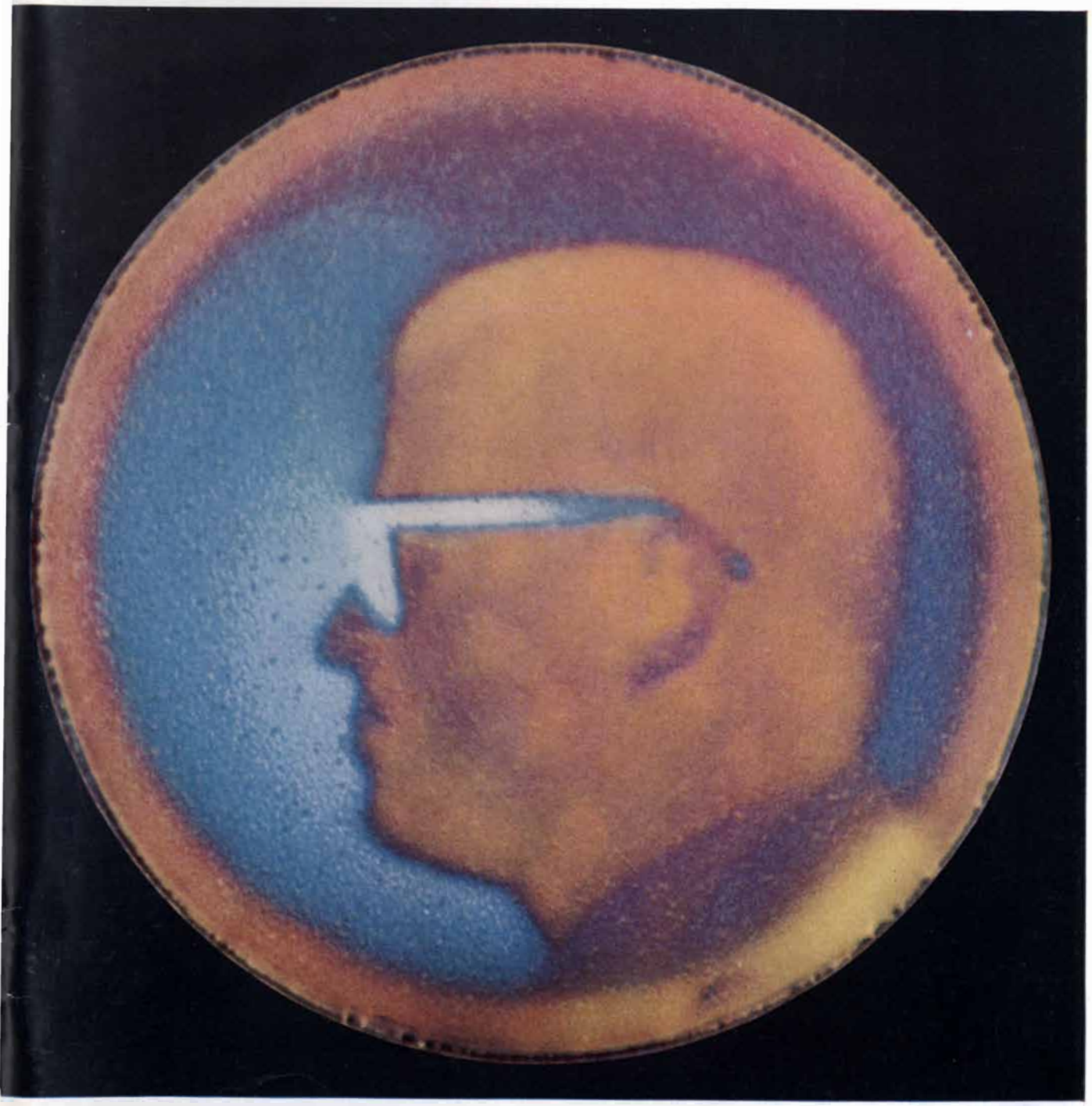
SCIENTIFIC AMERICAN



THERMOGRAM

SIXTY CENTS

February 1967

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This three-dimensional geological model is designed to help Anaconda geologists visualize what's under the earth's crust. They use all the tools and techniques of modern geology, geophysics, and geochemistry in preparing maps and models like this. Backed by the many years of Anaconda basic geological research, they analyze results to evaluate commercial significance and develop the best method of mining the ore body. The goal is to keep Anaconda's production capabilities ahead of the demand for metals. To achieve this goal, Anaconda is intensifying its program of laboratory and field research at geological headquarters throughout the hemisphere. This will provide a broader base for Anaconda's growth, and more copper for our expanding population. The Anaconda Co., 25 Broadway, N.Y., N.Y. 10004.

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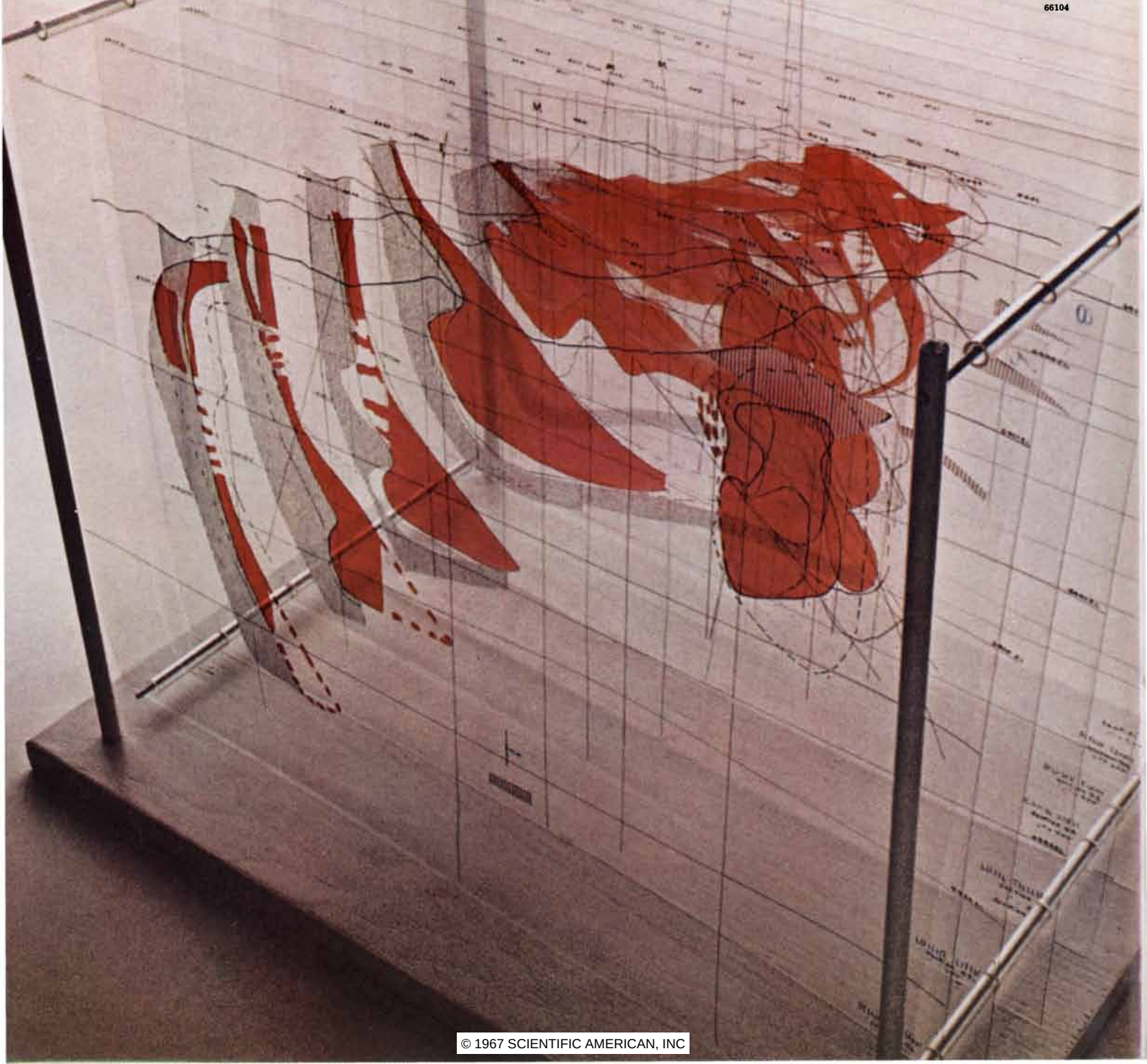

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For one thing . . . providing textbooks which have been studied by one out of every three Americans! D. C. Heath and Company — newest member of Raytheon's growing Education Division — has produced more than 195 million textbooks throughout its proud 80-year history, texts which encompass subjects from kindergarten level through graduate school. Heath also produces classroom films, audio and video tapes and learning kits which complement other products of the Education Division — products ranging from live biological specimens to complete language laboratories. By close cooperation with educators and through the creative use of a systems approach, Raytheon is rapidly moving toward its goal of becoming a leading supplier of the widest possible range of fully coordinated learning resources available to the educational community. Raytheon Company, Lexington, Massachusetts.

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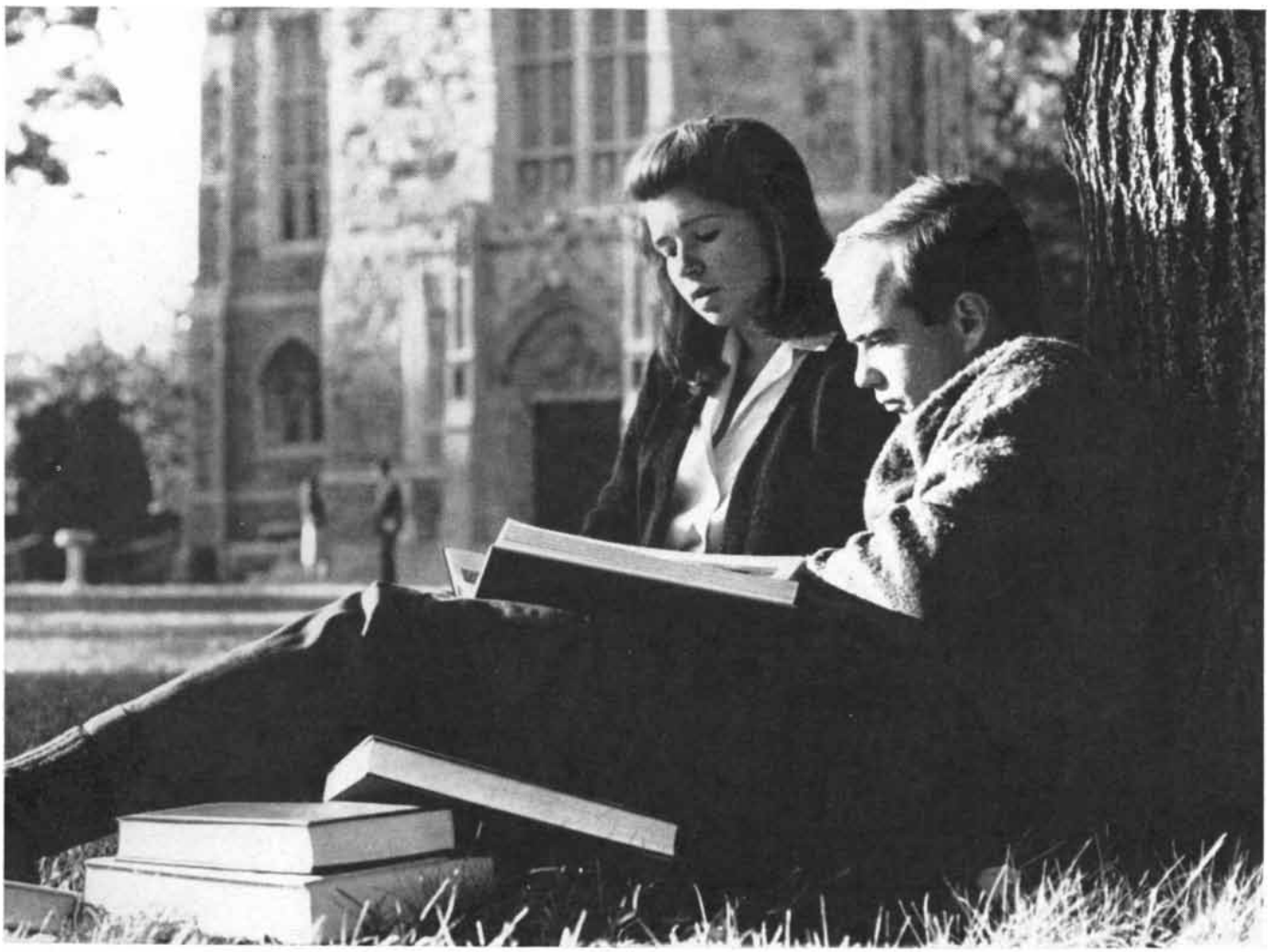

RECENT findings

RESEARCH LABORATORIES

Ford

Kinetic study of reactions of peroxy and phenoxy radicals in hydrocarbon systems yields previously unattainable information.

Much of the present knowledge of the ease of formation and chemical reactivity of free radicals and atoms has been obtained from kinetic studies of chain reactions in which these species occur as reactive intermediates. A free radical species of considerable interest in many areas of chemistry is the phenoxy radical. One system in which phenoxy radicals are generated as intermediates is the free radical initiated liquid phase oxidation of hydrocarbons containing trace amounts of phenolic compounds.

Work at Ford Motor Company Scientific Laboratory has revealed that the kinetic equations which describe the rates of oxygen absorption of liquid hydrocarbons containing phenols are of two types. The rate of oxygen absorption observed when hindered phenols and hydroquinones are the additives is directly proportional to the ratio of hydrocarbon to phenol concentration and is also first order in initiator concentration. This expression is consistent with a competition between the hydrocarbon and the phenolic compound for the chain carrying peroxy radical. The phenoxy radical formed then rapidly terminates or, equivalently, is incapable of any other kinetically significant reaction.

In contrast, an entirely different kinetic behavior is observed with all other phenolic compounds investigated. At a constant concentration of hydrocarbon and phenolic compound the rate of oxygen absorption is proportional to the one-half power in the initiator concentration. As shown in figure 1 the dependence of the rate on the phenol concentration cannot be described by integral orders throughout a wide range of concentrations. The data may be fitted (solid curve Fig. 1) to a general rate equation derived from a kinetic scheme which includes the chain restarting reactions of the phenoxy radical. Under these conditions there are two chain carrying radicals. At low concentrations the predominant chain carrying radical is the peroxy radical while at high concentrations of the phenol the phenoxy radical is the main species. The parameters obtained from this analysis have yielded previously unavailable information regarding the rates of formation, hydrogen abstraction reactions and modes of destruction of phenoxy radicals.

These parameters have then been analyzed in terms of the energies of the highest occupied molecular orbitals (HOMO) of the phenoxy radicals as calculated by the Hückel technique. One such correlation is presented in figure 2. It is seen that the log of the rates of hydrogen abstraction by the peroxy radical from the monohydroxyphenols is linearly related to energy of the HOMO of phenol. A similar correlation is obtained for the dihydroxyphenols. The relative rates of peroxy-phenoxy radical and phenoxy-phenoxy radical termination are also found to be extremely sensitive to structure; a variation of 10^3 is observed in the relative rates of these processes. Again, this effect may be correlated with the energy difference in the HOMO of the phenoxy and peroxy radicals.

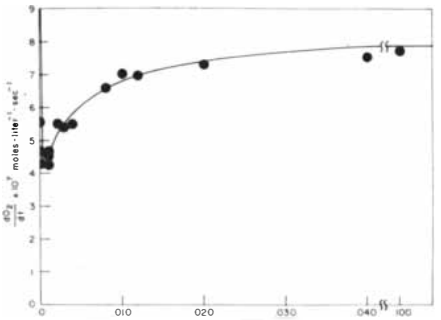

Figure 1. Rate of oxygen absorption versus concentration of 4-methoxyphenol for a chlorobenzene solution containing 0.099 M 9,10-dihydroanthracene and 0.0031 M 2,2', 3,3'-tetraphenylbutane at 60.0 C.

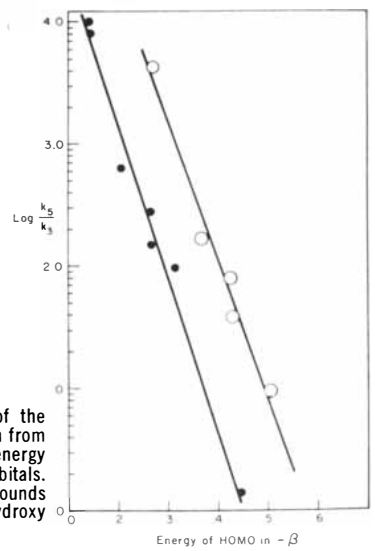

Figure 2. Correlation of the log of the relative rates of hydrogen abstraction from phenols by peroxy radical versus the energy of their highest occupied molecular orbitals. The dark points are dihydroxy compounds and the unshaded points monhydroxy compounds.

PROBING DEEPER FOR BETTER IDEAS

Ford

Established 1845 **SCIENTIFIC AMERICAN** February 1967 Volume 216 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The peculiar apparition of a bespectacled man on the cover is a thermogram: a picture made by infrared radiation. Thermograms can be made by several different kinds of thermograph; this one was produced by the Evaporograph of Baird-Atomic Incorporated. Other kinds of thermograph are being used experimentally for the purposes of medical diagnosis (see "Medical Thermography," page 94). The image shown on the cover appears on a thin membrane of nitrocellulose on which a film of oil is condensing. When an infrared image is focused on the "back" side of the membrane by a germanium lens, the oil tends to condense less at the points in the image where the radiation is more intense. Viewed in white light from the "front" side of the membrane, the various thicknesses of oil give rise to interference colors like those of an oil slick in the sunlight. In the thermogram on the cover the blue areas are coolest, the purple areas warmer, the pink areas still warmer and the yellow areas warmest. The man's glasses thus appear blue. The top of his head appears warm because he has a very short haircut.

THE ILLUSTRATIONS

Cover photograph by Sol Mednick

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39	Joan Starwood
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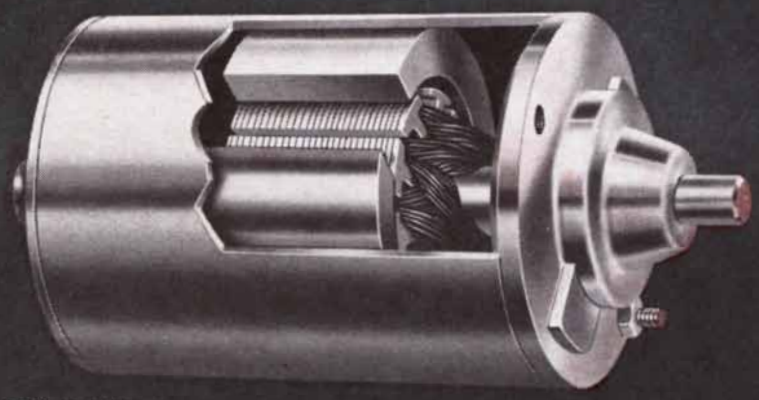
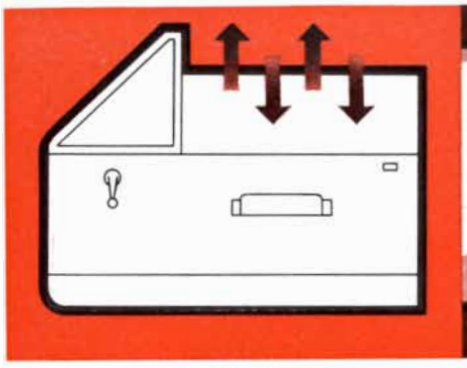
uses Allen-Bradley Oriented Ceramic Permanent Magnets...

because of their uniformity in staying within specifications, and delivery schedules—though tight—are kept!



American Bosch permanent magnet motors are used for...

power windows



electric windshield wipers

power seats

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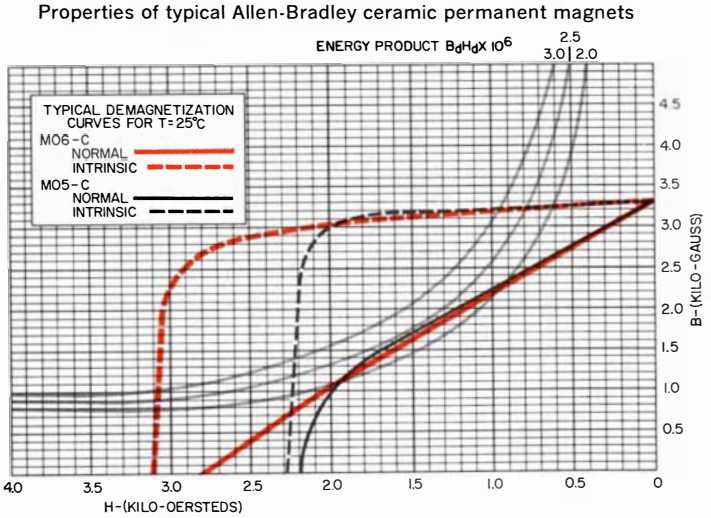
Properties of typical Allen-Bradley ceramic permanent magnets



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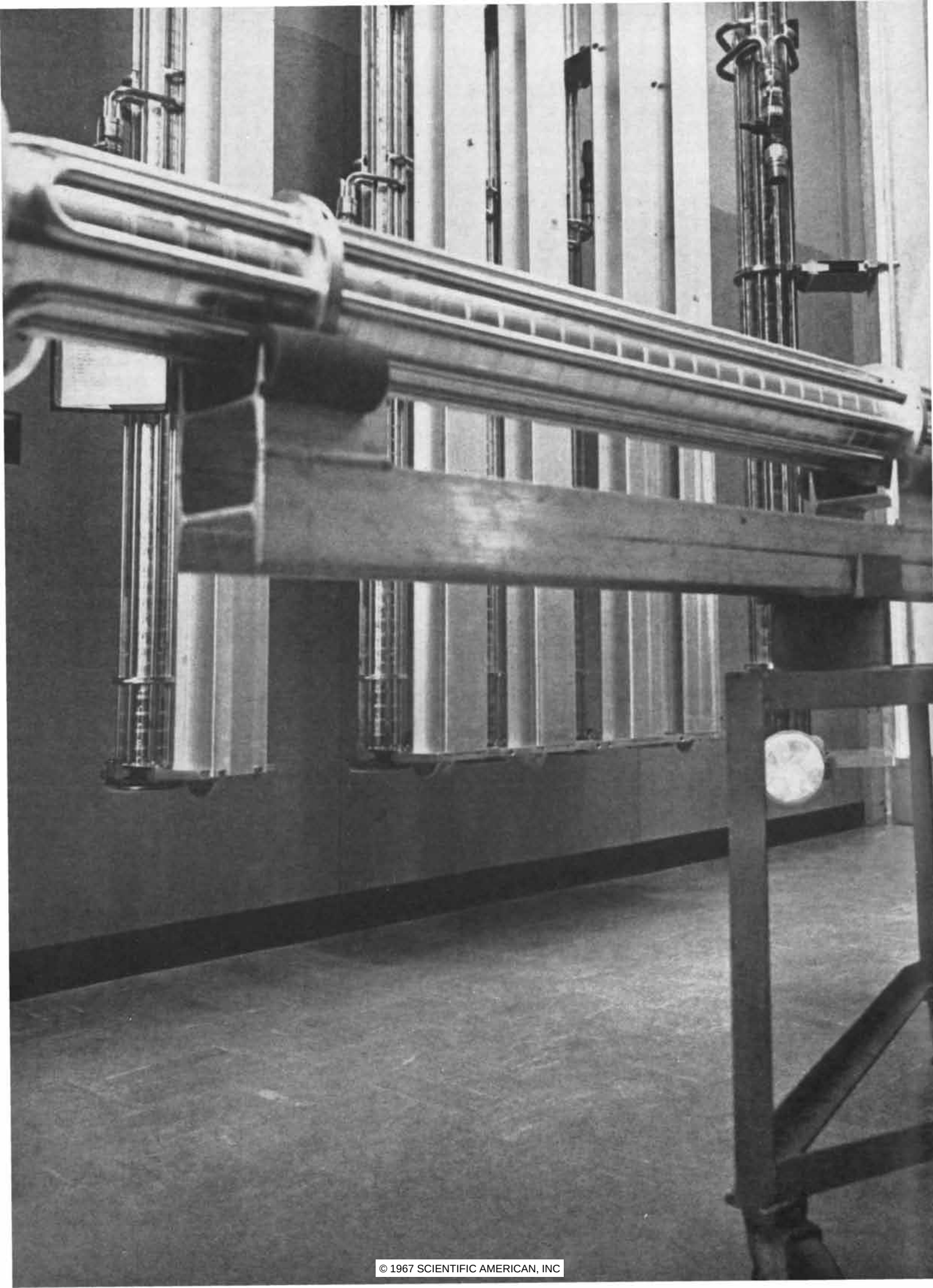
QUALITY ELECTRONIC COMPONENTS

866-3ABP



This was only 1/1000th of the job.

It's a ten-foot section of a linear electron accelerator recently completed at Stanford University, Palo Alto, California. The entire unit runs 10,000 feet—almost two miles. The accelerator compares to an electron microscope and will permit highly refined exploration of the atomic nucleus. Basically it's made of pure copper tube 4 inches O.D.

Fabrication of the tube presented a monumental machining challenge. Each section is composed of copper cylinders 4 inches in diameter and 1 inch long, and copper disks 4 inches in diameter, ¼ inch thick.

According to Ben Stillman, machine shop head at Stanford, only diamond tools could do the job properly. Finish-machining copper with metallic tools would have been difficult, if not impossible, because of the high abrasiveness of copper. Surface-finish of both inside and outside diameters were machined to less than 16 millionths of an inch in roughness. This can ably be achieved with diamond tools.

But you don't have to make 10,000-foot-long electron accelerators to take advantage of diamond tools. Manufacturers and metal fabricators are finding that diamond tools often make tough jobs routine. That's why diamond grinding wheels, dressing tools and lapping compounds are being used more and more widely.

Are you frightened by the cost of diamond tools? Forget it. Because if you cut, sharpen, grind or smooth *anything*, you can probably use diamond tools profitably. Your tool and wheel maker can show you how. Or write to this magazine for more information.

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Shannon, Ireland

LETTERS

Sirs:

Charles F. Powers and Andrew Robertson say in their article "The Aging Great Lakes" [SCIENTIFIC AMERICAN, November, 1966]: "We still know far too little about the complicated processes that are under way or about what measures are necessary to conserve this great continental resource. Obviously the problem calls for much more study and for action that will not be too little and too late."

They will be interested to know that the Canadian and U.S. national committees for the International Hydrological Decade have joined to sponsor an International Field Year on the Great Lakes as part of their IHD program. The Field Year will be 18 months long (April, 1970, through September, 1971) and only one lake, probably Ontario, will be studied. The Steering Committee for the Field Year, composed of four Canadian and four American scientists, has outlined a program and a schedule.

The IFYGL program has four primary interests: (1) atmospheric water budget, (2) surface- and groundwater budget, (3) energy balance and (4) major circulation patterns. The Steering Committee recognizes that its program is restricted to selected physical aspects of Great Lakes hydrology and will welcome opportunities to cooperate in coordinating its program with studies involving chemical and biological aspects. It also will coordinate its efforts with studies of other physical aspects not included in the program. Some coordination with the International Biological Program is probable.

The tentative schedule calls for planning and feasibility studies through 1967, preoperation studies and project design through 1968, instrumentation and communication testing and coordination through March, 1970, the 18-month period of data collection through September, 1971, and data analysis and report preparation through 1973.

We have reason to hope that the Field Year will provide an impetus to studies of the Great Lakes. The development of the scientific understanding of their phenomena is basic to any plans for their management.

L. A. HEINDL

U.S. National Committee
for the International
Hydrological Decade
Washington

Sirs:

Genko Uchida's informative article "Technology in China" [SCIENTIFIC AMERICAN, November, 1965] is unfortunately flawed by a grossly misleading projection of economic growth based on an untenable parallel with Japanese economic development. Uchida compares China's present income per capita of $100 or less with that of Japan in 1945, and therefore projects a growth of Chinese income per capita to $500–$600 (the present Japanese figure) in 20 years or so. But in 1945, as everyone knows, Japan was not producing at all. That was the year in which World War II ended, and in which both Japanese industry and agriculture were either damaged or paralyzed by the lack of transportation, power and so on. Japan's per capita income in 1945 was less than a third of the income of the prewar years. Although it is difficult to adjust these figures for changes in the purchasing power of the yen and of the dollar, Japanese prewar national income, not even counting the boom period of the 1930's, had reached between $250 and $300 per capita.

By 1945 *production* had fallen off, practically to zero in manufacturing. But not only was most of the existing plant, while not producing, in a state in which it could resume production very fast; within five years most of the war damage had been repaired. But also the true "factors of production" in a modern industrial society, technological knowledge, experienced managers, administrators and technologists, skilled and trained workers and so on, were largely intact, had indeed probably been substantially augmented during the war.

If present-day China is to be compared to anything, it would seem, therefore, to be the earlier Japan, the Japan that began to modernize 100 years ago. And even though 19th- and early 20th-century Japan had shown some of the fastest growth rates on record, it took *at least* 50 years, from the mid-1880's to the mid-1930's, for Japan's per capita income to grow from $100–$125 to $250–$300 per year. This, rather than the 15 to 20 years Mr. Uchida projects, would therefore appear to be the "catching up" period one should expect for China, assuming that she is capable of paralleling the Japanese performance in becoming an industrialized country.

There are other dubious assumptions in Mr. Uchida's economics. Between 1945 and today, for instance, Japan has had a remarkably low rate of population growth; the lowest for any major nonwhite country. While Chinese figures are not known with any certainty, they are believed to be among the highest in the world today, and probably even a good deal higher than the Japanese population growth in the 19th and early 20th centuries. The Japanese advance, 100 years ago, and then again 20 years ago after World War II, was above all based on a very fast increase in agricultural productivity, both times released by reforms in land taxation and land tenure, which greatly increased the incentives to the individual farmer. If anything like this has been happening in China, it has not yet shown itself in harvest figures, in sharp contrast to the Japanese experience in both, where tremendous increases in agricultural yield followed immediately on the reforms of the 1870's and the 1940's. Also it would seem very doubtful that China today actually has more modern technology, more technologists and more modern industrial equipment at her disposal than China before the Communists took over. While the present Chinese regime has been able to attract and to put to productive work a technological elite, very large numbers of the technological "middle class," the production engineers, works managers and so on who were at work in pre-Communist China, have apparently emigrated and are today working in Taiwan, Hong Kong and Singapore,

Scientific American, February, 1967; Vol. 216, No. 2. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

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Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

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which may be the major reason behind the tremendous economic expansion and rapid industrialization of these three non-Communist Chinese economies. Similarly, China, before the Communists, acquired each year a much larger stock of foreign machinery than she now seems to produce, if the figures for truck and locomotive production given by Mr. Uchida are representative. Again, the comparison with Japan may be instructive. It was the tremendous increase in the yield and production of two agricultural commodities, silk and tea, in 19th-century Japan that gave that country a capacity to import machinery on which its expansion largely rested. In contrast, China today has become a net importer of agricultural commodities.

I do not intend to belittle the Chinese achievement or to deny the possibility of rapid Chinese industrial growth. But if the Japanese experience is to be used as a prototype, very rapid growth of the Chinese industrial economy, and particularly of the Chinese national income and standard of living, would not appear exceedingly probable.

PETER F. DRUCKER

Graduate Business School
New York University
New York, N.Y.

Sirs:

In my article I did not compare the present Chinese economy with the Japanese economy in 1945. I compared it with the Japanese economy in 1950. This is stated on page 45 of the article.

At least one well-known Japanese economist, Shinichi Ichimura, believes that the average per capita income of Japan in 1950 was equal to its prewar peak of 1938. Accordingly I believe that to use 1950 as a starting point in my comparisons was not unreasonable.

There are, however, many estimates of the Japanese per capita income at various times. My colleagues and I are now working on a detailed study of the development of industrial technology in Japan. This study, which will be completed next year, may help to clarify the relation between economic growth and industrial technology in Japan.

I have no comment on Mr. Drucker's other remarks.

GENKO UCHIDA

Ministry of International
Trade and Industry
Tokyo

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It no longer makes economic sense to have different computers for different kinds of jobs.

Sigma 5 will control your plant, do your scientific and engineering computation, and look after your accounting and inventory. All at once.

Nobody will have to stand in line. Everyone will be protected against loss or interference. Sigma 5 can deal with foreground real-time interrupts in 6 microseconds without losing control of any of its other jobs, yet every background user will get his answers faster than he needs them.

Nobody loves a lazy computer.

If your Sigma 5 ever has an idle microsecond it will be your fault.

Sigma 5 doesn't stop computing to wait for input/output. It doesn't reserve idle capacity to take care of on-line peaks.

Instead it dynamically and very rapidly shifts from one task to another in order to keep all its power working all the time. Input/output is managed independently by one built-in and five optional I/O processors, with up to 160 automatic I/O channels.

The bigger the better.

One reason why Sigma 5 gets more efficient as it grows larger is that when memory modules are added interleave and overlap occur. This not only increases the effective speed of the central processor but raises input/output capability too.

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Sigma 5 is program-compatible with Sigma 7. The software for both has already been developed and is being delivered now with Sigma 7's.

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8 automatic I/O channels in CPU, plus 5 optional I/O processors, either multiplexor IOP's (500,000 bytes/sec.) or selector IOP's (37 million bits/sec.) in any desired combination.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1917: "Now that Germany has thrown overboard the pledges which she gave the United States after the sinking of the *Suffolk* and has cast all considerations of humanity to the winds, the United States has been brought as close to the possibility of war with Germany as the eyelid is to the eyeball. It seems to be generally assumed that if, as the outcome of Germany's submarine policy, there should be war between the two countries, it would be ushered in by some formal declaration of war. On our side it might be, but we are fully convinced that the only declaration of war which Germany would ever make would take the form of the sudden appearance of her submarines in our harbors and a savage attack upon our naval and merchant ships. In other words, we should see a repetition on a larger and more frightful scale of the torpedo attack on Port Arthur with which Japan commenced hostilities against Russia. The ships lost by Russia in that surprise attack so weakened her that Japan at once obtained the command of the sea."

"The President of the United States appeared some days ago before the Senate and made a most notable and unusual address which has attracted the attention of all civilized countries and has brought both criticism and praise for its many suggestions and proposals. His principal thought has apparently been the organization among nations of a league to enforce peace—by some styled a dream, by others something that is practicable. At any rate, a few extracts from his speech will show the at least startling nature of his statements. In one place he remarks, 'No peace can last or ought to last which does not recognize and accept the principle that governments derive all their just powers from the consent of the governed and that no right anywhere exists to hand peoples about from sovereignty to sovereignty, as if they were property.' What would disturb our people most in a league with other nations would be the 'entangling alliances' against which Washington cautioned his fellow countrymen; the Monroe Doctrine would apparently also be set aside. But under this head the President makes a strong argument: 'I am proposing, as it were, that the nations should adopt the doctrine of President Monroe as the doctrine of the world.' "

"A new field for investigation suggested by Col. G. O. Squier relates to high-frequency vibrations in air, with possible applications as a means of communication. At present we do not know of the existence of vibrations in air much exceeding 40,000 to 60,000 cycles per second, but far more rapid vibrations may occur in nature, though they are beyond the limit of perception by the human senses. Col. Squier remarks that electromagnetic waves of high frequency existed through all time unperceived until Hertz devised a 'detector.' He suggests that efforts be made to devise a detector for air vibrations capable of revealing their presence or absence up to a frequency of 500,000 or a million cycles per second."

"Three months ago we had occasion to speak of Professor Barnard's discovery of a faint star with the unprecedentedly large proper motion of 10.3 seconds of arc per year, and of the probability that it would be found to be one of our nearest neighbors in space. This anticipation has now been verified by the results of direct observation, which show that this star is actually nearer us than any other, with the single exception of our nearest neighbor, Alpha Centauri."

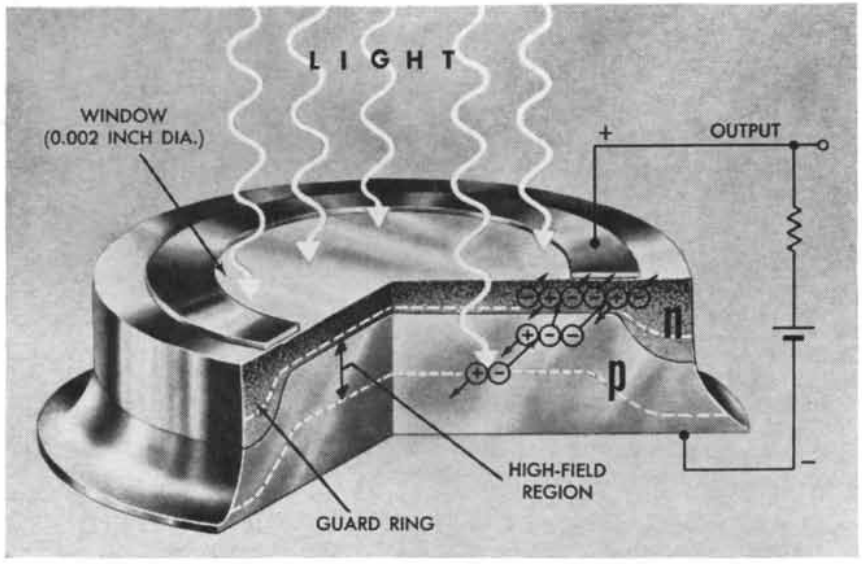
Scientific American.

FEBRUARY, 1867: "Prof. Agassiz tells us that the climate of the immense valley of the Amazon is delightful. A cool breeze goes up the river at all times, the thermometer varying between the extremes of 72 and 92 degrees, and averaging 84. He says that although warned beforehand that he was going into a region of death, he found that there were no dangers and hardly any discomforts to be met with. Perhaps the Professor was unduly propitiated by his unprecedented haul of fish. The entire region is a vast plain—an unbroken expanse of wood and water—having a descent of only 210 feet in 3,000 miles. The annual swellings of the river rise from 30 to 50 feet and convert the whole

Report from

BELL LABORATORIES

Photodiodes with gain

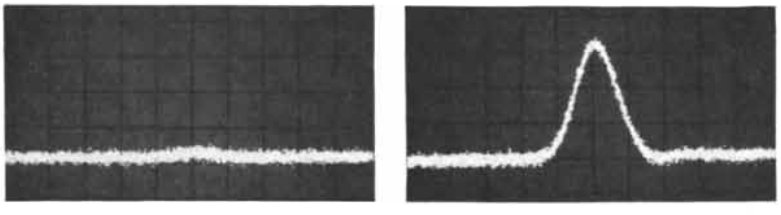


Cross-section of one form of the new photodiode. For the avalanche effect, positive voltage is applied to the n region and negative to the p (i.e., against the direction of easy current flow).

A photon, in being absorbed, creates an electron-hole pair. Electrons, formed in this way within the high-electric-field region of the junction, move toward the n-side. In so doing, they pick up energy, strike other atoms and create more pairs of electrons and holes. (A similar but opposite process occurs for the holes.) This "chain reaction"—the avalanche effect—produces relatively large currents and gives the diode its gain.

It is important that the avalanche multiplication factor be uniform over the entire window area . . . that no small area exhibit a particularly high multiplication factor. To achieve this, we start with homogeneous germanium and create a "guard ring" in which the density of charge-carrying impurities is relatively low. This low density results in a reduced electric field where the p-n junction meets the circumference . . . where breakdown currents would otherwise occur.

Because the time required for avalanche is very short, the diode responds to modulation frequencies as high as 60 GHz.

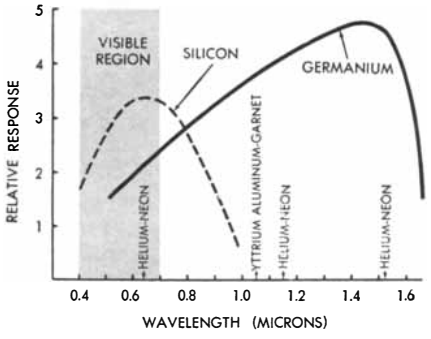


Performance of Bell Laboratories' germanium avalanche photodiode (right) compared with that of an otherwise identical non-avalanche type. Under a weak light signal (40 μW) the output of the ordinary diode is lost in noise. High gain of the new avalanche type, however, permits the signal pulse to be clearly seen.

In a typical photodiode, a negative and a positive charge carrier—called an electron-hole pair—are created for each photon that penetrates the diode's surface. Now, Bell Laboratories scientists W. T. Lynch and H. Melchior have made experimental germanium photodiodes that have gain, developing up to 250 such electron-hole pairs per photon. And the new photodiodes respond to light of wavelengths from the visible region well into the infrared . . . to 1.6 microns.

The gain in these diodes stems from the "avalanche" effect (left). This requires carefully selected germanium and a special construction feature—a "guard ring"—developed here some years ago.

PHOTODIODE RESPONSE CURVES



In opto-electronic systems using infrared light from helium-neon or yttrium-aluminum-garnet lasers, for instance, the response of the new diode (above right) could be used in detecting modulation signals, and its high output would permit omission of some stages of amplification. (The "avalanche effect" was discovered at Bell Laboratories; the first avalanche photodiodes were of silicon and cut off below 1 micron in the "near" infrared.)

Bell Telephone Laboratories
Research and Development Unit of the Bell System

VACUUM COATED STEELS

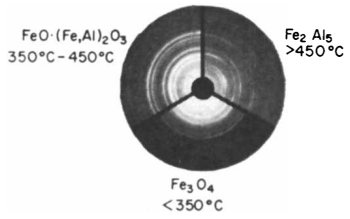
An idea borrowed from the electronics field, "vacuum evaporation", has multiplied the number of potential steel coatings to create a new generation of valuable products.

by R. P. Morgan, Research Manager

As if to emphasize the technological changes which are taking place in many of its processing operations, the steel industry recently borrowed an idea from the electronics field, scaled it up a hundred times and introduced a new steel coating process. The technique, used in the production of transistors and other space age electronic components, consists of evaporating metallic or non-metallic materials in high vacuum and condensing them onto a prepared substrate to form a coating. Youngstown Steel has been working with this process for the past four years, exploring its general utility. In many cases, special surface properties have been obtained on steel strip which could not have been economically achieved by other means, and from this work a new generation of coated steel products has emerged.

Research has reached a stage where a high speed pilot line is being used to prepare coils of steel with different coatings for customer evaluation. A key feature of the system is a series of remarkably effective roll seals. These seals enable a clean strip to pass continuously from the atmosphere into the high vacuum evaporation chamber operating at a pressure below 10^{-4} Torr, and out again. Inside the evaporating chamber, a specially designed crucible containing the coating material is heated by a beam of high energy electrons to some characteristic temperature at which large quantities of vapor are rapidly evolved. For example, with aluminum this temperature is about 1700°C. The vapor is immediately condensed onto the moving steel strip to form the desired coating. A number of individual evaporators is used in order to increase the operating speed and to produce a coating on both sides of the strip ranging in thickness from 0.001 to 1.0 mil. The use of the electron beam as a heating device permits the evaporation of a wide range of coating materials including those with very high evaporation temperatures.

One of the important technical problems in this field is that of obtaining good adhesion between the condensate and the steel substrate. Procedures vary for each material; however, again taking aluminum as an example, the steel must be pickled and subsequently preheated to a temperature of 400°C in vacuum before deposition of the coating. Electron diffraction studies of the interface between the steel and the aluminum have shown that a magnetite film is present at substrate temperatures below about 350°C, (see illustration) and is accompanied by poor adhesion.



VARIATIONS IN INTERMEDIATE LAYER BETWEEN VACUUM DEPOSITED ALUMINUM AND STEEL

As the substrate temperature is increased towards 450°C, an alumina spinel of varying composition is formed and the adhesion and corrosion resistance of the coating increase markedly. At temperatures above 450°C, an Fe_2Al_5 phase can be detected. Adhesion at this point is excellent but rapid total conversion of thin films to the brittle intermetallic can occur. This operating range is therefore generally avoided. Other coating metals of low melting point and high vapor pressure, such as zinc, require more critical control of substrate temperature. In addition, they require the use of an intermediate layer of a second metal to secure acceptable adhesion.

Other aspects of the process are under investigation including those connected with the control of coating properties and those related to the development of new equipment designs for more efficient operation. Data are steadily being accumulated through operation of the pilot facility and this information will eventually be used to further the construction of full scale production equipment.

Much of the work which has already been carried out points to the unusual flexibility of the new technique and the commercial significance of the products. For example, the "tin" can which is, of course, basically a "steel" can could be manufactured by substituting another metal for tin. Aluminum or chromium are contenders in this respect. They provide an attractive finish, are readily available, and have chemical properties which encourage their use in certain food containers.

There are many additional examples of ways in which vapor deposited coatings can be used to broaden the performance of a steel product. Zinc, for special automotive applications, and stainless steel for architectural usage are both promising materials. Experiments have already shown that stainless steel compositions can be evaporated and condensed to form finishes with great corrosion resistance. The application of metals such as copper for brazability, or titanium for chemical inertness is also under consideration.

A great deal of additional research and development will be necessary to create the systems which will economically process a hundred thousand tons of these new strip products a year. Nevertheless, it is apparent at this time that the steel industry in its search for effective new techniques has discovered in vacuum evaporation a method with significant potential.

Steel and steel application problems are continually under investigation at Youngstown's research center in support of Youngstown's position as a major supplier of a wide variety of low carbon and low alloy products. The work on coated products represents only a small part of the 24 hour a day research effort. If you think Youngstown can help you, call at your convenience, or write Department 251 E6.

Youngstown Steel

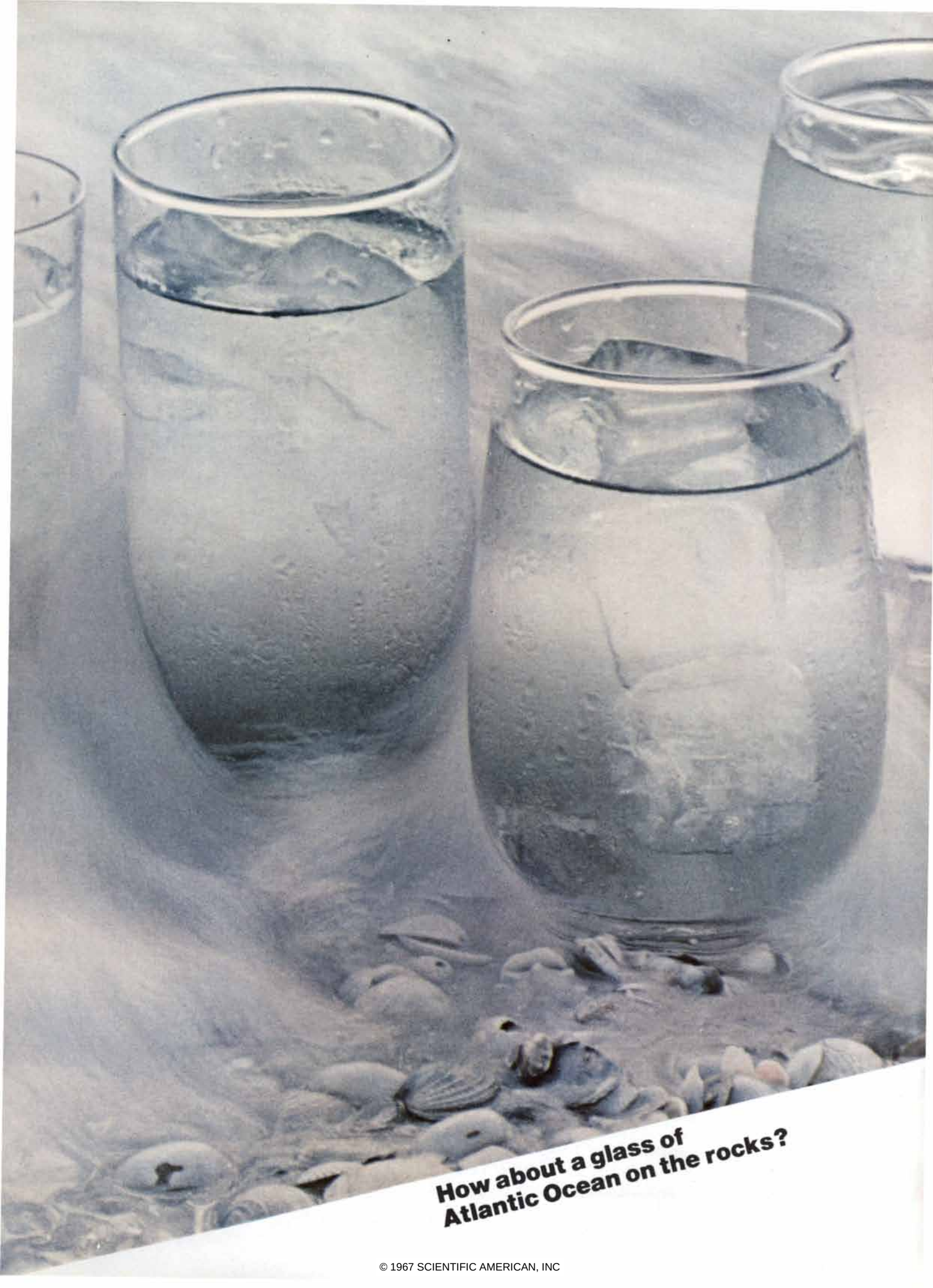
THE YOUNGSTOWN SHEET AND TUBE COMPANY · YOUNGSTOWN, OHIO 44501

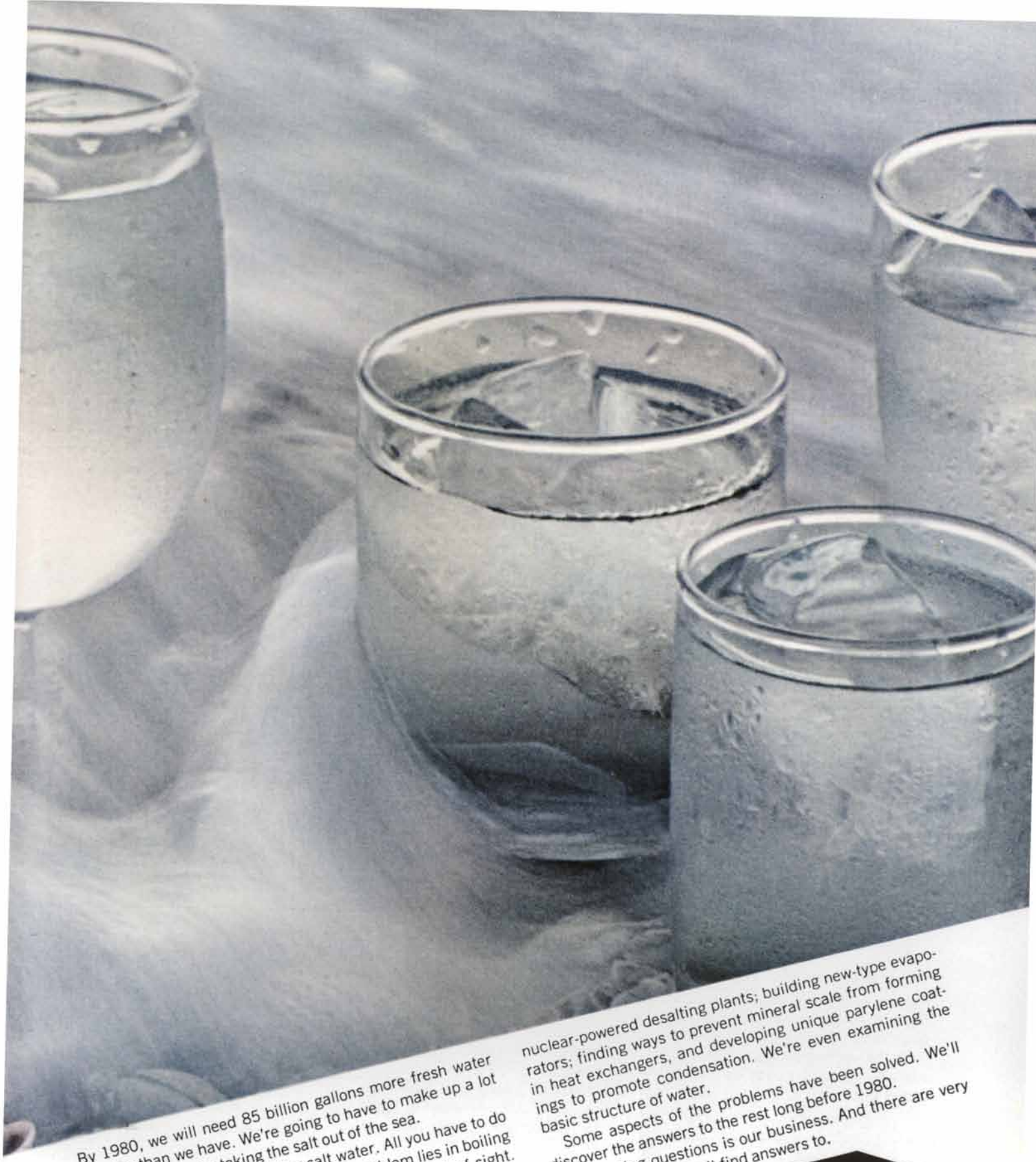
into an ocean for some months of the year, centering in June, and communication is then carried on by boat paths among the tree tops. The primitive and universal forest is almost impenetrable. The length of the valley is 2,000 miles and the width 1,000 miles. The waters are coffee-colored, except those of the rivers that rise in the woody plain, which are more like molasses. In some places it is equally impossible to see across them or to see through them. We should think the country must be delightful and healthy—for alligators—and possibly for naturalists."

"Mr. James Parker describes in *Engineering* an apparatus for propelling vessels by steam without an engine. The steam is issued in extremely small jets, each shooting into the center of an open pipe a quarter of an inch in diameter, conducting into a hot water chamber, into which the jet carries with it a current of compressed air. This compressed and heated air is admitted upon the surface of the water in closed tanks by the ordinary slide valve, and its force is employed to eject the water through propelling pipes on the plan of the *Waterwitch*, described in SCIENTIFIC AMERICAN not long since. The steam and compressed air may also be driven into a dry hot receiver and thence used in a large-cylinder engine. The contrivance is a modification of the caloric, or hot-air, engine."

"It is reported that a remarkable fall of meteoric rocks and stones, from a perfectly serene sky, took place at Kniahynia, Hungary, between four and five o'clock, P.M., on the 9th of June, 1866. With a detonation like that of 100 cannon a gray, cloud-like body passed in view, seeming enveloped in smoke but not luminous, and within two or three minutes a noise like the rattling fall of a multitude of stones was heard, continuing (its echoes doubtless included) 10 or 15 minutes. About 60 of the smaller stones were picked up quite hot. The largest, weighing 550 lbs., was broken in two by the shock and buried itself 11 feet in the earth. Eye witnesses 12 miles to the west of the place (between the phenomenon and the sun) describe the meteor as of a luminous yellow and orange, followed by a train of a blue tint."

"Dr. Louvel has satisfactorily demonstrated the fact before a French commission that animal and vegetable substances can be kept unchanged for any length of time in a vacuum."





By 1980, we will need 85 billion gallons more fresh water per day than we have. We're going to have to make up a lot of that shortage by taking the salt out of the sea.

There's no trick to desalting salt water. All you have to do is boil it and condense the vapor. The problem lies in boiling enough of it while keeping costs from soaring out of sight. Along with your water bills.

Union Carbide is working on ways to lower that cost... some of it under Government contracts. We're designing nuclear-powered desalting plants; building new-type evaporators; finding ways to prevent mineral scale from forming in heat exchangers, and developing unique parylene coatings to promote condensation. We're even examining the basic structure of water.

Some aspects of the problems have been solved. We'll discover the answers to the rest long before 1980.

Answering questions is our business. And there are very few questions we don't find answers to.

UNION CARBIDE

THE DISCOVERY COMPANY

We want

Some 67 million Americans have flown. Many, hundreds of times.

Some 128 million Americans have never flown at all.

Our goal is simple.

To make flying more enjoyable, more convenient for those who fly frequently.

To make it more attractive, more affordable for those who have never flown.

To make it the finest way to travel for everyone.

We're doing it in many different ways.

We make everyone feel more at home.

From a warm smile of welcome from the man who takes a passenger's luggage when he drives up to the terminal.

To the warm greeting of a Stewardess who takes his coat as she welcomes him aboard.

We made dining a pleasure.

We brought gourmet meals to First Class, along with fine china, crystal and silver.

We introduced Famous Restaurant flights, where the food is prepared by the restaurant itself. Such as The Pump Room on First Class flights from Chicago, and Voisin from New York.

Even in Coach, we're out to make food surpass anything that used to be served in First Class.

We made waiting obsolete.

By answering our telephones within 20 seconds.

Installing a computerized reservation system that takes only four-fifths of a second to confirm seat availability.

everyone to fly.

CHARGE-A-TRIP, AIR SHUTTLE AND WHISPERJET ARE SERVICE MARKS OF EASTERN AIR LINES, INC.

Improving on-time performance.

And by trying to get luggage to the pickup area at the same time the passenger gets there, give or take a couple of minutes.

We made schedules make business sense.

We invented the Air Shuttle so businessmen could commute without reservations between New York and Washington, or New York and Boston.

We schedule flights that go out and back in one business day, with time for a family evening at home.

Others that reach the destination early enough for a good night's sleep, and a fresh start in the morning.

Still others so frequent it's possible to leave almost any hour, day or night.

We're buying an all-jet fleet.

Big jets like the Super DC-8, that will fly more people farther than any other commercial airliner.

Small jets like the Whisperjet 2, that let people from smaller cities with smaller airports enjoy the pleasure of jet travel.

We made money no object.

With Charge-A-Trip.

It lets you charge everything (fare, hotels, meals, rental cars and such), and then pay it back over 2 years with nothing down.

We helped bring air fares down to earth.

Round Trip Excursion Fare: one-fourth off for everyone. Family Fare: one-third off for wives, two-thirds off for children. Stand-by Youth Fare: half off.

It's all leading somewhere.

Getting more people to experience the beauty, the serenity, the convenience of flight.

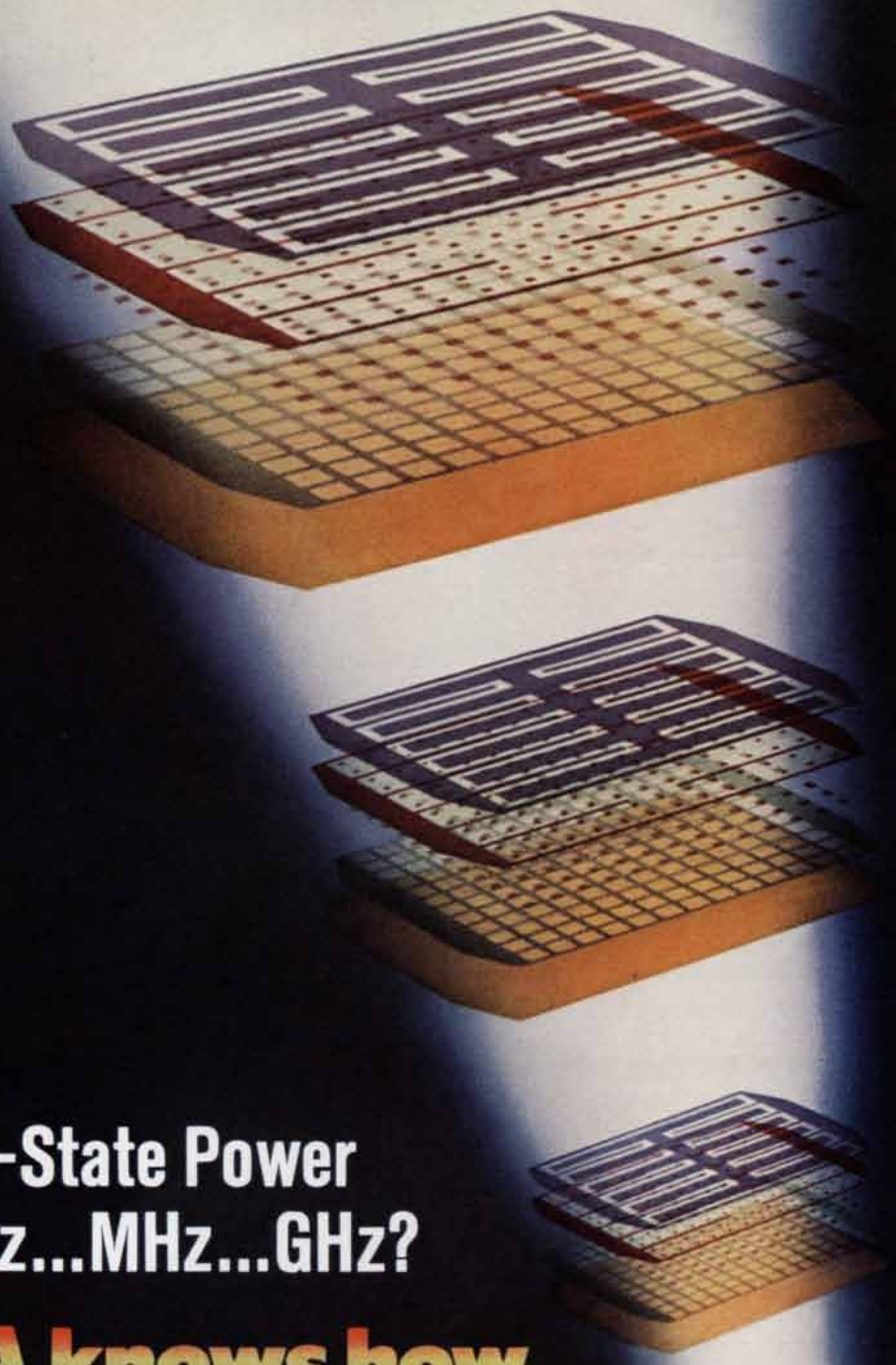
Of course, we can't expect everyone to fly with us.

But on this very day, we will carry more than 40,000 passengers. More than all but one of the world's airlines.

And by doing what we're doing, we feel we'll continue to get our fair share.

We want everyone to fly.

EASTERN



Need Solid-State Power at kHz...MHz...GHz?

RCA knows how

Shown symbolically here is the process used to manufacture overlay transistor sites as developed at RCA. The screens at the top of the picture are reduced photographically hundreds of times in size until as many as 4,000 individual transistors are placed on a single silicon disc as small as a half-dollar. These sites are then cut apart into individual pellets, and mounted into headers as shown in the foreground of the picture.

Are you looking for a solid-state power source—with all of its inherent advantages—to deliver one watt . . . 50 watts . . . 100 watts or more? At frequencies from 30 MHz to one GHz? Or in the L-band—and even higher into microwave frequencies? Would you welcome efficiency well beyond any ordinary solid-state device? Or new simplicity in circuit design? RCA knows how . . . with "overlay" technology!

In learning the way, RCA changed an entire industry's concepts of semiconductor design and manufacture—answering military and industrial requirements by advancing the state of the art and at the same time meeting the dual demands of performance and cost.

How was this done? RCA knew that to increase the power output of a transistor, the emitter periphery had to be lengthened; however, to increase the transistor's operating frequency, its emitter area had to be decreased. The answer to these conflicting requirements of large periphery and small area was easy to visualize—and physically impossible to create. (The ultimate goal for maximum power and frequency is an emitter of infinite length and zero width, providing maximum periphery and minimum area.) The nearest practical equivalent to the impossible is a matrix of square or circular emitter elements of minimal dimensions—used in a wholly-new transistor structure.

Known as the overlay transistor, this new device received its name from the fact that multiple small emitter elements are placed on a base substrate and interconnected by means of a metallic overlay. The first overlay transistor, the RCA 2N3375, is shown in cross-section (not to vertical scale) in *Fig. 1*. Aluminum paths carry emitter and base currents to the bonding wires, with the emitter current path separated from the base region by silicon-oxide insulation. *Fig. 2*—greatly magnified—shows the single 2N3375 pellet after mounting in a JEDEC TO-60 stud-mount package.

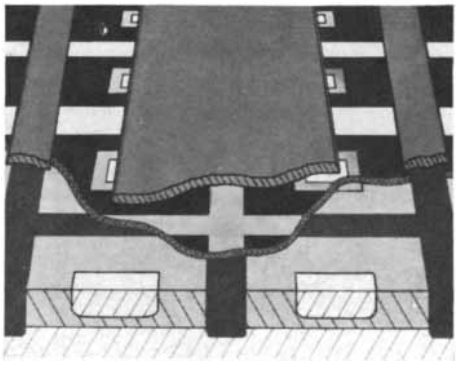


Fig. 1

Since RCA developed and introduced this new overlay concept, the industry has virtually standardized on this construction. Now, equipment designers are putting overlay transistors to work in a wide range of new electronic applications—including those for telemetry, two-way communications, and tropospheric scatter devices. These equipments are now more efficient, more compact, and require less maintenance.

New performance potentials realized for the first time with overlay include: fast switching; improved output linearity; increased

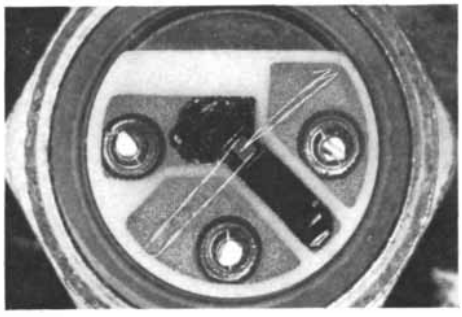


Fig. 2

bandwidth and gain . . . and higher power and frequency capabilities. The power/frequency/size configuration of RCA overlay transistors makes them ideal for use in mobile transceivers, where they eliminate troublesome vibrator and inverter power supplies by operating at 12 VDC or 24 VDC. Community Antenna Television Systems (CATV) are now economically practical through the use of overlay devices in line amplifiers. Single-sideband transmitters for two-way communications now use overlay transistors in Class-A, Class-AB, and Class-B amplifier stages.

