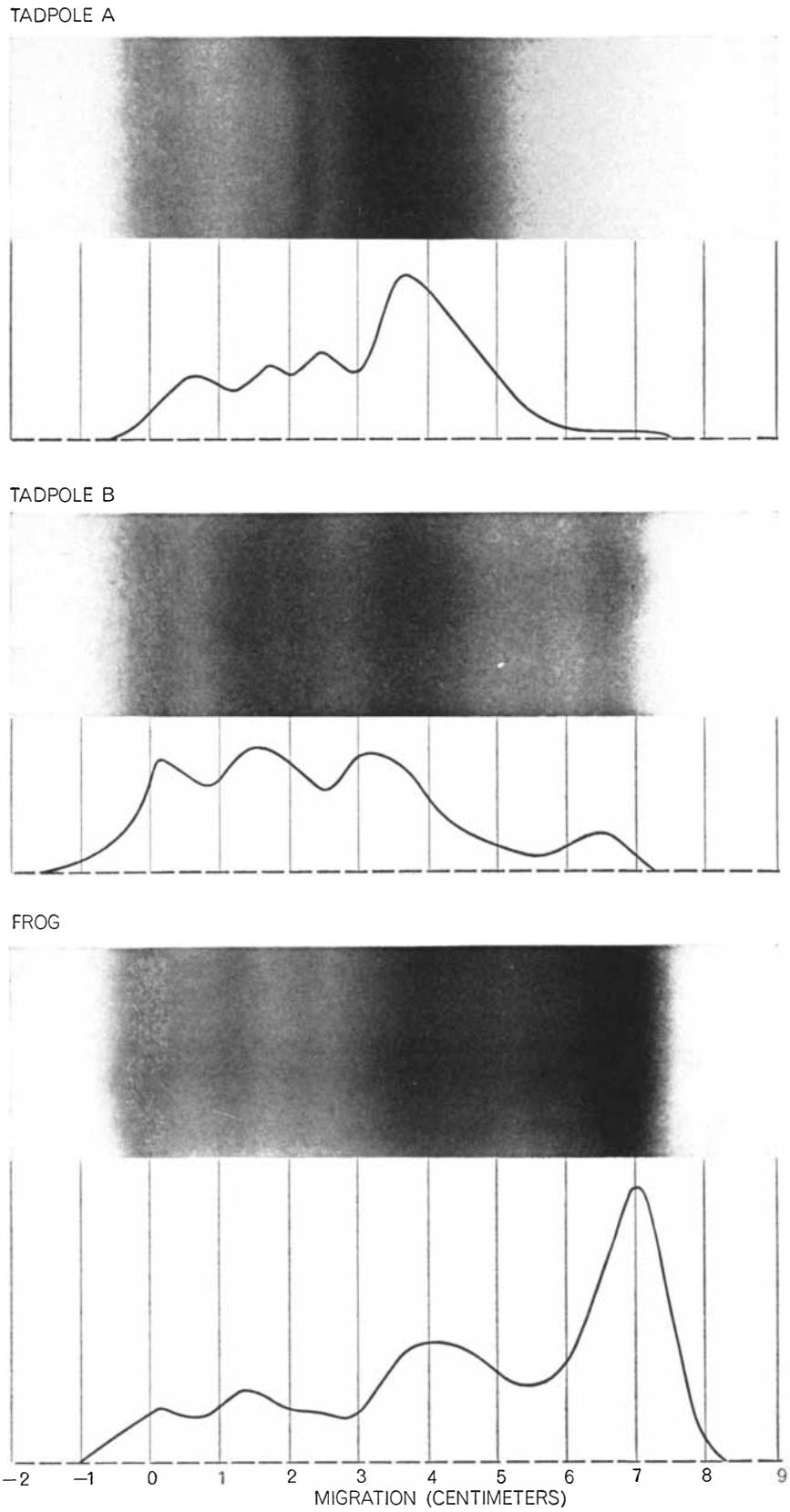
Herner and I undertook to identify differences in the molecular structure of tadpole hemoglobin and frog hemoglobin that would explain these functional differences. Hemoglobin is a "conjugated" protein—a combination of a protein group and a heme group containing iron. We first confirmed, by comparing the absorption spectra of he-



AMMONIA-UREA CYCLE is a series of reactions by which ammonia, a toxic end product of nitrogen metabolism, is converted in most land animals to urea, a nontoxic waste product. Each reaction is catalyzed by a specific enzyme, here designated by the letter *E*. Each of these enzymes has been found to increase its activity in the metamorphosing tadpole.



CHEMICAL ADAPTATION in metamorphosis is illustrated by the shift from ammonia excretion to urea excretion (*black curve and scale*). This is accompanied by a sharp rise in arginase activity (*colored curve and scale*). Forelimbs emerge at the point shown by arrow.



SERUM PROTEINS change during metamorphosis, as shown by electrophoresis patterns for *R. heckscheri* tadpoles in early metamorphosis (*A*) and six days after injection of triiodothyronine (*B*) and for an adult frog. In each case there is a photograph of the electropherogram of serum proteins from one animal and a curve showing the relative density of the stained protein from a number of similar animals: a composite electropherogram. Albumin, which migrates seven centimeters, is negligible in Tadpole *A*, begins to increase in *B* and is dominant in the frog. The general increase in serum proteins is also evident here.

moglobins in solution, that the heme portion was the same in tadpoles and frogs; the difference had to be in the protein. We then analyzed the hemoglobin of the Southern bullfrog *Rana grylio* by paper electrophoresis. Tadpole hemoglobin formed one reddish-brown band on the paper 11 centimeters from the point of origin. It appears to be the fastest moving hemoglobin yet reported. Treatment with triiodothyronine induced metamorphosis and changed the mobility of the hemoglobin. First the 11-centimeter band moved to 10½; then a new fraction appeared at 7. Similarly, at an intermediate stage of spontaneous metamorphosis we found two approximately equal bands. Finally, in adult frogs, there were two bands, the more predominant one at 6½ centimeters and the other at 7½. Giovanni Chieffi and his co-workers at the University of Naples later got comparable results with a somewhat different technique when they studied a European species, *R. esculenta*.

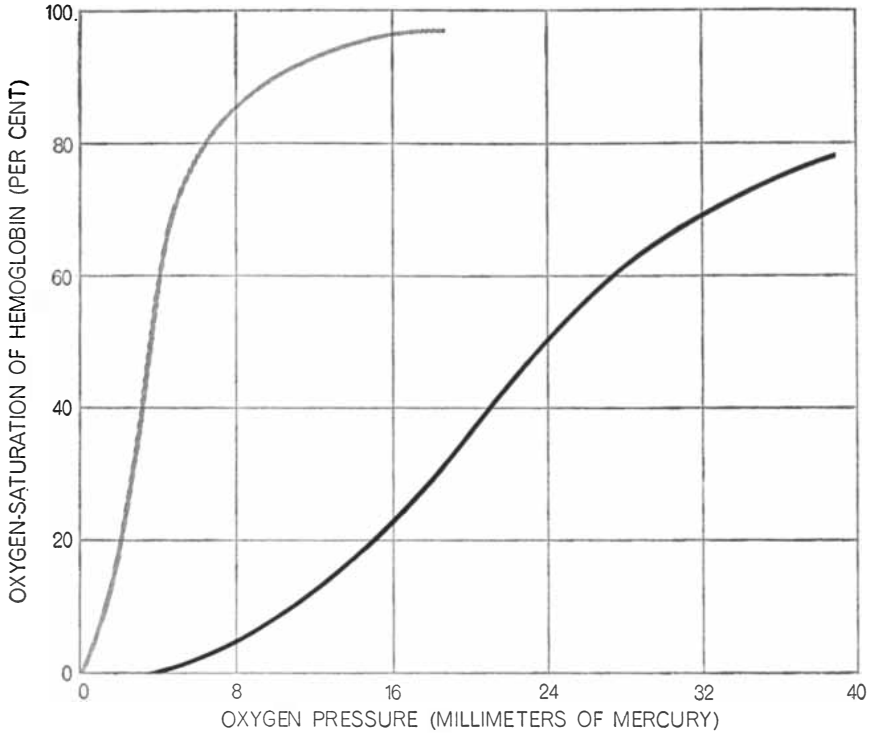
The change in electrophoretic mobility indicated an alteration of the amino acid composition of the hemoglobin protein, and the general reduction in mobility suggested a relative increase in positively charged amino acids in the course of metamorphosis. When, several years later, C. David Trader and I analyzed hemoglobins for key amino acids, we found that there is indeed a build-up of the positively charged histidine, arginine and lysine and a reduction in aspartic and glutamic acids, which are negatively charged. Another difference, which Riggs has also noted, involves cysteine, the sulfur-containing amino acid that can serve as a cross link between the peptide chains that make up a protein molecule. Tadpole hemoglobin does not contain cysteine; frog hemoglobin does.

In our laboratory at Florida State University we are now trying to identify the amino acid changes of metamorphosis in more detail with the protein "fingerprint" method. This calls for breaking down a protein into its component peptides and subjecting the mixture of peptides to chromatography in one direction and high-voltage electrophoresis in a second dimension. The resulting pattern of peptide spots on the paper is the protein's fingerprint. By comparing the fingerprints of two similar proteins one can determine in which peptides they differ. Subsequent analysis of these differing peptides identifies the variant amino acids. It was by this method that Vernon M. Ingram, now at the Massachusetts Institute of Technology, discov-

ered that the hemoglobin of individuals suffering from sickle-cell anemia differs from normal human hemoglobin only in one amino acid of the 600 or so in the molecule [see "How Do Genes Act?" by Vernon M. Ingram; SCIENTIFIC AMERICAN, January, 1958]. When we compare the peptide fingerprints of tadpole and frog hemoglobin, we expect to find much larger differences.

Another way to contrast two large molecules is to determine their molecular weights. This is done indirectly, by spinning them at high speed in an ultracentrifuge to determine their sedimentation rate. Trader, Joseph S. Wortham and I have compared the sedimentation patterns of frog hemoglobins during metamorphosis. In the tadpole we find a single protein peak with a sedimentation constant of 4.3 Svedberg units. (The unit is named for the Swedish chemist Theodor Svedberg.) This corresponds to a molecular weight of 68,000, the same as normal human hemoglobin. As metamorphosis proceeds a new hemoglobin at about 7.0 Svedberg units begins to appear, and it becomes predominant in the fully metamorphosed animal. This sedimentation constant corresponds to a hemoglobin with a molecular weight of about twice 68,000. It is still not at all certain whether this difference reflects the advent of a new hemoglobin molecule or the tendency of two molecules with a weight of 68,000 to react with each other and form a double molecule. In line with the latter possibility Casemiro V. Tondo and F. M. Salzano in Brazil have recently reported a human hemoglobin with a sedimentation constant of 6.0 Svedberg units, which they suspect may be another double hemoglobin molecule. The details of the relation between differences in amino acid composition and sedimentation constant remain to be clarified, but it is already certain that major changes in molecular architecture underlie the functional modifications in frog hemoglobin during metamorphosis.

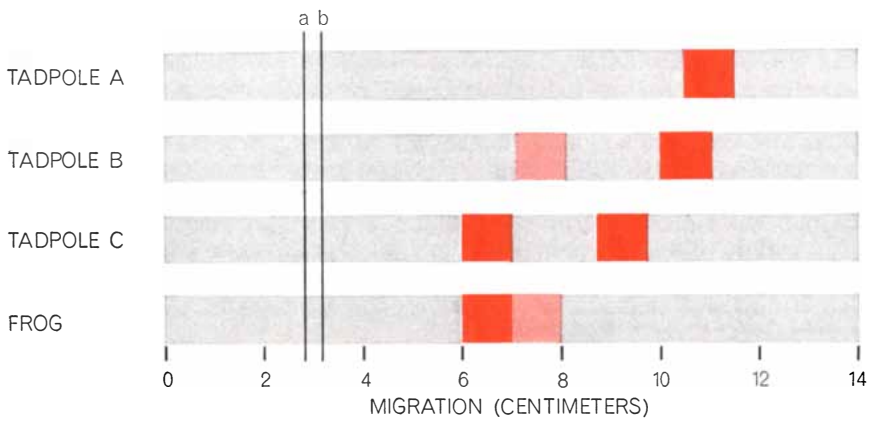
There are a number of other molecular transitions in metamorphosis that are clearly of adaptive importance but have not yet been intensively investigated. The tadpole lives primarily on algae and larger aquatic plants and has the long, coiled intestine characteristic of herbivorous animals. The frog eats insects and other invertebrate animals and its intestine is shorter, as in most carnivores. Accompanying this structural modification there is an enzymatic change to handle the switch to a high-protein diet. There



TADPOLE HEMOGLOBIN binds oxygen more tightly (*gray curve*) than frog hemoglobin does (*black curve*). Tadpole hemoglobin is thus adapted to binding the maximum oxygen from water; frog hemoglobin is adapted to releasing oxygen easily to meet metabolic needs.

is an increase in the activity of pepsin and trypsin, two of the enzymes involved in digesting proteins. The pancreas, which makes most of the digestive enzymes, increases its metabolic activity and the intestine increases its secretory activity.

Thyroid hormone not only initiates metamorphosis but also stimulates respiration, or oxygen consumption. It has nevertheless been impossible so far to get experimental evidence for increased oxygen uptake in the course of spontaneous metamorphosis. The problem is that it is difficult to compare the respiration of a rather docile aquatic tadpole with that of an active, long-legged frog; methods suitable for one will not work with the other. On the other hand, we have been able to measure significant increases in the oxygen consumption of tadpoles treated with thyroxine or triiodothyronine. If there is an increase in respiration during spontaneous as well as induced metamorphosis, it may well serve the purpose of making extra energy available for the many biochemical processes involved in the transition from tadpole to frog.



ELECTROPHORETIC MOBILITY of *R. grylio* hemoglobin changes in the course of metamorphosis. Before metamorphosis (*Tadpole A*) the hemoglobin forms a single band, 11 centimeters from the origin, in paper-electrophoresis experiments. After treatment with triiodothyronine (*B*) or partial spontaneous metamorphosis (*C*), this band becomes less mobile; a new band appears, increasing in density until it is dominant in the frog. Lines at about three centimeters show migration of human fetal (*a*) and adult (*b*) hemoglobin.

A fascinating transformation in certain visual pigments occurs during metamorphosis and has been studied intensively by George Wald and his associates at Harvard University. It is interesting in that although it serves no obvious adaptive purpose it does seem to provide a nice link between metamorphosis and evolution. Two kinds of pigment are found in the rods—the night-vision photoreceptor cells—of the eyes of vertebrates. One is the red pigment rhodopsin, which is formed by the combination of the protein opsin and retinene, a derivative of vitamin A_1. The other is a purple pigment, porphyropsin, in which opsin is combined with retinene 2, a derivative of vitamin A_2. The rhodopsin system is found in most salt-water fishes and terrestrial vertebrates, the porphyropsin system in fresh-water fishes. Wald found that the bullfrog tadpole—like a fresh-water fish—has the purple porphyropsin in its rods. This changes in the course of metamorphosis, however, and the pigment in the adult bullfrog's rods is the red rhodopsin.

This change has not yet been confirmed for many other frog species, but even if it is generally the case, it is hard to see what function it serves. The absorption spectra of the two pigments are different, and there is no apparent relation between the two spectra and the environments of the tadpole and the frog. Perhaps the change is a relic of the biochemical evolution that accompanied the invasion of the land. Wald has proposed that all vertebrates are descended from fresh-water fishes that undertook two great evolutionary migrations, one onto the land and the other into the oceans, and for some reason switched to rhodopsin in the course of both migrations. The frog makes the same switch in the course of metamorphosis. All this is reminiscent of the situation with regard to nitrogen excretion: fresh-water fishes are ammonotelic, most land vertebrates and salt-water fishes are not and the frog is both.

There are a number of other biochemical changes in metamorphosis that are not clearly adaptive in themselves —in the sense that the urea shift provides an essential metabolic pathway or the increase in serum albumin a needed

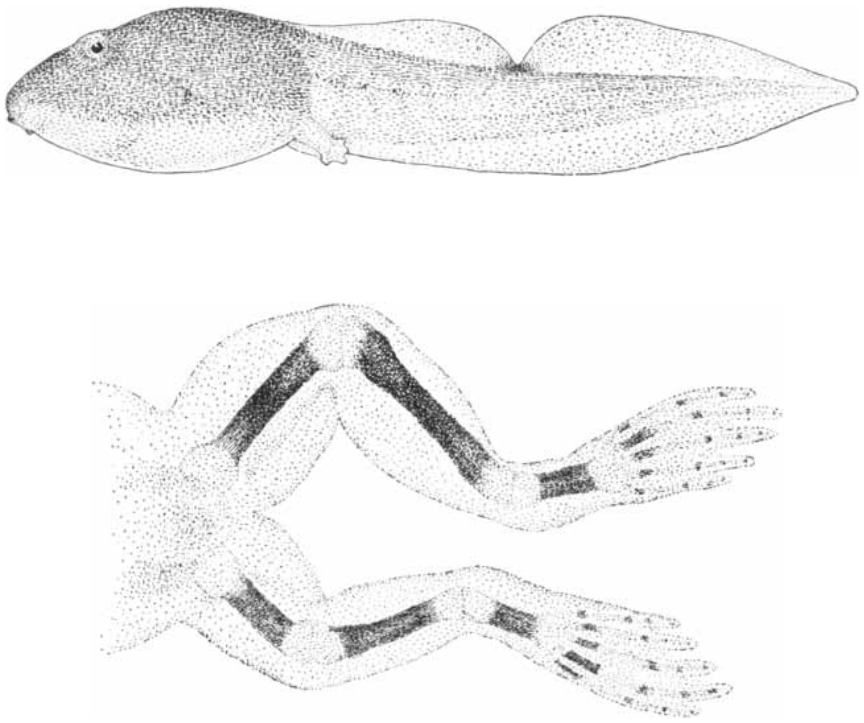
blood component—but seem rather to be the means by which major structural and functional modifications are accomplished. Among the most important are the events associated with the disappearance of some tissues and the synthesis of new ones.

How, for example, does the tadpole lose its tail? It has been assumed for some time that tail resorption is accomplished by intracellular degradative enzymes—that the tail tissues in effect dissolve themselves. In the past decade a number of workers, led by Christian de Duve of the Catholic University of Louvain, have proposed that most cells hold the seeds of their own destruction in the form of organelles called lysosomes: tiny bags of digestive enzymes. The lysosomes apparently play a digestive role in the normal life of the cell and may also, on the death of the cell, burst and liberate their enzymes to dissolve the cell itself [see "The Lysosome," by Christian de Duve; SCIENTIFIC AMERICAN, May].

In order to assess the role of these degradative enzymes in tail resorption we have recently studied the activity of an important hydrolytic enzyme called beta-glucuronidase. Helga Kubler of our laboratory measured the concentration in tail tissue of the soluble form of this enzyme, that is, of enzyme that has been released from lysosomes and is therefore presumably available for hydrolytic action. She found that this concentration increases about 20 times in the course of spontaneous metamorphosis. When metamorphosis is induced by thyroid hormone treatment, there is a fivefold increase in enzyme level. In tadpole liver and in muscle tissue outside the tail, however, there is no such increase.

Beta-glucuronidase is just one of a number of enzymes that De Duve has described as "lysosomal" and that have been found by several workers to be particularly active during tail resorption. Others are cathepsin, deoxyribonuclease, acid and alkaline phosphatase and several dipeptidases. The most impressive increase is shown by cathepsin, a protein-digesting enzyme. Rudolf Weber of the University of Berne showed a few years ago that as the tail gets smaller the concentration of cathepsin goes up as much as 30 times; eventually the tail contains almost nothing but lysosomal enzymes. Apparently thyroid hormone triggers reactions that release these digestive enzymes from the lysosomes and in doing so free them to dissolve the cells of the tail.

While the tail is disappearing, of course, other tissues are growing. The



DIFFERENTIAL EFFECT of thyroxine on different tissues was shown in experiments by Jane Couffer Kaltenbach of Mount Holyoke College. These drawings are based on her photographs. A pellet containing thyroxine, implanted in a tadpole's tail, caused a striking resorption of fin tissue in the immediate vicinity (*top*). Thyroxine similarly implanted in a leg stimulated instead abnormally rapid growth of the bones and muscles (*bottom*).

most reliable indicator of new-tissue formation is the synthesis of nucleic acids: DNA, the genetic material in the chromosomes of every cell, and RNA, the synthesizer of proteins. In 1959 Frank J. Finamore of Southern Illinois University and I injected radioactive phosphate into tadpoles undergoing induced metamorphosis and into non-metamorphosing animals. Since phosphate is a constituent of the nucleic acids, the amount of labeled phosphate that subsequently appeared in DNA and RNA was assumed to be a measure of the synthesis of these substances. The results were quite different when we analyzed nucleic acids from the liver and tail. The liver, which grows during metamorphosis and steps up its production of enzymes and other proteins, showed a significant increase in phosphate uptake in the metamorphosing animals. The tail nucleic acids, on the other hand, incorporated less phosphate after hormone treatment, reflecting the reduction of synthetic activity.

Such results as these pose what is perhaps the key question about metamorphosis: Granted that thyroid hormone initiates the processes of transformation, why does it affect different tissues in such different ways? It is quite clear that metamorphosis stems from an interaction of an extrinsic stimulus—the hormone—with intrinsic factors in the inherently and differentially sensitive individual tissues with which it comes in contact. Joseph L. Schwind of Cornell University demonstrated the acute sensitivity of tadpole tissues with some dramatic experiments in 1933. He transplanted the eye of a tadpole, together with its supporting tissues, to the tail of another tadpole. The graft took. As the tail began to disappear during metamorphosis, however, the eye resisted the degenerative process that was taking place in the tail cells around it. It migrated forward and finally came to rest in the sacral region. A limb transplanted to the tail behaved in much the same way, again demonstrating the specificity of the reaction to thyroid hormone.

Jerry J. Kollros of the State University of Iowa has also illustrated the differing response of various tissues to the same stimulus. He first removed the pituitary gland from leopard frog tadpoles to prevent normal thyroid-gland activity. Then, by exposing the animals to very small amounts of thyroxine, he induced some of the changes of metamorphosis but not others. There was typical resorption of tissue in the neck region, for example, but not in that of the tail. There were characteristic changes in the mouth and skin pigments but little limb development. Apparently a hormone concentration sufficient to trigger some changes will not trigger others.

Does the thyroid hormone give rise to different intermediate substances that in turn affect different tissues? Jane Couffer Kaltenbach of Mount Holyoke College has shown that thyroxine acts directly on local tissues. When a pellet that contains thyroxine is implanted in the tail, it causes tissue resorption in the immediate vicinity and, if the amount of thyroxine is small enough, has no other effect. When a thyroxine pellet is embedded in a hind leg, however, it induces precocious growth, not dissolution [*see illustration at left*].

The final answer to what makes tadpole tissues react in different ways to thyroid hormone may come only with further understanding of the genetic apparatus of the various tissues. Embryologists now believe that different genes become active at different times in different tissues during the developmental process. In Germany, Ulrich Clever of the Max Planck Institute for Biology and P. Karlson of the University of Munich have obtained the first evidence that a hormone can modify chromosomal activity. They worked with the giant chromosomes of the common midge, *Tendipes* (*Chironomus*) *tentans*, examining the "puffs" that are visible on such chromosomes and are believed to indicate increased genic activity at a particular gene site. When they injected ecdysone, a hormone that promotes molting in insects, into midge larvae, a new puff appeared on one of the chromosomes and an existing puff disappeared. Clever and Karlson concluded that the primary effect of ecdysone is to alter the activity of specific genes. It is possible that the complex differentiations of amphibian and other metamorphoses result from the impact of hormones on the genetic apparatus.

The relation between metamorphosis and evolution can be considered a special case of the old idea that ontogeny (the life history of an organism) recapitulates phylogeny (its evolutionary history). The biochemistry of metamorphosis may not precisely parallel the biochemistry of evolution, but in many ways the two must be very close: they both reflect adaptation, differentiation and the interactions of the genetic apparatus and the environment.

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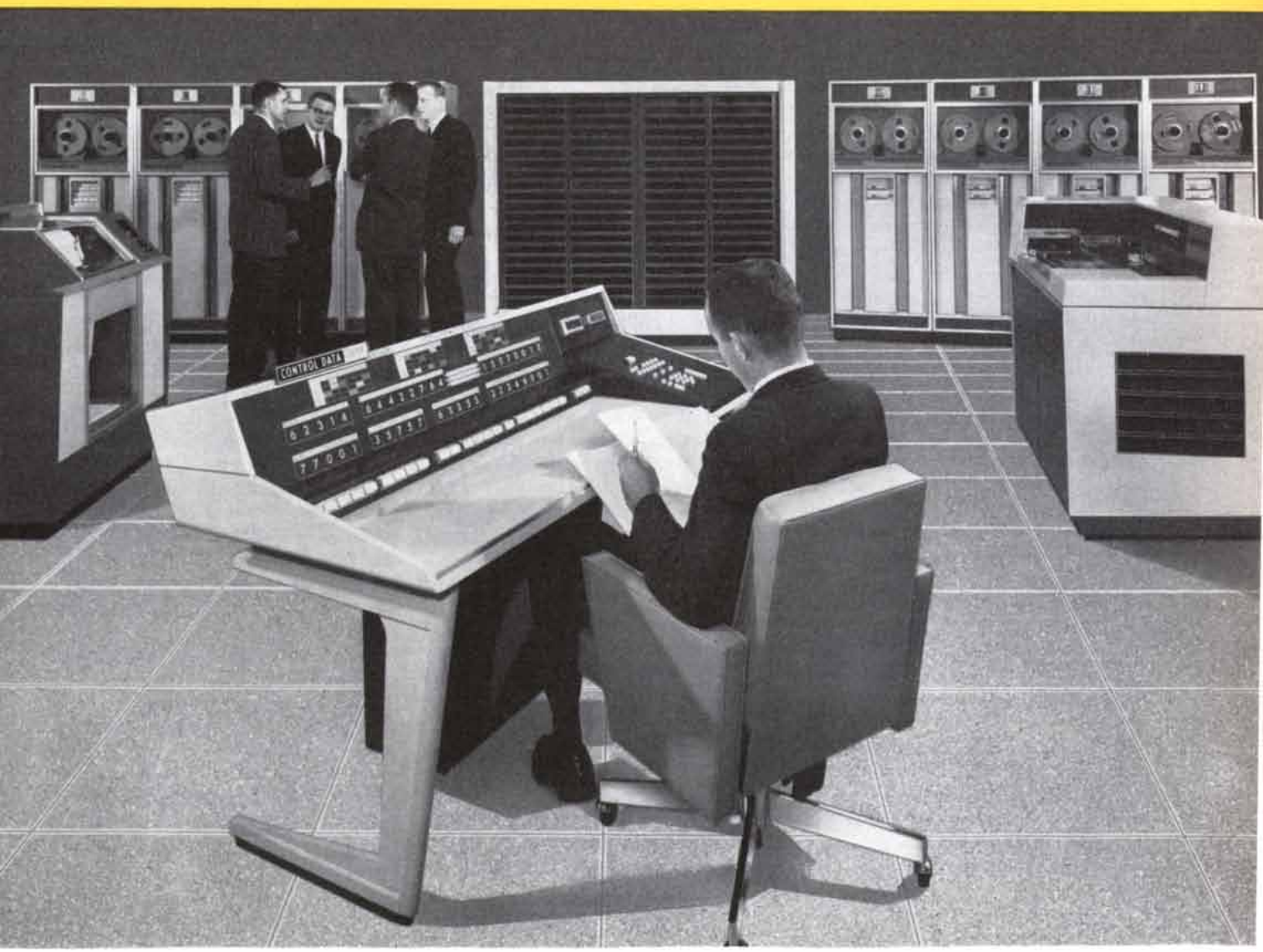


ANCIENT GLASS

Modern instruments of chemical and physical analysis now reveal that the ancient Egyptian and Roman glassmakers were sophisticated technicians as well as skillful artists

by Robert H. Brill

Glass is one of the most ubiquitous materials of modern technology, and men have made it for some 3,500 years, yet in comparison with other materials it is imperfectly understood. For example, there is technical debate as to what glass really is—what constitutes the molecular basis of its properties [see "Glass," by Charles H. Greene; SCIENTIFIC AMERICAN, January, 1961]. The glass that has survived from the ancient world is similarly enigmatic. In several ancient civilizations glassmaking was one of the most refined technological arts, and some ancient glasses are quite difficult to duplicate today. There are, however, broader questions: Exactly how did the ancient glassmakers make their glasses? Where and when and under what circumstances did men first make glass? The study of such questions with the aid of modern physical and chemical techniques has begun to illuminate not only the origins of glass but also the technological and cultural context of these origins.

Although there is debate as to the fundamental nature of glass, for the purposes of this article it will be sufficient to speak somewhat arbitrarily of glass as a fourth state of matter that combines the rigidity of a crystal with the largely random molecular structure of a liquid. Literally hundreds of thousands of glasses, each with its characteristic properties and chemical composition, have been made; thus the word "glass" is a generic term, and instead of speaking of glass it is better to speak of glasses, as we speak of ceramics, metals and textiles.

Ancient glasses are also diverse, but to clarify the problems they present it will be helpful to consider the making of an ordinary modern glass. The raw materials might consist of quartz sand, soda (sodium carbonate, Na_2CO_3) and lime (calcium oxide, CaO). The quartz provides silica (SiO_2), which is the basic stuff of glass. Quartz, however, melts at such a high temperature (above 1,700 degrees centigrade) that a flux must be added to it; this is the function of the soda. The lime is added because soda-silica glasses are soluble in water, and lime makes them much less so.

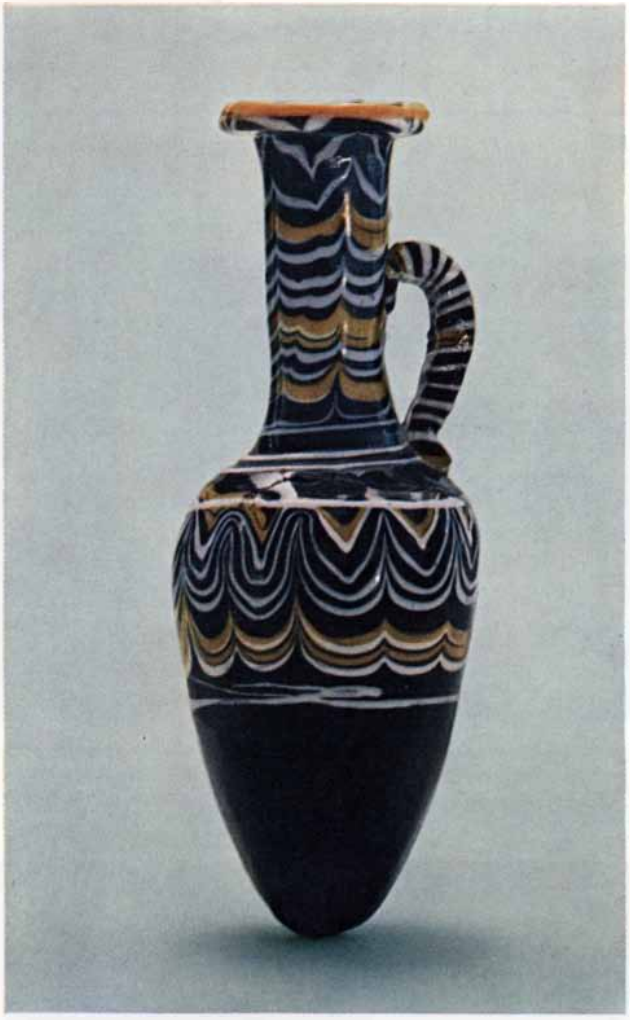
The three raw materials are crystalline, and when they are heated to, say, 1,200 degrees C., their crystal structures collapse; small groups of atoms move about and assume the random structure of a liquid. If the melt were now cooled slowly to room temperature, the atoms would crystallize in a somewhat different way; the result would be a mass of crystals of quartz, sodium disilicate ($Na_2Si_2O_5$) and devitrite ($Na_2O{\cdot}3CaO{\cdot}6SiO_2$). If, however, the melt is cooled quickly, it becomes so viscous that the atoms cannot quite find their way to their positions in the crystal lattices, particularly in the lattice of a crystal as complex as devitrite. As a result they are "frozen" into a random network of silicate chains with sodium and calcium ions interspersed throughout adjacent to negatively charged oxygen atoms [*see illustration on page 124*]. Other glasses of course contain different atoms, but the properties of all glasses are fundamentally based on this structure.

It is difficult to determine where and when men first made use of these properties. Dates as early as 2600 B.C. have been claimed for glass beads, but at least some of these dates are questionable. If we limit the argument to glass vessels, and include only those vessels that have a glassy nature throughout, it is certain that such vessels were made in Egypt early in the Eighteenth Dynasty (1580–1358 B.C.). A contemporaneous date, however, can be assigned to a few glass vessels from Mesopotamia, so that the question of the origin of glass remains open.