Taking advantage of power-frequency capabilities of overlay, RCA is bringing new devices and applications into being almost daily. *Fig. 3A* charts the power-frequency capabilities of seven typical RCA overlay geometry RF power transistors now generally available. *Fig. 3B* shows the resultant system capability obtainable with these and future devices.

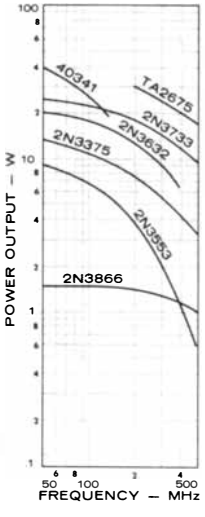


Fig. 3A

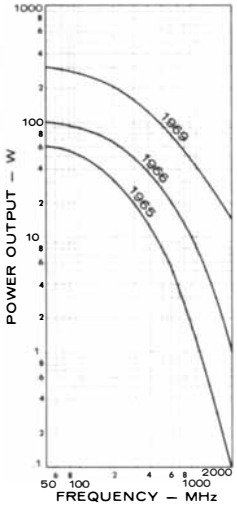


Fig. 3B

To produce the overlay transistor, RCA had to evolve new production techniques which are continually being refined for the introduction of still-newer devices and newer concepts. For example, to make overlay devices, new photo-masking and printing techniques and skills had to be developed. No one anywhere had them—until RCA showed the way to produce emitter elements—first only half a mil on a side and then even smaller. Special production equipment had to be evolved to cope with accuracy demands verging on the unbelievable—the equivalent of one inch plus or minus a tenth inch per mile! *Fig. 4* shows the basic silicon wafer, containing as many as 4,000 individual complete transistor pellets, contrasted with a half-dollar to show size. Typical package configurations used with RCA overlay designs appear in *Fig. 5*.

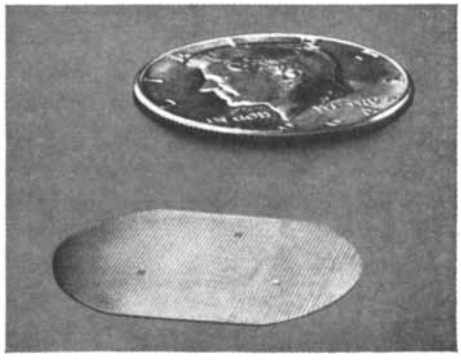


Fig. 4

The new construction techniques developed by RCA have led, for example, to the production of an overlay device that provides built-in resistance at each of more than 100 emitter elements in a single transistor. This eliminates catastrophic failure caused by excessive current flowing through a single emitter element. Evaluation and adoption of the overlay principle by the industry proves its acceptance as an industry standard.

What next? You will find at RCA your best one-source answer to specific semiconductor needs—at present state-of-the-art levels, or far beyond them. To your advantage is RCA's *complete* understanding of all facets of a problem, whether metallurgy or solid-state physics, miniaturized packaging of components . . . or developing new methods and new concepts. This unique RCA capability is reinforced by advanced production skills—nowhere better shown than in the case of overlay and its effect on the entire transistor industry.

How can RCA help you? Perhaps you have solid-state RF power-source problems? If so, consult your RCA Field Representative or write RCA Commercial Engineering, Section B95EC, Harrison, N. J.

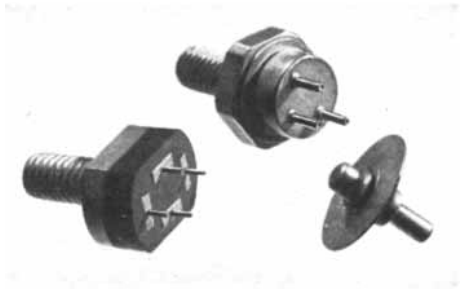


Fig. 5

RCA ELECTRONIC COMPONENTS AND DEVICES

The Most Trusted Name in Electronics

THE AUTHORS

N. W. PIRIE ("Orthodox and Unorthodox Methods of Meeting World Food Needs") is head of the department of biochemistry at the Rothamsted Experimental Station in England. A Fellow of the Royal Society, he has interested himself not only in biochemical matters but also in social issues. Among the former are the separation and the properties of several plant viruses; factors controlling the infectability of plants by viruses, and the preparation of edible proteins from leaves. Pirie writes: "That is recounted in 100-plus papers. Another 100-plus deal in a general way with fractionation of macromolecules and the criteria of purity; classification of viruses and similar entities; contraception and the population problem; protein sources and other aspects of world food supplies, and strictures on government policies on such issues as air raid precautions, nuclear weapon testing and the planning of scientific research." Pirie was graduated from the University of Cambridge and served in the biochemical laboratory there from 1929 to 1940, when he went to the Rothamsted Station.

PHILIP C. HANAWALT and ROBERT H. HAYNES ("The Repair of DNA") are respectively associate professor of biological sciences at Stanford University and associate professor of biophysics and medical physics at the University of California at Berkeley. Hanawalt majored in physics at Oberlin College, from which he was graduated in 1954, and did graduate work in physics and biophysics at Yale University, from which he received a Ph.D. in 1959. Haynes obtained a bachelor's degree in physics and a Ph.D. in biophysics from the University of Western Ontario. Haynes writes that he was "raised a true-blue Canadian Tory" but during a year as an exchange fellow in England "was subverted by the success of the British National Health Service and began drinking in workingmen's pubs." Looking back, he says, "it is clear that it was this experience that ensured I would later be on the side of the angels and the Free Speech Movement in Berkeley." Both Hanawalt and Haynes are teaching introductory courses in biology. Haynes writes: "Although I have always spent most of my time in research, I am convinced that recent events at Berkeley will accelerate the swing back to teaching in academia; and somewhat to my surprise I found teaching Biology 1 to be a rather exhilarating experience. In spite of my political stance at Berkeley, my interest in fine food and wine, poetry and ballet appears to be disconcertingly nonproletarian. However, it was in a scruffy Oxford pub that Hanawalt and I began our continuing collaboration."

ALLAN COX, G. BRENT DALRYMPLE and RICHARD R. DOELL ("Reversals of the Earth's Magnetic Field") are with the U.S. Geological Survey. Cox, a geophysicist, is also a research associate at Stanford University; Dalrymple is a geologist, and Doell is a geophysicist who was recently appointed chief of theoretical geophysics in the Geological Survey. All received doctoral degrees from the University of California at Berkeley—Cox in 1959, Dalrymple in 1963 and Doell in 1955. Cox writes that their collaboration on the work they describe in their article "began in 1961 around a campfire in the White Mountains of California."

MICHEL JOUVET ("The States of Sleep") is associate professor of experimental medicine at the medical school of the University of Lyons. Born in the Jura region of France, he interrupted his education during World War II to serve with the Maquis, the French underground movement that conducted guerrilla operations against the Germans in France. After receiving the degree of doctor of medicine from the University of Lyons in 1956, he spent a year at the University of California at Los Angeles in the department of neurophysiology. His research in neurophysiology has included not only sleep but also conditioned reflexes.

JAMES L. DYE ("The Solvated Electron") is professor of chemistry at Michigan State University and chairman of the department's section on physical chemistry. He was graduated from Gustavus Adolphus College in Minnesota in 1949 and obtained a Ph.D. from Iowa State University in 1953. He joined the faculty at Michigan State University in 1953. In 1961–1962 he was at the Max Planck Institute for Physical Chemistry in Göttingen studying fast-reaction techniques.

R. WAYNE KRAFT ("Controlled Eutectics") is professor of metallurgy and materials science at Lehigh University. He was graduated from that university in 1948 and spent six years as a research metallurgist in industry before beginning graduate work at the University of Michigan, from which he received a doctorate in metallurgical engineering in 1958. For the next four years he was supervisor of the fundamental materials research group at the United Aircraft Corporation. He joined the Lehigh faculty in 1962.

JACOB GERSHON-COHEN ("Medical Thermography") is professor of radiologic research at the Temple University School of Medicine and director emeritus of the division of radiology at the Albert Einstein Medical Center in Philadelphia. He was graduated from the University of Pennsylvania in 1922 and received a medical degree there two years later. At the same university he obtained in 1936 the degree of doctor of science in medicine. In addition to his work at Temple, Gershon-Cohen conducts a private practice in radiology and serves as a consultant radiologist. He has done research on a number of medical problems; besides thermography they include mammography, the physiology of the gastrointestinal tract, the role of viruses in cancer, and telognosis (diagnosis at a distance). Recently he has been concerned with what he describes as "the chaos in medical education."

D. D. KOSAMBI ("Living Prehistory in India"), who died as his article was being prepared for publication, was an Indian mathematician and historian. Educated in India and at Harvard University, he began a career in mathematics. Some of his investigations led him to an interest in the history of India. "The sources were so poor," he once wrote, "that I had to learn Sanskrit and edit some of them myself." His writings include two historical books: *An Introduction to the Study of Indian History* and *The Culture and Civilisation of Ancient India in Historical Outline*. Kosambi also edited some works of poetry. He was the author of the article "Scientific Numismatics," which appeared in the February 1966 issue of SCIENTIFIC AMERICAN.

S. A. BARNETT, who in this issue reviews *On Aggression*, by Konrad Lorenz, is a senior member of the department of zoology at the University of Glasgow. He is the author of the article "Rats," which appeared in the January issue of SCIENTIFIC AMERICAN.

If she doesn't fill out that rental form in 2 minutes flat, strip her of her Avis button.

The record: 47 seconds, Aileen Gray, Denver.

Time her.

(Many Avis girls break 90. After record holder Gray's 47, there's Alice Webb in Seattle, with 48.)

So if she goes over 2 minutes, her Avis button is yours.

And don't think it won't hurt.

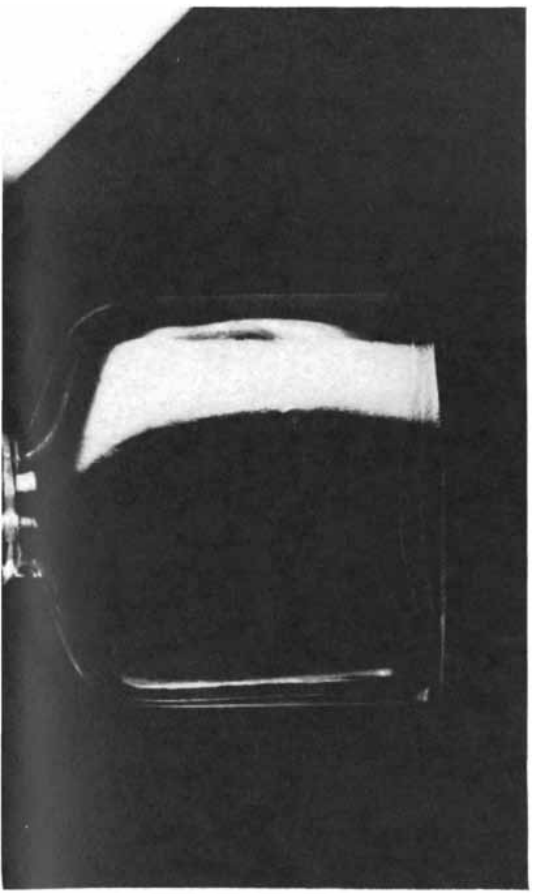
When you wear a button that says, "We try harder," and somebody tells you to take it off, they're telling you something about yourself.

Try it the next time you rent a shiny new Plymouth from Avis.

2 minutes. If she takes a second longer, tell her to hand the button over.

Please don't try to remove it yourself.

Forgers foiled again by "guardian green."



"Guardian green" is an ingenious printing ink produced by our Sinclair & Valentine division. It looks innocent enough when printed as a background color on a check. Until a forger alerts it by using an eraser or an ink eradicator. Then it becomes a kind of visual burglar alarm, changing color. Sinclair & Valentine, one of the world's largest manufacturers of printing inks, makes just about every kind of ink you've ever heard of, and many you haven't.

To meet the demands of modern printing, the printing ink industry is undergoing a technological revolution. Printing inks have changed more in the last 20 years than they did in the previous 500.

Mass magazines are now printing around a half-billion pages per issue, and at fantastic speeds. Often, four colored inks are used, each one printed atop the other. The ink must cover the surface of the paper immaculately, then dry instantly.

Research people at Sinclair & Valentine have been manipulating organic chemicals to produce inks that will print in every conceivable color on every conceivable surface. Some 80,000 color samples are now on file.

Designs on floor tiles are printed, as are wood patterns on plastic desk tops. Billions of printed paper, glass, plastic and metal containers pour off assembly lines.

Printing inks themselves have taken on extraordinary qualities. Sinclair & Valentine produces inks that are electro-conductive, magnetic, fluorescent, opaque, translucent, scented, flexible, glossy, dull, metallic. They produce inks that are resistant to alcohols, alkalies and acids, inks that bleach, inks that change color with water, heat, or atmospheric pressure variations, inks that transfer by electrostatic action.

Printing ink can no longer be regarded as a practical art. Today it is a science.

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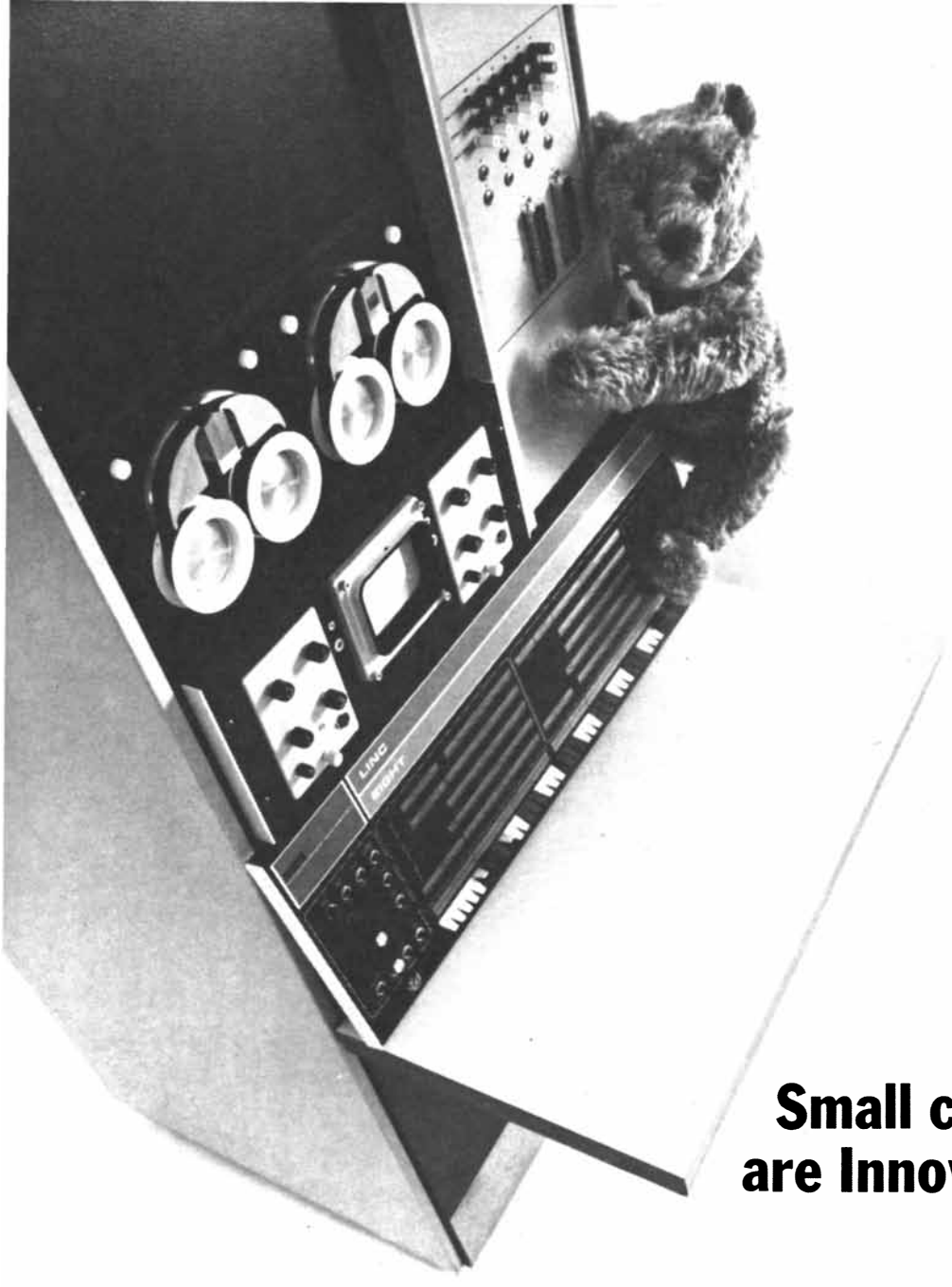

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Established 1845 SCIENTIFIC AMERICAN February 1967 Volume 216 Number 2

Orthodox and Unorthodox Methods of Meeting World Food Needs

The orthodox methods must be pressed, but it seems they cannot solve the problem without the aid of the unorthodox ones. And the adoption of unorthodox methods calls for basic changes in cultural attitudes

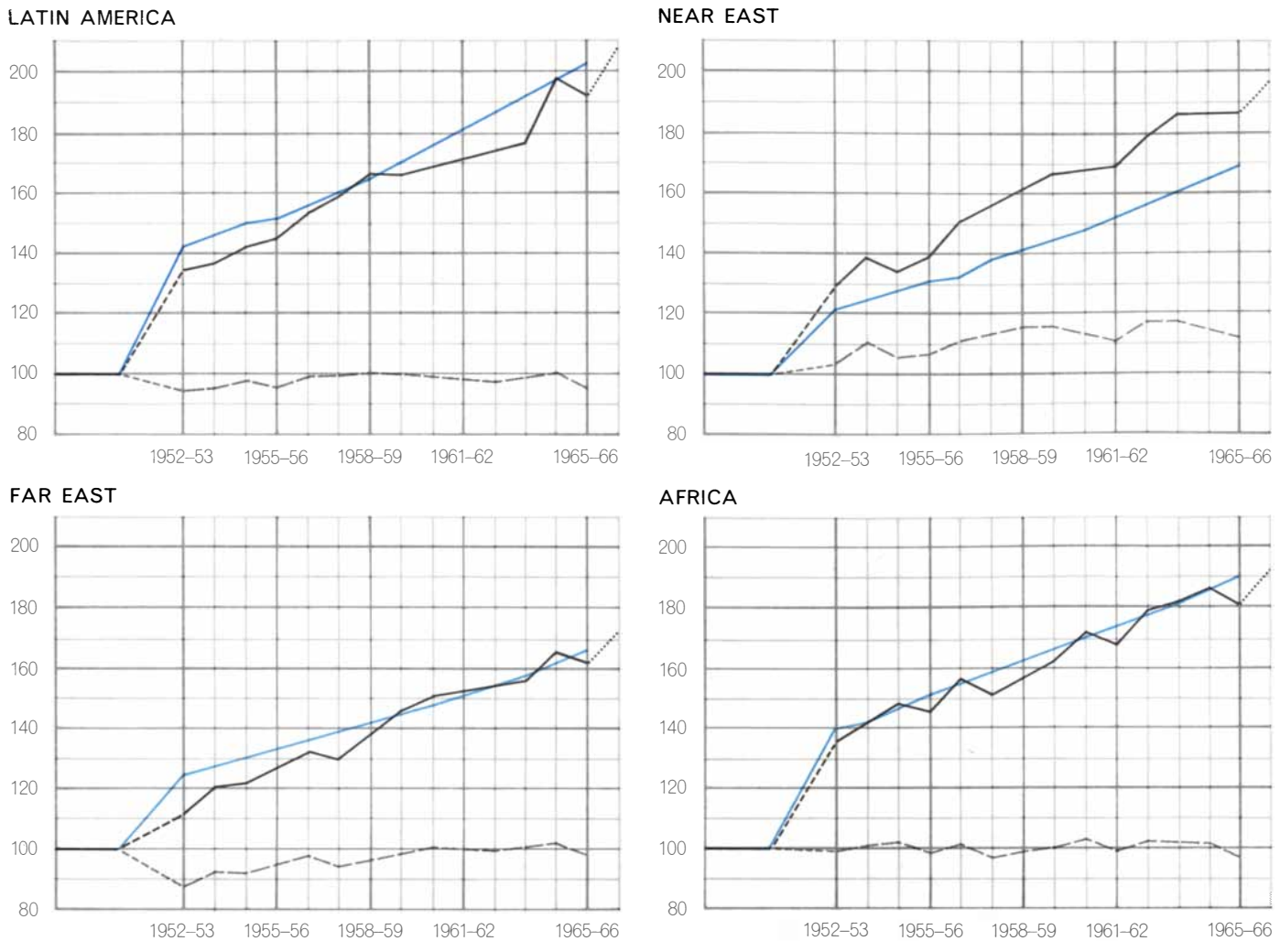
by N. W. Pirie

The world has been familiar with famine throughout recorded history. Until the present century some people have been hungry all the time and all the people have been hungry some of the time. Now a few industrialized countries have managed, by a mixture of luck, skill and cunning, to break loose from the traditional pattern and establish systems in which most of the population can expect to go through life without knowing hunger. Instead their food problems are overnutrition (about which much is now being written) and malnutrition. Malnutrition appears when the food eaten is supplying enough energy, or even too much, but is deficient in some components of a satisfactory diet. Its presence continually and on a large scale is a technical triumph of which primitive man was incapable because he lacked the skill to process the food he gathered in a manner that would remove some of the essential components but leave it palatable and pleasing in appearance. Furthermore, until the development of agriculture few foods contained the excess carbohydrate that characterizes much of the world's food today. The right policy in technically skilled countries, however, is not to try to "go back to nature" and eat crude foods. Processing does good as well as harm. What we now need is widespread knowledge of the principles of nutrition and enough good sense to use our technical skill prudently.

It is salutary to remember how recently this pattern was established. There was some hunger in Britain 50 years ago and much hunger 50 years before that. Still earlier many settlements in now well-fed regions of Australia and the U.S. had to be abandoned because of starvation. It is said that scurvy killed about 10,000 "forty-niners," and California was the scene of some of the classic descriptions of the disease. One has to learn how to live and farm in each new region; it cannot be assumed that methods that are successful in one country will work elsewhere. It is therefore probable that methods will be found for making the currently ill-fed regions productive and self-sufficient. The search for them should be started immediately and should be conducted without too much regard for traditional methods and preconceptions.

The problem can be simply stated: How can human affairs be managed so that the whole world can enjoy the degree of freedom from hunger that the industrialized countries now have?

It is well known that in many parts of the world not only is there a food shortage but also the population is increasing rapidly. Some of the reasons for this situation are fairly easy to establish. When the conditions of life change slowly, compensating changes can keep pace with them. In Europe during the 16th century half of the children probably never reached the age of five. There are no general statistics for this period, but in the 17th century 22 out of the 32 British royal children (from James I to Anne) died before they were 21, and it is unlikely that the poor fared better than royalty. The establishment of our present standards of infant mortality had little to do with medical knowledge. Until this century the farther away one could keep from doctors, except for the treatment of physical injury, the better. It was increasing technical skill in bringing in clean water and getting rid of sewage that made communities healthy, and this skill was applied by people who had never heard of germs or, like Florence Nightingale, disbelieved what they were told. But the change came slowly enough for families to adjust the birthrate to suit the new conditions. Moreover, there was incompletely filled land to be used. What René Dubos calls the "population avalanche" is on us because it is now possible to undertake public health measures on a larger scale and finish them quicker than heretofore.



POPULATION AND FOOD PRODUCTION are compared for four developing regions in these charts prepared by the Food and Agriculture Organization of the United Nations. The colored curve is population; the solid black curve, food production; the broken gray curve, food production per caput. The figures for population are in millions; those for food production are given according to an index of 100 for the prewar average. The food production figures for 1965–1966 (July 15, 1965, to July 15, 1966) show the effects of adverse weather in many parts of the world. In that period world food production per caput fell 2 percent. The dots at end of food production curve show increase required to regain per caput level of 1964–1965. Mainland China is not represented in Far East figures.

Once the principles are understood the hygiene of an area can be improved quickly by a few people, and the population as a whole gets the advantage of improved health without having to take any very active steps to achieve it. Even where methods for improving conventional agriculture are known their application is of necessity slower, because it depends on a change in the outlook of most of the people in a farming community rather than in the outlook of the few who control water and sewage. Furthermore, fecundity is potentially unlimited but food production is not. Clearly, therefore, the "avalanche" will have to be stopped. It is important to remember, however, that it cannot be stopped in any noncoercive way without the cooperation of the people; that means more education, which means more hygiene and so, at least for a time, a still greater increase in the population. The first result of an effective campaign for contraception will be an increase in population rather than a diminution. More effort should be put into the encouragement of contraception. And more research is needed on improved methods, leading to the ideal: that people should have to do something positive to reverse a normal state of infertility, so that no conception would be inadvertent. This, however, is a complement to, and not a substitute for, work on the production of more food. Strained as existing supplies are, it seems inevitable that they will be strained still further during the next half-century. After that the entire world may have established the population equilibrium that now exists in some industrialized countries.

The normal humane reaction in the presence of misery is pity, and this reaction is followed, where appropriate, by charity. Hence the immense effort that is now being put into shipping the food surpluses, accumulated in some parts of the world, to areas of need. This is commendable and spiritually satisfying to the donor, but for two reasons it has little effect on the real problem. The amount of surplus food is not large enough to make much of a dent in the world's present need. The surplus could be increased, but the logistic problem of shipping still greater quantities of food would be formidable. The more serious objection to charity, except during temporary periods of crisis, is that it discourages the recipient. A century ago the philanthropist Edward Denison remarked: "Every shilling I give away does fourpence worth of good by keeping the recipients' miserable bodies alive and eightpence worth of harm by helping to destroy their miserable souls." Nearly 1,000 years ago Maimonides categorized

the forms of charity and concluded that the most commendable form was to act in such a way that charity would become unnecessary.

Trade is the obvious alternative to charity. Unfortunately the developing countries are in a poor bargaining position. Since 1957 the prices paid for their primary products declined so much that the industrialized countries made a saving of $7,000 million and an extra profit of $3,000 million because of the increased cost of manufactured goods. The developing countries thus lost $10,000 million—about the same as the total "aid" they received from commercial, private and international sources. (The figures are from the *Financial Times* of London for July 19, 1965.) With the market rigged against them in this way it is not likely that they will soon be able to buy their food as countries such as Britain do. At present the industrialized countries are exporting about 30 million tons of grain a year, largely against credit. It is unlikely that this state of affairs can last; half of the world cannot permanently feed the other half.

The idea that the developing parts of the world should be fed by either charity or trade depends on the assumption that they are in some way unsuited for adequate food production. This idea is baseless. Once the methods have been devised, food can be produced in most places where there is sunlight and water; for political stability food must be produced where the mouths are. Any country dependent on imports for its main foodstuffs is to some extent controlled by others.

The problem can be more narrowly stated: How to produce enough food in the more populous parts of the world?

Food production can and will be increased in many orthodox ways. There is still some uncultivated but cultivable land, irrigation and drainage can be improved and extended, fertilizers can be used on a much greater scale and the general level of farming technique can be improved. If all the farmers in a region were as skilled as the best 10 percent of them, there would probably be enough food for everyone today. These improvements could be achieved by vigorous government action and without further research.

In the Temperate Zone plant breeders have greatly increased cereal yields during the past 20 years, and these improved varieties could be used more widely. There have been no comparable developments with food crops in the Tropical Zone, but there is no reason to think that progress there could not be equally spectacular. This research should not be limited to cereals. In many parts of the wet Tropics yams (*Dioscoria* and *Colocasia*) are staple foods but the varieties used contain little protein. There is, however, some evidence that the protein content of yams varies; a New Guinea variety called Wundunggul contains 2.5 percent nitrogen. If this nitrogen is all in protein, the yam contains 15 percent protein and is worthy of serious study.

It is generally agreed that pests and diseases rob us of as much as a third of our crops. When the improvements outlined above have been made, the proportional loss as well as the absolute one could become greater, since well-nourished crops, growing uniformly in large fields, are particularly susceptible. The cost of treatment may be only a tenth of the value of the crop saved; the methods are well publicized by firms making pesticides. There is no need to labor this aspect of the problem here. More attention should, however, be given to losses during storage; the need for

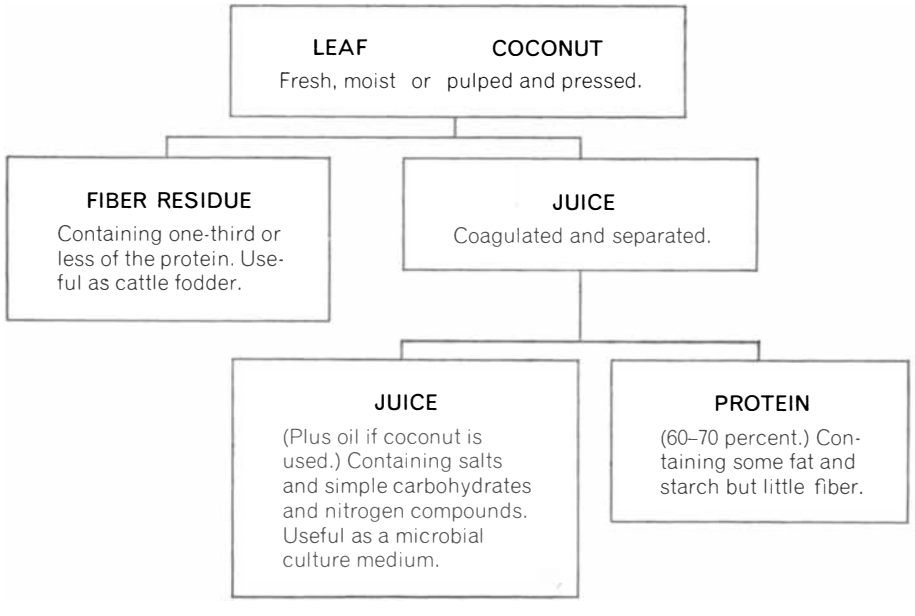
SYNTHETIC FOOD is represented by Incaparina, made of maize, sorghum and cottonseed by the Quaker Oats Company. The product has been skillfully promoted by Quaker Oats in Central America. The Spanish words at the top of this 500-gram package mean: "For 25 glasses or portions." Those below "Incaparina" mean: "It is very nourishing and costs little."

satisfactory storage techniques for use in primitive conditions is especially acute. So much mystical nonsense has been written by believers in the merits of "natural" foods that most scientists show understandable impatience at the idea that pesticide residues may be harmful to the ultimate consumer of the protected crop. Furthermore, a food shortage may well do more harm to a community than sensibly applied pesticides can do. There is, nevertheless, great scope here for research on improved techniques.

There are such good prospects that productivity can be increased by each, or even all, of these methods if they are assiduously developed that it seems to many experts that there is no immediate need for any more radical approach to the problem of world feeding. This is the attitude of the United Nations Food and Agriculture Organization (F.A.O.). One cannot praise too highly its work in compiling statistics and persistently calling attention to the need for agricultural improvements. On the other hand, while recognizing that the F.A.O. is not a research organization, one can deplore its equally persistent tendency to denigrate every unorthodox approach to the problem. History may partly excuse this attitude. Ever since the time of Malthus prophets have been making our flesh creep with warnings of impending famine. Conditions have remained much the same—or have improved. These prophecies remain unfulfilled because 400 years of exploration enabled new land to be cultivated, 200 years of biological research laid the foundation for scientific agriculture, and 50 years of rational chemistry made it possible to produce fertilizers by fixing the nitrogen of the air. The cautious prophet should therefore not say that hunger is inevitable but that it is probable unless the relevant research is done on an adequate scale. The time to do it is now, before the need has become more acute.

The main product of agriculture is carbohydrate. The foods that make up the world's diet—the cereals, potatoes, yams, cassava and so on—are from 1 to 12 percent protein on the basis of dry weight. An adult man needs 14 percent protein in his food; children and pregnant or lactating women need from 16 to 20 percent. However great an increase there may be in the consumption of conventional bulk foods, there will be a protein deficit. Moreover, it will be exacerbated if food is made palatable by the addition of fats and sugar, which give energy but contain no protein. Too much stress cannot be laid on the fact that the percentage of protein in a diet is the vital thing; increased consumption of low-protein food makes the consumer fat but as malnourished as before.

Recognition of the importance of protein sources, and their deficiency in most of the world's diet, has come slowly. It is nonetheless gathering momentum. Fifteen years ago little attention was paid to protein sources by international agencies and gatherings such as the International Nutrition Congress. Now protein is one of the main themes. Audiences at these gatherings are a step ahead of the management. At the International Congress of Food Science and Technology last year, for example, the session "Novel Protein Sources" proved more popular than those who had allocated the rooms had foreseen; that session was more uncomfortably overcrowded than any other. The remainder of this article will be exclusively concerned with protein. All the components of a diet are needed, but the need for protein will be the most difficult to meet.



LEAVES AND COCONUT are a source of protein if fiber and juice are removed from them. This chart shows the steps of the process and also indicates the uses of by-products.

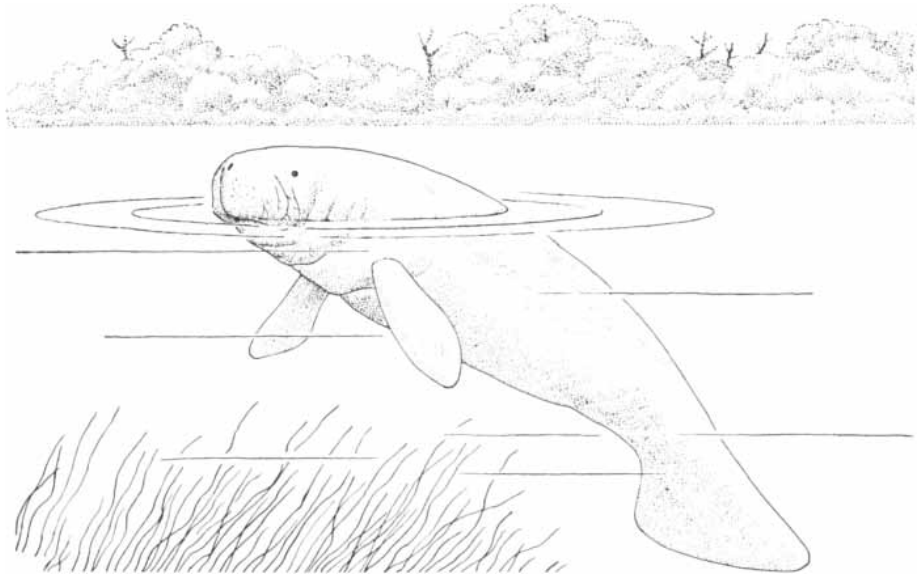
Animal products—meat, milk, cheese, eggs, fish—are widely esteemed and are used as protein concentrates to improve diets that are otherwise mainly carbohydrate. About a third of the world's cattle population is in Africa and India; most of these animals are relatively unproductive and are maintained largely for reasons of prestige and religion. It is easy to sidestep the main problem and argue that the protein shortage in these countries could be ameliorated, even if it could not be abolished, if herds were culled and the remainder made fully productive. The more thoughtful Africans and Indians realize this, and the situation will doubtless change. But every community tends to devote an amount of effort to nonproductive activity that seems to outsiders unreasonable. In the Middle Ages cathedrals were built by people who lived in hovels, and we now spend more on space research than on research in agriculture and medicine. Change is inevitable, and contemporary forms of religious observance and prestige are certain to be modified; the transition will not be hastened by nagging from outside.

According to most forecasters, the need to grow crops on land now used to maintain animals will lead to a decline in meat consumption in industrial countries, and the essential disappearance of meat is sometimes predicted. Although the decline is probable, the disappearance is not. There is much land that is suitable for grazing but not for tillage. Furthermore, there will always be a great deal of plant residue that (perhaps after supplementation with urea) can be more conveniently used as animal feed than in any other way. It is by no means certain, however, that we will always use the ideal herbivore. There is good reason to think that several species of now wild herbivore, running together, give a greater return of human food in many areas of tropical bush or savanna than domesticated species [see "Wildlife Hus-

bandry in Africa," by F. Fraser Darling; SCIENTIFIC AMERICAN, November, 1960]. In addition, wild herbivores generally yield more protein per pound "on the hoof" than domestic species. These are matters that are being investigated by the International Biological Program. Even better results may be achieved after a few years of skilled breeding. Ruminants such as the antelope and the water buffalo are not the only species worthy of attention, and land is not the only site available for grazing. The capybara, a large rodent, is well adapted to South America and is palatable. Water weeds, and plants growing in swamps and on lake margins, contribute hardly anything to human nutrition. They could be collected and fed to land animals, but it would seem to be more efficient to domesticate the *Sirenia* (the freshwater manatee and the marine dugong) and use them as sources of meat. These herbivores are wholly aquatic and so, unlike semiaquatic species such as tapirs and hippopotamuses, do not compete for food with more familiar animals.

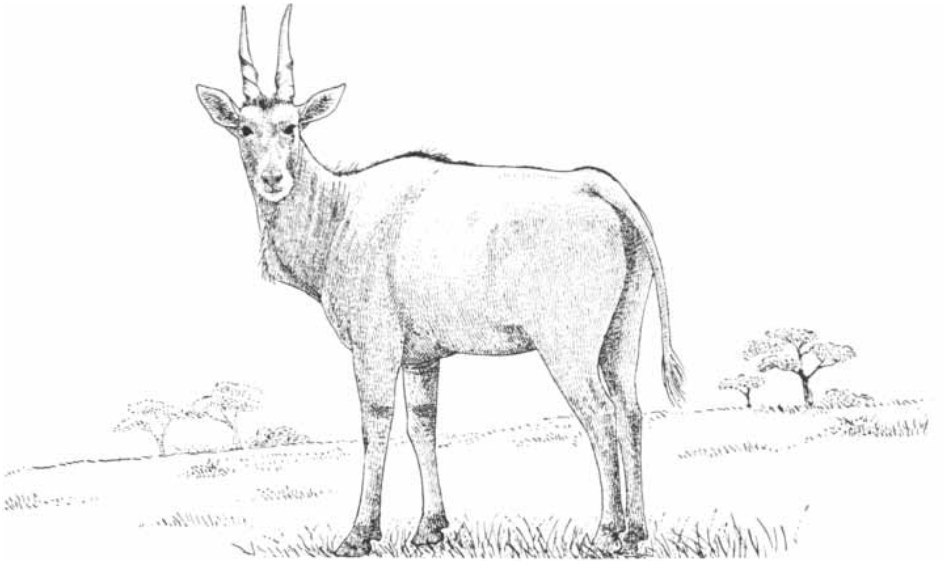
It is usual in articles such as this one to stress the importance of fish. This is admirable, but stress should not be allowed to drift into obsession. The more cautious forecasters estimate that the fish catch could be increased only two- or threefold without depleting stocks. Moreover, much of the world's population lives far from large bodies of water, and since fishing has an accident rate twice as high as coal mining it is likely to remain a relatively unattractive occupation. In the past decade the wet weight of fish caught annually increased from 29 million tons to 52 million, but the proportion used as human food decreased from 83 percent to 63. The remainder was used as fodder, mainly in the already well-fed countries. When still more fish are caught, the temptation to use a still larger proportion as fodder will be greater because much of the extra catch will consist of unfamiliar species. By grinding and solvent extraction these unfamiliar fishes can be turned into an edible product containing 80 percent protein. This process has suffered from every form of misfortune: the use of unsuitable solvents, commercial overstatement, excessive hygienic caution and political intrigue. It is nevertheless sound in principle and will do much to increase the amount of food protein made on an industrial scale and distributed through international channels.

One also hears of "fish farming." Activity that could properly be given this



MANATEE, an aquatic mammal, is an example of an unorthodox source of meat. It can also control aquatic weeds, which it eats. An adult manatee is between nine and 15 feet long.

CAPYBARA, a large rodent that lives in South America, has also been suggested as a source of meat. Like the manatee, it feeds on aquatic weeds. An adult is about four feet long.



ELAND, a large African antelope, is an accepted meat animal. Its importance as a food source is that it is adapted to grazing on marginal lands that are not suited to agriculture.

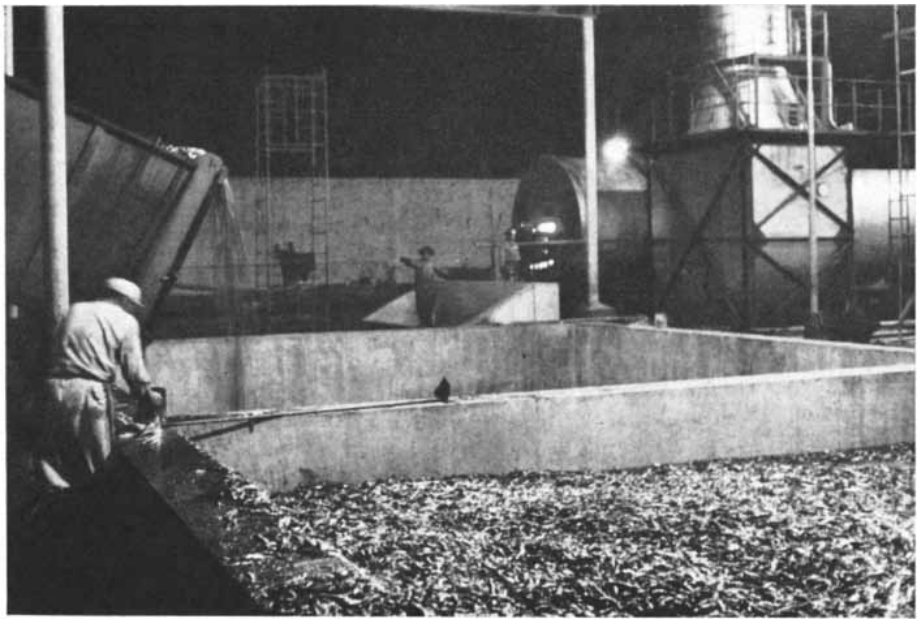
title is possible in lagoons but unlikely in the oceans because fish move too freely, and fertilizer, intended to encourage the growth of their food, spreads too easily into the useless unlit depths. With mollusks and crustaceans, farming becomes much more promising and deserves more scientific attention than it gets. Food for such marine invertebrates does not seem to be the limiting factor; many of them can use the world's largest biological resource, the million million tons of organic matter in suspension in the sea. Sedentary mollusks are limited by predators and attachment sites. The predators could be controlled and the sites, with modern materials, could be increased.

Animals that live on something that we could not use as food—forage growing in rough country, straws and other residues, phytoplankton and other forms of marine organic matter—cannot properly be said to have a "conversion efficiency." We either use an animal converter or these materials are wasted. Efficiency has a real meaning when we consider animals that live either on crops that people could eat or on crops grown on land that could have grown food. The inefficiency of animal conversion, expressed as pounds of protein the animal must eat to make a pound of protein in the animal product that people eat, is much greater than is generally realized. This unawareness probably arises from the tendency among animal feeders to present their results as the ratio of the dry food eaten to the wet weight (including all inedible parts) of the carcass produced. Furthermore, the figures generally relate only to one phase of the animal's life, without allowance for unproductive periods. It is unlikely that the true efficiency of protein conversion is often greater than one pound of food protein for every seven pounds of fodder protein; it is generally less. Although animal products are highly esteemed in most countries, their production is an extravagance when it depends on land or fodder that could have been used to feed people. The extravagance may be tolerated in well-fed countries but not in those that are short of food.

As I have indicated, the world's main food crops need to be supplemented with protein. Peas and beans, which are 25 to 40 percent protein, are traditionally used. Green vegetables and immature flowers are gaining recognition. They can yield 400 pounds of edible protein per acre in a three-to-four-month growing period, but because they contain fiber and other indigestible components a person cannot get more than two or three grams of protein from them in a day. This amount, however, is much more than is normally consumed, and such plants offer a rewarding field for research. The varieties cultivated in industrialized countries are often ill-adapted to other climatic conditions. The work of vegetable improvement that was done in Europe in the 18th and 19th centuries should now be replicated in the wet Tropics. Biochemical control would be needed to ensure that what is being produced is not only nontoxic but also nutritionally valuable. This would be an excellent project for the International Biological Program; the raw materials have worldwide distribution and the need is also worldwide.

The residue that is left when oil is expressed from soya, groundnut, cottonseed and sunflower is now for the most part used as animal feed or fertilizer or is simply discarded. It contains about 20 million tons of protein, that is, twice the world's present estimated deficit. Because its potential value is not yet widely realized, most of this material is at present so contaminated, or damaged by overheating during the expressing of the oil, that it is useless as a source of human food. But methods are being devised, notably in the Indian state of Mysore and in Guatemala, for processing the oilseeds more carefully in order to produce an acceptable food containing 40 to 50 percent protein. The avoidance of damage during processing is not the only problem that arises with oilseeds; each species contains, or may contain, harmful components, for example gossypol in cottonseed, enzyme inhibitors in soya and aflatoxin in peanuts. Gossypol can be extracted or low-gossypol strains of cotton can be used (it is said, however, that these are particularly attractive to insect pests); enzyme inhibitors can be destroyed, and the infestation that produces aflatoxin can be prevented by proper harvesting and storage. The alternative of extracting a purified protein concentrate from the residues is often advocated. This approach seems mistaken; it increases the cost of the protein fivefold. In addition, the process is in the main simply the removal of starch or some other digestible carbohydrate, and carbohydrate has to be added to the protein concentrate again during cooking.

The residue left after expressing oil from an oilseed can be used because it contains little fiber. Coconuts and the leaves from many species of plants are also potential protein sources, but they contain so much fiber that it is essential to separate the protein if more than two or three grams is being eaten each day. The process of separation, although simple, is still in its infancy, and many improvements remain to be made. Units for effecting it are working in Mysore, at the Rothamsted Experimental Station and elsewhere. In wet tropical regions the conventional seed-bearing plants often do not ripen, but coconuts thrive and leaves grow exuberantly. It is in these



TANKS ARE FILLED WITH LITTLE FISH from a truck (*left*) at a fish meal plant in the Peruvian port of Callao. The fish are anchovetas, a variety of anchovy. By grinding and solvent extraction they are converted into a product that contains 80 percent protein.

BAGS OF FISH MEAL are piled in the yard of the same plant. Fish meal is currently used primarily as a supplement to feed for domestic animals. In 1965 Peru harvested 7.46 million metric tons of fish, a catch that makes it the world's leading fishing nation.

regions that protein separation has its greatest potentiality.

The protein sources discussed in the last two paragraphs would be opened up by handling conventional agricultural products in unusual ways. Attention is also being given to completely novel forms of production based on photosynthesis by unicellular algae and other microorganisms. The early work was uncritical and, considering the small increases in the rate of fixation of carbon dioxide given by these methods compared with conventional agriculture, the necessary expenditure on equipment was out of proportion. It is an illusion to think that algae have any special photosynthetic capacity. Their merit is that it is much easier to spread an algal suspension, rather than a set of slowly expanding seedlings, uniformly over a sunlit surface so as to make optimal use of the light. Recently more realistic methods, using open tanks and the roofs of greenhouses in which other plants can be grown during the winter, have been tried in Japan and Czechoslovakia. The product resembles leaf protein in many ways but contains more indigestible matter because the algal cell walls are not removed; it may prove possible either to separate the protein from the cell walls or to digest the walls with enzymes.

All the processes discussed so far depend on what might be called current photosynthesis. Microorganisms that do not themselves photosynthesize can produce foodstuffs from the products of photosynthesis in the immediate past (straw, sawdust or the by-product liquor from leaf-protein production) or in the remote past (petroleum, coal or methane). The former substrates would have to be collected over a wide area, whereas the latter are concentrated in a few places and so lend themselves to convenient large-scale industrial processing. At first sight this seems advantageous, and in fact it would be so were we merely concerned with increasing the amount of food in the world. That will be the problem later; now the important thing is, as I have said, to make food where the mouths are, and elaborate and sophisticated techniques are not well adapted to this end. The most valuable aspect of the research now being done in many countries on microbial growth on fossil substrates such as petroleum is that it will familiarize people with the idea of microbial food and so will hasten its acceptance when it is produced from local materials.

Finally, there is synthetic food. Plants make fats and carbohydrates so economically that it is unlikely synthesis could be cheaper. Many of the abundant plant proteins do not have an amino acid composition ideally suited to human needs. These proteins are sometimes complementary, so that the deficiencies of each can be made good by judicious mixing. When this is not possible, the deficient amino acids can be synthesized or made by fermentation and then added to the food. Production of amino acids for this purpose will probably be possible only in industrialized countries; their use may therefore seem to violate the principle that food must be where the mouths are. The quantities needed, however, are small. It is obviously better to upgrade an abundant local protein by adding .5 percent of methionine to it rather than import a whole protein to make up this one deficiency.

The food that is now needed or that will soon be needed in the underprivileged parts of the world might be supplied by charity, by the extension of existing methods of agriculture or by novel processes. I have argued that the first cannot be satisfactory and that it would be dangerous to assume that the second will suffice. Without wishing in any way to minimize the importance of what is being done in these two directions, it seems necessary to take novelties seriously. By definition a novelty is novel. That is to say, it may have an unfamiliar appearance, texture or flavor. In commenting on any of the proposals made—the use of strange animals, oilseed residues or leaf and microbial protein—it is irrelevant to say that they are unfamiliar. If the world is to be properly fed, products such as these will probably have to be used. Our problem is to make them acceptable.

Socrates, when one of his companions said he had learned little by foreign travel, replied: "That is not surprising. You were accompanied by yourself." Similarly, food technologists, accustomed to the dietary prejudices of Europe and the U.S., are apt to project their prejudices onto other communities. They have two opposite obsessions: to

fabricate a "chewy" texture in their product and to produce a bland stable powder with an indefinite shelf life. Neither quality is universal in the familiar foods of most of the world. The former may have merits, although these probably do not outweigh the extra difficulties involved. It is odd that, at a time when people in industrialized countries are beginning to revolt against uniform and prepacked foods, we should be bent on foisting the latter quality off on others. Instead, novelties should be introduced into regions where they will most smoothly conform with local culinary habits. Novel forms of fish and mollusks are probably well adapted to Southeast Asia, where fermented fish is popular. Leaf, oilseed or microbial protein would fit smoothly into a culture accustomed to porridge, gruel and curry. It is important to remember the irrational diversity of our tastes. Even in Europe and the U.S. a flavor and appearance unacceptable in an egg is acceptable in cheese, a smell unacceptable in chicken is acceptable in pheasant or partridge, and a flavor unacceptable in wine is acceptable in grapefruit juice. These things are a matter of habit, and habits, although they will not change in a day or even a month, can readily be changed by suitable example and persuasion. The essential first step is to find out what is meant by the word "suitable."

Enough experience is now accumulating for us to define the parameters of success. The four most important are:

First, research on the novelty should be done privately and completely, so that when popularization starts there can be no rationally based doubts about the merits of the product.

Second, the novelty should manifestly be eaten by the innovators themselves. It is folly to ask people to practice what we only preach—we must practice it ourselves.

Third, example is the main factor leading to a change in habits; it is therefore essential to get the support of influential local people—from film stars to political leaders. Care should be taken that the first users are not underprivileged groups (prisoners, refugees and so on), because the stigma will not easily be removed.

Last, an adequate and regular supply of the product should be assured before there is any publicity, because it is hard to reawaken interest that has waned because the product is not obtainable.

All these proposals, except that of the simplest form of agricultural extension, call for research. It is worth considering who should do it and what form opposition is likely to take. Opposition to innovation is an interesting and underinvestigated part of psychopathology. It takes three main forms: total, quasi-logical and "instant."

Total opposition is the denial of the problem. Even today there are those who, in the course of condemning some specific proposal, sometimes deny that a protein shortage exists or is impending. This is a point that should be settled at the very beginning: "Do we have a problem or not?" Fortunately for research, and for humanity, the international agencies are in agreement that we do.

Quasi-logical opposition comes from economists. They may accept the problem but argue that some proposed solutions will be too expensive. There are two relevant questions: "Compared with what?" and "How do you know when it has not been tried?" When there are several equally feasible methods for getting the extra food that is needed in a region, a comparison of their probable costs is obviously worthwhile. But when all costs are, for various reasons, unknown, the exercise becomes futile because assumptions play a larger part in it than rigid economic argument, and scientists are better qualified than economists to make the assumptions; they know more of the facts, are aware of more possibilities and are less subject to romantic illusion.

"Instant opposition" arises because innovators are apt to irritate right-minded people, and enthusiasm invites skepticism. The innovator must therefore expect to run into trouble. When someone made the old comment that genius was an infinite capacity for taking trouble,

MUSSELS ARE GROWN in this floating "park" in Vigo Bay on the northwestern coast of Spain. Suspended from each of the large anchored raftlike structures are ropes on which the mussels are seeded and grow to maturity (*see photograph on opposite page*).

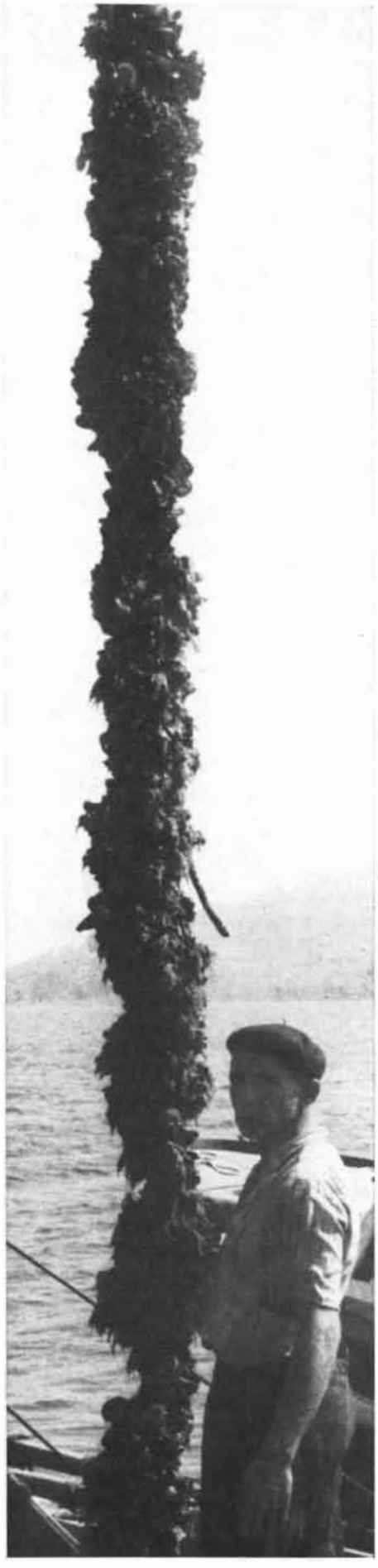
Samuel Butler replied: "It isn't. It is an infinite capacity for getting into trouble and for staying in trouble for as long as the genius lasts." In an attenuated form the principle applies even when genius is not involved. There are many different ways of getting into trouble, and it is as naïve and illogical to assume that an idea must be correct because it is meeting opposition as it is to take "instant opposition" seriously.

The governments of countries with a food shortage know that, for a decade at least, more people will be better fed if money is spent on importing food rather than on setting up a research project on means to make more food from local products for local consumption. The more farsighted statesmen realize that ultimately the research will have to be done, but it is hard to resist political pressure, and resistance is hampered by the high cost of primitive agriculture. In a market in New Guinea local sweet potatoes cost three times as much per calorie as imported wheat, and fresh fish cost twice as much per gram of protein as canned fish. So poor countries are hardly likely to mount research projects.

At the other extreme are the giants of private enterprise. They already do very well selling soft drinks and patent foods in underdeveloped countries, and their skill in creating a market, regardless of the real merits of their product, is unrivaled. Thus baby foods, which few experts regard as superior to mother's milk, were used in Uganda by 42 percent of the families in 1959, whereas only 14 percent had used them in 1950. Undoubtedly there are efficient firms that operate with strict integrity, and a few of them have ventured into the production of low-cost protein-rich foods. After the necessary research and preliminary publicity had been done with money from international sources, the Quaker Oats Company has done a masterly job in making, distributing and popularizing Incaparina (maize, sorghum and cottonseed) in Central America. And skilled advertising increased the sales of Pronutro (soya, peanuts and fish) tenfold in two years. Other attempts have failed because the possible profit, when one is selling to poor people without misleading them with meretricious advertising, is too small to cover the costs of the preliminary educational campaign. That, as I have suggested, can be managed only with the cooperation of governments and the local leaders of opinion.

Large-scale private enterprise will probably not find this activity lucrative, and from some points of view the methods of production that would be used may not be desirable. Already more than a third of the world's city population (12 percent of the total population) live in shantytowns on the fringes of cities, and rural depopulation is accelerating. This, together with transport difficulties, makes it at least arguable that research attention should be focused on simple techniques adapted for use in a large village or small town, rather than on fully industrialized techniques. The latter have their place, but they should not become our exclusive concern.

If neither the governments of needy countries nor private enterprise is likely to undertake the necessary research and development, it remains for the governments of industrialized countries, the international agencies and the foundations. So far these groups have been reluctant to admit that any radical changes in research policy will be needed, but times are changing. The novelties are now at least mentioned by the F.A.O. even if only to be gently damned with a few misstatements. On the Barnum principle, "I don't care what people say about me so long as they talk about me," this is a step forward. The governments of wealthy countries supply most of the support for the international agencies, they support other forms of aid, and much knowledge that is of use in poorer countries is an international by-product of their more parochial research. They may feel that they are already doing their share. Our best hope must therefore lie with the foundations. Several institutes of food technology are needed to undertake fundamental and applied research on the production of food from local products for local consumption. At least one of the institutes should be in the wet Tropics and all should give particular attention to protein sources. Using locally available material, each institute should study all the types of raw material discussed here. This will ensure that similar criteria are applied to all of them and that the assessment of their merits is made objectively and is not colored by interinstitutional rivalry. These institutes should also be responsible for work on the presentation and popularization of the products made. It may be that an extension of normal agriculture will meet the world's food needs for a few more years, but ultimately more radical research will be needed. It would be prudent to start it before the need is even more pressing than it is at present.



ROPE COVERED WITH MUSSELS is lifted from the water after mussels are mature.

The Repair of DNA

The two-strand molecule that incorporates the genetic information of the living cell is subject to damage. Experiments with bacteria reveal that the cell has a remarkable ability to repair such damage

by Philip C. Hanawalt and Robert H. Haynes

One of the most impressive achievements of modern industry is its ability to mass-produce units that are virtually identical. This ability is based not solely on the inherent precision of the production facilities. It also involves intensive application of quality-control procedures for the correction of manufacturing errors, since even the best assembly lines can introduce faulty parts at an unacceptable rate. In addition industry provides replacement parts for the repair of a product that is subsequently damaged by exposure to the hazards of its natural environment. Recent studies have demonstrated that living organisms employ analogous processes for repairing defective parts in their genetic material: deoxyribonucleic acid (DNA). This giant molecule must be replicated with extraordinary fidelity if the organism is to survive and make successful copies of itself. Thus the existence of quality-control mechanisms in living cells may account in large part for the fact that "like produces like" over many generations.

Until recently it had been thought that if the DNA in a living cell were damaged or altered, for example by ionizing radiation, the cell might give rise either to mutant "daughter" cells or to no daughter cells at all. Now it appears that many cells are equipped to deal with some of the most serious hazards the environment can present. In this article we shall describe the experimental results that have given rise to this important new concept.

The instructions for the production of new cells are encoded in the sequences of molecular subunits called bases that are strung together along a backbone of phosphate and sugar groups to form the chainlike molecules of DNA. A sequence of a few thousand bases constitutes a single gene, and each DNA molecule comprises several thousand genes. Before a cell can divide and give rise to two daughter cells, the DNA molecule (or molecules) in the parent cell must be duplicated so that each daughter cell can be supplied with a complete set of genes. On the basis of experiments made with the "chemostat"—a device for maintaining a constant number of bacteria in a steady state of growth—Aaron Novick and the late Leo Szilard estimated that bacterial genes may be duplicated as many as 100 million times before there is a 50 percent chance that even one gene will be altered. This is a remarkable record for any process, and it seems unlikely that it could be achieved without the help of an error-correcting mechanism.

The ability of cells to repair defects in their DNA may well have been a significant factor in biological evolution. On the one hand, repair would be advantageous in enabling a species to maintain its genetic stability in an environment that caused mutations at a high rate. On the other hand, without mutations there would be no evolution, mutations being the changes that allow variation among the individuals of a population. The individuals whose characteristics are best adapted to their environment will leave more offspring than those that are less well adapted. Presumably even the efficiency of genetic repair mechanisms may be subject to selection by evolution. If the repair mechanism were too efficient, it might reduce the natural mutation frequency to such a low level that a population could become trapped in an evolutionary dead end.

Although the error-correcting mechanism cannot yet be described in detail, one can see in the molecular architecture of DNA certain features that should facilitate both recognition of damage and repair of damage. The genetic material of all cells consists of two complementary strands of DNA linked side by side by hydrogen bonds to form a double helix [*see upper illustration on page 38*]. Normally DNA contains four chemically distinct bases: two purines (adenine and guanine) and two pyrimidines (thymine and cytosine). The two strands of DNA are complementary because adenine in one strand is always hydrogen-bonded to thymine in the other, and guanine is similarly paired with cytosine [*see lower illustration on page 38*]. Thus the sequence of bases that constitute the code letters of the cell's genetic message is supplied in redundant form. Redundancy is a familiar stratagem to designers of error-detecting and error-correcting codes. If a portion of one strand of the DNA helix were damaged, the information in that portion could be retrieved from the complementary strand. That is, the cell could use the undamaged strand of DNA as a template for the reconstruction of a damaged segment in the complementary strand. Recent experimental evidence indicates that this is precisely what happens in many species of bacteria, particularly those that are known to be highly resistant to radiation.

The ability to recover from injury is a characteristic feature of living organisms. There is a fundamental difficulty, however, in detecting repair processes in bacteria. For example, when a population of bacteria is exposed to a dose of ultraviolet radiation or X rays, there is no way to determine in advance what proportion of the population will die. How can one tell whether the observed mortality accurately reflects all the damage sustained by the irradiated cells or whether some of the damaged

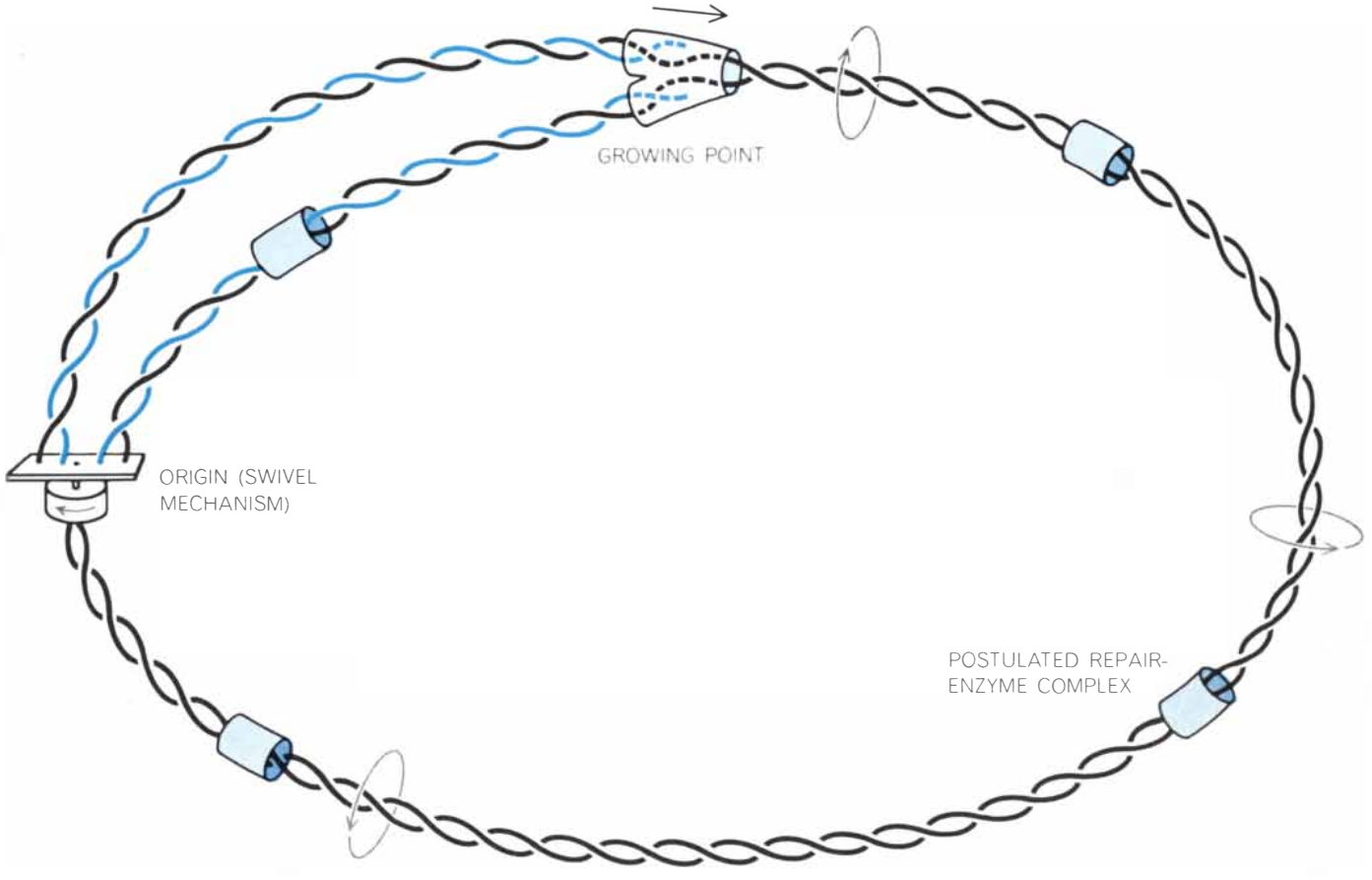
cells have repaired themselves? Fortunately it is possible to turn the repair mechanism on or off at will.

A striking example can be found in the process called photoreactivation [*see bottom illustration on page 40*]. Although hints of its existence can be traced back to 1904, photoreactivation was not adequately appreciated until Albert Kelner rediscovered the effect in 1948 at the Carnegie Institution of Washington's Department of Genetics in Cold Spring Harbor, N.Y. Kelner was puzzled to find that the number of soil organisms (actinomycetes) that survived large doses of ultraviolet radiation could be increased by a factor of several hundred thousand if the irradiated bacteria were subsequently exposed to an intense source of visible light. He concluded that ultraviolet radiation had its principal effect on the nucleic acid of the cell, but he had no inkling what the effect was. In an article published before the genetic significance of DNA was generally appreciated, Kelner wrote: "Perhaps the real stumbling block [to understanding photoreactivation] is that we do not yet understand at all well the biological role of that omnipresent and important substance—nucleic acid" [see "Revival by Light," by Albert Kelner; SCIENTIFIC AMERICAN, May, 1951].

It is now known that the germicidal action of ultraviolet radiation arises chiefly from the formation of two unwanted chemical bonds between pyrimidine bases that are adjacent to each other on one strand of the DNA molecule. Two molecules bonded in this way are called dimers; of the three possible types of pyrimidine dimer in DNA, the thymine dimer is the one that forms most readily [*see upper illustration on page 39*]. It is therefore not surprising that a given dose of ultraviolet radiation will create more dimers in DNA molecules that contain a high proportion of thymine bases than in DNA molecules with fewer such bases. Consequently bacteria whose DNA is rich in thymine tend to be more sensitive to ultraviolet radiation than those whose DNA is not.

Richard B. Setlow, his wife Jane K. Setlow and their co-workers at the Oak Ridge National Laboratory have shown that pyrimidine dimers block normal replication of DNA and that bacteria with even a few such defects are unable to divide and form colonies [see "Ultraviolet Radiation and Nucleic Acid," by R. A. Deering; SCIENTIFIC AMERICAN, December, 1962]. In the normal replication of DNA each parental DNA strand serves as a template for the synthesis of a complementary daughter strand. This mode of replication is termed semiconservative because the parental strands separate in the course of DNA synthesis; each daughter cell receives a "hybrid" DNA molecule that consists of one parental strand and one newly synthesized complementary strand. The effect of a pyrimidine dimer on DNA replication may be analogous to the effect on a zipper of fusing two adjacent teeth.

Claud S. Rupert and his associates at



REPLICATION OF BACTERIAL CHROMOSOME, a ring-shaped molecule of deoxyribonucleic acid (DNA), has now been shown to take two forms: normal replication and repair replication. In the former process the two strands that constitute the double helix of DNA are unwound and a daughter strand (*color*) is synthesized against each of them. In this way the genetic "message" is transmitted from generation to generation. The pairing of complementary subunits that underlies this process is illustrated on the next page. In repair replication, defects that arise in individual strands of DNA are removed and replaced by good segments. It is hypothesized that "repair complexes," composed of enzymes, are responsible for the quality control of the DNA structure. Although this diagram shows the swivel mechanism for unwinding the parent strands to be at the origin, it may in fact be located at the growing point.

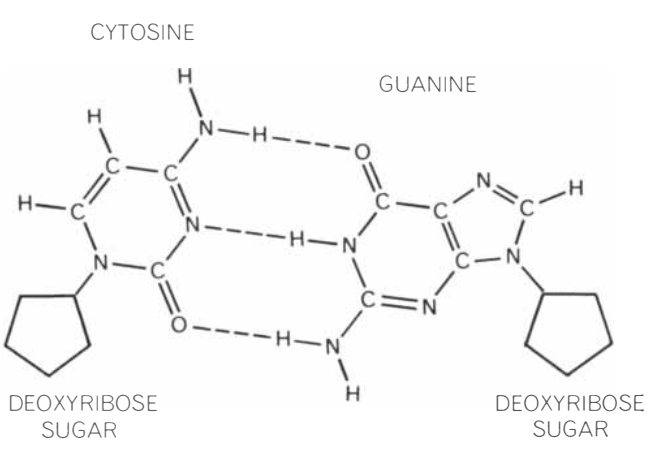
Johns Hopkins University have shown that photoreactivation involves the action of an enzyme that is selectively bound to DNA that has been irradiated with ultraviolet. When this enzyme is activated by visible light (which simply serves as a source of energy), it cleaves the pyrimidine dimers, thereby restoring the two bases to their original form. Photoreactivation is thus a repair process that can be turned on or off merely by flicking a light switch.

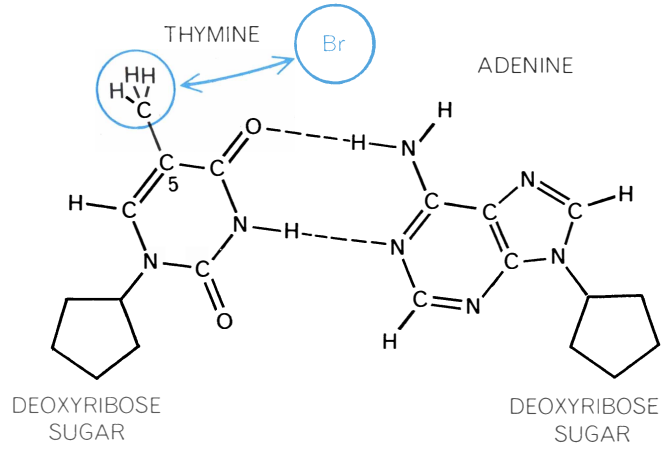
Let us now consider another kind of repair mechanism in which light plays no role and that is therefore termed dark reactivation. This type of repair process can be turned off genetically, by finding mutant strains of bacteria that lack the repair capabilities of the original radiation-resistant strain. The "*B/r*" strain of the bacterium *Escherichia coli*, first isolated in 1946 by Evelyn Witkin of Columbia University, is an example of a microorganism that is particularly resistant to radiation. The first radiation-sensitive mutants of this strain, known as B_{s-1}, were discovered in 1958 by Ruth Hill, also of Columbia.

Not long after the discovery of the B_{s-1} strain a number of people suggested that its sensitivity to radiation might be due to the malfunction of a particular enzyme system that enabled resistant bacteria such as *B/r* to repair DNA that had been damaged by radiation. This was a reasonable suggestion in view of the steadily accumulating evidence that DNA is the principal target for many kinds of radiobiological damage. Experiments conducted by Howard I. Adler at Oak Ridge and by Paul Howard-Flanders at Yale University lent further support to this hypothesis. It had been known for some years that bacteria can exchange genes by direct transfer through a primitive form of sexual mating [see "Viruses and Genes," by François Jacob and Elie L. Wollman; SCIENTIFIC AMERICAN, June, 1961]. Howard-Flanders and his co-workers found that bacteria of a certain radiation-resistant strain of *E. coli* (strain *K*-12) have at least three genes that can be transferred by bacterial mating to radiation-sensitive cells, thereby making them radiation-resistant. Since genes direct the synthesis of all enzymes in the living cell, these experiments supported the hypothesis that B_{s-1} and other radiation-sensitive bacteria lack one or more enzymes needed for the repair of radiation-damaged DNA.

The question now arises: Do the enzymes involved in dark reactivation operate in the same way as the enzyme that

DNA MOLECULE is a double helix that carries the genetic message in redundant form. The backbone of each helix consists of repeating units of deoxyribose sugar (*pentagons*) and phosphate (*black dots*). The backbones are linked by hydrogen bonds between pairs of four kinds of base: adenine, guanine, thymine and cytosine. The bases are the "letters" in which the genetic message is written. Because adenine invariably pairs with thymine and guanine with cytosine, the two strands carry equivalent information.

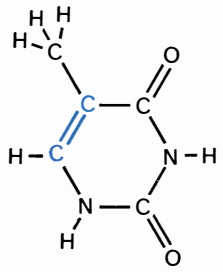




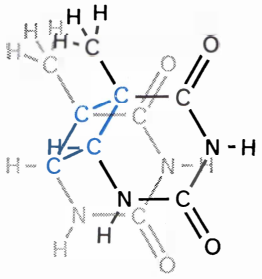
DNA BASES are held together in pairs by hydrogen bonds. The cytosine-guanine pair (*left*) involve three hydrogen bonds, the thymine-adenine pair (*right*) two bonds. If the CH_3 group in thymine is replaced by an atom of bromine (*Br*), the resulting molecule is called 5-bromouracil. Thymine and 5-bromouracil are so similar that bacteria will incorporate either in synthesizing DNA. Because the bromine compound is so much heavier than thymine its presence can be detected by its effect on the weight of the DNA.

is known to split pyrimidine dimers in the photoreactivation process? Another possibility is that the resistant cells might somehow bypass the dimers during replication of DNA and leave them permanently present, although harmless, in their descendant molecules.

The actual mechanism is even more elegant than either of these possibilities; it exploits the redundancy inherent in the genetic message. The radiation-resistant strains of bacteria possess several enzymes that operate sequentially in removing the dimers and replacing the defective bases with the proper complements of the bases in the adjacent "good" strand. We shall recount the two key observations that substantiate this postulated repair scheme.



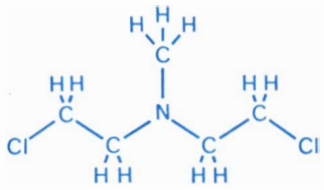
THYMINE

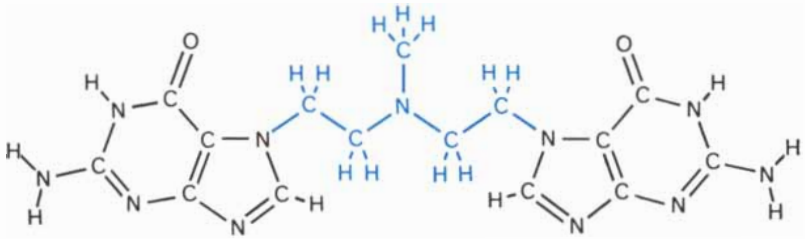


THYMINE DIMER

EFFECT OF ULTRAVIOLET RADIATION on DNA is to fuse adjacent pyrimidine units: thymine or cytosine. The commonest linkage involves two units of thymine, which are coupled by the opening of double bonds. The resulting structure is known as a dimer.

NITROGEN MUSTARD





GUANINE GUANINE

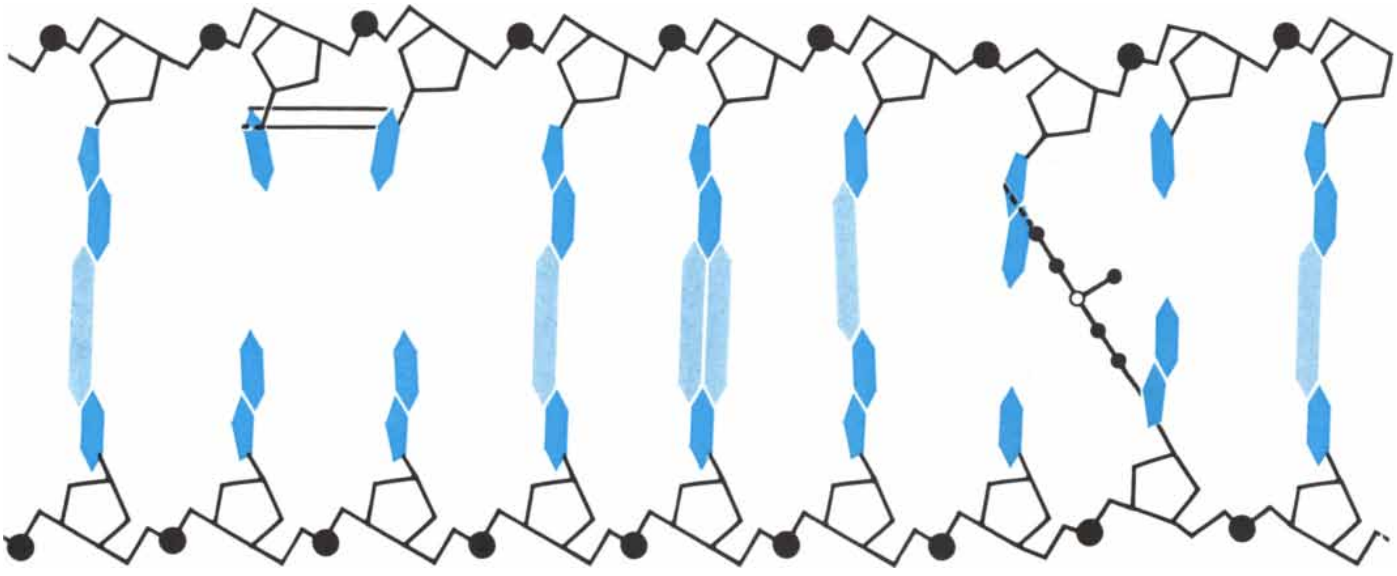
EFFECT OF NITROGEN MUSTARD, a compound related to mustard gas, is to cross-link units of guanine within the DNA molecule. Unless repaired, the structural defects caused by nitrogen mustard and ultraviolet radiation can prevent the normal replication of DNA.

The excision of dimers was first demonstrated by Richard Setlow and William L. Carrier at Oak Ridge and was soon confirmed by Richard P. Boyce and Howard-Flanders at Yale. In their studies cultures of ultraviolet-resistant and ultraviolet-sensitive bacteria were grown separately in the presence of radioactive thymine, which was thereupon incorporated into the newly synthesized DNA. The cells were then exposed to ultraviolet radiation. After about 30 minutes they were broken open so that the fate of the labeled thymine could be traced. In the ultraviolet-sensitive strains all the thymine that had been incorporated into DNA was associated with the intact DNA molecules. Therefore any thymine dimers formed by ultraviolet radiation remained within the DNA. In the ultraviolet-resistant strains, however, dimers originally formed in the DNA were found to be associated with small molecular fragments consisting of no more than three bases each. (Thymine dimers can easily be distinguished from the individual bases or combinations of bases by paper chromatography, the technique by which substances are separated by their characteristic rate of travel along a piece of paper that has been wetted with a solvent.) These experiments provided strong evidence that dark repair of ultraviolet-damaged DNA does not involve the splitting of dimers in place, as it does in photoreactivation, but does depend on their actual removal from the DNA molecule.

Direct evidence for the repair step was not long in coming. At Stanford University one of us (Hanawalt), together with a graduate student, David Pettijohn, had been studying the replication of DNA after ultraviolet irradiation of a radiation-resistant strain of *E. coli*. In these experiments we used as a tracer a chemical analogue of thymine called 5-bromouracil. This compound is so similar to the natural base thymine that a bacterium cannot easily tell the two apart [*see right half of lower illustration on opposite page*]. When 5-bromouracil is substituted for thymine in the growth medium of certain strains of bacteria that are unable to synthesize thymine, it is incorporated into the newly replicated DNA. The fate of 5-bromouracil can be traced because the bromine atom in it is more than five times heavier than the methyl (CH_3) group in normal thymine that it replaces. Therefore DNA fragments containing 5-bromouracil are denser than normal fragments containing thymine. The density difference can be detected by density-gradient centrifugation, a technique introduced in 1957 by Matthew S. Meselson, Franklin W. Stahl and Jerome Vinograd at the California Institute of Technology.

In density-gradient centrifugation DNA fragments are suspended in a solution of the heavy salt cesium chloride and are spun in a high-speed centrifuge for several days. When equilibrium is reached, the density of the solution varies from 1.5 grams per milliliter at the top of the tube to two grams per milliliter at the bottom. If normal DNA from *E. coli* is also present, it will eventually concentrate in a band corresponding to a density of 1.71 grams per milliliter. A DNA containing 5-bromouracil instead of thymine has a density of 1.8 and so will form a band closer to the bottom of the tube.

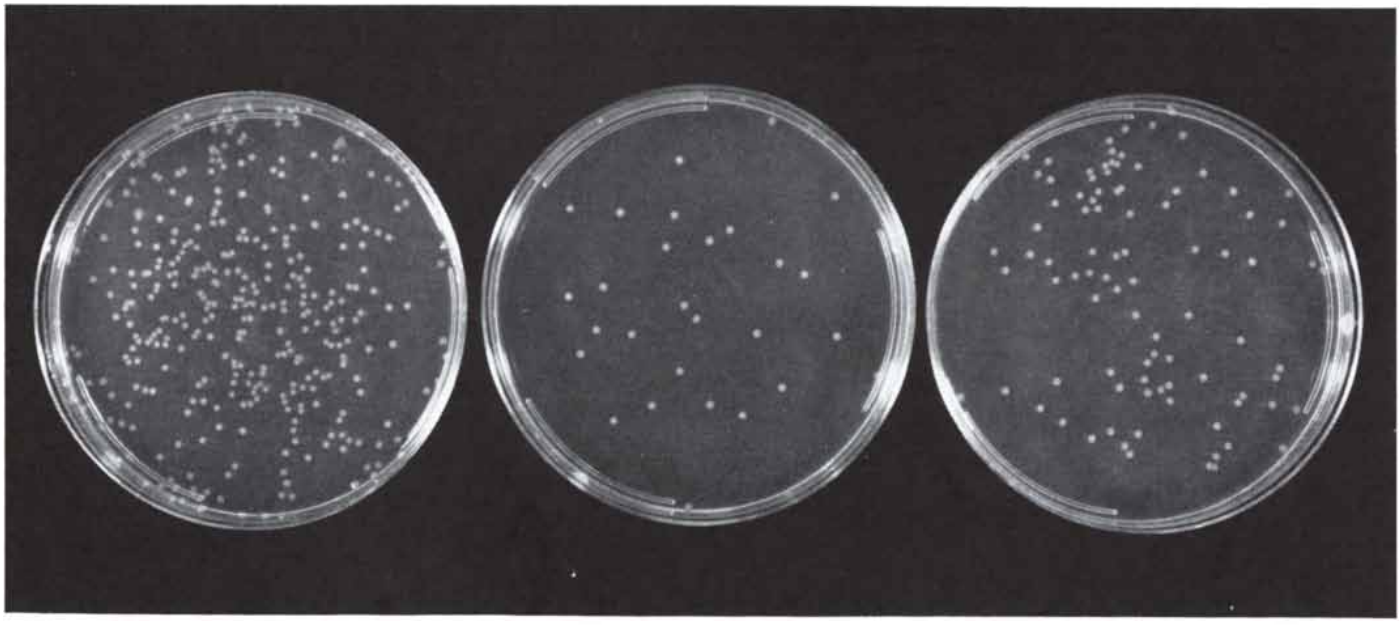
The entire genetic message of *E. coli* is contained in a single two-strand molecule of DNA whose length is nearly 1,000 times as long as the cell itself. This long molecule must be coiled up like a



DEFECTS IN DNA probably distort the symmetry of its helical structure. To make the distortions more apparent this diagram shows the DNA in flattened form. A thymine dimer appears in the left half of the structure; a guanine-guanine cross-link is shown in the right half. The authors believe the repair complex recognizes the distortions rather than the actual defects in the bases.

skein of yarn to be accommodated within the cell [see "The Bacterial Chromosome," by John Cairns; SCIENTIFIC AMERICAN, January, 1966]. Such a molecule is extremely sensitive to fluid shearing forces; in the course of being extracted from the cell it is usually broken into several hundred pieces.

If 5-bromouracil is added to a culture of growing bacteria for a few minutes (a small fraction of one generation), the DNA fragments isolated from the cells fall into several categories of differing density, each of which forms a distinct band in a cesium chloride density gradient. The lightest band will consist of unlabeled fragments: regions of the DNA molecule that were not replicated during the period when 5-bromouracil was present. A distinctly heavier band will contain fragments from regions that have undergone replication during the labeling period. This is the band containing hybrid DNA: molecules made up of one old strand containing thymine and one new strand containing 5-bromouracil in place of thymine. If synthesis proceeds until the chromosome has completed one cycle of replication and has started on the next cycle, some DNA fragments will have 5-bromouracil in both strands and therefore will form a band still heavier than the band containing the hybrid fragments. Finally, one fragment from each chromosome will include the "growing point" where the new strands are being synthesized on the pattern of the old ones, and thus will consist of a mixture of replicated and unreplicated DNA. This fragment, which is presumably shaped like a Y, will show up in the density gradient at a position



PHOTOREACTIVATION, a type of DNA repair process, is demonstrated in this photograph of three bacterial culture dishes. The dish at the left is a control: it contains 368 colonies of *B/r* strain of *Escherichia coli*. The middle dish contains bacteria exposed to ultraviolet radiation; only 35 cells have survived to form colonies. The bacteria in the dish at right were exposed to visible light following ultraviolet irradiation; it contains 93 colonies. Thus exposure to visible light increased the survival rate nearly threefold.

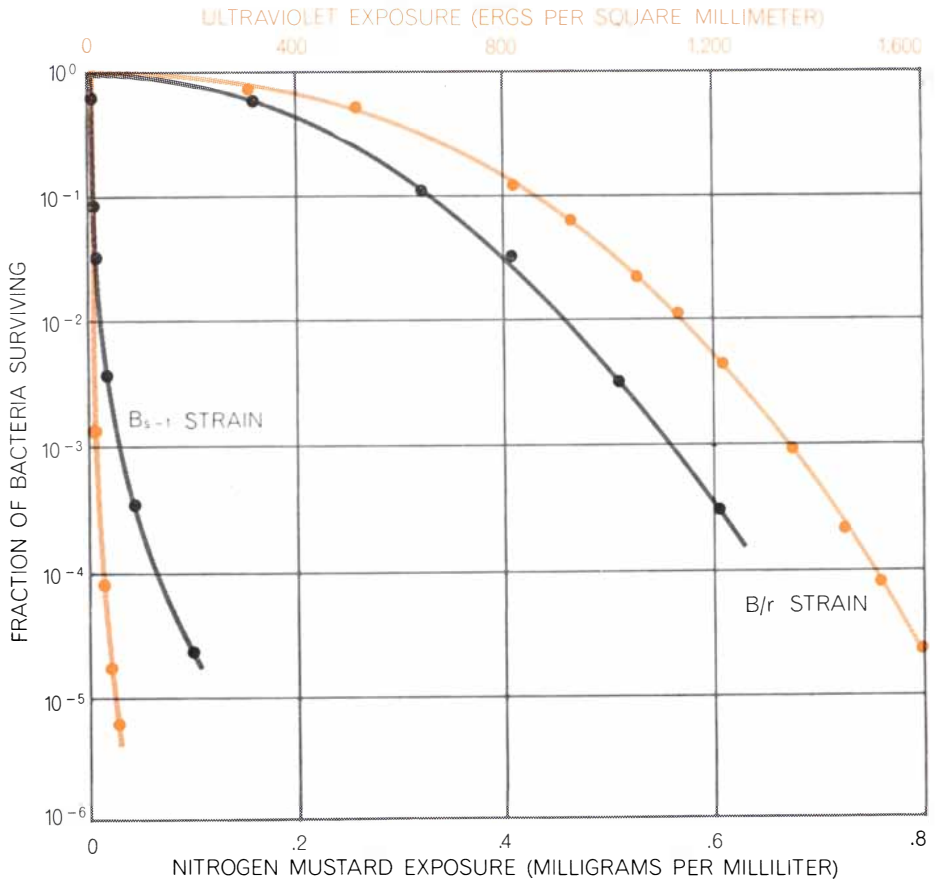
intermediate between the unlabeled DNA and the hybrid fragments containing 5-bromouracil.

When we used this technique to study DNA replication in bacteria exposed to ultraviolet radiation, we observed a pattern quite different from the one expected for normal replication. The DNA fragments containing the 5-bromouracil appeared in the gradient at the same position as normal fragments containing thymine! There could be no doubt of this because in these experiments we used 5-bromouracil labeled with tritium (the radioactive isotope of hydrogen) and thymine labeled with carbon 14 [*see illustration on next page*].

This pattern, which at first seems puzzling, is just the one to be expected if many thymine dimers—created at random throughout the DNA by ultraviolet radiation—had been excised and if 5-bromouracil had been substituted for thymine in the repaired regions. As a result many DNA fragments would contain 5-bromouracil, but no one fragment would contain enough 5-bromouracil to affect its density appreciably.

How can we be sure that the density distribution of 5-bromouracil observed in the foregoing experiment arises from "repair replication" rather than from normal replication? A variety of tests confirmed the repair interpretation. By using enzymes to break down the DNA molecule and separating the bases by paper chromatography we verified that the radioactive label was still in 5-bromouracil and had not been transferred to some other base. Various physical studies showed that the 5-bromouracil had been incorporated into extremely short segments that were distributed randomly throughout both DNA strands. This mode of DNA replication was not observed in the B_{s-1} strain of *E. coli,* the radiation-sensitive mutant that cannot excise pyrimidine dimers and therefore could not be expected to perform repair replication. Moreover, repair replication was not observed in the radiation-resistant bacteria in which visible light had triggered the splitting of pyrimidine dimers by photoreactivation; this indicates that repair replication is not necessary if the dimers are otherwise repaired *in situ.*

Finally it was shown that DNA repaired by dimer excision and strand reconstruction could ultimately replicate in the normal semiconservative fashion. This is rather compelling evidence for the idea that biologically functional DNA results from repair replication and that the process is not some aberrant



RESISTANCE TO LETHAL AGENTS is demonstrated by certain strains of *E. coli* but not by others. The *B/r* strain, for example, shows a high tolerance to doses of ultraviolet radiation (*colored curves*) and nitrogen mustard (*black curves*) that kill a large percentage of the sensitive B_{s-1} strain. This result suggests that the DNA repair mechanism of the *B/r* strain is effective in removing guanine-guanine cross-links produced by nitrogen mustard as well as in removing thymine dimers formed by exposure to ultraviolet radiation.

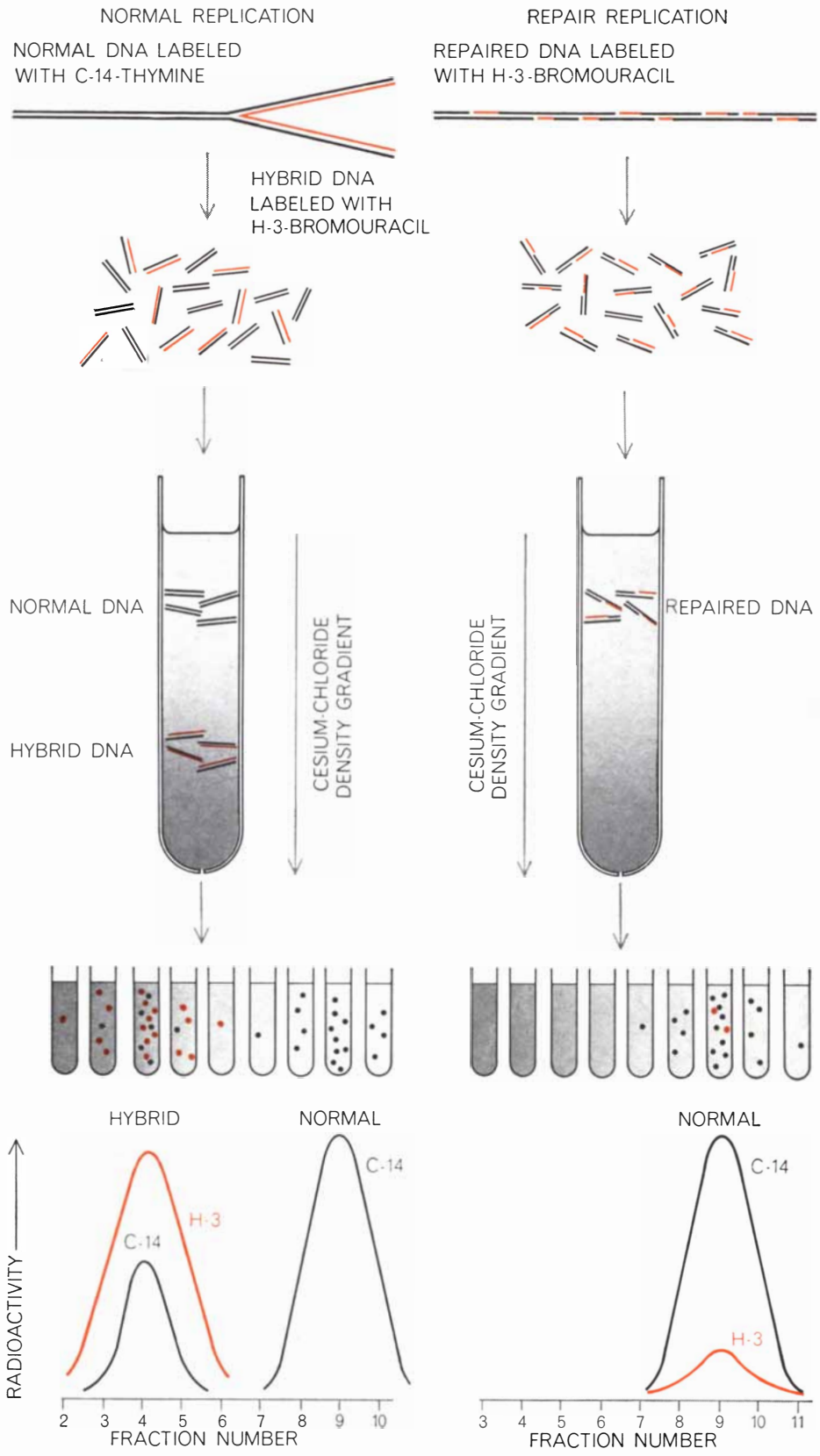
form of synthesis with no biological importance.

How can one visualize the detailed sequence of events that must be involved in this type of repair? Two models have been suggested, and the present experimental data seem to be equally compatible with each. The two models are distinguished colloquially by the terms "cut and patch" and "patch and cut" [*see illustrations on page 43*]. The former refers to the model originally proposed by Richard Setlow, Howard-Flanders and others. The latter refers to a model that took form during a discussion at a recent conference on DNA repair mechanisms held in Chicago.

The cut-and-patch scheme postulates an enzyme that excises a short, single-strand segment of the damaged DNA. The resulting gap is enlarged by further enzyme attack and then the missing bases are replaced by repair replication in the genetically correct sequence according to the rules that govern the pairing of bases.

In the patch-and-cut scheme the process is assumed to be initiated by a single incision that cuts the strand of DNA near the defective bases. Repair replication begins immediately at this point and is accompanied by a "peeling back" of the defective strand as the new bases are inserted. This patch-and-cut scheme is attractive because it could conceivably be carried out by a single enzyme complex or particle that moves in one direction along the DNA molecule, repairing defects as it goes. Furthermore, it does not involve the introduction of long, vulnerable single-strand regions into the DNA molecule while the repair is taking place. Both models are undoubtedly oversimplifications of the actual molecular events inside the living cell, but they have great intuitive appeal and are helpful in planning further studies of the DNA repair process.

Repair replication would be of interest only to radiation specialists if it were not for the evidence that DNA structural defects other than pyrimidine dimers can be repaired and that similar repair



TWO KINDS OF REPLICATION can be demonstrated by growing bacteria first in a culture containing thymine labeled with radioactive carbon 14 and then in a culture containing 5-bromouracil labeled with radioactive hydrogen 3. In normal replication (*left*), also known as semiconservative replication, daughter strands of "hybrid" DNA incorporate the 5-bromouracil (*color*). Because 5-bromouracil is much heavier than the thymine for which it substitutes, fragments of hybrid DNA form a separate heavier layer when they have been centrifuged and have reached equilibrium in a density gradient of cesium chloride. When the radioactivity in the various fractions is analyzed (*bottom left*), carbon 14 appears in two peaks but hydrogen 3 occurs in only one peak. If the experiment is repeated with DNA fragments that have undergone repair replication (*right*), they all appear to be of normal density. This implies that relatively little 5-bromouracil has been incorporated and also that the repaired segments are randomly scattered throughout the DNA molecule.

phenomena occur in organisms other than *E. coli*. We shall review some of the evidence indicating that repair replication is of general biological significance.

Just as strains of *E. coli* vary considerably in their sensitivity to ultraviolet radiation, so they vary considerably in their sensitivity to other mutagenic agents. One such agent is nitrogen mustard, so named because it is chemically related to the mustard gas used in World War I. It was the first chemical agent known to be capable of producing mutations and chromosome breaks in fruit flies and other organisms. Its biological action arises primarily from its ability to react with neighboring guanine bases in DNA, thereby producing guanine-guanine cross-links [*see lower illustration on page* 39].

If one compares the survival curves of different strains of bacteria treated with nitrogen mustard with survival curves for bacteria subjected to ultraviolet radiation, one finds that the curves are almost identical [*see illustration on preceding page*]. This similarity led us to suggest that it is not the altered bases themselves that are "recognized" by the repair enzymes but rather the associated distortions, or kinks, that the alteration of the bases produces in the backbone of the DNA molecule. On this hypothesis one would predict that a wide variety of chemically different structural defects in DNA might be repaired by a common mechanism.

A substantial amount of biochemical evidence has now accumulated in support of this idea. We have established, for example, that repair replication of DNA takes place in *E. coli* that have been treated with nitrogen mustard. Others have found evidence that defects produced by agents as diverse as X rays, the chemical mutagen nitrosoguanidine and the antibiotic mitomycin *C* can all be repaired in radiation-resistant strains of *E. coli*. Walter Doerfler and David Hogness of Stanford have even found evidence that simple mispairing of bases between two strands of DNA can be corrected.

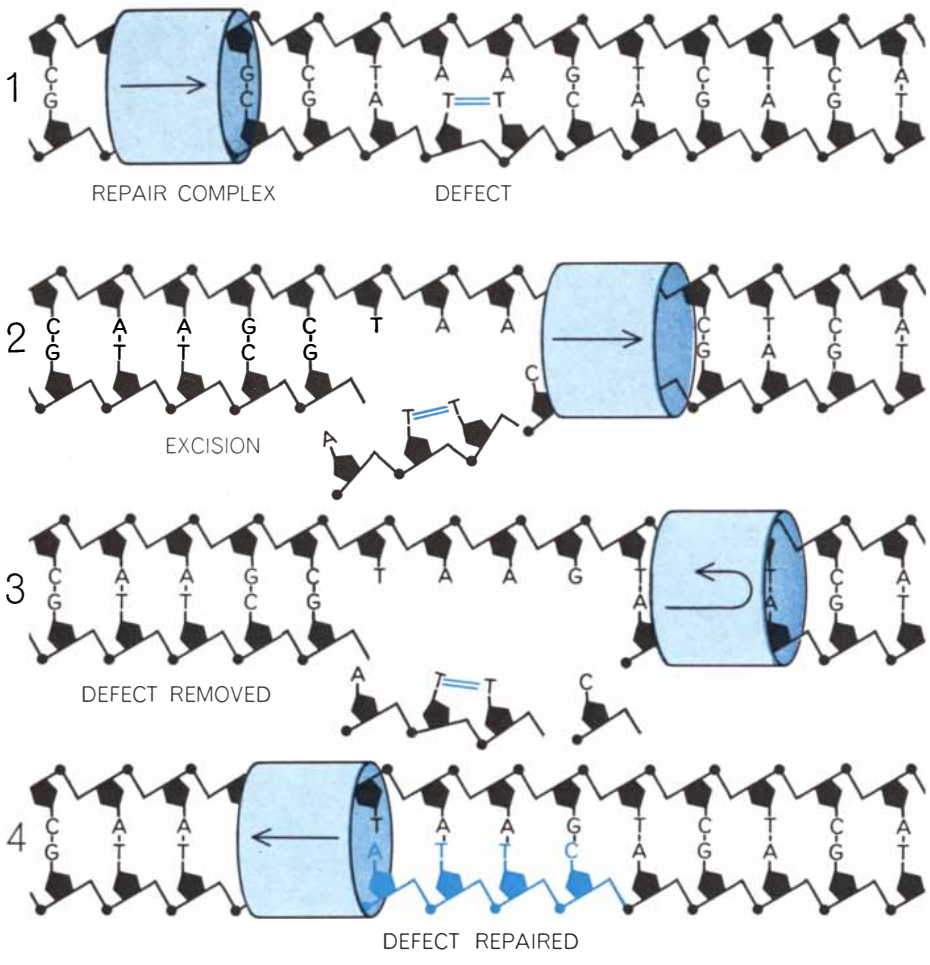
Finally, it now seems that certain steps in repair replication may also be involved in such phenomena as genetic recombination and the reading of the DNA code in preparation for protein synthesis. Evidence for these exciting possibilities has begun to appear in the work of Howard-Flanders, Meselson (who is now at Harvard University), John M. Clark, Jr., of the University of California at Berkeley, Crellin Pauling of the University of California at Riverside and other investigators.

Repair replication has also been observed in a number of bacterial species other than *E. coli*. For example, Douglas Smith, a graduate student at Stanford, has demonstrated the repair of DNA in the pleuropneumonia-like organisms, which are probably the smallest living cells. These organisms, which are even smaller than some viruses, are thought to possess only the minimum number of structures needed for self-replication and independent existence [see "The Smallest Living Cells," by Harold J. Morowitz and Mark E. Tourtellotte; SCIENTIFIC AMERICAN, March, 1962]. This suggests that repair replication may be a fundamental requirement for the evolution of free-living organisms.

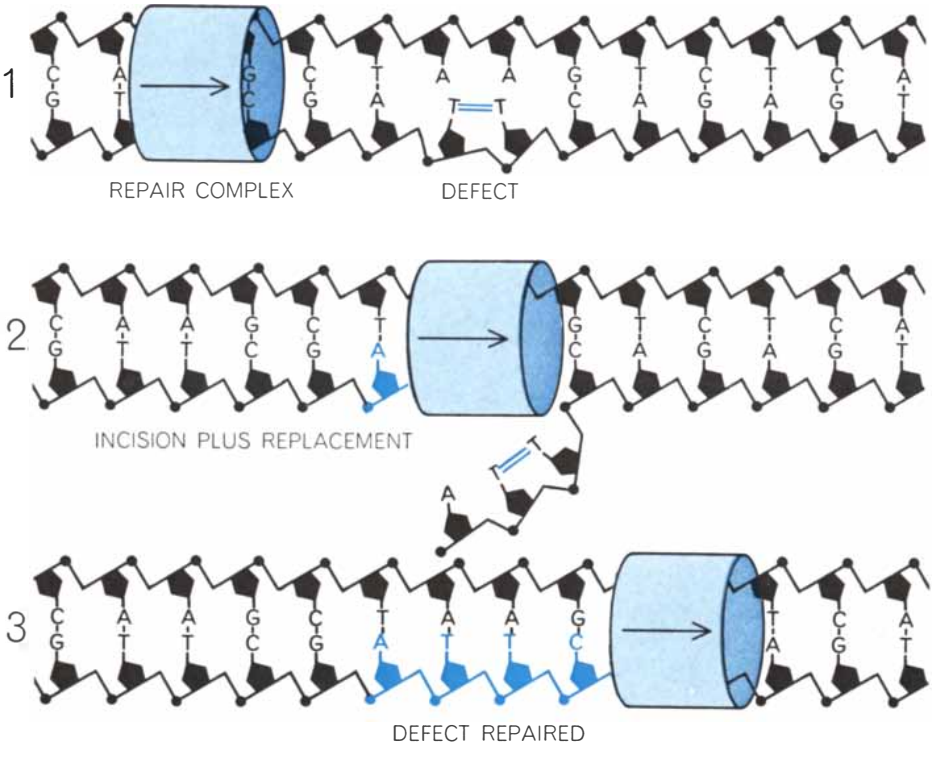
In view of the impressive versatility of the repair replication process it is natural to ask if there is any type of DNA damage that cannot be mended by the cell. The evidence so far is limited and indirect, but William Rodger Inch, working at the Lawrence Radiation Laboratory of the University of California, has found that the *B/r* strain of *E. coli* is unable to repair all the damage caused when it is exposed to certain energetic beams of atomic nuclei produced by the heavy-ion linear accelerator (HILAC). Considering the extensive damage that must be done to cells by a beam of such intensely ionizing radiation, the result is not too surprising.

The discovery that cells have the facility to repair defects in DNA is a recent one. It is already apparent, however, that the process of repair replication could have broad significance for biology and medicine. Many questions remain to be investigated: What is the structure of the various repair enzymes? Are they organized into particulate units within the cell? What range of DNA defects can be recognized and repaired? Does DNA repair, as we now understand it, take place in the cells of mammals, or do even more complicated processes underlie the recovery phenomena that are observed after these higher types of cells are exposed to radiation? Might it be possible to increase the radiosensitivity of tumors by inhibiting the DNA repair mechanisms that may operate in cancer cells? If so, the idea could be of great practical value in the treatment of cancer.

These and many related questions are now being investigated in many laboratories around the world. Once again it has been demonstrated that the study of what may appear to be rather obscure properties of the simplest forms of life can yield rich dividends of much intellectual and practical value.



"CUT AND PATCH" repair mechanism was the first one proposed to explain how bacterial cells might remove thymine dimers (*1*) and similar defects from a DNA molecule. The hypothetical repair complex severs the defective strand (*2*) and removes the defective region (*3*). Retracing its path, it inserts new bases according to the rules of base pairing (*4*).



"PATCH AND CUT" mechanism has been proposed as an alternative to the cut-and-patch scheme. On the new model the repair complex inserts new bases as it removes defective ones.

Reversals of the Earth's Magnetic Field

Some volcanic rocks are magnetized in a direction opposite to that of the present magnetic field of the earth. The reason is that the earth's field has reversed nine times in the past 3.6 million years

by Allan Cox, G. Brent Dalrymple and Richard R. Doell

When molten volcanic rocks cool and solidify, the magnetic minerals in them are magnetized in the direction of the earth's magnetic field. They retain that magnetism, thus serving as permanent magnetic memories (much like the magnetic memory elements of a computer) of the direction of the earth's field in the place and at the time they solidified. In 1906 the French physicist Bernard Brunhes found some volcanic rocks that were magnetized not in the direction of the earth's present field but in exactly the opposite direction. Brunhes concluded that the field must have reversed. Although his observations and conclusion were accepted by some later workers, the concept of reversals in the earth's magnetic field attracted little attention. In the past few years, however, it has been definitely established that the earth's magnetic field has two stable states: it can point either toward the North Pole as it does today or toward the South Pole, and it has repeatedly alternated between the two orientations.

There was no basis in theory for anticipating this characteristic of the earth's magnetic field. Moreover, theory on the whole subject of the earth's magnetism is so rudimentary that the mechanism of reversal is still far from being understood. Nevertheless, the magnetic memory of volcanic rocks, together with the presence in the same rocks of atomic clocks that begin to run just when their magnetism is acquired, has made it possible to draw up a time scale that shows no fewer than nine reversals of the earth's field in the past 3.6 million years. This time scale is a valuable tool for dating events in the earth's history and may help earth scientists to deal with such large questions as how much the continents have drifted.

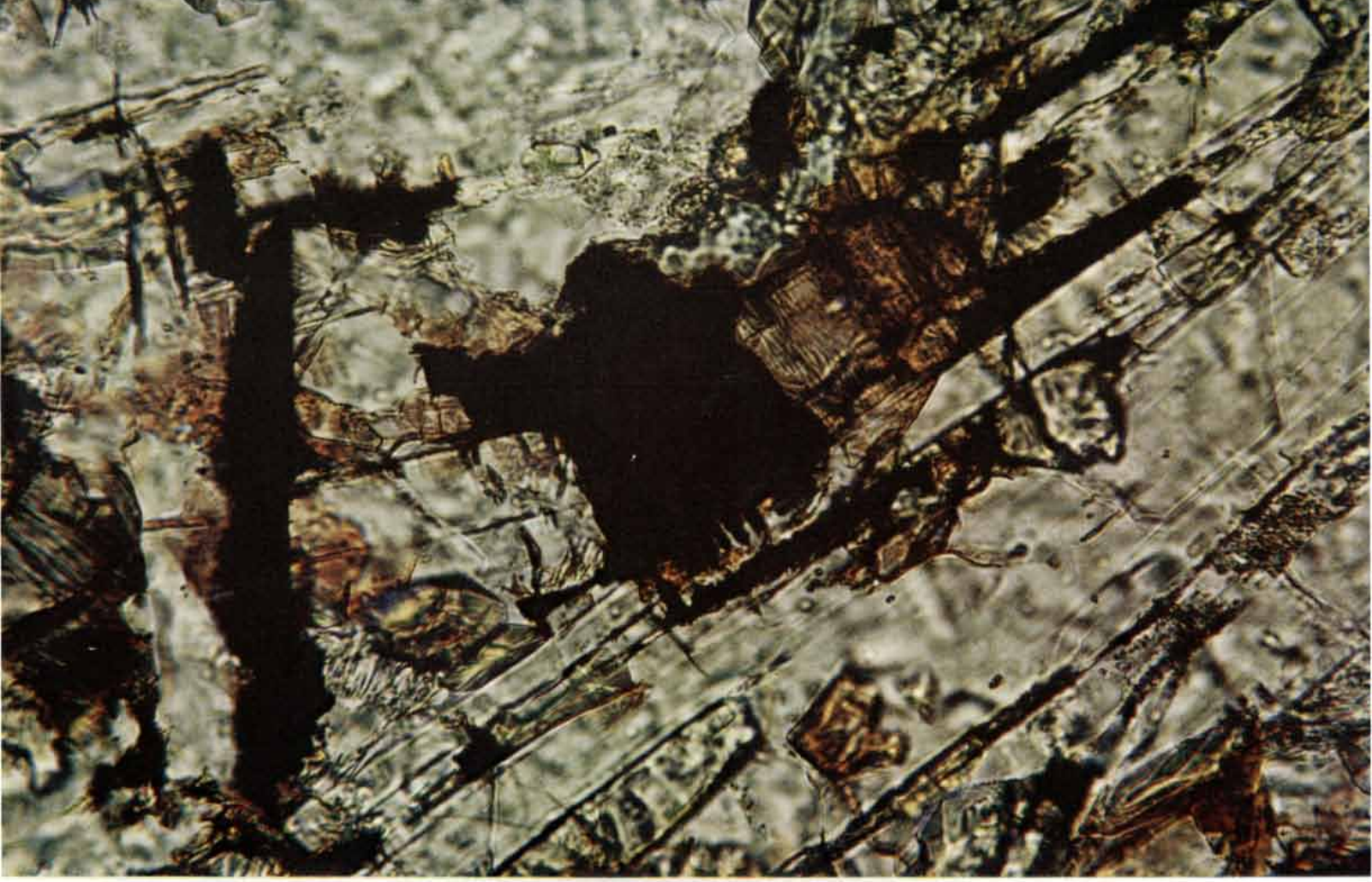
The earth's magnetic field is the field of an axial magnetic dipole, which is to say that it is equivalent to the external field of a huge bar magnet in the core of the earth aligned approximately along the planet's axis of rotation (or to the external field of a uniformly magnetized sphere or of a loop of electric current in the plane of the Equator). The lines of force in such a field are directed not toward the geographic poles but toward the magnetic poles, and the angle at any point between true north and the direction of the field is called the declination. The lines of force are also directed, except at the Equator, toward or away from the center of the earth, and the angle above or below the horizontal is called the inclination. It is along these lines of force that the memory elements in volcanic rocks have been oriented.

The memory elements themselves are magnetic "domains": tiny bodies in which magnetism is uniform. These bodies consist of various iron and titanium oxides that can be recognized quite easily under the microscope because, unlike most rock-forming minerals, they are opaque to transmitted light and are excellent reflectors of incident light [*see illustrations on opposite page*].

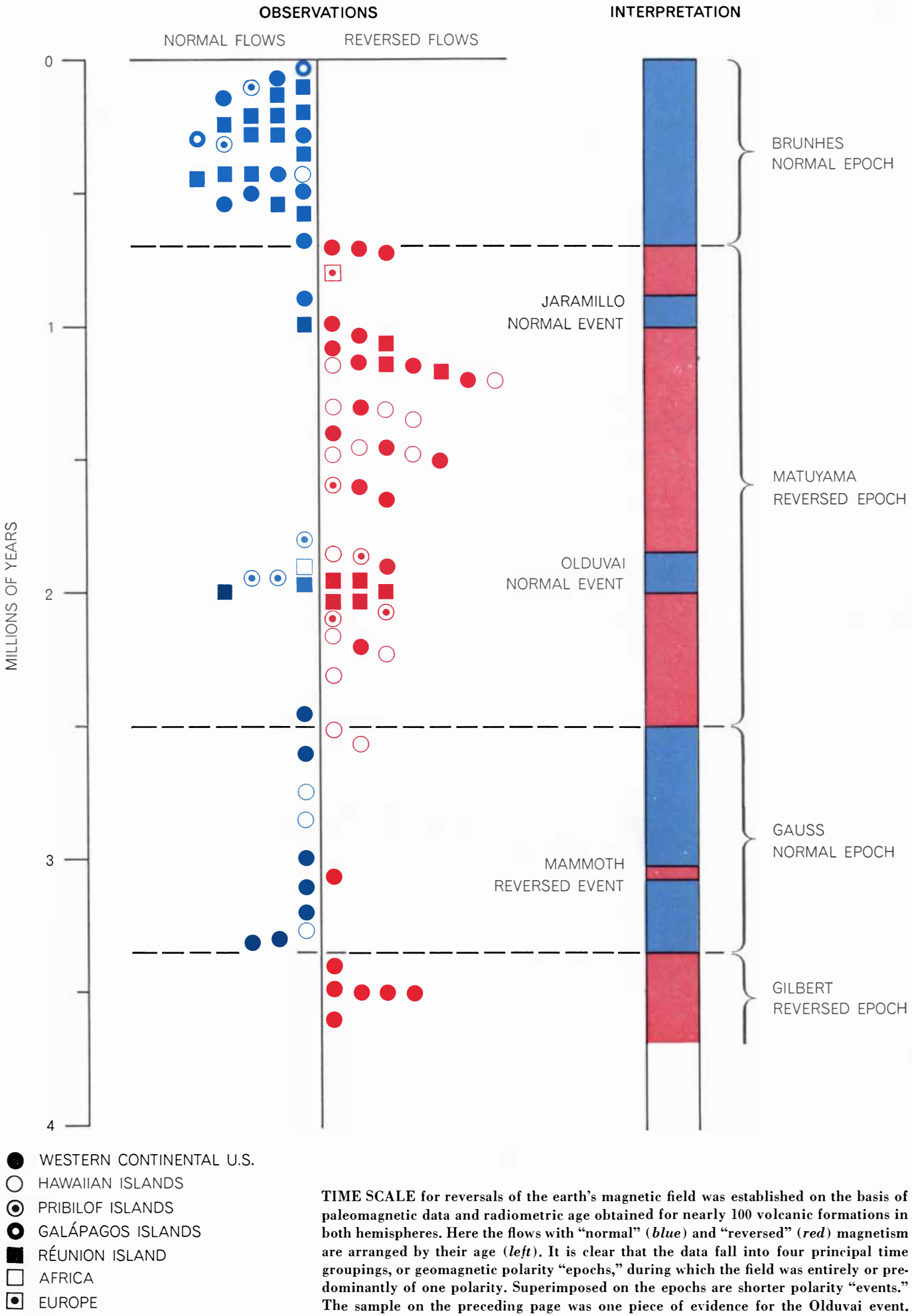
At high temperatures the iron and titanium oxides are nonmagnetic. They become magnetic only after they cool to a critical point called the Curie temperature, which for the common minerals in volcanic rocks may be as high as 680 degrees centigrade or as low as about 200 degrees, depending on chemical composition. These temperatures are well below those at which rocks crystallize (about 1,000 degrees C.), so that it is clear that rocks are not magnetized by the physical rotation and orientation in the earth's field of previously magnetized grains in the molten lava, as was once thought. As the minerals begin to cool through the Curie temperature, even the earth's weak field of less than one gauss is adequate to partly magnetize them. That is because this initial magnetization is "soft," like that of iron or ordinary steel, both of which are easily magnetized by weak magnetic fields. As the rocks continue to cool, the minerals undergo a second abrupt change: the initially soft magnetism acquired in the earth's field is frozen in and becomes "hard," like the magnetism of a man-made permanent magnet.

The pertinent question for the geophysicist is how well these magnetic memory elements function as recorders of the earth's field. Do they record its direction accurately? The most direct way to assess the accuracy of volcanic rocks as recorders is to measure the magnetism of such rocks that flowed out and cooled recently in places where the magnetic field that existed at the time of flow is known. We have made such measurements on three lava flows that formed on the island of Hawaii in the years 1907, 1935 and 1955.

To obtain samples of undisturbed rock from the solid parts of a lava, a hollow cylindrical diamond drill is generally used. From five to eight cylindrical "cores" are taken from each lava flow to obtain a representative magnetic direction for the entire flow rather than for one isolated sample; each core's orientation with respect to the horizontal and to true north is accurately recorded before it is removed. Back in the laboratory the sample's magnetic vector is determined with a magnetometer [*see middle illustration on page 47*]. The results of the measurements on the three formations indicate that lava flows record the direction of the earth's magnetic field with an



BASALT from the Pribilof Islands, seen in two photomicrographs made by Norman Prime of the U.S. Geological Survey, is one of the samples studied by the authors. The magnetic minerals, complex intergrowths of iron and titanium oxides, are opaque and therefore appear dark in transmitted light (*top*) and very bright in reflected light (*bottom*). The large clear minerals that are pale green in the top photograph and black in the bottom one are feldspars and contain the radioactive potassium isotope used for dating. The age of this rock is 1.95 million years; its magnetism approximately parallels that of the present field. Magnifications are about 600 diameters.



TIME SCALE for reversals of the earth's magnetic field was established on the basis of paleomagnetic data and radiometric age obtained for nearly 100 volcanic formations in both hemispheres. Here the flows with "normal" (*blue*) and "reversed" (*red*) magnetism are arranged by their age (*left*). It is clear that the data fall into four principal time groupings, or geomagnetic polarity "epochs," during which the field was entirely or predominantly of one polarity. Superimposed on the epochs are shorter polarity "events." The sample on the preceding page was one piece of evidence for the Olduvai event.

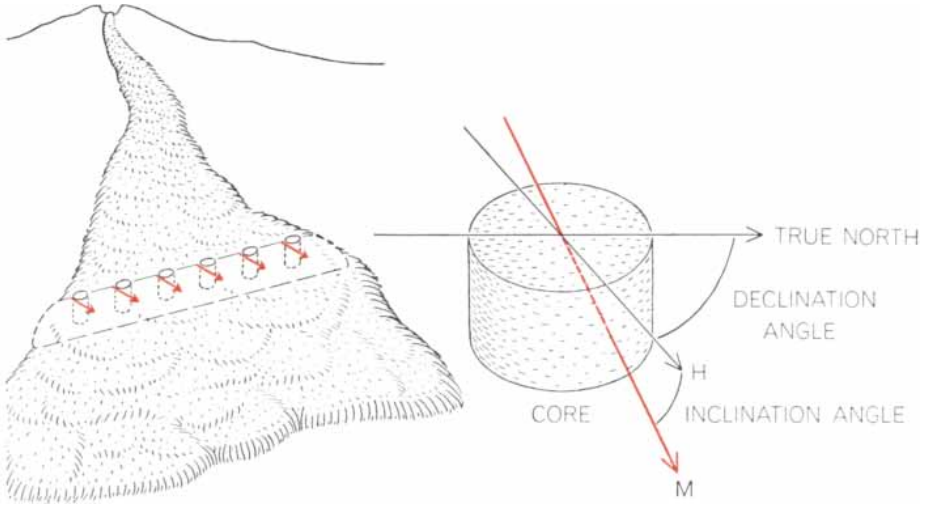
accuracy of several degrees, which is ample for most geophysical applications.

If rock magnetism is to provide a record of the ancient earth's field, the magnetic record must also be stable. Is the magnetism of rocks soft like that of iron and ordinary steel or is it hard like that of permanent magnets? This question of stability is so critical that laboratory tests to deal with it have become an integral part of paleomagnetic research. The usual technique is to place a sample from a rock formation in a kind of magnetic "washing machine," subject it to a rapidly alternating magnetic field and determine the amount of magnetism that survives. The natural magnetism of most volcanic rocks turns out to be comparable in stability to the magnetism of the hardest permanent magnets [*see illustration on next page*]. Once the magnetic hardness of the rocks from a given flow is established, the magnetic cleaning process can be used to strip away from each sample whatever soft magnetism has been acquired (from such sources as lightning strokes) since the rock solidified, leaving only the hard magnetism that reflects the direction of the original ambient field.

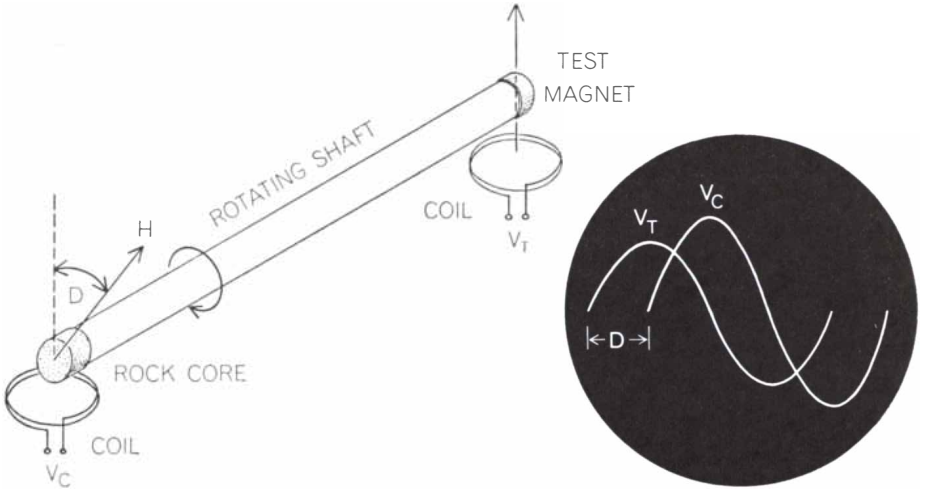
It is clear, then, that paleomagnetism is accurate and stable enough to provide information about past states of the earth's magnetic field. In assessing such information one must of course take into consideration the movement of rock masses that takes place over a period of geologic time; the deviation of a sample's magnetism from the direction of the present field could reflect mountain-building, warping along faults or continental drift. Our studies of magnetic reversal have been restricted, however, to relatively young rocks and to volcanic formations we can be fairly sure are still oriented as they were when they solidified.

We began our paleomagnetic research on the island of Hawaii, where we had tested the technique and where the superb lava flows exposed on the flanks of volcanoes provide magnetic records going back about half a million years. We collected samples from 107 of these flows and found that their declination angles clustered at around 10 degrees east of true north and their inclination angles at around 30 degrees below the horizontal [*see illustration on page 49*]. This was just about what we expected on the basis of the dipole nature of the earth's field.

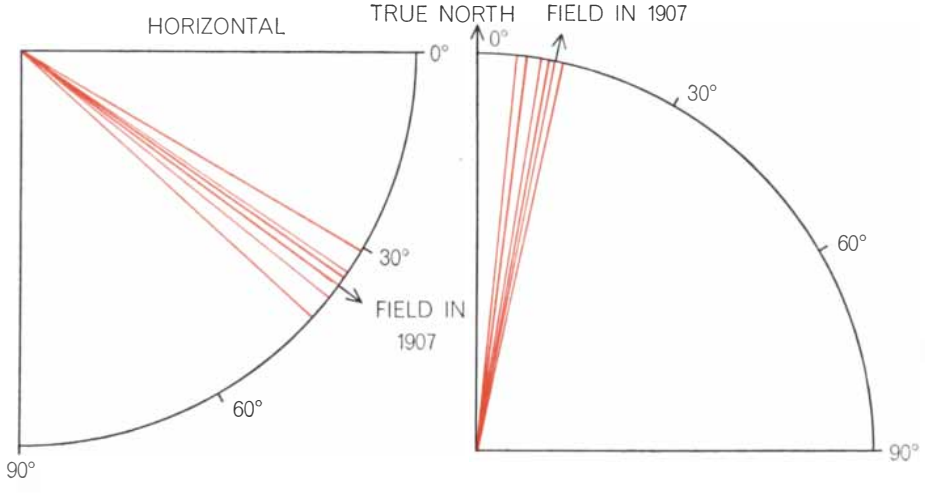
Studies of other young volcanic rocks along the eastern edge of the Pacific



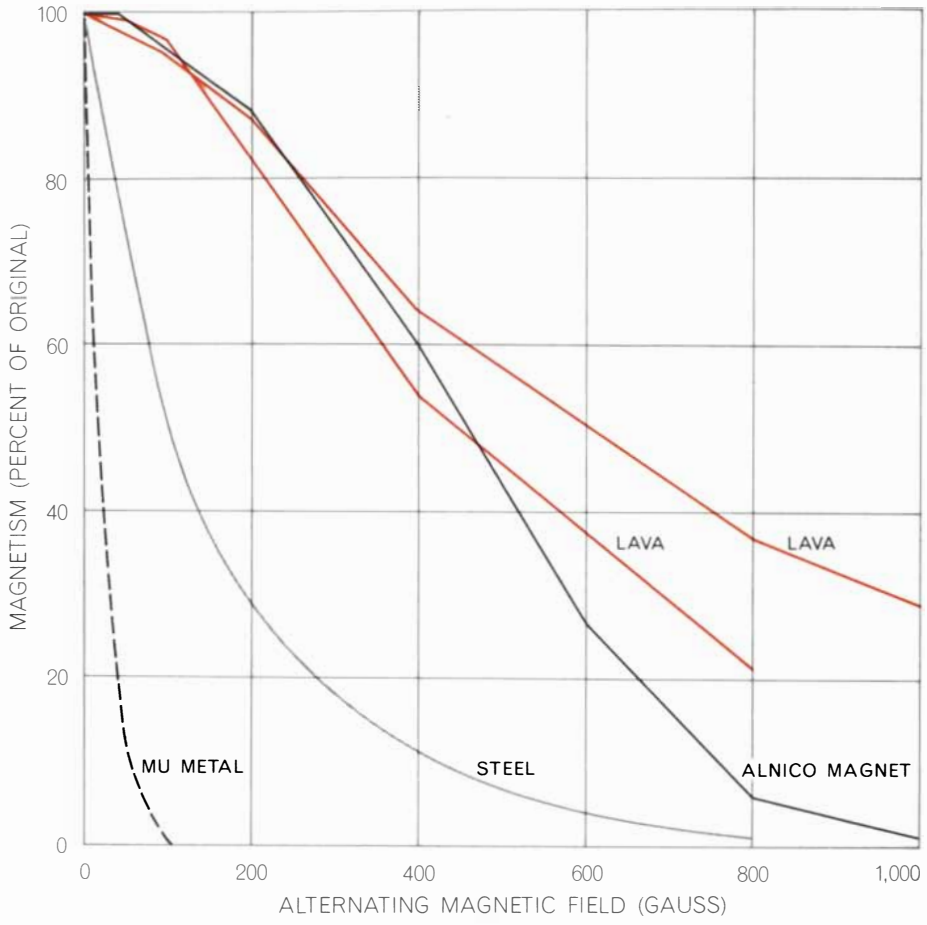
SAMPLES for paleomagnetic studies are cores drilled from volcanic formations. The direction of magnetization (*M*) is expressed as the declination angle between true north and the horizontal projection (*H*) of *M* and the inclination angle of *M* above or below horizontal.



CORE is mounted on a magnetometer. As the shaft rotates, electrical signals (V_C and V_T) are induced in the coils by the core and a test magnet and can be displayed on an oscilloscope. The intensity and direction of the core's magnetism are determined by comparing the magnitudes of the signals and their phase shift, which is equal to the declination (*D*).



ANGLES (*color*) of inclination (*left*) and declination (*right*) of six cores from a 1907 Hawaiian lava flow cluster about the known angles of the 1907 field. Although angles obtained from individual cores vary, the average values are accurate measures of the historic field.



"HARDNESS" of the magnetism of basalt samples is expressed as the amount of magnetism remaining after "washing" in alternating magnetic fields of various strengths. The stability of the rocks' magnetism is far greater than that of the alloy "mu metal" or of steel; it is comparable to that of the alloy Alnico, of which permanent magnets are often made.

ocean basin have yielded similar results. At the high latitude of the Pribilof Islands in the Bering Sea the magnetic vectors of the lava flows are inclined steeply downward, as one would expect for a dipole field in high latitudes, whereas in the Galápagos Islands on the Equator the magnetic vectors are almost horizontal. Measurements in many parts of the world indicate that during the time spanned by these young lava flows (roughly half a million years) the earth's field was essentially dipolar and was aligned as it is today.

Quite different results are obtained when paleomagnetic techniques are applied to somewhat older lava flows. Only about half of these flows are magnetized in the same direction as the younger ones; the remainder are magnetized in the opposite direction. For example, some volcanic rocks at middle latitudes in the Northern Hemisphere are magnetized toward the south and upward, rather than toward the north and downward [*see upper illustration on page 50*]. In recent years this "antiparallel" magnetism has been found in thousands of samples of volcanic rock from all over the world by scores of investigators working independently. Sampling has been particularly intensive in the range of ages between 3.5 million years ago and the present, and the paleomagnetic results obtained are always remarkably similar. The magnetic vectors fall into two groups: "normal" vectors nearly parallel to the present field of the earth and "reversed" ones that are nearly opposite. Most of the data are clustered within 30 degrees of these two directions, with very few vectors oriented in intermediate directions [*see lower illustration on page 50*].

The immediate implication is that the earth's magnetic field has indeed reversed its direction in the past. Brunhes so interpreted his results in France in 1906, although he cautiously restricted field-reversal to the area from which he collected his samples. In 1929 Motonori Matuyama also found evidence that the field had reversed, but he too restricted his conclusions to the area in Japan from which his samples had come. The accumulating evidence that reversed magnetic directions are invariably opposite to the present field direction at the sampling site led in time to the hypothesis that the sample reversals are not local but global; in other words, that the entire field reverses.

An important alternative explanation must be considered before the field-reversal hypothesis can be accepted. The alternative is that rocks magnetized in reverse may possess some special mineralogical property that causes them to become so magnetized in a normal field. The existence of such "self-reversal" in rocks was suggested in 1950 by John Graham, then at the Carnegie Institution of Washington's Department of Terrestrial Magnetism, as an explanation for the occurrence of both normal and reversed magnetism in rock samples that had formed simultaneously. Graham's suggestion stimulated the French physicist Louis Néel to examine the problem from the viewpoint of solid-state physics, and Néel soon discovered several ways in which self-reversal might occur. Experimental confirmation came almost immediately. At the Philips Research Laboratories in the Netherlands, E. W. Görter synthesized an iron-chromium-manganese compound that underwent self-reversal, and S. Uyeda and T. Nagata of the University of Tokyo found a self-reversing volcanic rock.