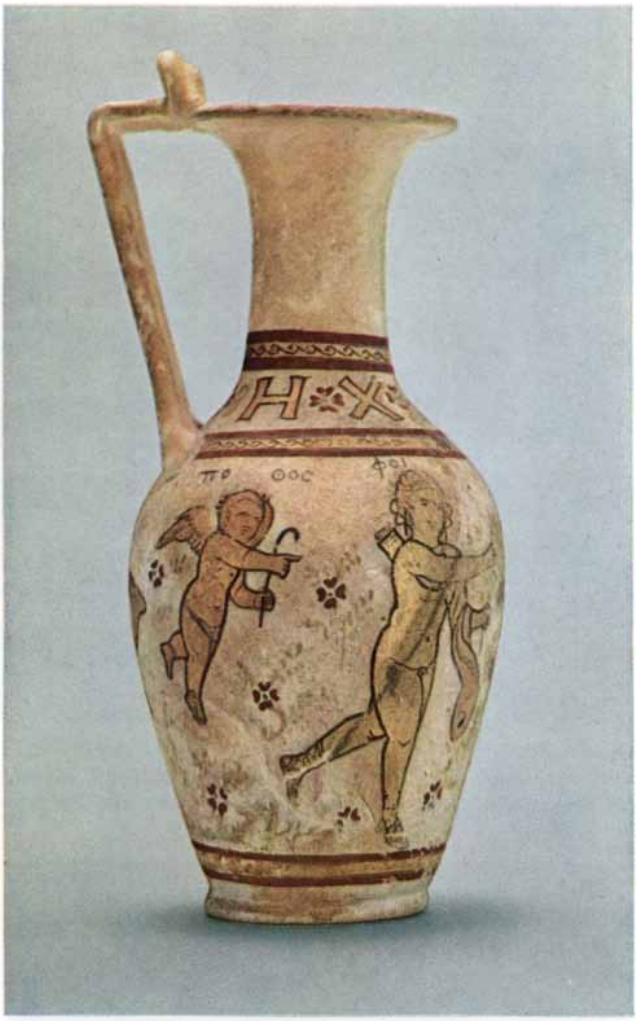
There are two plausible hypotheses as to how glass was discovered. Some scholars believe that glass arose from metallurgical operations; the smelting of copper and lead ores often produces glassy slags. It is known that copper was being smelted from azurite and malachite by 3000 B.C. at mining centers in Asia Minor, perhaps a little later on Cyprus (which gave copper its name) and on the Sinai Peninsula in a region that later became famous as King Solomon's Mines. Experimentation with the siliceous slags from the smelting furnaces might well have led to the making of glass. The fact that many early glazes and glasses were colored blue by the addition of copper lends some support to this hypothesis. The connection may not be as simple as it appears, however; the slags contain only a little copper and are much richer in iron than either the early glazes or glasses.

The second hypothesis is that glass arose from an evolutionary sequence of ceramic materials: the family of highly siliceous ceramics coated with alkali glazes, the oldest of which date back to earlier than 3000 B.C. in Egypt. These materials are quite distinct from clay-bodied pottery, which will not ordinarily take an alkali glaze. The coating of pottery with glazes does not seem to have been invented until long after glass had come into use.

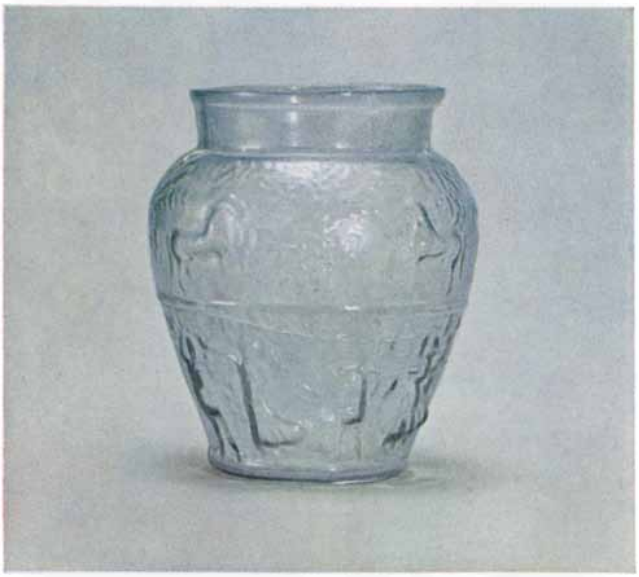
The immediate predecessor of glass in the sequence is the material known as faïence, which was used mostly to make small objects such as jewelry and is found in profusion at archaeological sites in Egypt and elsewhere. The surface of faïence is a transparent glass, usually blue or green, but its body is a white



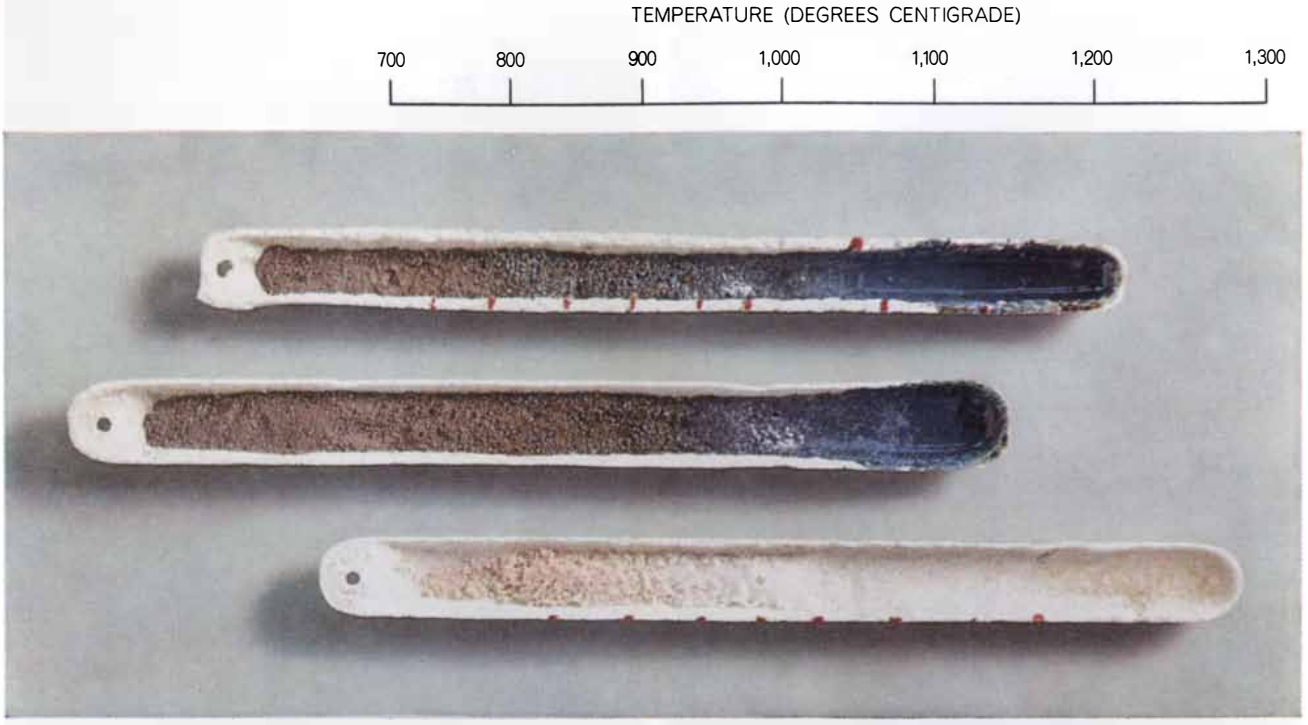
EGYPTIAN GLASS VESSEL was molded around a core of clay or sand, which was then scraped out. The colors and design of the vessel are characteristic of the Eighteenth Dynasty (1580–1358 B.C.).



DAPHNE VASE was "free-blown" in Syria about A.D. 200. Originally a translucent white glass, it has weathered to its present condition. Cupid urges Apollo after Daphne, who is on the other side.

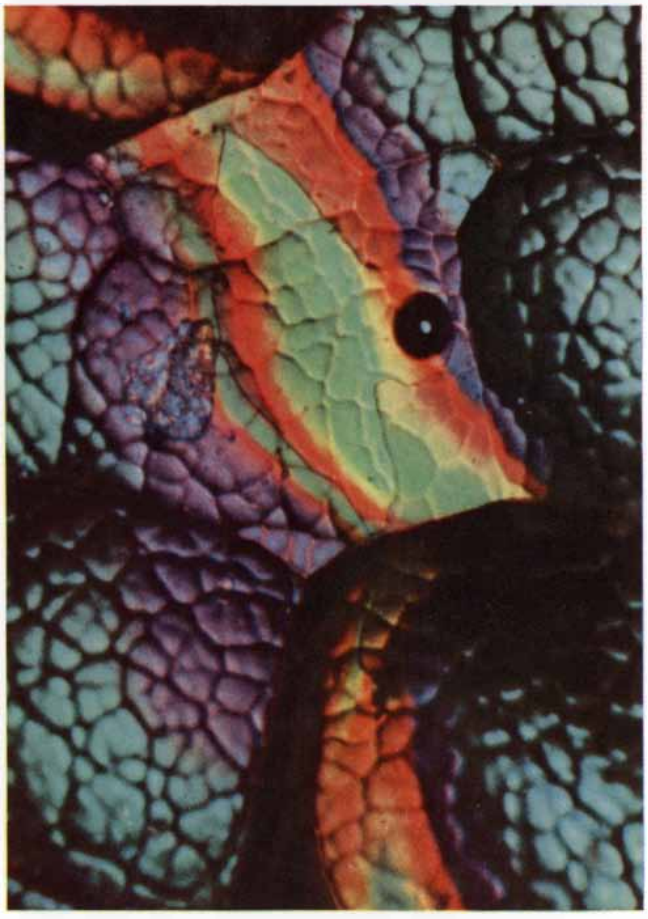


GLADIATOR BEAKERS, dating from about A.D. 50 to 150, represent another outgrowth of the Roman invention of glass blowing: the proliferation of cheap, mass-produced glassware. The beakers were blown into molds and were probably sold at gladiatorial contests as souvenirs; the one at the left shows a pair of gladiators in combat. The amber glass owes its color to the presence of iron combined in an iron polysulfide complex; the blue glass, to free iron impurities. All objects are from the Corning Museum of Glass.



GLASS WAS PRODUCED in the laboratory by mixing the raw materials (desert sand, limestone and natron) used by the ancient glassmakers and heating the mixture in a gradient furnace. The two boats at top contain Egyptian mixtures with a copper colorant added; the first was heated for four hours and the second for three. The colorless Roman mixture at bottom was heated for 16 hours.

ISLAMIC SHARD, about 1,000 years old, shows the iridescent colors that result when light is reflected from the thin weathering layers. Originally this was a clear glass with a pale greenish tint.



PHOTOMICROGRAPH of the pitted surface of another piece of Islamic glass is magnified about 900 diameters. The band of spectral colors is caused by a slight displacement of the weathering layers.

porous material consisting of crystalline grains of quartz loosely bound together by a glassy phase. In some specimens a thin layer of powdered material lies between the glaze and the body.

Chemical analysis reveals that the body of faïence usually consists simply of silica with a small admixture of soda and impurities. The study of several specimens by the technique of X-ray diffraction shows that the grains of silica uniformly have the crystal structure known as alpha quartz. This indicates that the material was heated to a temperature no higher than 870 degrees C.; if it had been, at least some of the alpha quartz would have been converted into the structure called tridymite.

The formation of the body of faïence is easily duplicated in the laboratory. Finely powdered quartz is moistened into a firm paste with a solution of sodium carbonate (called natron in ancient Egypt), formed in a clay mold and fired. During the firing the sodium carbonate attacks the surface of the quartz grains, giving rise to a glassy coating. When the grains cool, they are attached wherever they are in contact.

In this ordinary faïence the crystalline quartz grains predominate; there is a large proportion of empty space and only a small amount of glassy material. It is clear, however, that a few simple variations in the process described above, which could easily have occurred accidentally or as a result of tinkering, could have yielded a glass. If more sodium carbonate had been introduced and if the mixture had been fired at a higher temperature or for a longer time, the reaction between the quartz and the sodium carbonate could have proceeded further, so that the quartz grains would have been fewer and smaller and the material would have been mostly glassy. Having once made this crude glass, or "paste," the Egyptian faïence makers could readily have gone on with a little further experimentation to produce a true glass, that is, a material without any crystalline grains. There is, in fact, a type of faïence known as glassy faïence, the structure of which is intermediate between the structure of ordinary faïence and that of true glass, but it is not certain that it was made before the invention of glass itself.

It is puzzling that the Egyptians did not start making glass before they did. They had been making faïence for at least 1,000 years, and the accidents such as those described above must have occurred. It is possible that the invention of glass had to await the development of furnaces that could reach the temperatures required, although elsewhere in the ancient world suitable kilns seem to have long been in existence. We simply do not know enough about the Egyptian furnaces. If we assume that they could reach the necessary temperatures, what else could have been missing? Perhaps the need for glass, or the presence of the right person at the right time to see and seize the opportunity when it arose.

Another chemical cousin of glass is the material called Egyptian blue. Unlike faïence or glass, it is a specific compound: a crystalline silicate of copper and calcium with the formula $CuO{\cdot}CaO{\cdot}4SiO_2$. Like faïence, however, it was made both as a porous material and as a more compact one with a large proportion of glassy matrix. Egyptian blue was ground for use as a pigment, for example in wall paintings, and was molded into decorative jewelry. Some specimens of it look deceptively like glassy faïence, but they can be distinguished with certainty by X-ray diffraction. It is a remarkably stable material, as is indicated by the recovery of a mass of fused Egyptian-blue pellets from a Roman shipwreck; although the material had lain submerged in a Sicilian harbor for nearly 2,000 years it was scarcely corroded.

Wherever and however glass was invented, there is no doubt that glassmaking first really flourished in Egypt during the Eighteenth Dynasty. This was a period of great political vigor and of great achievements in industry and the arts, a period associated with such celebrated names as Thutmose, Hatshepsut, Amenhotep, Ikhnaton and Tutankhamen. The tombs of the Egyptian nobles at Thebes have yielded many beautiful "cored" glass vessels [*see illustration at top left on page 121*]. They were used as containers for cosmetics, such as the eye paint kohl, and were usually fashioned of dark blue glass decorated with surface zigzags of white and yellow glasses. The Egyptians apparently were not interested in using glass as a transparent substance. They favored deeply colored glasses, perhaps because these resembled semiprecious stones such as lapis lazuli.

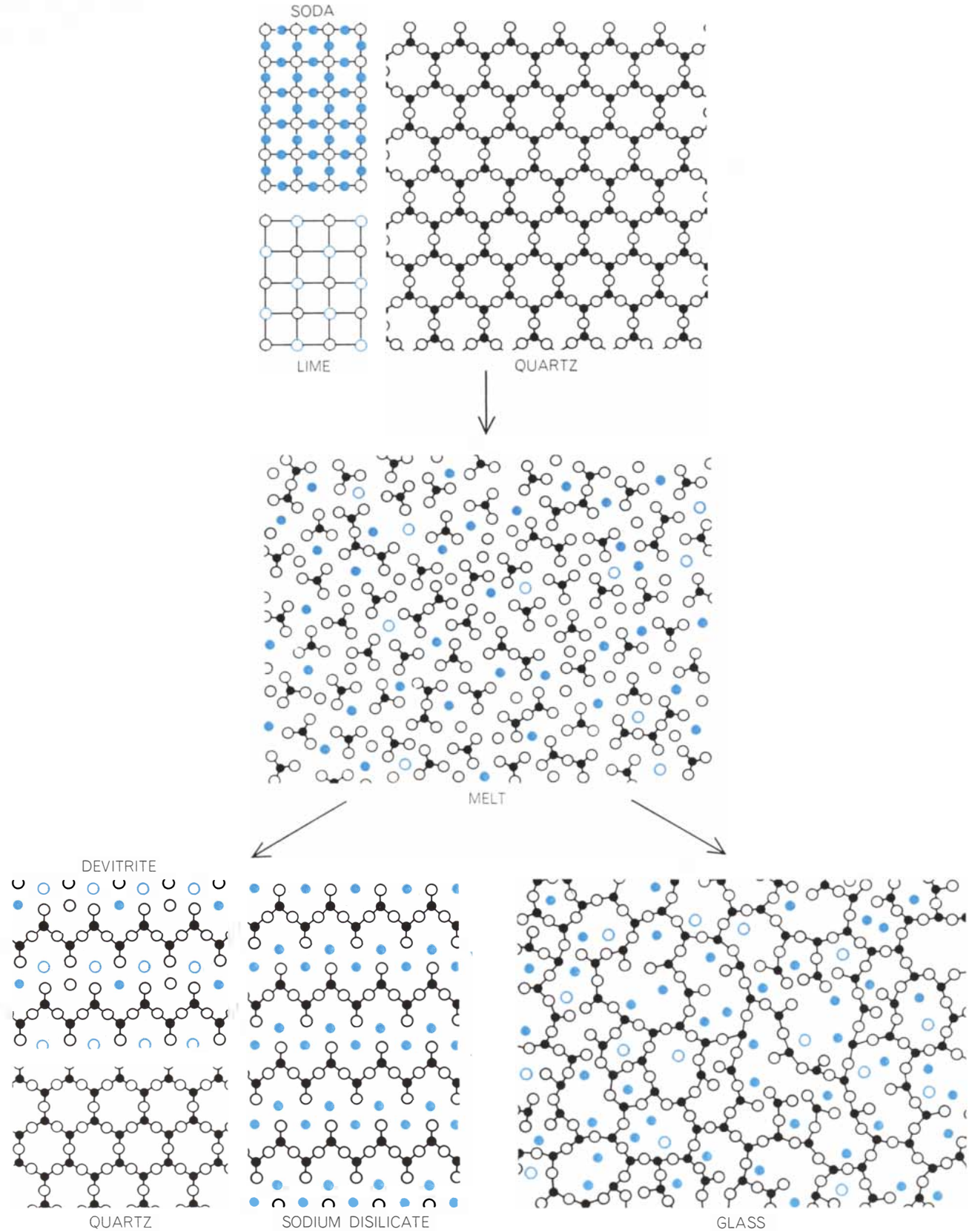
Glass blowing was unknown in this period. The vessels were formed around a core of clay or sand, which was scraped out after the object was finished. Most of the vessels still show traces of core material adhering to the inside surface, and some even bear the impression of a textile covering over the original core. The vessel was built up by dipping or rolling the core in softened glass. Later it was decorated by the application of threads of colored glass, which were then rolled flat into the surface. More elaborate decorations were made by "combing" a reheated vessel with a pointed tool, after which the vessel was polished. It was once thought that such vessels had been built up by winding softened canes of glass around the core, but the idea does not hold up under microscopic examination; this examination reveals no fine structure of streamers or trains of bubbles, which would inevitably be present if that method had been employed.

These sophisticated and beautifully made glass objects appear almost too abruptly during the Eighteenth Dynasty, suggesting that the Egyptians may have learned the technique from some older glass industry elsewhere. In any case the splendid burst of glass production in Eighteenth Dynasty Egypt seems to have lapsed with equal suddenness into a hiatus that lasted for several centuries.

Meanwhile, in the period of the eighth, seventh and sixth centuries B.C., an apparently independent glass industry arose in Syria and along the Palestinian coast. Glass was also made at the same time farther east in the Assyria of Sargon II; this may have been an outgrowth of earlier glassmaking in Mesopotamia. The skills and artistry of the descendants of these glassmakers were absorbed into the second major phase in the history of glass.

It was in Roman times that glassmaking developed into a large-scale industry, an industry that in many aspects is surprisingly akin to the one we know today. This development was brought on by the invention of glass blowing, probably sometime late in the first century B.C. The whole character of glass vessels changed: thin-walled vessels replaced the heavier forms of earlier periods. The new technique made possible the rapid production of simple utilitarian vessels, and glass became a household commodity. A middle-class Roman family probably owned glass storage containers, drank from glass vessels, looked through crude glass windowpanes and bought souvenir glass cups with the names of its favorite gladiators molded into them [*see bottom illustrations on page 121*]. Even the final resting place of many Romans was a glass funerary urn.

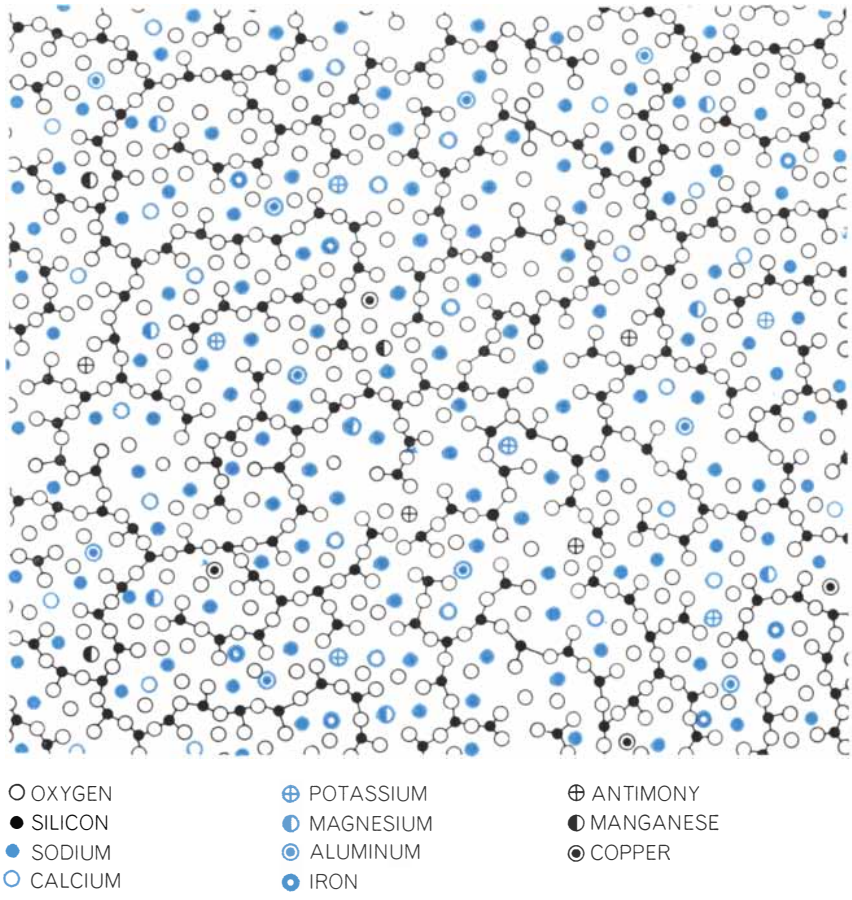
Everywhere the Romans went, there also went glass. Glass objects from Roman times are found in abundance out to the ends of the Empire, as far north and west as Scandinavia and



SODA-LIME GLASS is manufactured by mixing soda, lime and silica (in the form of sand or crushed quartz crystals) in the approximate proportions depicted at the top. When this mixture is heated, the regular crystal lattices break down into small molecular groups and take on the random configurations of a liquid (*middle*). If the melt is cooled slowly, the molecules crystallize out into three different compounds (*lower left*). If the melt is cooled quickly, the molecules become "frozen" into a metastable or glassy state (*lower right*). These two-dimensional diagrams are highly schematic and are intended only to suggest the ordered three-dimensional structures of the crystals. The diameters of individual atoms have been reduced for clarity.

Britain and as far east and south as eastern Syria and Ethiopia. The Romans are usually praised for their practical skills rather than for their aesthetic achievements, but in the case of glass they excelled on both counts. In addition to a vast number of utilitarian objects they left a legacy of luxury glass whose beauty has hardly been surpassed in any period; an example is provided by the Daphne Vase at the top right on page 121.

With the decline of Rome the centers of glassmaking, with a few exceptions in western Europe, returned to the Middle East. The Byzantine Empire contributed some magnificent glass objects and brilliant mosaics that utilized hundreds of thousands of tiny glass tesserae. Then, along with so many other chemical arts, glassmaking knowledge was preserved by the world of Islam until the coming of the Renaissance in the West. In Islam glassmaking flowered for the third time, combining Roman knowledge with indigenous traditions. Characteristic of the period were richly enameled lamps and deep-cut vessels. In the 12th century the pendulum began to swing westward again in the hands of the glassmakers of Venice and the artisans who made stained-glass windows for the great cathedrals. It was from all these roots—ancient, medieval and Renaissance—that the modern glass industry evolved.



TYPICAL ROMAN GLASS is a soda-lime-silica glass with large quantities of free metallic ions introduced by impure raw materials and low-quality refractory vessels. The relatively few copper ions in this mixture are sufficient to give the glass a deep blue color.

The investigation of how ancient glass was made has had to proceed with the handicap that few remains of the ancient glassmakers' factories or tools have survived. In 1891 and 1892 the Egyptologist Sir Flinders Petrie excavated the site of an Eighteenth Dynasty factory at Tell el 'Amarna, but it is said that little remains to be seen there today. The same is true of most other reported sites. Hence most investigations of ancient glass technology have been conducted in the chemist's laboratory. Some assistance is provided, however, by ancient literary sources.

Among the thousands of clay cuneiform tablets found in the library of Ashurbanipal at Nineveh is a series containing detailed—although sometimes puzzling—directions for preparing glass. The tablets were written in about the seventh century B.C., but on the basis of literary style they have been shown to be copies of texts several centuries older. The texts were first translated some years ago and have since been a source of controversy

This year, however, a new translation of these and related texts by Leo A. Oppenheim of the Oriental Institute of the University of Chicago revealed certain errors in the earlier translations. Oppenheim's version of the texts, supported by chemical and technological reasoning, leaves little doubt that they describe the manufacture of colored glass emulating semiprecious stones. By following the recipes, making guesses as to the identity of some of the ingredients, it is possible to make glass.

The most direct means of studying ancient glass remains chemical analysis. The first analyses of glasses of any sort were those of a few pieces of glass from a Roman mosaic found on Capri. These were reported in 1797 by Martin Heinrich Klaproth of Germany, best known today as the discoverer of uranium. There were no really systematic chemical studies of ancient glass, however, until this century. The leading workers have been W. E. S. Turner of the University of Sheffield, Wilhelm Geilmann of Mainz and Mikhail A. Besborodov of Leningrad, all of whose pioneering efforts have served as points of departure for research in ancient glass.

Chemical analysis shows that the composition of ancient Egyptian and Roman glasses was surprisingly close to that of some glasses made today. Virtually all the ancient glasses were soda-lime-silica glasses with impurities introduced by impure raw materials and the corrosion of the refractory vessels in which the glass was made. In medieval times potash generally replaced soda.

The source of silica was sand and possibly on occasion crushed pebbles. The most likely source of soda was natron, which consists chiefly of sodium carbonate and bicarbonate; it was available in vast desert deposits at Wadi el Natrun between Cairo and Alexandria. In this large, flat basin a group of lakes rises up annually after the flooding of the Nile, apparently fed by underground seepage. When the lakes are evaporated by the hot desert sun, natron is laid down along with other salts. The Egyptians used natron for a cleansing agent, for the preparation of mummies and almost certainly for the manufacture of glass. The Mesopotamian tablets, on the other hand, specify the ashes of the "naga" plant as a source of soda.

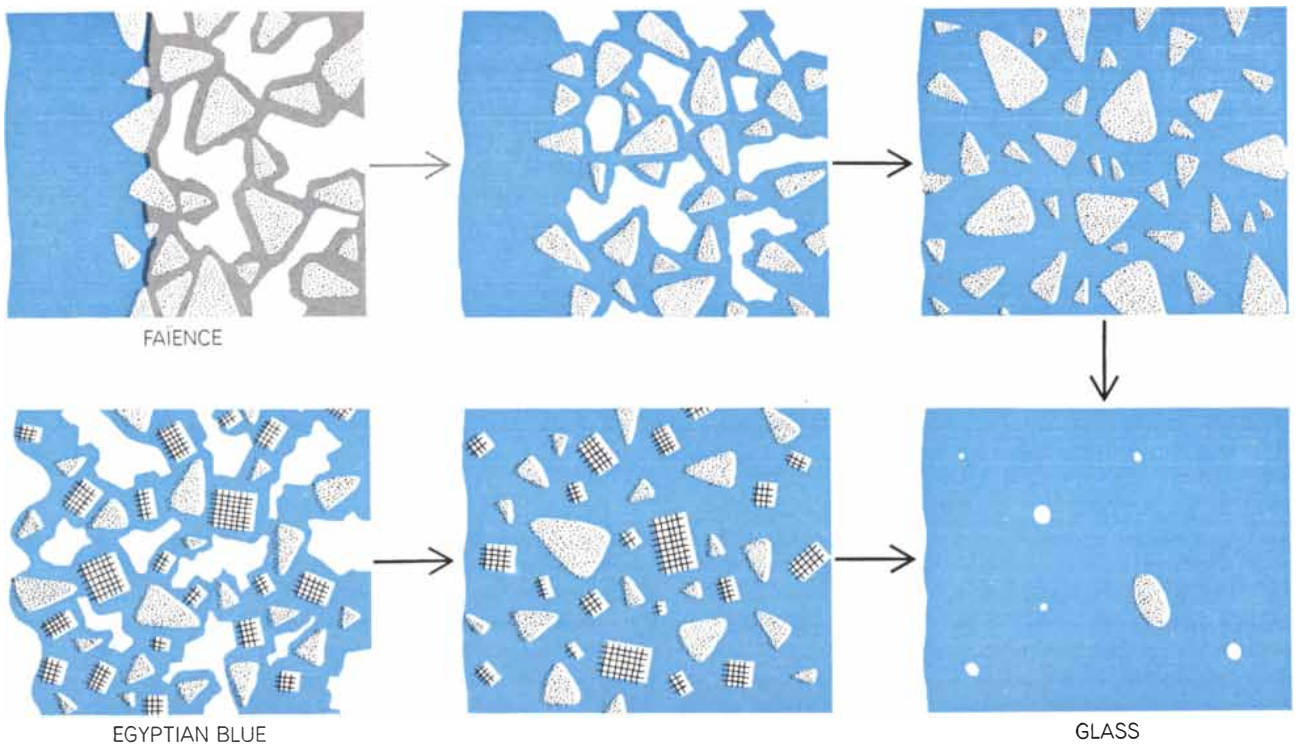
As for lime, it is possible that in Egypt this ingredient may have been supplied accidentally by desert sands that have a high proportion of limestone grains, but it is more likely that lime was a separate ingredient. Lime was certainly used intentionally in Roman times, because the calcium content of Roman glasses is quite uniform. Chalk, limestone or burned shells would have been convenient sources of lime; all served in later periods. The Mesopotamian tablets in some places specify "ground red shells from the sea"; this could have been a lime ingredient.

An important study of more than 400 specimens of ancient glasses has recently been completed by Edward V. Sayre of the Brookhaven National Laboratory and Ray W. Smith. Their findings, based chiefly on spectrographic analysis, indicate that ancient glasses can be divided into a small number of distinct categories, depending on their contents of antimony, manganese, potassium, magnesium and lead. At this stage the categories are only broadly defined, but continuing work is bringing them into clearer focus. This study has established, among other things, the deliberate addition by ancient glassmakers of antimony and manganese, probably to eliminate color from their glasses. Clear glasses containing antimony date back to about the seventh century B.C. and those containing manganese to the first century B.C.

The colors of ancient glasses were produced by agents that are much the same as those in use today; the greenish cast of most ancient pieces is due, however, to the unintentional presence of iron impurities in the raw materials. The Roman glassmakers sometimes turned this to their advantage. For example, one of the two gladiator beakers at the bottom of page 121 is blue and the other is amber, yet each color is caused by iron. Iron is usually present in glass as a mixture of ferrous ions (Fe^{++}) and ferric ions (Fe^{+++}). The ferrous ion, a strong absorber of light in the red region of the spectrum, tends to color the glass blue; the ferric ion, a weaker absorber in the violet, tends to color it yellow. The combined visual effect of the two ions is green. The blue beaker in the illustration is noticeably bluer than most other Roman glasses, which indicates that it was probably melted or worked in a mildly reducing (nonoxidizing) atmosphere that would increase the proportion of ferrous ions. The color of the other beaker is due to an iron polysulfide complex, and it was probably produced by preparing the glass in a still stronger reducing atmosphere. The same kind of process is followed today in making amber glasses for railroad signals and beer bottles.

We have already noted that many of the ancient glasses were blue owing to the presence of oxidized copper. Cupric ions give glass the same color they give water, which nicely illustrates the close analogy between the structure of glass and that of a liquid. Another blue coloring agent, detected in many ancient glasses such as the Egyptian cored vessel at the top left on page 121, is cobalt. A minute content of cobalt oxide, of the order of .05 per cent, will impart a deep blue color to glass.

The ancient glassmakers must have been mystified by the way in which a metal the color of copper or a green mineral such as malachite could result in a blue glass or even a brilliant red opaque one. When a copper-containing glass is melted in a reducing atmosphere, particles of red cuprous oxide and/or copper itself can be precipitated in suspension throughout the glass. The addition of lead to the mixture will help the process, because lead increases the solubility of copper at high temperatures and causes this solubility to decrease rapidly as the temperature is lowered, thereby enabling more cuprous oxide to be precipitated. The ancients evidently were aware of this in an empirical way; most



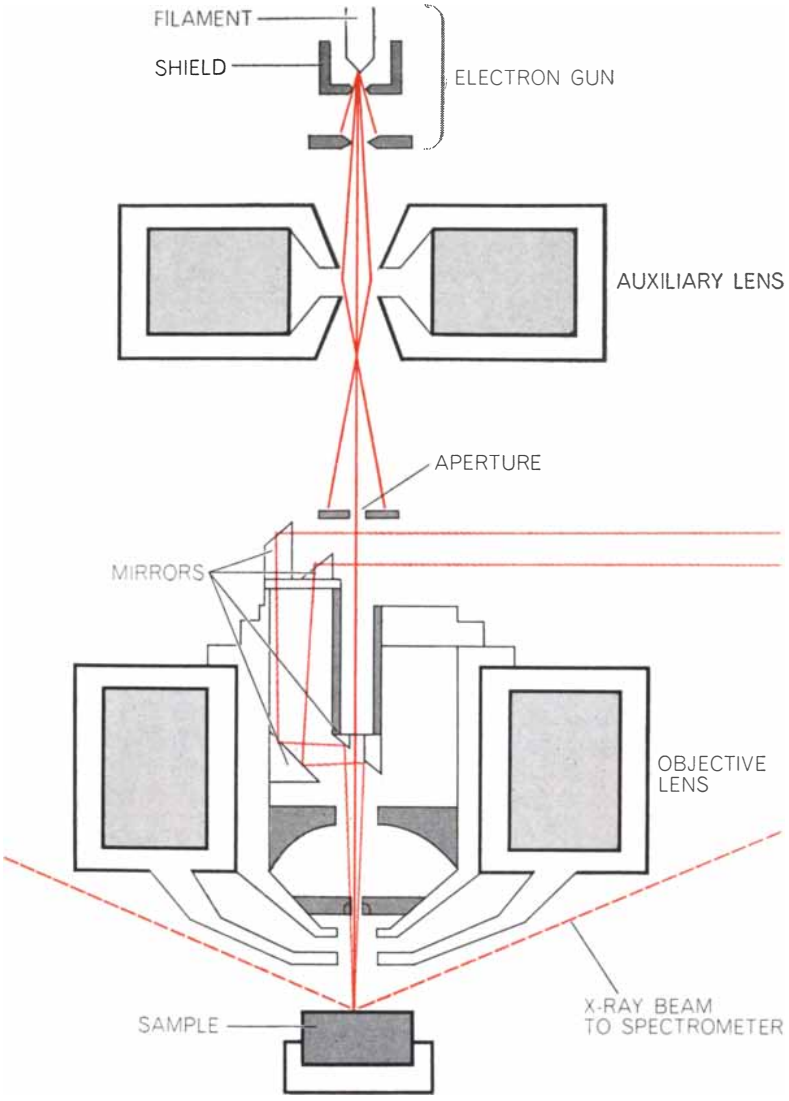
GLASS MAY HAVE EVOLVED in three steps from ordinary faïence (*top left*) or in two steps from porous "Egyptian blue" (*bottom left*). Each transition indicated by a black arrow represents a grinding up and refiring of the previous product. Stippled areas indicate individual grains of crushed quartz; hatched areas indicate copper calcium tetrasilicate crystals; irregular white areas indicate air spaces. In the drawing of faïence that appears at the top left the gray areas represent a colorless connective glass.

of the few early glasses that contain lead have this opaque red color.

That the ancient artisans were quite aware of the difference between oxidizing and reducing atmospheres is also clear from the Mesopotamian recipes for manufacturing "a fine red lapis lazuli." The recipes specify that the batch, which contains copper, must be heated in a smoky (that is, nonoxidizing) fire and the finished product allowed to cool inside the closed oven. They knew then, as we do today, that if the molten material were exposed to air its surface would be oxidized in a matter of seconds to a transparent greenish color. To make "a blue lapis lazuli" the ancient craftsman was directed to prepare the batch in a smokeless fire, which would keep the copper in its blue oxidized state.

Another coloring agent with diverse effects is manganese. When added as manganese dioxide, the manganese acts as an oxidizing agent, and by oxidizing the ferrous iron to ferric removes part of the greenish color due to iron impurities. Ancient glassmakers, however, also added manganese to their glasses for coloring purposes: in some valence states manganese gives rise to an amethyst color. When clear glass has been exposed to the sun for a very long time, the reoxidation of reduced manganese by the action of ultraviolet rays can give the glass a pink or purplish cast. This "solarization" effect is responsible for the violet color of so-called desert glass and for the well-known violet windows in the old houses along Beacon Street in Boston.

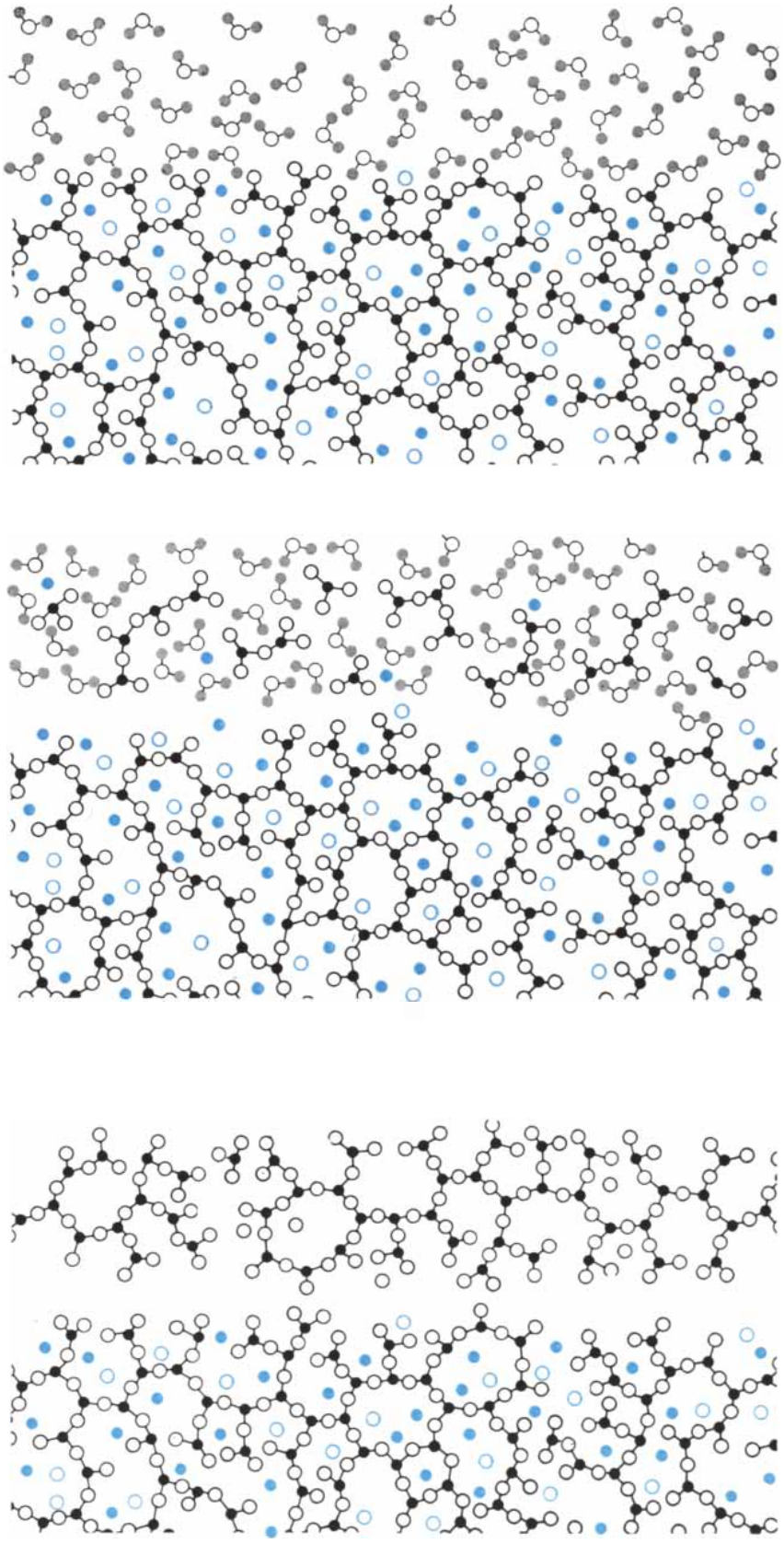
X-ray diffraction studies and electron-beam-probe microanalysis show that early glassmakers produced their white opaque glasses with the calcium-antimony compound $Ca_2Sb_2O_7$ and yellow opaque glasses with the lead-antimony compound $Pb_2Sb_2O_7$. All the colors of ancient glasses mentioned here have now been successfully duplicated.



ELECTRON-BEAM PROBE was used to perform chemical analyses of ancient glass objects without damaging them. When the beam of electrons (*solid colored line*) strikes the sample, the atoms at or near the surface of the sample are excited to higher energy states and emit X rays (*broken colored lines*). A spectrometer collects the X rays and measures their wavelength and intensity. These measuremnts are then converted into weight percentages of the elements detected. The beam can be focused on an area as small as one or two microns in diameter. The light colored line indicates the optical path from sample to viewer.

It has also been possible to reconstruct in laboratory experiments the conditions in the ancient glassmaking furnaces about which we know so little. One of these experiments, performed at the Corning Museum of Glass, employs a refractory boat heated in such a way that there is a temperature gradient along the boat, one end being a few hundred degrees hotter than the other [*see top illustration on page 122*]. The boat is filled along its length with a mixture of the raw materials the ancients used for glassmaking: sand, natron, limestone and coloring oxides. At the hot end of the boat these materials melt to a very nice glass; at the cooler end the temperature is too low and most of the material remains unreacted. By examining the boat almost as one would read a yardstick one can determine the lowest temperature at which an acceptable glass can be made in a reasonable time. In the case of the blue Egyptian glasses in the illustration this temperature is about 1,060 degrees C.; for the colorless Roman glass it is 1,100 degrees. The temperature requirements of early glassmaking have also been investigated by synthesizing the glasses and measuring how their viscosity varies with temperature. Such tests have shown, for example, that in order to make the typical Roman glass shown schematically in the illustration on page 125 fluid enough for glass blowing it had to be heated to at least 1,080 degrees.

An ordinary campfire probably cannot produce a temperature much higher than 700 degrees, which is insufficient to melt glass or make Egyptian blue. It is also probably insufficient to produce ordinary faïence. The ancient glassmakers must therefore have built furnaces similar to pottery kilns. Old Roman pottery kilns that have recently been reconstructed in England have been able to reach temperatures as high as 1,100 degrees without a forced draft. Very likely they could develop even higher temperatures with the help of chimneys, bellows and the proper orientation with



WEATHERING LAYERS are formed when a piece of glass is subjected to alternating wet and dry seasons. During the rainy season (*top and middle*) soil water penetrates the glass surface and leaches out the metallic ions, leaving behind a partially depolymerized silica gel. During the next dry season (*bottom*) the water evaporates and the silica tends to repolymerize into a physically separate layer. The entire process is repeated during the next seasonal cycle. The layers are about one micron thick. Gray dots represent hydrogen atoms.

respect to the winds prevailing in the locality.

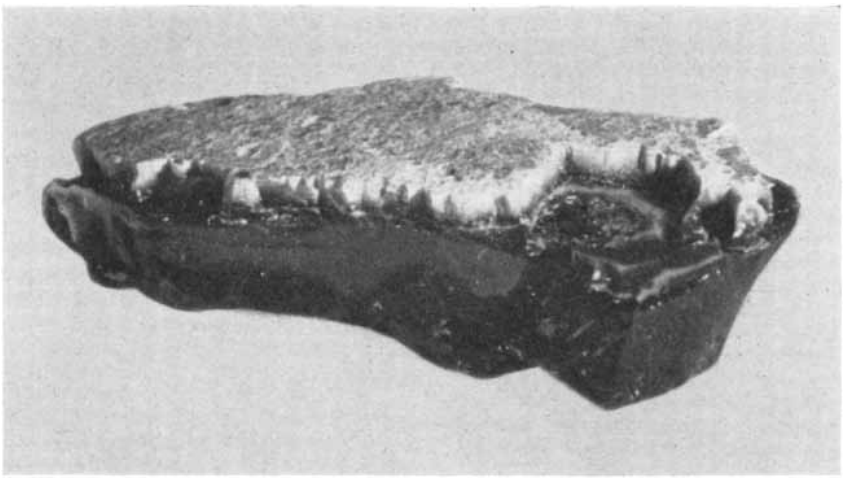
The glassmaker's highest art consists not only in producing beautifully colored glasses but also in forming exquisite designs with his uniquely versatile material. One of the most remarkable examples of ancient art in glass is the Roman plaque that appears on the cover of this issue of *Scientific American*. Fabricated in either the first century B.C. or the first century A.D., the plaque was designed as a piece of jewelry or as an inlay. It measures about three centimeters by two centimeters, and its intricate design is made up of no less than nine different colored glasses. The design runs through the plaque; it is exactly the same on both sides except that each is the mirror image of the other. This fact and microscopic examination of the details indicate how the object was made.

Let us focus our attention on the yellow and dark-colored grape-cluster motif in the design. First the artist collected on the tip of a metal rod (now known as a pontil iron) a small molten mass of dark blue glass. Then he rolled or dipped this mass in a molten yellow glass. The new mass was now drawn out into a cane, yielding a dark blue core surrounded by a yellow casing. Next the cane was broken into short lengths and eight pieces were assembled in a bundle. This was heated until the canes fused together into a single rod. Now the cross section was an eight-member cluster of the blue and yellow motif. This rod was in turn heated and drawn out into a cane. The effect was to miniaturize the whole design because the cross-sectional pattern remained unchanged as all the elements were reduced in diameter. The grape-leaf motif we see in the plaque is the cross section of such a cane.

The plaque as a whole consists of between 20 and 30 separate design elements. Some of these were used more than once, and some are not simple round canes but have been shaped by grinding or reheating. Notice particularly the three leaf motifs above the head and the 12 repeats of the beard design. Finally the canes were assembled and fused at about 785 degrees into one bar several inches long. From such a bar a number of plaques could be made by sawing or breaking off cross-sectional slices and polishing them. Under the microscope the plaques show not only repetitions of identical design elements but also boundaries and imperfections that leave no doubt that they were formed chiefly by this technique. (The

same technique and a few cents' worth of modeling clay or plastic can provide pleasant diversion for a rainy afternoon.)

The study of the plaque was facilitated by the technique of electron-beam-probe microanalysis, which was applied by Sheldon H. Moll of the Advanced Metals Research Corporation in co-operation with the author. With this technique a tiny bit of material is probed with a thin beam of electrons; the X rays generated by the passage of the electrons through the material can then be sorted into a spectrum revealing the material's constituents [*see illustration on page 127*]. Even individual flakes of opacifying agents, too small to be seen without the aid of a microscope, were analyzed. The beauty of the method is that it does not require the destruction of the sample or any part of it.

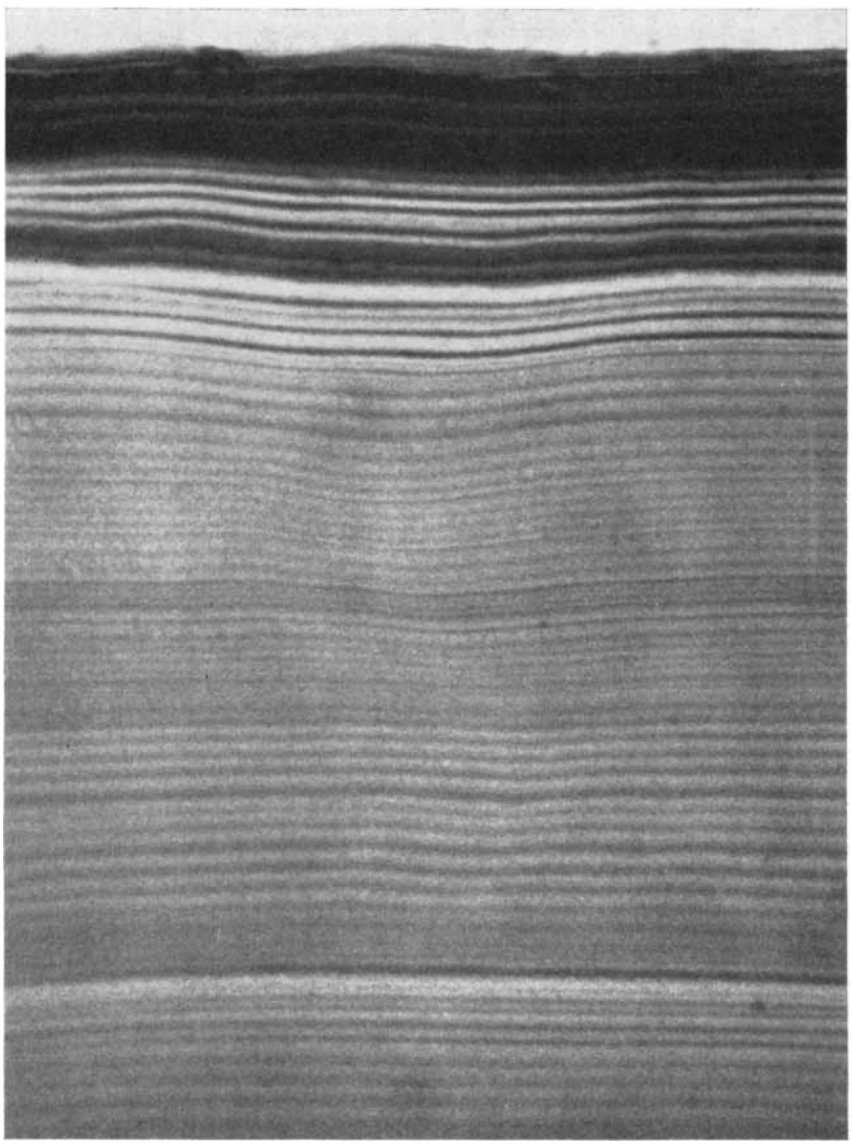


FRAGMENT OF OLD WINE BOTTLE, recently found on the sea bottom off Port Royal in Jamaica, was submerged during an earthquake in 1692. A count of the weathering layers in its crust yielded a date of 1691, plus or minus five years. Presumably the layers were formed as a result of slight annual variations in the water temperature at the bottom of the sea.

Most people, when they look at ancient glass for the first time, are surprised to see how badly it is corroded. We think of glass, unlike metals, as being highly resistant to chemical attack. Actually most man-made glasses are subject to slow corrosion by water, which over a long period of time leaches out the soda, lime and some other components, leaving behind the silicate skeleton of the glass. In arid desert areas glass may be very well preserved; for example, ancient Roman glasses discovered a few years ago in their original wrappings in caves near those in which the Dead Sea Scrolls were found were still in pristine condition. Most of our samples of ancient glass, however, come from buried sites where for centuries they have been subjected to periodic soaking. As a result many are covered with a crust of corrosion products that can be as much as two millimeters thick.

Although they vary greatly in color, texture and thickness, these weathering crusts have one feature in common: they invariably consist of thin transparent layers stacked one on another [*see illustration at right*]. These layers are usually .0005 to .003 millimeter thick and consist almost completely of amorphous silica with no coloring ions present. The partial reflection of light from the layers, however, produces interference effects that often give pieces of ancient glass a brilliant iridescence, such as we see (for the same reason) in soap bubbles, in some bird feathers and in films of oil on water.

The existence of the layers suggests that the number of layers, like the number of rings in a tree trunk, may be an index of the age of the glass. This idea has indeed proved useful for dating

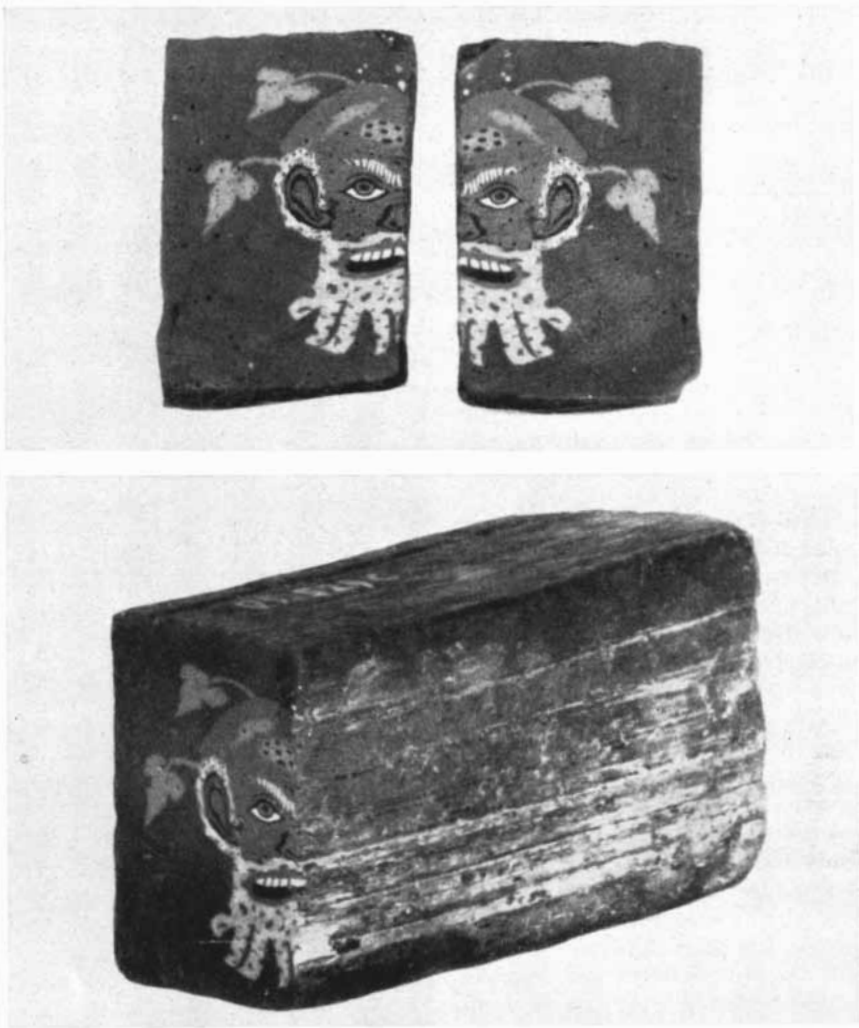


CROSS SECTION of the weathering crust on another 17th-century wine bottle is magnified about 750 diameters in this photomicrograph. Clear substance at top is the supporting plastic.

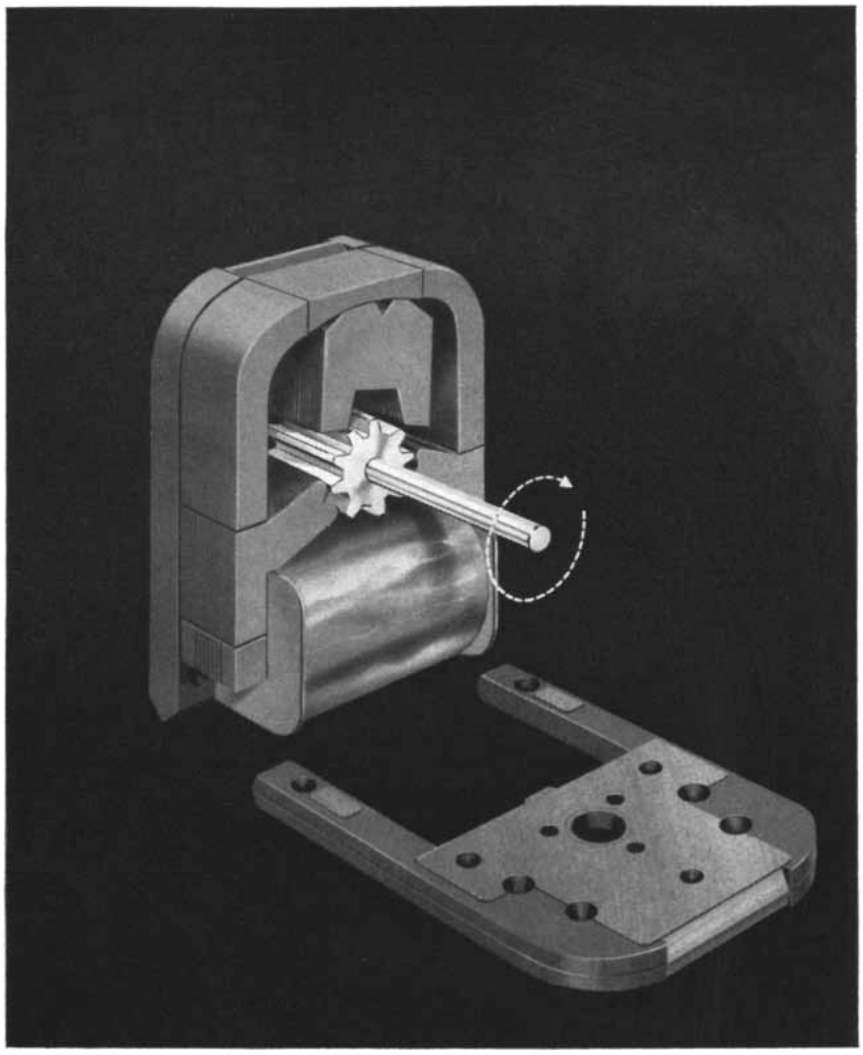
some ancient specimens. The hypothesis that the formation of the layers reflects annual cycles of rainfall and temperature was tested by counting the number of layers in samples of glass that had been buried or submerged for known periods of time. The method was shown to be successful for a few glass objects of the late Roman and Islamic periods and for several from more recent times. It is of course important that the complete weathering crusts be intact on the fragments to be dated. Unfortunately this is not often the case; the layers are so thin and fragile that they usually flake away in the soil long before they are excavated.

One particularly interesting example of weathered glass is a wine bottle recently recovered from the bottom of the sea off Port Royal in Jamaica. It is difficult to explain why this bottle should have a stratified weathering crust; nevertheless, a count of the layers in the crust indicated it had been submerged since 1691 plus or minus five years, and the historic fact is that part of the city of Port Royal sank into the sea during an earthquake in the year 1692. Presumably the layers in this case were formed as the result of annual variations in temperature at the bottom of the sea, but the little information we have indicates that the difference is only of the order of four degrees C.

It is clear, then, that much work remains to be done on ancient glass, and that even with the advantages gained by using the most modern instruments the laboratory can provide, the student of ancient glass must still enlist the aid of workers in many fields. He must call on the geochemist to tell him about trace elements in ancient glasses, on the botanist to tell him about the "naga" plant and on the oceanographer to tell him about chemical conditions on the sea bottom. Above all, he looks forward to the day when an archaeologist will unearth the site of an ancient glass factory.



MOSAIC PLAQUES AND BAR from which they were cut are in the Freer Gallery of Art in Washington. The plaques are similar to the one on the cover of this issue. The lateral grooves on the bar show that it was assembled from many small canes of colored glass.



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QUICK CLAY

It is a water-soaked glacial deposit that sometimes changes suddenly from a solid to a rapidly flowing liquid, causing disastrous landslides in parts of Scandinavia and Canada

by Paul F. Kerr

A farm owned by a man named Borgen lies on a plain near the Norwegian city of Oslo. A shallow ravine runs through the farm. On the afternoon of December 23, 1953, Borgen was walking along the ravine and noticed a small landslide at one point in the bank. The slide was so insignificant that even an expert in soil mechanics would hardly have given it a second thought. Farmers in Norway, however, are aware that the clay of their country sometimes behaves peculiarly. Borgen hurried home and moved his family to a neighbor's house some distance away.

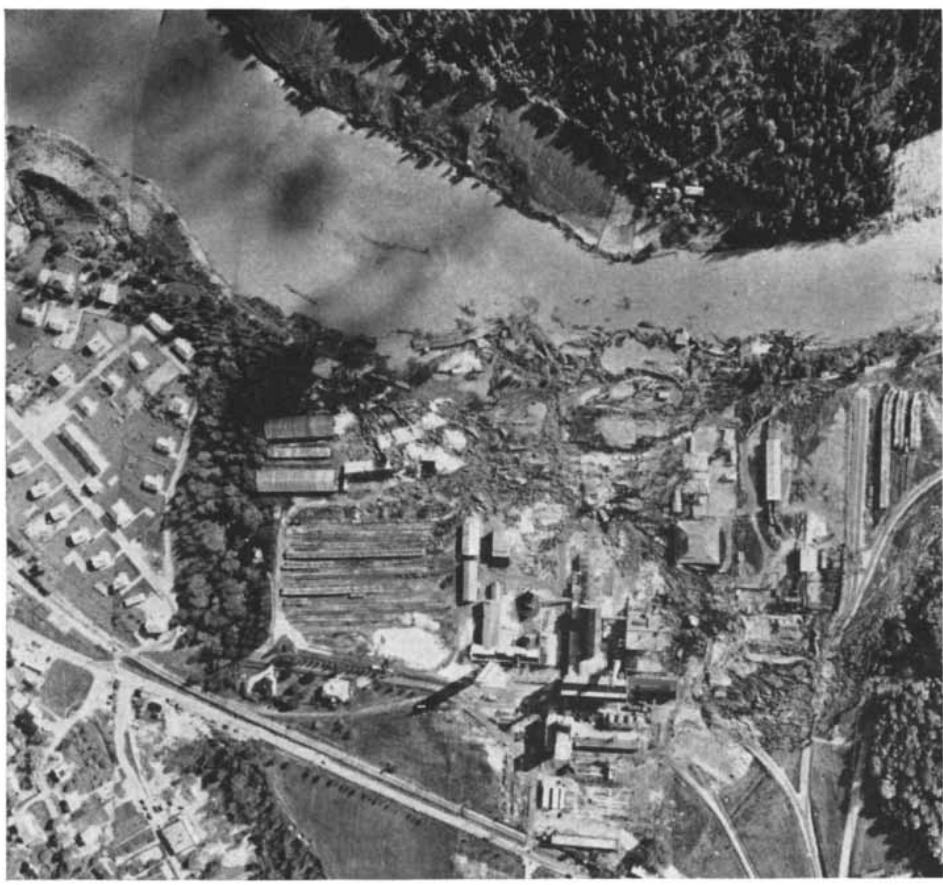
The next morning the site of his home had vanished—house, barn and all. In its place was a circular crater some 650 feet in diameter and 30 feet deep. Many of the things that had stood on the site were deposited against a highway bridge more than a mile down the ravine, where in the morning Borgen found a cow and a horse plastered with mud climbing out of a soupy lake.

During the night a section of the ravine bank had suddenly opened, and a river of mud about 75 feet wide had poured down the ravine. The land on which the farmhouse stood had suddenly become fluid and flowed through the channel formed by the collapse of the ravine bank. The avalanche of mud and buildings had stopped only after piling up against the bridge.

The Borgen incident, reported in detail by the Norwegian mineralogist I. Th. Rosenqvist, is a characteristic example of the behavior of the substance known as quick clay. This singular material acts like certain gels (for example iron hydroxide) that, when suddenly jarred, promptly turn into a liquid. Such substances are called thixotropic, a Greek-derived term meaning "turning by touch." Quick clay, a natural aggregate made up of very fine mineral particles and water, behaves in a similar fashion. A liquid thixotropic gel, however, in time reverts to its solid state, whereas a quick clay does not.

Quick clay can be changed from solid to fluid by an earthquake, an explosion or even the jar of a pile driver. It will then flow rapidly along any slope or almost no slope at all. Quick clay can slide like an avalanche over flat land with a slope of less than one degree, rafting along heavy structures in its path.

The areas where quick-clay slides are reported most frequently are Norway and Sweden, which have several each year, and the valleys of the St. Lawrence, Ottawa and Saguenay rivers in Canada. It appears that some have also occurred



QUICK-CLAY SLIDE of June 7, 1957, at Göta in Sweden was one of the largest of modern times. Clay beneath a pulp mill suddenly became liquid and rafted most of the buildings and huge stacks of logs up to 220 feet toward the Göta River. Three workers were killed,

in Maine, Vermont and northern New York. The most damaging slide on record was one that took place at Verdal in Norway in 1893. It wrecked a settled area of three and a half square miles and killed 120 persons. Two similar disasters, which have been studied in more detail, occurred during the 1950's.

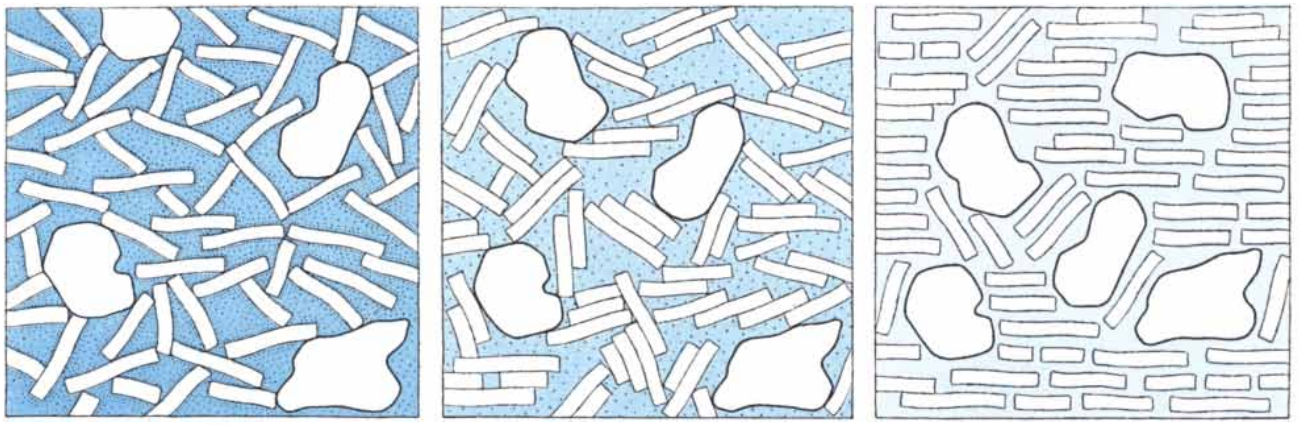
At 11:40 A.M. on November 12, 1955, an area within the town of Nicolet in Quebec suddenly began to slide away. In less than seven minutes the rapidly departing clay left a hole 600 feet long, 400 feet wide and 20 to 30 feet deep in the heart of the town. It carried away a school (the Académie Commerciale), a garage, several other buildings and a bulldozer. The whole mass flowed into the Nicolet River, and the schoolhouse wound up on the riverbank near a bridge, where it caught fire. Fortunately it was empty, its students having been dismissed for a midday recess, but three persons in the town lost their lives in the landslide.