It is thus apparent that at least some volcanic rocks are not infallible magnetic recorders. Like laboratory recorders that are hooked up backward, they sometimes record a signal that is not only wrong but is exactly wrong by 180 degrees. If all reversed magnetism could be explained in this way, the experimental evidence for reversals in the earth's magnetic field would vanish. An obvious experiment is to heat and then cool rock samples in a known field and measure their acquired magnetization. This operation has been performed on many hundreds of rock samples with reversed magnetism, and fewer than 1 percent have turned out to be self-reversing.

Therefore the laboratory evidence favors the field-reversal hypothesis. Like many rock-forming processes, however, the acquisition of natural magnetism cannot be reproduced with complete fidelity in the laboratory. The missing ingredient is time, and for certain of the theoretical self-reversing processes this ingredient is crucial. For example, John Verhoogen of the University of California at Berkeley has shown theoretically that whereas certain iron oxides containing impurities of aluminum, mag-

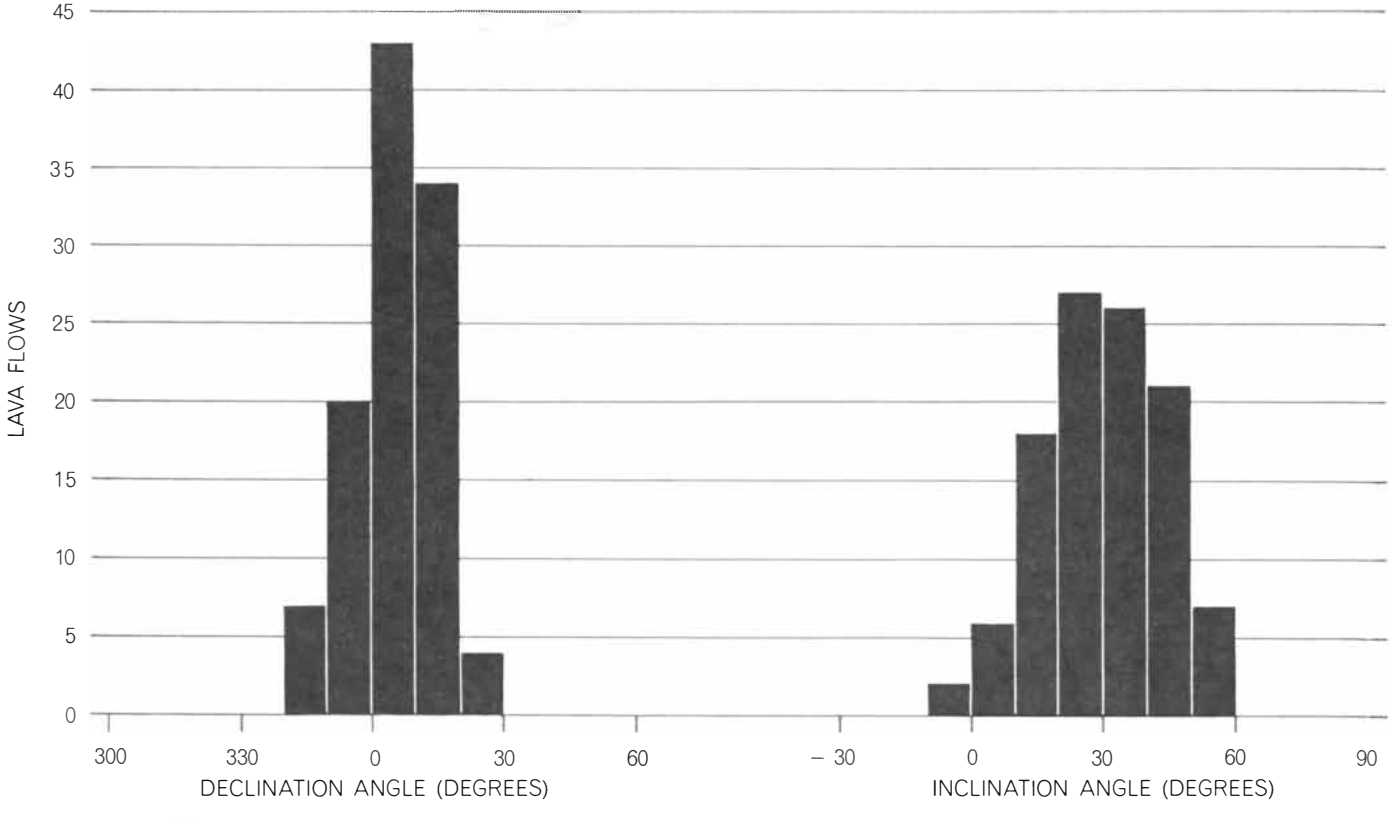
nesium or titanium would be magnetized normally when cooled rapidly in a normal magnetic field, the magnetism could be reversed as the atoms in the cooled oxide reordered themselves toward an equilibrium distribution. The calculated time required for this self-reversal is on the order of 100,000 to a million years, so that it could hardly be reproduced in the laboratory. The theoretical studies by Néel and Verhoogen showed that the fact that self-reversal is rare in the laboratory does not make it safe to conclude that it is equally rare in nature. How, then, could one determine the geophysical significance of reversed magnetism? Two main lines of experimental attack have been pursued during the past decade, each closely related to one of the two proposed reversal-producing processes.

One approach was to search for a correlation between the magnetism of rocks and their mineralogy. Even though self-reversals may not always be reproducible in the laboratory, if all reversed magnetism is due to a process occurring on the mineralogical level, rocks with reversed magnetism should be somehow different from those with normal magnetism; chemical processes being the same the world over, the unique mineralogical properties associated with reversed magnetism should appear in rocks from all over the world.

This approach has been pursued most actively by P. M. S. Blackett at the Imperial College of Science and Technology in London and Rodney Wilson at the University of Liverpool. In some sequences of rocks Wilson has found a correlation between reversed magnetism and mineralogical properties, but in other rocks he finds no such correlation. Like Wilson, we have occasionally noted a correlation between mineralogy and magnetism within a sequence from one locality, but such a local correlation may well stem from the tendency of volcanic flows to occur in pulses. Between two successive pulses separated by a long time interval the mineralogical character of the lavas commonly changes; if the polarity of the earth's field also happens to change in this interval, there will be an apparent correlation between mineralogy and polarity. In short, mineralogical investigations have not yielded evidence that all or even most reversed magnetism is produced by self-reversal.

The second experimental approach followed from an implication of the field-reversal theory: If the earth's magnetic field alternates between intervals when it is normal and intervals when it is reversed, the geologic ages of normal and reversed rocks should fall into corresponding intervals. Data bearing on the age and magnetism of rocks should provide a yes-or-no answer to the validity of the field-reversal theory and, if the theory is valid, should yield a time scale for reversals. Matuyama had noted in 1929 that the geologic age of all the rocks with reversed magnetism in Japan was early Pleistocene (about a million years ago), whereas younger rocks invariably had normal magnetism. The strongest possible evidence in support of the field-reversal theory would be to extend Matuyama's study to show that rocks from all parts of the world, regardless of mineralogy, occur in similar normal and reversed sequences that are time-dependent.

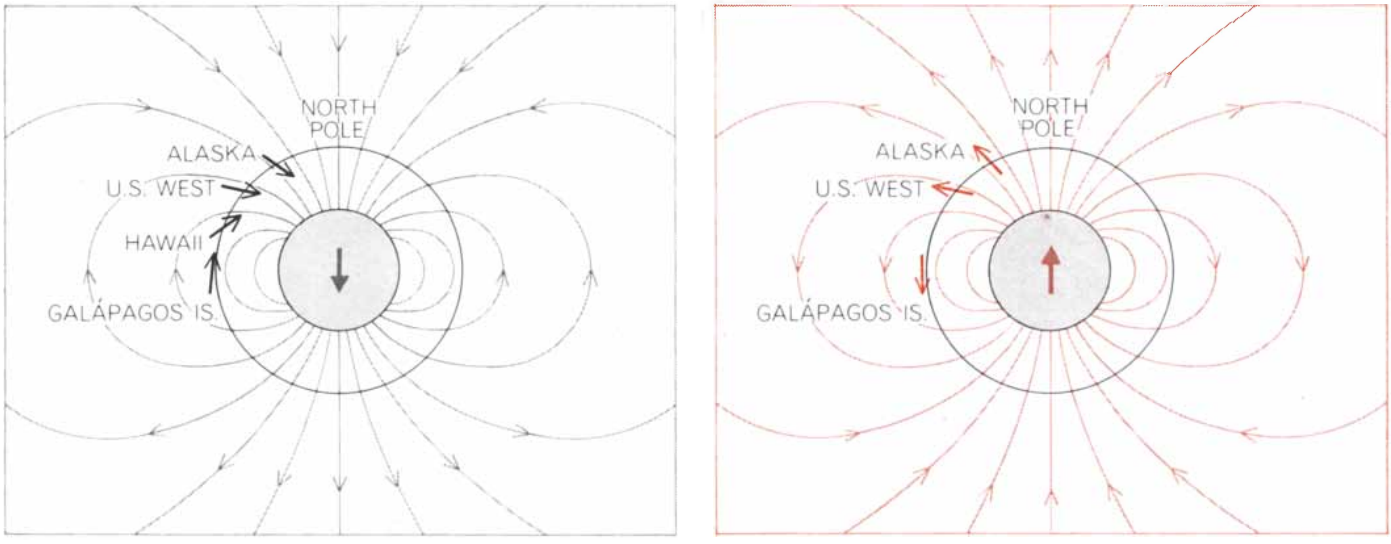
The difficulty lay in finding a sufficiently precise method for establishing the age relations of normal and reversed rocks. Many techniques that yield fairly precise age relations when applied to older rocks are based on plant and animal fossils; these techniques begin to break down when applied to the past million years or so because of the slow rate at which evolution proceeds and the time required for plant and animal migrations. A solution that suggested itself was some kind of radioactive clock, and



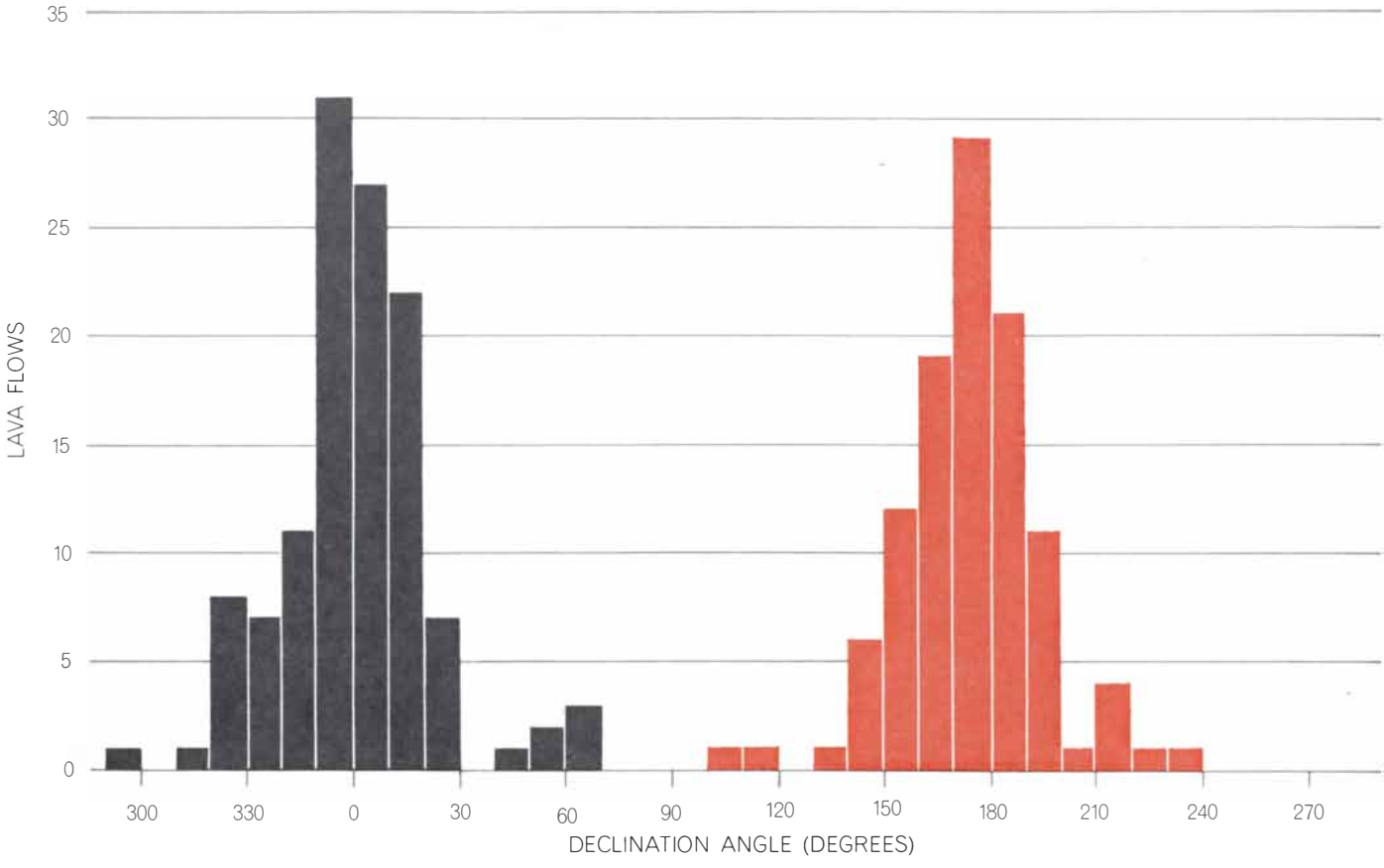
PALEOMAGNETIC RESULTS are shown for 107 volcanic formations on the island of Hawaii. Each angle represented in these histograms is an average derived from five or more cores in one lava flow. The data are grouped in a mean northerly direction and at a mean inclination of about 30 degrees below the horizontal. That is, they roughly parallel the present direction of the earth's field.

our search quickly narrowed to the potassium-argon clock first suggested in 1940 by Robley D. Evans of the Massachusetts Institute of Technology and now widely applied in geological investigations. Potassium 40, a radioactive isotope that constitutes .012 percent of all potassium, can be found as a chemical constituent in most rock-forming minerals. It decays at a known and constant rate to argon 40, a gas that forms no known compounds.

The argon is trapped within the crystal structure of the minerals, and if the minerals are not heated or changed in some way, it accumulates there. Its amount is a function of the amount of potassium present and the length of time since the decay and entrapment processes began. Therefore by measuring the amount of potassium 40 and argon 40 in a rock one can calculate its age. Argon will not accumulate as long as the rock is in a molten state, so for volcanic rocks



INCLINATION ANGLES from flows in Alaska, the U.S. West (California, Idaho and New Mexico), the island of Hawaii and the Galápagos Islands are shown by the heavy colored arrows. The flows range up to three million years in age. The angles fall into two distinct groups: a "normal" group aligned with the earth's present field, that of a bar magnet pointed toward the South Pole (*left*), and a "reversed" group appropriate to an oppositely oriented field (*right*). All the flows on Hawaii had normal magnetism.



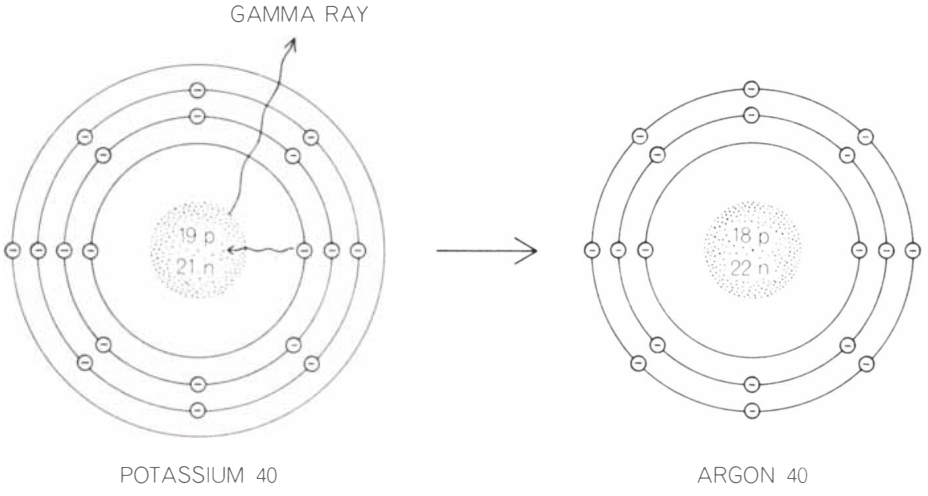
DECLINATION ANGLES from 229 flows up to three million years old in Alaska, the western U.S., Hawaii and the Galápagos Islands display a similar twofold grouping: northerly (normal) and southerly (reversed). Intermediate directions are seldom observed.

the potassium-argon clock is started only when the rock solidifies.

The amount of potassium 40 in a sample is usually determined by measuring all the potassium in the sample by standard chemical methods and then calculating the potassium 40 from its known relative abundance. The argon determination is more difficult because the amounts are extremely small. In a typical 10-gram sample of basalt a million years old the amount of argon 40 from potassium 40 is 10^{-9} (.000000001) gram, and the accuracy of the dating depends on the accuracy with which this argon can be measured. A sample of the rock or mineral is placed in a gas-extraction apparatus and melted to release the accumulated argon 40. Reactive gases such as oxygen, nitrogen and water are removed. During the extraction a known amount of isotopically enriched argon, called the tracer, is mixed with the gas from the sample, so that the final argon gas consists of three components: the argon 40 whose amount is to be determined; the tracer, which is mostly argon 38 but which also contains some argon 36 and argon 40, and contaminating argon from the atmosphere, for which a correction must be made. This argon mixture is analyzed with a mass spectrometer that gives the relative amounts of the three isotopes of argon. Knowing the amount of the enriched tracer and its isotopic composition, and the relative composition of atmospheric argon and of the total gas mixture, one can calculate the amount of argon derived from potassium 40. This information is used with the results of the potassium analysis to determine the age of the rock.

For the reversal problem the potassium-argon method has several distinct advantages over other dating methods. It can be applied to a wide variety of volcanic rocks. It is also the only dating method that can be applied in the range from a few thousand to several million years ago. And, as we have noted, the potassium-argon clock starts to run at exactly the same time the magnetic record is frozen into a volcanic rock.

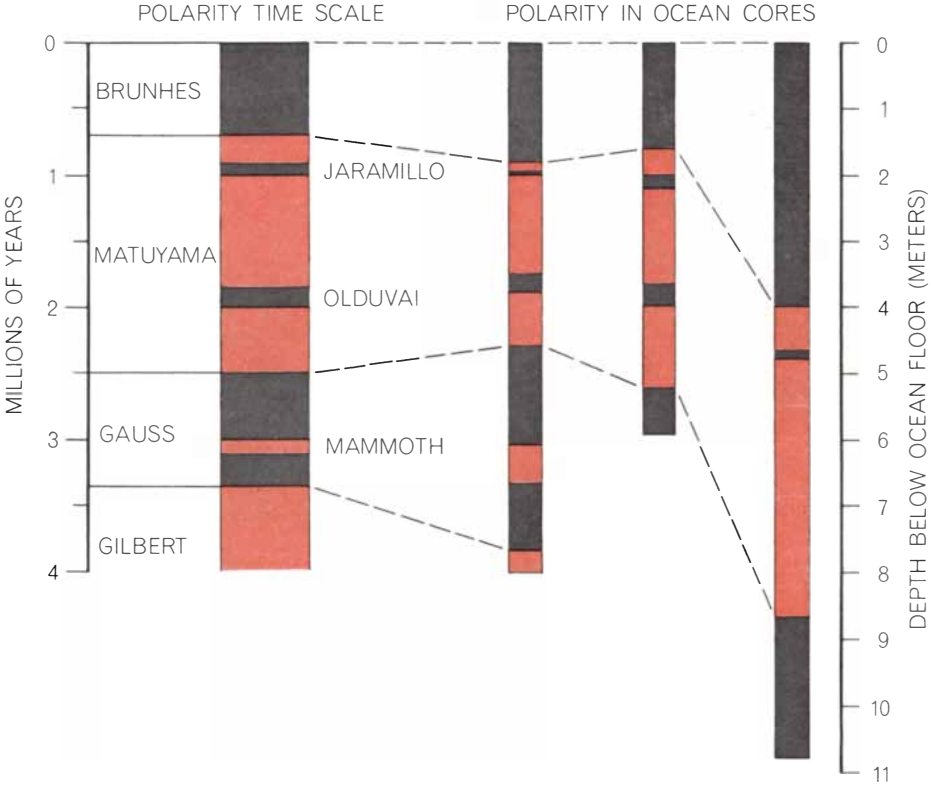
The potassium-argon dating method has now been successfully applied to rocks from nearly 100 magnetized volcanic formations with ages ranging from the present back to 3.6 million years [*see illustration on page 46*]. This work has been done primarily by ourselves at the U.S. Geological Survey laboratory in Menlo Park, Calif., and by Ian McDougall, D. H. Tarling and F. H. Chamalaun at the Australian National University. Relevant data have also been contributed by M. Rutten of the University of Utrecht and by C. S. Grommé, R. L. Hay, J. F. Evernden and G. H. Curtis of the University of California at Berkeley. The rocks that were investigated came from different parts of the world and are of different types, so that the available data come from heterogeneous sources.



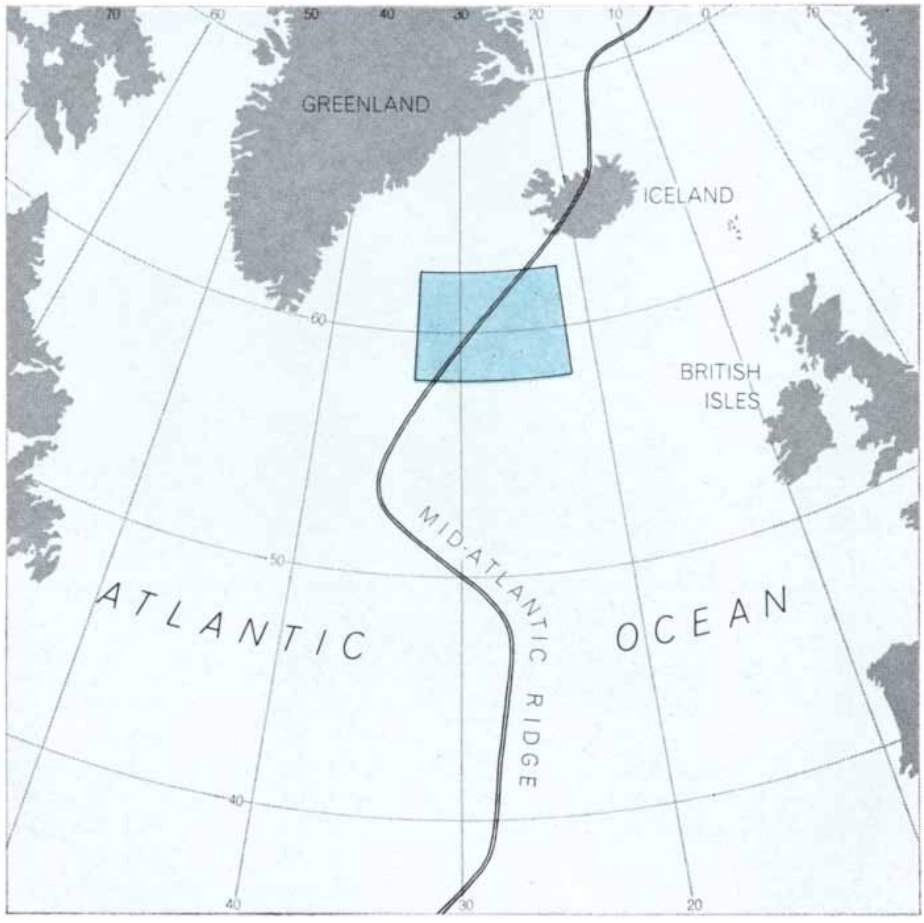
POTASSIUM-ARGON CLOCK by which reversals of the earth's field are dated is based on the decay of potassium 40 to yield argon 40. In the decay an extranuclear electron captured by the potassium nucleus converts a proton to a neutron and a gamma ray is emitted.

As the illustration on page 46 shows, the ages of these magnetically normal and magnetically reversed rocks are well grouped in distinct sequences, leaving little room for doubting the reality of geomagnetic field reversals. To explain them by self-reversal would require an unreasonable kind of coincidence involving synchronous worldwide changes in the nature of the processes by which minerals are formed and magnetized.

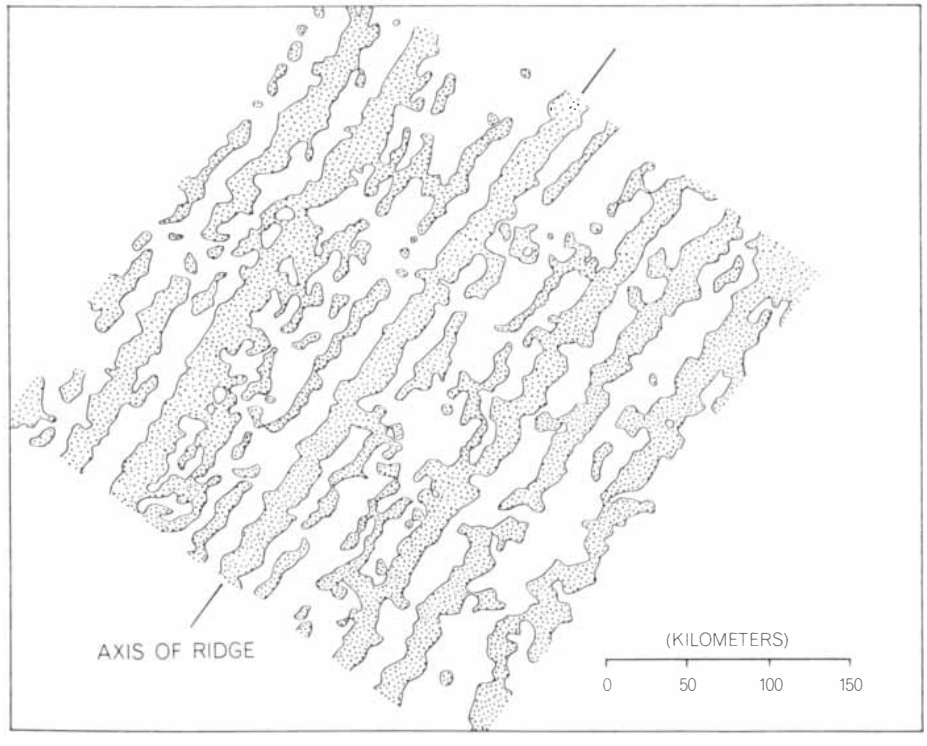
Four major normal and reversed se-



DEEP-SEA SEDIMENTS confirm the field-reversal time scale. Magnetic particles become oriented in the direction of the earth's field as they settle through the water; a core that samples many layers of sediments may record a series of normal (*gray*) and reversed (*color*) epochs and events. Here cores from antarctic waters are correlated with the time scale.



MAGNETIC ANOMALIES have been discovered in ocean floors, particularly along mid-ocean rises. One pattern was mapped in an area (*dark color*) on the mid-Atlantic ridge.



ANOMALY PATTERN in the area delineated on the map at the top of the page is strikingly symmetrical. The parallel bands in which the earth's field is stronger (*stippled*) or weaker (*white*) than the regional average are oriented along the ridge's axis. The magnetic bands are presumably produced by bands of rock with normal and reversed magnetism.

quences are defined by the paleomagnetic and radioactive-clock data for the past 3.6 million years. We call these major groupings geomagnetic polarity epochs and have named them for people who made significant contributions to our knowledge of the earth's magnetic field. Superimposed on the polarity epochs are brief fluctuations in magnetic polarity with a duration that is an order of magnitude shorter. We call these occasions polarity events and have named them for the localities where they were first recognized.

The polarity events are important for theories of the earth's magnetism because they emphasize the irregular nature of reversals of the earth's field. The first polarity event to be discovered was the "Olduvai" normal event, which is recorded in a flow in Olduvai Gorge in Tanzania that was investigated in 1963 by Grommé and Hay. At first the Olduvai flow was thought to lie within the "Gauss" normal polarity epoch and hence was not recognized as an anomaly. When better dating of the epochs placed the date of the Olduvai flow within the "Matuyama" reversed epoch, it appeared to be an unexplained anomaly in an otherwise coherent picture.

The explanation that the Olduvai result represents a brief, worldwide fluctuation in polarity was first advanced by us after we discovered in the Pribilof Islands three lava flows that are normally magnetized, like the Olduvai flow, and that have similar ages of about 1.9 million years. These flows were sandwiched between reversed flows that gave slightly older and slightly younger ages, providing the evidence that confirmed the existence of polarity events. Since then we have recognized and named two additional events: a reversed one that was recorded 3,050,000 years ago at Mammoth, Calif., and a normal one recorded about 900,000 years ago in some rocks near Jaramillo Creek in New Mexico. The Jaramillo event was recently confirmed by Chamalaun and McDougall in their study of lava flows on Réunion Island in the Indian Ocean, where they also found two additional flows that represent the Olduvai event.

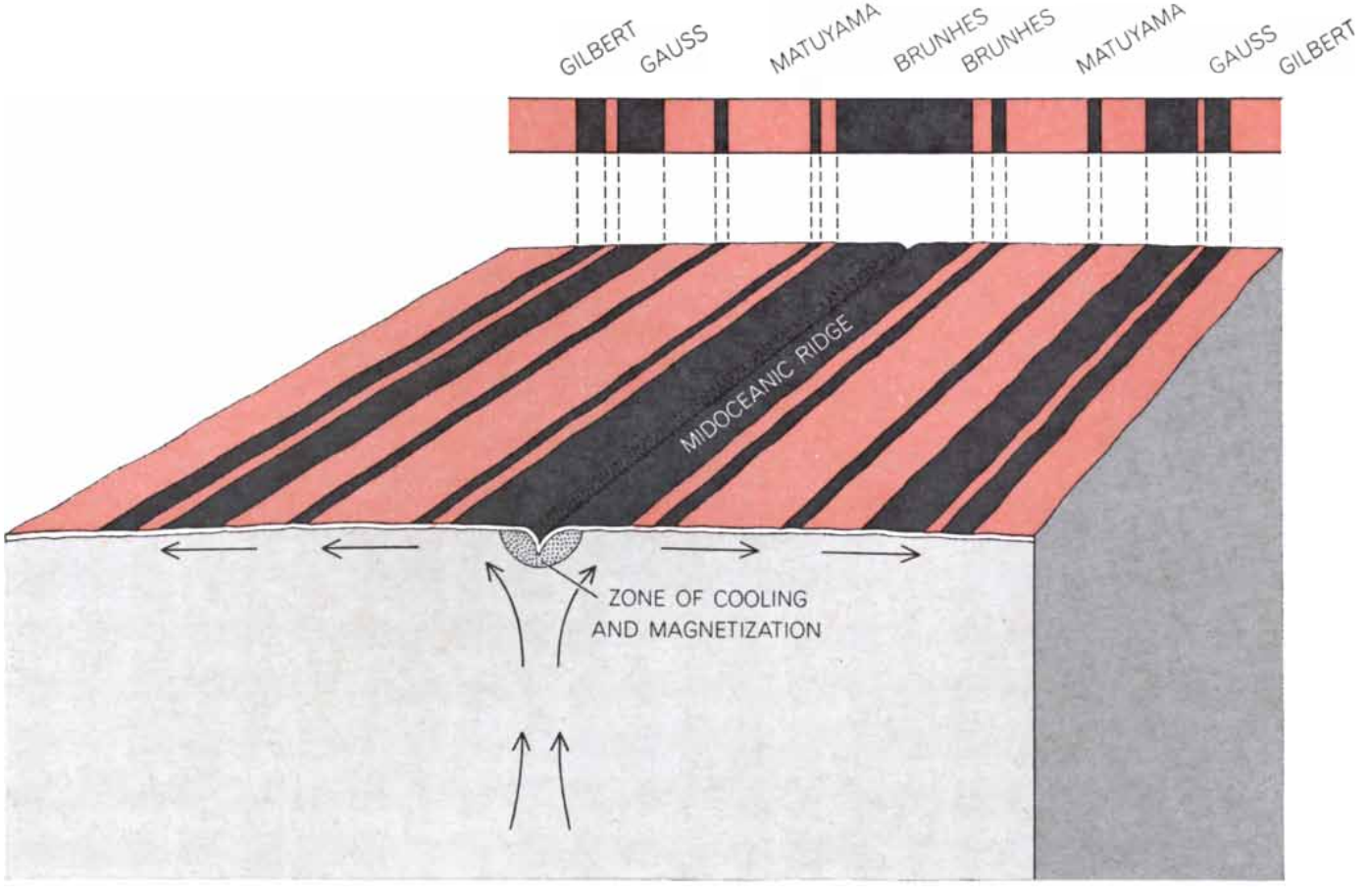
Only rarely does a sequence of lava flows succeed in capturing a record of a polarity transition. This indicates that the time required for a complete change of the earth's magnetic field from one polarity to another is amazingly short; our best estimate of the transition time is 5,000 years. This is based on the ratio between the number of lava flows that happen to have recorded the earth's

field during a transition and the number of flows with clearly defined normal or reversed directions. An indirect estimate of this kind is necessary because the potassium-argon dating method is unable to resolve age differences as small as 5,000 years. On the scale of geologic time, polarity transitions appear to be almost instantaneous, and they therefore provide sharp time markers indeed.

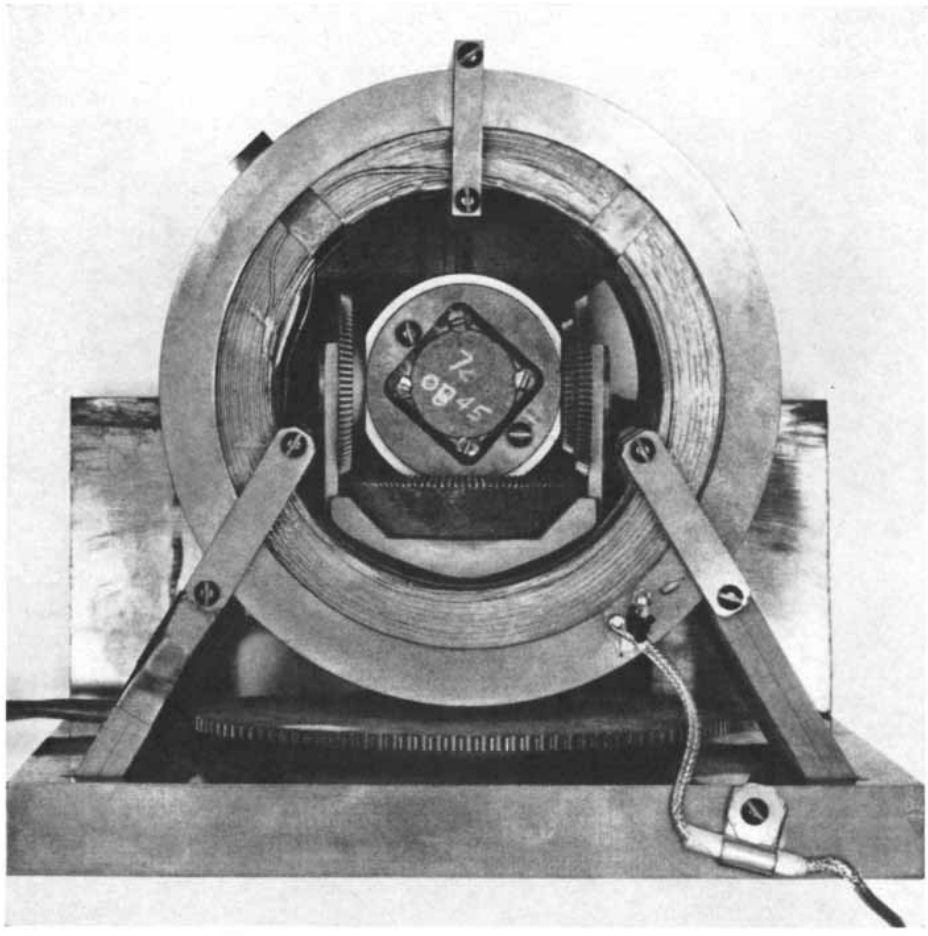
The idea that the earth's magnetic field reverses at first seems so preposterous that one immediately suspects a violation of some basic law of physics, and most investigators working on reversals have sometimes wondered if the reversals are really compatible with the physical theory of magnetism. The question is meaningful only within the context of a broader question: Why does the earth have a magnetic field? Geophysicists are simply not sure. After centuries of research the earth's magnetic field remains one of the best-described and least-understood of all planetary phenomena. The only physical mechanism that has been proposed as the basis of a tenable theory is the mechanism of a magnetohydrodynamic dynamo. According to this theory, which has been developed primarily by Walter M. Elsasser, now at Princeton University, and Sir Edward Bullard of the University of Cambridge, the molten iron-and-nickel core of the earth is analogous to the electrical conductors of a dynamo. Convection currents in the core supply the necessary motion, and the resulting electric currents create a magnetic field. The entire regenerative process presumably began with either a stray magnetic field in the earth's formative period or with small electric currents produced by some kind of battery-like action [see "The Earth as a Dynamo," by Walter M. Elsasser; SCIENTIFIC AMERICAN, May, 1958].

The mathematical difficulties of this theory are immense. It is impossible to predict what the intensity of the earth's field should be or whether it fluctuates or remains stationary. Certainly the theory is in too rudimentary a state for one to predict whether reversals should or should not occur or should occur only under certain conditions. On the other hand, complete mathematical solutions have been obtained for simple theoretical models of dynamos, and these models do show spontaneous reversals of magnetic field; some of the models show sequences of reversals that are strikingly similar to the geomagnetic polarity time scale. These results at least demonstrate that magnetic reversals are possible in self-regenerating dynamos. The fact remains that observations are leading theory in this area of investigation, and any complete theory of geomagnetism will eventually have to accommodate the observed reversals of the field.

Meanwhile geologists are applying the reversal time scale to establish age relations among rocks they would be hard put to date any other way. An especially important application is in determining the ages of deep-sea sediments, which are very difficult to date beyond the short range of 200,000 years. It has long been recognized that fine-grained sediments may become magnetized in the earth's field as they drift slowly downward in quiet water. Recently C. G. A. Harrison and B. M. Funnell of the Scripps Institution of Oceanography and N. D. Opdyke and D. E.



SPREADING of the ocean floor could explain the magnetic-anomaly patterns. According to one theory (*see text*) convection currents bring molten material up under the mid-ocean ridge, where it cools, becomes magnetized and then spreads laterally away from the ridge. Symmetrical bands of normal and reversed rocks would be produced by the combined effect of field reversal and spreading.



"MAGNETIC WASHING MACHINE" devised by the authors subjects a sample placed in the chamber (*center*) to an alternating magnetic field while rotating it about three perpendicular axes. The sample's hard magnetism is unaffected, but the soft component, forced to change direction repeatedly, is destroyed as the alternating current is reduced to zero.

Hayes and their colleagues at the Lamont Geological Observatory of Columbia University have observed magnetic reversals in the sediments of deep-sea cores [*see bottom illustration on page 51*]. In one core in particular (from the Bellingshausen Sea near Antarctica) Opdyke and Hayes found a polarity record going back to the "Gilbert" epoch, or 3.6 million years, in which the pattern of reversals is remarkably similar to the pattern of our polarity time scale. Even the brief polarity events are clearly discernible. These findings confirm the reversal time scale determined from volcanic rocks and suggest that polarity studies can provide a method for determining rates of sedimentation and for establishing worldwide correlations among various deep-sea sediments, two problems that have long perplexed oceanographers. Magnetic studies are also helping to establish stratigraphic links between marine and continental rocks. Magnetic-reversal stratigraphy has shown, for example, that sediments of glacial origin on Iceland and at the bottom of the Bellingshausen Sea were both deposited at about the end of the "Gauss" normal polarity epoch, or about 2.5 million years ago—a fact of considerable importance for Pleistocene geology.

Reversals may explain certain puzzling magnetic anomalies characteristic of many oceanic areas, particularly those adjacent to the mid-ocean rises, or ridges [see "The Magnetism of the Ocean Floor," by Arthur D. Raff; SCIENTIFIC AMERICAN, October, 1961]. These anomalies are parallel bands, extending for hundreds and even thousands of miles, in which the intensity of the earth's magnetic field is higher or lower than the average for the region. It is easy to see how the presence of normal and reversed magnetized rock formations in the crust of the earth, which would add to and subtract from the earth's main dipole field, could account for such findings. Many of the magnetic-anomaly patterns, however, display a striking symmetry around the crests of certain mid-ocean ridges [*see illustrations on page 52*] that is difficult to explain on the basis of familiar volcanic processes.

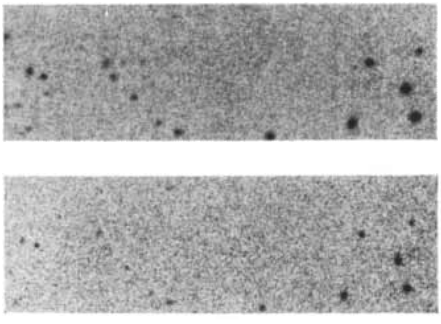
Recently F. J. Vine, now at Princeton University, and J. H. Matthews of the University of Cambridge have pointed out that ideas advanced by Harry H. Hess of Princeton and by the Canadian geophysicist J. Tuzo Wilson to account for certain characteristics of ocean basins and their margins and also for the drifting of continents may shed light on the symmetrical anomalies. Hess and Wilson had suggested that convection currents in the earth's mantle, the layer below the crust, may bring material up to form a mid-ocean ridge and then move the material outward, away from the ridge [see "Continental Drift," by J. Tuzo Wilson; SCIENTIFIC AMERICAN, April, 1963]. If successive bands solidified and were magnetized during successive polarity epochs, Vine and Matthews reported, the symmetry of the patterns could be explained on this basis. So could the particular spacing of the bands along the mid-Atlantic ridge, for example, provided that the sea floor is spreading at the rate of about one centimeter per year [*see illustration on preceding page*]. This rate is consistent with earlier estimates by Wilson. Although the hypothesis of sea-floor spreading seems to be inconsistent with some other lines of evidence and has been resisted by many oceanographers and geologists, the magnetic evidence seems to reinforce it.

Reversals of the earth's magnetic field may even have implications for the history of life on our planet. R. J. Uffen of the University of Western Ontario pointed out in 1963 that if the magnetic field of the earth disappears or is greatly attenuated during a reversal in polarity, the earth would lose some of its magnetic shielding against cosmic rays; with the resulting increase in radiation dosages, mutation rates should increase. Paleomagnetic evidence for the behavior of the earth's field during polarity transitions is fragmentary, but there are indications that the field may be only about a fifth as intense as in normal times. Uffen argues on paleontological grounds that rates of evolution were exceptionally high at times when the earth's magnetic field was undergoing many changes in polarity, although the support for this conclusion in the paleomagnetic record is rather weak. Cores examined by Opdyke and Hayes do provide some support for Uffen's theory in that major changes in the assemblages of microfossils appear near two of the magnetic-polarity changes. Much additional information is needed, however, before it will be possible to judge the extent to which field reversalsmay have affected life on the earth.

The hope of doing each other some good prompts these advertisements

You want a fast emulsion?

We have recently made a photographic emulsion based on a new line of reasoning (*J. of the Optical Society of America*, 55:907) and sent it out on some plates to the Palomar Observatory. Here is a comparison at 10× of what the new plate saw (*top*) with what was seen



before in a certain tiny piece of sky near Messier 101.

The new emulsion extends the limit of optically observable celestial objects by another magnitude or two. You might think that to record such a faint trickle of photons—perhaps the oldest physical entities sensible to man—might require a new high in emulsion speed. Not so. The trick was turned by going to a slower emulsion, but of a very special nature. It doesn't lose the tiny difference made by the age-old photons among all the other photons around, even with the hour-long exposure required for a statistically significant sampling of the photons.*

Though a plateful of spaghetti impresses far more inhabitants of this planet than does a plateful of new galaxies, we ourselves are sufficiently impressed to make the plate a regular product, hereafter designated KODAK *"Spectroscopic" Plate, Type IIIa-J. Information about it and other plates and films designed for long-time exposures can be obtained from Dept. 918, Eastman Kodak Company, Rochester, N.Y. 14650.*

Here are three men from Dept. 918 photographed by the light of a single match. They are exploring the extent of customer interest in the film on which they were photographed. Unlike the emulsion for plumbing the universe, this one is just plain more sensitive to light than any we have ever before offered.

Plain? That depends. It depends on processing. An experimental product still designated "S.O. 166," this film can be processed to a negative in the routine way—by hand or in a KODAK VERSAMAT Film Processor—and appear to be no faster than our older superfast films. With those films, if you try to compensate for too skimpy exposure by tripling the development time, all you do is convert more silver halide into black silver without much reference to the light values in the subject you were trying to photograph. With S.O. 166, extended development can multiply the effective light sensitivity as much as fourfold before the fog closes in. There is some sacrifice in sharpness and granularity, but the resolving power is enhanced by the higher contrast that is obtained. For streamer chambers (research hardware for the other end of the scale from galaxies), re-entry studies, fast rises on P-11 phosphor screens, surveillance of dimly lit antisocial activities, and applications that require fleeting signals to be recorded on a go or no-go basis, S.O. 166 is probably great and should outsell galactic plates by a factor of many thousands.

The three on a match would be interested to learn of your requirements. Don't expect any S.O. 166 yet for the family camera.

A corporation's thoughts about "science"

A corporation is an artificial person. It can therefore aspire to immortality. Furthermore the device affords a convenient façade for lively mortals.

If we hadn't had good people we wouldn't be where we are today, but we don't have enough of them to face the problems of the years ahead.

We are getting smarter. We now understand that just people aren't enough. We require *individuals*—no two too much alike.

Ideally, we hope by these words to attract into our midst an individual who will proceed to scientific accomplishments that freshman textbooks of the 1990s can scarcely ignore. An alternative ideal outcome would be to attract another and very different individual who will eventually turn from direct personal contribution to science and will wind up as chairman of the corporation's board of directors in the 1990s.

The effort will still have been worthwhile if it merely advises a few scientists that our size, organic integration, and diversification mean for the individual freedom of choice where his scientific interests and experiences can lead him as the years go on. We serve human needs both through the photographic process and through technologies now grown far away from photography. Thus we find economic support for a very broad range of fundamental studies on which the technologies may possibly feed. Hence the freedom in area of work.

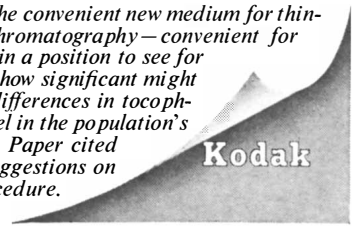
We have come to appreciate also the need for freedom in choosing an approach to scientific problems. Strongly motivated scientists we can set free to put up to 100% of their working time into research. They can have assistance and auxiliary laboratory services by colleagues themselves well recognized as experts in their techniques—a situation that fortunately prevails in the Kodak Research Laboratories. They can communicate freely with peers and yet need not carry the "teamwork" figure of speech to where one forgets his own name in return for a dry stall and an assured bag of oats.

Anyone of any race who is approaching the threshold of a working career in chemistry, physics, or possibly in biology and who feels himself or herself sufficiently swayed by this eloquence to try to match interests developed in graduate school against what we currently imagine to be our own research interests should establish communication through Dr. Dudley B. Glass, Eastman Kodak Company, Rochester, N.Y. 14650.

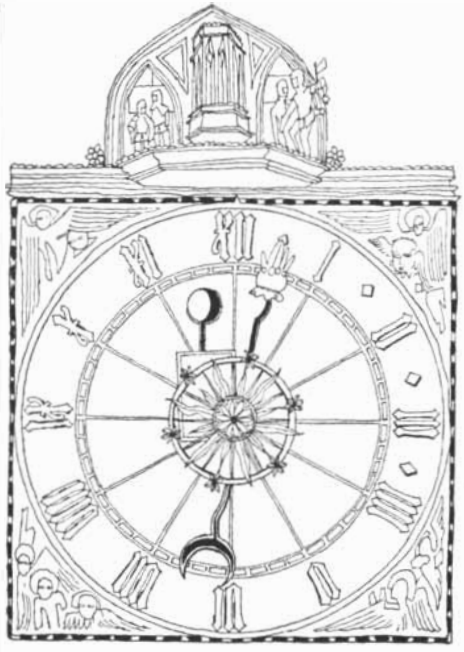
Vitamin E in Pittsburgh and Rochester

We have reported a curious finding in *The American Journal of Clinical Nutrition* (17:351). Blood level of α-tocopherol (the substance principally responsible for the physiological vitamin E effect) averaged 358 ± 21 μg per cent in a group of 37 Pittsburghers whose serum lipids we were permitted to analyze. None of them had given their physicians any clinical evidence of vitamin E deficiency, but many were in an economic status that had brought them with other medical problems to a public hospital. This compared with 507 ± 32 μg per cent for a group of 37 persons in Rochester, N.Y., randomly picked from a healthy, working population, some of whom had been taking multivitamin tablets but no special vitamin E supplementation.

Besides vitamin E in bulk for the pharmaceutical and animal agriculture industries, Distillation Products Industries (Division of Eastman Kodak Company), Rochester, N.Y. 14603, also markets EASTMAN CHROMAGRAM *Sheet, the convenient new medium for thin-layer chromatography—convenient for anyone in a position to see for himself how significant might be the differences in tocopherol level in the population's plasma. Paper cited gives suggestions on the procedure.*



*Controlled baking of the plate yields greater sensitivity by improving its reciprocity characteristic and its quantum efficiency. This means that you get to use a lot of photons that would otherwise be lost and therefore get your sampling done in a shorter time. Contrary to our naive conjecture, you do not lose the advantage of improved S/N which was acquired by going to a fine-grain emulsion and long exposure. Moral: you can have your cake and eat it too—if it's baked twice, once at the factory and once in your own oven!



SCIENCE AND

Death in America

After reaching an all-time low in 1954, the U.S. death rate climbed by 4.7 percent in the next decade, from 919 deaths per 100,000 population to 961.9 in 1963. Although much of this increase can be attributed to the changing age composition of the population, there were also significant changes in the death rate from different causes. Among diseases showing the sharpest 10-year increase were two closely associated with cigarette smoking: arteriosclerotic heart disease and respiratory cancer (chiefly lung cancer). The former increased by 23 percent and the latter by 46 percent in the decade 1954–1963.

The 13 leading causes of death and the 10-year change for each are shown in the following table. (The first number is the 1963 death rate per 100,000 population; the second number is the percent change since 1954; a blank indicates that the change is less than 7 percent.)

Arteriosclerotic heart disease	290.0	+23%
Stroke	106.7	
Cancer of the digestive organs	49.3	−7%
Pneumonia and influenza	37.5	+48%
Diseases of infancy	33.3	−15%
Hypertensive heart disease	32.4	−30%
Accidents (except motor vehicle)	30.3	−10%
Nonrheumatic endocarditis	29.7	−28%
Respiratory cancer	24.9	+46%
Motor vehicle accidents	23.1	
Genital cancer	21.2	−7%
General arteriosclerosis	19.9	
Diabetes mellitus	17.2	+10%

As in the past, there continue to be striking differences between white death rates and nonwhite rates in certain categories. Among whites, for example, the death rate from arteriosclerotic heart disease is more than 70 percent higher than it is among nonwhites. Whites also experience higher death rates than nonwhites for cancer of the stomach and lung. On the other hand, nonwhites have a death rate from hypertensive heart disease that is nearly 130 percent higher than the white death rate. Nonwhites also have a higher death rate than whites for diabetes, pneumonia and accidents other than those caused by motor vehicles.

In the 10-year period 1954–1963 there was a slight decline of about 5 percent in the infant mortality rate. This is another category, however, in which the nonwhite death rate is significantly higher than the white death rate: 41.5 deaths per 1,000 live births for nonwhite infants compared with 22.2 deaths per 1,000 for white infants. In the category of infant mortality even the white U.S. rate is higher than that in countries such as Australia (19.5 deaths per 1,000), Finland (18.2), the Netherlands (15.8) and Sweden (15.4).

The data are from recent booklets in the series "Vital and Health Statistics," published by the U.S. Department of Health, Education, and Welfare.

The 200-BeV Accelerator

After weighing the merits of six sites, selected as "finalists" a year ago in a competition that drew more than 200 entries, the Atomic Energy Commission has voted unanimously to locate its 200-billion-electron-volt accelerator laboratory in Weston, Ill., a farming community some 30 miles southwest of Chicago. The machine and its supporting facilities will cost nearly $400 million and will require a staff of 2,000.

The five sites that lost out to Weston in the final selection were Ann Arbor, Mich.; Brookhaven National Laboratory on Long Island; Denver, Colo.; Madison, Wis., and Sierra Foothills, near Sacramento, Calif. Because the new accelera-

tor will be a national facility, open to users from all over the U.S. (and from foreign countries), Weston's central location was probably the single most important factor in its selection. Weston is within 30 miles (40 minutes) of Chicago's O'Hare International Airport, which can be reached by nonstop jet from most major U.S. cities and many foreign countries. It is within easy driving distance of several major Middle Western universities. Finally, the new accelerator will be only 15 miles from the Argonne National Laboratory, which already has important facilities for high-energy research.

The 200-BeV accelerator will be an alternating-gradient proton synchrotron, similar in principle to the 33-BeV synchrotron at Brookhaven and the 28-BeV synchrotron at the European Organization for Nuclear Research (CERN), in Geneva, which are the two largest accelerators in the world. A 70-BeV alternating-gradient proton synchrotron is under construction at Serpukhov in the U.S.S.R. The Weston machine will have a particle-accelerating ring with a diameter of 4,600 feet and will require 480 magnets weighing a total of 9,200 tons. For purposes of comparison, the Brookhaven and CERN machines are about 845 feet in diameter and incorporate 240 magnets weighing 4,000 tons. The conceptual design for the 200-BeV accelerator was developed at the Lawrence Radiation Laboratory of the University of California. If Congress provides the funds, as is expected, the accelerator could be operating by 1976.

Genetic Passenger

Ever since it became clear that genes are segments of the deoxyribonucleic acid (DNA) molecule some biologists have wondered if it might someday be possible to alter the genetic material of a human being, for example to supply a deleted gene and thereby remedy some metabolic deficiency. How would one introduce the desired genetic information? One possibility that has now received some preliminary experimental support would be to administer a harmless virus that bears the required gene.

The Shope papilloma virus, which causes tumors in rabbits, also induces the synthesis of a distinctive form of the enzyme arginase that lowers the concen-

tration in the rabbits' blood of the amino acid arginine. The question arose whether the same effect might be obtained in human beings, but one may not infect people with animal viruses for experimental purposes. It occurred to Stanfield Rogers of the Oak Ridge National Laboratory that he could get at the question indirectly: he compared the blood of a number of people who had worked with, and therefore been exposed to, the Shope virus with the blood of randomly selected controls.

According to Rogers' report in *Nature*, many of the research workers exposed to the virus were found to be carrying "virus information." They had generally lower arginine levels than controls did and a number of them had lower levels than had ever been reported before. Eight out of 12 serum specimens from people exposed to the Shope virus showed specific antibodies against the distinctive form of arginase but not against normal rabbit-liver arginase, indicating that the virus DNA had supplied the information for the synthesis. The blood of the research workers did not contain demonstrable neutralizing antibodies against the Shope virus itself, indicating that the infected cells were not synthesizing the protein outer coat of the virus.

The Shope virus, Rogers suggests, is a harmless "passenger" virus in these people. It is possible that there are other such viruses. Perhaps some of them carry genes that would be useful in the treatment of genetic disease. It is conceivable that a harmless virus might even be utilized as a vector for specific information in the form of tailor-made DNA that could be attached to the virus and transferred by the process known as transduction. The evidence for such possibilities is only suggestive at this point; far more experimentation, including more direct tests in animals of the manner in which enzyme production and activity is induced in the host, will be necessary before manipulation of human DNA is considered a serious possibility.

Epidemic Hysteria

In the generations that have passed since such occurrences as the "dancing mania" or fits en masse in a nunnery, epidemic hysteria has seemed to disappear. Or has it? A recent instance, affecting nearly a third of the 550 pupils of a Church of England girls' school in Blackburn, Lancashire, has now been reported to the *British Medical Journal* by Peter D. Moss, a pediatrician at the local hospital, and Colin P. McEvedy, a London psychiatrist. An intensive survey of faculty and students revealed that on the first day of the epidemic, a Thursday, 141 girls complained of dizziness, faintness, shivering, tooth-chattering, headache, nausea and similar symptoms. Eighty-five of the girls were hospitalized and school was dismissed for a long weekend. When classes resumed on Monday, 79 girls made similar complaints and 54 were hospitalized; school was then dismissed for the rest of the week. The next Monday, 11 days after the initial outbreak, 58 girls made the same complaints; none were hospitalized and that day's episode was the final event in the waning epidemic.

Noting that the girls were not malingering and the school staff was not being deceived, Moss and McEvedy report that in spite of intensive studies no possible physical basis for the incident could be discovered. The investigators learned, however, that on the day before the initial outbreak the student body had constituted the audience at a ceremony under royal patronage performed at the Anglican cathedral in Blackburn. The ceremony was notable for a three-hour delay, during which 20 of the schoolgirls had to break ranks and lie down because of faintness. On at least one school bus the next morning an air of excitement prevailed and there was much discussion about who had fainted and how often. "The stage," Moss and McEvedy write, "was set."

During the first two morning periods that day 10 girls complained of faintness. They were sent to sit on chairs in the school's central corridor, but a teacher who feared they might hurt themselves should they actually faint and fall had them lie on the corridor floor instead. The 10 girls were thus seen in this position by the rest of the student body at morning recess; the hysteria became epidemic and soon reached a rate of one collapse per minute.

The ceremony at the cathedral was almost certainly the trigger: all 20 of the girls affected on that occasion collapsed again on the first day of the school epidemic, whereas not one of nine girls who had been absent was affected. A pattern of repeaters was also evident: 95 of the girls stricken on the first day of the school epidemic were present the following Monday and 51 of them succumbed for a second time. Moreover, of the 58 girls stricken on the last day of the epidemic, 52 had been victims in either the first or the second outbreak.

Pointing out that abnormally rapid breathing, a common result of panic, can produce all the symptoms of which the girls complained, the investigators conclude that whatever the triggering effect of the cathedral incident the victims' emotional vulnerability probably arose from a general anxiety existing in Blackburn because of a recent outbreak of poliomyelitis.

Gondwanaland Fitted

A close match in the relative ages of two adjoining geological provinces on opposite sides of the Atlantic Ocean has provided support for the Gondwanaland hypothesis, which states that a supercontinent made up of segments of present-day India, Australia, Antarctica, Africa and South America existed in Paleozoic times, 230 million and more years ago, only to be broken apart later by continental drift. The new evidence, developed by investigators at the Massachusetts Institute of Technology and the University of São Paulo, flows from the fact that the rocks of West Africa are divided into two chronologically distinct groups. Those in Ghana, the Ivory Coast and westward are two billion (±100 million) years old, according to both potassium-argon and rubidium-strontium measurements. In Dahomey, Nigeria and to the east, however, the rocks are scarcely a quarter of this age, being only 550 million (±50 million) years old.

Speaking at the recent annual meeting of the Geological Society of America in San Francisco, P. M. Hurley of M.I.T. stated that, when the investigators "fitted" the two continents together on paper, they predicted that a similar age division would be found in South American rocks, with the dividing line located just east of São Louis on Brazil's northern coast. Subsequent studies have not only confirmed the predicted location of the dividing line but also shown that the difference in the ages of the Brazilian rocks on each side of the boundary is almost identical with that of their African counterparts. The studies strongly suggest that the South American and African formations once composed a single mass.

Perfect Blade

It has long been known that a tiny perfect crystal of a metal—a "single" crystal—is in many properties superior to an ordinary sample of the same metal, which is composed of many single crystals. Now entire gas-turbine blades,

We can't imagine that everyone on our Astrojets wants the same thing to eat.

We can't even imagine what one person wants to eat.

Take that little guy on the left, for example. We had him figured for a fresh fruit salad bowl.

So when his Travel Agent suggested he try our whole First Class dinner, we went along with it. But we were betting he wouldn't make it past the appetizer. Let alone the filet mignon with Bordelaise sauce, the parsleyed buttered potatoes, the Boston salad and the rolls and coffee.

He made it. And he even asked for seconds on the dessert.

We can probably keep him happy just by switching around all our different menus, and giving him a choice of three entrees every time.

Or by offering him a six-course, carefully paced dinner on our Captain's Table flights.

Or recipes prepared by the chefs at "21" on our famous "21" Club transcontinental flights.

But if he's one of our professional travellers, who flies up to 50 times a year, he still might not be satisfied.

Sometimes he'll keep everything he wants on the menu, and reserve a bowl of chili instead of his main course. Or beef enchiladas. Or a chef's salad. Or even a roast beef sandwich on rye.

As his friends can tell you, we'll be ready for that, too.

American built an airline
for professional travellers.
(And you'll love it.)

American Airlines

from three to six inches long, are being cast in the form of single crystals at Pratt & Whitney Aircraft. The blades, which are made of a nickel-based alloy, are distinguished by two highly desirable properties for service in the extremely hot interior of modern gas-turbine engines: superior resistance to thermal shock and high ductility. Both properties tend to reduce the cracking and "fatigue" of metal parts caused by heat.

The precision casting technique used to fashion the single-crystal blades is an outgrowth of an earlier process developed by Pratt & Whitney for the directional solidification of turbine parts. This process imparted increased ductility and thermal-shock resistance by eliminating the crystal grain boundaries that lie at right angles to the principal stress axis, which coincides with the long axis of a turbine blade. The new process, devised by B. J. Piearcey and F. L. VerSnyder, completely eliminates the grain boundaries. The process is carried out by enclosing a shell mold of the blade in a gradient furnace. The temperature in the furnace is maintained above the melting point of the alloy before pouring, and solidification is allowed to take place by controlling the cooling rate and the temperature gradient throughout the solidification cycle. According to Piearcey and VerSnyder, their technique "is reproducible, requires no 'seeding' to establish the crystal orientation and appears to be adaptable to commercial foundry practice."

The Taste of Water

What gives a drink of water a pleasant or unpleasant taste? The question becomes increasingly relevant as the growing demand for water necessitates the use of such supplies as desalinated seawater and groundwater with an unusually high content of minerals. Working with a panel of judges, the Sensory Evaluation Laboratory of the Food Science Department at the University of California at Davis has been attempting to develop a body of information on the palatability of water. One of the findings is that, contrary to what one might think, water that is pure in the sense that it contains no minerals is not particularly tasty. Water from which the minerals had been removed by distillation drew from the judges such adjectives as "cardboardy" and "insipid."

Another finding puts in doubt the widely held opinion that chilling improves the taste of water. The judges reported that tap water and distilled water tasted better at room temperature than at refrigerator temperature. The only water that seemed to be made more palatable by chilling was an experimental concoction containing 1,000 parts per million of certain minerals. The minerals were those normally found in water (sodium, calcium and magnesium sulfates; calcium, magnesium and sodium chlorides, and sodium carbonate and sodium bicarbonate), but the concentrations were at a level that public health agencies have recommended as a maximum.

The survey also found that one kind of water can evoke sharply different opinions. The experimenters made one series of water samples increasingly salty. The saltier the water got, the better a third of the judges liked it; the reaction of the other judges was just the opposite. In the remaining two years of the three-year project, which is sponsored by the U.S. Public Health Service, the experimenters want to find out how it is that the same kind of water can produce completely opposing reactions. Other objectives are to test the effects of temperature, minerals, chlorination and fluoridation on the taste of water and to explore the question of how mineralized or treated water affects such beverages as coffee and soft drinks.

The Strength of Eggshell

The broken egg, a bane of egg producers, egg dealers and housewives, may become less common as a result of a new invention: a gauge that measures the thickness of eggshells. The gauge, developed by Paul E. James of the Agricultural Research Service of the U.S. Department of Agriculture, directs high-energy electrons (from a radioactive source) at an egg and counts the number of particles that bounce back. The higher the count, the thicker the shell. The gauge now operates at only four eggs per minute; James is seeking to increase its capacity.

In commercial use the device would presumably enable large-scale egg producers to monitor their output to determine which strains of hen were laying thin-shelled eggs subject to breakage. These hens could then be replaced by others that laid eggs with thicker shells. In that way the egg business could reduce a loss from breakage that amounted to about $25 million in 1965, when some 930 million of the 62 billion eggs produced in the U.S. broke on the way from producer to consumer.

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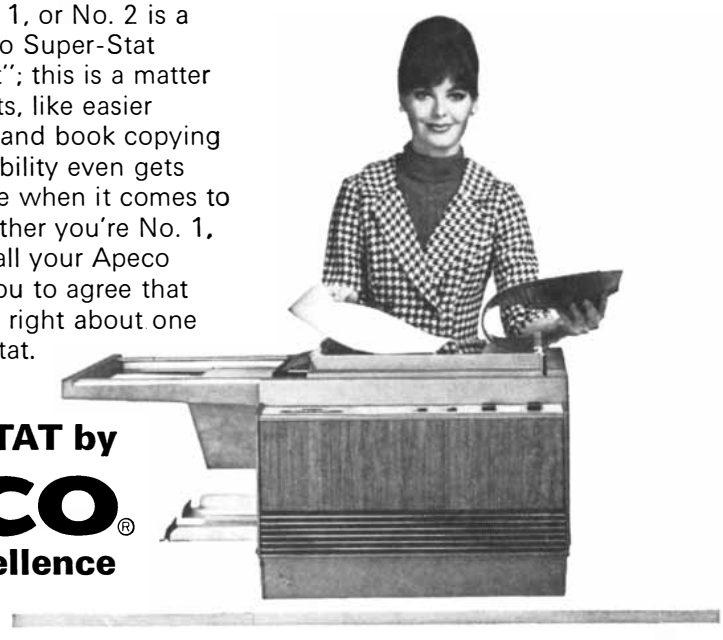

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THE STATES OF SLEEP

Light and deep sleep differ physiologically, deep sleep having much in common with being awake. Studies with cats now suggest that the two states of sleep are induced by different biochemical secretions

by Michel Jouvet

Early philosophers recognized that there are two distinctly different levels of sleep. An ancient Hindu tale described three states of mind in man: (1) wakefulness (*vaiswanara*), in which a person "is conscious only of external objects [and] is the enjoyer of the pleasures of sense"; (2) dreaming sleep (*taijasa*), in which one "is conscious only of his dreams [and] is the enjoyer of the subtle impressions in the mind of the deeds he has done in the past," and (3) dreamless sleep (*prajna*), a "blissful" state in which "the veil of unconsciousness envelops his thought and knowledge, and the subtle impressions of his mind apparently vanish."