A considerably larger slide had devastated the south end of the town of Surte in southern Sweden, a community of several thousand people, on September 29, 1950. The town sits in a flat valley on glacial clay deposits at least 120 feet deep. It seems that a pile driver, preparing a foundation for a new building, may have started the slide. At 8:10 A.M. a large section of the town, most of it residential, began to slip away toward the nearby Göta River. The huge mass, estimated to contain some 106 million cubic feet of soil and gravel and bearing 31 houses, flowed rapidly over the flat terrain. It picked up a paved highway and railroad roadbed in its path and finally plunged into the river, almost completely choking the channel. According to witnesses the entire slide took place in less than three minutes. It killed one person, injured 50 and destroyed the homes of 300.

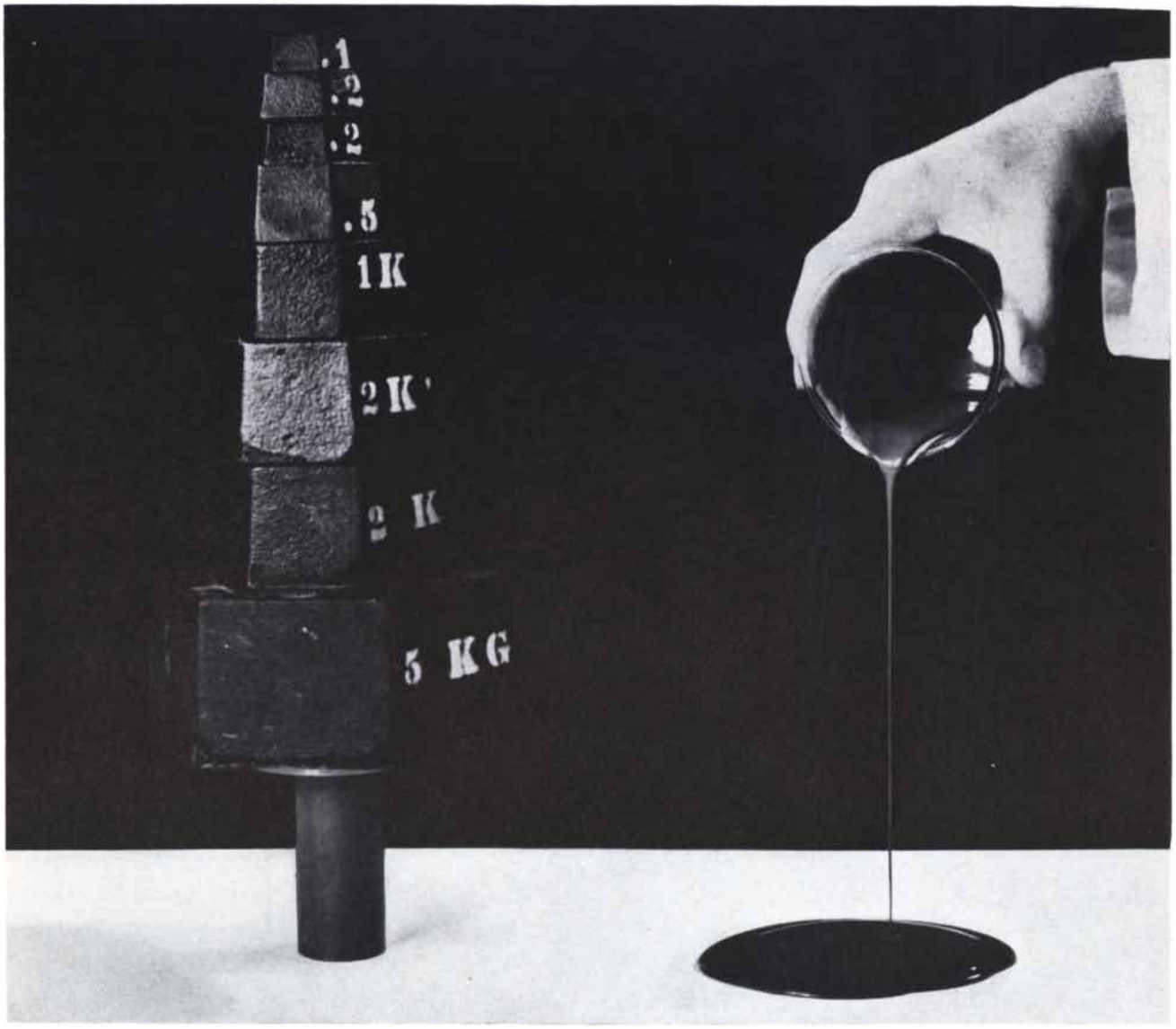
Clearly the quick-clay phenomenon has practical as well as scientific interest, particularly for those concerned with the location of towns, airfields and farms. The Air Force Cambridge Research Laboratories, the Royal Swedish Geotechnical Institute in Stockholm, the Norwegian Geotechnical Institute in Oslo, the Mineralogical Laboratory of Columbia University and the National Research Council of Canada have all conducted studies of quick clay, focusing in particular on the mechanism of its movement and on possible ways of preventing slides.

Broadly speaking, a material slides when it has the following three characteristics: a layered fine structure, a high content of particles less than two microns in diameter and a high content of water. Even clay can hold its place on a fairly steep slope if it is dry. But when a hillside with a high content of clay absorbs much water, it tends to become unstable. Thus rainstorms may be responsible for most landslides. Asbestos, an unusual material, illustrates the action of water particularly well. Near the town of Coalinga in the coastal mountains of California remarkable landslides have occurred in a soft, powdery rock made up largely of short-fiber asbestos. These landslides, draped over the mountainside on slopes ranging from five to 20 degrees, have made scars hundreds of feet across and about a mile long. When the asbestos is dry, it remains firmly in place, but when it is wet, it may start to slide.

some buildings were destroyed, many were badly damaged and some survived almost intact. Most of the stacks of logs remained standing. The slide also blocked a canal by the river. In the mile-long, 800-foot-wide area of the slide the ground sank as much as 25 feet. This panorama, from the Royal Swedish Geotechnical Institute in Stockholm, is a mosaic of seven aerial photographs.



COLLAPSE OF QUICK CLAY is shown on microscopic scale in these schematic cross sections. Undisturbed clay (*left*) is thought to possess a "house of cards" structure. The "cards" are the flat bits of clay minerals. Irregular blobs represent sand grains and tiny dots are dissolved salt, which provides electrolytic "glue" for structure. Water (*color*) is being squeezed out as clay collapses (*middle*). Most of salt was leached out before collapse. Remolded or collapsed clay (*right*) contains very little water.



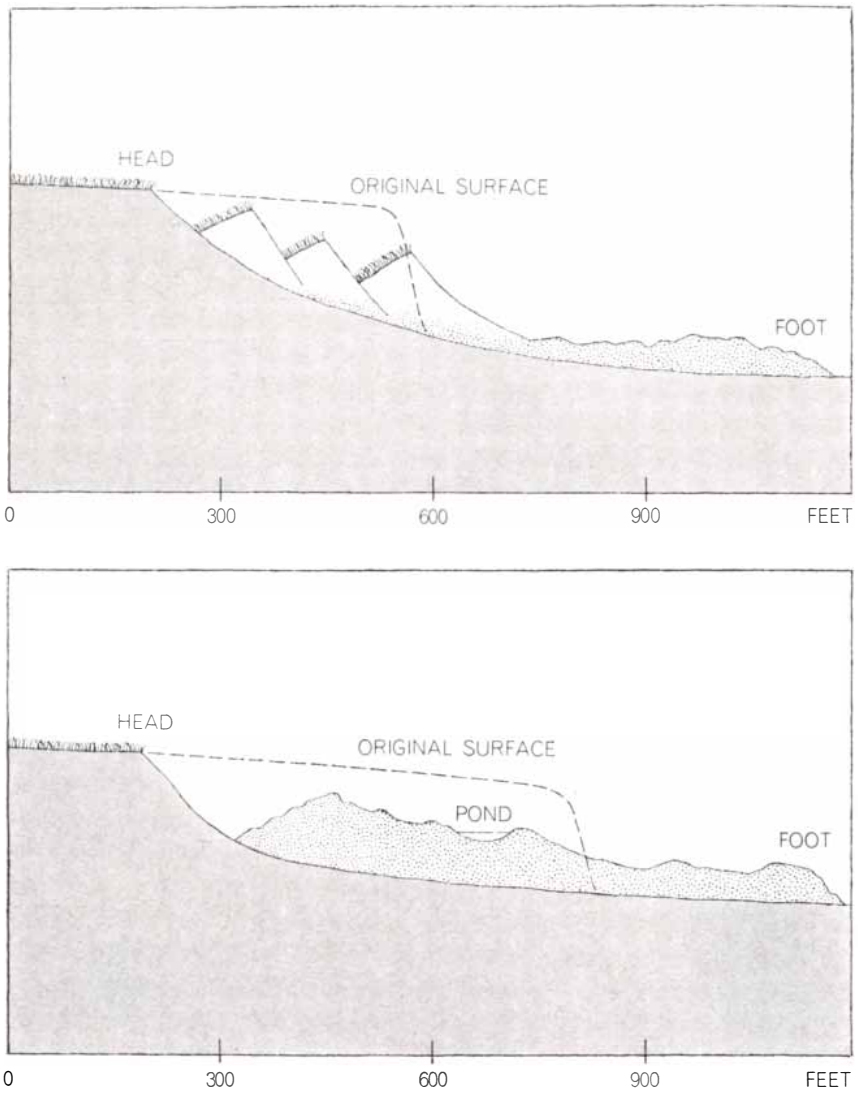
TWO SAMPLES OF SAME QUICK CLAY show startling contrast. Column of undisturbed clay (*left*) holds 11 kilograms (24 pounds). It can support 2,100 pounds per square foot of surface. Another piece of the same clay pours like a liquid after being stirred in a beaker. No water was added. Demonstration was made by Carl B. Crawford of the National Research Council of Canada.

Quick clay is an extreme case; it is by far the most mobile of all the common solid materials on the earth's surface. It has both a high water content and a mineral texture that allows it to flow with the utmost ease. A mass of quick clay that has lain undisturbed for thousands of years can be jarred into motion by any sudden shock.

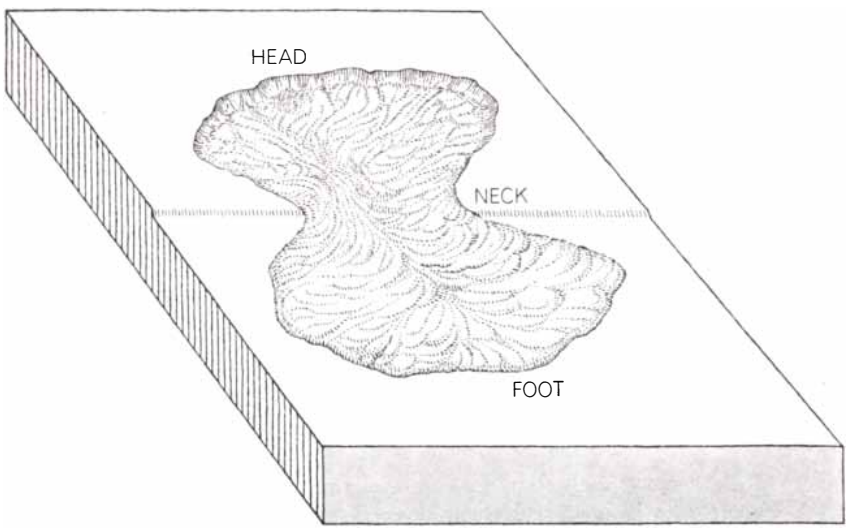
Investigation with refined methods has elicited a good deal of information about the composition of quick clays and the history of their formation. With the electron microscope one can see that the clay is made up largely of flaky particles less than two microns in diameter. X-ray examination shows that these flakes are crystals of various silicate minerals. They have been identified mainly as illite, montmorillonite, chlorite and kaolinite.

The quick clays in Norway, Sweden and Canada were formed during the last advance of the great ice sheets of the Pleistocene epoch. They are essentially pulverized rock and other fine material that the glaciers ground off the land and deposited on what was then the sea floor around the Scandinavian peninsula, which was much smaller then than it is now, and in the Champlain Sea, which covered Canada's present St. Lawrence Valley. After the retreat of the ice some 10,000 years ago, the submerged areas gradually rose above water; in Scandinavia the uplift has raised some of the old sea-floor deposits to as much as 650 feet above sea level. Evidence of the elevation of the land can be seen plainly along the Norwegian coast, where rock quarries of early man that once were at the water's edge now stand well above sea level.

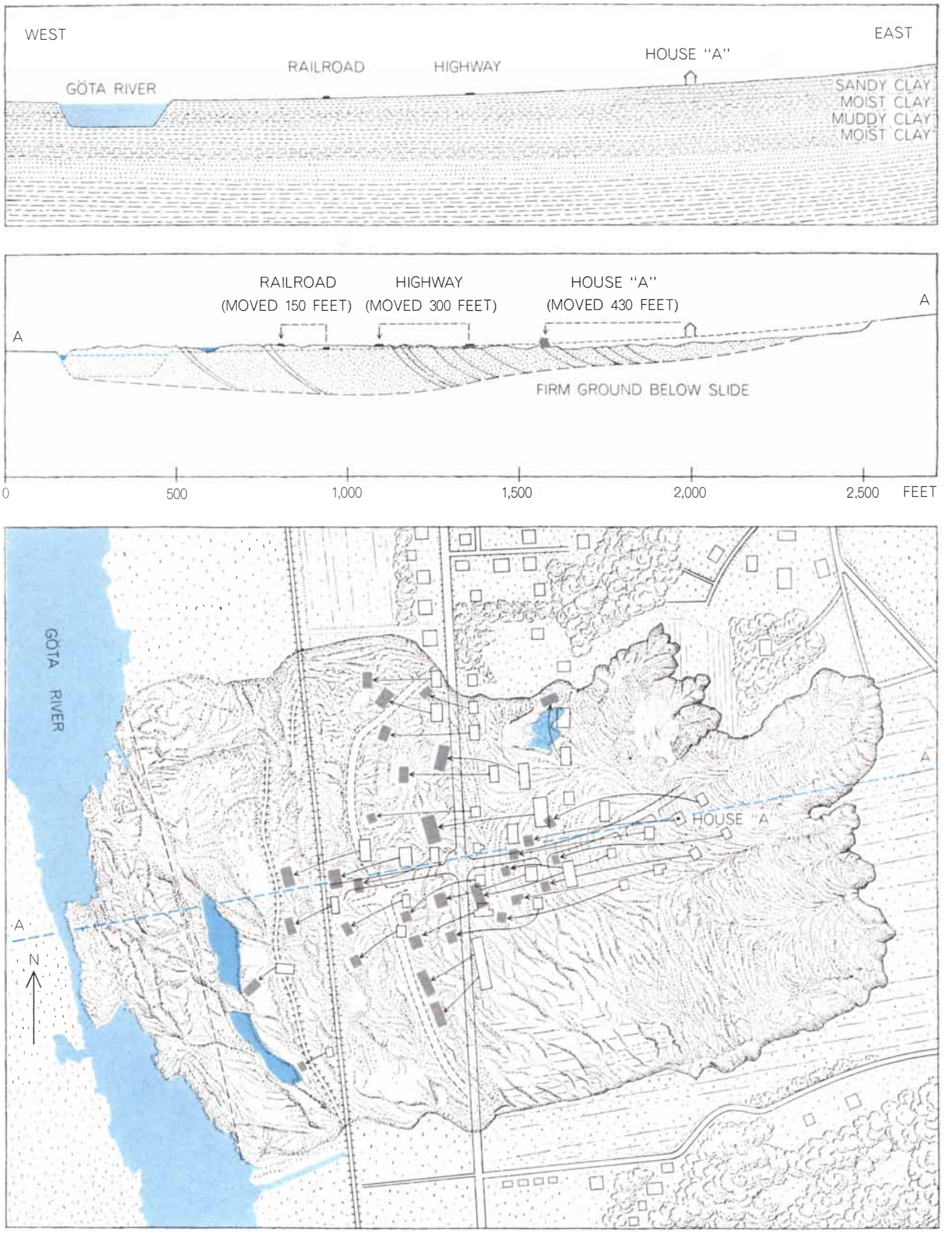
Thus much of the land around the Scandinavian peninsula and in eastern Canada contains strata of clay that were originally laid down on the sea bottom. The quick clays are recognizable by their several distinctive properties. They are generally dark blue-gray when wet. Their sensitivity—that is, the ease with which they can be triggered to flow—depends on four main physical features: (1) usually more than 50 per cent of the solid matter in the clay mass consists of particles less than two microns in diameter; (2) the fine particles are not coagulated but are loosely dispersed through the mass; (3) the water content of the mass is often higher than 50 per cent by weight; (4) the salt content of this water is comparatively low (usually less than five grams per liter, whereas that of sea water is about 35 grams per liter). The amount of salt is



TWO TYPES OF SLIDE are shown schematically. At top three blocks of earth have rotated in a clay-water slurry. In the other slide total liquefaction has occurred and water forced out of the clay has formed a pond. The vertical dimension is exaggerated five times.



TYPICAL SLIDE has a figure-eight appearance. Material that leaves a hollow at the head region piles up at the foot. The low cliff at the neck is often the bank of a river.



GREAT SLIDE AT SURTE on the Göta River in Sweden took place in 1950. Cross sections along broken colored line *A-A* in vertical view at bottom show low slope and other conditions before slide (*top*) and after slide (*middle*). Slide involved both liquefaction and rotation of soil. Houses were rafted as shown by arrows in bottom diagram. Highway and railroad also moved. Occupants of houses were aware of rocking, rising and falling motions but not of sliding. As the structures came to rest at crazy angles, one house split in half and another overturned. The entire slide took less than three minutes, moved 106 million cubic feet of soil and gravel, killed one person, injured 50 and destroyed the homes of 300. Water from the clay formed several large ponds.

important because electrolytes in a mass of clay tend to bind the clay particles together; consequently, as salt is leached out of the clay, it becomes more thixotropic.

Each of these features has been examined closely in the laboratory. Electron micrographs of samples of Norwegian quick clay have shown that in sensitive clay the fine particles tend to be separated and dispersed, whereas in clay that has flowed and become remolded the particles are packed closely together in aggregates. Justus Osterman and his co-workers at the Royal Swedish Geotechnical Institute have pointed out that the particles in clay tend to be dispersed by the action of certain natural chemicals, such as the organic acids in peat bogs and some alkaline earths, in much the same way that the mud used in oil-well drilling is kept loose and fluid by the addition of tannic acid.

Salt, as we have noted, has the opposite effect: it acts to hold the clay together. The quick clays laid down in ocean bottoms started with a high salt content, but in the millenniums since they were lifted above water much of the salt has been leached out of them, particularly at high elevations, as Rosenqvist has found in Norway. A few quick-clay bodies were originally deposited in fresh water; these, of course, contain little salt. It has been shown that quick clays with a low salt content rank high in sensitivity to thixotropic disturbance.

Apparently the most critical of all the factors is water content; the more water in the mass, the higher its sensitivity. (The index of sensitivity is technically taken to be the difference in shear strength before and after the clay has flowed; this ratio is sometimes as high as 100 to one.) A quick clay commonly contains so much water that after a slide it often leaves small ponds in its wake.

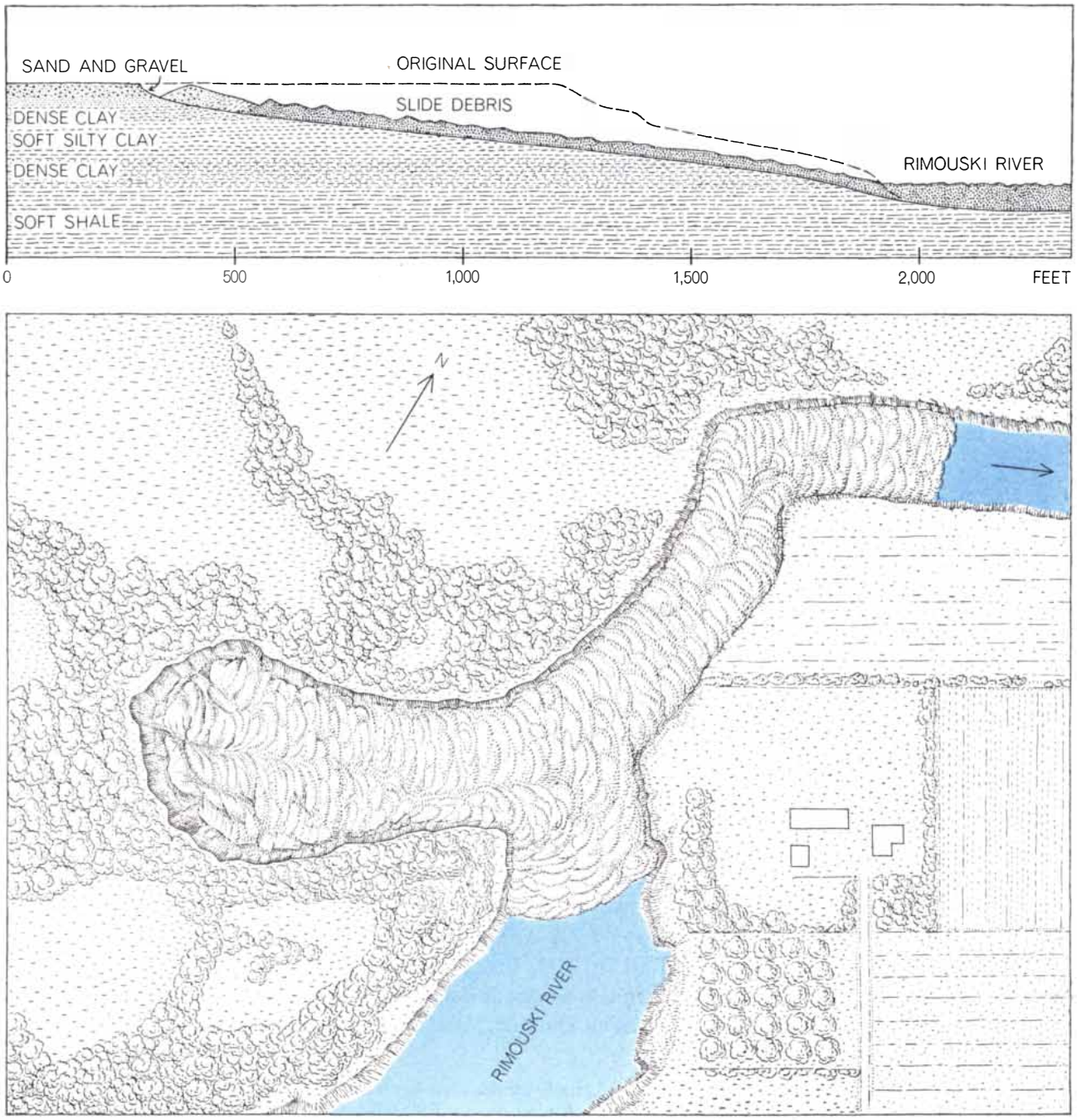
The area of the Nicolet slide in Quebec was found afterward to be heavily charged with water. A sewer in this area had broken down a few months before, and the subsequent accumulation of sewer water in the clay may well have been responsible for the slide. A heavy accumulation of water was also found in the slide area at Surte in Sweden, one of the most thoroughly studied of all quick-clay avalanches.

The Surte terrain is a classic example of a build-up of marine glacial clay deposits. In late glacial times, when the old valley of the Göta River in southwestern Sweden was covered by ocean, the valley became filled with an extreme-

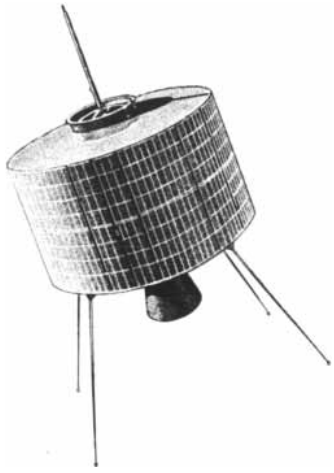
ly fine flour of rock particles scoured down from the hills by the melting ice. Geological processes later raised the accumulated strata above sea level. Over the centuries river water permeated the clay strata and leached out much of the sea salt. The combination of high water content and removal of the salt left the clay mass in an unstable condition, and it would appear that the hammering of a pile driver, used in Surte for the first time in 1950, in addition to the normal train and highway traffic, were sufficient to start the clay sliding.

Can quick-clay slides be prevented? So far this problem has received much less attention than the causes of slides and the nature of the quick clays themselves. Some investigators believe that control of these slides would be economically impracticable; they point out that the cost of exploring and applying preventive treatment to a farm area, for example, might be greater than the value of the land. Studies of the problem of preventing slides are nevertheless being conducted, particularly by Osterman's group at the Royal Swedish Geotechnical Institute.

At least two obvious possibilities invite exploration. One is control of the water content of the quick clay. If percolation of water into the clay can be prevented, this may keep the water content below the critical level and also



SLIDE IN QUEBEC on the Rimouski River was caused partly by the 14-degree slope (*cross section at top*), much steeper than slopes usually associated with quick-clay slides. A layer of soft, silty clay heavily charged with water formed a slip surface. The debris filled the river for several thousand feet and created a temporary lake. Hummocky surface is typical of clay slide.



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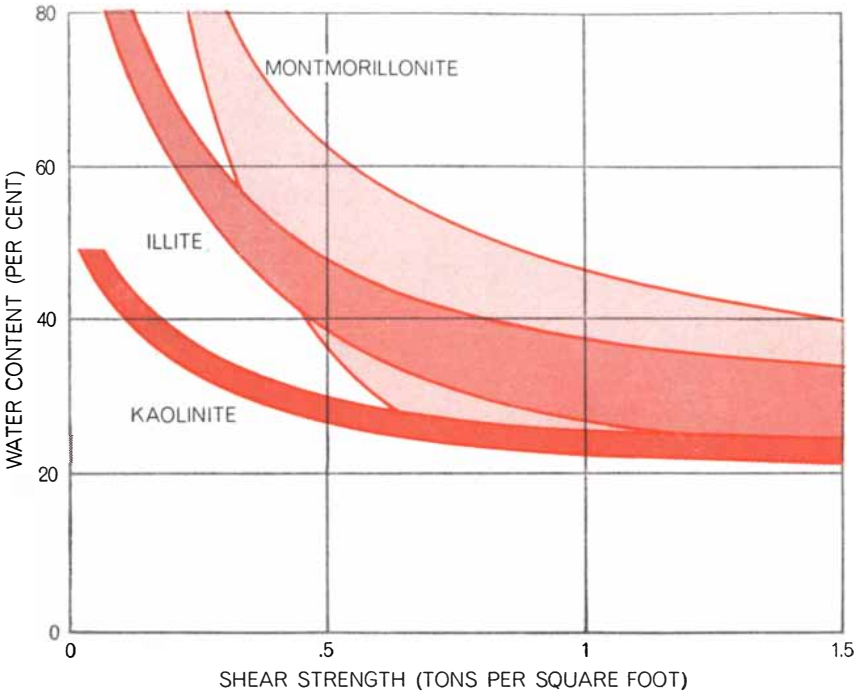


SHEAR STRENGTH of minerals common to quick clay declines rapidly as water content rises. Bands indicate the range of strengths found at the various per cents of water.

stop the leaching out of salt and other binding electrolytes. Therefore drainage of both the surface and the underground water in quick-clay areas might be effective as a slide-preventing measure.

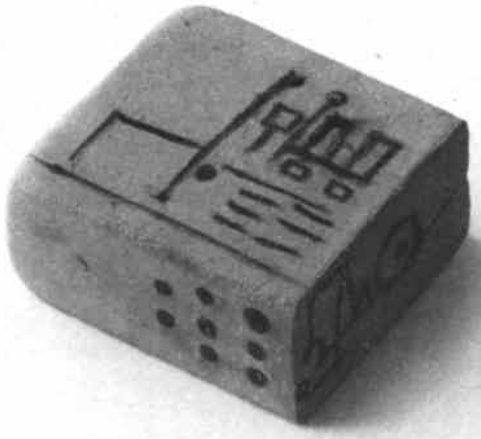
The other possibility that is being tested is artificial injection of electrolytes into the quick clay. Applying salt and lime by means of shallow-bore holes in test plots, experimenters have had some success in improving the cohesion and stability of the clay.

Whether or not effective and practical methods of control will eventually be worked out, it is important to know where the dangerous areas are. Considerable work in mapping them has already been done. Fortunately aerial photography is helpful, because it shows up the scars of quick-clay slides. The Geological Survey of Canada has made photographs and maps of more than 50 slide areas in the valleys of the St. Lawrence, Saguenay and Ottawa rivers. Geological agencies in Norway, Sweden and the U.S. also have made aerial photographs of slide areas. These are not, however, the only countries in the world where quick clay is a matter of concern. It appears that southern Chile and possibly the Peruvian Andes may also have such deposits.

Furthermore, some of the well-known "turbidity currents" on ocean floors seem to be akin to quick-clay slides [see "The Origin of Submarine Canyons," by Bruce C. Heezen; SCIENTIFIC AMERICAN, August, 1956]. These flows of mud, sand and rock debris, which have been studied extensively by Bruce C. Heezen, Maurice Ewing and David B. Ericson of the Lamont Geological Observatory of Columbia University, have a great deal in common with the clay flows on land. It was once believed that the ocean slides occurred only on the sea-floor slopes off the continents, but it now appears that they take place also in the flat ocean basins and even in some of the deepest oceanic troughs.

On November 18, 1929, the transatlantic telegraph cables between the U.S. and Europe began to go out one after another. Within a period of 13 hours 17 minutes, 12 submarine cables stopped transmitting. The interruption followed a sharp earthquake whose epicenter was placed at the Grand Banks south of Newfoundland. The cable breaks were attributed at the time to the shock of the quake. Many years later, however, the Lamont investigators found that the breaks must have been caused by a massive flow of mud started by the earthquake.

These studies have established reasonably well that the area of flow was some 230 miles wide and proceeded for about 400 miles—not merely down the slope of the continental shelf but far along the flat ocean floor. At the last cable severed by the slide the slope of the floor was



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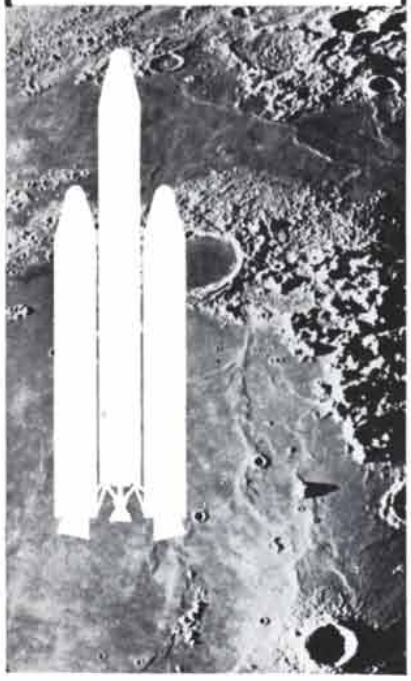
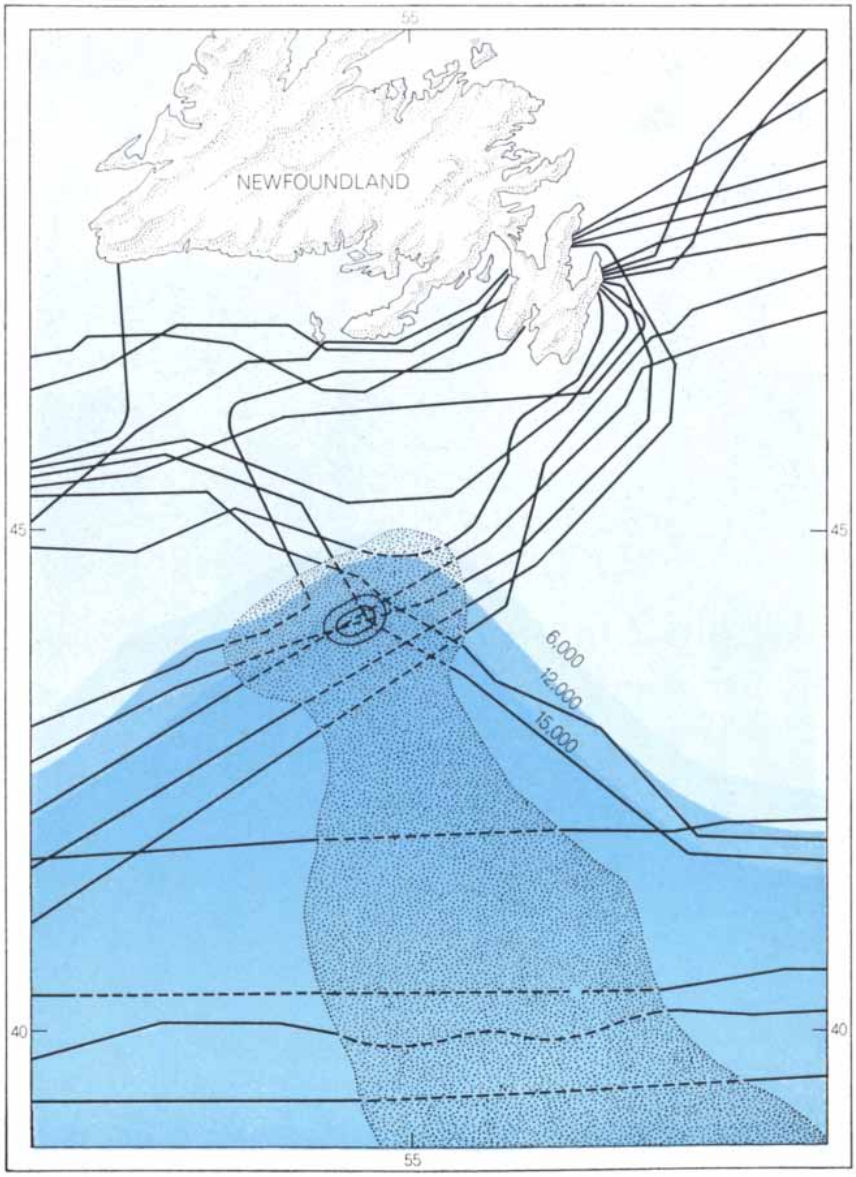


less than one degree, yet the flow was rushing along at no less than 14 miles per hour (judging from the known time and distance between this cable break and the one before).