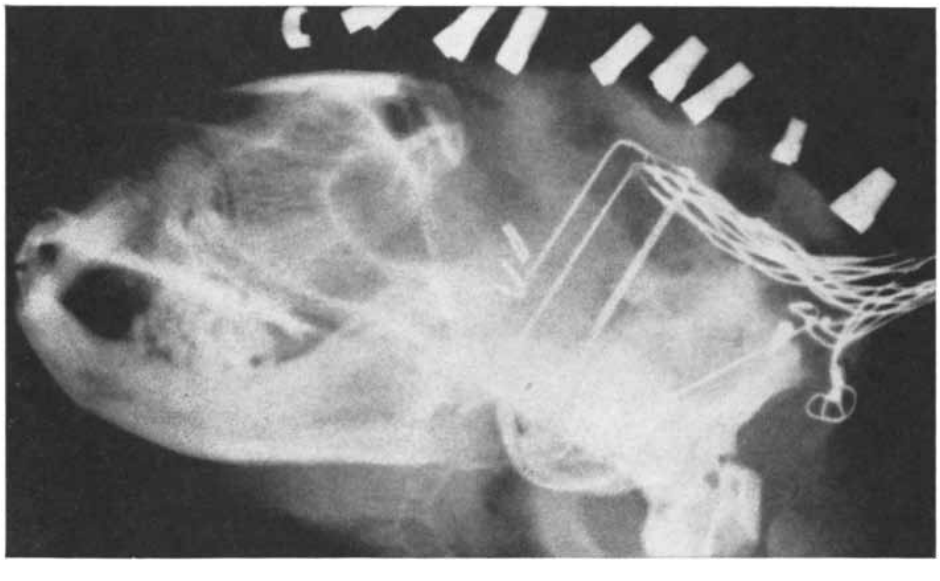
States 2 and 3 obviously are rather difficult to investigate objectively, and until very recently the phases of sleep remained a subject of vague speculation. Within the past few years, however, studies with the aid of the electroencephalograph have begun to lift the veil. By recording brain waves, eye movements and other activities of the nervous system during the different sleep states neurophysiologists are beginning to identify the specific nervous-system structures involved, and we are now in a position to analyze some of the mechanisms responsible.

Brain Activities in Sleep

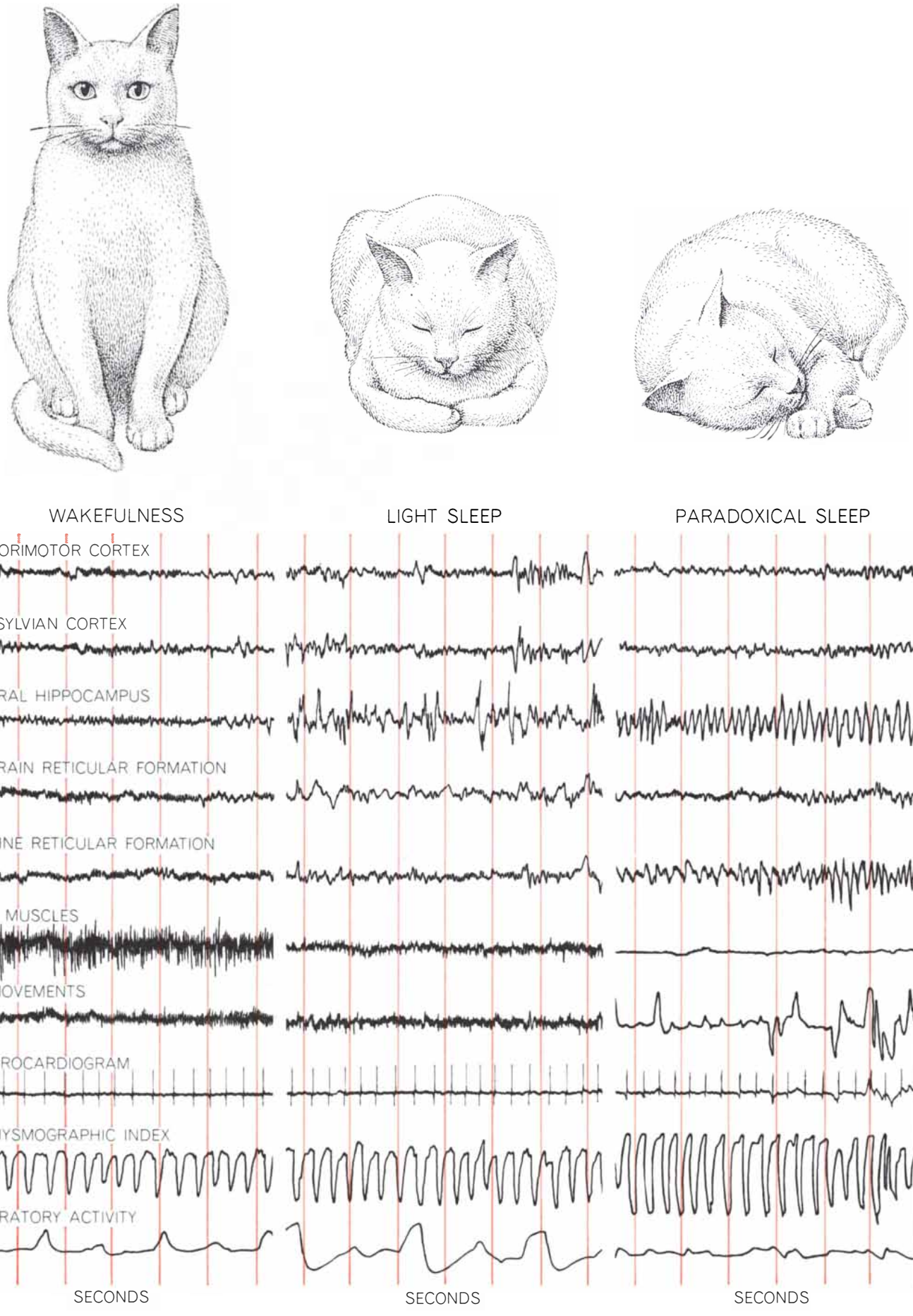
Lucretius, that remarkably inquisitive and shrewd observer of nature, surmised that the fidgetings of animals during sleep were linked to dreaming. Some 30 years ago a German investigator, R. Klaue, made a significant discovery with the electroencephalograph. He found that sleep progressed in a characteristic sequence: a period of light sleep, during which the brain cortex produced slow brain waves, followed by a period of deep sleep, in which the cortical activity speeded up. Klaue's report was completely overlooked at the time. In the 1950's, however, Nathaniel Kleitman and his students at the University of Chicago took up this line of investigation. Kleitman and Eugene Aserinsky found (in studies of infants) that periods of "active" sleep, alternating with quiescent periods, were marked by rapid eye movements under the closed lids. Later Kleitman and William C. Dement, in studies of adults, correlated the eye movements with certain brain-wave patterns and definitely linked these activities and patterns to periods of dreaming [see "Patterns of Dreaming," by Nathaniel Kleitman; SCIENTIFIC AMERICAN, November, 1960]. In 1958 Dement showed that cats may have periods of sleep similarly marked by rapid eye movement and fast cortical activity. He called such periods "activated sleep."

Meanwhile at the University of Lyons, François Michel and I had been conducting a series of experiments with cats. In the cat, which spends about two-thirds of its time sleeping, the process of falling asleep follows a characteristic course, signaled by easily observable external signs. Typically the animal curls up in a ball with its neck bent. The flexing of the nape of its neck is a clear sign that the muscles there retain some tonus, that is, they are not completely relaxed. In this position the cat lapses into a light sleep from which it is easily awakened.

After about 10 to 20 minutes there comes a constellation of changes that mark passage over the brink into deep sleep. The cat's neck and back relax their curvature, showing that the muscles have completely lost tonus: they are now altogether slack. At the same time there



X RAY OF CAT'S HEAD shows a cluster of electrodes with which the author obtained a record of the electrical signals from various parts of the cat's brain. The cat's mouth is at the left; one electrode at far right measures the changes in the animal's neck-muscle tension.



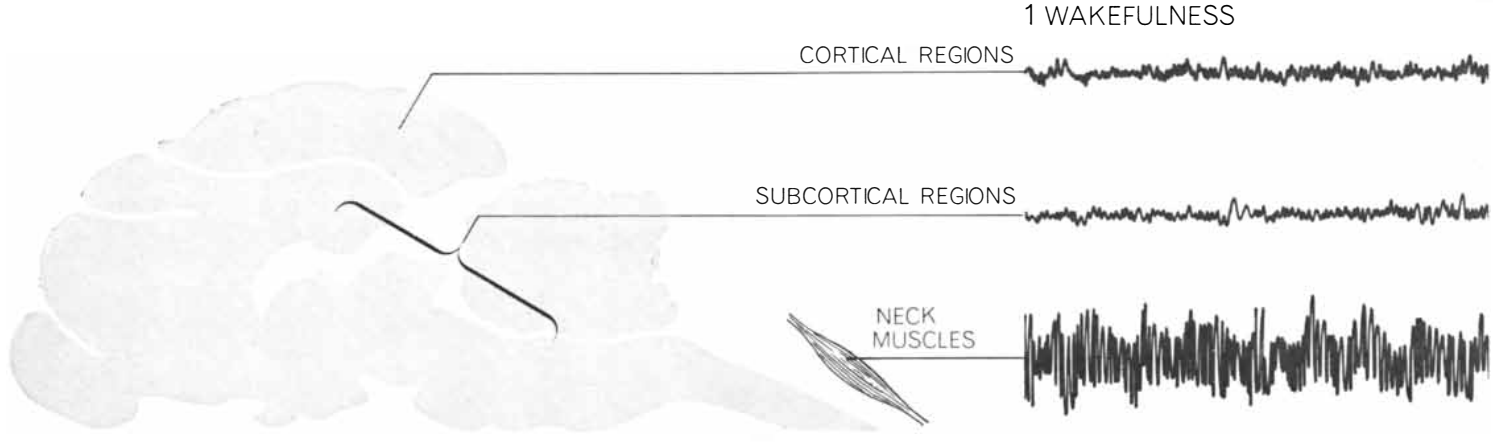
CHARACTERISTIC RHYTHMS associated with deep sleep in a cat (*group of traces at right*) are so much like those of wakefulness (*left group*) and so different from those of light sleep (*middle group*) that the author has applied the term "paradoxical" to deep sleep. Normal cats spend about two-thirds of the time sleeping. They usually begin each sleep period with 25 minutes of light sleep, followed by six or seven minutes of paradoxical sleep. In the latter state they are hard to wake and their muscles are relaxed.

CAT'S BRAIN, seen in front-to-back section, has a number of segments. Some of the principal ones are identified in the illustration at the top of the opposite page. Many segments of the cat's brain, such as the cerebellum (*top right*), have no role to play in sleep.

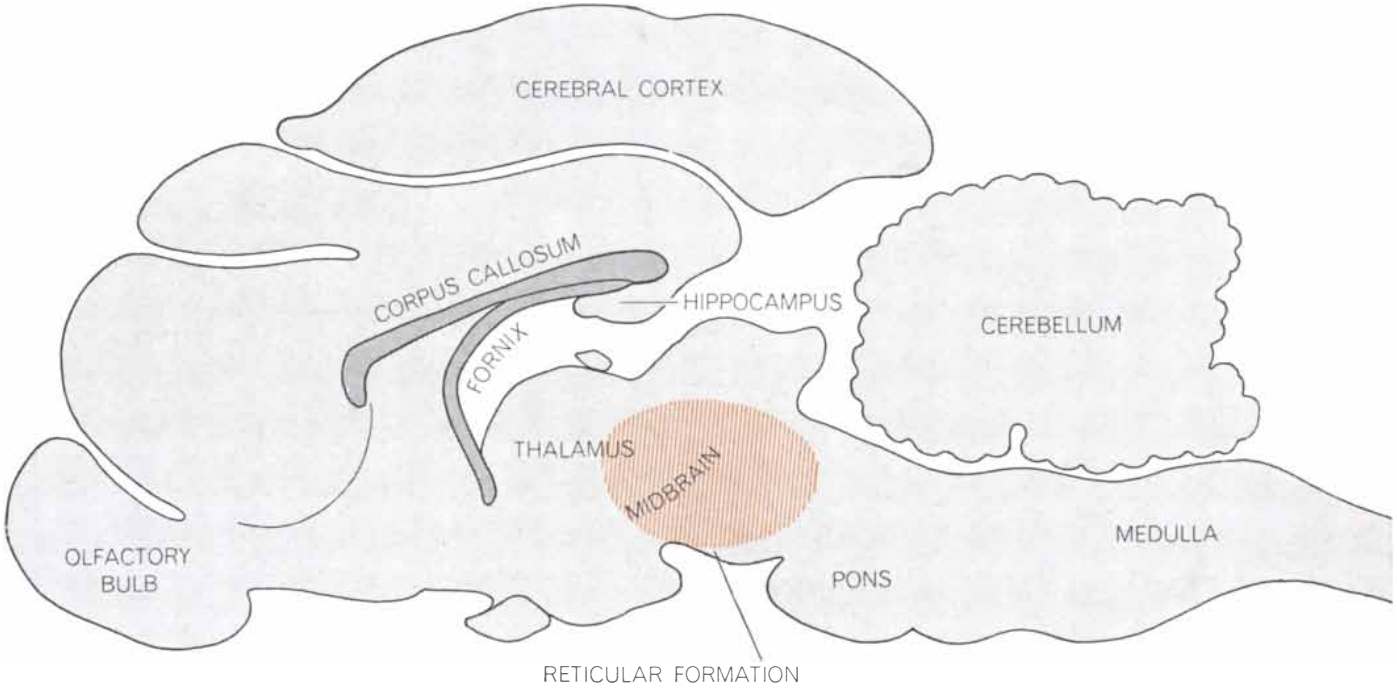
are bursts of rapid eye movements (eight to 30 movements in each burst) in either the side-to-side or the up-and-down direction, like the movements in visual use of the eyes. Occasionally these eyeball movements behind the closed eyelids are accompanied by a sudden dilation of the pupils, which in the main are tightly constricted during sleep. Along with the eye movements go events involving many other parts of the body: small tremors of muscles at the ends of the extremities, causing rapid flexing of the digits and now and then small scratching motions; very rapid movements of the ears, the whiskers, the tail and the tongue, and an episode of fast and irregular breathing.

It is somewhat startling to realize that all this activity goes on during a period in which the animal's muscular system is totally atonic (lacking in tension). The activities are also the accompaniment of deep sleep, as is indicated by the fact that it takes an unusually high level of sound or electrical stimulation to arouse the cat during this phase. The state of deep sleep lasts about six or seven minutes and alternates with periods of lighter sleep that last for an average of about 25 minutes.

To obtain more objective and specific information about events in the brain during sleep we implanted electrodes in the muscles of the neck and in the midbrain of cats. We used animals that were deprived of the brain cortex, since we wished to study the subcortical activities. In the course of extended recordings of the electrical events we were surprised to find that the electrical activity of the neck muscles disappeared completely for regular periods (six minutes long), and the condition persisted when sharp spikes of high voltage showed up now and then in the pontine reticular formation, situated just behind the "arousal center" of the midbrain. These electrical signs were correlated with eye movements of the sleeping animal. Further, we noted that in cats with intact brains both the abolition of muscle tonus and the sharp high-voltage spikes were strikingly correlated with the rapid eye



VARYING RHYTHMS are identified with the various states of sleep. From left to right, a wakeful cat (*1*) shows high-speed alternations in electric potential in both cortical and subcortical regions of the brain, as well as neck-muscle tension. In light sleep (*2*) the cat shows a slower rhythm in the traces from the cortical and subcortical regions, but neck-muscle tension continues. The phasic, or



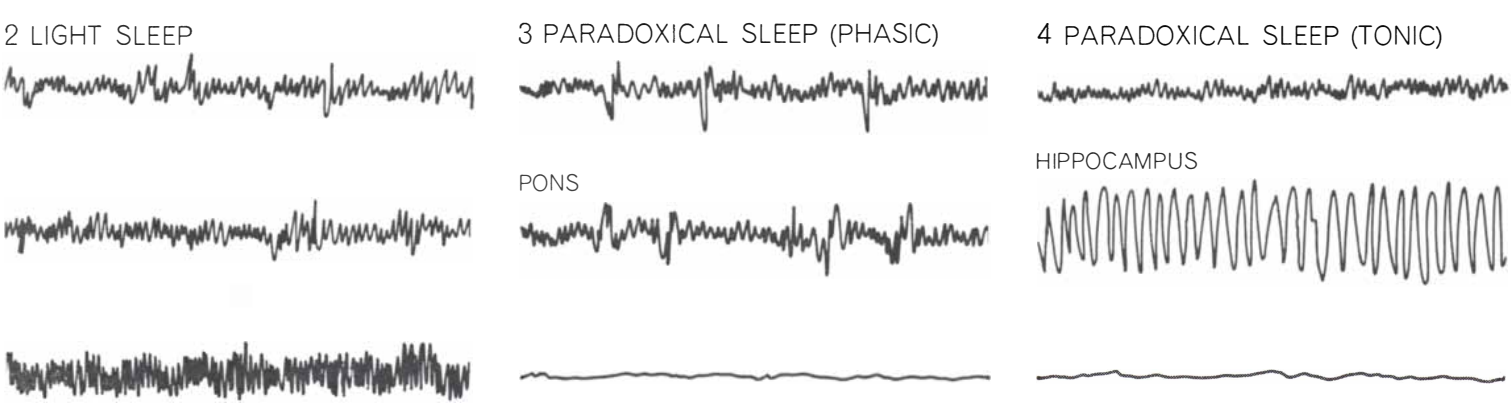
BRAIN SEGMENTS associated with sleep include the reticular formation, which controls wakefulness. This region is under the control of an area in the lower brain. When the control is blocked by making a cut through the pons, a normal cat becomes insomniac.

movement and fast cortical activity Dement had described. These findings presented a paradox. It was surely strange to find fast cortical activity (generally a sign of wakefulness) coupled with complete muscular atony (invariably a sign of deep sleep)!

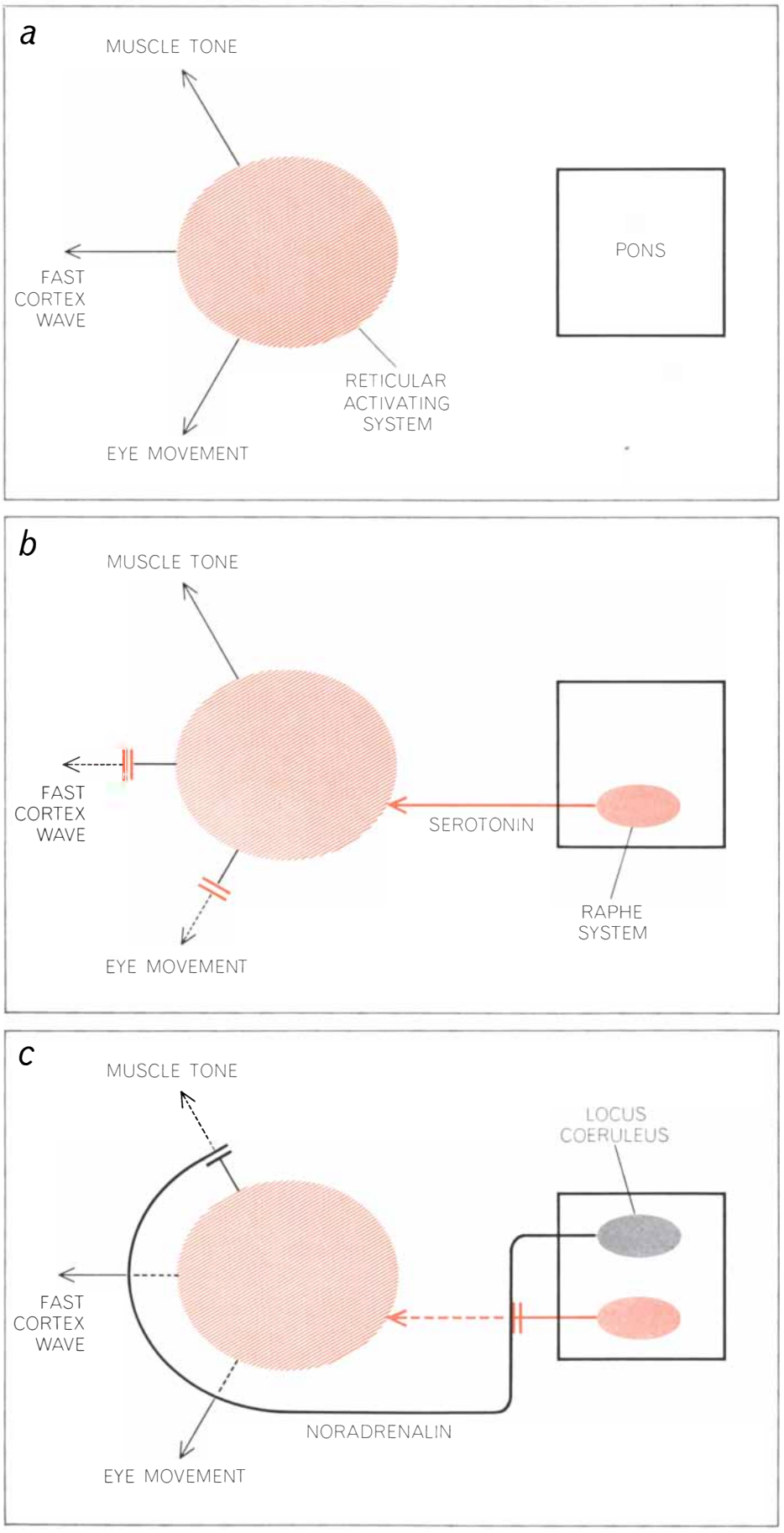
The Two Sleep States

We named this strange state "paradoxical sleep." It is also called deep sleep, fast-wave sleep, rapid-eye-movement (REM) sleep and dreaming sleep, whereas the lighter sleep that precedes it is often called slow-wave sleep. We consider paradoxical sleep a qualitatively distinct state, not simply a deepened version of the first stage of sleep. Very schematically (for the cat) we can describe the three states—wakefulness, light sleep and paradoxical sleep—in the following physiological terms. Wakefulness is accompanied by fast, low-voltage electrical activity in the cortex and the subcortical structures of the brain and by a significant amount of tonus in the muscular system. The first stage of sleep, or light sleep, is characterized by a slackening of electrical activity in the cortex and subcortical structures, by the occurrence of "spindles," or groups of sharp jumps, in the brain waves and by retention of the muscular tension. Paradoxical sleep presents a more complex picture that we must consider in some detail.

We can classify the phenomena in paradoxical sleep under two heads: tonic (those having to do with continuous phenomena) and phasic (those of a periodic character). The principal tonic phenomena observed in the cat are fast electrical waves (almost like those of wakefulness) in the cortex and subcortical structures, very regular "theta" waves at the level of the hippocampus (a structure running from the front to the rear of the brain) and total disappearance of electrical activity in the muscles of the neck. The principal phasic phenomena are high-voltage spikes, isolated or grouped in volleys, that appear at the level of the pons and the rear part of the cortex (which is associated with the visual sys-



periodic, aspects of paradoxical sleep (*3*) are marked by isolated spike discharges from the rear of the cortex and the pons, as well as by rapid eye movement and limb movements. Loss of neck-muscle tension is a tonic (*4*) rather than a phasic phenomenon. Other tonic, or continuous, aspects of paradoxical sleep are high-speed cortical rhythms and regular "theta" waves from hippocampus.



WORKING HYPOTHESIS, proposed by the author to provide a bridge between the neurophysiology and the biochemistry of sleep, suggests that the normal state of wakefulness (*a*) is transformed into light sleep (*b*) when a secretion produced by the nuclei of raphe modifies many effects of the reticular activating system. Paradoxical sleep follows (*c*) when a second secretion, produced by the locus coeruleus, supplants the raphe secretion and produces effects that resemble normal wakefulness except for the loss of muscle tension.

tem). These spikes make their appearance about a minute before the tonic phenomena. Just as the latter show up, the peripheral phasic phenomena come into evidence: rapid eye movements, clawing movements of the paws and so on. The high-voltage spikes during paradoxical sleep in the cat come at a remarkably constant rate: about 60 to 70 per minute.

Our continuous recordings around the clock in a soundproofed cage have shown that cats spend about 35 percent of the time (in the 24-hour day) in the state of wakefulness, 50 percent in light sleep and 15 percent in paradoxical sleep. In most cases the three states follow a regular cycle from wakefulness to light sleep to paradoxical sleep to wakefulness again. An adult cat never goes directly from wakefulness into paradoxical sleep.

Thus we find that the two states of sleep have well-defined and clearly distinct electrical signatures. Equipped with this information, we are better prepared to search for the nervous structures and mechanisms that are responsible for sleep and dreaming.

The Suppression of Wakefulness

The first and most important question we must answer is this: Does the nervous system possess a specific sleep-producing mechanism? In other words, should we not rather confine our research to the operations of the mechanism that keeps us awake? Kleitman has put the issue very clearly; he observes that to say one falls asleep or is put to sleep is not the same as saying one ceases to stay awake. The first statement implies that an active mechanism suppresses the state of wakefulness—a mechanism analogous to applying the brakes in an automobile. The second statement implies that the wakefulness-producing mechanism simply stops operating—a situation analogous to removing the foot from the accelerator. Thus the mechanism responsible for sleep would be negative or passive, not active.

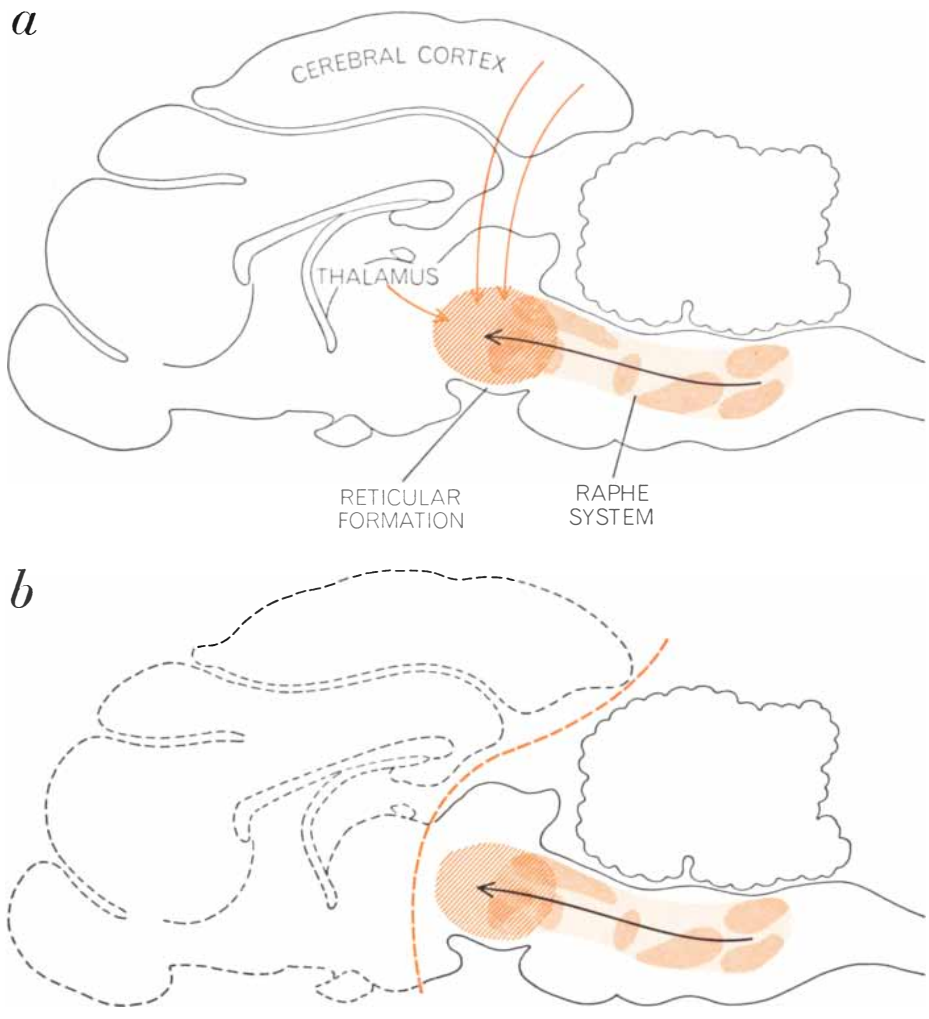
Now, it has been known for nearly two decades that the brain contains a center specifically responsible for maintaining wakefulness. This was discovered by H. W. Magoun of the U.S. and Giuseppe Moruzzi of Italy, working together at Northwestern University [see "The Reticular Formation," by J. D. French; SCIENTIFIC AMERICAN, May, 1957]. They named this center, located in the midbrain, the reticular activating system (RAS). Stimulation of the RAS center in a slumbering animal arouses the animal; conversely, destruction of the center

causes the animal to go into a permanent coma. To explain normal sleep, then, we must find out what process or mechanism brings about a deactivation of the RAS for the period of sleep.

On the basis of the known facts about the RAS there seemed at first no need to invoke the idea of a braking mechanism to account for deactivation of the system. The Belgian neurophysiologist Frédéric Bremer suggested that the RAS could simply lapse into quiescence as a result of a decline of stimuli (such as disturbing noise) from the surroundings [see "Sleep," by Nathaniel Kleitman; SCIENTIFIC AMERICAN, November, 1952].

Several years ago, however, explorations of the brain by the Swiss neurophysiologist W. R. Hess and others began to produce indications that the brain might contain centers that could suppress the activity of the RAS. In these experiments, conducted with cats, the cats fell asleep after electrical stimulation of various regions in the thalamus and elsewhere or after the injection of chemicals into the cerebrum. Interesting as these findings were, they were not very convincing on the question at issue. After all, since a cat normally sleeps about two-thirds of the time anyway, how could one be sure that the applied treatments acted through specific sleep-inducing centers? Moreover, the experiments seemed to implicate nearly all the nerve structures surrounding the RAS, from the cerebral cortex all the way down to the spinal cord, as being capable of inducing sleep. It was implausible that a sleep-inducing system could be so diffuse. Nevertheless, in spite of all these doubts, the experiments at least pointed to the possibility that the RAS might be influenced by other brain centers.

Moruzzi and his group in Italy proceeded to more definitive experiments. Seeking to pin down the location of a center capable of opposing the action of the RAS, they focused their search on the lower part of the brainstem. They chose a site at the middle of the pons in front of the trigeminal nerve, and with cats as subjects they cut completely through the brainstem at that point. The outcome of this operation was that the cats became insomniac: they slept only 20 percent of the time instead of 65 percent! The brain cortex showed the characteristic electrical activity of wakefulness (fast, low-voltage activity), and the eye movements also were those of a wakeful animal pursuing moving objects. The experiments left no doubt that the cut had disconnected the RAS from some structure in the lower part of the brainstem that normally exercised control over the waking center. It was as if a brake had been removed, so that the RAS was essentially unrestricted and kept the animal awake most of the time.



BRAIN STRUCTURES involved in light sleep include the raphe system, which, by producing the monoamine serotonin, serves to counteract the alerting effects of the brain's reticular formation (*"a," color at left*). The author suggests that other nearby structures act to modulate the fast wave pattern of the alert cortex into the slower pattern typical of light sleep. Such slow activity, however, is known to depend on higher as well as lower brain structures (*b*); when a cat is deprived of its cerebral cortex and thalamus, the wave pattern characteristic of light sleep disappears. The reason for this is not yet understood.

The new evidence leads, therefore, to the conclusion that sleeping is subject to both active and passive controls. The active type of control consists in the application of a brake on the RAS by some other brain structure or structures; the passive type corresponds to a letup on the accelerator in the RAS itself.

Sleep Centers

What, and where, are the sleep-inducing centers that act on the RAS? Our suspicions are now focused on a collection of nerve cells at the midline of the brainstem that are known as the "nuclei of raphe" (from a Greek word meaning "seam" and signifying the juncture of the two halves of the brain). In Sweden, Annica Dahlström and Kzell Fuxe have shown that under ultraviolet light these cells emit a yellow fluorescence that shows they are rich in the hormone-like substance serotonin, which is known to have a wide spectrum of powerful effects on the brain and other organs of the body [see "Serotonin," by Irvine H. Page; SCIENTIFIC AMERICAN, December, 1957]. Suspecting from various preliminary pharmacological experiments that serotonin might play a role in sleep, we decided to test the effects of destroying the raphe cells, which are the principal source of the serotonin supply in the brain. We found that when we destroyed 80 percent of these cells at the level of the medulla in cats (the animals could not have survived destruction of a larger percentage), the cats became even more sleepless than those on which Moruzzi had performed his operation. In more than 100 hours of continuous observation with electrical recording instruments, our animals slept less than 10 per-

cent of the time. Our results were closely related to those of Moruzzi's. His operation dividing the brainstem cut through the raphe system. We found that when we destroyed only the raphe cells on one side or the other of the site of his cut, our animals were reduced to the same amount of sleep (20 percent) as those on which he had performed his experiment. This gives us further reason to believe the raphe system may indeed be the main center responsible for bringing on sleep in cats.

These new developments bring serotonin into a prominent place in the research picture and offer an avenue for biochemical attack on the mysteries of sleep. The fact that the raphe cells are chiefly notable for their production of serotonin seems to nominate this substance for an important role in producing the onset of sleep. We have recently been able to demonstrate a significant correlation between the extent of the lesion of the raphe system, the decrease in sleep and the decrease in the amount of serotonin in the brain as measured by means of spectrofluorescent techniques.

In physiological terms we can begin to see the outlines of the system of brain structures involved in initiating the onset of sleep and maintaining the first stage of light slumber. At the level of the brainstem, probably within the raphe system, there are structures that apparently counteract the RAS and by their braking action cause the animal to fall asleep. Associated with these structures there presumably are nearby structures that account for the modulations of electrical activity (notably the slow brain waves) that have been observed to accompany light sleep. This slow activity seems to depend primarily, however, on the higher brain structures, particularly the cortex and the thalamus; in a decorticated animal the pattern characteristic of light sleep does not make its appearance. We must therefore conclude that the set of mechanisms brought into play during the process of falling asleep is a complicated one and that a number of steps in the process still remain to be discovered.

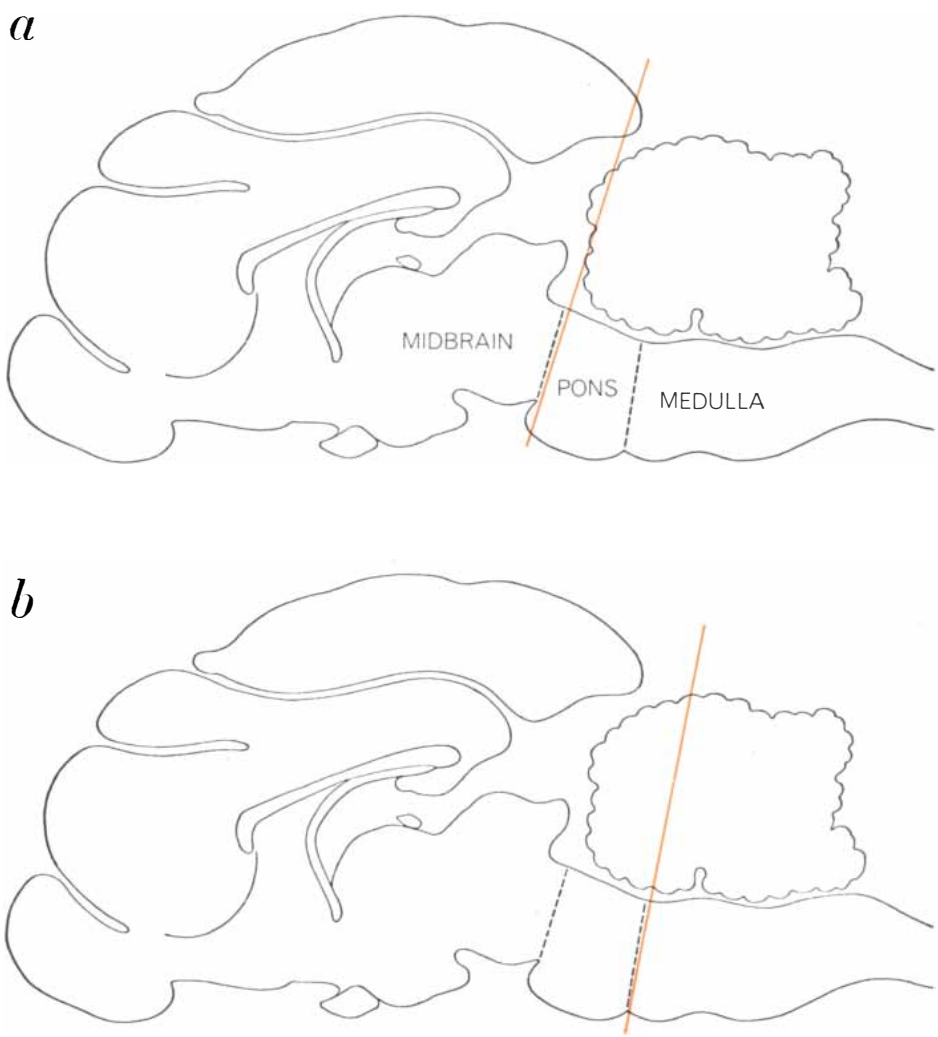
Paradoxical Sleep

In searching for the structures involved in paradoxical, or deep, sleep we are in a somewhat better position. When an animal is in that state, we have as clues to guide us not only the electrical activities in the brain but also conclusive and readily observable signs such as the disappearance of tonus in the muscles of the neck. This is the single most reliable mark of paradoxical sleep. Furthermore, it enables us to study animals that have been subjected to drastic operations we cannot use in the study of light sleep because they obliterate the electrical activities that identify the falling-asleep stage.

A cat whose brainstem has been cut through at the level of the pons, so that essentially all the upper part of the brain has been removed, still exhibits the cycle of waking and deep sleep. Such an animal can be kept alive for several months, and with the regularity of a biological clock it oscillates between wakefulness and the state of paradoxical sleep, in which it spends only about 10 percent of the time. This state is signaled, as in normal animals, by the typical slackness of the neck muscles, by the electroencephalographic spikes denoting electrical activity in the pons structures and by lateral movements of the eyeballs.

When, however, we sever the brainstem at a lower level, in the lower part of the pons just ahead of the medulla, the animal no longer falls into paradoxical sleep. The sign that marks this cyclical state—periodic loss of muscle tonus—disappears. It seems, therefore, that the onset of paradoxical sleep must be triggered by the action of structures somewhere in the middle portion of the pons. Further experiments have made it possible for us to locate these structures rather precisely. We have found that paradoxical sleep can be abolished by destroying certain nerve cells in a dorsal area of the pons known as the locus coeruleus. Dahlström and Fuxe have shown that these cells have a green fluorescence under ultraviolet light and that they contain noradrenalin. Hence it seems that noradrenalin may play a role in producing paradoxical sleep similar to the one serotonin apparently plays in bringing about light sleep.

What mechanism is responsible for the elimination of muscular tonus that accompanies paradoxical sleep? It seems



PARADOXICAL-SLEEP STRUCTURES evidently lie far back along the brainstem. A cat deprived of all its higher brain function by means of a cut through the pons (*a*) will live for months, alternately awake and in paradoxical sleep. If a cut is made lower (*b*) along the brainstem, however, the cat will no longer fall into paradoxical sleep, because the cut destroys the brain cells in that region, which produce another monoamine, noradrenalin.

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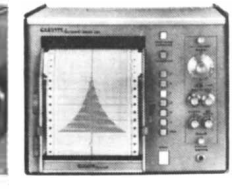

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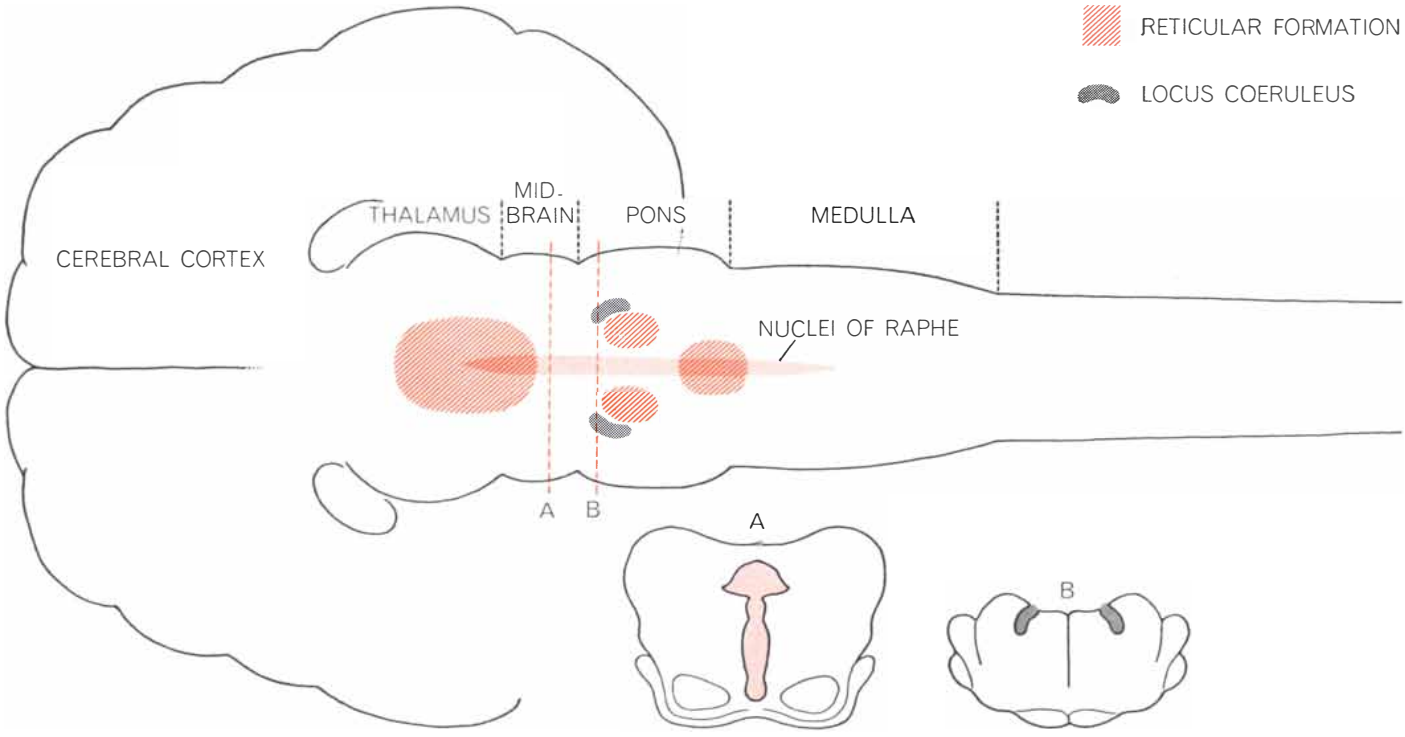


CAT'S BRAINSTEM is the site of the two groups of cells that produce the substances affecting light and paradoxical sleep. The nuclei of raphe (*color*) secrete serotonin; nerve cells lower down the pons, known as the locus coeruleus (*gray*), secrete noradrenalin.

most likely that the source of this inhibition lies in the spinal cord, and Moruzzi and his colleague Ottavio Pompeiano are making a detailed investigation of this hypothesis.

The objective information about paradoxical sleep developed so far gives us some suggestions about the mechanisms involved in dreaming. The controlling structures apparently are located in the dorsal part of the pons. They give rise to spontaneous excitations that travel mainly to the brain's visual tracts, and it seems possible that this excitation is related to the formation of the images that one "sees" in dreams. Regardless of how strongly the brain is stimulated by these spontaneous impulses (as Edward V. Evarts of the National Institute of Mental Health and others have shown by means of microelectrode recordings of the visual system), during sleep the body's motor system remains inactive because a potent braking mechanism blocks electrical excitation of the motor nerves. This inhibitory mechanism seems to be controlled by the hormone-secreting nerves of the locus coeruleus structure. If this structure is destroyed, the animal may periodically exhibit a spasm of active behavior, which looks very much as if it is generated by the hallucinations of a dream. In such episodes the cat, although it evinces the unmistakable signs of deep sleep and does not respond to external stimuli, will sometimes perform bodily movements of rage, fear or pursuit for a minute or two. The sleeping animal's behavior may even be so fierce as to make the experimenter recoil.

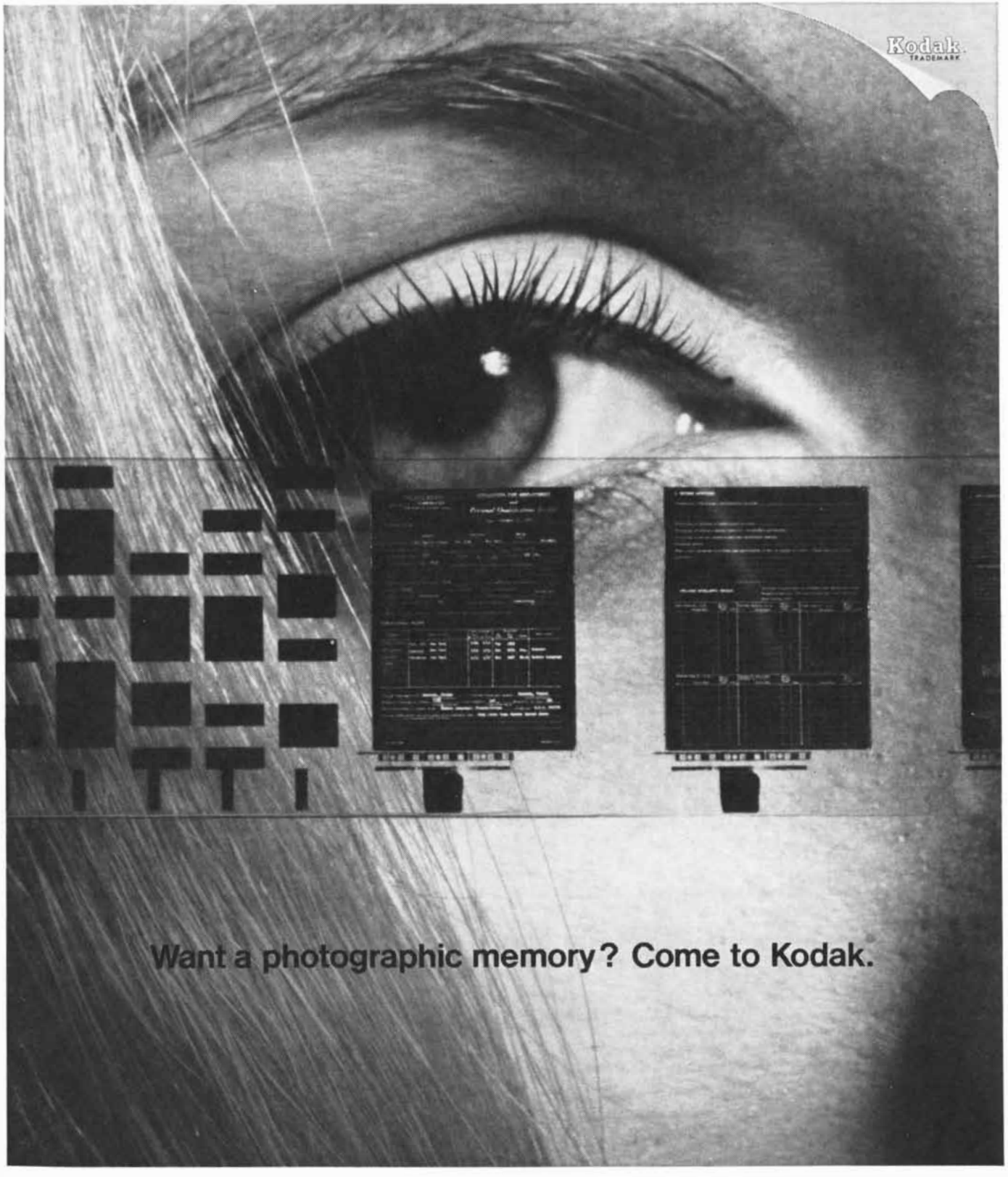
All in all the experimental evidence from mammals obliges us to conclude that sleep has a fundamental duality; deep sleep is distinctly different from light sleep, and the duality is founded on physiological mechanisms and probably on biochemical ones as well. Can we shed further light on the subject by examining animal evolution?

The Evolution of Sleep

Looking into this question systematically in our laboratory, we failed to find any evidence of paradoxical sleep in the tortoise and concluded that probably reptiles in general were capable only of light sleep. Among birds, however, we start to see a beginning of paradoxical sleep, albeit very brief. In our subjects—pigeons, chicks and other fowl—this state of sleep lasts no longer than 15 seconds at a time and makes up only .5 percent of the total sleeping time, contrasted with the higher mammals' 20 to 30 percent. In the mammalian order all the animals that have been studied, from the mouse to the chimpanzee, spend a substantial portion of their sleeping time in paradoxical sleep. We find a fairly strong indication that the hunting species (man, the cat, the dog) enjoy more deep sleep than the hunted (rabbits, ruminants). In our tests the former average 20 percent of total sleep time in paradoxical sleep, whereas the latter average only 5 to 10 percent. Further studies are needed, however, to determine if what we found in our caged animals is also true of their sleep in their natural environments.

The evolutionary evidence shows, then, that the early vertebrates slept only lightly and deep sleep came as a rather late development in animal evolution. Curiously, however, it turns out that the opposite is true in the development of a young individual; in this case ontogeny does not follow phylogeny. In the mammals (cat or man) light sleep does not occur until the nervous system has acquired a certain amount of maturity. A newborn kitten in its first days of life spends half of its time in the waking state and half in paradoxical sleep, going directly from one state into the other, whereas in the adult cat there is almost invariably a transitional period of light sleep. By the end of the first month the kitten's time is divided equally among wakefulness, light sleep and paradoxical sleep (that is, a third in each); thereafter both wakefulness and light sleep increase until adulthood stabilizes the proportions of the three states at 35, 50 and 15 percent respectively.

Considering these facts of evolution and development, we are confronted with the question: What function does paradoxical sleep serve after all? As Kleitman reported in his article "Patterns



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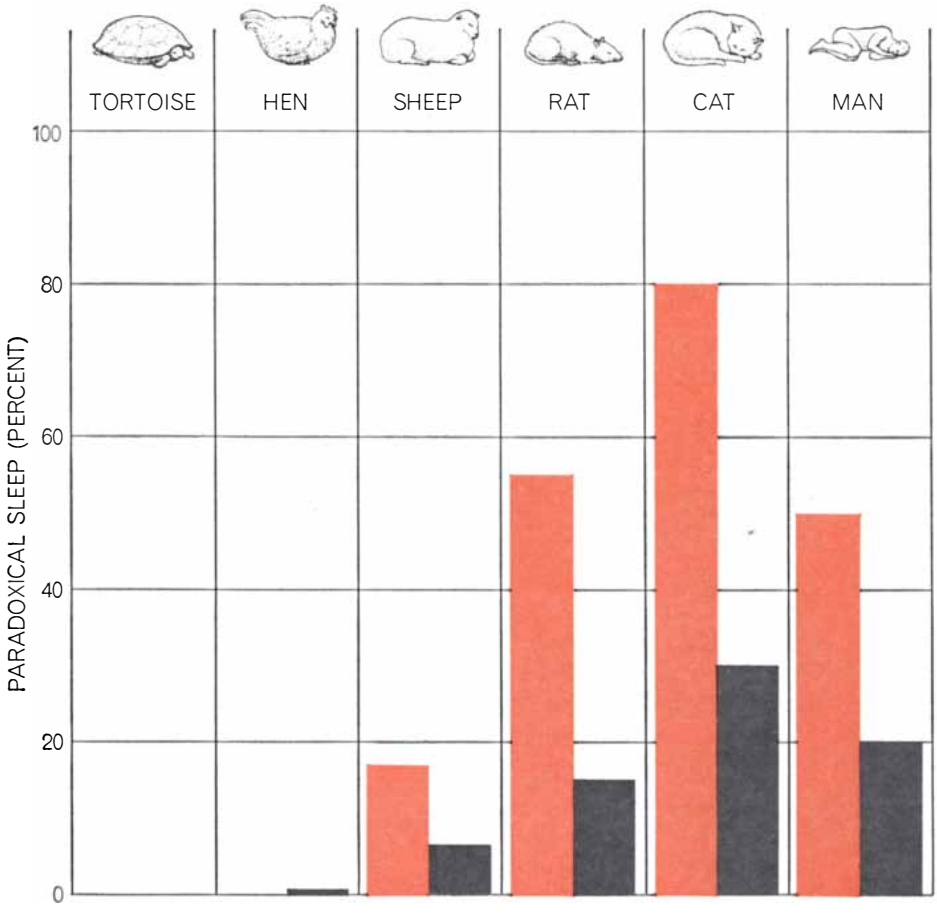

PARADOXICAL SLEEP among three vertebrate classes of increasing evolutionary complexity is shown as a percentage of each animal's time spent in light sleep. None is known in the case of the reptile, a tortoise; in the case of the hen it is only two-tenths of 1 percent of the total. In the case of each of the four mammal species shown, the newborn spend at least twice as much time in paradoxical sleep (*color*) as do their adult counterparts (*black*).

of Dreaming," Dement found that when he repeatedly interrupted people's dreams by waking them, this had the effect of making them dream more during their subsequent sleep periods. These results indicated that dreaming fulfills some genuine need. What that need may be remains a mystery. Dement's subjects showed no detectable disturbances of any importance—emotional or physiological—as a result of their deprivation of dreaming.

We have found much the same thing to be true of the deprivation of paradoxical sleep in cats. For such a test we place a cat on a small pedestal in a pool of water with the pedestal barely topping the water surface. Each time the cat drops off into paradoxical sleep the relaxation of its neck muscles causes its head to droop into the water and this wakes the animal up. Cats that have been deprived of paradoxical sleep in this way for several weeks show no profound disturbances, aside from a modest speeding up of the heart rate. They do, however, have a characteristic pattern of aftereffects with respect to paradoxical sleep. For several days following their removal from the pedestal they spend much more than the usual amount of time (up to 60 percent) in paradoxical sleep, as if to catch up. After this rebound they gradually recover the normal rhythm (15 percent in deep sleep), and only then does the heart slow to the normal rate. The recovery period depends on the length of the deprivation period: a cat that has gone without paradoxical sleep for 20 days takes about 10 days to return to normal.

The Chemistry of Sleep

All of this suggests that some chemical process takes place during the recovery period. Let us suppose that the deprivation of paradoxical sleep causes a certain substance related to the nervous system to accumulate. The excess of paradoxical sleep during the recovery period will then be occupied with elimination of this "substance," presumably through the agency of "enzymatic" factors that act only during paradoxical sleep.

There is reason to believe that certain enzymes called monoamine oxidases, which oxidize substances having a single amine group, play a crucial role in bringing about the transition from light sleep to paradoxical sleep. We have found that drugs capable of inhibiting these enzymes can suppress paradoxical sleep in cats without affecting either light sleep or wakefulness. A single injection of the drug nialamide, for example, will eliminate paradoxical sleep from the cycle for a period of hundreds of hours. We have also found that this potent drug can suppress paradoxical sleep in cats that have first been deprived of such sleep for a long period in the pool experiment.

The findings concerning the probable importance of the monoamine oxidases in the sleep mechanism raise the hope that it may soon be possible to build a bridge between neurophysiology and biochemistry in the investigation of sleep. If it is indeed a fact that these enzymes play an important role in sleep, this tends to strengthen the hypothesis that serotonin and noradrenalin, which are monoamines, are involved in the two states of sleep—serotonin in light sleep and noradrenalin in paradoxical sleep. There are other bits of chemical evidence that support the same view. For example, the drug reserpine, which is known to prevent the accumulation of monoamines at places where these compounds are usually deposited, has been found to be capable of producing some specific electrical signs of paradoxical sleep in experimental animals. Further, the injection of certain precursors involved in the synthesis of serotonin in the brain can produce a state resembling light sleep, whereas drugs that selectively depress the serotonin level in the brain produce a state of permanent wakefulness.

We can put together a tentative working hypothesis about the brain mechanisms that control sleep. It seems that the raphe system is the seat responsible for the onset of light sleep, and that it operates through the secretion of serotonin. Similarly, the locus coeruleus harbors the system responsible for producing deep sleep, and this uses noradrenalin as its agent. In cyclic fashion these two systems apply brakes to the reticular activating system responsible for wakefulness and also influence all the other nerve systems in the brain, notably those involved in dreaming.

Dreaming itself, particularly the question of its evolutionary origin and what function it serves, is still one of the great mysteries of biology. With the discovery of its objective accompaniments and the intriguing phenomenon of paradoxical sleep, however, it seems that we have set foot on a new continent that holds promise of exciting explorations.

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

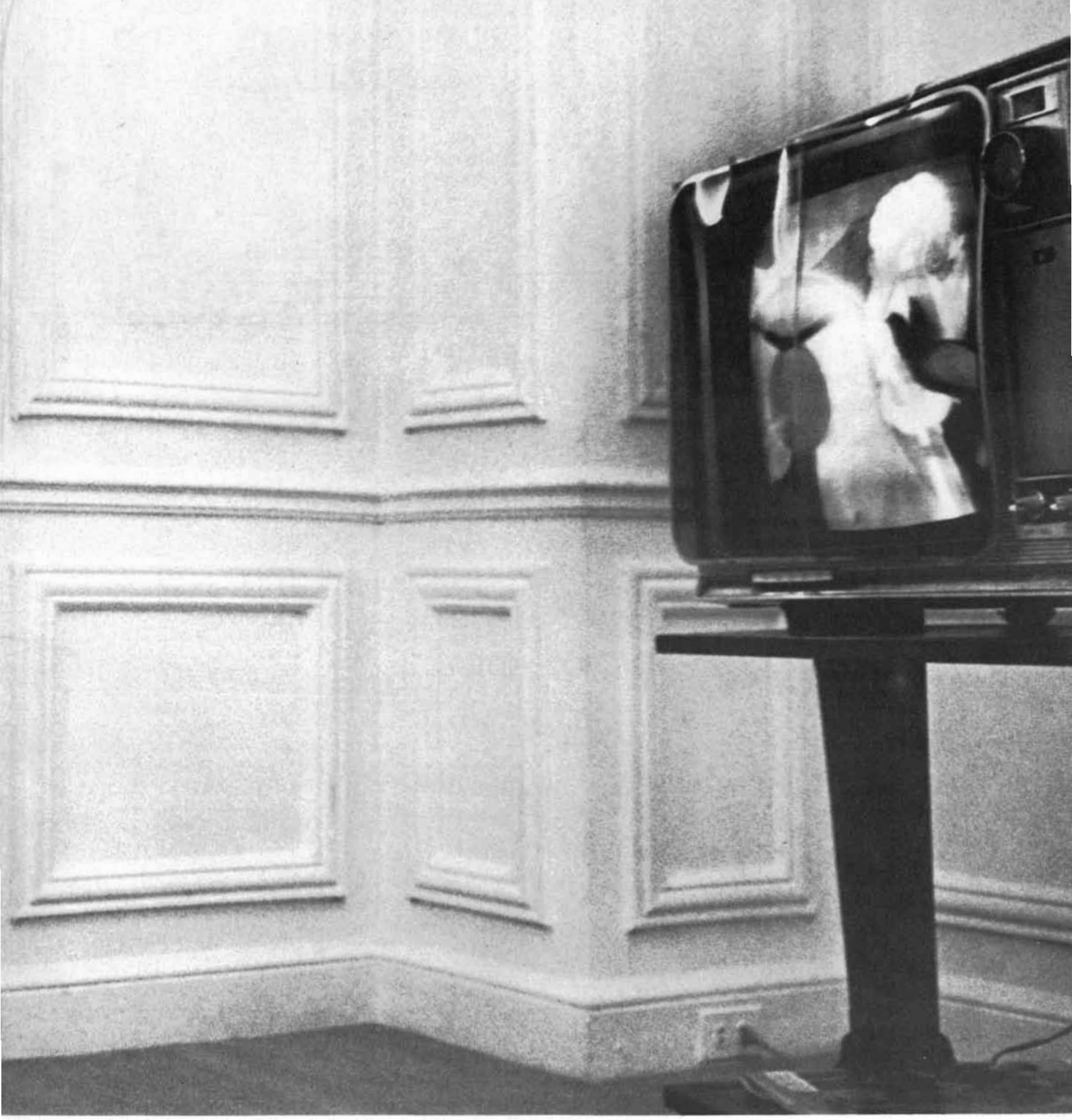
He must be taught to use binocular vision. To help him, the professional eye examiner may prescribe an unusual form of therapy: watching television with the Polaroid/American Optical TV Trainer.

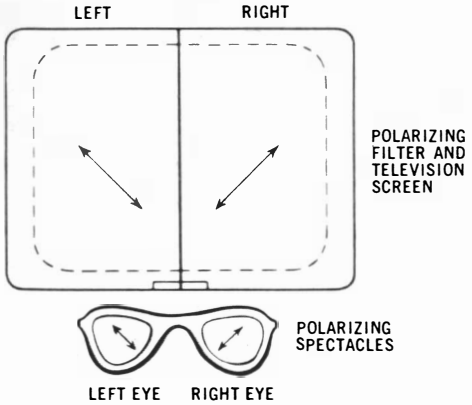
The TV Trainer is simple. It consists of a pair of Polaroid polarizing spectacles and a special polarizing filter which attaches to an ordinary TV screen. (Since 1937 Polaroid polarizing filters have been put to many uses. From polariscopes to sunglasses. From analyzing the atmospheres of planets to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

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

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

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





(The arrows indicate the polarizing axes.)

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

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

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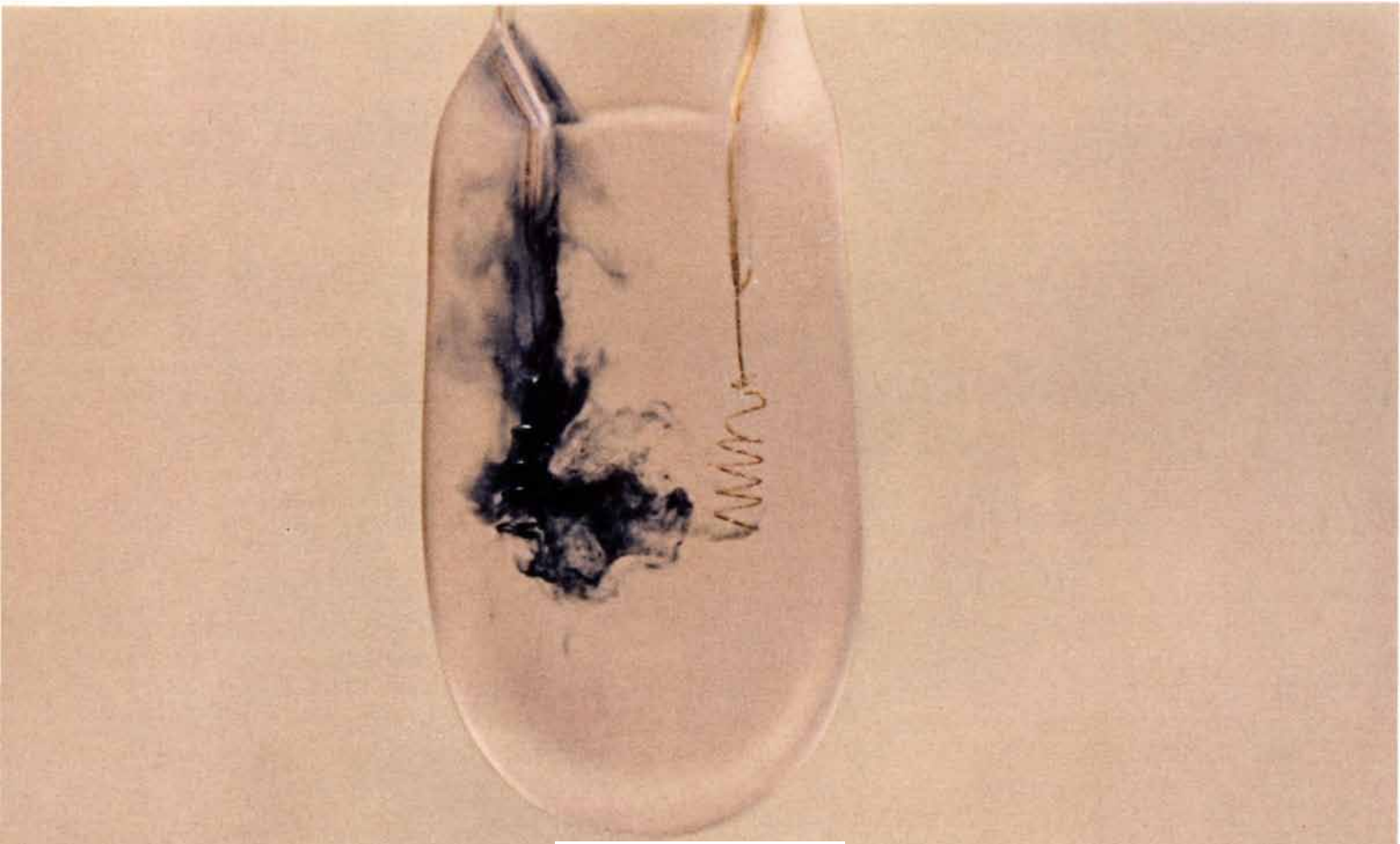
LUMP OF SODIUM (Na) dissolving in pure liquid ammonia (NH_3) produces a deep blue solution (*above*) in which each sodium atom is ionized to form a solvated positive ion of the metal (Na^+) and a solvated electron (e^-) that is free to move over a number of solvent molecules. Hydrogen gas (H_2) evolved by the reaction of the solvated electron with ammonia forces small pieces of metal to be ejected into the solvent, resulting in the blue streaks.