Apparently the main body of the flow was fine clay, bearing along on its surface a great quantity of sharp sand and fine gravel. Cores from a number of places on the deep sea floor show that it contains a high proportion of very fine clay, with the minerals illite, montmorillonite and chlorite predominating. These are the same materials that predominate in the quick clays on land. Furthermore, it seems more than a coincidence that the oceanic flows, like those of quick clay, can be triggered by an earthquake or a similar shock, can flow rapidly over almost flat terrain and are capable of carrying along immense masses of heavy material.

It seems likely that much of the clay of the ocean floor is in a sense thixotropic and is sometimes set in motion by the same mechanisms as the quick-clay slides on land. This is an interesting hypothesis that deserves exploration; the movement and deposition of material on the ocean floor is one of the main themes in the formation of the solid surface of the earth.



UNDERSEA SLIDE in 1929 cut 12 submarine cables in sequence from north to south. An earthquake triggered the slide. Its epicenter is marked by the concentric rings. Region of cable damage outlines probable slide area (*stippling*). Changes in color shading denote depth. Much of area had slope of less than one degree, but sliding material traveled rapidly.

VARIAN INSTRUMENTS AT WORK

VARIAN associates
INSTRUMENT DIVISION, PALO ALTO, CALIFORNIA
IN EUROPE: VARIAN A.G., ZUG, SWITZERLAND

The first NMR signals offered no indication that these Nobel prize-winning experiments would soon provide scientists with a versatile new analytical technique.

But NMR (Nuclear Magnetic Resonance) has grown rapidly, in its usefulness and in its applications. No longer restricted to laboratories where dedicated research chemists struggled with rudimentary equipment, today's NMR instruments are used routinely in many industrial plants, laboratories, and research facilities.

Many applications use "wide-line" NMR for non-destructive analytical study and quality control of products and processes. The instrument is Varian's PA-7 Process Analyzer. It is highly sensitive, simple to operate, can take hundreds of measurements a day, and provides direct readout.

Applications for the PA-7 are virtually unlimited. Its sensitivity to hydrogen makes it ideal for monitoring the moisture level of samples, or for measuring per cent crystallinity of fats, oils, and glycerides. It can be used to observe solid-to-liquid phase transitions in polymers, and can provide quantitative measurements of other nuclei such as fluorine, sodium, phosphorous, boron, lithium, and aluminum. Nearly any material falls within the scope of the PA-7—latexes, pulps, starches, resins, pigments, colloids, alkalies, foodstuffs.

To make personal inspection of Varian NMR and EPR instruments more convenient we have set up fully equipped Applications Laboratories in Pittsburgh, Pa.; Zurich, Switzerland; and Palo Alto, Calif. Here you can meet with Varian scientists to discuss your problems, run your own samples, and examine the capabilities and limitations of various instruments.

If you would like to make an appointment to visit one of these labs, please describe your problem briefly in a letter to Wayne Lockhart, Analytical Instruments.

When Varian scientists began their investigations into the uses of nuclear resonance, they unknowingly committed Varian to the manufacture of electromagnets.

It was a case of necessity in view of our interest in analytical instrumentation. Experiments which involved observation of phenomena in intense uniform magnetic fields began to be limited by the quality of available magnet systems.

In particular, we needed exceedingly stable fields which had high homogeneity over a large experimental volume—prerequisites for advanced NMR studies.

There was only one thing to do. We had to improve the state-of-the-art performance for large electromagnets.

Since a wide variety of scientific investigations needed similar high performance magnet systems, we formed a Magnet Product Group to make these products and skills available to the scientific community.

As a result, Varian now offers an ever-growing line of magnet systems which range from a simple 4-inch 'C' frame magnet system through the 6-, 9-, 12-inch and the high-field 15- and 22-inch magnet systems. This experience has also been applied to the development of unique high-performance superconducting solenoid systems, and to the revolutionary new FIELDIAL* magnetic field regulator.

For more information write Bob Abler, Magnet Products Manager.

*Trademark

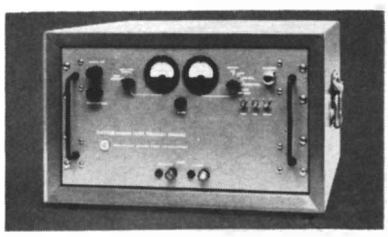
Atomic clocks, whose precision and stability are unsurpassed in the world of measurement, are an outstanding example of how basic scientific principles translate into practical instruments.

Varian scientists started with a complex laboratory experiment which was evolved into our rubidium vapor frequency standard. In this instrument, electron transfer between energy levels is monitored during optical pumping. These transition frequencies are so stable that they provide an ultra-reliable reference against which crystal oscillators are calibrated. Formerly, these crystal oscillators were the last word in frequency control.

To evolve a routinely produced instrument from this elaborate prototype was a taxing but scientifically rewarding challenge. The result was that today rubidium frequency standards are performing impressively in many critical applications which involve measurement and control of time and frequency.

Missile tracking and timing systems use them to recover range and velocity data on deep-space probes; VLF propagation studies and communications control systems find them helpful; they are also valuable as laboratory standards because they give drift-free stability (parts in 10^{11}) and have the reliability of proven solid-state systems.

Frequency comparison is now the most precise method for making physical measurements; atomic standards are the best way to compare frequencies. Naturally, these precise instruments demand sophisticated circuitry and packaging techniques and, as a result, cost more than typical crystal units. Scientists who make measurements in fields which demand exceptionally high accuracy are convinced that the results justify the expense. Gordon Harper, Instrument Special Products, will gladly tell you more.



MATHEMATICAL GAMES

A mixed bag of problems, and answers to last month's board-game questions

by Martin Gardner

It has been more than a year since this department presented a group of short, unrelated problems (aside from April's collection of joke questions, which had no serious mathematical import). This month we offer such a group, none of which calls for a knowledge of advanced mathematics. The answers will be given next month.

1.

Raphael M. Robinson, a mathematician at the University of California at Berkeley, is known throughout the world for his solution of a famous minimum problem in set theory. In 1924 Stefan Banach and Alfred Tarski dumfounded their colleagues by showing that a solid ball can be cut into a finite number of point sets that can then be rearranged (without altering their rigid shape) to make two solid balls each the same size as the original. The minimum number of sets required for the "Banach-Tarski paradox" was not established until 20 years later, when Robinson came up with an elegant proof that it was five. (Four are sufficient if one neglects the single point in the center of the ball!)

Here, on a less significant but more recreational level, is an unusual minimum problem recently devised by Robinson for which the minimum is not yet known. Imagine that you have before you an unlimited supply of rods all the same length. They can be connected only at their ends. A triangle formed by joining three rods will be rigid but a four-rod square will not: it is easily distorted into other shapes without bending or breaking a rod or detaching the ends. The simplest way to brace the square so that it cannot be deformed is to attach eight more rods [*see illustration at right*] to form the rigid skeleton of a regular octahedron.

Suppose, however, you are confined to the plane. Is there a way to add rods to the square, joining them only at the ends, so that the square is made absolutely rigid? All rods must, of course, lie perfectly flat on the plane. They may not go over or under one another or be bent or broken in any way. The answer is: Yes, the square *can* be made rigid. But what is the smallest number of rods required?

Readers are asked to try to solve the problem and, if they succeed, to save their solution or send it to this department. Next month we shall publish the minimum answer Robinson has so far been able to achieve.

2.

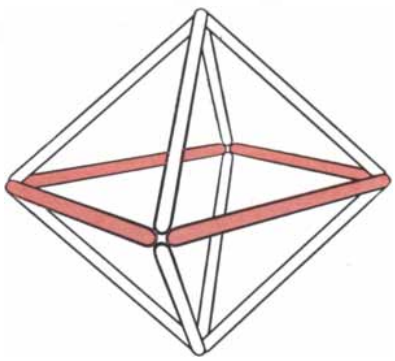
Bill, a student in mathematics, and his friend John, an English major, usually spun a coin on the bar to see who would pay for each round of beer. One evening Bill said: "Since I've won the last three spins, let me give you a break on the next one. You spin *two* pennies and I'll spin one. If you have more heads than I have, you win. If you don't, I win."

"Gee, thanks," said John.

On previous rounds, when one coin was spun, John's probability of winning was, of course, 1/2. What are his chances under the new arrangement?

3.

Three-dimensional mazes are something of a rarity. Psychologists occasion-



Bracing a square in three dimensions

SILICOLOGY

Can You Answer the Four Most Frequently Asked Questions About Silicones?

We made a survey recently. Engineers across the country were asked about silicones. Surprisingly, many hadn't examined silicones; some even dismissed silicones as costly, esoteric materials for emergencies only...to be considered when all others failed.

Rigid urethane foam (right) with silicone surfactant added.

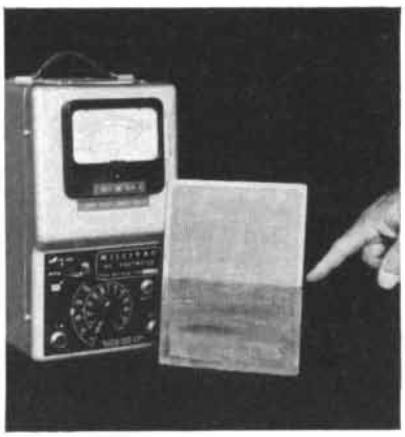
Four questions were almost always raised. Read them, and their answers. You'll agree that silicones deserve your scrutiny.

Aren't silicones too expensive?

No. Many times silicones actually end up being more economical than other materials. For example, silicone rubber tubing for vending machines lasts considerably longer than ordinary rubber. Costing less than three cents per foot, this tubing won't affect taste or odor. And delivered food is always pure. UCARSIL metal protectants apply so thin (0.01 mil) that you get a square foot of silicone protection for about a penny. Silicone-based paints last 25 to 50 percent longer than organic coatings, which cost less to buy but more to use. That's because there are fewer time-consuming reapplications. If you use rigid urethane foams, silicone surfactants can cut your costs. You'll get more foam, lower density, and better insulation with the same amount of raw material.

But, aren't silicones only for temperature extremes?

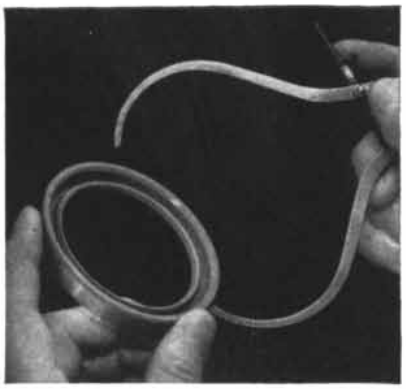
Not exclusively. While silicones are known for their thermal stability, they offer many other valuable properties. For example, silicone rubber oxygen masks are extremely light, odorless, and non-irritating to the skin. They resist ozone and strong sunlight, offer good tear resistance and strength. A new one-million-pound-capacity spring uses the precisely known compressibility of UNION CARBIDE L-45 Silicone Fluid. Regarded as "the highest force spring ever produced in a single unit," it measures only a foot in diameter, can support three of the world's largest locomotives. For aerospace applications, silanes act as chemical bridges between resins and glass reinforcement to provide stronger laminates with greater resistance to moisture as well as heat.



UCARSIL R-101 treated half (upper) of copper circuit board remains untarnished.

Are silicones hard to work with?

Easier than most materials. Silicone rubber, for example, can be easily shaped to the close tolerances required for automotive transmission seals. Silicone rubber can be transfer-, compression-, or injection-molded. And Union Carbide has highly versatile masterbatch bases for silicone rubber. With only one or two of these bases and detailed instructions, an entire product line can be custom built.



Silicone rubber is shaped to the close tolerance required by transmission seal.

Where can I get silicones?

Union Carbide has the complete line, whether you need silicone resins, elastomers, fluids, coatings, or silanes.

Do you have any problems that silicones might solve? As the leading innovator in silicones technology, Union Carbide is constantly developing new products to do a better job. Information is available from your Silicones Man. See him soon! And in the meantime, complete and mail the coupon below.

UNION CARBIDE

SILICONES

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Silicones Division
Union Carbide Corporation
Dept. 3K84-0303, 30-20 Thomson Ave.
Long Island City, New York 11101

In Canada: Union Carbide Canada, Ltd. Bakelite Division, Toronto 12.

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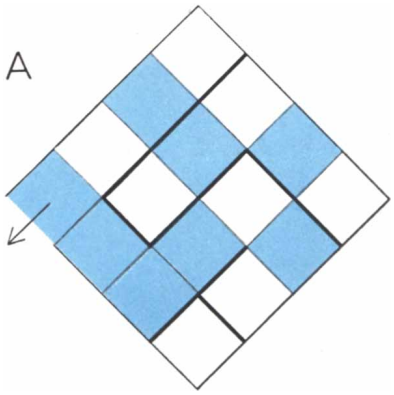
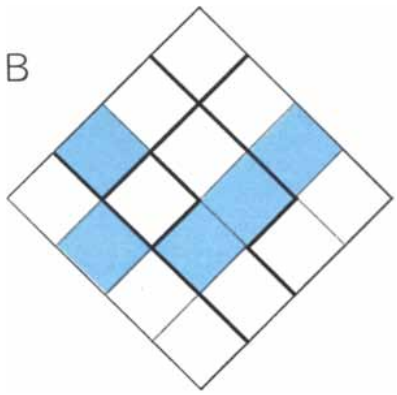
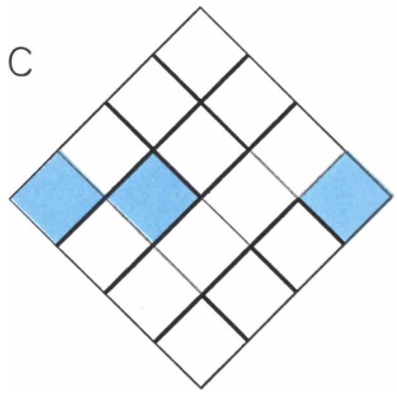
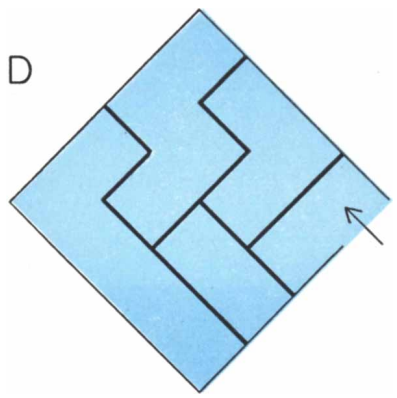
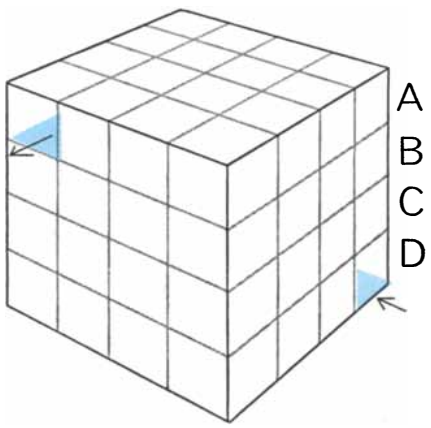










A three-dimensional maze

ally use them for testing animal learning, and from time to time toy manufacturers market them as puzzles. A two-level space maze through which one tried to roll a marble was sold in London in the 1890's; it is depicted in *Puzzles Old and New* by "Professor Hoffmann" (London, 1893). Currently on sale in this country is a cube-shaped, four-level maze of a similar type. Essentially it is a cube of transparent plastic divided by transparent partitions into 64 smaller cubes. By eliminating various sides of the small cubical cells one can create a labyrinth through which a marble can roll. It is a simple maze, easily solved.

Robert Abbott, author of the new Stein and Day book *Abbott's New Card Games,* recently asked himself: How difficult can a four-by-four-by-four cubical space maze, constructed along such lines, be made? The trickiest design he could achieve is shown at the left and below. The reader is asked not to make a model but to see how quickly he can run the maze without one.

On each of the four levels shown at the left in the illustration, solid black lines represent side walls. Color indicates a floor; no color, no floor. Hence a small square cell surrounded on all sides by black lines and uncolored is a cubical compartment closed on four sides but open at the bottom. To determine if it is open or closed at the top it is necessary to check the corresponding cell on the next level above. The top level (*A*) is of course completely covered by a ceiling.

Think of diagrams *A* through *D* as floor plans of the four-level cubical structure shown at the right in the illustration. First see if you can find a path that leads from the entrance on the first level to the exit on the top level. Then see if you can determine the shortest path from the entrance to the exit. Next month's answer will disclose some topological dodges for finding the shortest path through any type of maze.

4.

Lenox R. Lohr, president of the Museum of Science and Industry in Chicago, was kind enough to pass along the following deceptively simple version of a type of combinatorial problem that turns up in many fields of applied mathematics. A traveler finds himself in a strange town without funds; he expects a large check to arrive in a few weeks. His most valuable possession is a gold watch chain of 23 links. To pay for a room he arranges with a landlady to give her as collateral one link a day for 23 days.

Naturally the traveler wants to damage his watch chain as little as possible. Instead of giving the landlady a separate link each day he can give her one link the first day, then on the second day take back the link and give her a chain of two links. On the third day he can give her the single link again and on the fourth take back all she has and give her a chain of four links. All that matters is that each day she must be in possession of a number of links that corresponds to the number of days.

The traveler soon realizes that this can be accomplished by cutting the chain in many different ways. The problem is: What is the smallest number of links the traveler needs to cut in order to carry out his agreement for the full 23 days? More advanced mathematicians may wish to obtain a general formula for the longest chain that can be used in this manner after *n* cuts are made at the optimum places.

5.

Word puzzlists have long been fascinated by a type of puzzle called the word square. The best way to explain this is to provide an example:

M	E	R	G	E	R	S
E	T	E	R	N	A	L
R	E	G	A	T	T	A
G	R	A	V	I	T	Y
E	N	T	I	T	L	E
R	A	T	T	L	E	R
S	L	A	Y	E	R	S

Note that each word in the above order-7 word square appears both hori-

. . . army's new mobile missile . . .

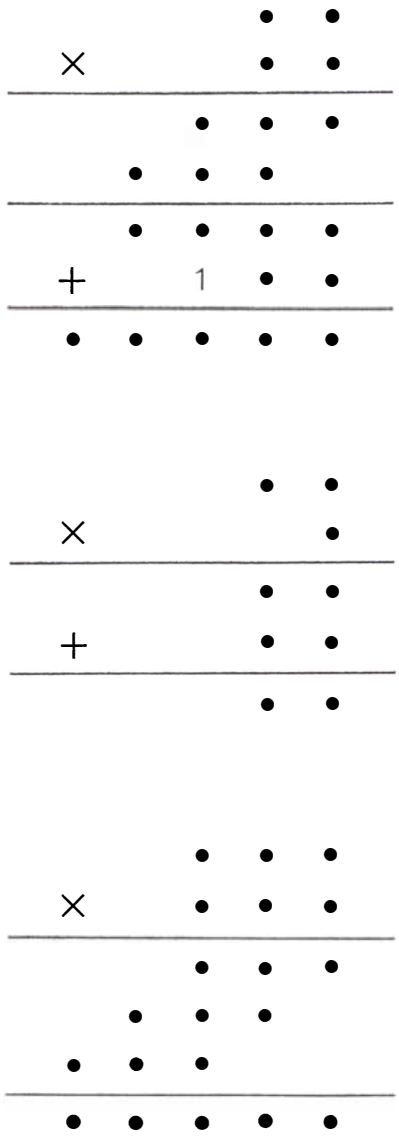
The Army is developing the highly mobile *Lance* missile to provide close support for tactical combat divisions requiring either conventional or nuclear fire power for their wide variety of missions.

To give the kind of low-cost, rugged reliability necessary for ground troop environments, the LTV Michigan division of Ling-Temco-Vought is developing *Lance* around a pre-packaged, storable, liquid propulsion system. The resulting accuracy, reliability and transportability of the weapon is expected to give it outstanding battlefield advantages.

Lance is mounted on its own self-propelled, tracked launcher which can take it where the trouble is — matching the sure-footed maneuverability of other tactical military vehicles, including the ability to swim rivers and lakes.

The design simplicity of *Lance* which is intended to permit minimum reaction time in combat, maximum mobility and high reliability is the result of LTV's sound, versatile engineering.

LTV LEADERSHIP THROUGH VERSATILITY



Three cryptarithms

zontally and vertically. The higher the order, the more difficult it is to devise such squares. Word square experts have succeeded in forming many elegant order-9 squares, but no order-10 squares have been constructed in English without the use of unusual double words such as Pango-Pango.

Charles Babbage, the 19th-century pioneer in the design of computers, explains how to form word squares in his autobiography, *Passages from the Life of a Philosopher*, and adds: "The various ranks of the church are easily squared; but it is stated, I know not on what authority, that no one has succeeded in squaring a bishop." Readers of *Eureka*, a mathematics journal published by students at the University of Cambridge, had no difficulty squaring *bishop* when they were told of Babbage's re-

THIS IS GLASS

A bulletin of practical new ideas from **CORNING**

Look homeward, laser

It's part of the useful nature of a laser beam to be unswervingly, unendingly directional.

But that means, if you plan to track a satellite with a laser beam, you have to figure a way to bounce the beam back off the satellite and down to a receiving station. Otherwise, it's bye-bye beam.

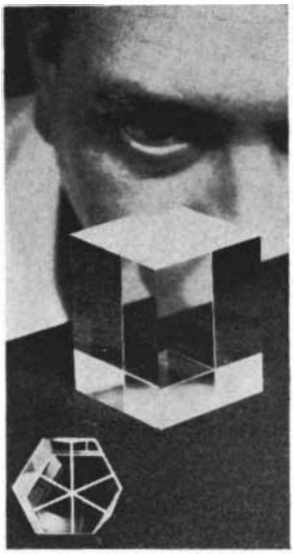
You do it with mirrors—but the mirrors are rather special.

There are 360 of them on the S-66 polar ionosphere beacon satellite. Each one is a precision, multiface reflector made from a cube of our fused silica.

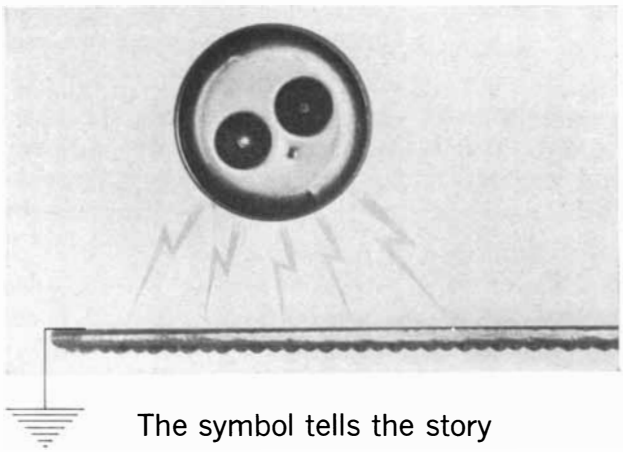
This kind of glass is one of the highest-purity materials man can make. We form it directly from silica without any other constituents in a process that yields 99.999+% purity.

Attach fused silica like that to the outside of a satellite and you could orbit it for 60 years before space radiation would discolor it and affect its reflectance.

You could orbit it *forever* and not adversely affect its dimensional stability with day/night temperature variations.



If playing precision boomerang with laser beams is outside your area of competence, you still might profit some day from knowing about the availability of a material as ultra-pure, ultra-stable, ultra-radiation-resistant as our fused silica. So might we.



The symbol tells the story

Because this ground traps radiated radio frequency interference generated by fluorescent lamps. It's attached to a special glass panel that captures the RF waves. Very useful where such waves might become a nuisance . . . like in a room containing sensitive electronic equipment whose readings might become garbled under unshielded lamps.

The glass panel that handles this task with such ease is our PYREX® brand EC #70 panel. Recent improvements put it in a class where it allows a properly designed fluorescent fixture to pass all three of these MIL-I specs: 16010A, 6181D, and 26600.

What's in such a panel? First there's a 5/32″ clear borosilicate piece of glass. To it we bond, permanently, an electrically conductive coating. It's the coating that picks up the RF waves. It will last as long as the glass. Which is plenty long. And that's just an estimate. To one of the long edges of the panel we also bond a 3/8″ grounding strip. Simple? Certainly. But ingenious. And effective.

The front surface of this particular panel is the same as our popular-for-lighting Pattern #70 panel. It contains uniformly distributed, hexagonal, pyramidal prisms to provide maximum control of light and surface brightness.

Properly coated, other PYREX brand EC products bounce infrared rays, make excellent shielding in places like steel mills. Or with the suitable electrical connections such a panel gives you a uniform source of heat.

Send today for our new 22-page brochure which discusses the fluorescent radio frequency problem and its solution in more detail.

Sizzler of a swizzler

We don't recommend it, but you could safely run one of our VYCOR® brand immersion heaters up to red heat and then plunge it into a cold liquid. It won't break from heat shock.

The only reason we don't recommend doing it is that it might cause severe localized overheating of the liquid.

But it makes a pretty effective demonstration of why VYCOR brand tubing is such a great jacket for a radiant heating element.

Together with its virtual immunity to thermal shock, VYCOR brand tubing is exceptionally corrosion resistant—a combination that suits it well to industrial drying or curing applications over spattering or splashing conveyor lines.

This remarkable 96% silica glass transmits about 90% of the infrared emitted by the heating element in the form of long-wave radiation. This is the energy that's most readily converted into heat by any mass, regardless of size or color.

If infrared can solve a heating problem for you—indoors, outdoors, or under water—ask us about VYCOR brand tubing or our complete VYCOR brand heaters.

"Engineering with Glass"

That's the title of a recently published bulletin that will give you more information on the Corning materials we've discussed—and on many others.

We commend it to your attention. You can get a copy from the Technical Products Division, Corning Glass Works, 4911 Crystal Street, Corning, New York.

CORNING

CORNING GLASS WORKS

marks. The square shown below (from the magazine's October 1961 issue) was one of many good solutions received:

B I S H O P
I L L U M E
S L I D E S
H U D D L E
O M E L E T
P E S E T A

As far as I know, no one has yet succeeded—perhaps even attempted—to square the word "circle." Since I myself know of no solution, there will be no answer next month, but if any readers succeed in squaring the circle, results will be reported in the February issue. Only words found in an unabridged English dictionary may be used. The more familiar the words, the more praiseworthy the square.

6.

Assume an idealized, perfectly running watch with a sweep second hand. At noon all three hands point to exactly the same spot on the dial. What is the next time at which the three hands will be in line again, all pointing in the same direction? The answer is: Midnight.

The first part of this problem—much the easiest—is to prove that the three hands are together only when they point straight up. The second part, calling for more ingenuity, is to find the exact time or times, between noon and midnight, when the three hands come *closest* to pointing in the same direction. "Closest" is defined as follows: two hands point to the same spot on the dial, with the third hand a minimum distance away. When does this occur? How far away is the third hand?

It is assumed (as is customary in problems of this type) that all three hands move at a steady rate, so that time can be registered to any desired degree of accuracy.

7.

Of the three remarkable cryptarithms on page 148 the first [*top*] is easy, the second [*middle*] is moderately hard and the third [*bottom*] is so difficult that I do not expect any reader to solve it without the use of a computer.

Problem 1: Each dot represents one of the 10 digits from 0 to 9 inclusive. Some digits may appear more than once, others not at all. As you can see, a two-digit number multiplied by a two-digit number yields a four-digit product, to which is added a three-digit number starting with 1. Replace each dot with the proper digit. The solution is unique.

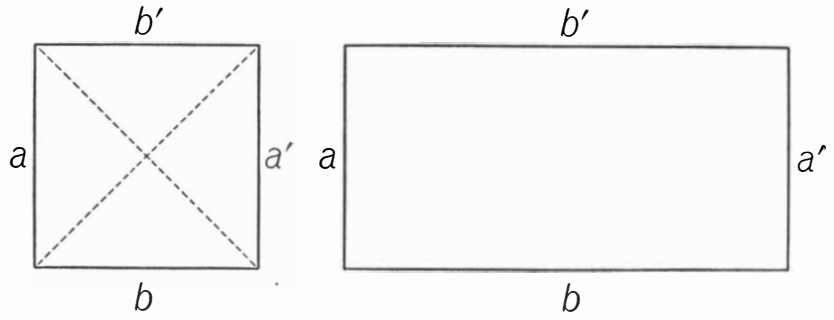
Problem 2: As in the first cryptarithm, a multiplication is followed by an addition. In this case, however, each dot is a digit from 1 to 9 inclusive (no 0) and each digit appears once. The answer is unique.

Problem 3. Each dot in this multiplication problem stands for a digit from 0 to 9 inclusive. Each digit appears exactly *twice*. Again, the answer is unique.

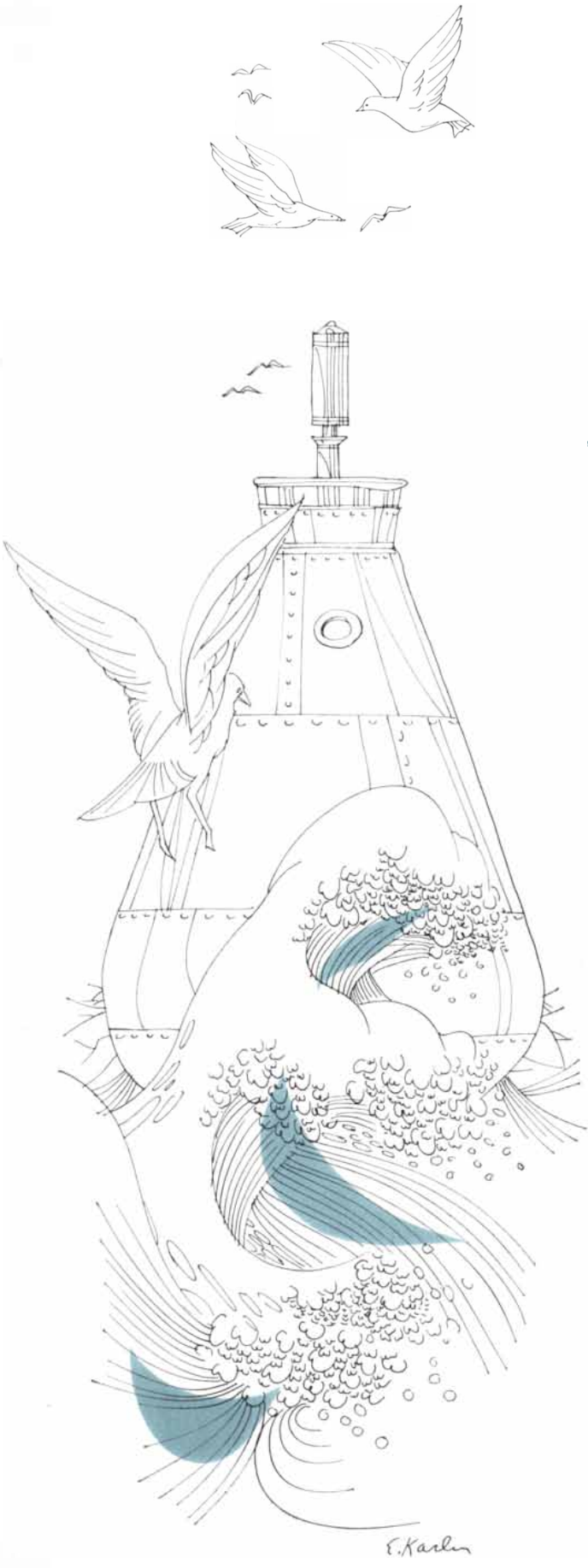
8.

When the eight chess pieces of one color (pawns excluded) are placed alone on the board in the standard starting position, 51 different moves can be made. Rooks and bishops can each make seven different moves, knights and the king can each make three, the queen can make 14. By changing the positions of the pieces it is easy to increase the number of possible moves. What is the maximum? In other words, how can the eight pieces of one color be placed on an empty board in such a way that the largest possible number of different moves can be made?