PLATINUM ELECTRODES can also be used to "inject" electrons directly into liquid ammonia (*below*) simply by making one electrode (*left*) slightly negative with respect to the other electrode (*right*). Positive ammonium ions (NH_4^+) produced by the reaction at the positive electrode migrate toward the negative electrode, where they react rapidly with solvated electrons to form hydrogen. In both photographs the less dense blue solution rises to the surface.



THE SOLVATED ELECTRON

It is an electron that is released into solution when certain metals are dissolved in a liquid such as ammonia. It can also be released by ionizing radiation, and it may play a role in many chemical reactions

by James L. Dye

Drop a lump of sodium into a container of pure liquid ammonia and something very peculiar happens. The silvery metal reacts with the clear liquid to form a deep blue solution. The exact nature of this solution has intrigued chemists for more than a century. We now know that in ammonia each sodium atom becomes a positively charged ion, freeing one of its electrons to move independently through the solvent. These "excess" electrons, by-products of the ionization process, are called solvated electrons.

Until quite recently the study of solvated electrons was confined chiefly to solutions of highly reactive alkali metals (sodium, lithium, potassium, rubidium and cesium) in a small group of solvents (ammonia, certain amines closely related to ammonia, and a few ethers). In addition, it was known that solvated electrons could be obtained by "injecting" them directly into such solvents by means of a negatively charged electrode.

Beginning in 1960 workers in Britain and the U.S. showed that they could produce solvated electrons with extremely short lifetimes by exposing a wide variety of solvents, including water, to a burst of high-energy ionizing radiation. Since then hundreds of chemical reactions involving solvated electrons have been studied with the aid of such "radiolytic" techniques. In spite of their brief existence, solvated electrons appear to play an important role in the chemical processes that occur in a liquid when radiation is absorbed. It is still too early to tell what general implications, if any, this fact has for biology, but it seems certain that solvated electrons are involved in some way with the sequence of chemical reactions that leads to radiation damage in living tissues.

It was the German chemist W. Weyl who discovered in 1864 that a deep blue solution can be formed by dissolving either sodium or potassium in ammonia. He also noted that by boiling away the ammonia he was able to recover the pure metals. Attracted by Weyl's discovery, the French chemist A. Joannis investigated the metal-ammonia solutions and concluded that they must contain "metal ammoniums," ordinary chemical compounds of metal and ammonia. Joannis' view of the matter stood unchallenged for many years. Then in 1897 an undergraduate at the University of Kansas named Hamilton P. Cady measured a property that contradicted the accepted view; he found that the electrical conductivity of the metal-ammonia solutions was much higher than it was for solutions of simple salts in ammonia. Ten years later a student of Cady's, Charles Kraus (now professor emeritus at Brown University), embarked on a series of studies of the metal-ammonia solutions that spanned the period from 1907 to 1934. Kraus's measurements of the physical properties of the solutions were remarkably accurate, and in many instances his data are the best available today. It was Kraus who first showed that the "metal ammoniums" were really solutions of metal ions and solvated electrons.

The easiest way to produce solvated electrons in the laboratory is still to dissolve one of the alkali metals in a suitable solvent. My colleagues and I at Michigan State University have carried out a variety of experiments on metal-amine solutions using this simple approach. By varying the proportion of the metal to the solvent one can obtain solutions of any desired concentration up to the limit of solubility. In ammonia this limit can be in excess of five moles of metal per liter of solution. (A mole, or gram molecule, is the amount of a substance that has a weight in grams equal numerically to its molecular weight.) Dilute solutions of sodium in ammonia are blue, whereas concentrated solutions have a bronzelike luster. The metal-containing solutions are generally less dense than the solvents, and in some cases the system separates into two liquid layers, the less dense concentrated phase floating on the denser dilute phase [*see illustration on page 80*]. In fact, a saturated solution of lithium in ammonia is the lightest-known liquid at room temperature, having a density less than half that of water.

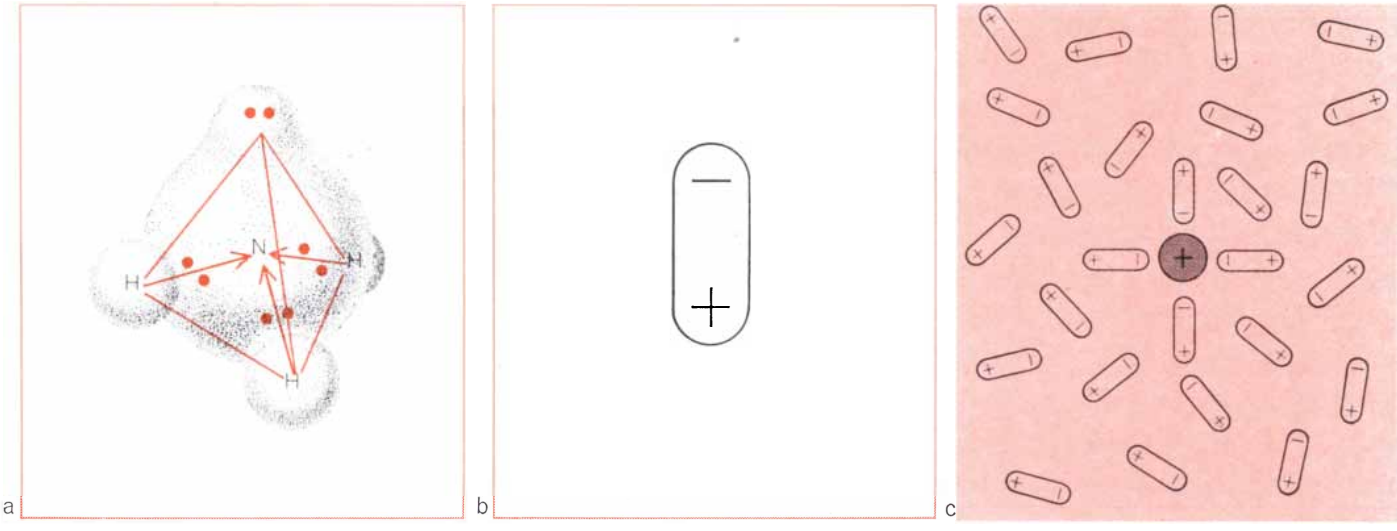
The reason so few solvents have been found suitable for solvation experiments is that the solvated electron is extremely reactive. Most solvents react rapidly with the solvated electron. In water, for example, the reaction is so fast that any attempt to dissolve sodium (Na) in water (H_2O) results merely in the production of sodium hydroxide (NaOH) and hydrogen gas (H_2). Even in ammonia (NH_3) the solutions will decompose spontaneously if the solvent is not pure or if the apparatus has not been cleaned carefully. It is only because the reaction of the solvated electron with ammonia is comparatively slow in the absence of a catalyst that the properties of metal-ammonia solutions can be studied at all.

Before considering the complications that arise when solvated electrons interact with one another and with substances other than the solvent, I should like to describe briefly the process of solvation itself. To begin with, how can a free electron become bound to a solvent molecule? Although a very weak binding of excess electrons can take place even in liquid helium, we are interested only in the much stronger binding

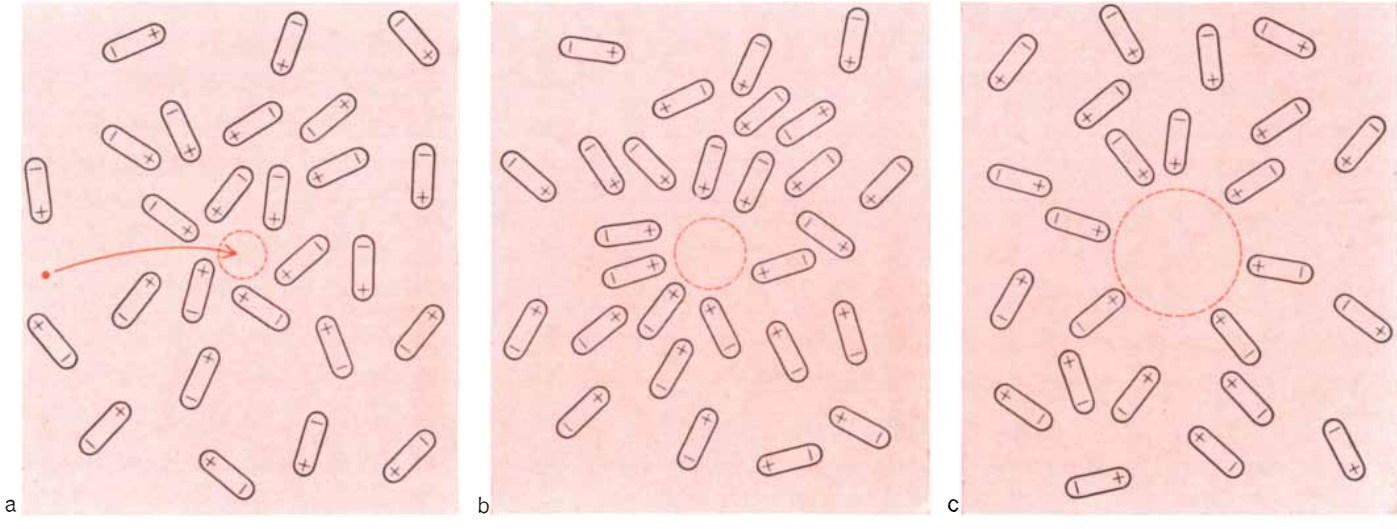
of electrons in "polar" liquids—liquids whose molecules resemble permanent magnetic dipoles because of the separation of electric charges within each molecule [*see upper illustration below*]. A positively charged ion will attract the negative ends of such solvent dipoles, whereas a negatively charged ion will attract the positive ends of the dipoles. In either case the ions are said to be solvated.

In the case of actual positive and negative ions the first layer of solvent molecules around the ion is rather tightly bound to the ion and moves with it through the solution. By their partial orientation even the second and third solvent layers contribute significantly to the solvation energy of the ion. An electron differs from an actual negative ion, however, in that the electron can move much more rapidly than the heavier solvent molecules. As a result the solvent dipoles cannot rotate fast enough to "point" toward the electron as it moves about. Thus the solvent dipoles orient themselves toward the average position of the electron.

This partial orientation of solvent molecules in turn provides a "binding center" for the electron, which can then become "trapped" in a polarized center of its own making [*see lower illustration below*]. The time required to form such a trap is only a hundred-billionth of a second. Solvent molecules in addition to those nearest the center of the trap are also partially oriented, tending to have their positive ends toward the center. Normal thermal agitation can destroy this secondary alignment and cause the actual orientation around a



SOLVATION of a positive ion results from the attractive force that exists between the ion and the negatively charged ends of the molecules in a "polar" solvent such as ammonia. In the pyramid-shaped ammonia molecule (*a*) each pair of bonding electrons (*colored dots*) is more strongly attracted to the nitrogen atom (*N*) than to a hydrogen atom (*H*) in the base of the pyramid. As a result the electron pairs tend to move toward the nitrogen atom (*colored arrows*). This makes the nitrogen end of the molecule negative and the hydrogen end positive. The ammonia molecule is represented schematically as an electric dipole in *b*. A positive ion will tend to hold the closest layer of such dipoles in a rather fixed orientation (*c*). A secondary solvation layer is also partially oriented toward the positive ion.



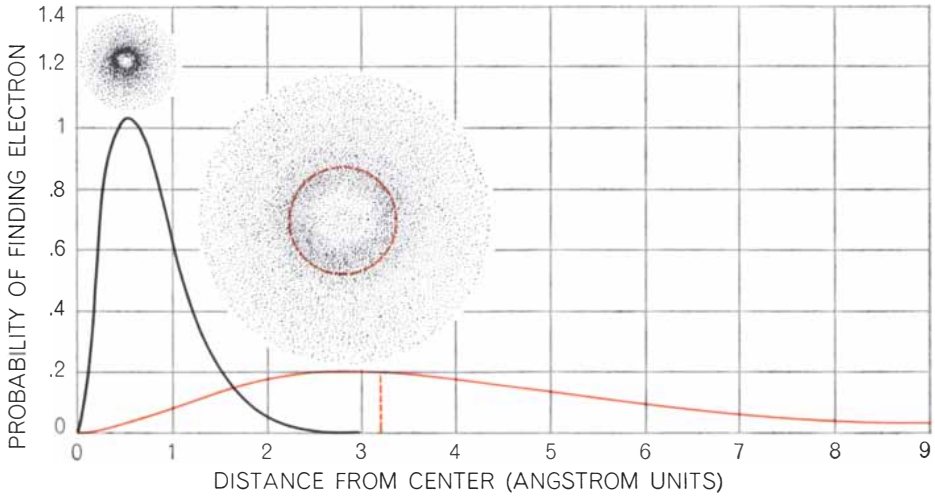
SOLVATED ELECTRON differs from a solvated negative ion in that the electron can move much more rapidly than the heavier solvent molecules. In *a* a low-energy electron is attracted to a region of accidental polarization caused by the random thermal motion of the solvent molecules. In *b* the molecules in the immediate vicinity of the electron cannot rotate fast enough to point their positive ends toward the electron as it moves about; instead the molecules orient themselves toward the average position of the electron. In *c*, about a hundred-billionth of a second later, the fully formed "trap" provides a strong attractive center for the electron. The positive ends of the molecules tend to repel one another, resulting in the formation of an enlarged cavity completely empty of solvent molecules.

particular electron to vary with time. Because of such fluctuations, an actual solution contains traps that have many different solvent-molecule orientations, with the result that a broad range of binding energies is possible for the solvated electron.

Since the positive ends of the solvent dipoles tend to point toward the center of the trap, a repulsive force exists between these identically charged ends. The repulsive force pushes the solvent molecules away from the center of the trap, causing the formation of an enlarged cavity completely empty of solvent molecules. The normal attractive forces between the solvent molecules (which hold the liquid together in the first place) limit the size of this cavity. For a solvent such as water, which has comparatively strong bonds between molecules, the cavity is probably not much larger than the vacancies normally present in most liquids. In liquid ammonia, however, the cavity appears to have a diameter of some 6.5 angstrom units. This means that an empty space large enough to hold four or five ammonia molecules can be formed by the repulsive forces between the solvent dipoles surrounding a solvated ion.

The "cavity model" of solvation was proposed in 1946 by the late Richard Ogg of Stanford University and has since been extensively developed by a number of investigators, notably Joshua Jortner of the University of Tel Aviv. Although not everyone accepts the cavity model, it is generally agreed that solvated electrons in polar solvents are trapped by some kind of reorientation or distortion of the solvent molecules.

The center of average positive charge for a given trap is strictly localized and can move only when the solvent molecules move. The solvated electron, on the other hand, can move rapidly not only within the cavity but also among the solvent molecules in the vicinity of the trap. The motion of the electron cannot be described in detail, but the average electron density, which extends over a large number of solvent molecules, can be estimated. When this average distribution is compared with the average electron charge distribution for, say, a hydrogen atom [*see illustration on this page*], it is evident that the solvated electron, which is attracted only to a fluctuating region of positive charge, is much freer to roam about than an electron that is attracted to the positively charged proton at the center of a hydrogen atom. The extent to which the solvated electron penetrates the solvent is indicated by the comparatively large fraction of time the electron spends outside the limits of the cavity.



AVERAGE CHARGE DISTRIBUTIONS for a solvated electron in ammonia (*colored curve*) and for an electron in a hydrogen atom (*black curve*) are compared. Both charge distributions are spherically symmetrical about the center. The solvated electron is much freer to roam about and spends much of its time outside the cavity (*broken colored line*).

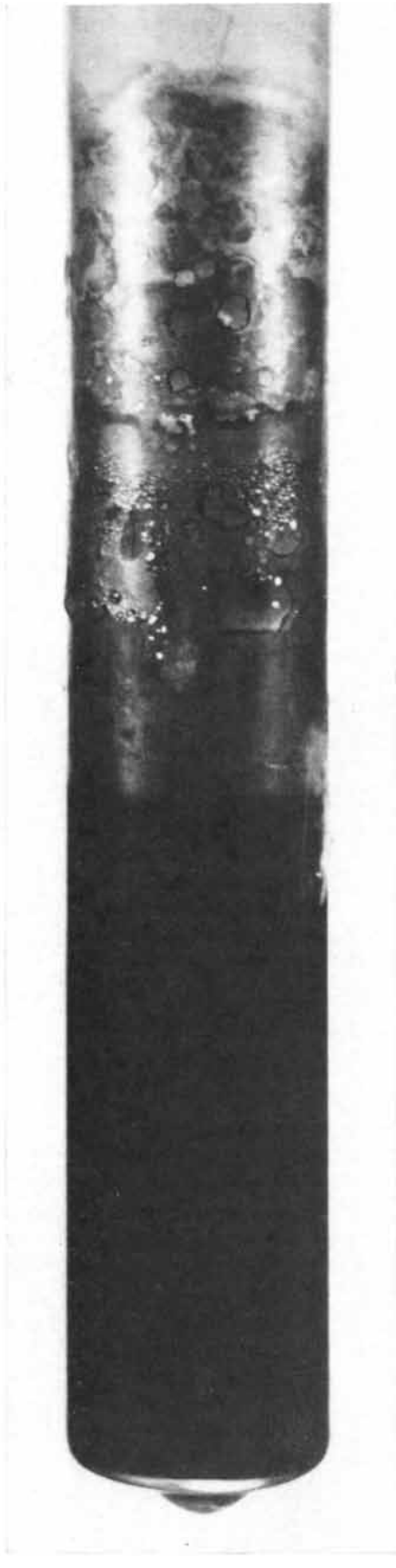
Because solvated electrons interact so readily with positive ions, the properties of isolated solvated electrons can be determined only by studying very dilute solutions. Most of our knowledge of the physical properties of solvated electrons comes from studies of metal-ammonia solutions, conducted over a period of many years, whereas information about the chemical activity of such electrons comes largely from the radiolytic experiments of recent years.

The property that best distinguishes a solvated electron from the rest of the electrons in a solution is its binding energy. Solvated electrons are rather loosely bound and are free to move over a number of solvent molecules. Localized electrons, on the other hand, are strongly bound to particular solvent molecules and cannot move easily from one molecule to another. It has been recognized for many years that when certain molecules are exposed to high-energy radiation, they are ionized, that is, they lose some of their electrons. The radiation can consist of alpha rays, beta rays or gamma rays from radioactive or cosmic sources, or it can be produced in the laboratory in the form of X rays or beams of electrons or other accelerated particles.

The minimum energy required to ionize a molecule of water is 13 electron volts (eV). Typical particle beams used in radiation chemistry have energies of several million electron volts (MeV) per particle. This means that a single high-energy particle can ionize many molecules of water. Moreover, electrons can be ejected from a water molecule with a considerable transfer of energy, so that they may be capable of ionizing other water molecules. Meanwhile the primary energetic particle can continue to ionize water molecules until its energy has been spent. In this way a single 5-MeV particle can give rise to the ionization of about 200,000 water molecules.

What happens to an electron that has been ejected from a water molecule? The excess energy of the electron is quickly lost to the surrounding water molecules (within 10^{-13} second). Meanwhile the positive water ion (H_2O^+) left behind can react with a neutral neighbor (H_2O) to form the very reactive hydroxyl radical (OH) and the stable hydronium ion (H_3O^+). During the next time period (until 10^{-11} second has elapsed) the electron can either be recaptured by the H_3O^+ ion to produce a hydrogen atom (H) and water (H_2O) or it can interact with the water molecules to become hydrated, that is, solvated in water.

The possibility of electron hydration was recognized as early as 1953 on theoretical grounds by Robert L. Platzman of the Argonne National Laboratory, but it was not until the 1960's that the production of hydrated electrons by the radiolysis of water was recognized. In the meantime it was widely thought that hydrogen atoms and hydroxyl radicals resulted from the radiolysis, and that these radicals then reacted further to produce hydrogen



CONCENTRATED SOLUTION of sodium in liquid ammonia separates into two phases at low temperatures. The more concentrated phase (*top half of test tube*), which has a metallic bronze color, is less dense and floats on the dilute phase (*bottom half of test tube*), which is deep blue. At higher temperatures two phases would merge into one.

and water. At a conference in 1953 Platzman was asked: "Do I understand that you think that irradiated ammonia ought to turn blue if it is pure?" He answered with remarkable foresight: "More than that. I think irradiated water turns blue and we just don't see it."

After 1952 it became increasingly apparent that more than one reducing, or electron-supplying, agent is produced when water is subjected to radiolysis. Because the products formed by reactions of the hydrated electron and of the hydrogen atom are usually indistinguishable, it was difficult to separate the effects of the two entities. Direct measurements of reaction rates could not be made at the time, so that it was necessary to determine relative rates by the study of competing reactions. Such studies in both Britain and the U.S. in the late 1950's confirmed the presence of two reducing agents. For example, Nathaniel Barr and Augustine Allen of the Brookhaven National Laboratory showed in 1959 that reducing agents resembling hydrogen atoms produced under one set of conditions reacted at about the same rate with oxygen as with hydrogen peroxide, but when produced under another set of conditions they reacted far more rapidly with oxygen than with hydrogen peroxide. Barr and Allen suggested that different reducing agents are formed by the two methods and that one of the agents is the hydrated electron.

In 1962 Gideon Czapski and Harold Schwarz of Brookhaven compared the reaction rate of this second agent with several charged and uncharged ions in solutions containing various electrolytes. Their work demonstrated conclusively the presence of a single negative charge. Close on the heels of this discovery Edwin Hart of Argonne, working with Jack Boag at the Research Unit in Radiobiology in Northwood, England, studied the absorption of light by a solution immediately after bombarding the solution with a pulse of 1.8-MeV electrons. The solution absorbed light in the red region of the spectrum over a broad range of wavelengths with an absorption spectrum reminiscent of the one observed in metal-ammonia solutions [*see top illustration on page 83*]. Within 10 millionths of a second or so the new absorption peak had disappeared. The hydrated electron, present in water for aeons as a result of cosmic radiation, had finally been discovered! The reaction of the hydrated electron with the water, which might have removed the electron so fast that it could not be observed, was thus shown to be relatively slow.

During the same period Robert Dewald, Leo de Meyer, Manfred Eigen and I, working in Eigen's laboratory at the Max Planck Institute for Physical Chemistry in Göttingen, also studied the reaction of solvated electrons with water, but with an amine solvent instead of pure water [*see illustration on page 82*]. Using alkali metals dissolved in the amine ethylenediamine as the source of solvated electrons, we verified that the reaction with water is relatively slow and secured quantitative reaction-rate data for the amine solvent. The latest data for this reaction in pure water, obtained from radiolytic experiments, give practically the same rate constant we found in the amine solvent.

Since the initial observation of the absorption spectrum of the hydrated electron, numerous studies have been made on radiation-produced solvated electrons in water and in many other solvents. The lifetimes are shorter than the "twinkling of an eye," so that only instruments can "see" the color, but the spectrum leaves no doubt that the characteristic blue color of solvated electrons is present for a short time after irradiation. Radiolysis of ammonia and amines indicates that the absorption spectrum of the solvated electron resulting from radiation is the same as the spectrum produced by dissolving alkali metals.

After the radiation-produced hydrated electron had been identified, it was shown that the same entity can also be produced by less drastic means. Absorption of ultraviolet light by many negative ions results in the production of hydrated electrons, which are identified by their characteristic absorption spectrum. Hydrated electrons can also be produced chemically in alkaline solutions by the reaction of hydrogen atoms with hydroxide ions. It is now clear that the hydrated electron must be seriously considered as an intermediate reactive entity in a great many chemical reactions and in processes, such as photosynthesis, that involve the absorption of light energy.

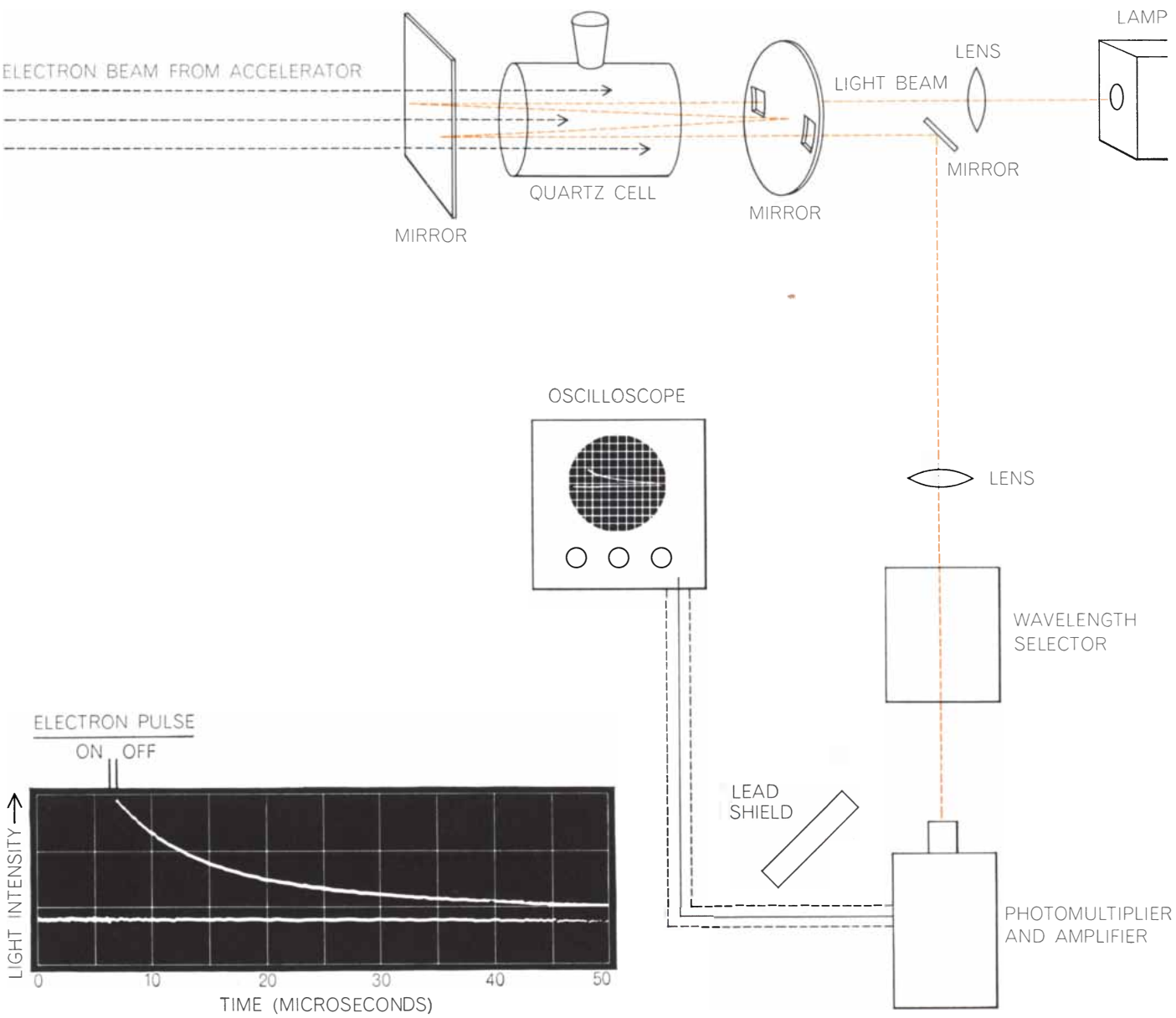
The hydrated electron is a powerful reducing agent. With a number of molecules such as molecular oxygen (O_2), atomic hydrogen (H), hydrogen peroxide (H_2O_2), the hydroxyl radical (OH), nitric oxide (NO), a number of organic compounds and many metal ions, reduction is so fast that it takes place nearly every time a solvated electron gets within a distance of about three

angstroms from the molecule being reduced. The speed of such reactions is controlled by the rate at which the reacting partners can diffuse toward each other. Many new reactive entities have been discovered as products of such chemical reactions involving hydrated electrons.

When higher concentrations of electrons are produced by radiolysis at high intensities, a new and surprising diffusion-controlled reaction can be observed. Hydrated electrons are found to react with one another and with the surrounding water molecules to produce molecular hydrogen (H_2). The existence of this fast reaction is surprising because there is no evidence for a comparable reaction in liquid ammonia even on a time scale of days or weeks, nor has the reaction been observed in any other solvent. Evidently the structure of liquid water plays an important role in the production of molecular hydrogen by this reaction. The proof that molecular hydrogen is formed directly rather than through the intermediate production of hydrogen atoms was a result of some experiments in radiation chemistry performed at Argonne by Leon Dorfman and Irwin Taub.

Although radiation chemistry has provided much information about the optical spectrum and the reactivity of the solvated electron, most of the physical properties have been studied with metal-ammonia solutions. These studies have also shown that interactions of electrons and ions produce new entities at higher concentrations.

Because of its negative charge the solvated electron can transport electricity through the solution. Studies of the electrical conductivity of various metal-ammonia solutions have spanned the entire concentration range from extreme dilution up to saturation. The con-



TYPICAL APPARATUS for the study of solvated electrons produced by the radiolysis, or radiation-induced ionization, of solvent molecules is depicted here. The chemical changes that take place in the solution are observed by measuring the absorption of light by the solution immediately after bombarding the solution with a pulse of high-energy electrons. The mirror system enables the light beam to traverse the solution several times. The photograph at lower left shows an oscilloscope trace produced by the pulse-radiolysis of an alkaline water solution. The straight horizontal line shows the signal in the absence of any pulse. The curved line shows the signal for a 15-million-electron-volt pulse lasting four-tenths of a microsecond. For most of the trace the decrease in absorbance results from the reaction of solvated electrons (e^-) with water (H_2O) to form hydrogen gas (H_2) and hydroxide ions (OH^-).

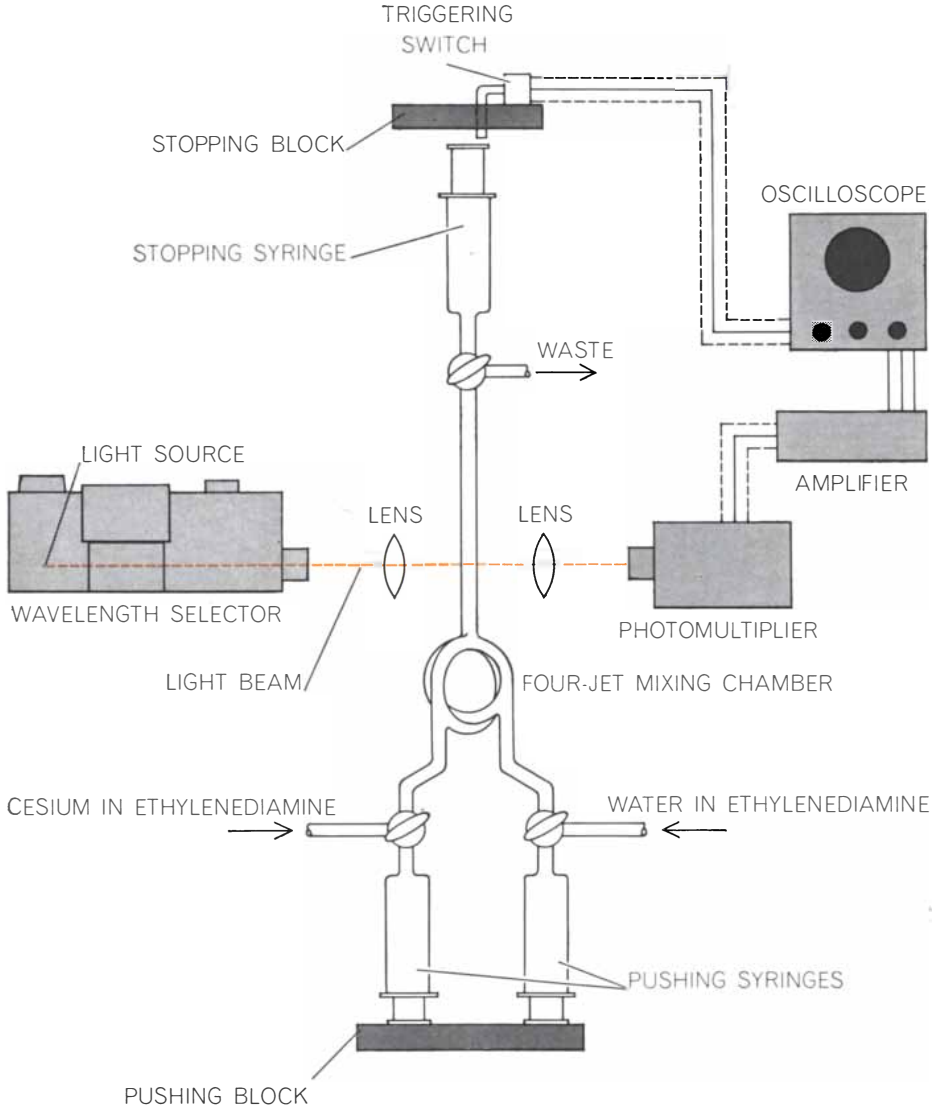
ductance in concentrated solutions is quite high, similar to that of a liquid metal. In dilute solutions the conductance drops considerably, reaching a minimum at about .04 mole of metal per liter of solution [*see bottom illustration on opposite page*]. Below this concentration the conductance again rises steadily with decreasing concentration. The value of the curve at zero concentration represents the sum of the contributions by the metal ion and the solvated electron. Using the known conductance of the metal ion, one can deduce that the solvated electron is a better conductor by a factor of about seven than normal ions in ammonia are. This conductance is much smaller than one would expect for a free electron and lends support to the idea that the electrons are localized in traps. The conductance is too large, however, to be explained on the basis of trap migration. The obvious conclusion is that the electron migrates by "hopping" from one trap to another or by leaving an old trap and creating a new one.

The decrease in conductance with increasing concentration shows that electron migration is retarded by interaction with the positive ions. Such a phenomenon is common for salts in solvents such as ammonia because of strong interactions of positive and negative ions to form nonconducting ion pairs. The simplest picture of the interaction of solvated electrons (e^-) and metal ions (M^+) is the formation of a neutral pair, $M^+ \cdot e^-$, in which the electron is still attracted to the trap but is also attracted to the positive ion. Over this concentration range the optical spectrum shows little change, in agreement with the ion-pair assumption. Some investigators believe the important neutral entity is a "monomer" in which the solvated positive ion has trapped the electron and the normal solvent trap has been destroyed.

The reason for the increase in conductance above the minimum at .04 is not known. Our measurements of electron mobility, made between 1954 and 1960 at Michigan State, have verified that the anomalous behavior is indeed caused by a negatively charged entity. The increase may come about because of the ability of electrons to jump from trap to trap at higher concentrations, whereas at lower concentrations the electrons must form new traps when they leave old ones. If this hypothesis is correct, it implies the existence of doubly occupied traps.

Double occupancy can also be inferred from the results of certain magnetic measurements. A single electron has a magnetic moment that arises from its intrinsic spin. This moment can interact with a magnetic field in a fashion analogous to the interaction of a compass needle with the earth's magnetic field. The electron does not behave like a compass needle, however; quantum mechanics requires that it exist in only two magnetic states, which are separated by a discrete energy difference that depends on the strength of the magnetic field. It is possible to study the "flipping" of the electron from one such "spin state" to the other with the techniques of electron paramagnetic resonance. Such studies, as well as more conventional magnetic measurements, show that solvated electrons exist separately in sufficiently dilute solutions, but that there is a tendency for the electron's magnetic moments to pair up at higher concentrations. Even in solutions as dilute as .01 mole per liter, only half of the electron spins are uncoupled at −33.5 degrees centigrade (the boiling point of pure ammonia).

The exact nature of the neutral entity and the spin-paired entity is very much an open question at present and forms the basis for lively discussions whenever workers in the field get together. The contenders for the neutral entity are the simple ion pair, $M^+ \cdot e^-$, and the monomer, M, with its spherically symmetrical charge distribution. The spin-paired entity has been viewed

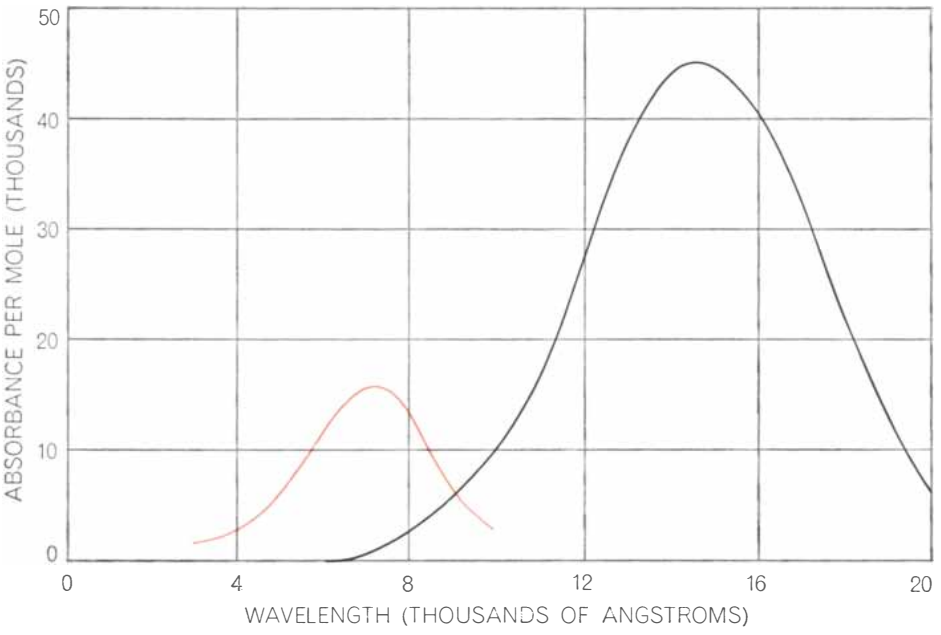


STOPPED-FLOW APPARATUS was used by the author and his colleagues at the Max Planck Institute for Physical Chemistry in Göttingen to measure the reaction rates of solvated electrons with water, using alkali metals dissolved in the amine ethylenediamine as a source of the solvated electrons. The reactants are mixed rapidly and then the flow is suddenly stopped. Changes in the absorption of light after stopping are measured as a function of time. In this way reaction times as short as a thousandth of a second can be measured. The reaction of the solvated electron with water was found to be comparatively slow.

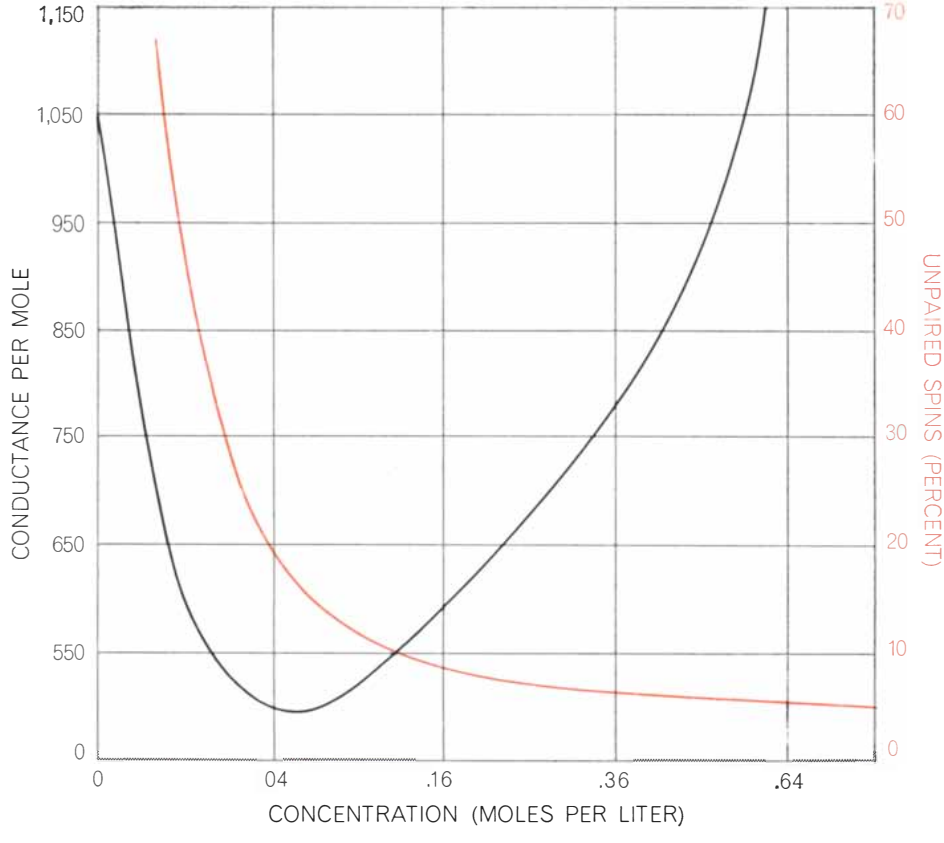
as a doubly occupied trap, e_2^{--} (probably also associated with a positive ion); a triple ion, $e^- \cdot M^+ \cdot e^-$; a quadruple ion, $(M^+ \cdot e^-)_2$; a pair of monomers associated to form a dimer, M_2, and finally as a negative alkali-metal ion, M^-. Because both the optical spectra and the magnetic-resonance spectra are simple and change little with concentration, it is difficult to decide among these possibilities.

It might appear that one should turn to the amines rather than ammonia for the answers. Indeed, a number of investigators have done so. Our own efforts are now largely directed toward alkali-metal solutions in a variety of amine and ether solvents. Rather than simplifying matters, however, this approach has opened a Pandora's box of new complications. Of all the solvents in which stable metal solutions can be formed, ammonia has by far the highest dielectric constant and therefore favors ionization to form the metal ion and solvated electrons. As a result of their low dielectric constants amine solutions give rise to new entities involving interactions of electrons with the metal ions. Alkali-metal dimers appear to be present also in amine solutions. At least two new optical absorption peaks appear in their spectra, as well as new monomeric entities with interesting magnetic properties. These studies have given us powerful new tools for the study of electron-ion interactions, but they have not answered the original questions raised by the metal-ammonia studies.

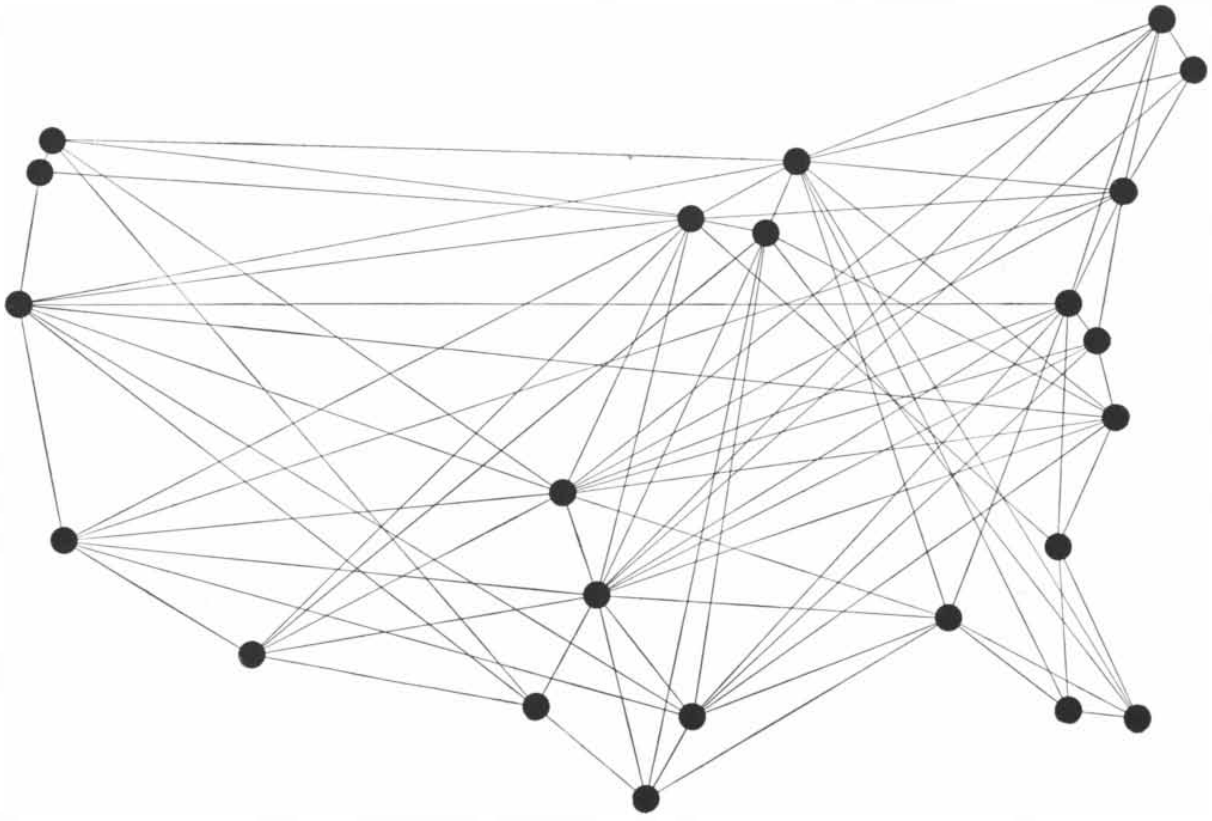
It is interesting to speculate about future developments in this burgeoning field. Radiation chemistry has provided a new method for studying the reactions of the solvated electron. New entities formed by reactions of the solvated electron are reported every month, and the number of solvents used continues to increase. As measurement techniques improve they will be applied to reactive intermediates with shorter and shorter lifetimes. It is likely that many of the properties of the solvated electron that have so far been measured only in metal-ammonia solutions will also be measured using radiation-produced solvated electrons. Because of the renewed interest in the field many new studies of metal-ammonia and metal-amine solutions have been initiated. They will undoubtedly yield a better understanding of the solvated electron and of the entities produced by the interaction of solvated electrons with each other and with metal ions.



COMPARISON of the light-absorption spectra of solvated electrons produced by a metal-ammonia solution (*black curve*) and by the radiolysis of water (*colored curve*) shows the basic similarity of the two products. Both solutions absorbed light in the red region of the spectrum over a broad range of wavelengths. A mole, or gram molecule, is the amount of a substance that has a weight in grams equal numerically to its molecular weight.



ELECTRICAL CONDUCTANCE of a solution of potassium in liquid ammonia (*black curve*) is high in a concentrated solution (*right*) but drops considerably in a dilute solution (*left*), reaching a minimum at about .04 mole of metal per liter of solution. Below this concentration the conductance again rises steadily with decreasing concentration. The value of the curve at zero concentration represents the sum of the contributions by the metal ion and the solvated electron. Since the conductance of the metal ion is known, one can deduce the conductance of the solvated electron. The decrease in conductance with increasing concentration is related to the percentage of unpaired electron spins (*colored curve*) in the solvent.



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CONTROLLED EUTECTICS

A combination of metals with a particularly low melting point is called a eutectic. By controlling the way a eutectic solidifies it is possible to produce alloys with a host of useful properties

by R. Wayne Kraft

The plumber's solder is an alloy of lead and tin mixed in certain proportions that give the combination a particularly low melting point. This kind of combination, which is not necessarily confined to metals, is called a eutectic, from a Greek word meaning "easily melted." Eutectics are an old and familiar story (although the term may not be). One well-known eutectic material is the low-melting alloy (composed of bismuth, indium, tin and cadmium) used in fire-sprinkler systems; another is cast iron, a combination of iron and carbon that owes its convenience for being cast into intricate shapes to the fact that its high carbon content gives it a considerably lower melting temperature than that of steel.

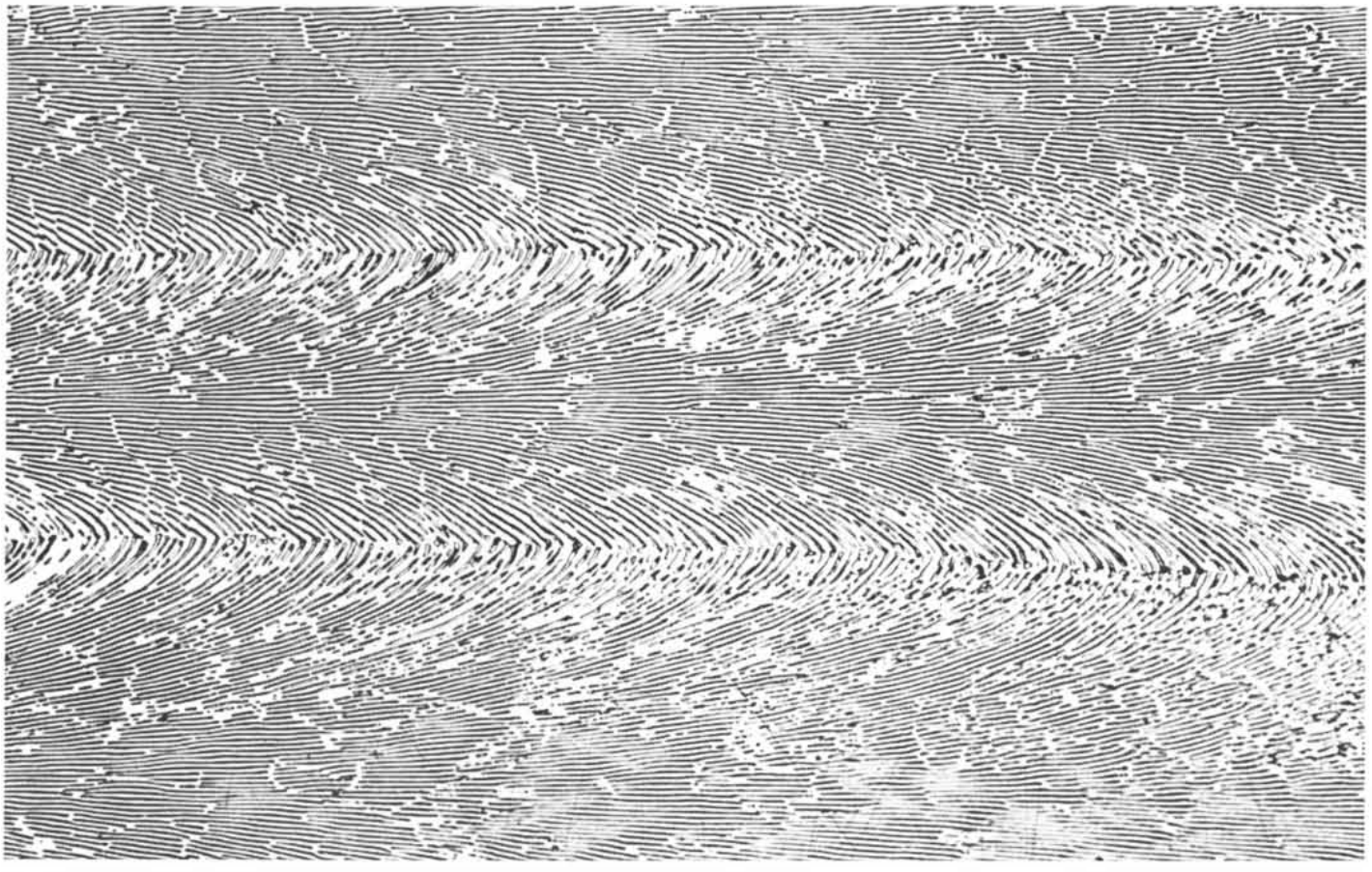
Familiar stories in science and technology sometimes have a way of taking an unexpected turn. Within the past few years this has happened in the study of eutectics. It has come about because eutectics, in addition to having low melting temperatures, have another characteristic that differentiates them from other materials. If eutectics are examined under the microscope, it can be seen that all of them consist of two or more types of crystal intimately mixed together. Until quite recently metallurgists paid relatively little attention to this feature, but it is now receiving considerable notice. The reason is that experiments have shown that the microscopic structure of most eutectics can be drastically changed by controlling the manner in which the material is allowed to solidify. This change in structure endows the materials with interesting new properties: magnetic, electrical, optical, thermal and mechanical. Thus the way has been opened for the development of a new class of materials with a wide range of usefulness.

The new view of eutectics was foreshadowed by experiments carried out in 1958 by Harry W. Weart and D. J. Mack of the University of Wisconsin. It had been known for some time that the particular shape and arrangement assumed by eutectic crystal aggregates is strongly influenced by the type of alloy and the way it solidifies. For example, the individual crystals are sometimes sharply angular, sometimes rounded, sometimes fiber-like, sometimes plate-like; occasionally they are curly like minute cornflakes or bunched like tiny rose petals. Rapid cooling usually produces a microstructure very different from that observed when an alloy is cooled slowly. With this background of knowledge Weart and Mack studied the microscopic structure of metallic eutectics that were formed in elongated crucibles in which the material was changed from the molten to the solid state by a cooling wave that proceeded slowly, like an advancing wall, from one end of the crucible to the other. In so doing they observed a striking phenomenon: In the solidified alloys the crystal aggregates were organized in "colonies," or distinguishable arrays [*see illustrations on opposite page*].

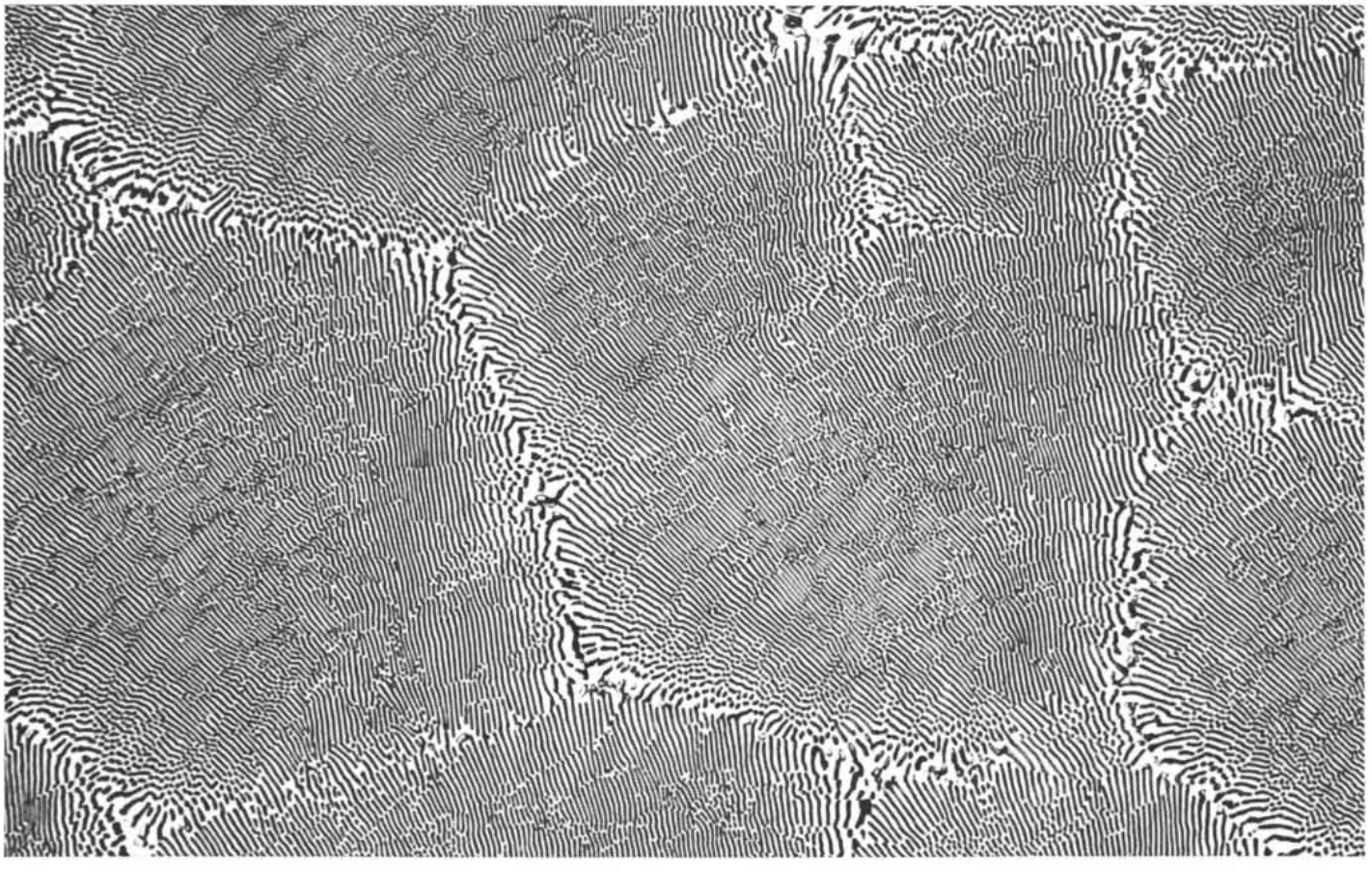
At about the same time that these experiments were in progress William A. Tiller of the Westinghouse Research Laboratories was studying the theoretical aspects of eutectic solidification. From these efforts a theory was developed to account for the formation of the colony structure.

Consider a solution of salt in water. This mixture, like many metal alloys, freezes over a range of temperatures rather than at one specific temperature the way distilled water or a pure metal does. Not only does a salty solution freeze over a range of temperatures but also the temperature at which freezing begins is lowered by adding salt to the solution. (That is why salt is put on highways in the winter.) As a given liquid solution—say 90 percent water and 10 percent salt—is cooled below 32 degrees Fahrenheit, it will arrive at a temperature at which the solution is saturated; then ice crystals begin to precipitate out of the liquid. With further reduction in temperature more and more of the material precipitates, until finally, at a temperature corresponding to the bottom of the freezing range, the entire salty solution is converted to solid. The freezing range is called the slushy region.

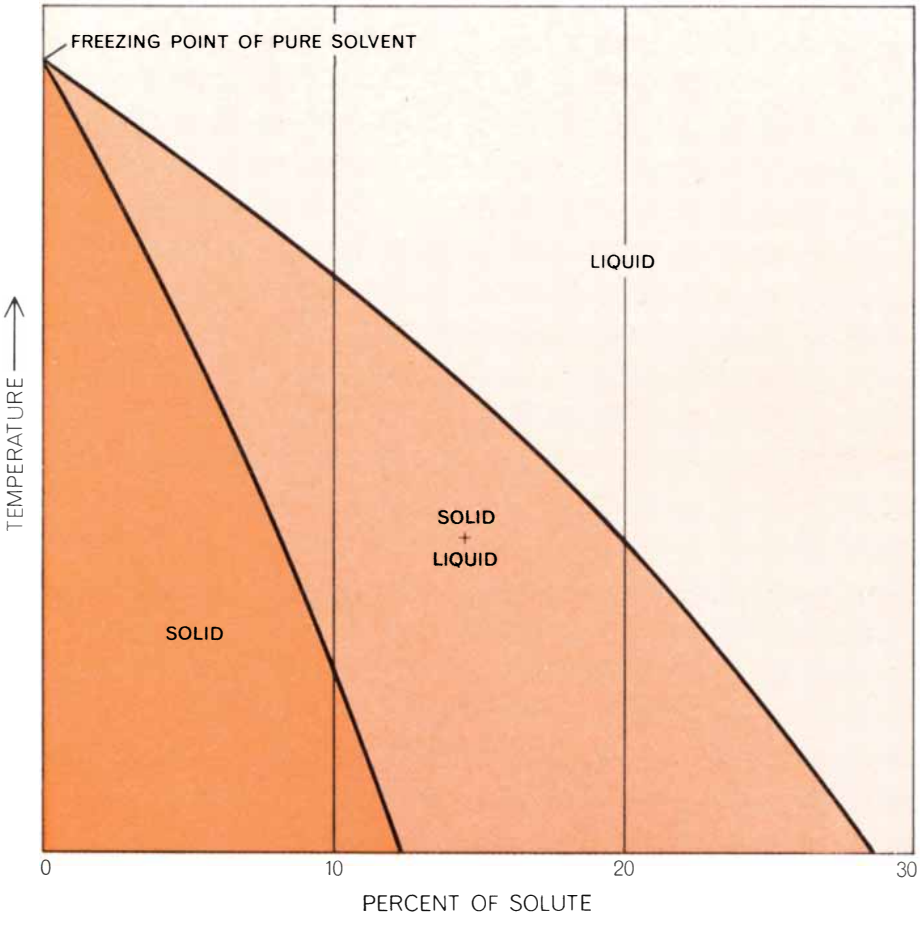
An alloy composed of two metals, one dissolved in the other in the liquid state, is analogous to this water-salt situation. The graph called a phase diagram can be plotted showing the freezing range for different compositions [*see illustration on page 88*]. Essentially this is only an idealized account of the transition; it represents a series of still pictures, so to speak. Each line on the chart describes the situation with the two phases in equilibrium (that is, with the relative proportions and composition of the phases in the material unchanging). Because the transformation of a liquid to a solid is a dynamic process, one must consider the complications that enter into the picture during the change from the liquid state to the solid one. These complications had been investigated in the early 1950's by Tiller, Kenneth Jackson, John W. Rutter and Bruce Chalmers at the University of Toronto [see "How Water Freezes," by Bruce Chalmers; SCIENTIFIC AMERICAN, February, 1959]. They had found that, as freezing advances in a liquid containing a substance in solution, atoms of the soluble substance are rejected from the solid phase



EUTECTIC "COLONIES," separate arrays of crystal aggregates in a solid metal alloy, are formed when the alloy is solidified in one direction (in this case from left to right). The magnification of both photomicrographs on this page is approximately 300 diameters.



CROSS SECTION of the eutectic alloy shown above in longitudinal section was cut at right angles to the direction of solidification. The boundaries of the eutectic colonies are evident. Photographs were made at the United Aircraft Research Laboratories.



PARTIAL PHASE DIAGRAM for an alloy composed of two metals, one dissolved in the other while in the liquid phase, describes the situation when the relative proportions and compositions of the two phases are in equilibrium. Unlike the pure solvent, the solution freezes over a range of temperatures. In this case the solute lowers the freezing temperature of the solvent. A drop in the temperature or the addition of solvent atoms to a point below the liquid saturation line (*upper curve*) will cause the precipitation of a solid crystalline phase. An increase in temperature or the addition of solute atoms to a point above the solid saturation line (*lower curve*) will result in the formation of a liquid phase.

and pile up in front of the advancing interface between the solid and the liquid. As a result, under certain conditions a layer of liquid at the interface becomes supercooled [*see top illustration on opposite page*]. Any projections from the solid surface into this supercooled region then tend to grow rapidly and give the interface a corrugated, cellular form [*see bottom illustration on opposite page*].

From these known facts Tiller, and independently Weart and Mack, deduced an explanation of the colonies formed when eutectic alloys were solidified in an elongated crucible. Atoms of impurity in the molten material would be rejected from the solid state and would accumulate in front of the advancing interface. This region in front of the moving surface of solidification would become supercooled (that is, remain liquid although it was below the freezing temperature of the eutectic), and as a consequence a cellular interface would develop on the advancing solid, with impurity atoms collecting at the boundaries between the cells. It had been known from earlier work that the individual crystals of a eutectic (which often have the shape of lamellae, or thin platelets) form perpendicularly to the local freezing interface. The longitudinal extension of the cellular interface produced by the advance of the solidification front would thus account for the division of the solid into colonies of platelets that Weart and Mack had observed in their elongated-crucible experiments.

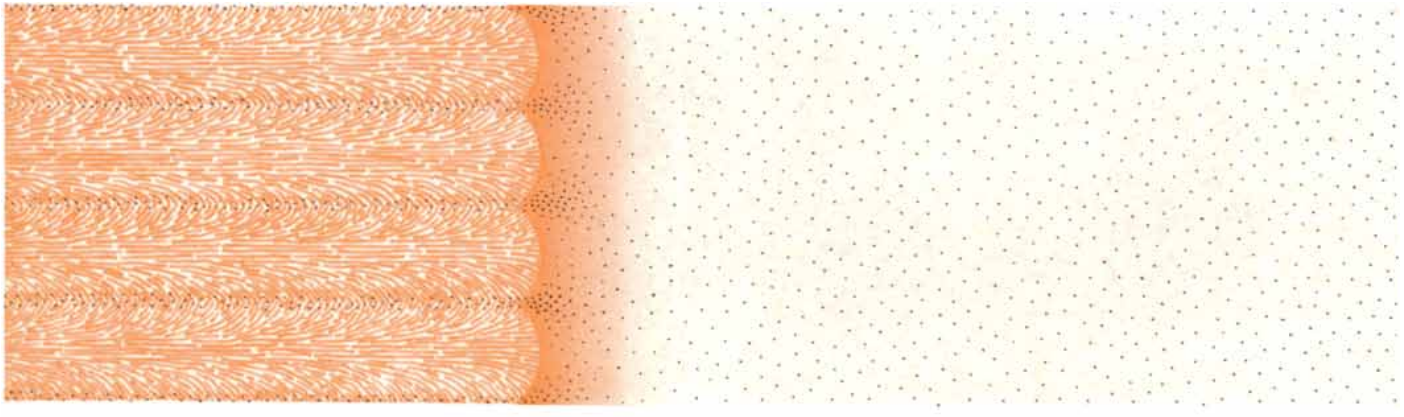
Darryl L. Albright and I, who were then investigating eutectics in the United Aircraft Research Laboratories, were immediately attracted to this new theory. If the theory was correct, one should be able to control the solidification of a eutectic so that it developed a predetermined microstructure with useful properties. Chalmers' group at Toronto had found that, in the solidification of a single metal, supercooling and cellular development at the freezing interface could be prevented by eliminating impurities from the metal, by applying a steep temperature gradient at the interface or by slowing the rate of solidification of the metal (which would allow more time for dissolved impurity atoms to diffuse away from the interface and thus would minimize supercooling). It appeared, therefore, that control of these factors might provide a means of shaping the microstructure of a eutectic alloy.