I shall be interested to see the best



Möbius-strip problem



They whistle 'Sailor, beware!'

Before there was a U.S.—as early as 1767—buoys have been used in our territorial waters to mark channels, to indicate shoals and wrecks. They are of many types. One of the most ingenious is a whistle buoy, provided with an apparatus operated by the waves which compresses and discharges air to make its distinctive sound, especially valuable in fogs.

It may shortly be superseded by an atomic-powered undersea beacon. Nuclear fuel creates steam which vibrates metal to produce a high-pitched squeal audible for twenty miles.

Ranges of twenty-five times that distance are possible with REL's tropo scatter radio. But range is only one reason it's part of so many military and civilian communications systems. Its flexibility also has great appeal: the flexibility that permits transmission of telephone, telegraph or telemetry—or all three simultaneously.

Flexibility marks REL's thinking, too. That's why you can depend on REL's bringing fresh solutions to your communications problems.

REL

Radio Engineering Laboratories

A division of Dynamics Corporation of America

Long Island City 1, New York

Creative careers at REL await a few exceptional engineers.
Address résumés to James W. Kelly, Personnel Director.

answers readers can achieve, although it will not be possible to acknowledge them. The answer to be given next month is thought to be the maximum, with a pattern that is unique except for a trivial variation in the position of one piece.

The two bishops should be placed on opposite color squares to conform with standard chess practice, and the move of castling is not considered. Actually neither qualification is necessary because in both cases a violation would only restrict the freedom of pieces to move.

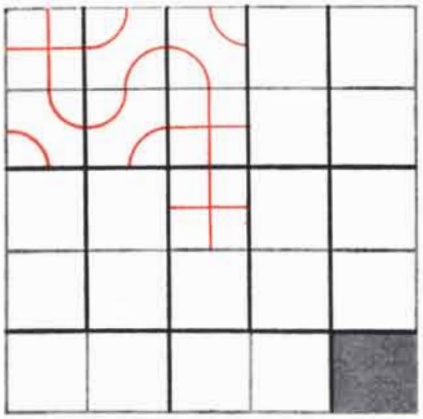
9.

Stephen Barr's method of folding a Möbius strip from a square sheet of paper was explained in this department last July. The square [*at left in illustration on page 150*] is simply folded in half twice along the dotted lines, then edge b is taped to b'. The result is a band with a half-twist, one-sided and one-edged; it is a legitimate model of a Möbius surface even though it cannot be opened out for easy inspection.

Suppose instead of a square we use a paper rectangle twice as long as it is high [*at right in illustration on page 150*]. Is it possible to fold *this* into a Möbius surface that joins b to b'? One can fold or twist the paper in any way, but of course it must not be torn. Assume that the paper can be made as thin as desired. The surface must be given a half-twist that allows the entire length of edge b to be joined to the entire length of edge b'. It would not be difficult to make the strip by joining a to a'; the problem is to find a way to do it by connecting the pair of longer edges.

Once the reader has either found a way to do it or concluded that it is impossible, a more interesting question arises: What is the smallest value for a/b that will allow a Möbius strip to be folded by the joining of b to b'?

The following question was asked last month: Which side wins the French Military Game if Black is given the privilege of starting his piece on any vacant cell? The question was first answered by the Dutch mathematician Frederik Schuh in his book *Wonderlijke Problemen*, published in Holland in 1943 (pages 189–192). White can always trap Black if he plays rationally. A complete analysis cannot be given here, but the following table shows White's winning responses to Black's six different



Strategy for five-by-five game of Black

opening plays (the cells are numbered as indicated last month):

Black	White
2	A35
4 (or 6)	A15 (or A35)
5	123
7 (or 9)	A15 (or A35)
8	A15
B	123

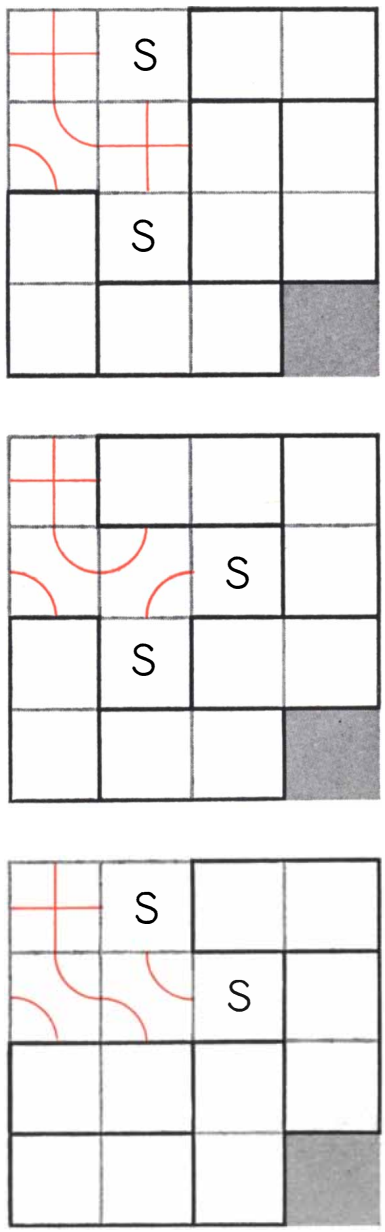
The topological game of Black, for which readers were asked to devise a winning strategy, is won by the first player if the total number of cells is odd, by the second player if the number of cells is even.

When the play is on an odd-celled board, say a five-by-five, the first player's strategy is to suppose the board, except for the lower right corner cell, is completely covered with dominoes [*see illustration above*]. The way the dominoes are placed is immaterial. Each move by the second player starts the path on a new domino. The first player then plays so that the path *remains on that domino*. This forces the second player to complete the domino and start the path on another one. It is obvious that the second player eventually will be forced to the border or to an edge of the lower right corner cell.

On even-celled boards the strategy by which the second player wins is more complicated. The board is thought of as being covered with dominoes except for the upper left and lower right corner cells.

Since the two missing cells are the same color, however (supposing that the board is colored like a checkerboard), it is clearly impossible to cover the remaining cells completely with dominoes: there will always be two uncovered cells of the same color. Elwyn R. Berlekamp,

who cracked the game, calls these two uncovered cells a "split domino." The split domino is taken care of by the following clever maneuver: The second player makes his first move as shown in the top drawing below. This forces the first player to play in the second cell of the main diagonal, and his three possible plays are shown. In each case the unused line of his play will connect two cells of the same color. These two cells, labeled S in the drawings, are regarded as the split domino. The remaining cells (excluding the lower right corner cell) can now be covered with dominoes. Again, the pattern is arbitrary. The second player wins by the domino method previously explained.



Strategy for four-by-four game of Black

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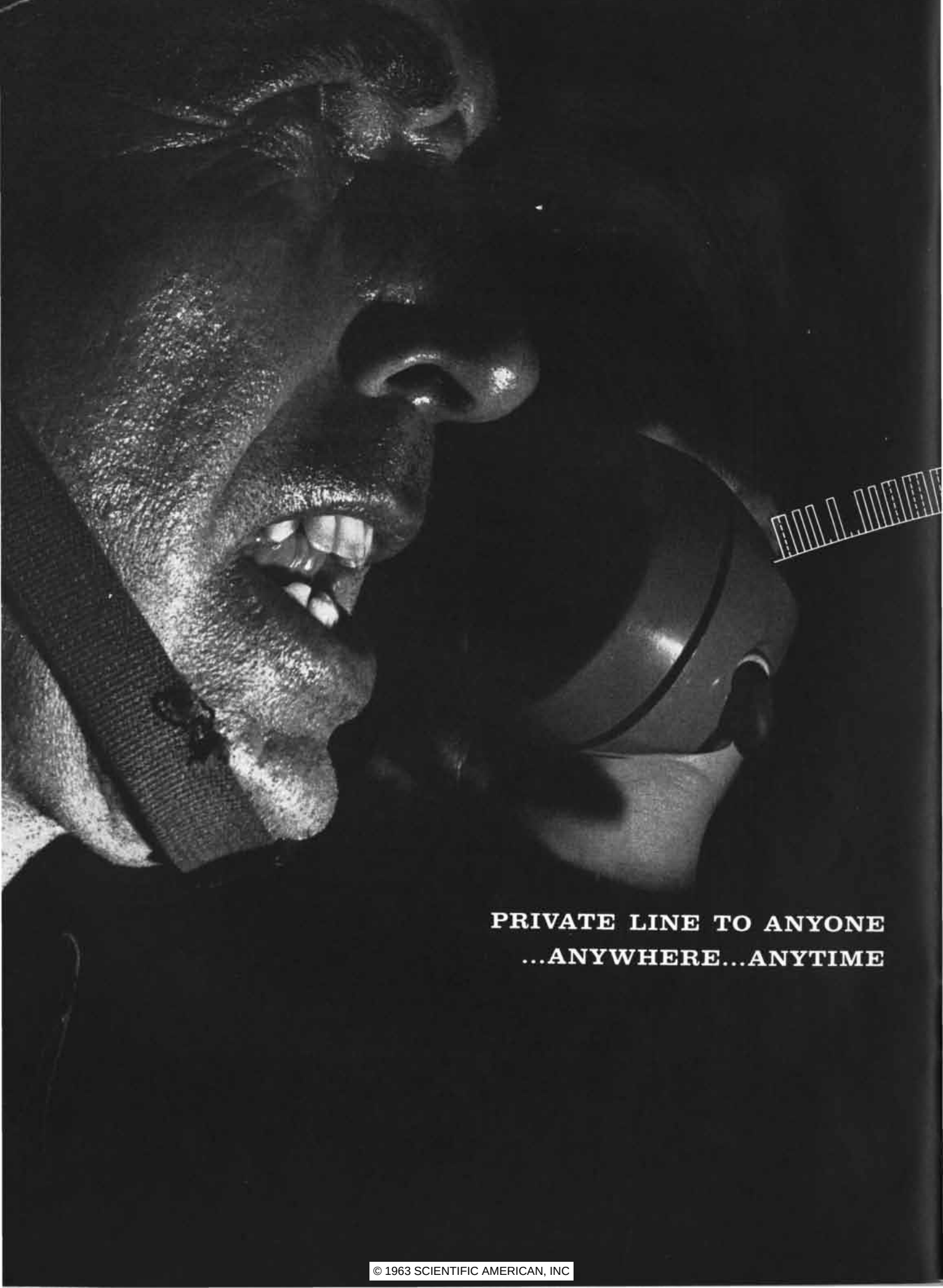

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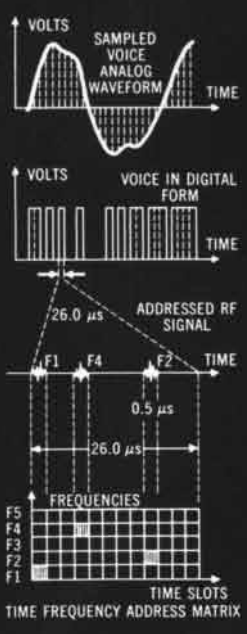

TIME FREQUENCY ADDRESS MATRIX

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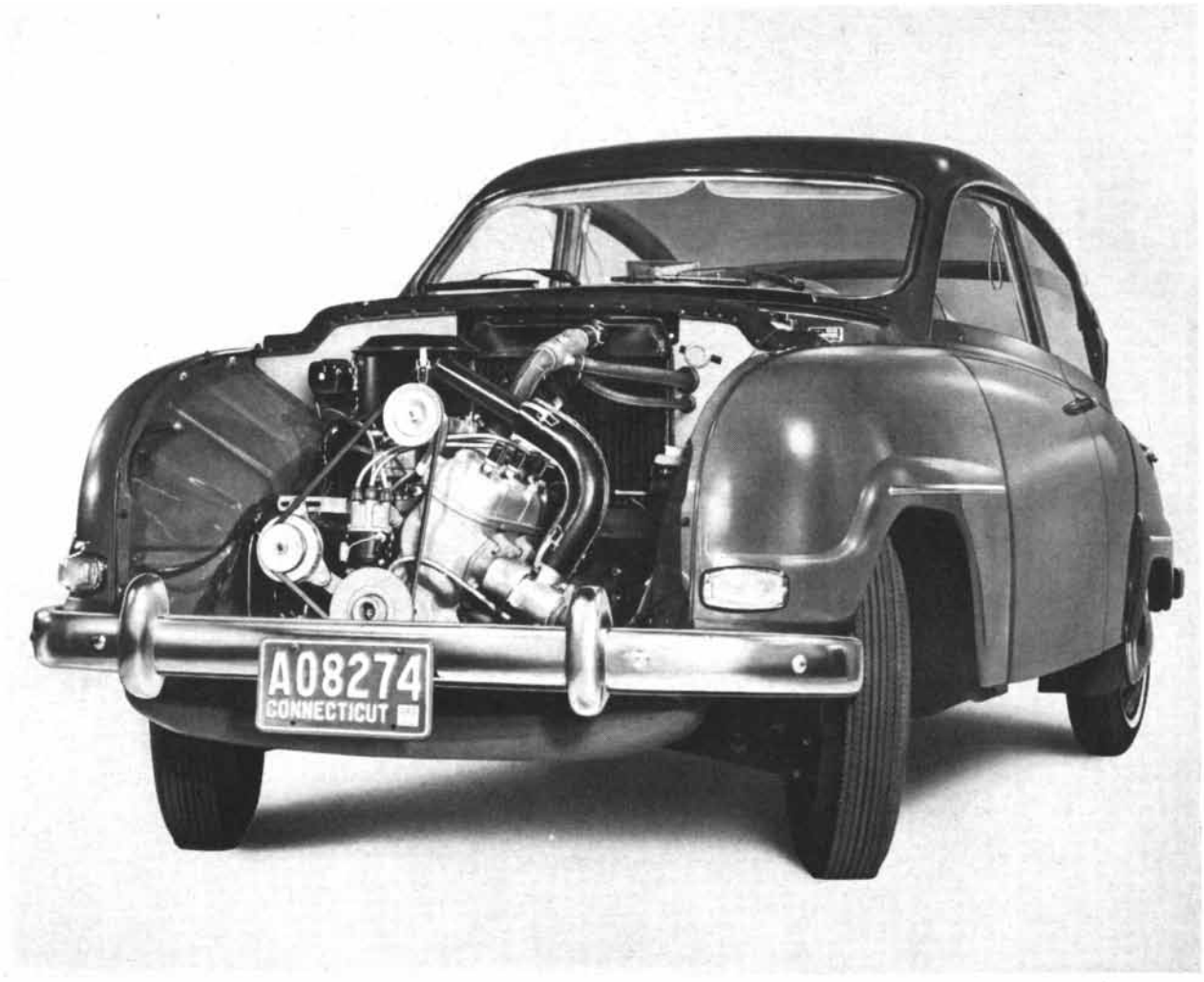

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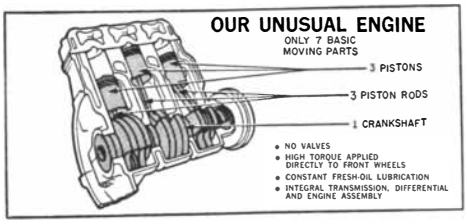
*Engine, transmission and differential warranted for 2 years or 24,000 miles.

Bonneville Salt Flats 1963: Modified SAAB 96 hits 103.56 mph.



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THE AMATEUR SCIENTIST

How to grind, polish and test an aluminum telescope mirror

Conducted by C. L. Stong

Amateurs who make small telescopes tend to overlook the virtues of metal mirrors. This is not to suggest that better mirrors can be made of metal than of glass, even in the case of small instruments; when the advantages of the two are compared, glass usually emerges as the preferred material. Glass takes a good polish, its reflecting film of metal can be replaced easily and it retains its shape except during periods of changing temperature. Glass held a decisive advantage over metal in the days when mirrors were silvered, since tarnished silver can be removed from glass and replaced inexpensively at home in a single evening. Now aluminum has replaced silver as the reflecting surface. Aluminum acquires a protective film of oxide and with reasonable care the surface retains its brightness for years. But the aluminum film is applied to glass by a process of evaporation in a vacuum that requires an apparatus beyond the reach of most amateurs, who must send their mirrors to a commercial establishment for resurfacing. A small solid aluminum mirror, on the other hand, can be repolished at home in an evening. Preserving the shape of the reflecting surface during repolishing can be troublesome, however, and until the novice gets the knack repolishing may take the instrument out of service almost as long as the aluminizing procedure would. Once it has been repolished, the surface of the solid metal acquires the oxide coating, stays bright for a long time and retains its optical figure during changes of temperature that would put a glass mirror out of business.

W. C. Peterson, an amateur telescope maker of Pittsburgh, Pa., made his first aluminum mirror 20 years ago and has not touched glass since he switched to metal. "In brief," he writes, "my process involves two disks of metal, one for the mirror and one that serves as a tool. One surface of the mirror blank is made concave and one surface of the tool convex so that the pair mate like a shallow ball and socket. The metal can be worked easily with a scraper and file if the experimenter does not have access to a lathe. The roughed-out blanks are ground together with successively finer grades of abrasive until their surfaces mate. Then the concave member of the pair is given a prepolish with pumice and finished like a mirror with rouge on a lap made of hard pitch.

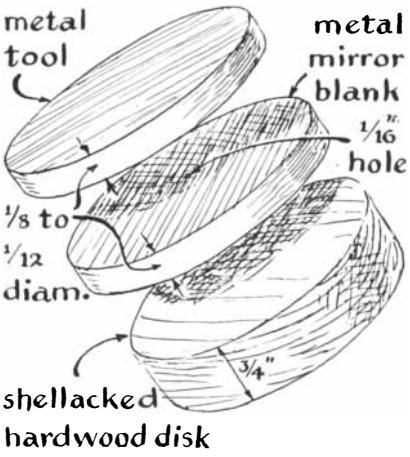
"I have made excellent mirrors of stainless steel but advise the novice to begin with aluminum. Any of the hard bright aluminum alloys work well. They come in the form of bar stock and odd lengths can be procured occasionally from dealers in nonferrous metals; specially cut blanks are available from Henry Prescott, Main Street, Northfield, Mass. I recommend for an introductory exercise a pair of blanks in the form of disks three inches in diameter and 1/2 inch thick. The thickness must be at least a twelfth of the diameter so that the blank will not flex during the grinding operation and distort the desired curvature, but certainly it need not be thicker than an eighth of the diameter.

"I begin by drilling a carefully centered hole about 1/16 inch in diameter and 1/4 inch deep in one side of each blank as a reference center. I also make four disks of hardwood of the same diameter, about 3/4 inch thick, and shellac them to seal the wood against moisture. Their use will become apparent.

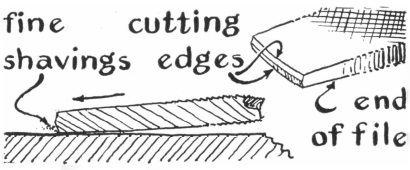
"The next requirement is a pair of sheet-metal templates to serve as guides for roughing the blanks to the desired curvature. The depth of the curve determines the ratio of the diameter of the mirror to its focal length, the *f* number. In my experience—and most amateur telescope makers will agree—the relative aperture should not be more than *f*/8 or less than *f*/10, with *f*/9 as a fine compromise. In the case of a three-inch mirror, a focal length of 27 inches would represent a good choice. It is not always possible for the beginner to grind a curve that hits the specified focal length on the nose, but by aiming for 27 inches he can usually achieve a curve that ranges between 24 and 30 inches and is therefore within the accepted limits. The radius of the curvature is equal to twice the focal length. The radius of an acceptable three-inch mirror should therefore fall somewhere between 48 and 60 inches, with 54 inches the best length. I improvised a compass with which to scribe this radius: a six-foot stick with a screw at one end and an ice pick at the other. With the end of the stick screwed to the floor, the ice pick is inserted through a hole in the other end 54 inches from the screw. A three-inch-square sheet of zinc or hard brass is tacked lightly to the floor and the scriber is guided across the middle of the sheet to cut a deep groove completely across the metal. Then the sheet is flexed until it breaks along the arc, and the edges are dressed lightly with a file. The halves serve as the templates, one convex and one concave.

"To make a tool for roughing out the curve of the mirror, grind the end of a flat file to the shape of a thumbnail for use as a scraper [*see second illustration from top on next page*] and wrap the body of the file with electrical tape for a handle. With this tool scrape one side of the blank selected for the mirror until its curvature fits the convex template. This may sound like a job for a lathe, but the work can be done about as easily by hand. Aluminum is soft and only a small amount of metal must be removed—less than half the thickness of a dime. Then use a file to shape the other blank convex to fit the concave template. Do not strive for precision, but try to avoid deep gouges.

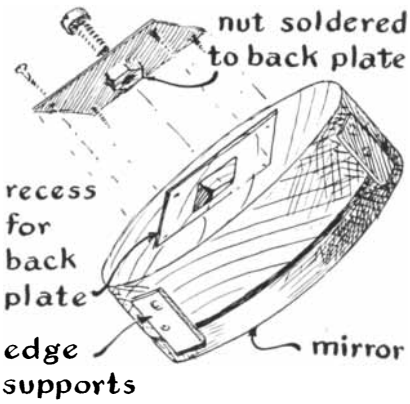
"The unscraped side of each blank is now cemented to one of the disks of hardwood. I use common roofing tar as cement—the kind that comes in lumps—and flow it onto the work by heating it with an electric soldering iron. A thin layer of tar is applied to the metal and the wood and the disks are simply pressed together. Seal any crack that develops



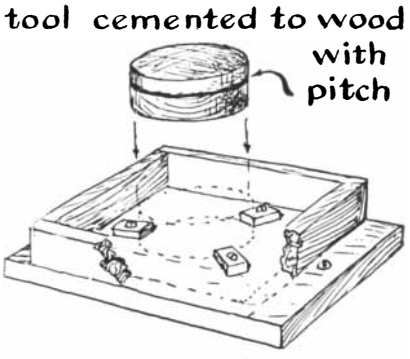
Components of the metal mirror



Shaping mirror with homemade scraper



Mounting bolt for mirror



Tray for holding grinding tool

between the disks by applying the hot iron. Before cementing the mirror to its wood backing I drill a hole through the wood disk large enough for a No. 6 machine screw and attach a nut to the inner face of a metal plate that is then recessed over the hole, as shown in the accompanying drawing [*third illustration from top at left*]. This provides a convenient fixture on which to mount the mirror in the telescope.

"Next I make a shallow wooden tray about six inches square and one inch deep, with three cleats screwed to the bottom 120 degrees apart and spaced to make a snug fit with the convex tool blank [*see bottom illustration at left*]. The tray should be attached rigidly to a firm bench that is about waist-high. Mount the tool in the tray, apply about a quarter of a teaspoon of carborundum grit to the tool and wet it with an equal amount of water. Invert the mirror over the tool and grind by pushing the mirror back and forth. The length of the strokes should be adjusted so that the mirror overhangs the tool about 1/2 to 3/4 inch at the end of each stroke. The center of the mirror should pass directly over the center of the tool. Only two grades of carborundum are used: 220 mesh and 320 mesh. The work will require less than a quarter of a pound of each grade in the case of a three-inch mirror. Normally carborundum is shipped in minimum lots of one pound, but smaller quantities can be obtained from the Edmund Scientific Company of Barrington, N.J.

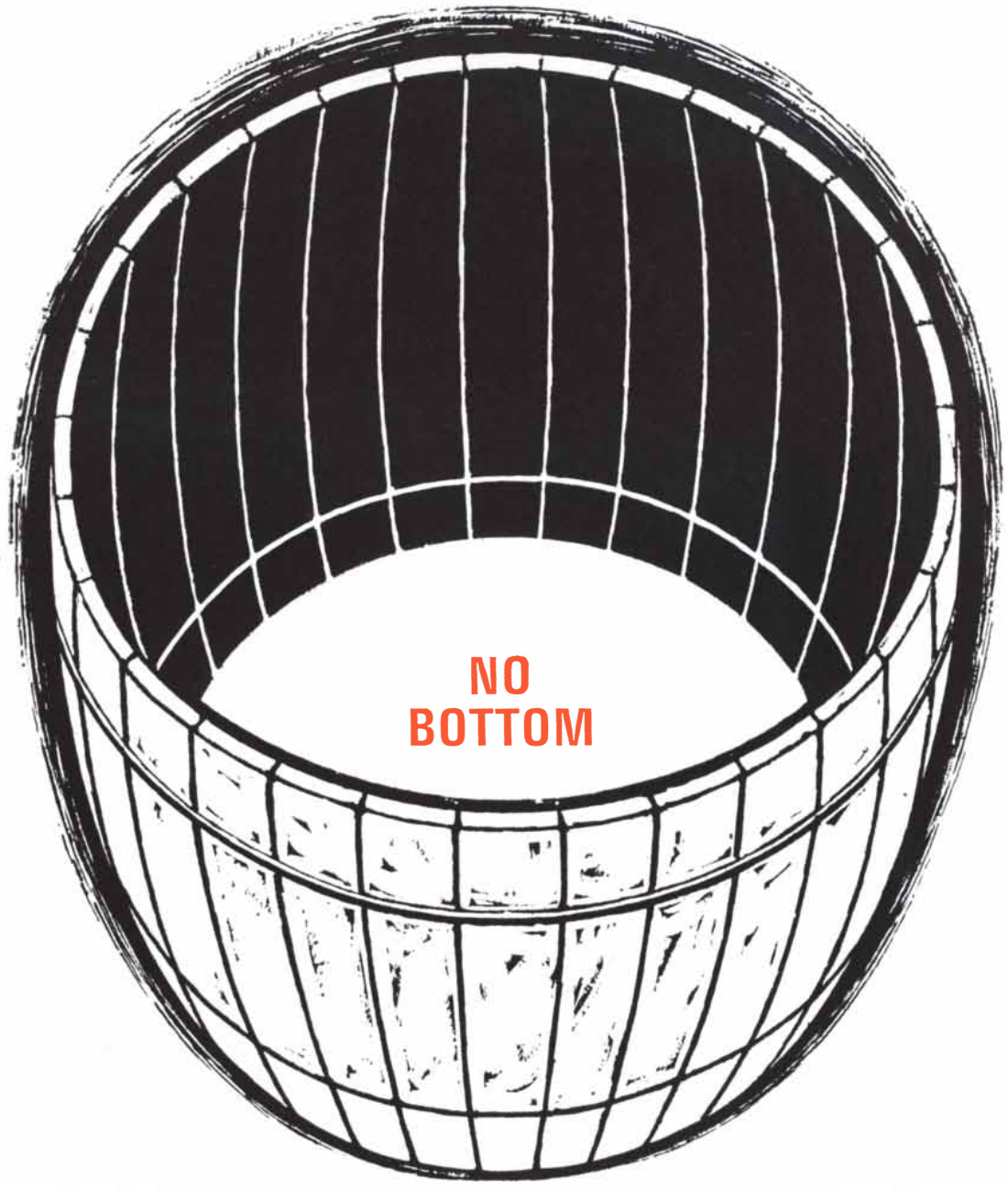
"The length of the stroke is not critical, but short strokes make the curvature shallow and long ones deepen it. Rotate the mirror slowly while stroking and work it around the tool to distribute the grinding uniformly. Add water to the carborundum from time to time and replace the grit as it turns to mud and becomes ineffective. There is no hard and fast rule for adding water and replacing grit, but you develop a feel for the procedure rather quickly. Grit makes a grinding sound when it is working well, and the mirror slides over the tool with little effort. Spent grit should be wiped from the metal with a rag. (Do not flush it down the drain because it will probably clog the plumbing.)

"When the surfaces of both blanks are fully ground, flush the mirror with clean water and while it is still wet reflect an image of the sun against a wall or a screen of cardboard. Move the mirror toward and away from the screen until the sun's image is sharpest (smallest); the distance between the mirror and the screen should be between 24 and 30 inches. If it is not, check the accuracy of the templates and if necessary make up a new set and start again from the beginning. When you are satisfied that both blanks have been accurately ground with 220-mesh grit, switch to 320 and continue until all evidence of the coarser abrasive disappears.

"The next procedure may sound strange to glassworkers, although it is not new. A polishing lap is prepared of hard pitch—one that would selectively deepen the curve in the center of a glass mirror and result in what experienced telescope makers refer to as 'the fatal hyperbola' or 'a turned-down edge.' Although an extremely hard lap is rarely used for glass, it works like magic on aluminum and accounts for the ease with which beginners can make metal mirrors. One of the remaining wood disks now comes into play. Chunk tar of the roofing variety is first melted with the soldering iron and flowed over the wood to a depth of 1/8 inch. It will have little tendency to overflow. Then about a third to half as much lump rosin is melted, flowed into the tar and thoroughly blended with it. (Powdered rosin will not mix with tar. If rosin is available only in powdered form, melt it and after the batch cools break it into lumps.)

"Paint the surface of the warm pitch with polishing rouge that has been mixed with water to the consistency of heavy cream, place the concave face of the mirror squarely over the painted surface and swirl the mirror until the curve of the pitch conforms with that of the mirror. 'Press' the assembly by allowing it to stand and cool to room temperature. If pockets or bubbles are found in the pitch when the mirror is subsequently removed from the lap, use some of the runoff for patching the holes. Flow in just enough of the tar-rosin mixture to fill the holes. Then paint the patches with rouge and press the entire lap with the mirror as before. To test the pitch for hardness, make a firm cut across the lap with a wet knife; the pitch should splinter and make a crackling sound. To soften add tar, to harden add rosin. The edge of the lap is then trimmed with the wet knife.

"The prepared lap is now charged with 320-mesh carborundum (not rouge!) and stroked with the mirror as during rough grinding. I do not favor any form of circular stroke, but one must continuously rotate the mirror and more or less work around the tool in all possible orientations to preserve the element of randomness. Now to the crux of the



...TO THE BARREL

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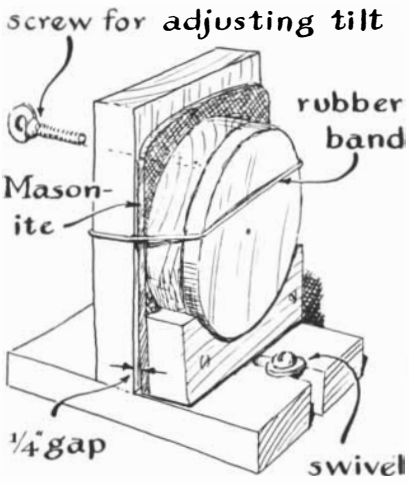
procedure: The worker must examine the pitch lap every two or three minutes, re-press it if necessary and occasionally remake it when the tar and rosin become thin at the edge. I re-press for 10 to 15 minutes after every 10 or 15 minutes of polishing. If the room is cooler than about 70 degrees Fahrenheit, I warm the lap under a hot-water faucet before pressing.

In an astonishingly short time the mirror takes on some polish and forms a clear image of the sun even when dry. The focal length can now be confirmed more accurately with a Foucault-test apparatus. In principle this test consists of viewing the reflected image of a pinhole source of light—an artificial star. Both the pinhole and the observer's eye must be at a distance from the mirror that is equal to just twice the focal length of the mirror. Of course, when the pinhole is precisely twice the focal distance from the mirror and squarely on the optical axis of the mirror, the focal point will fall on the pinhole itself. But if the pinhole is shifted slightly to the right of the optical axis, its focused image will shift the same distance to the left, where it can be observed. The image can be found by exploring the general area with the aid of a ground glass until a spot of light appears on the glass. When the eye is moved to a position a foot or so directly behind the image and the ground glass is taken away, a minute 'star' will be seen hanging in mid-air. This is the image of the pinhole. If the eye is now brought close to the image, the face of a fully polished mirror of spherical figure will be seen as a glowing disk that resembles the full moon, because light from the pinhole strikes every part of the mirror and is reflected equally from every part into the eye. The image of the pinhole is real, and it can be examined with a magnifying glass.

"The complete Foucault-test apparatus includes a bracket for supporting the mirror, a lamp house, a movable sector containing the pinholes, a magnifying glass and a knife edge—all mounted on a base fixture that moves on a rail, as shown in the accompanying illustration [*below*]. When the image of a large pinhole is examined during the early stages of polishing, the edge will appear to be irregular and the face of the metal will have a grainy texture caused by myriad pits. Often the surface will resemble the rough skin of a tangerine. As polishing continues, the image will gradually become disk-shaped and the colors will simultaneously change from chocolate through orange and yellow to brilliant white, even when the smallest pinhole of the apparatus is used.

"The polish rarely progresses evenly to the edge of the mirror, even though the tool is kept true. To correct the tendency of the center to polish first, I cut a lopsided, long-armed star with four or five points from the middle of the lap and extend the tips of the star to within half an inch of the edge. This has the effect of accelerating the action of the abrasive toward the edge. In spite of directions given by many books for polishing glass, never remove pitch from the edge portions of the lap when making a mirror of metal. If the edge fails to polish after treatment with the star lap, the worker has missed the boat somewhere along the line and must return the mirror to the tool and try again.