We constructed an apparatus for solidifying eutectics in a long crucible under controlled conditions and performed our first experiments with an alloy of aluminum and an intermetallic copper-aluminum compound ($CuAl_2$). The results of these experiments beautifully corroborated the Tiller-Weart-Mack theory. The crystal particles in the alloy arrayed themselves in almost perfectly parallel lamellae about a ten-thousandth of an inch in thickness [*see top illustration on page 91*]. Our specimens, which constituted fairly sizable ingots, showed that the concept of controlled eutectics was indeed a practical one.

At about the same time we announced these results J. P. Chilton and William C. Winegard of the University of Cambridge, who apparently had been thinking along similar lines, published a paper reporting they had produced essentially the same structure in the lead-tin eutectic. Since then many investigators have announced successes in creating parallel lamellar eutectics composed of various materials: metallic, semimetallic and ceramic. Other forms also have been produced, notably eutectic alloys in which one metal takes the form of parallel fibers embedded in a matrix consisting of the other metal [*see bottom illustration on page 91*]. By leaching the matrix away with acid it has been found that these microscopic fibers may run to considerable length—sometimes on the order of inches long, or tens of thousands of times more than their diameter. Although the parallel lamellar and parallel fibrous microstructures are not the only ones that have been produced when eutectic solidification is controlled, these two are the most common and scientifically most interesting.

Each partner in a eutectic has its own characteristic crystal structure. In the aluminum-copper system, for example, the aluminum platelets have a cubic crystal structure and the intermetallic aluminum-copper ($CuAl_2$) platelets have a tetragonal structure (similar to cubic, but with one of the three mutually per-

SOLIDIFICATION of a eutectic alloy in an elongated crucible (*a*) proceeds from left to right as the crucible is withdrawn from the furnace. After an initial transient period a state of dynamic equilibrium is reached, and the buildup of rejected solute atoms in front of the advancing solid-liquid interface achieves a steady state (*b*). The temperature profile (*curved line in* "*c*") corresponding to the equilibrium freezing temperature was obtained from the liquid saturation line in the illustration on the opposite page. If the slope of the actual temperature gradient (*straight solid line*) is small enough, a supercooled region (*hatched area*) exists in front of the advancing interface. Supercooling can be avoided by increasing the slope of the actual temperature gradient (*straight broken line*).



FINE STRUCTURE of the solid-liquid interface in the eutectic alloy depicted at the top of this page corresponds to a moderate amount of supercooling. Projections from the solid surface into the supercooled region tend to give the interface a corrugated, cellular form. Solute atoms (*black dots*) rejected from the solid phase tend to accumulate at the cell boundaries and are incorporated into the solid in these regions. The longitudinal extension of the boundaries accounts for the division of a eutectic solid into colonies. The length of the supercooled region with respect to the total length of the specimen is greatly enlarged in these diagrams for clarity.

pendicular edges shorter than the other two). We have observed, using specially developed X-ray diffraction methods, that when the alloy is forced to assume the parallel microstructure by control over the solidification process, certain crystallographic directions in one or both phases tend to line up parallel to the solidification direction. Unfortunately we are not yet able to predict in advance how they will line up (even though we often know how each phase, freezing by itself, would line up) because of a complicated mutual influence of each phase on the other. We have nevertheless been able to measure the results. They show that controlled eutectics, in addition to exhibiting a pronounced directionality in the size, shape and distribution of the metal particles, also tend to have a pronounced preferred orientation of the crystal structures in the particles. These are the characteristics (providing, for example, directional conduction of electricity) that make controlled eutectics so interesting and potentially useful.

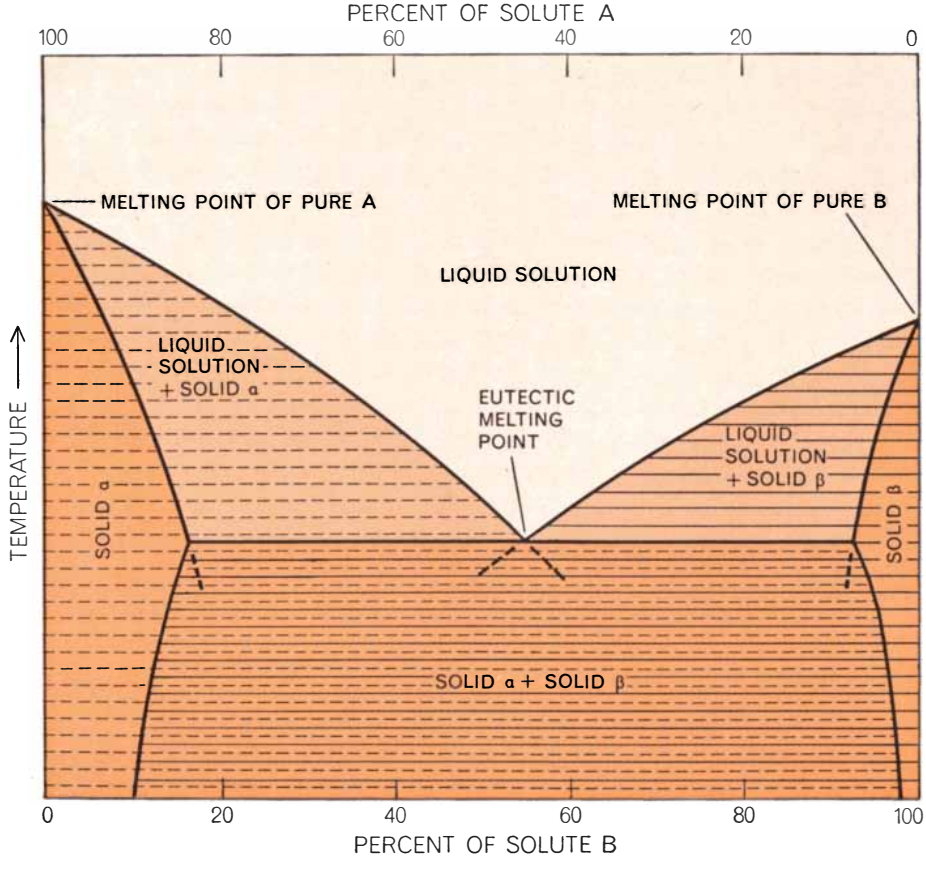
What, now, are the possible applications of controlled eutectics? This class of materials carries the potentiality of giving directionality to almost all the properties inherent in crystalline solids, indeed, essentially every property except density. The field is therefore very broad, and many possibilities are now being explored in various laboratories.

One particularly inviting area is the application of eutectics to the production of permanent magnets. A parallel array of ferromagnetic crystals in the fibrous form, embedded in a nonmagnetic matrix, should have excellent characteristics for this purpose. At Lehigh University, Albright has produced such a material. Using a mixture of iron and iron sulfide, he applied controlled solidification to create a eutectic in which a great number of fine, needle-like crystals of magnetic iron are arrayed in parallel in the sulfide matrix. Albright has demonstrated the magnetic sensitivity of this material by building an experimental model of a magnetometer [*see illustration on page 92*]. The magnetic project is being pursued further at Lehigh with experiments on other alloy systems, and similar investigations are in progress at the United Aircraft Laboratories under the leadership of F. S. Galasso. At United Aircraft the investigators have produced magnetic materials consisting of parallel iron rods in a matrix of iron antimonide (a compound of iron and antimony).

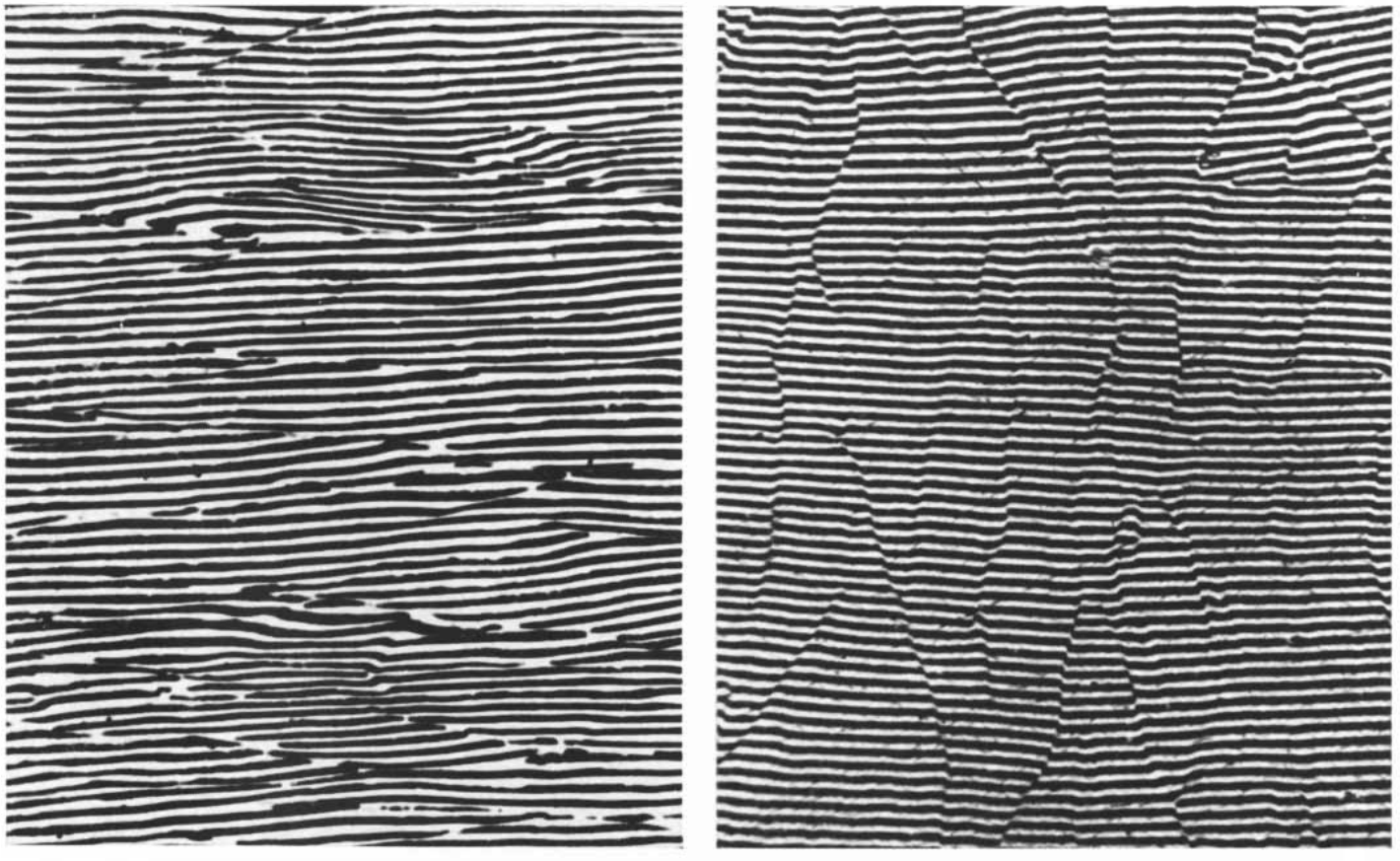
Another promising field for controlled eutectics is in the realm of electricity and electronics. At the Siemens Laboratories in Germany a group has developed a system in which fibers of an electrical conductor, nickel antimonide, are embedded in a matrix of indium antimonide, a semiconductor with high electrical resistance. When a magnetic field is applied, the electrical resistance of this system increases markedly. It can be used as material for probes to measure extremely weak or extremely strong magnetic fields. Another promising application of the same material is as a polarization filter for infrared radiation. At United Aircraft studies are being made of the possible use of the conductor-nonconductor combination to convert an electron beam into a beam of visible light. At the Radio Corporation of America Laboratories, W. K. Liebmann and E. A. Miller have made a eutectic, consisting of antimony fibers in an indium antimonide matrix, that has several unique properties: the thermoelectric power in the perpendicular direction across the fibers is four times greater than along the fibers; the electrical conduction along the fibers is 10 times higher than across them, and the conduction of heat also is much greater along the fibers than in a perpendicular direction.

At Lehigh we are studying the possibility of creating eutectic devices that will act as efficient converters of energy by means of interrelated thermal, magnetic and electrical effects. Another interesting investigation at Lehigh, recently conducted by Sander Levy, looked into the possibility that the superconducting properties of metals might be affected by directionality. Little effect was found in the tests as far as they went, but the studies did help to clarify the theory of superconductivity.

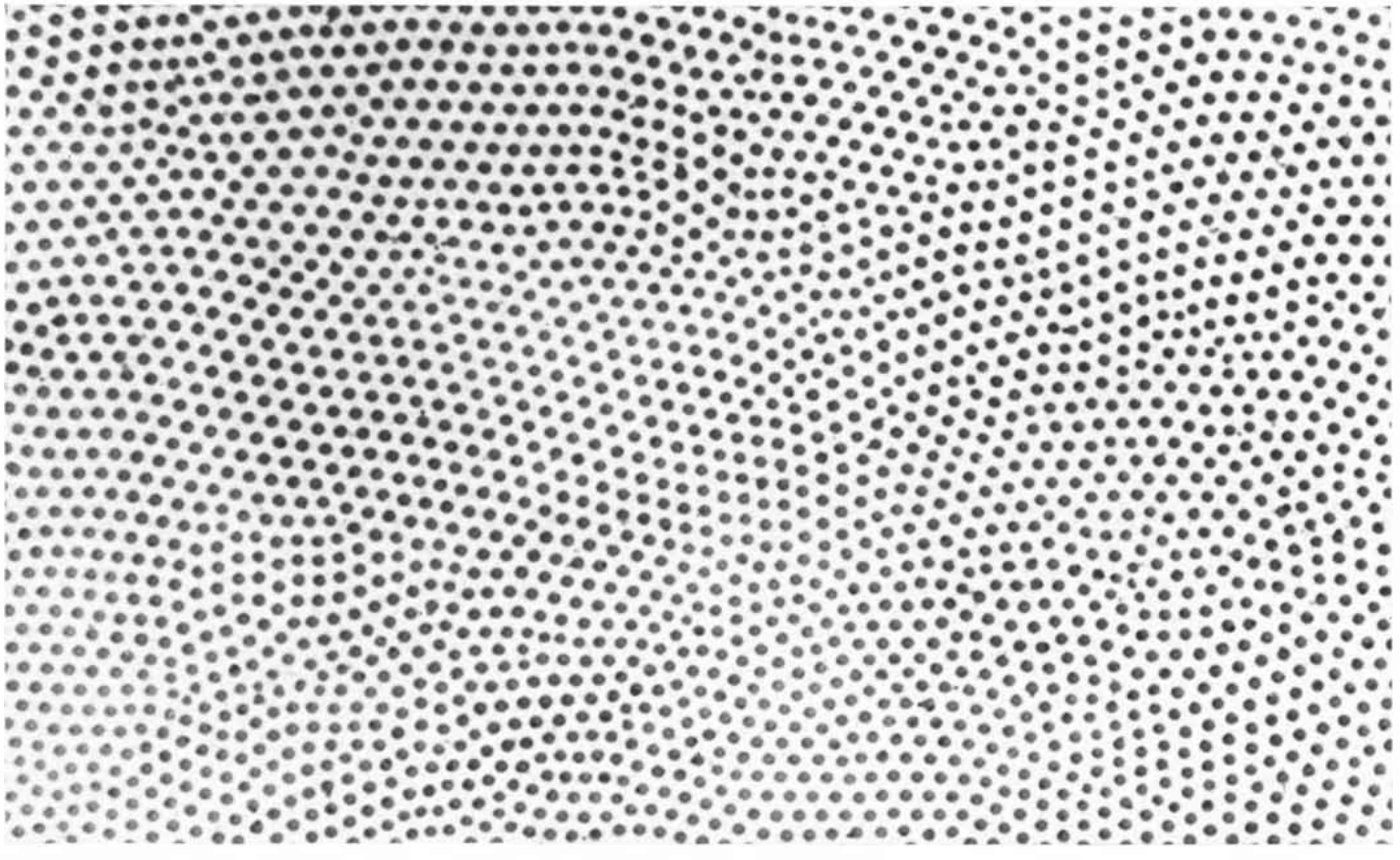
Perhaps the most intriguing of all the uses that lie ahead for controlled eutectics is their application to the manufacture of extremely strong materials. It is now generally accepted that the strongest possible material that can be made is one in which very strong crystal fibers, or "whiskers," are embedded in a ductile matrix [see "Metal 'Whiskers,'"



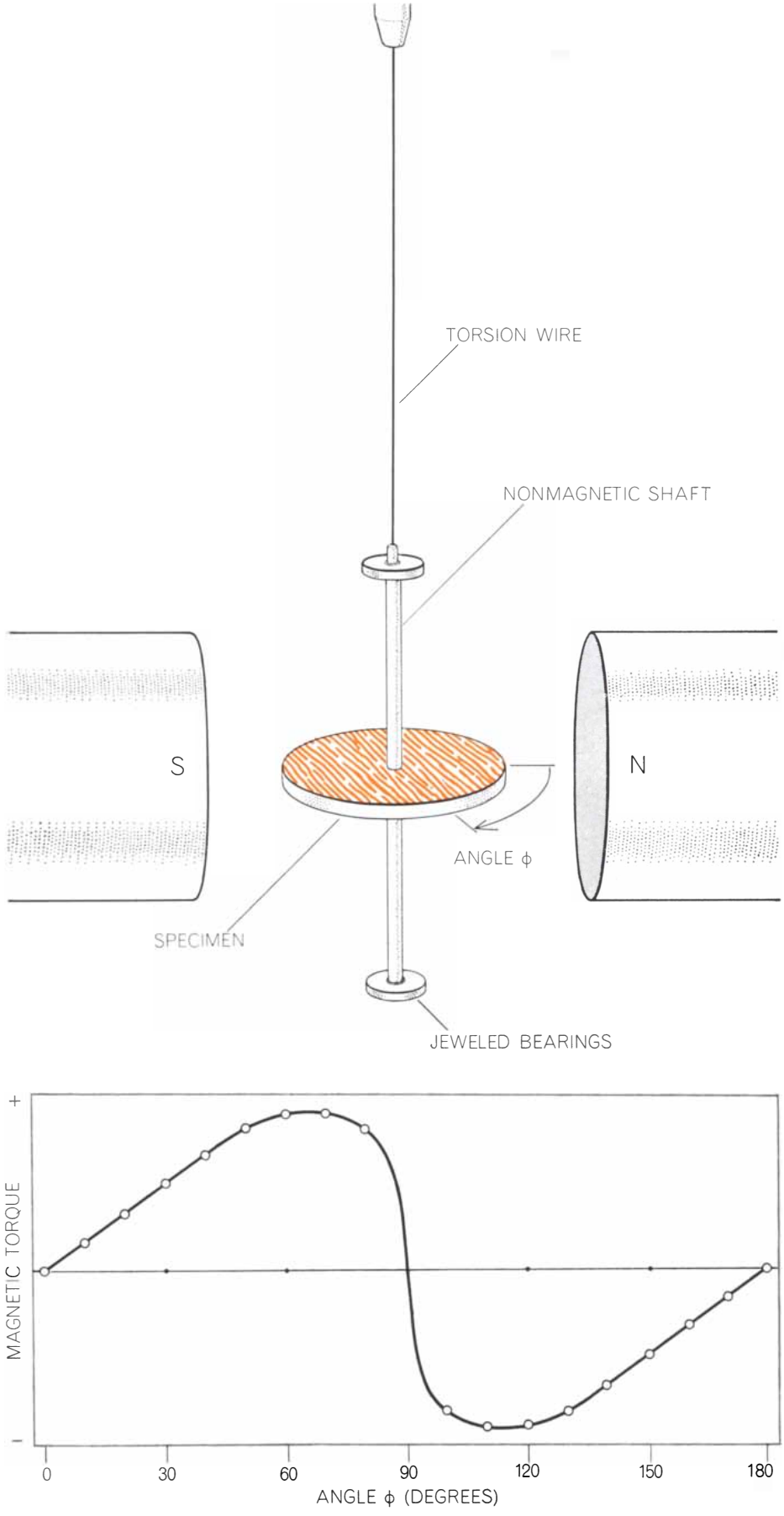
EUTECTIC PHASE DIAGRAM represents the simultaneous double saturation of the eutectic liquid by two different crystalline solids; in other words, solute *A* lowers the melting point of solvent *B* at the same time that solute *B* lowers the melting point of solvent *A*. The eutectic melting point is the lowest melting temperature of any alloy between *A* and *B*. Solid α is a solid solution of *B* atoms dissolved in a crystal lattice characteristic of *A*. Solid β is a solid solution of *A* atoms dissolved in a crystal lattice characteristic of *B*.



CONTROLLED LAMELLAR EUTECTIC is composed of lamellae, or thin layers, that lie parallel to the direction of solidification, which advanced from left to right in the longitudinal section at left. The section at right was cut at right angles to the solidification direction. The eutectic shown here is an alloy of aluminum (Al) and a copper-aluminum compound ($CuAl_2$) produced by the author and Darryl L. Albright at the United Aircraft Research Laboratories. The lamellae are about a ten-thousandth of an inch thick.



CONTROLLED FIBROUS EUTECTIC is an alloy in which one metal takes the form of fibers embedded in a matrix consisting of the other metal. In this cross-sectional view the metallic fibers appear as gray dots distributed in a distorted hexagonal array.



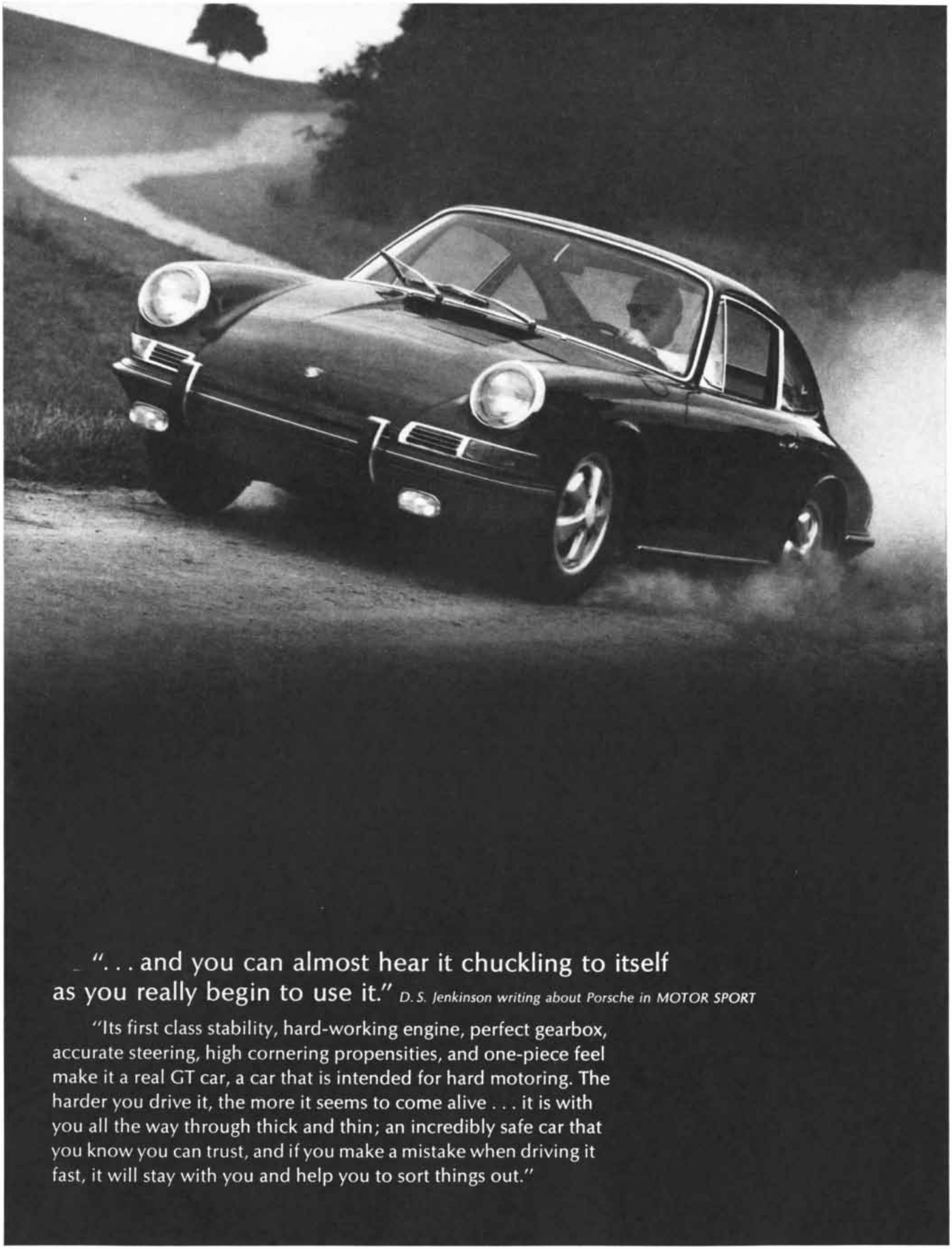
TORQUE MAGNETOMETER (*top*) was built by Albright at Lehigh University to test the magnetic sensitivity of eutectic materials composed of a parallel array of ferromagnetic crystals in the fibrous form (*color*), embedded in a nonmagnetic matrix. The torque observed for a controlled eutectic consisting of iron fibers in an iron sulfide matrix is indicated in the graph at bottom. The point of zero torque at 90 degrees is not a point of rest but rather a point at which the torque changes rapidly from a positive to a negative value.

by S. S. Brenner, SCIENTIFIC AMERICAN, July, 1960, and "Fiber-reinforced Metals," by Anthony Kelly, February, 1965]. Eutectics that have fibers arrayed in parallel fulfill these specifications beautifully.

Some time ago Frank D. Lemkey and I, using a special apparatus we had built for measuring the tensile strength of fine crystal fibers, found that individual chromium fibers too fine to be seen with the unaided eye had a strength of more than a million pounds per square inch—twice the strength of the strongest steel known today. These fibers had been produced in a controlled-eutectic alloy of chromium and copper. Since then, at United Aircraft and in our laboratory at Lehigh, several other eutectic alloys embodying very strong whiskers have been produced; the alloys are based variously on nickel, niobium and magnesium. Lemkey and M. Salkind at United Aircraft recently reported that a eutectic consisting of niobium-carbide whiskers in a niobium matrix had very high strength at temperatures up to 3,000 degrees Fahrenheit. Such a material obviously should be useful for many modern applications, for instance turbine blades in jet engines, where high heat-resistance is required. In our laboratory at Lehigh, Richard Hertzberg and I have produced an exceptionally strong eutectic alloy of magnesium and copper and other strong alloys based on magnesium or nickel.

The unique virtue of the controlled-eutectic approach to making strong materials is that the combination of components specifically required for such a material—parallel arrays of strong fibers fortifying a body of ductile metal—is produced in a single process as a natural product of the way in which the melt is solidified. This will be true of the production of eutectics for any specified purpose. The desired material will be obtainable simply by selecting elements that can interact eutectically and by applying to a suitable combination of these elements a solidification process designed to produce the necessary microstructure.

The field of controlled eutectics is still in its infancy. Only a few of the many potentially useful eutectic systems have been explored so far, and the stage of commercial development is not yet under way. Basic exploratory work in this new field is going forward in a spirit of high enthusiasm, however, in a number of laboratories on both sides of the Atlantic.



"... and you can almost hear it chuckling to itself as you really begin to use it." *D. S. Jenkinson writing about Porsche in MOTOR SPORT*

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PORSCHE STUTTGART

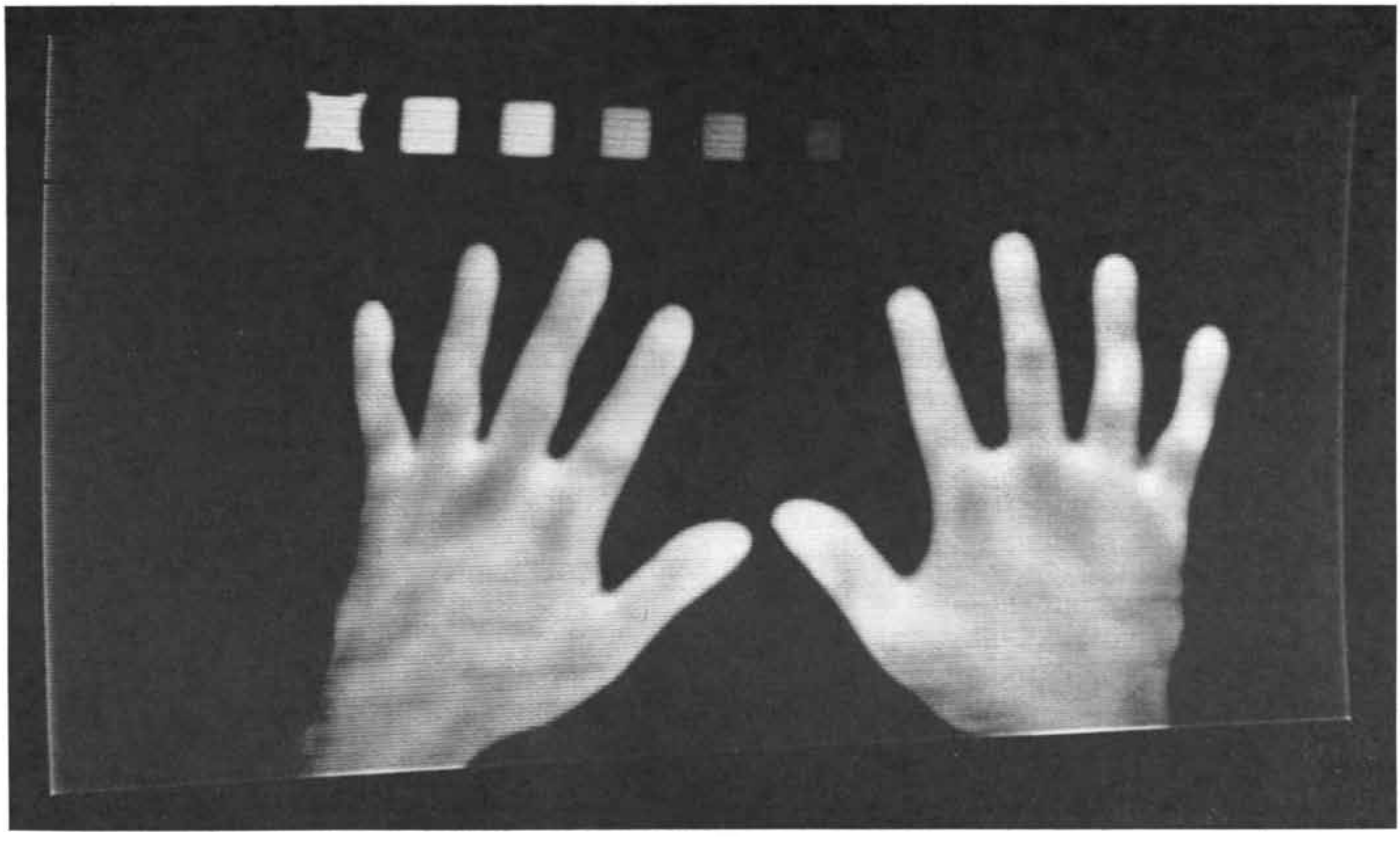
MEDICAL THERMOGRAPHY

Measurement of the heat emitted through the skin at various points on the body has proved valuable in the diagnosis of such disorders as tumors and arthritis and in observing the effects of treatment

by Jacob Gershon-Cohen

The concept of taking a sick person's temperature to gain information about his condition is so well established that one can scarcely imagine a physician, a nurse or a household without a clinical thermometer. In recent years the concept has been extended to making accurate measurements of heat emitted from a particular region of the body. This technique, called thermography, is based on the recognition that the temperature of the skin can vary from place to place depending on the cellular or circulatory processes taking place inside the body at each point. As practiced by a small but growing number of physicians, thermography has achieved interesting results in detecting tumors, determining the location and extent of arthritic disturbances, gauging the depth of tissue destruction from burns and frostbite and performing a number of other diagnostic functions.

One way to measure the emission of heat from the body is to attach heat-sensing devices to the skin. In our work at the Albert Einstein Medical Center in Philadelphia we have preferred to use an apparatus that scans a region of the body from a distance, detects variations in the emission of heat and transforms them into visible signals that can be recorded on photographic film. The result is a



THERMOGRAM OF HANDS shows variations of temperature. The thermogram was made with the heat-sensing apparatus known as the Barnes thermograph. The technique produces a photograph in which relatively warm areas appear lighter in color than relatively cool areas. At top is a gray scale usually placed alongside the region of the body being scanned; the scale emits heat at known values of temperature and so can be compared with the thermogram to provide an approximation of the temperatures of the region scanned. The slanting shape of the thermogram arises from the optical properties of the scanning system in the Barnes apparatus.

photographic print in which relatively warm parts of the region scanned are a light gray and relatively cool parts are a darker gray [*see illustration on opposite page*]. The apparatus is known as the Barnes thermograph; several other kinds of thermographic equipment, based on somewhat different principles, are available or in the process of development.

It is not generally realized, even among physicians, that the practice of accurately measuring temperature in illness is less than a century old. During the Civil War not a single doctor in the Union army possessed a thermometer. Fever as an indication of disease was known to the ancients, but until the 17th century its measurement depended solely on the sense of touch. The first attempt to measure body temperature by instrumental means might be said to date back to 1595, when Galileo invented a thermometer and his colleague Sanctorius of Padua began to test it. For 250 years the instrument was in and out of prominence without achieving a permanent niche in either physics or medicine, even though its adoption was advocated by some of the most learned men of the time.

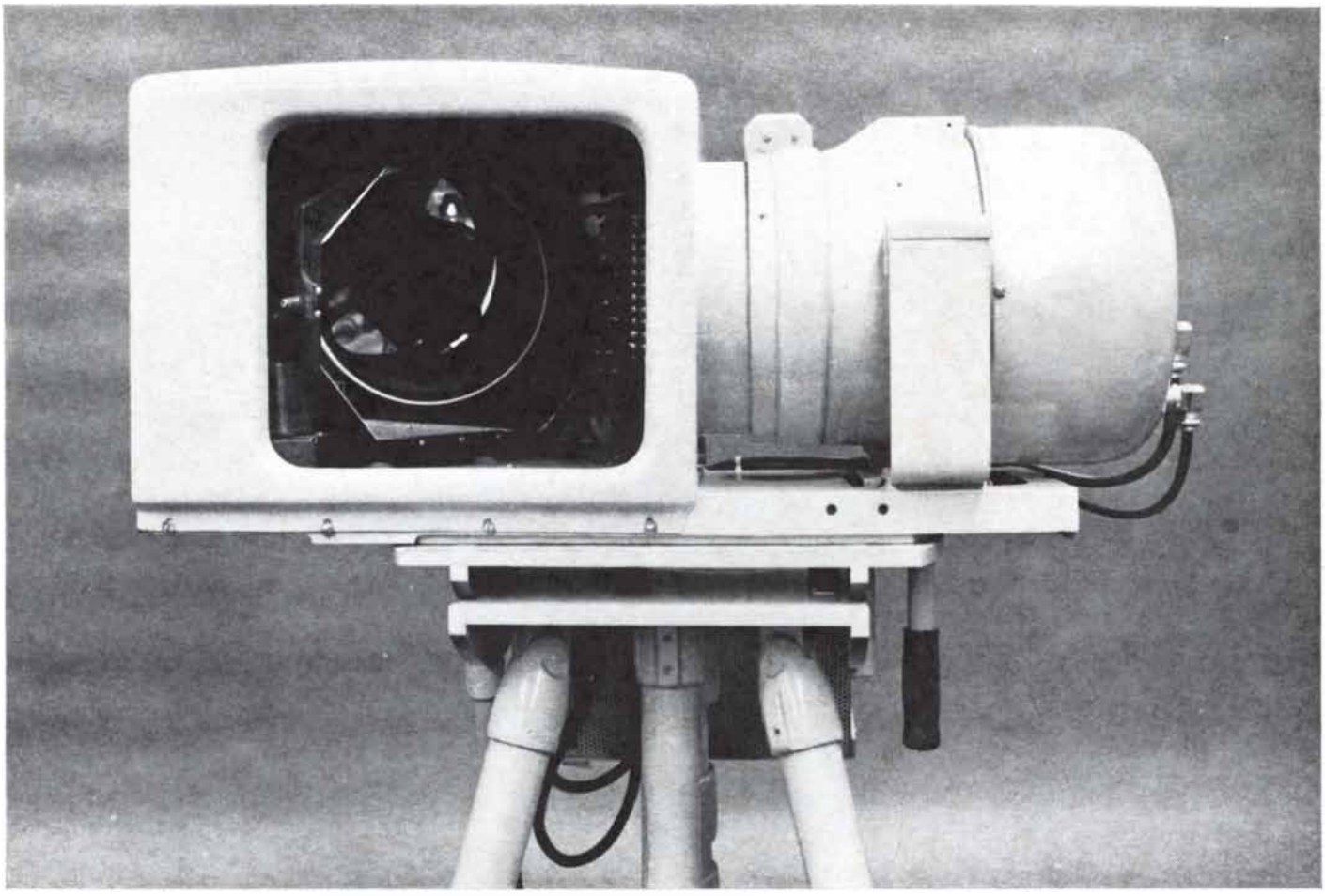
The 18th-century Dutch clinician Hermann Boerhaave, using a thermometer made for him by Gabriel Fahrenheit, learned how useful it was in practice among his patients in a 12-bed ward at the University of Leiden. One of his followers, Anton de Haen of Vienna, continued to apply Boerhaave's dictates and scattered reports of his findings through 15 volumes. He recorded the fluctuations of temperature that occurred in the aged, in fevers and in infections; he also noted the persistence of elevated temperature after apparent recovery in some illnesses. Most important, he recognized the contrast between the subjective feeling of warmth or coolness and the objective recording of the actual temperature. None of his observations stimulated professional imitation.

In 1851 Carl Wunderlich of Leipzig introduced the thermometer in his thriving clinic. He studied some 25,000 patients, and his individual observations are said to have totaled more than a million. Ultimately he formulated laws of thermometry in disease. When his work was widely confirmed, the use of the thermometer on a universal basis was at last established.

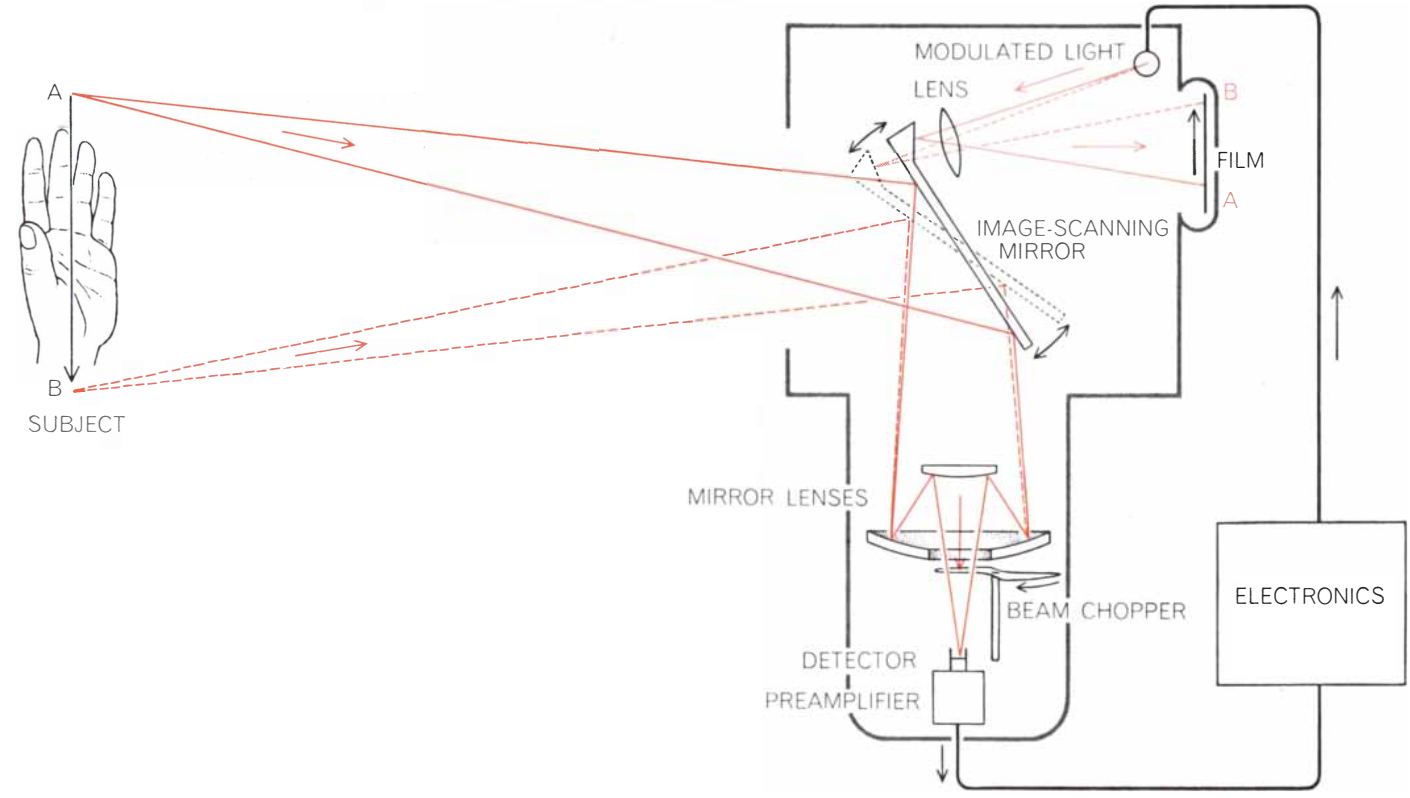
The inertia that has so often characterized the medical application of new measuring instruments was repeated early in this century after the introduction of exquisitely sensitive thermoelectric devices based on the work of Antoine C. Becquerel and Gilbert Breschet of France. In medical use the devices were usually applied to the skin. Possibly the potential of this form of thermometry was not appreciated because there have always been limitations in the ability of thermoelectric devices to measure local skin temperatures accurately. The reason is that pressing the sensing device against the skin changes the pattern of circulation in the area of contact and so affects the reading obtained by the instrument.

Our interest in thermography was aroused by reports from R. N. Lawson

THERMOGRAM OF PATIENT reveals a thyroid tumor in the light area below the throat. Tumors usually show a temperature one or two degrees centigrade higher than that of surrounding regions. Hence thermography has proved useful in early diagnosis of cancer.



BARNES THERMOGRAPH is an infrared camera. It detects heat emitted by an object such as the body; it transforms the energy of the heat into an electric current that operates a visible light of variable intensity, and it records the light on photographic film.



OPERATING PRINCIPLE of the Barnes thermograph is based on a heat detector. The detector compares infrared radiation (*dark color*) from a patient with that from a chopper, which is at a known temperature, and converts the measurements into electrical signals that are amplified to operate a gas-discharge tube. The tube emits visible light (*light color*) with an intensity that varies from dim to bright according to the amount of heat being detected. The light is then reflected onto photographic film to produce the thermogram.

of the Royal Victoria Hospital in Montreal and K. Lloyd Williams of the Middlesex Hospital in London that skin temperature over a cancer of the breast was higher than that over normal tissue. We had long been occupied with the detection of breast cancer by X-ray studies. The reports by Lawson and Williams alerted us to the significance of portraying skin temperatures with modern bolometers, which measure the intensity of heat by means of variations in the electrical resistance of a semiconducting material.

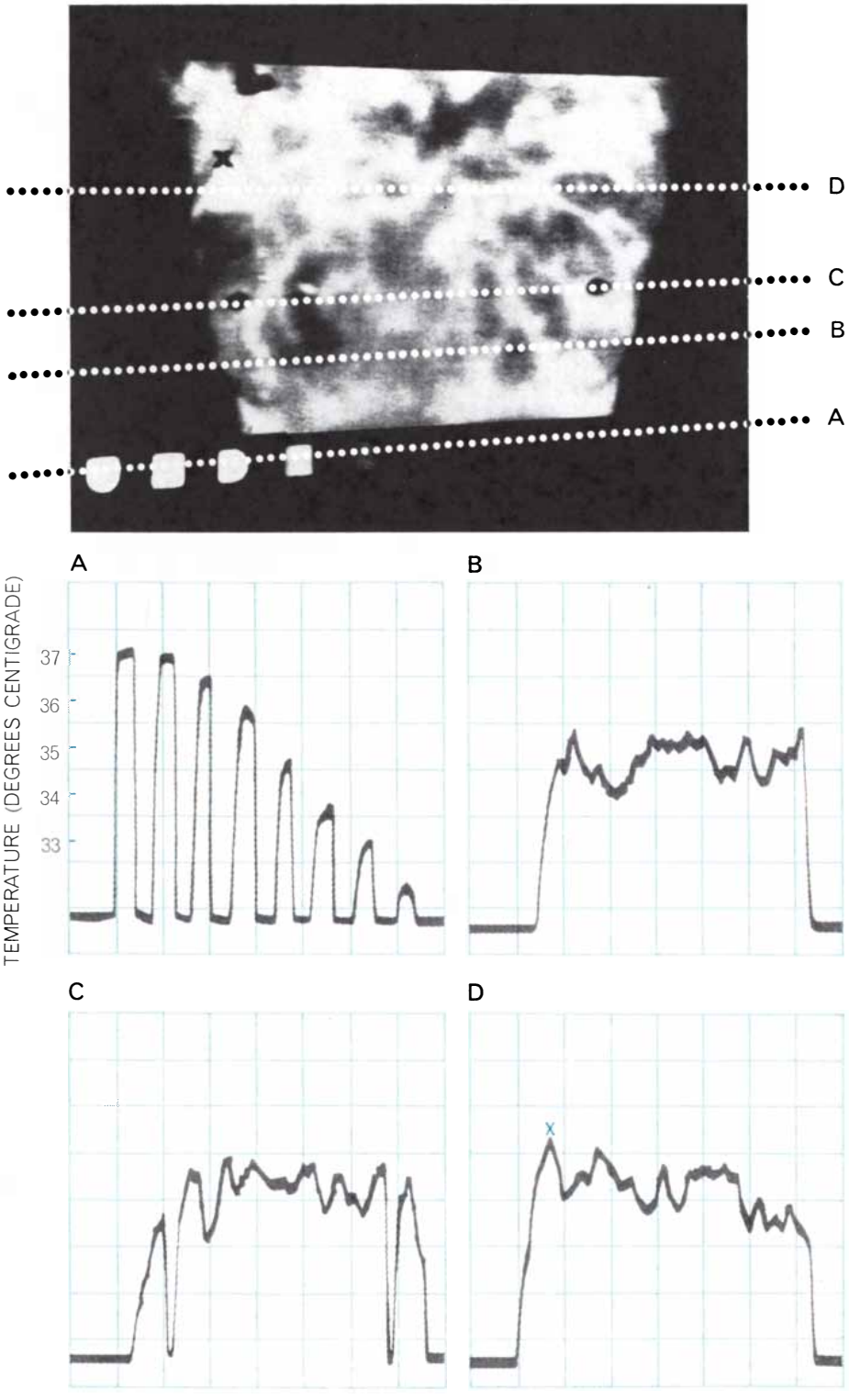
We approached R. Bowling Barnes, president of the Barnes Engineering Company of Stamford, Conn. He made available to us a "heat camera" that had been designed for military use. Preliminary studies with the apparatus were so promising that the Barnes firm designed the thermograph specifically for medical applications. Using two of the devices, my colleagues JoAnn and Erich E. Brueschke and I have studied more than 5,000 patients since 1962.

The pictorial representations of skin temperature produced by the thermograph are called thermograms. Essentially they are thermal maps. We have found that their proper interpretation affords exciting clues to the diagnosis, prognosis and treatment of many illnesses.

Some principles of physics and biology that underlie thermography can be stated briefly and will help the reader to understand the medical applications. Thermography deals with infrared radiation, named by Sir William Herschel in 1800 after he had observed that the bulb of a mercury thermometer was most strongly heated by radiation beyond the red end of the visible spectrum. The behavior of the invisible infrared waves is regulated by the same laws as all other electromagnetic waves.

Every object with a temperature higher than absolute zero emits energy at its surface. The wavelength and intensity of the radiation depend on the absolute temperature of the object and on the emissivity of its surface. The relation between temperature and radiated energy is defined by the Stefan-Boltzmann law, which states that the total radiation emitted by an object is proportional to the object's area and emissivity and the fourth power of its absolute temperature. Thus if the emissivity of an object is known, the energy received by a suitably designed detector of infrared radiation will be related to the fourth power of the object's temperature.

The emissivity of human skin is remarkably high in the range of infrared wavelengths between four and 20 microns. Indeed, J. D. Hardy of the J. B. Pierce Foundation Laboratory in New Haven, Conn., has found after intensive studies that the emissivity of human skin in that region of the spectrum is within 1 percent of that of a black body, a theoretical object that perfectly absorbs and emits energy. Hence broad-band measurements of the infrared energy emitted by the skin can be converted directly into values of temperature. With sensitive thermographic apparatus the differences in the amount of infrared radiation re-



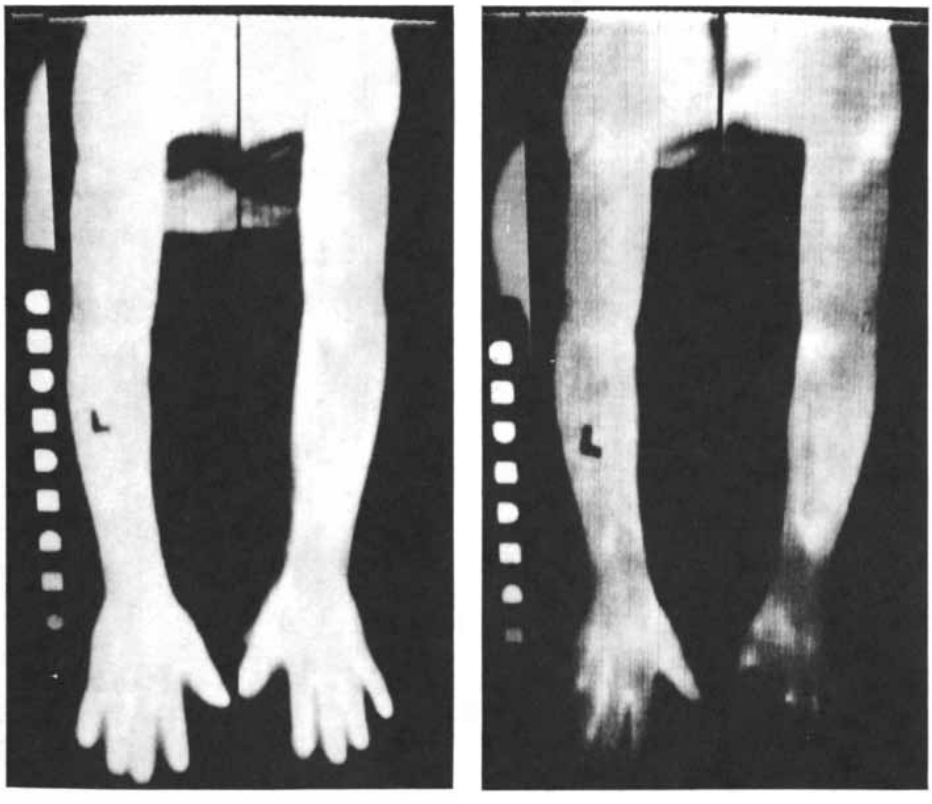
BREAST TUMOR appearing in a thermogram is marked with an *X*. The *L* above it signifies "left" and is placed on the patient because left and right in thermograms are often reversed from the order in ordinary photographs. The reason is that the patient is recumbent during thermography and heat from her body is reflected into the detector by an overhead mirror. Below the thermogram are graphs made by electronic devices; *A* shows the temperatures of the standard reference scale and *B–D* show the thermal profiles of the regions marked by the correspondingly lettered lines. Temperature of tumor is at *X* in graph *D*.

ceived by the detector can be recorded on thermograms as halftones that are light or dark in direct proportion to the temperature.

The heat-sensing device in the Barnes thermograph is a thermistor composed of nickel, cobalt and magnesium oxide in the form of a thin flake mounted on a sapphire. The thermistor, acting as a bolometer, changes its electrical resistance in proportion to the radiant energy received; the change is about 4 percent for each degree centigrade. The flow of radiation to the thermistor is interrupted regularly by a chopper [*see bottom illustration on page 96*]. By this means the thermistor is able to compare the radiation received from the subject with the radiation received from an artificial black body in the form of a black surface on the chopper. Accordingly the electric current in the thermistor fluctuates. After considerable amplification the current is strong enough to illuminate a gas-discharge tube, which glows with an intensity proportional to that of the radiation being detected by the thermistor. Light from the tube travels to the back side of the scanning mirror. From there the light is reflected into a Polaroid camera, which produces the thermogram.

The scanning mirror, placed at 45 degrees to the optical axis, is driven by cams to produce a horizontal sweep covering 20 degrees. After each horizontal scan the scanner is rapidly returned to its starting position; during the return a blanking circuit cuts off the light of the tube, and at the same time the scanning mirror is tipped upward by the width of one line. The process is repeated until a vertical height of 10 degrees has been scanned. The optical system has an instantaneous field of view of one angular mil, which is equivalent to an eighth of an inch at a focal distance of 10 feet. At this distance the thermograph's field of 10 by 20 degrees covers an area of 28 by 40 inches. The time required to scan such an area is four minutes. Each thermogram contains some 60,000 "bits" of temperature information.

Alongside each patient undergoing thermography we place a standard reference scale that emits heat at various known temperatures and appears in thermograms as different values of gray. The scale is visible in several of the thermograms accompanying this article. It is possible to compare the thermogram with the gray scale to arrive at an estimate of the temperature in each part of the patient's body shown in the thermogram. Because such a comparison is likely to be made differently by different observers, however, we also use a number of techniques by which the density of shading is determined electronically and displayed by means of oscilloscopes, isothermic charts and inked graphs on strips of paper. During the past three years the standard gray scale and the display techniques have undergone considerable improvement. The current thermograph affords temperature discriminations of about .5 degree C.



EFFECT OF NICOTINE on the circulation appears in thermograms of a man's arms before he smoked (*left*) and 15 minutes after he smoked a cigarette (*right*). Nicotine has constricted blood vessels, reducing the amount of blood in the arms and lowering their temperature.

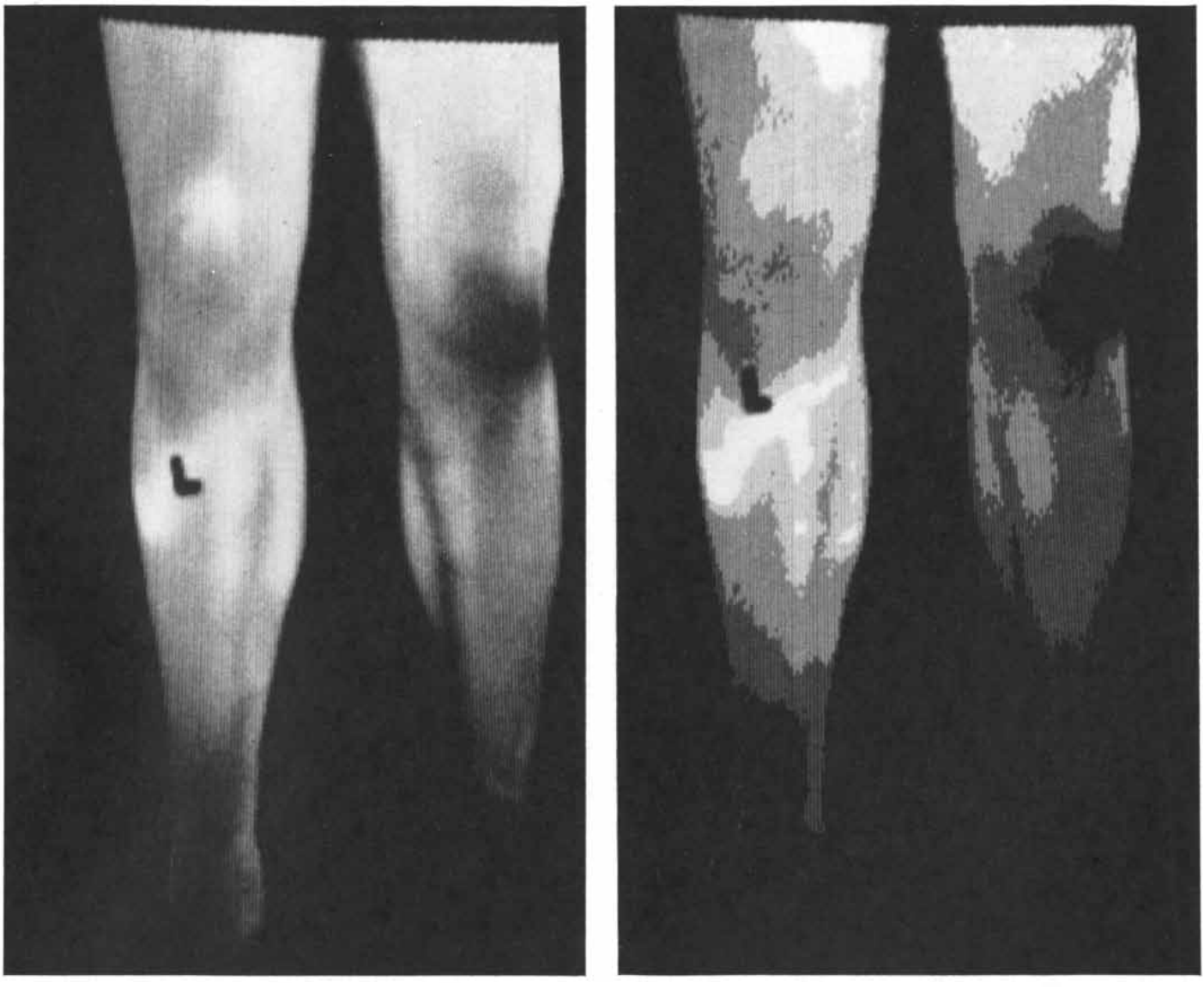
Skin temperatures are generally lower than the 37 degrees C. (98.6 degrees Fahrenheit) normally registered in the mouth. The range of skin temperatures is from 23 degrees C. to 36 degrees C. In normal circumstances the variations result from differences in the skin and under it and in the thermal conductivity of the tissues covered by the skin. In addition, of course, there are differences caused by disease or abnormal physiological states.

In making thermograms the pigmentation of skin presents no problems. It is possible, however, to encounter spurious effects from visible light and from reflections of infrared at short wavelengths. We guard against such effects by using filters; germanium lenses, for example, are used to exclude radiation with wavelengths shorter than 1.8 microns.

Foreign material such as lipstick, nail polish, rouge, carbon black and India ink placed on the skin will make it appear slightly cooler on thermograms, since the emissivity of these materials is lower than that of skin. Hair, because it has no blood vessels, comes into equilibrium with room temperature and consequently appears cool. Skin that is inflamed, swollen or situated directly above blood concentrations such as veins, infections, cancers and bruises will appear hotter than normal. Conversely, skin over areas with a decreased blood supply, which is characteristic of arteriosclerosis and thrombosis, will appear cooler.

Thermograms can be obtained of all parts of the body not covered by hair. The valuable diagnostic information they furnish can localize areas of immediate concern to the physician. The progress of disease and the efficacy of therapy can be monitored by a series of thermographic studies in many situations where the ordinary clinical thermometer would be inadequate.

During the past three years the breasts of more than 3,500 women have been thermographed in our institution. By correlating each thermogram with other diagnostic information, including X-ray studies, we have fairly well appraised the reliability of the technique. When the heat patterns are uniform over both



FAULTY CIRCULATION in legs is depicted in the dark areas of a photographic thermogram (*left*) and in an isothermic presentation of the same situation (*right*). In making the isothermic presentation the Barnes thermograph converts five values of temperature sensed by the infrared detector into five values of gray and reproduces the grays on film. The conversion is done electronically.

breasts and no localized "hot spot" is discernible, abnormality can usually be ruled out.

If a localized elevation of skin temperature of more than 1 degree C. is detected, the presence of a cancer is one of the possibilities that must be considered. More than 95 percent of all breast cancers have been found to be associated with a skin temperature at least 1 degree C. higher than the temperature of the uninvolved portion of the same breast or of a similar area of the opposite breast. The possibility of using these observations for screening the breasts of groups of healthy women is currently being tested in several institutions in New York and Philadelphia.

Medical thermography has been employed in many other medical and surgical problems. Thermographic "fingerprints" are yielded by malignant tumors, both localized and widespread; by fractures, abrasions, contusions and dislocations; by burns and frostbite; by localized infections; by arthritis, and by disturbances of the peripheral vascular system. Some striking results have been obtained from such thermograms.

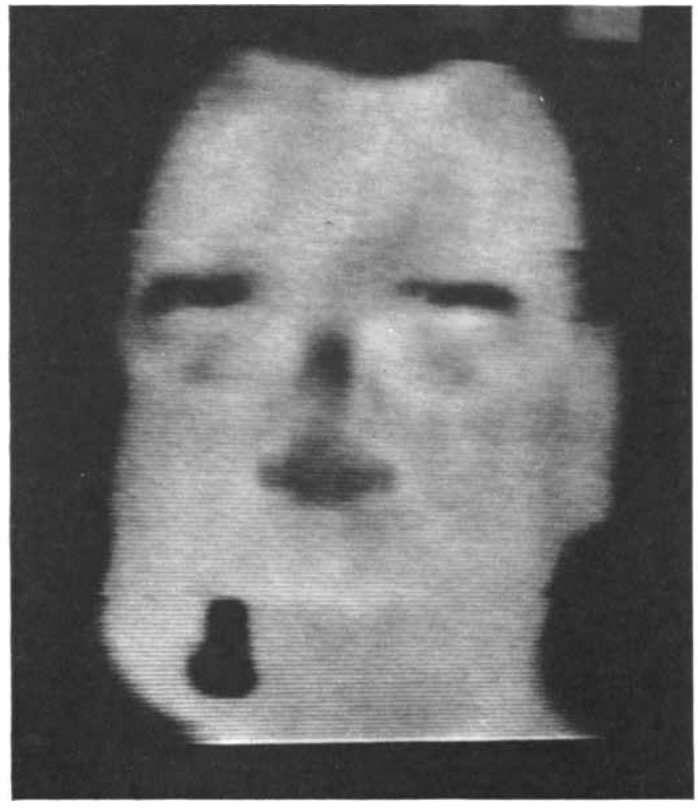
For example, new insights are afforded by thermography in the experimental study of the effects of drugs. The idea that nicotine has a widespread constrictive effect on the blood vessels of smokers is graphically confirmed by thermograms in a way never before possible [*see illustration on opposite page*]. Impaired circulation in arteries of the limbs and the neck can be seen in thermograms, often considerably in advance of detection by clinical means; hence therapy can be instituted sooner. The effectiveness of procedures to correct the impairment, whether by drugs or by surgery, can be ascertained by studying the heat patterns of the skin before and after treatment.

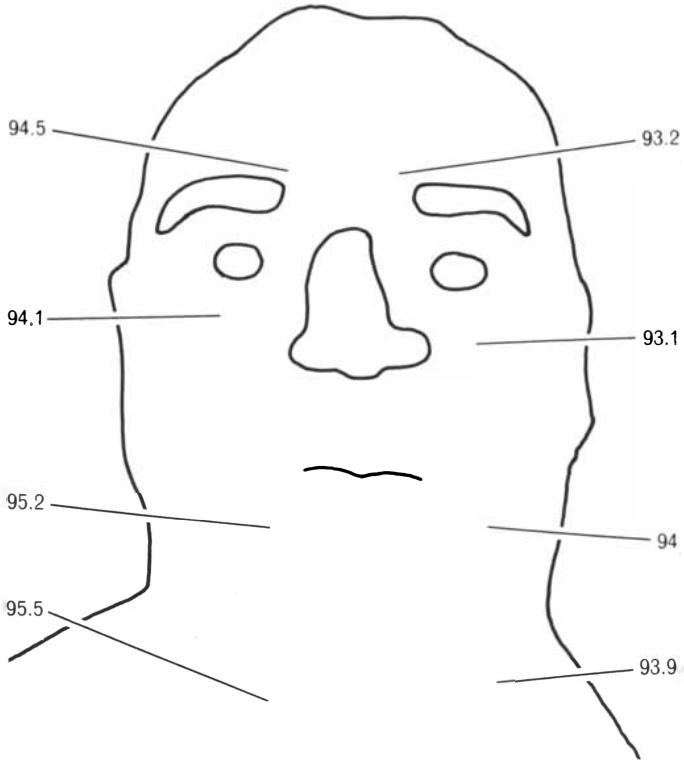
Again, the thermographic interpretation can be successful only in the context of complete studies. They include such accessory examinations as angiography (X rays of blood vessels after injection of a radio-opaque substance). Angiography might, for instance, demonstrate any of the following conditions near a gangrenous area in the foot of a diabetic patient: (1) no blood supply to the area; (2) dilated small arteries in the area surrounding inflammation; (3) an abnormal capillary blush around inflamed connective tissues. The thermographic patterns in these three situations might be at variance. Unless they were properly correlated they could lead to an incorrect interpretation.

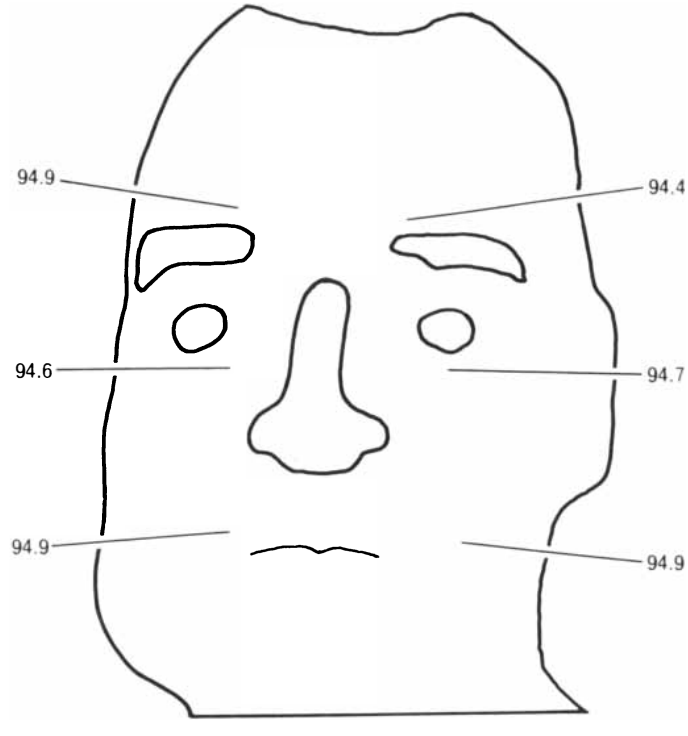
By repeated examinations of the skin

over involved joints the activity of arthritic processes can be followed. Thermographic patterns above the sites of fractures often disclose persistent residual heat long after the bone fragments have united. The effect arises because the injured soft tissues and blood vessels heal more slowly than the bone. In frostbite and burns the presence and location of devitalized tissue can be precisely mapped for removal by the surgeon. The viability of skin grafts is well portrayed by thermography.