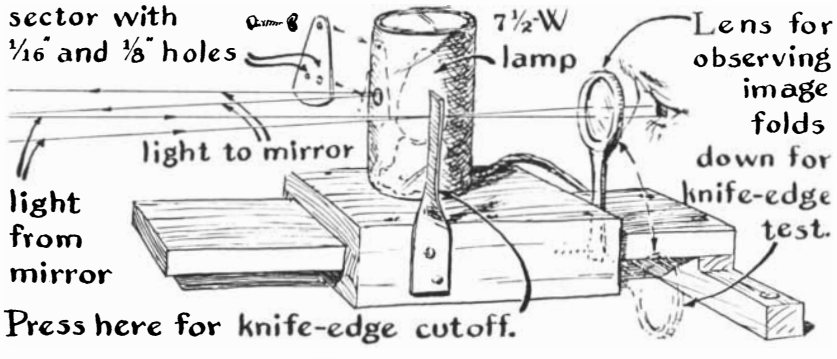
"When the pits have been reduced substantially, switch from 320-mesh carborundum to pumice. I find that conventional kitchen cleansers such as Ajax and Bab-O work splendidly. To make the change simply remelt the used lap, paint it with rouge and press. After the lap cools charge it with pumice and resume polishing. (The presence of embedded carborundum in the pitch does no harm.) After a few spells of polishing with pumice finish each period by adding rouge to the lap. After a while examine the image of the pinhole with the magnifying glass. At first it will appear as a relatively large, fuzzy patch of light, but as the polishing continues details will stand out with increasing clarity; bits of lint and the rough edges of the metal will be seen highly magnified. In effect, the mirror has started to function as the objective of a telescope. When the pinhole can be seen in sharp detail and all evidence of pits has vanished, make a new lap and switch from pumice to rouge.



Test bracket for supporting mirror

"The new lap for rouge must be made of clean tar and rosin, uncontaminated by carborundum or pumice. Use the remaining hardwood disk for this rouge lap and clean the working area thoroughly of all carborundum and pumice. Combine the tar and rosin in the same proportions as before. During succeeding spells of polishing, the rouge should change color promptly if all is going well. If the switch from pumice to rouge is made before all pits have been removed, the rouge may remain dark and the mirror will not take a brilliant polish. In that case go back to polishing with pumice. Laps sometimes misbehave, however, even when all pits have been removed. The mirror may tend to stick or to pick up pitch. This difficulty can usually be cured simply by adding a drop of ordinary mucilage to the wet rouge. If the mucilage fails to work, make a new lap. At this stage of polishing, incidentally, the mirror should never be removed from the lap for extended periods. Grooves about 1/8 inch in diameter should be cut through to the wood so that the pitch is divided into rectangles, each about an inch square. The pattern of rectangles should not be distributed symmetrically with respect to the center of the tool.

"After a brilliant polish is achieved



Details of Foucault-test apparatus

Displays

Through a Glass, Clearly

Looking at a display is rather like holding up a magnifying glass to one small bit of information from among a vast tonnage of data. When the computer has isolated the data essential to the moment, the display must then bring it up to the human eye with utmost clarity of meaning. And as a mass of programmed information increases, more and more flexibility will be demanded of both the systems and the display. Thus many important "software" questions about displayed information must be asked and answered. Where, for example, is that fine line between too little information and too much? How can rapidly changing data best be exhibited so that eye and brain quickly get the messages? When should facts and figures be shown in an ordinary manner, when in more dramatic fashion? How can displays anticipate the answering of unanticipated questions? Much of the work of SDC scientists and engineers is and has been linked together by the common denominator of displays, which in turn are the vital interaction link between machine and man... between computer and decision maker. The broad experience base being built by SDC men and women is, in turn, helping to shape the information systems of the future. If you are interested in shaping your own future in the science of systems, SDC offers opportunities of unusual scope and challenge. Human factors scientists, operations research scientists, systems-oriented engineers, and computer programmers are invited to write Mr. A. K. Granville, Jr., SDC, 2430 Colorado Ave., Santa Monica, California. Positions are open at SDC facilities in Santa Monica; Washington, D.C.; Lexington, Massachusetts; Paramus, New Jersey; and Dayton, Ohio. "An equal opportunity employer."

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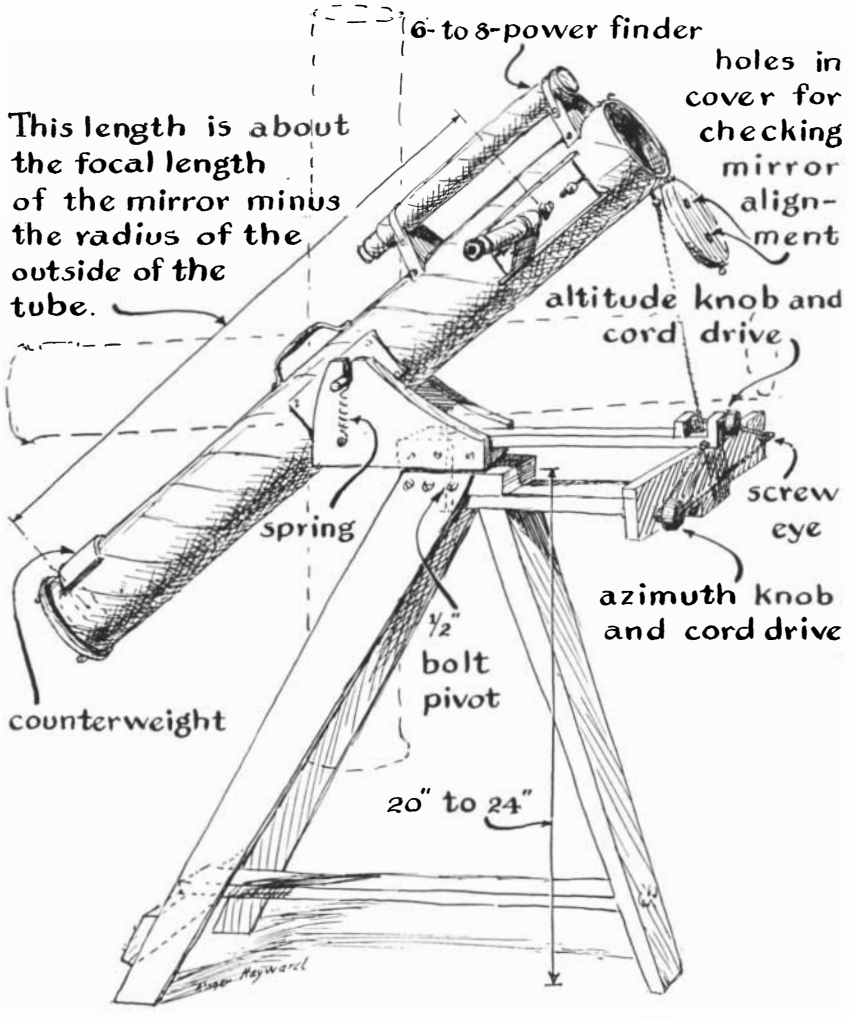
SDC

from the center of the mirror to the edge, as judged by eye, begin to use the Foucault knife-edge test. Turn the magnifying glass to the side, align the image of the pinhole so that it almost grazes the 'knife' and, with the eye directly behind the image so that the mirror is seen as a full moon, press the knife into the light rays. When the knife is between the mirror and the image, the apparent shadow cast by its edge will move across the face of the mirror from right to left. When the blade is between the image and the eye, the shadow will cross in the opposite direction, from left to right. Manipulate the blade until it cuts the focal point of the rays. The mirror will then darken when the knife is moved and no shadow will cross the disk.

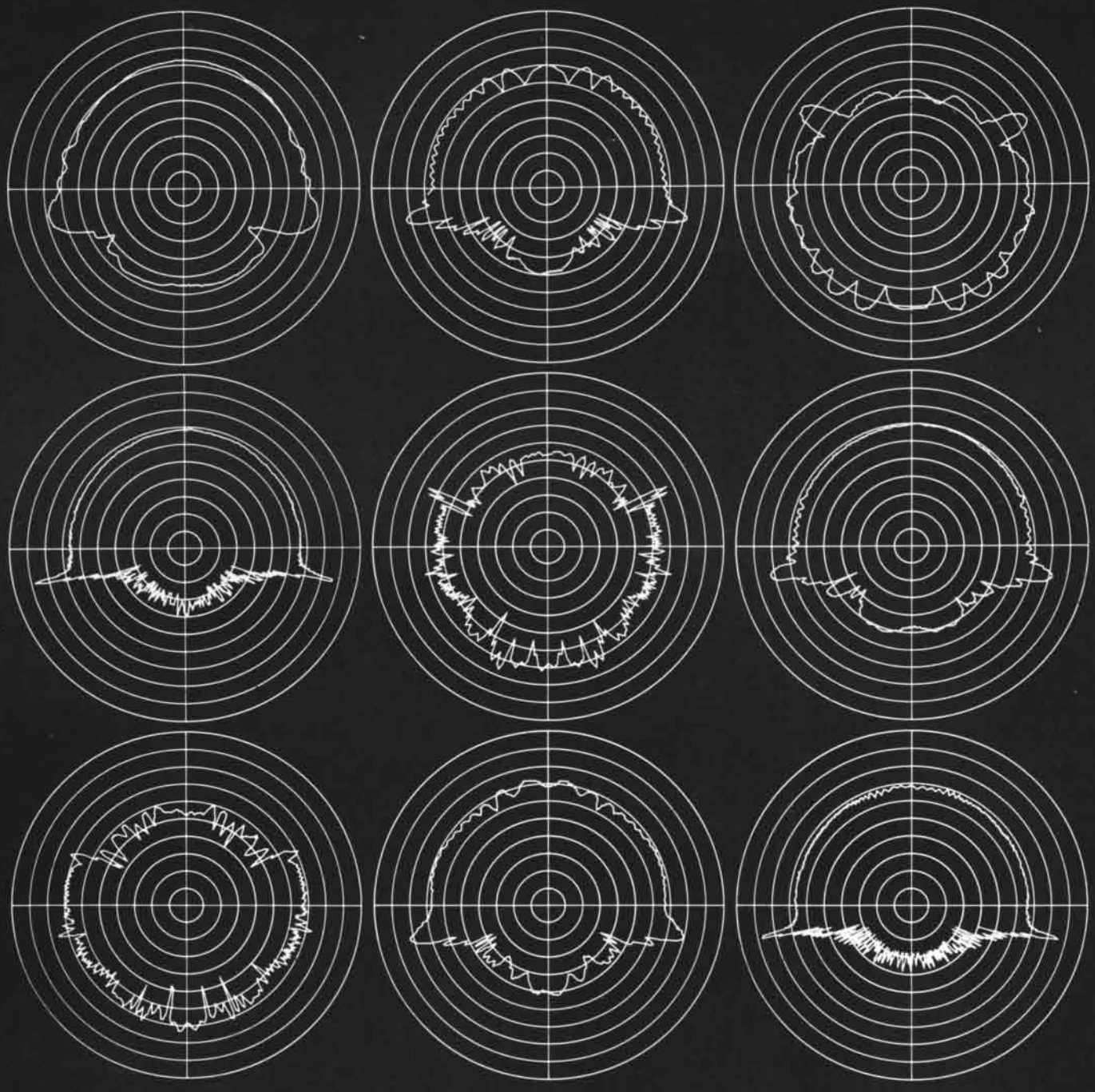
"If the curvature of the mirror is a perfect sphere, the surface will appear to be flat. If the knife blade is now moved very slightly ahead of the focal point, the surface will appear to be convex, like a ball, and if moved slightly behind, the surface will appear to be concave or cup-shaped. In the case of an $f/9$ mirror this is the desired test pattern; the beginner can consider himself lucky indeed if it appears early during the polishing procedure. Usually a disk will be seen that has either a pronounced bulge or a depression in the middle. Such figures are corrected by altering the lap—removing pitch as required—or by changing the length of the polishing stroke, or both. Strokes that result in the mirror overhanging the lap by more than about half an inch tend to deepen the center, to correct humps or bulges. Those shorter than the normal half-inch overhang tend to bring up the center (or to depress the edges). Continue to polish until the whole surface of the mirror darkens uniformly without bulges or depressions when the knife cuts the rays from a pinhole 1/16 inch in diameter at the focal point. This completes the mirror.

"Reflecting telescopes of many types have been developed during the 294



Assembled reflecting telescope after design by John Hadley

Backscatter Patterns



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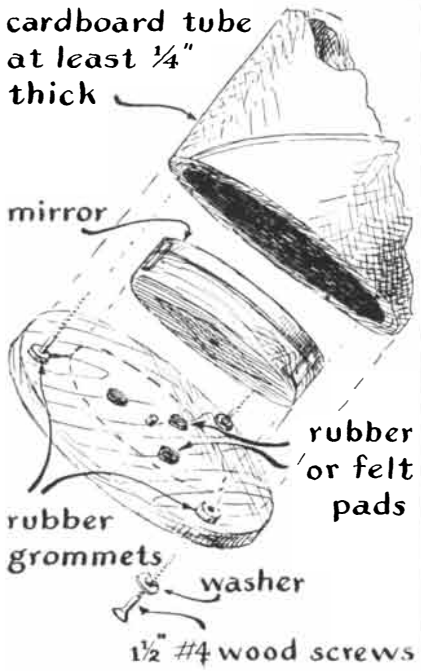
years since Isaac Newton invented the instrument, but I prefer the simple version contrived by John Hadley, an English experimenter, in the early 18th century [*see illustration on page 164*]. The optical assembly of my version of this instrument is supported in alignment by a heavy tube of cardboard of the kind on which rugs are rolled. It is strong, easy to cut and thick enough to take wood screws, even at the ends. I always saturate the screw holes with shellac for extra strength.

"The mirror is mounted on a disk of plywood, large enough to cap the end of the tube, by means of a machine screw that engages the nut recessed in the wood block of the mirror. Three equally spaced wood screws fasten the assembly to the lower end of the tube. The holes for the screws are equipped with rubber grommets and the axis of the mirror is aligned with the axis of the tube by adjusting the screws.

"An oblong hole can now be cut in the side of the tube near the top for admitting the eyepiece assembly. This assembly includes a small front-surface mirror for deflecting the rays to a focus just beyond the outer edge of the oblong hole. The position of the center of the hole is determined by subtracting the radius of the tube from the focal length of the completed mirror. Both the small mirror and the lenses for a variety of eyepieces [*see bottom illustration on next page*] are available from the Edmund Scientific Company.

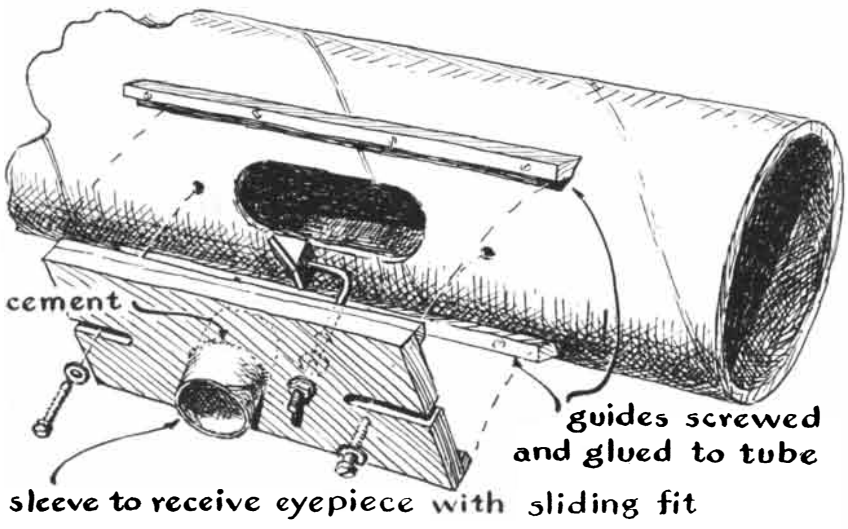
"The base of the Hadley telescope resembles a three-legged milking stool 20 inches high. The top is 10 inches long and about half as wide. A single bolt in the center attaches a trunnion assembly



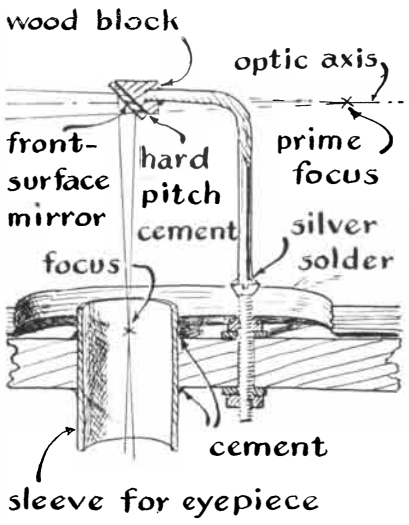
Details of mirror cell assembly

that rotates in azimuth on the bolt. A pair of bolts extending outward from the middle of the tube constitute the elevation axis. They engage slots in the trunnion and attach to the tube through a pair of metal plates screwed to the cardboard. The tube is held in the trunnion slots by a pair of helical springs.

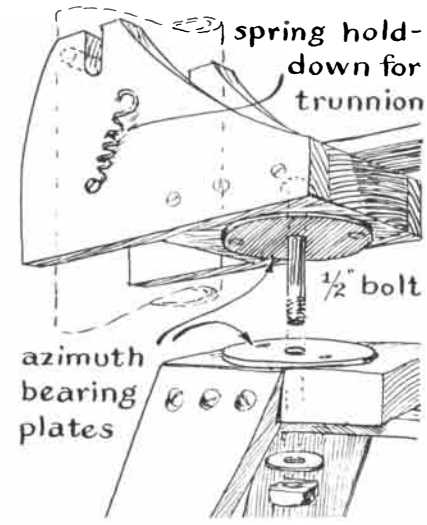
"Slow-motion drive in both azimuth and elevation is provided by a pair of miniature winches made of 1/4-inch rods that fit the plastic knobs of an old radio set. An outrider on the base supports the azimuth winch and its cord, which swing a lever arm fastened to the trunnion assembly. The elevation winch



Details of eyepiece holder

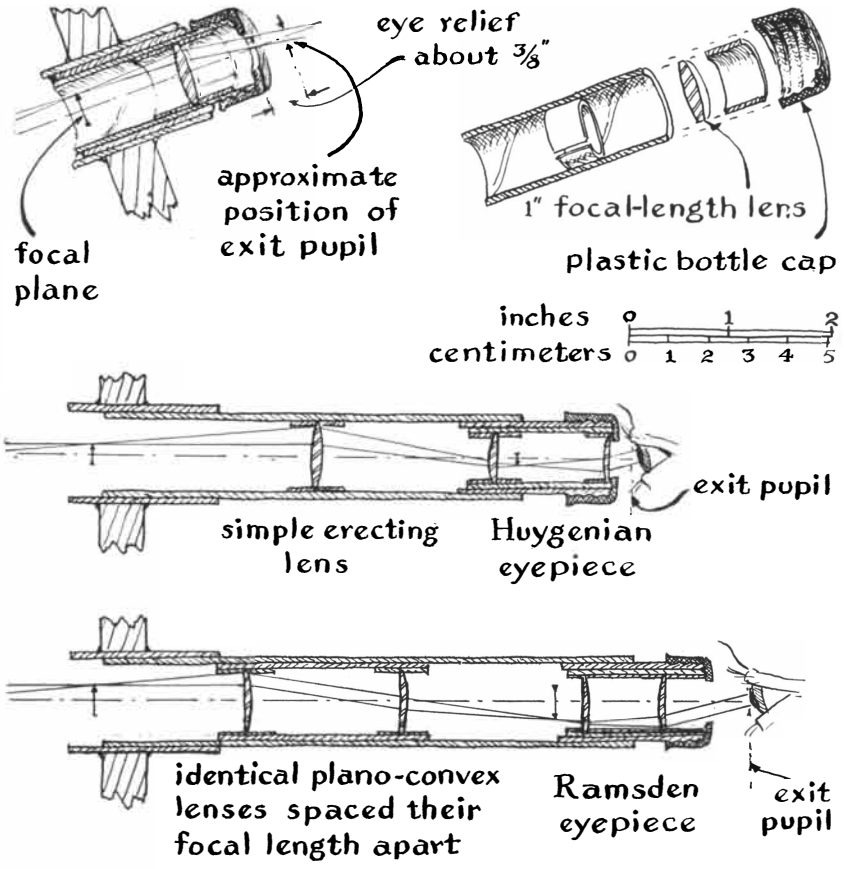


Diagonal mirror and focal plane



Details of trunnion assembly

is built into the end of the lever arm and its cord is fastened to the end of the tube. The bottom of the tube carries a small counterweight that keeps the elevation cord under tension. By modern standards the arrangement may seem somewhat primitive. I find that it has the offsetting virtues of low cost and simplicity. During the past three decades I have built many telescopes ranging in design from a replica of Newton's tiny instrument to the highly mechanized types so popular today. None is more convenient or pleasant to use, in my opinion, than Hadley's primitive design."



Various homemade eyepieces for Hadley telescope

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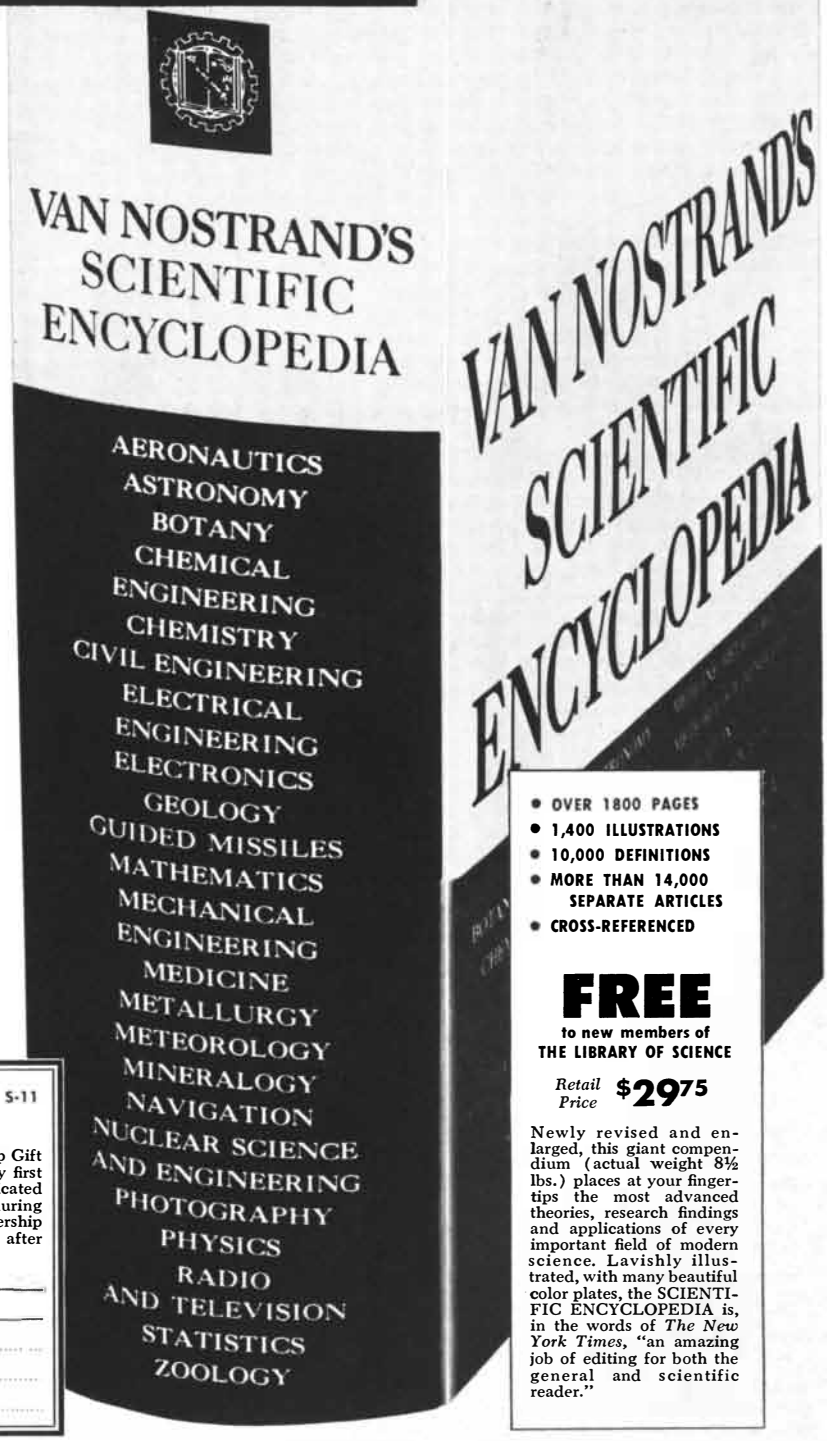

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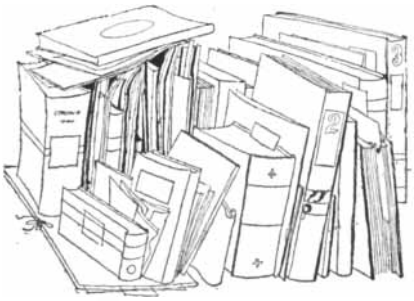

BOOKS

Concerning a new work about psychical research

by George A. Miller

LECTURES ON PSYCHICAL RESEARCH, by C. D. Broad. The Humanities Press ($10).

If you dream that your dog is dying the same night a locomotive kills him, how do you account for it? If you see a person guess the order of a deck of cards far more accurately than chance would predict, what do you think he is doing? If you hear others describe similar improbable occurrences, what conclusions do you draw?

Such are the puzzles that motivate psychical research. In the 81 years since the founding of the Society for Psychical Research, however, persistent inquiry by some extremely intelligent and imaginative people has failed to shed much light on the matter, and it has stirred up enormous argument and controversy.

The first question most of us ask ourselves is whether we should shrug these things off as interesting but fortuitous accidents or must assume that something unknown, perhaps something supernatural, causes them. Which is, at bottom, a very general kind of question. How improbable must an event be before we refuse to call it a coincidence? The answer to this more general question, as Thomas Bayes pointed out 200 years ago, must depend on the a priori probabilities of any alternative hypotheses. Therein, I believe, lies a major source of the passionate debate that has surrounded this unorthodox branch of the scientific enterprise.

If we reject the hypothesis that nothing more than coincidence is involved, then a second question follows: What possible mechanisms might account for the reported phenomena? If not chance, then what? Most (but not all) of the incidents that have been reported could of course be explained if we were willing to assume that individual minds are not as well insulated from one another as most people believe. If we conclude that some such assumption is necessary, then what is the channel of communication, and why is it so terribly noisy? Is there some perfectly natural phenomenon at work that scientists have not yet discovered but that we may someday understand and control? Or have we here a phenomenon that is essentially incompatible with the fundamental laws and methods of physics? Or does this distinction make any sense at all?

The questions are not easy to phrase, much less to answer, and the darkness that surrounds them has not been relieved by the emotional reactions they seem to inspire. When as distinguished a philosopher of science as C. D. Broad agrees to wrestle with them, we might hope at last to see the issues analyzed dispassionately and clearly set forth. Broad has lived a long time and has seen too many intellectual fashions come and go to be overly impressed by scientific prejudices. When he turns his philosopher's gaze on the disreputable domain of psychical research, he is not easily intimidated by the collective disdain of hardheaded scientists. He knows all too well that most of these critics have not even examined the evidence, because, like the Aristotelians who refused to look through Galileo's telescope, they know in advance that there can be nothing to it. To such as these Broad can give as good a sneer as he gets.

Moreover, Broad brings knowledge to his task—detailed knowledge of the tangled history of many efforts to collect evidence relevant to the existence of psychical phenomena. This knowledge, based on years of active participation in the affairs of the Society for Psychical Research, led to his being invited to deliver the Perrott Lectures on the topic at the University of Cambridge in 1959 and 1960. The present book, which appears in the International Library of Philosophy and Scientific Method under the editorship of A. J. Ayer, amplifies the materials prepared for those lectures.

The list of Broad's qualifications must include more than courage and knowledge. As a student of the philosophical bases of modern science, Broad understands far more deeply than most psychical researchers the perils and pitfalls of inductive logic. These are displayed for the reader, along with the evidence and Broad's own pointed opinions, in lively, readable, interesting prose. The issues raised by psychical research are by no means clear or unambiguous; the analysis of these ambiguities is proper work for a person with Broad's philosophical interest and training.

The adjectives "courageous," "knowledgeable," "thoughtful" and "eloquent" describe both the man and his book. I almost wish "convincing" could be added to the list; it is uncomfortable to find oneself in disagreement with so gifted and persuasive an author. The most any skeptic must grant when he closes this book is not that paranormal phenomena exist but merely that we cannot prove they do not exist. Which position falls considerably short of the one Broad himself has adopted.

Before reviewing the tiresome but still unanswered objections, I should outline the case Broad presents in support of his beliefs.

Psychical research is defined as the scientific investigation of ostensibly paranormal phenomena. Paranormal phenomena violate certain very general "basic limiting principles," mostly of a negative or restrictive kind, that are accepted without question by practically everyone raised under the influence of Western industrial society. Minds are private, the future must remain inscrutable, volition extends only to your own body, dead men tell no tales—these are examples of basic limiting principles. It is important to note that these principles are not necessarily laws of nature; to violate a basic limiting principle is not necessarily the same as to violate a natural law. Paranormal phenomena may result either from natural causes presently unknown to us or from supernatural causes whose nature may be forever unknowable; Broad's definition does not prejudge the issue. It is clear from the definition, however, that a belief in the reality of paranormal phenomena does not necessarily imply any belief in spirit-

ualism; it entails no assumption that consciousness continues after death.

Psychical research, so defined, encourages an essentially negative approach. When a reported incident seems paranormal, the psychical researcher must decide if any normal explanation can be given. Only if he fails to find a normal explanation can he classify the incident as paranormal—which places a heavy burden on his integrity and ingenuity in conducting the search for alternative explanations.

Ostensibly paranormal phenomena may occur sporadically (apparitions or phantasms, for example) or recurrently (haunted houses or communication through mediums). Sporadic instances do not lend themselves to experimental investigation, but they can be critically evaluated, classified and summarized. Recurrent phenomena will permit experimental controls and so may offer a better opportunity for answering some of the more puzzling questions that infest this whole domain of inquiry.

With his basic definitions out of the way, Broad turns next to the evidence. He first describes some of the classical experiments in guessing—those by S. G. Soal, by J. G. Pratt and Hubert Pearce, and by G. N. M. Tyrrell—in which certain people guessed the order of a haphazard sequence of events far better than chance would have led one to expect. In Soal's experiments, although sensitive guesses did not hit on the card the agent was thinking of at that instant, they did seem to hit the card he would think of next (an example of precognition), but even that failed when any possibility of telepathy was eliminated. Pearce was able (at a distance of several hundred feet) to guess the order of cards Pratt merely handled but did not look at—which seems to exclude telepathy. Tyrrell constructed an elaborate electromechanical device that enabled him to randomize various conditions, but he got his best results when he did not know what alternative the machine would select (when telepathy was impossible) or when he did not press the keys in a strictly random order. The odds cited against the various observed outcomes occurring by chance are all impressively large, the largest being 8×10^{26} to one in the case of the Pratt-Pearce experiment.

Readers who do not enjoy statistical arguments will find this discussion tedious; those who do like statistics will find some looseness in Broad's treatment. His unqualified statement that the number of hits is normally distributed, his reference to a variance formula as a standard deviation, his neglect of the effects of optional stopping, his willingness to aggregate the improbabilities of selected sessions, his superficial explanation of correlation coefficients—all cast doubt on his level of statistical sophistication. And everyone will find it difficult to keep in mind which conditions seemed to work best for which agents and recipients, or to draw any general conclusion from the heterogeneous results. In spite of questionable statistics and conflicting results, however, I am personally willing to concede that something unlikely was observed in these guessing experiments.

The second section of the book deals with paranormal hallucinations and the logical puzzle of what one might possibly mean by a veridical hallucination. The evidence has a 19th-century flavor I associate with Grandmother's library. Take, for example, the Wilmot case. On February 21, 1890, W. B. H. of Bridgeport, Conn., sent to Richard Hodgson of the Society for Psychical Research a manuscript that W. B. H. had written from memory five years earlier. The manuscript recorded a story told by S. R. Wilmot concerning certain experiences had in 1863 by Wilmot, his wife and W. J. Tait. The story, as later corrected by Wilmot and his wife, went as follows: Wilmot sailed from Liverpool in the ship *City of Limerick* in October, 1863. Ten days out he dreamed that Mrs. Wilmot, then at home in Connecticut, came to his stateroom clad in her nightdress. At the door she seemed to discover another occupant of the stateroom in addition to her husband, and she hesitated. Then she advanced to Wilmot's side, stooped down and kissed him and withdrew from the cabin. The other person in the stateroom was Tait, who occupied the berth above Wilmot. When Wilmot awoke in the morning. Tait accused him of having had a lady visitor; questioning revealed that Tait, while lying wide awake in his berth, had witnessed a scene corresponding exactly to what Wilmot had dreamed. Moreover, when Wilmot finally arrived home, Mrs. Wilmot asked him whether he had received a visit from her on the night in question. She, it seems, had been lying awake in bed worrying about her husband's safety, until at about 4:00 A.M. she "went out to seek" him. It was as if she crossed a wide, stormy sea, came at length to a low, black steamer, somehow went up its side and descended into the cabin, and passed through it into the stern until she came to her husband's stateroom. She seemed to see a man in the upper berth looking right at her, and for a moment she was afraid to go in. Then she went up to the side of Wilmot's berth, bent down and kissed him and went away.

"This," Broad comments, "is a very strange story. The only serious evidential weakness is that the first written report of it depends on the memories of Mr. and Mrs. Wilmot as they were some twenty years after the date of the events reported." As regards Mrs. Wilmot, it is an *out-of-the-body* experience. As regards Tait, it is a waking *quasi-perception* of a *phantasm of the living*. As regards Wilmot, it was a paranormal *dream*, whose contents corresponded with the simultaneous paranormal experiences of his wife and cabinmate. The case involves both *collective* and *reciprocal* visual *hallucinations*, which were *invasive* for Wilmot and Tait but *excursive* for Mrs. Wilmot. All in all, an excellent exercise in the lexicon of psychical research.

Why does Broad take such stories seriously? Obviously he believes in the integrity of his witnesses and the accuracy of their memories. More than that, however, he wants to believe them. As he admits, he has "a certain hankering after what I may call the 'mysterious' or the 'magical' and a strong desire that the current orthodoxy of many contemporary professional scientists (in particular experimental psychologists) may prove to be as inadequate as it certainly is arrogant and ill-informed." I believe, however, that the intellectual source of his confidence derives principally from the *Report of the Census of Hallucinations* conducted by the Society for Psychical Research and published in 1894.

The census was taken by 410 interviewers who asked about 17,000 persons this question: "Have you ever, when believing yourself to be completely awake, had a vivid impression of seeing or being touched by a living being or an inanimate object or of hearing a voice; which impression, so far as you could discover, was not due to any external physical cause?" Approximately 10 per cent of those interviewed answered this question in the affirmative. Of those who reported hallucinations, 80 gave reports of death coincidences, of which the psychical researchers judged 32 to be undoubtedly genuine. The total number of visual hallucinations of other people —including those that did not as well as those that did coincide with a person's death—was estimated to be about 2,100. In short, one in every 63 waking hallucinations about another person occurred within 12 hours of that person's death. On the basis of the death rate in England at the time, however, the fraction should

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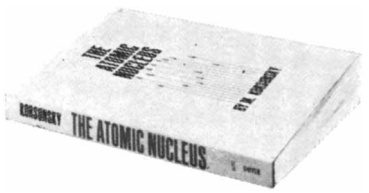

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have been only one in every 19,000 hallucinations if nothing more than chance were involved. "I think it is plain from these figures," Broad writes, "that there very probably is *some* connection, direct or indirect, normal or paranormal, between the occurrence of a waking hallucination of this particular kind and the occurrence, within a short period around that moment, of the death of the person referred to in the hallucination."

For those who relish a more-things-in-heaven-and-earth-Horatio philosophy, the third section of Broad's book is sure to be the most engrossing. Here Broad describes the performance of mediums: their trances, controllers, communicators and remarkable utterances. Here we meet Mrs. Leonard, a professional but highly co-operative medium whose various voices were independently given word-association tests; Mrs. Willett, an amateur chosen specifically by the shades of F. W. H. Myers and Edmund Gurney as the channel through which they could describe their intricate psychical philosophy to Sir Oliver Lodge and Lord Balfour; Mrs. Warren Elliott, a professional who was carefully investigated by H. F. Saltmarsh, and Emmanuel Swedenborg, whose spiritual life was greatly enriched by some remarkable visions of the next world. As in the case of hallucinations, there are well-known psychological phenomena involved; in this case the relevant facts have to do with dissociated personalities alternately controlling the same human organism. Broad's main concern is not with abnormal psychology but with the question of veridicality: Does the medium accurately express ideas or information that could not have been known to her by normal means?

Consider the Vandy case. Edgar Vandy was an engineer and inventor, 38 years old, who in August, 1933, died by accidental drowning. There was a certain amount of mystery as to the precise details of his death; Edgar's two surviving brothers, George and Harold, were unsatisfied by the outcome of the inquest. George Vandy had no belief in survival after death, but he had been a member of the Society for Psychical Research and thought it possible that trance mediums might possess some kind of paranormal powers that would enable them to throw further light on his brother's last moments. Accordingly he sought the advice of Drayton Thomas, who recommended three mediums. The Vandy brothers went to all three, and in addition Drayton Thomas had a "proxy-sitting" for them with Mrs. Leonard. In all there were six sittings devoted to Edgar Vandy. Broad examines in some detail the content of those six sessions, particularly their accuracy and the remarkable degree of correspondence among them. Concerning Edgar's death, all six agreed that he fell and hit his head, and that one or more people were present at the scene who might have saved him but failed to do so through cowardice or incompetence, but that Edgar wished to shield them. Five out of six sittings made reference to water and to drowning and stated that Edgar's death was a strangely unlucky event. Concerning the machine he had invented shortly before his death, four of the mediums gave information about it that, considering their general ignorance of such matters, was more or less accurate. "It is quite incredible," Broad says, "that the amount and kind of concordance actually found between the statements made by the various mediums at the various sittings should be *purely a matter of chance-coincidence*.... We must either suppose (without any direct evidence) elaborate fraud, in which the experimenter and the subjects must have collaborated; or we must admit the occurrence of modes of cognition which cannot at present be accommodated within the framework of accepted basic limiting principles."

The final chapter of the book—an epilogue on "Human Personality, and the Question of the Possibility of Its Survival of Bodily Death"—is a philosophical exercise in untangling terms and arguments. Broad bends over backward to present alternative possibilities and not final answers, but he points out that if one gives any credence to the mediumistic communications, they cannot *all* be plausibly accounted for by mere telepathy to the medium from persons still alive. His own view favors a dualistic solution of the body-mind problem: the psychic component of the medium's personality may be somewhat loosely combined with her body, which can thus become available to other psychic components. The psychic component of personality might be thought of as "a kind of highly complex and persistent vortex in the old-fashioned ether," which could persist for some time after bodily death but could have no new experience during the periods when it was not combined with the body of a medium. These ideas are presented merely as suggestions, not as conclusions. "For my part," Broad says, "I should be slightly more annoyed than surprised if I should find myself in some sense persisting immediately after the death of my present body. One can only wait and see, or alternately (which is no less likely) wait and not see."

How open must an open mind be? The history of science sparkles with geniuses who withstood and eventually overcame the entrenched prejudices of their day. Perhaps the advocates of paranormal phenomena also have hold of a higher truth; romantic sympathy for the underdog almost makes me hope they have. But in a world that has seen so much irrational nonsense accepted as truth, I can only set down my personal belief that this claim for the ultimate invasion of our privacy is fraudulent. An innocent fraud, perhaps, but no less vicious for its good intentions.

To which the reply may be, "But how do you explain ...?" I can explain nothing, of course. This failure might embarrass me more if psychical researchers offered any explanations I could not reject. But, as Broad points out, "to allege that a phenomenon is paranormal is to make a purely negative statement about it; it is not, in itself, to offer any kind of explanation of it." Indeed, there are no explanations to be had on either side of the argument; rational resolution cannot be expected from that direction at the present time.

In the absence of good arguments, therefore, let me raise two standard objections—the sampling problem and the problem of a priori probabilities—to justify my muleheaded satisfaction with the basic limiting principles of our society.

It seems to me that Broad underestimates the strength of the argument that in many instances there is nothing to be explained. When simplified, the demand for explanations seems to spring mainly from the improbability of the events that have been reported by psychical researchers. Improbability in and of itself, however, is no guarantee of paranormality.

If you continue to collect random data long enough, it is inevitable that something orderly will occur eventually; if you report only unusual occurrences, you can support any hypothesis that happens to appeal to you. Put it this way: Suppose you become seriously interested in psychical research. You undertake a prolonged and well-controlled experiment, let us say, in card-guessing. The results are inconclusive. Query: What will you do with your data? If you are like dozens of experimental psychologists I know, you will simply file them. You will probably not write them up and send them off to be published. I have no idea how many

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hundreds of failures had to go unreported before the handful of successes we know about could be obtained, but I am conscious of the considerable selectivity that underlies the reported results. Thus I am far less impressed than I should be, perhaps, when some gambler enjoys a remarkable string of good luck or some patient produces responses that correlate too well with an agent's random messages.

The dangers of selective sampling must not be underestimated. The time and effort that went into the *Census of Hallucinations*, for example, was largely wasted because of lack of adequate controls. The interviewers were people with an interest in the outcome; it is difficult to believe their respondents were not a specially selected subgroup. Broad himself, who is aware of all these objections but gives them far less weight than they deserve, remarks that a similar census should be conducted today with all the refinements that recent experience in taking Gallup polls would suggest, and hopes that "much more elaborate efforts would be made to ensure that those questioned constituted a fair sample." Until such a modern census is made, however, suspicion would seem the only rational attitude.

Many years ago a wise teacher told me that the really important question about telepathy is not is it true but why some people believe it is. At the time I thought he was prejudging the issue and I was surprised; he was not (in matters of science, at least) a bigoted man. Now I am not so sure. Perhaps what he meant was that it is impossible *not* to prejudge the issue.

Suppose that an experiment on telepathy is conducted without deliberate deceit or collusion, that appropriate controls are observed, that no mistakes occur in recording or analyzing the data, that impeccable use is made of probability theory—and still the correlation between the agent's and the patient's data is much closer than anyone would be willing to attribute to chance. Suppose, that is, we actually obtain bona fide evidence of communication between them. Now, even in this situation two choices are left open to us. We may be forced to grant that *something* went on between them, but we are not forced to grant that it was something paranormal. It is still possible that a perfectly normal chain of cause and effect was at work to produce the observed result.

How do we decide? Obviously we must eliminate every normal alternative hypothesis. This task is both painful and expensive, so that it may not always be pushed as far as it should be. In instances where the issue is important enough to justify the effort and expense, however, alternative explanations can often be found; I think of the debunking of "unidentified flying objects" as a case in point. But for each ostensible communication a new and specific explanation must be painstakingly established.

I suspect that many apparent instances of mind reading could be explained in terms of very subtle signals, perhaps unconsciously discriminated. It is tedious to keep insisting that tiny clues—tone of voice, hesitation, facial expression, eye movements, changes in breathing, muscular tensions—may suggest the performance the agent or experimenter wants; it would be even more tedious to collect evidence that such clues were effective in any particular instance. This is not an accusation of deliberate fraud; there is no question of dishonesty here. On the contrary, the problem arises because it is so terribly difficult to tell a lie, because there are so many different, but perfectly normal, channels of communication between people. No doubt psychical researchers have attempted to conceal their expectations, but this is an extremely difficult thing to do successfully. Broad admits such interactions are possible, but he thinks them less important than I do; that is, he assigns them a lower a priori probability.

The point is that one can usually imagine alternative hypotheses that do not involve paranormal phenomena, even though we may be in no position to state them explicitly. The fact that our experimental results were unlikely does not settle the question of what caused them to be unlikely. In this situation we are forced back on our a priori estimates of the probabilities of some rather vaguely phrased alternative hypotheses. For example, which is more improbable: that paranormal powers exist or that Mr. and Mrs. Wilmot did not remember precisely what happened 20 years before? Or again, which is more improbable: that Edgar Vandy's personality survived the death of his body or that the four mediums all had access to some other source of information? Even though we may admit that our card-guessing data could not have resulted by chance more than once, say, in a million times, we will still not believe in telepathy if we have already prejudged the existence of paranormal phenomena to be far less probable than that. There are some beliefs so strongly entrenched that no amount

of statistical evidence can shake them.

The important question—as my teacher said—is not whether something remarkable occurred but whether you are prepared a priori to believe that what took place was paranormal. The kinds of evidence presented to date are not sufficient to settle the issue.

Of course, new evidence may be produced at any moment—nonstatistical evidence that will persuade even the most arrogant disbelievers. It is difficult to disagree with Broad when he writes: "It seems to me unlikely that there will be progress in the study of paranormal phenomena ... unless and until someone hits upon methods of inducing paranormal powers in ordinary persons and sustaining them thereafter at a high level for some considerable time." Such an accomplishment would be a real breakthrough, in every sense of that overworked term.

I admit it may happen. But I wouldn't bet on it.

Short Reviews

THE MOUNTAIN GORILLA: ECOLOGY AND BEHAVIOR, by George B. Schaller. The University of Chicago Press ($10). The popular conception of the gorilla is based on the few that live in zoos, on comic-strip information and on King Kong, who kidnapped fair maidens and when provoked while in town knocked over tall buildings. Whereas the zoologist's conception is somewhat different, the gorilla, although discovered more than 100 years ago, has remained pretty much a creature of mystery. It has been shot, captured and photographed, but its "reputed belligerence and remote habitat discouraged firsthand scientific study." The author of this book was a member of the African Primate Expedition (1959–1960) and spent some 20 months in the study of the ecology and behavior of the mountain gorilla (*Gorilla gorilla beringei*) in the eastern Congo, western Uganda and Ruanda-Urundi. His data are based on 466 hours of direct observation during 314 encounters with gorillas, primarily in the region of the Virunga volcanoes. He usually tracked gorilla groups alone and after contacting them sat quietly and in full view of the animals. Through "repeated peaceful contact" six groups became accustomed to his presence. "All members of these six groups, as well as several other gorillas, were recognized individually." From this intensive observation he gathered a great mass of information, most of it entirely new.

In the Virunga-volcano region the gorillas frequent the mountain forests at an altitude of about 8,000 feet as well as the zone of giant senecios at altitudes of more than 13,000 feet. The population in this area consisted of about 200 gorillas. Schaller's report describes and evaluates every aspect of the gorilla's life: its habits of eating, nesting, mating and playing; its methods of communication and its expressions of emotion, such as beating its chest.

Gorillas grow at a prodigious rate. The baby is no more than a handful, but at one year the animal weighs about 15 to 20 pounds and at five 120 pounds; at adulthood the female weighs 150 to 250 pounds, the male 300 to 450 pounds. In acuity of sight, hearing and smell the gorilla is roughly comparable to man. Its personality in the wild compares with that observed in captivity: it is "markedly shut-in or introverted." Gorillas are mainly quadrupedal and terrestrial. They climb around in trees, but "cautiously."

Females appear to reach sexual maturity at the age of six to seven and males at about nine to 10. A female produces one offspring every three and a half to four and a half years unless the youngster dies in infancy. Disease is said to be the main cause of mortality. Gorillas may live as long as 35 years in zoos.

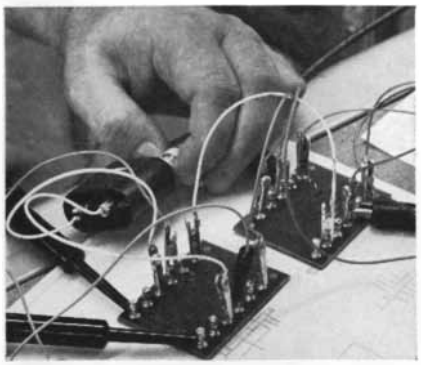
Social structure is in groups (which in Schaller's experience varied from two to 30 animals); activity is diurnal and falls between six in the morning and six in the evening. *Gorilla gorilla beringei* rises between six and eight and feeds intensively for two hours or more. Then it rests for about four hours, followed by more feeding and traveling. At six in the evening it beds down for the night. Its diet consists of various leaves, barks, piths and fruits. The animal uses its hands and teeth to rip, shred and tear the palatable parts of the plants it eats. (A curious fact is that Schaller never saw a free-living gorilla drink.) It builds crude platforms or nests of herbs and branches on which it rests during the day and sleeps during the night. Although these nests, when built in trees or on steep slopes, serve to keep the animals from falling or slipping, those on level ground "have no obvious function." Gorillas usually defecate while walking or while lying in the night nest; they urinate while squatting or lying. Like us, they adapt to the tedium and vicissitudes of life by sneezing, coughing, yawning, hiccuping, belching and scratching. They groom themselves readily, concentrating their activity on the arms, shoulders, abdomen and legs. Although they emit 22 more or less "distinct vocalizations," only eight of these are commonly heard in their daily routine. They grumble and grunt when they are not contented; they use abrupt grunts to keep the group together; they emit a series of hoots preceding the chest-beating display; when they quarrel, they bark and scream. Infants have a high screech when they are in danger of falling behind the group. In general, however, gorillas vocalize infrequently. Chest-beating, so well known to movie-goers, consists of nine fairly distinct acts that follow a series of hoots at an accelerating tempo. The animal "rises on its hind legs, throws an herb into the air, kicks up one leg, and, at the climax, beats its chest with the hands several times. It then runs sideways while slapping and tearing at the vegetation and finally thumps the ground with its palm." Only large males were observed to hoot. The display evidently has some part in intimidation and communication.

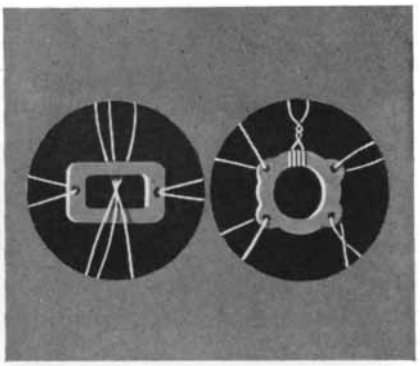
A silver-backed male leads each group and determines its behavior. He asserts the right of way along a trail, he has claim to a certain sitting place and he seems to decide what is to be done and when. Until gorillas are six years old they play a good deal, running, climbing, sliding and swinging; they also engage in social play, which consists of wrestling, chasing and such games as king-of-the-mountain and follow-the-leader. At six almost all play activity ceases. Associations are close, but interactions involving bodily contact are not pronounced in adults. Quarrels and other forms of aggressiveness are uncommon. Gorillas will even put up with human observers, which is somewhat surprising considering that most of the humans they have known are murderers or kidnapers. When a gorilla is pursued by a human, the animal will sometimes turn on and bite the attacker severely. But this kind of behavior is rare.

This is a first-class natural-history report, with many valuable tables and excellent photographs.

PALESTINE BEFORE THE HEBREWS, by Emmanuel Anati. Alfred A. Knopf, Inc. ($8.95). About 3,000 years ago the Hebrews, a Semitic tribe of Mesopotamian origin, broke into the land we call Palestine, the natural bridge between Asia and Africa, located between the Arabian Desert and the Mediterranean Sea. A landless motley, but effective warriors and apparently well led, they conquered Canaan, which already had its cities, destroyed the prevailing feudal system and spread over the country "the tribal democratic system of the marginal groups." With this revolution began the more or less full historical records that make possible the reconstruction of events in that part of the world over the past three millenniums. But although the long period of prehistory from the age of hunting and gathering down to the period of Joshua and his pastoral army—some 600,000 years—affords much sparser testimony, the bones and tools and other remains have made it possible for archaeologists, who have combed and dug up this region more intensively than any other in the world, to piece together a grossly imperfect yet fascinatingly informative jigsaw puzzle of the cultural history of man since he began making tools. The Italian-born archaeologist and anthropologist Emmanuel Anati, remembered for his excellent book *Camonica Valley*, reviewed in these columns in 1961, has for many years studied the prehistory of Palestine, both as a fieldworker and as an interpreter and synthesizer of the extensive archaeological reports of others. His account begins with a description of the geographical setting, the geology and the changing environment, and then traces man's cultural evolution in the Near East from the Pebble Culture through the Middle and Upper Paleolithic, the Mesolithic Interlude, the Chalcolithic and the Early Urban cultures. He writes about the tools, the burial customs, the making of pottery, the beginnings of agriculture and the domestication of animals, the dwelling places, and about the many rock drawings that enable not only the archaeologist but also the ordinary reader to imagine and to reconstruct the ways and feelings of Stone Age man. Altogether, Anati's story is a tour de force, scholarly and engrossing, impressive in its handling and weaving together of large amounts of disparate data, so that the jigsaw puzzle really appears to hold together and convey a true sense of how things were at different stages of prehistory and how they changed from one to another. It does not, of course, detract from the merits of the book to point out that other specialists will differ from Anati in quite a few of his interpretations. His views will nonetheless be respected and readers will find the work as illuminating and exciting as it is bold. Fully illustrated.

THE PAPERS OF BENJAMIN FRANKLIN: VOLUME VI, edited by Leonard W. Labaree and others. Yale University





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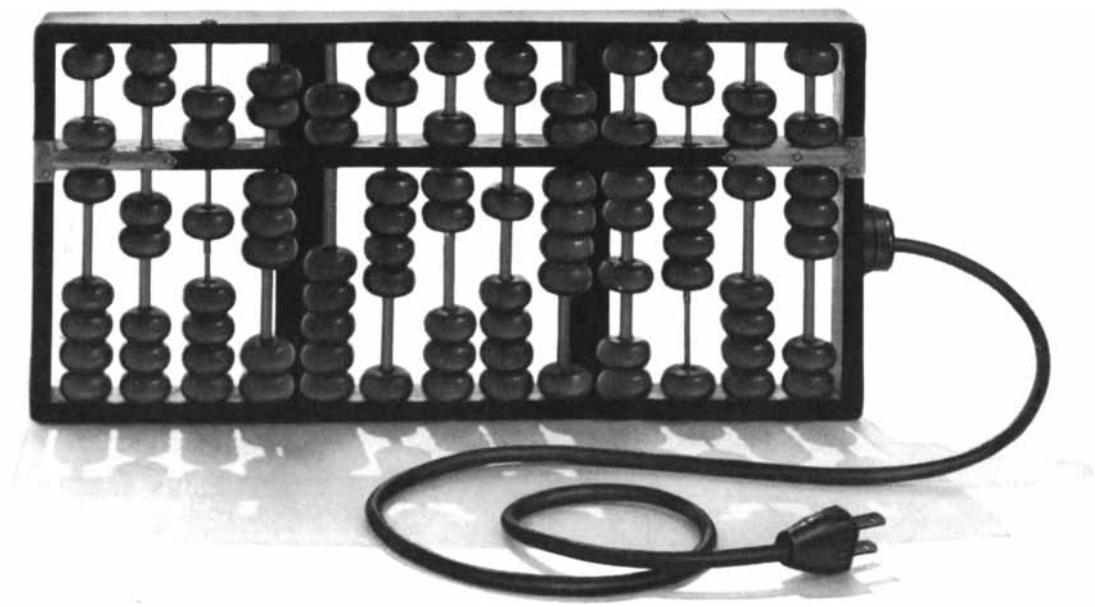

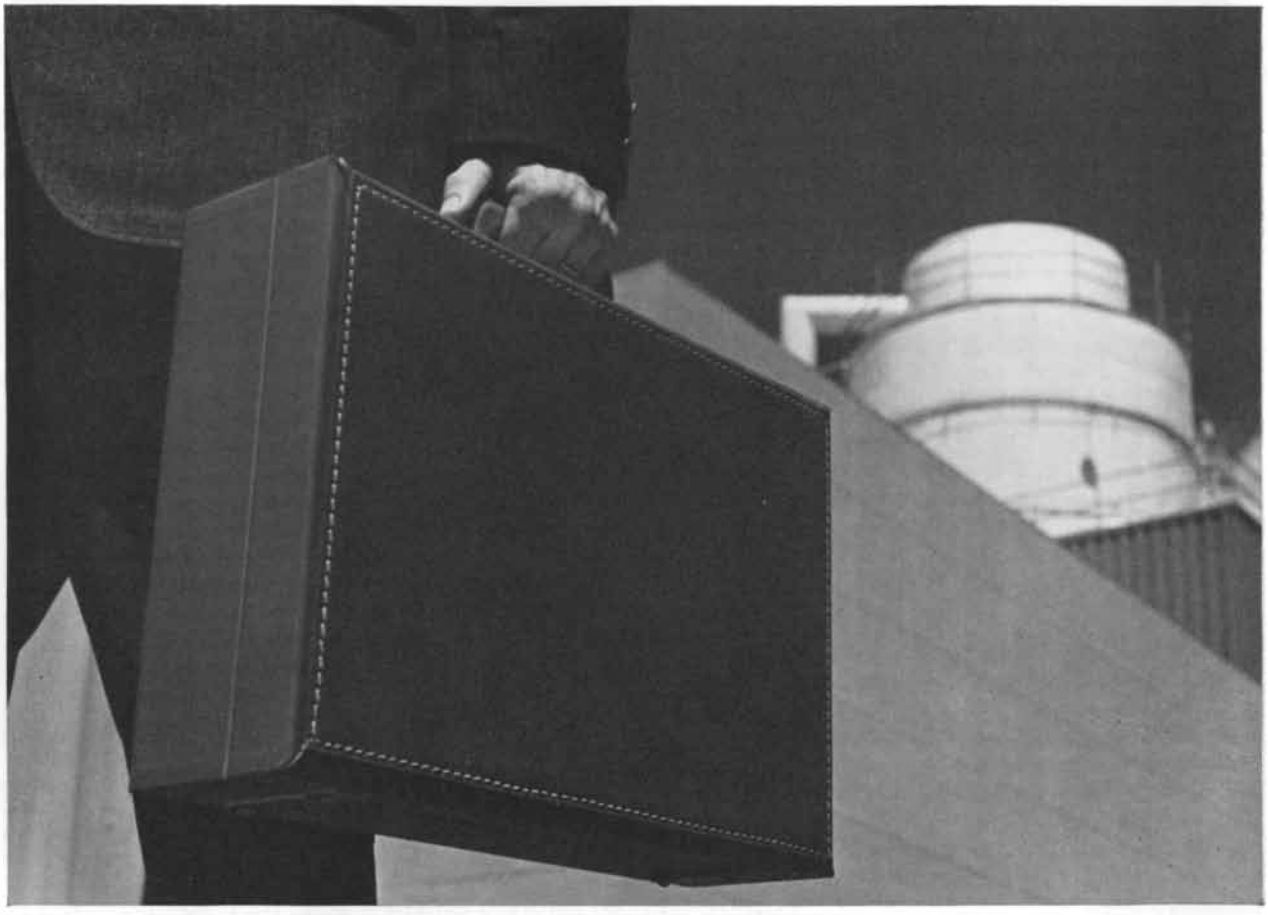

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Press ($10). This volume of the Yale edition of Franklin's papers covers the period from April 1, 1755, through September 24, 1756, during a large part of which he was concerned with the defense of Pennsylvania against the French and Indians, with raising money, wagons, horses, recruiting drivers and building a chain of frontier forts. As always, however, he refreshed his lively curiosity with correspondence on electricity and other scientific matters and found time to engage in literary work for his own amusement and for the edification of his friends. Franklin's *joie de vivre* is altogether infectious, no less for the readers than for the editors of this superb collection of his writings.

GRAPHS AND THEIR USES, by Oystein Ore; CONTINUED FRACTIONS, by C. D. Olds. Random House, Inc. ($1.95 each). Two volumes in the New Mathematical Library, a series addressed to high school students and laymen, several earlier volumes of which have been noted in this department. Ore's book covers many aspects of the use of graphs, from the efficient scheduling of a chess tournament, the cheapest way to build a railroad net and the theory of mathematical relations to the solution of certain puzzles and games and the analysis of the map-coloring problem. Olds ranges over a many-sided topic that was studied by the great mathematicians of the 17th and 18th centuries and that is still a subject of active investigation today. Paperbacks.

A PHYSICAL THEORY OF THE LIVING STATE: THE ASSOCIATION-INDUCTION HYPOTHESIS, by Gilbert N. Ling. Blaisdell Publishing Co. ($17.50). Many of the characteristic properties associated with large protein molecules are due to their interaction with small ions. Ling develops a quantitative theory concerning this interaction to explain diverse properties of living systems ranging from ion potentials to developmental embryology. His chief assumptions are that in protein solutions the charged particles do not act independently but are associated and that a small change in the number or kind of ions attached to one portion of a protein molecule can, by induction, trigger larger changes in the state of the entire protein structure. The first point is generally accepted, and Ling backs it with solid arguments. The second has much less experimental support and requires a more tentative description. It is difficult to demonstrate that the effect of exchanging one sodium ion for one potassium ion is transmitted

through the entire protein structure. It is even more difficult to explain adequately all the specificity observed in biological phenomena using only the electrostatic properties of proteins and ions. Ling's tone is professional; this is not a layman's book. It is, however, a magnificent volume. Any scientist-bibliophile will be delighted with the glossy paper, the generous format and the lavish figures and illustrations. There are appendixes through H, a 75-page glossary and a table of symbols that must represent a typesetter's nightmare. Perhaps most revealing of the current state of quantitative, mechanistic biology is Appendix G. After sections devoted to complex mathematical derivations and various experimental methods Ling gives us "A Simple Criterion for Choosing Healthy Common Leopard Frogs (*Rana pipiens* Schreber)." And what is this exact criterion? Healthy frogs have chartreuse spots on their thighs.

THE LIFE OF BIRDS, by Joel Carl Welty. Alfred A. Knopf, Inc. ($12.95). This book, evidently a reprint of a textbook issued by another publisher, is an admirable survey of the basic facts of bird biology directed toward the general student. In a lucid, lively and unpretentious style the author, professor of zoology at Beloit College, discusses every essential aspect of bird life: methods of flight, the kinds of birds, their structure and physiology, reproduction, behavior, songs, calls and other sounds, courtship and mating habits, numbers, care and development of young, ecology, geography, migration and orientation, origin and evolution. Wherever one dips into the book one finds interesting information not only about birds themselves but also about the many modern scientific techniques of research and observation such as radar studies of migration, sound-spectrogram analyses of songs and calls, stroboscopic photography and aerial surveys. This reviewer knows of no better book to introduce the subject to the nonspecialist reader and to give him the pleasure of partaking of the latest knowledge about these wonderful creatures. It is abundantly illustrated with charts, diagrams and photographs; there is a full list of references and useful suggested readings at the end of each chapter.

PHILOSOPHY A TO Z, edited under the supervision of James Gutmann. Grosset & Dunlap, Inc., Publishers ($4.75). This volume, published as part of the publisher's Universal Reference Library,

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consists of articles on all branches of philosophy, from the Chinese and Japanese to modern symbolic logic, translated from the philosophy volume in the German *Fischer Lexikon*, an encyclopedic survey prepared by a large number of German scholars. The text has been modified and enlarged for U.S. usage (that of students primarily) and additional articles have been provided on such subjects as idealism (Abraham Edel), Islamic philosophy (Richard Walzer) and pragmatism (H. Standish Thayer). There are brief bibliographies for each department. Other volumes of this library already published or in preparation concern, among other subjects, anthropology, music, astronomy, chemistry and sociology.

A HISTORY OF CHEMISTRY: VOLUME III, by J. R. Partington. St Martin's Press ($25). The third volume of Partington's massive scholarly history deals mainly with the 18th century and with some topics of French chemistry (already considered in Volume II) touching on the 17th century. The method of the preceding volume is followed: certain chapters treat of the development of the subject by countries, whereas others center around great pioneers such as Lavoisier, Dalton, Priestley, Cavendish and Scheele. Particularly noteworthy is the description of Lavoisier's work, to which Partington gives more than 130 pages, constituting the fullest and clearest account to be found in the English language. It has been argued against Partington that as a historian he suffers from a common pedantic disease, namely that he is quite unable to throw away any fact he has gathered, even if it is only remotely relevant to the topic under discussion, and that anyone consulting his work, particularly the thousands of bibliographical references, has to waste a great deal of time refining the ore. It is true that the history suffers from what might be called a certain fullness and that the lush footnotes are at times quite terrifying, but it is greatly unfair to accuse Partington of being dull. For anyone who does not mind the side journeys, the many snippets of curious fact, this volume, like its predecessor, will provide much enjoyment in addition to being a rich resource as a reference.

Notes

A HANDBOOK OF PSYCHOANALYSIS, edited by Hans Herma and Gertrud M. Kurth. The World Publishing Co. ($1.65). An anthology of writings by leading psychoanalysts, designed to acquaint the ordinary reader with concepts, theories and applications of the subject. A paperback.

EXPERIMENTAL CHEMOTHERAPY, edited by R. J. Schnitzer and Frank Hawking. Academic Press ($38). This first volume of a projected three-volume treatise is devoted to the chemotherapy of protozoan and metazoan infections. The purpose of the work is to condense the existing knowledge of the use of drugs in curing infectious diseases and neoplastic growth. Illustrations and detailed bibliographies.

MOLECULAR GENETICS: PART I, edited by J. Herbert Taylor. Academic Press ($14.50). The first volume of a co-operative treatise that deals with genetics from the molecular point of view. With this departure from the classical approach to the mechanism of heredity, genetics has developed into a broad science of interest to biochemists, virologists and cytologists as well as to geneticists and general biologists.

SOLAR RESEARCH, by Giorgio Abetti. The Macmillan Co. ($3.95). A clearly written introduction to solar research for students or beginners, dealing with such topics as the latest theories of sunspots, of radio observations and of solar effects on terrestrial phenomena, cosmic rays and the sun, the interior of the sun and the utilization of solar energy.

FOUNDATIONS OF WESTERN THOUGHT, edited by James Gordon Clapp, Morris Philipson and Henry M. Rosenthal. Alfred A. Knopf, Inc. ($10.75). Selections, with introductions by the editors, from the writings of six major philosophers: Plato, Aristotle, Descartes, Berkeley, Hume and Kant. A convenient source of readings for the student and for others interested in philosophy.

INTERSTELLAR MATTER IN GALAXIES, edited by L. Woltjer. W. A. Benjamin, Inc. ($12.75). Proceedings of a conference held at the Institute for Advanced Study in 1961. Some 33 papers were presented dealing with these main topics: characteristics of interstellar matter in our galaxy and in other galaxies, and small- and large-scale dynamics of interstellar matter. Illustrations.

A SHORT HISTORY OF SCIENTIFIC IDEAS TO 1900, by Charles Singer. Oxford Paperbacks ($2.45). A soft-cover reissue of Singer's brief, instructive survey first published in 1959.

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