During pregnancy the location of the placenta, knowledge often vital to the safe delivery of the child and the health of the mother, can be determined with considerable accuracy by thermography. The technique obviates the necessity of using potentially harmful X rays or radioactive isotopes. The activity of many skin conditions can be accurately mapped. Malignant pigmented moles can be distinguished from benign ones.







EFFECT OF TREATMENT can be observed by thermography. At top left is a thermogram of a patient with impaired circulation to the head because of blockage of a carotid artery. Below it is a diagram showing the temperatures in degrees Fahrenheit of regions of the head. At right are a thermogram and a corresponding diagram made after the patient had undergone an operation to correct the difficulty. Low temperatures that were evident before the operation because of faulty circulation have disappeared.

Because every person has his own heat patterns, and because the patterns vary widely in appearance, it is essential that skill and experience in interpreting thermograms be acquired. The techniques are mastered in much the same way that the radiologist acquires proficiency in the interpretation of X-ray films, which are also a mosaic of grays. Even when abnormal heat patterns are seen, one cannot come to a diagnostic conclusion without recourse to other measures such as a careful appraisal of symptoms, physical signs and the results of laboratory procedures, including X-ray studies. The thermograph is an excellent diagnostic adjunct, but it is not conclusive in itself. As improvements accrue with time and experience, however, the techniques should prove increasingly reliable. Its potential applications are only now being explored; indeed, thermography is at much the same stage that roentgenology had reached at the turn of the century.

By discussing at some length the Barnes thermograph, which is the instrument we have used, I do not mean to minimize the importance of the other kinds of apparatus that have been developed for thermography. One of them, the Evaporograph, made by Baird-Atomic Incorporated of Cambridge, Mass., is based on ideas put forward by Marianus Czerny of Germany in 1929, when he described a means of making heat radiation visible. His name for the technique was evapography.

In the Evaporograph a thin membrane of nitrocellulose divides an evacuated cell into two compartments. The entire cell is situated between an optical system and a viewing system [*see illustration on next page*]. One of the compartments is heated, and when oil is introduced into it, the oil condenses on one side of the membrane. The infrared image is focused on the other side of the membrane, which is coated with a thin film of gold black to increase the membrane's capacity for absorbing heat. The intensity of heat radiation in the image varies from point to point, with the result that the thickness of the film of oil condensing on the other side correspondingly varies. When the oil film is illuminated with white light, the interference of the light waves at points of differing thickness gives rise to an image with colors resembling those in an oil slick. From the rates of change in the thickness of the film, temperatures in the entire field can be determined by using a reference point of known temperature and emissivity. With an appropriate optical system the oper-

ator can observe and photograph the image simultaneously. The resulting thermograms are qualitatively interesting, even promising, but at least for the present they do not have sufficient temperature discrimination for medical purposes.

Another system of thermography is the Pyroscan, developed by S. Smith and Sons of London. In this system a photoconductive detector such as indium antimonide is employed. The sensitivity of the detector can be enhanced by cooling it with liquid nitrogen. The detector has a fast response but is limited to recording wavelengths no longer than 5.4 microns. The emission of radiation from the human body extends out to considerably longer wavelengths, the maximum emission occurring at 9.5 microns. The scanning time for the Pyroscan is only 30 seconds for a field of view as large as the chest, and the image can be displayed on electrostatic paper.

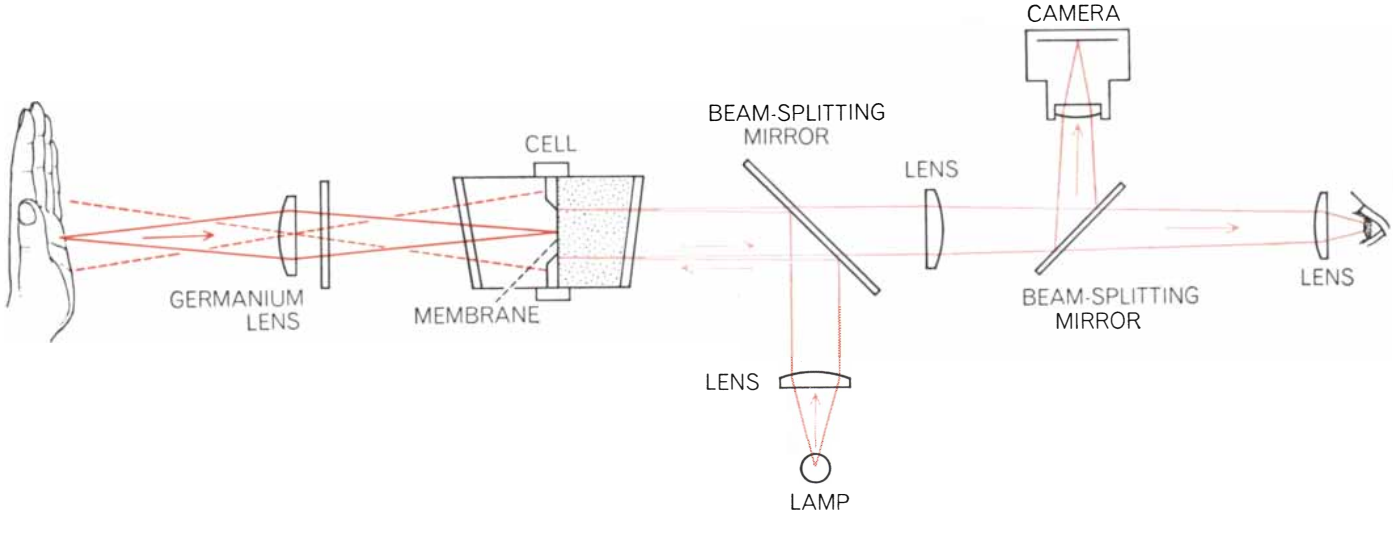
A variation of this system has been developed in Sweden by AGA Aktiebolag. Here the processed infrared radiation signals are used to modulate the intensity of a beam from a cathode ray tube. The beam sweeps across the tube face in a pattern corresponding to the scanning pattern of a television camera. The thermal picture so obtained is made up of light and dark areas that correspond to the higher and lower surface temperatures of the body. The display is virtually free of flicker because the camera operates continuously at 16 frames per second. Permanent records can be obtained with a Polaroid camera or a 35-millimeter camera in a manner allowing simultaneous viewing and recording.

A quite different approach to thermography was investigated until recently by a research group at the General Electric Company. The effort was based on observations of Edmond Becquerel in 1843 that infrared radiation will quench the phosphorescent afterglow of certain materials that have been excited by visible light or ultraviolet radiation. For thermography a coating of cadmium sulfide is applied to the skin with an aerosol device, and the coated area is flooded with ultraviolet radiation. The varying infrared radiation from the underlying skin produces a pattern of point-by-point quenching of differing intensities. The pattern can be photographed and qualitatively studied.

Several drawbacks in the system caused the group to suspend its work. They included the inconvenience of applying and removing the chemical coating, the unevenness of the coating, the possibility that the absorption of phosphorescent compounds through the skin would be toxic, and the lack of sufficient temperature discrimination. A variation called "projection thermography" has been tried; in it the image of the body under observation is focused on a phosphor screen. Unfortunately this technique has proved to be even less sensitive than the original one.

Experiments in the use of several other kinds of apparatus for thermography are under way in various laboratories. Lasers and masers, which generate radiation of precisely controlled wavelengths, show promise for thermographic application. The Golay pneumatic cell might prove to be an infrared detector capable of producing a useful output signal by mechanical means. The cell consists of a small chamber filled with gas, a window capable of transmitting infrared radiation and a blackened receiver of thin foil. When infrared energy falls on the receiver, the temperature of the gas increases, causing the foil to distend a small, flexible mirror. An optical system measures the extent of the distortion. Liquid crystals, which exhibit changes in light-reflecting properties when they are heated or cooled, also show possibilities for thermography [see "Liquid Crystals," by James L. Fergason; SCIENTIFIC AMERICAN, August, 1964]. Infrared radiation falling on a heat-absorbing surface coated with liquid crystals of a substance such as cholesterol will produce a thermal pattern in color.

The future of thermography as a diagnostic adjunct in all branches of medicine and surgery seems bright. One obstacle to the rapid spread of the technique may be the cost of the apparatus; the present price of a Barnes thermograph is about $25,000. Still, it seems reasonable to expect from the experience we and other investigators have gained that thermography will add a significant new dimension to the diagnosis and prognosis of disease. I also foresee the likelihood that research in biology will profit from thermographic techniques, particularly with the introduction of heat sensors for microscopy and in vivo spectrometry.



EVAPOROGRAPH records infrared radiation by means of a film of oil. A germanium lens collects the radiation and focuses it on a thin membrane in the detector, which is a cell from which air has been evacuated. The portion of the cell on the other side of the membrane is lined with blotting paper moistened with oil. When that part of the cell is heated, oil condenses on the membrane in a film that varies in thickness according to the differing temperatures on the other side of the membrane. In white light the film has varied colors; the image is reflected to an eyepiece and to a camera. A thermogram made in this way is on the cover of this issue.

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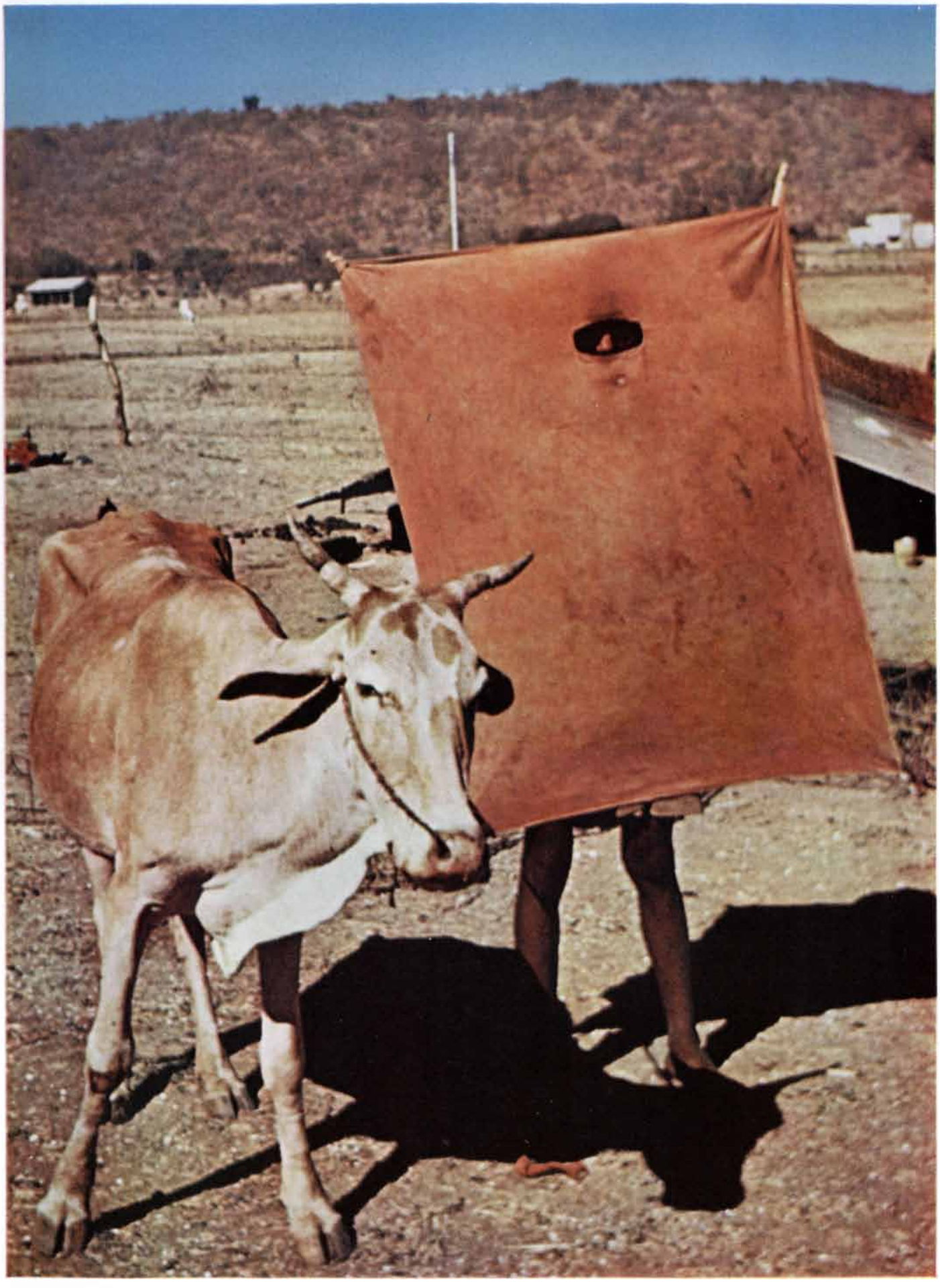


TRIBAL HUNTER from the central plateau of peninsular India stalks game such as quail by hiding behind a cloth screen and moving beside a grazing cow until the quarry is within reach. One of the Ras Phasé Pardhi tribesmen of Maharashtra, the hunter belongs to an aboriginal society whose ancient tradition of ordeal by fire may have inspired the more modern Hindu ritual of fire walking.

Living Prehistory in India

In India, as in many other lands, herdsman has succeeded hunter and farmer has succeeded both. A study of tribal groups that still pursue these ancient livelihoods helps to illuminate a shadowy past

by D. D. Kosambi

The basic task of the prehistorian is to learn as much as he can about the lives of the vanished people he chooses to study. Since by definition he works with evidence other than written records, he sometimes turns for illuminating parallels to living peoples who themselves have no written history. Perhaps nowhere in the world can such parallels be found more readily than in India. For one thing, even the written material from ancient India cannot be considered history. Scarcely a single historical figure who lived before the Moslem period (beginning in the 12th century) can be dated with any degree of accuracy, and more general accounts show little concern for facts or common sense. What is perhaps more to the point, there exist in India today many tribal peoples whose customs go back to preliterate times. Representing some 30 million (about 6 percent) of India's total population of 440 million, these peoples preserve many features—in fossilized form, as it were—of Indian prehistory.

How is it that peoples whose way of life has remained largely unchanged from prehistoric times have survived in India, which has had cities and civilization since early in the third millennium B.C.? The answer lies in the availability of food. In India today food shortages are all too well known, but they are a comparatively recent development; even now they are limited to village farmers working marginal lands and to the nation's impoverished city dwellers. In most of India nature is so kind that for thousands of years it has been possible for people to live with comparative ease simply by hunting and primitive food-gathering. This is still the case in areas where overcultivation and excessive clearing of forest have not eliminated the land's natural cover. Not only are fish and game abundant but also a variety of other natural products are enough in themselves to provide a balanced diet. Fruits, nuts, berries, leafy vegetables, tubers such as the yam, mushrooms, honey—more than 100 such natural products can be gathered in season. A large number of foodstuffs that can be stored from one season to the next grow in both wild and cultivated forms. In this category are sesamum (which provides an edible oil), emmer wheat, rice, a wide variety of beans and the sorghums and millets. Indeed, in the days of Gautama Buddha (sixth and fifth centuries B.C.) the millet *Panicum frumentaceum* was gathered wild and not cultivated at all.

This abundance of vegetable resources, supplemented by the milk and other dairy products available to the herders of cattle, sheep and goats, means that even hunting is not really crucial to survival. One can support life reasonably well in the balmy Indian climate without killing anything. This is a basic reality that does more than merely account for the survival of primitive tribal groups in India today: it clarifies the origins of Indian social thought. The characteristically Indian religions—such as Buddhism and Jainism—regard the taking of life as a sin. It is scarcely conceivable that such an ethic could have developed if an economy of bloodless food-gathering had not provided prehistoric Indians with an adequate livelihood.

The Iron Age people who practiced plow agriculture in India were at first limited to the plain of the Ganges. From that rich region they moved southward into the Deccan: the great forested plateau of peninsular India [*see illustration on page 108*]. This invasion was not accompanied by the violence that marked Rome's Iron Age conquest of tribal Gaul and pacification of the forests beyond the Rhine. As the advancing plowmen from the north met the forest herders and food-gatherers of the south, the contact seems to have initiated a process of mutual acculturation. The food-gatherers learned to adjust to agriculture and the farmers not only came to rely heavily on food-gathering to supplement their diet but also brought wild foodstuffs under cultivation. This two-sided adjustment between gatherer and producer provides both the fabric and the pattern of India's past. It is notably reflected in today's social organization and accounts for the origin of caste and the caste system [see "The 'Untouchables' of India," by M. N. Srinivas and André Béteille; SCIENTIFIC AMERICAN, December, 1965].

In many parts of India the names of the local tribal people are identical with those of the local agricultural castes, even though the difference in caste between tribesman and farmer prevents intermarriage and other forms of contact between them. The identity of names probably stems from an original unity, when immigrant farmers and indigenous food-gathering tribesmen at first made common cause in the forest region. The two major characteristics of the caste system—prohibitions against marriage outside the group and against acceptance of food from the hands of a stranger—are taboos that are typical of food-gathering tribal societies. One can imagine the caste system originating as a somewhat later effort of the indigenous food-gatherers to establish themselves as being superior to the immigrant plowmen.

If this is the case, one may ask why the caste of farmers is now higher than that of tribesmen. Answers are not hard to find. First, whatever their initial handicaps, the farmers, simply by practicing agriculture, had a sounder eco-

nomic base than the tribal people, and in India, as elsewhere, social rank corresponds closely to position on the economic scale. Second, because of their somewhat better food supply the farmers must almost from the first have multiplied faster than the tribesmen and thus would soon have outnumbered and dominated them.

Although there are caste inequalities between farmers and tribal peoples today, plentiful evidence of mutual acculturation remains, particularly in the area of religion. Many of the supposedly "Hindu" gods of the Brahman pantheon, for example, have their actual origin in tribal cults. By the same token, when tribal people abandon their aboriginal ways and take to farming for a livelihood, they abandon their ancient gods and adopt Hindu religious practices.

PACKHORSES belonging to shepherds of the Dhangar caste are led by the women to the next campsite in a round of travel that may cover as many as 400 miles during the eight months of the dry season. The Dhangar men do not follow the roads but let their sheep graze cross-country. Each night they pen the flock in the fields of local farmers, who pay for the manuring that results.

MODERN MICROLITH is made by a Dhangar shepherd, who smashes a nodule of chalcedony with a stone hammer and anvil. He will use one of the razor-sharp chalcedony fragments as a knife for castrating lambs. The knife is thrown away after one use.

Much of the ritual that accompanies both the Hindu religion and the aboriginal ones seems bizarre to modern eyes. Nonetheless, to dismiss ritual as mere superstition (or worse, to follow the fad of explaining it in psychoanalytic terms) is to throw away a genuine opportunity to study both the history and the prehistory of India.

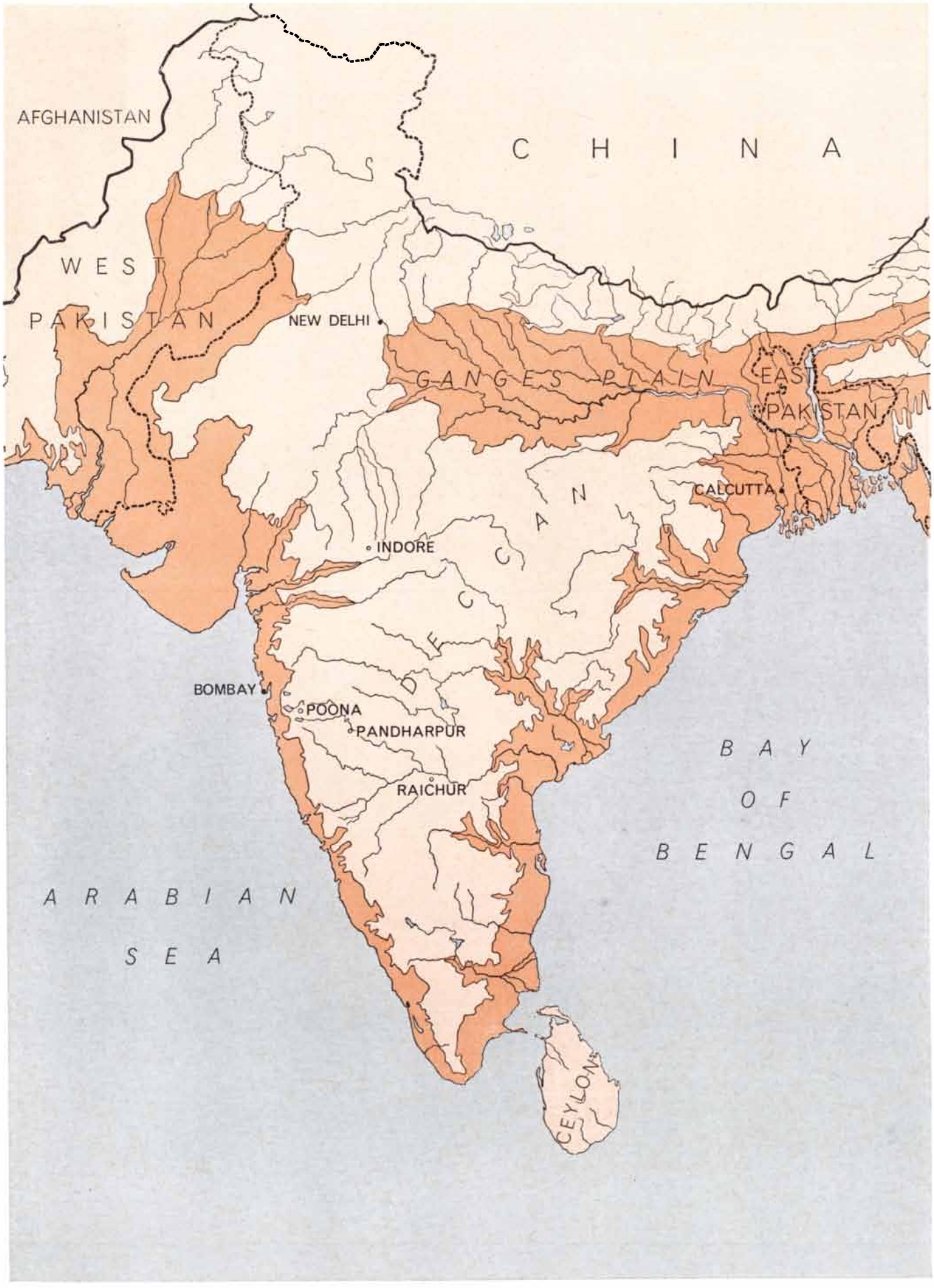
My own fieldwork has been confined to portions of the Deccan plateau and the adjacent west coast of peninsular India, an area in which my familiarity with local dialects and customs has made detailed investigations of tribal and village life possible. One of the first tribal groups I had a chance to study was the Ras Phasé Pardhi. These people, who now live in Maharashtra, originally came from Gujarat to the north and speak a dialect of Gujarati. The Pardhi are nomadic and are accompanied on their travels by a few scrawny cattle. The men do some casual labor and are skilled at stalking and snaring birds and other small game [*see illustration on page 104*]. The basic Pardhi occupations today, however, are begging and theft—practiced by men and women alike. The Pardhi consider stealing a crime only if the victim is a fellow tribesman.

Pardhi religious ritual is a mixture of adopted and aboriginal elements. The principal object of worship is a silver plaque of modern manufacture that bears the image of a Hindu goddess. Nonetheless, the major ritual—a fertility dance—gives every sign of being genuinely ancient. The performer is a male, the head of one of the small bands into which the tribe is divided. He dresses as a woman and is not merely a priest in the ritual. In his own words, "I *am* the goddess."

Part of the fertility ritual provides an interesting example of reciprocal acculturation between Hindu and aborigine. The dancer at one point plunges his hand into a pan of boiling oil, evidently without ill effect. This kind of ordeal is apparently an ancient Pardhi custom. At a Pardhi trial, for example, one proof of innocence is to walk a fixed number of steps while carrying a red-hot piece of iron. The parallel Hindu ordeal—walking on hot coals—has no sanction in Brahman scripture; ordeals are not mentioned in the earliest Hindu sacred books. In fact, fire walking apparently did not become a part of Hindu ritual until about the beginning of the Christian era, when it was adopted primarily as a means of proving innocence in the face of strong evidence of guilt. One can scarcely avoid

ANCIENT MICROLITHS have been found by the author in surface deposits at many sites in peninsular India. Carefully produced flakes such as these provided aboriginal hunters and herdsmen with tools for working bone and wood and for cutting flesh and hides.

TRANSFORMATION from function to ritual is evident in this 2,000-year-old sandstone ring, the inner face of which is decorated with alternating human figures and plants. Rings of this kind but without decoration are found at Neolithic sites throughout India; they were used to weight the digging sticks with which the earliest farmers planted seed. By 200 B.C., when this example was made, the rings were talismans rather than farmers' implements.



PENINSULAR INDIA is dominated by its ancient volcanic highlands, called the Deccan, bordered on the east and west by the subcontinent's narrow coastal lowlands and on the north by a wide, rich, densely populated alluvial plain formed by the Ganges River.

the conjecture that the Hindu ordeal was adopted from some aboriginal Indian rite such as the ones preserved today in the Pardhi dance and trial.

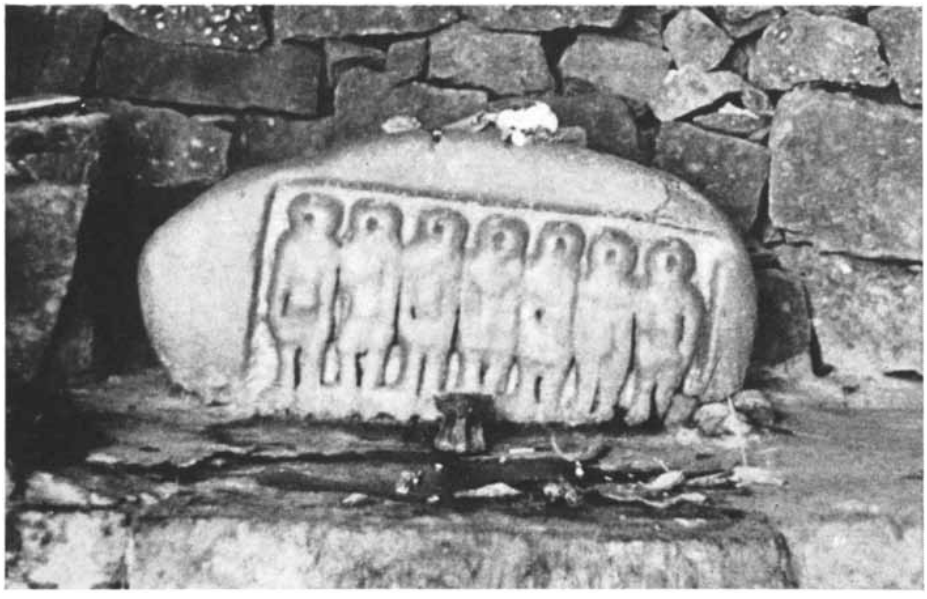
Another primitive group in the Deccan—the Dhangars—are a caste rather than a tribe. Some of them are farmers; others specialize in the manufacture of woolen blankets. At least one Dhangar family, the Holkars, took up the military life early in the 18th century and rose to princely status as the maharajas of Indore. Today the members of one Dhangar group follow tribal ways and earn a living as itinerant herdsmen. Each Dhangar band numbers about 12 people. Leading a flock of perhaps 300 sheep, the band spends the eight dry months of the year in a round of travel that rarely covers less than 200 miles and may range as far as 400 miles.

The women of the band travel the roads, moving from one preselected campsite to another and preparing the meals [*see upper illustration on page 106*]. The men herd the grazing sheep cross-country and leave them in some farmer's field at night. The sheep's overnight droppings are valuable fertilizer for which the farmer pays either in cash or in produce. These payments, together with small earnings from the sale of wool, a few skins and occasionally an animal, provide the livelihood of these pastoral nomads.

During the four months of the rainy season the Dhangar herdsmen move from their farmland pastures to traditional campsites on the plains that are dry enough to keep the sheep safe from the hoof rot they contract on muddy ground. At these rainy-season camps are sheep pens, solidly constructed of dry-stone masonry, that must have been built in prehistoric times. Some of the richest deposits of prehistoric stone tools I have found in India are close to Dhangar rainy-season camps. The same is true of many rock engravings that also appear to be prehistoric.

The stone tools are the tiny blades called microliths. It is a curious fact that although the Dhangars do not recognize the microliths as tools when they see them, they make and use similar tools themselves. When a lamb is to be castrated, a Dhangar shepherd takes a nodule of chalcedony and shatters it, using two other rocks as hammer and anvil [*see lower illustration on page 106*]. He then selects a sharp flake of chalcedony to use as a castration knife. After the stone flake is used it is ritually boiled together with the lamb's testicles and thrown away.

One of the traditional rituals in the Maharashtra region of the Deccan—the great pilgrimage to Pandharpur—may have originated in the days when everyone's life involved the kind of seasonal wandering that is still the way of the Dhangar shepherds. At the very least the pilgrimage is out of keeping with a settled agricultural way of life. The journey to Pandharpur can take as long as three or four months and traditionally begins at the start of the rainy season. That such a custom could have arisen in a farming society seems improbable; the rainy months are the ones during which the farmer does the larger part of his productive work.



SEVEN SISTERS, once possibly a college of priestesses who served an aboriginal mother-goddess in peninsular India before the invaders of the Deccan introduced worship of a father-god, are still revered in Maharashtra. This sculpture in their honor stands near the National Chemical Laboratory in Poona; it has a coating of red lead that symbolizes blood.

Other seemingly illogical mixtures of old ways and new are common in peninsular India. One example I have observed combines the plow technology of later times with a much earlier form of agriculture—the "slash and burn" method, in which farmland is created by cutting down and burning the natural vegetation. When the farmers of Maharashtra grow millet today, they clear hillsides by the slash-and-burn technique and plant the crop with the aid of primitive digging sticks. In the level valley fields where wheat and rice are raised, however, the same farmers plow and fertilize by modern methods.

The most spectacular example of fossilized ritual I have encountered is *bagad,* or "hook-swinging." Both the law and public opinion discourage this practice in India today, but hook-swinging posts are still to be found near many temples throughout the Deccan. According to historical accounts the ritual required that a pair of sharp metal hooks be thrust into a selected victim's back, penetrating the flesh just above the hips. The hooked man was then hoisted clear of the ground and left to swing, painfully suspended only by the two hooks. This gruesome rite was conducted on one special day each year. Foreign observers could discover no particular reason for it and rather too willingly attributed it to the savagery of the people who practiced it. None of these people had told them that to be hook-swung was a signal honor and a prerogative jealously guarded by a very few of the oldest farming families in each district.

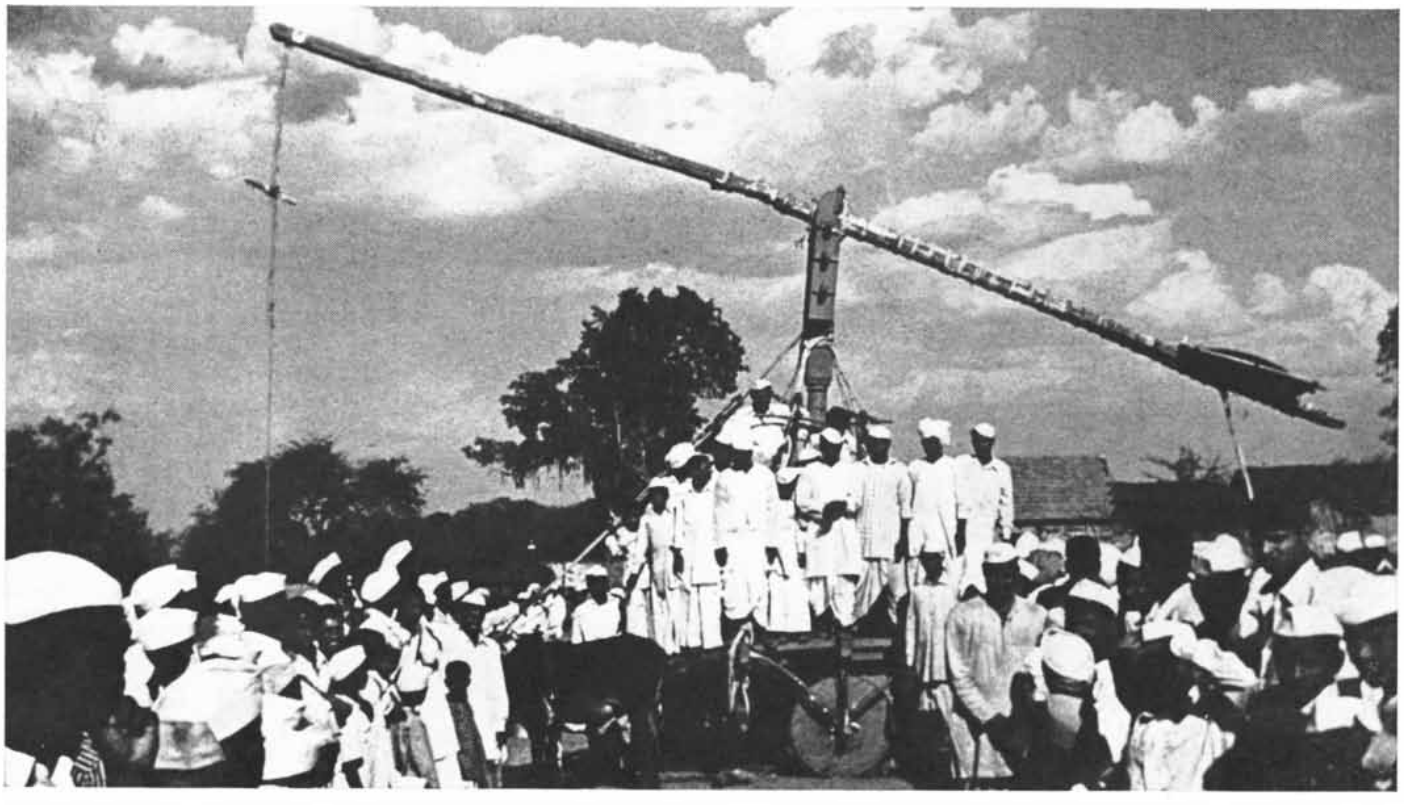
Today hooks are still set in living flesh each year in a few remote villages. I was recently able to witness such a ceremony. I must preserve the anonymity of both the village and the participants in the ritual, but I can say that it took place at the time of the April full moon. In this village the man to be swung must be selected from among the young married men of clan *X,* in spite of the fact that the village headman, the leading village families and all the richest farmers are members of clan *Y.* This privilege stems from the fact that the earliest immigrants in the area were members of clan *X,* and that it was they who first heard the call of the god Mhatoba, in whose honor the ritual takes place.

In this village the two swinging posts are set up in a cart that is used only on this one day of the year. Nowadays the celebrant's weight is no longer borne by the hooks throughout the ceremony. Be-

tween swings he sits more or less comfortably astride a bar suspended from a crossbeam that is balanced between the two uprights [*see upper illustration below*]. A new crossbeam is ceremonially cut each year in a jungle some 40 miles from the village; this jungle is said to be the place from which clan *X* originally migrated. Relays of specially chosen villagers carry the beam back to the village. They are permitted to put down their burden and rest only at specific points along the way.

At the outset of the hook-swinging ceremony candidates for the honor gather with a group of electors under a specific tree outside the village. After the celebrant has been chosen the electors and the candidates return to the village, running through a sacred course in groups of three. The man in the middle

RITUAL "VICTIM" of the annual hook-swinging *bagad* ceremony rests on his perch as he starts off to bless all the farm fields of his Maharashtra village. Two metal hooks thrust into the small of the back were at one time all that suspended the hook-swinger throughout the ceremony. To be selected for the swinging ritual is an honor that is jealously confined to the men of one clan in the village.



RITUAL CART on which the *bagad* uprights and swinging pole are mounted stands unused all year long except for this day. Those surrounding the cart include the electors, who annually choose a hook-swinger from among the eligible clan's young married men.

of each trio is a member of clan *X;* he is flanked by men of clan *Y*. The celebrant and his two escorts are the last to run the course. When they have done so, the celebrant is led to the local temple. There he is ritually bathed, declared *deva* (temporarily divine) and dressed in a special costume (a red turban and red silk trousers) that leaves him naked from the waist up.

The celebrant now goes to the site of the village's annual *holi* (spring festival) bonfire. He stands on the fire's ashes as the village carpenter thrusts the two steel hooks into the small of his back [*see illustration at right*]. Every man in the village crowds around to watch the operation. The celebrant is then decked with garlands and led to a nearby field. There the *bagad* cart, drawn by a pair of bullocks, is waiting. A rope that is attached to each hook is looped behind the celebrant's back and tied to the crossbeam, which rests on the two *bagad* uprights. The celebrant individually blesses each child born since the last hook-swinging; when this has been done, he makes his first swing suspended by the hooks. A cheer goes up, the god-elect nimbly climbs astride his resting bar and the cart jolts off across the fields.

At prescribed points along the route the cart stops and the celebrant descends from the bar to make a predetermined number of swings. After all the village's fields have been blessed in this manner, the procession continues through the fields of a neighboring village to the place where the god Mhatoba's temple stands. The people have gathered from miles around. A number of goats are now sacrificed, the order of their slaughter being established by the rank of the clan offering the sacrifice.

When the sacrifices are over, the hook ropes are untied from the *bagad* beam and the god-elect climbs down from his bar. He enters the temple, the hooks are removed and his wounds are anointed with ashes from Mhatoba's sacred fire. Once this is done the god-elect reverts to human status. During the ceremony I observed, the celebrant was in a state of exaltation and showed no trace of pain. Although he received no medical treatment other than the application of wood ash, two weeks later the marks on his back were scarcely visible.

When I asked about this village tradition, I was told that the form of the hook-swinging ceremony had originally been quite different. In the "good old days," my informants said, the god-elect from clan *X* was killed at the end of the procession, along with another god-elect annually chosen from the low-caste clan Z. The two men were beheaded, their heads were set on stone slabs that are still in place in front of Mhatoba's temple, and Mhatoba's ceremonial palanquin was paraded over the grisly offerings. I was told that the original practice had been continued until only one male member of clan Z remained alive. At that point, it was said, Mhatoba himself appeared and declared that life need no longer be taken. It would suffice, he said, if on the sacred day the elected representative of clan Z had his thigh ceremonially cut and the representative of clan *X* was hooked and swung. In fact, my informants told me, the thigh-cutting ritual is still followed each year within the temple. The representative of clan Z has his thigh cut at the same time the hook-swinger descends from his cart. Like the hook-swinger's wounds, the clan Z celebrant's wound is anointed with ashes from Mhatoba's sacred fire.

HOOK-SWINGER, ritually dressed in silk breeches and garlanded with flowers, is about to be tied to the swinging pole by means of the ropes attached to the two hooks that dangle from his back. The author found that hook-swinging was a substitute for human sacrifice.

What are the prehistoric elements in this bizarre tangle of ritual and tradition? For that matter, how much of the supposed tradition is actually credible? As a start, I see no reason to doubt that human sacrifices really took place in the "good old days." Although human sacrifice was eliminated from formal Hindu ritual before the sixth century B.C., the custom continued in many parts of India until recently. To judge by today's police

record of ritual murders, human sacrifice is still practiced among a number of tribal peoples.

As recently as the 1780's the Brahman rulers of Poona, wishing to ensure the impregnability of Lohogad Fort, saw to it that a young married couple was buried alive under the fort's foundations. An unmarried man was similarly sacrificed by the Moslem builders of Chakan Fort; a cult in his honor survives to this day. Not all the victims of human sacrifice went unwillingly to their death. Evidence is provided by the barber caste of Kurkumbh, which is proud to hold first place in worship at the shrine of the goddess Phirangai. The barbers' priority is traditionally based on a feat performed by a member of the caste who had been given the task of escorting the goddess to Kurkumbh from her former residence some 200 miles away. The goddess agreed to make the move, with the usual kind of fairy-tale provision that she would travel no farther than the first place at which her escort turned his head and looked behind him. The barber resisted temptation all the way, staring fixedly before him until he reached Kurkumbh. On his triumphant arrival he volunteered on the spot to make a sacrifice of his unturned head.

Assuming that the account of Mhatoba's original bloody rites is authentic, how are these rites related to the prehistory of peninsular India? An answer to this question requires an examination of the deity's history. Mhatoba is a god to whom tradition assigns two distinct places of origin. One is the same jungle, 40 miles from his present temple, from which his worshipers procure the *bagad* crossbeam each year. Here Mhatoba has a second temple. It stands on a hillock, at the base of which I have found a fair number of crude microliths; the presence of these stone tools is good evidence that the area supported a prehistoric population. At this place of worship Mhatoba is called Bapuji-Baba, or "Father-God," and it is dangerous for any woman to approach him.

Mhatoba's other place of origin is about the same distance from the hook-swingers' village but in a different direction. The site is unmarked, but tradition states that at this place the deity first appeared and immediately made his presence known by kidnaping seven virgin sisters. Mhatoba thereupon traveled cross-country to the vicinity of the hook-swingers' village, where he paused by a pool in the river. There, for no known reason, he drowned all seven sisters. When a passing member of the Koli tribe ventured to criticize Mhatoba's behavior, the god drowned him as well. Near the pool today there is a shrine to the seven sisters and the unfortunate Koli. The pool itself is considered cursed. No one bathes there, nor is its water used for farm animals. Within the shrine the crude representations of the seven sisters are coated with red lead, which is commonly used by Indian villagers as a substitute for the blood of sacrificial animals [*see illustration on page 109*]. I have found surface deposits of microliths nearby, as I did at the temple where Mhatoba is known as Bapuji-Baba.

In spite of his murder of the kidnaped maidens, Mhatoba is known in one aspect as a "married" god. Next to his statue in the hook-swingers' temple stands a statue of a goddess named Jogubai. The hilltop Mhatoba, with his reputation for being dangerous to women, has no such consort. Why should the god be single in one aspect and married in the other? To find the answer I undertook a survey of all the district's temples. I quickly learned that the goddess Jogubai, like Mhatoba, was worshiped in several places, although there was no tradition that she had come to the district from some other region. I also encountered several more Mhatobas. In many places Mhatoba and Jogubai were "married," as they are at the hook-swingers' temple. In other places, however, either the god or the goddess was worshiped alone, and the local worshipers knew nothing about Mhatoba or Jogubai being "married" elsewhere.

It is my belief that Mhatoba and Jogubai are a pair of deities who originally belonged to two different population groups and quite probably to different eras of prehistory as well. As I interpret the evidence, Mhatoba was at first an aggressively male god of the kind who was worshiped by the Gavalis, a late wave of pastoral invaders who entered

MEGALITHIC MONUMENT, erected by prehistoric inhabitants of the Deccan, has become the center of a modern cult. The object of veneration is an unhewn stone, called Manzrai, or "Cat Mother," that lies under one of the boulders in the middle of the pile.

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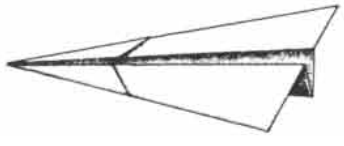

FIG. 1: Paper plane circa 1920, the classic paper plane. Smoothness of flight, grace, but under-powered.

FIG. 2: First developed among paper airplane designers in the 1930's. Still under-powered—no jet engines available.

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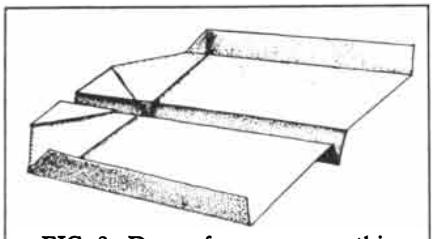

FIG. 3: Drawn from memory, this plane was last seen in 12th floor stairwell at 415 Madison Ave. Four jet engines would have materially improved its performance.

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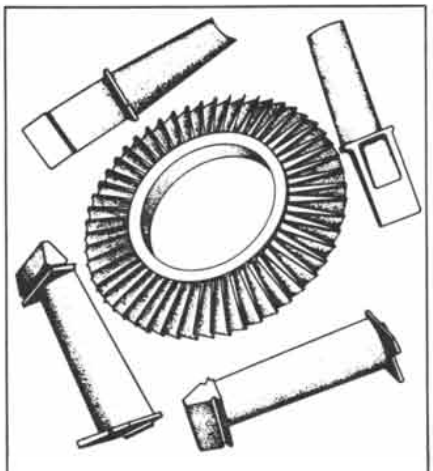

FIG. 4: Typical Howmet castings in high temperature superalloys for jet turbines.

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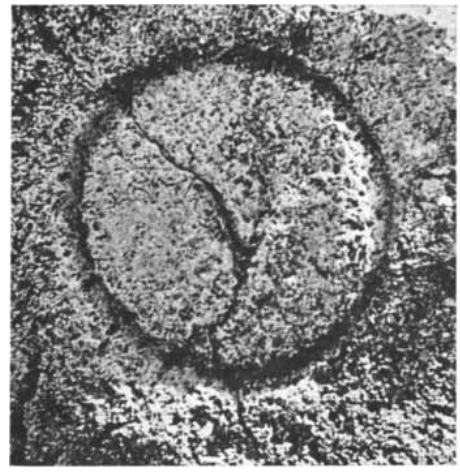
GODDESS'S SHELTER is the dark hollow (*right*) under one stone of a prehistoric megalithic monument near Poona. The deity, whose worship only began in the 18th century, is a huntress named Bolhai. The deep circle cut into the boulder is 12 inches in diameter, a size characteristic of most of the circles that decorate the megalithic monuments of the Deccan. It was probably outlined with a hand, the thumb and little finger acting as a compass.



CIRCULAR GROOVE decorates the flat surface of a basalt boulder that is part of another ancient megalithic monument in the vicinity of Poona. This circle is the same size as the one shown in the illustration at left.

the Deccan from northern India. These people herded cattle but did not use the plow. They reached Raichur in the middle of the Deccan plateau by about 2000 B.C.; recently obtained carbon-14 dates indicate that they were still practicing their pastoral way of life as late as 1000 B.C. The preceding wave of pastoral invaders from the north herded sheep and goats; therefore the skins they used for various purposes were the comparatively thin sheepskin and goatskin. The Gavalis had to work with thick cattle hides, and accordingly their microlithic tools were somewhat heavier and coarser. This difference is evident in the microliths found near the Bapuji-Baba temple.

Jogubai, on the other hand, is the kind of mother-goddess I associate with the earliest inhabitants of the Deccan: the primitive food-gatherers. These are the same people who with enormous effort erected all over peninsular India hundreds of megalithic monuments consisting of large piles of boulders. After they had piled the boulders together they also marked them with deep grooves. It is an interesting coincidence that wherever a modern cult is associated with one of these ancient megalithic monuments it is almost without exception a mother-goddess cult.

If it is correct to assume that the mother-goddess was first in the area and that the father-god was a pastoralist intruder, how do the traditions of the hook-swingers' village fit such a sequence? In their temple goddess and god are joined in "marriage"; I take this to be symbolic of a situation in which conflict between food-gatherer and pastoralist was resolved by peaceful fusion. The virgins drowned by Mhatoba might represent a sacred college of priestesses dedicated to the worship of the mother-goddess. The fact that Mhatoba is now married to Jogubai shows that even the destruction of her priestesses was not enough to suppress her worship.

The conflict between mother-goddess and father-god could not have been resolved peaceably everywhere. Throughout Indian theological art, from the earliest representation of a horned "proto-Shiva" on Harappan seals of the third millennium B.C. to gaudy pictures sold in Indian bazaars today, runs a theme of conflict between a female deity and a "buffalo demon," in which the goddess is the victor. In Kalighat paintings, for example, Shiva's wife Parvati tramples him. The goddess Durga-Parvati is called "she who tramples the buffalo demon."

In this connection Jogubai appears in another temple in the district not in the role of consort to Mhatoba but as consort to the more primitive male deity Maskoba, who is recognized as the counterpart of the buffalo demon. Just as the union of Jogubai and Mhatoba in the hook-swingers' temple can be taken to symbolize conflict resolved, so perhaps this marriage to the buffalo demon symbolizes conflict perpetuated. This much is certain: The prehistoric fusion of two distinctly different societies has left marks that remain to this day. Indeed, in some parts of the countryside both the buffalo demon and the goddess who tramples him are worshiped by the same believers but in separate shrines.

Two points, however, should be made clear. First, although instances of goddess-worship are still to be found all over India, there is no reason to believe the country's prehistoric food-gatherers were worshipers of a universal mother-goddess. To attribute any universal custom to primitive and segregated peoples is obviously hazardous. Second, it is important to emphasize that even when some ancient monument is found to be a center of goddess-worship today, there is little possibility that the modern cult represents a survival from prehistory. The early food-gatherers had no fixed abode and the early pastoralists were constantly on the move; accordingly any continuity of worship at a single site is implausible.

Nonetheless, coincidence can sometimes achieve what piety cannot. At the village of Theur the goddess of childbirth is worshiped at a megalithic monument that stands on the summit of a prehistoric mound. This goddess—Satvai, or "Mother Sixth"—takes her name from the fact that sacrifices are made to her on the sixth day after the birth of a child. The boulders that compose the monument at Theur are of a stone so hard that it will turn the edge of a modern mason's chisel. Yet every one of them bears smooth grooves with a semicircular cross section, some over an inch in depth, that were evidently produced by patient rubbing in prehistoric times. Prominent among the grooved designs is a representation of a cowrie shell, the traditional symbol of the female. It appears certain that the deity worshiped at the Theur mound thousands of years ago was a goddess, just as the deity is today. Here, with the Pardhi snarers, the Dhangar shepherds and the hook-swinging devotees of Mhatoba, is further evidence that the prehistory of India is still alive.

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MATHEMATICAL GAMES

Mathematical strategies for two-person contests

by Martin Gardner

The word "games" in the title of this department has a broad meaning synonymous with "recreations," but from time to time the monthly topic has been games in the narrower sense of actual contests between players. This month we consider a variety of two-person games, some old and some new, for which mathematical strategies are known. First, here is a trio of simple games that are related to each other in an amusing and surprising way.

1. Nine playing cards, with values from ace to nine, are face up on the table. Players take turns picking a card. The first to obtain three cards that add to 15 is the winner.

2. On the road map at the bottom of the opposite page players take turns eliminating one of the nine numbered highways. This is done by coloring the complete length of the road, even though it may go through one or two towns (*circles*). Pencils of two different colors are used to distinguish the moves of the two players. The first to color three highways that enter the same town is the winner. (The Dutch psychologist John A. Michon, who invented this game, calls it "Jam" because those are his initials and because the object of the game is to jam crossings by blocking highways.)

3. Each of the following words is printed on a card: HOT, HEAR, TIED, FORM, WASP, BRIM, TANK, SHIP, WOES. The nine cards are placed face up on the table. Players take turns removing a card. The first to hold three cards that bear the same letter is the winner. (The Canadian mathematician Leo Moser, who devised this game, calls it "Hot.")

For each game the question is: If both players make their best moves, is the game a win for the first player, a win for the second player or a draw? Perhaps the reader has already experienced what the Gestalt psychologists call "closure" and recognized that all three games are isomorphic with ticktacktoe!

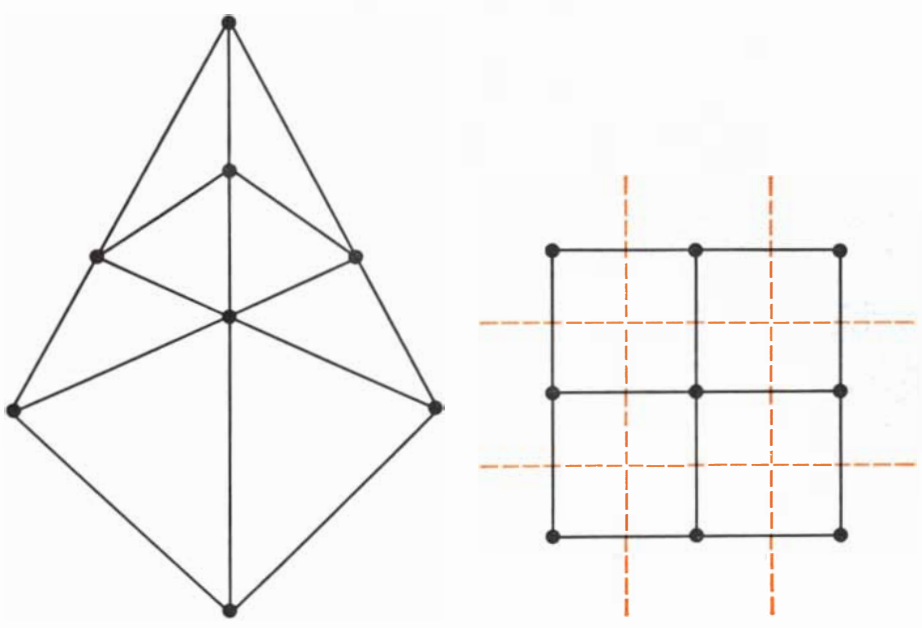
It is easy to see that this is the case. For the first game we make a list of all the triplets of distinct digits from 1 to 9 that have a sum of 15. There are exactly nine such triplets. They can be interlocked on a ticktacktoe board as shown at the top of the opposite page to form the familiar order-3 magic square on which every row, column and main diagonal is one of the triplets. Each numbered card drawn by a player corresponds to a ticktacktoe play on the cell of the magic square that bears that digit. Each set of triplets that wins in the card game corresponds to a winning ticktacktoe row on the magic square. Anyone who can play a perfect game of ticktacktoe and who also memorizes the magic square can immediately play a perfect game in this card version.

The map at the bottom of the opposite page is topologically equivalent to the symmetrical graph shown at the left in the illustration on this page. This is in turn the "dual" of the graph obtained by connecting the centers of the nine cells of a ticktacktoe board as shown at the right in the illustration. Each numbered cell of the magic square corresponds to a numbered highway on the map and each town on the map corresponds to a row, column or main diagonal on the magic square. As before, there is an equivalence relation between plays on the map and plays in ticktacktoe.

The isomorphism of Moser's word game and ticktacktoe becomes obvious when the nine words are written inside the cells of a ticktacktoe matrix as shown at the top of page 118. Each set of three-in-a-row words has a common letter, and there are no such sets other than the nine displayed in this way. Again, memorizing the square of words instantly enables a perfect-game ticktacktoe player to play a perfect game of Hot. Since ticktacktoe played rationally is always a draw, the same is true of the three equivalent games, although the first player naturally has a strong advantage over a second player who is not aware that he is playing disguised ticktacktoe or who may not play a perfect game of ticktacktoe.

One who grasps the essential identity of the three games will have obtained a valuable insight; mathematics abounds with "games" that seem to have little in common and yet are merely two different sets of symbols and rules for playing the *same* game. Geometry and algebra, for example, are two ways of playing exactly the same game, as Descartes's great discovery of analytic geometry shows.

There are many games of the "take away" type in which players alternately



Graph of Jam map **(left)** ***and its ticktacktoe "dual"*** **(right)**

take away an element or subset from a set, the winner being the person who acquires the last element. The best-known game of this kind is nim, played with a set of counters arranged in an arbitrary number of rows, with an arbitrary number of counters in each row. On his turn a player may take as many counters as he wishes, provided that they all come from the same row. The person who takes the last counter wins. A perfect strategy is easily formulated in the binary system, as explained in *The Scientific American Book of Mathematical Puzzles & Diversions.*

A starting pattern for nim, as it was played throughout the 1962 French movie *Last Year at Marienbad*, is shown at the bottom of the next page. Sixteen cards are arranged in four rows of one, three, five and seven cards. (The triangular pattern symbolizes the triangular love game played in the picture.) To determine whether the first or the second player can win we write the numbers of cards in each row in the binary system, then add the columns:

1	1
3	11
5	101
7	111
	224

If the sum of every column is an even number (or zero if the addition is made modulo 2), as in this case, the pattern is called "safe." This means that the first player is certain to lose against an expert, for regardless of how he plays he will leave an "unsafe" pattern (one with at least one column that has an odd sum), and the second player can convert this to another safe position on his next move. By always playing to leave a safe pattern he is sure to get the last counter.

Michel Hénon, a mathematician at the Centre National de la Recherche Scientifique in Paris, recently thought of a delightful nim variant, played with scissors and pieces of string. It is best approached, however, by first explaining an older variant of nim called kayles, to which the string game is closely linked.

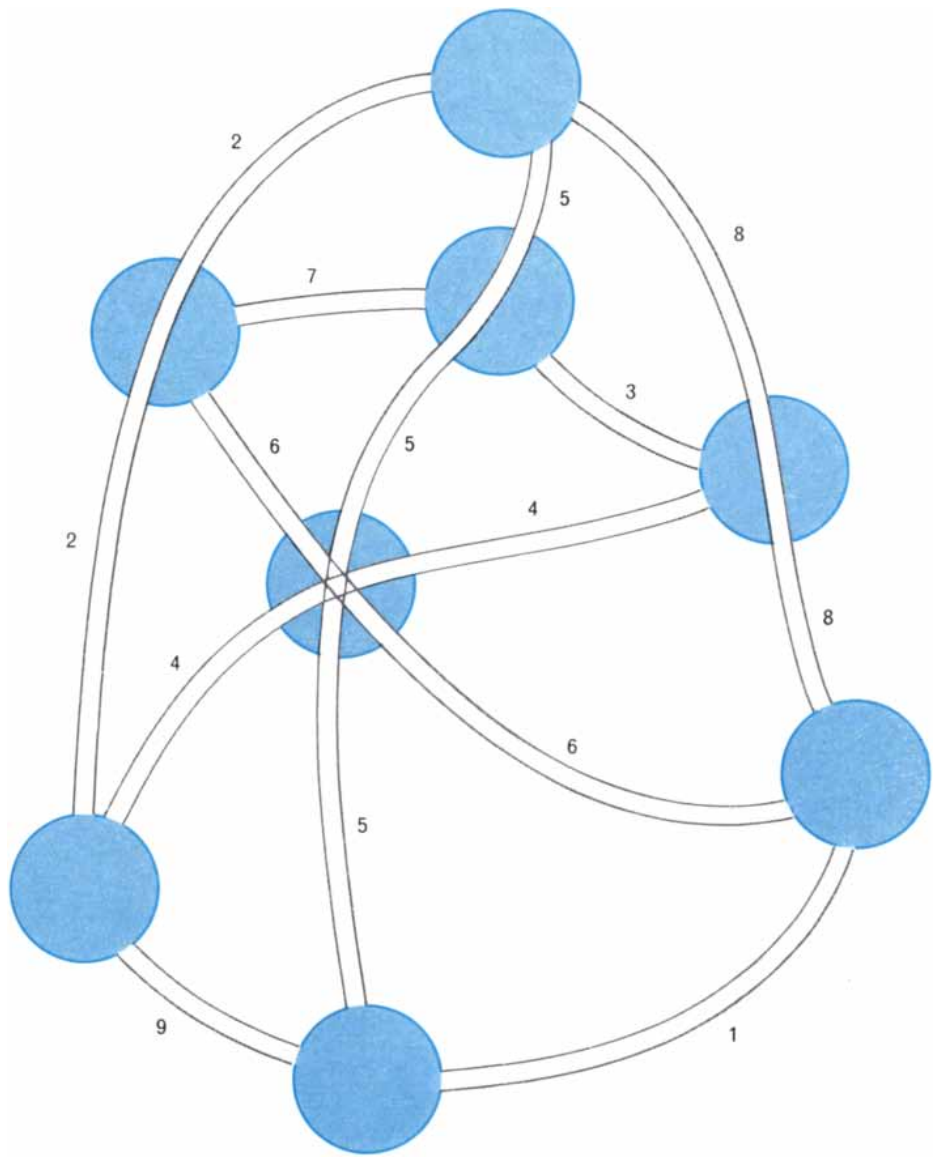
Kayles was invented by the English puzzle expert Henry Ernest Dudeney, who introduced it in Problem 73 of his first book, *The Canterbury Puzzles* (1907). It is now called kayles because Dudeney presented it as a problem that might have arisen in playing a popular 14th-century game of that name in which a ball was rolled at wooden pins standing side by side. The ball's size was such that it could knock over either a single pin or two touching pins. Mathematical kayles is best played on the table with coins, cards or other objects simply by arranging them in an arbitrary number of rows, exactly as in nim, with an arbitrary number of objects in each row. Now, however, we must think of each row as a linked chain. One may remove one link or two adjacent links. If the object or pair of objects is taken from inside a chain, it breaks the chain into two separate chains. For instance, if the first player takes the center card from the bottom row of the Marienbad pattern, it breaks the seven cards into two separate chains of three links each. In this way the number of chains is likely to increase as the game continues.

Kayles also lends itself to binary analysis, but not as directly as nim. For every chain we associate a binary number,

2	9	4
7	5	3
6	1	8

Ticktacktoe version of card game

but that number (except for the three smallest cases) is not the same as the decimal number of the cards in the chain. The chart shown at the bottom of page 119, supplied by Hénon, gives the required binary number, here called the k number, for integers 1 through 70. After 70 a curious periodicity of 12 num-



Map for the game of Jam

HOT	FORM	WOES
TANK	HEAR	WASP
TIED	BRIM	SHIP

Key to the game of Hot

bers sets in. If the number is above 70, divide it by 12, note the remainder, then use the chart at the bottom right of the illustration. To decide if a kayles pattern is safe or unsafe, one uses k numbers like the nim binary numbers.

Consider the Marienbad starting position, which is safe in nim and therefore a win for the second player. Is it also safe in kayles? Using k numbers we find:

1	1
3	11
5	100
7	10
	122

The sums are not all even, so the position is unsafe in kayles. Only one move by the first player will create a safe pattern, thereby ensuring a win. Can the reader discover it?

The derivation of the k numbers is too complicated to explain here. The interested reader will find it detailed by R. K. Guy and C. A. B. Smith in *Proceedings of the Cambridge Philosophical Society,* Vol. 52, 1956, pages 516–526, and by Thomas H. O'Beirne in *Puzzles and Paradoxes,* Oxford University Press, 1965, pages 165–167. Note that no k number has more than four digits. As a result there are 16 different four-term combinations of odd and even that can occur as column sums, only one of which is even-even-even-even. As Hénon points out, this enables us to conclude, with a high degree of accuracy, that if a kayles starting position is chosen at random from all possible patterns, the probability is extremely close to 1/16 that it will be safe.

There are helpful rules that a kayles player can follow without having to analyze each pattern. Two equal chains are safe because whatever your opponent does to one you can do exactly the same to the other. For example, if the two chains are 5 and 5 and he takes the second card in one, you take the second in the other. This leaves chains of 1, 1, 3, 3. If he takes two cards from a 3-chain, you take two from its twin. If he takes a 1-card chain, you take the other. It follows that if the starting position is one single chain, the first player has an easy win. If the chain has one or two cards, he takes them. If it has more than two cards, he takes one or two from the center to leave two equal chains and then continues as explained. If a pattern has an even number of equal pairs of chains, the position is clearly safe, since whatever the first player does to one chain the second player does to that chain's twin.

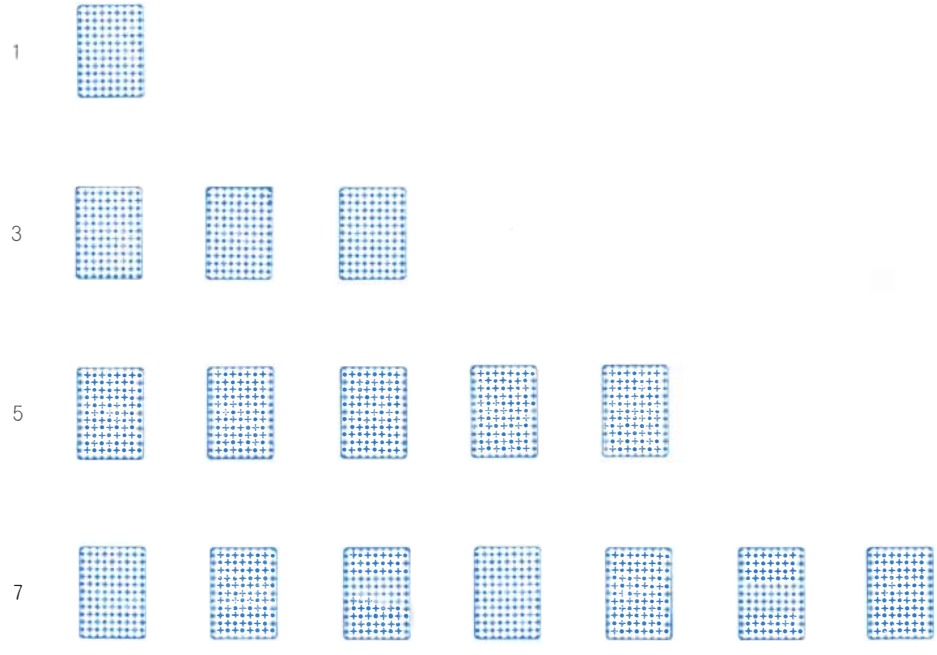
It is also good to remember the following safe patterns for two or three chains with no more than nine cards in each. The safe doublets (aside from two equal chains, which are always safe) are 1–4, 1–8, 2–7, 3–6, 4–8 and 5–9. Safe triplets can be calculated in the head by memorizing the following three groups: 1, 4, 8; 2, 7 and 3, 6. Any triplet made up of one digit from each group is safe.

Let us turn now to Hénon's two-person string game. We are given an arbitrary number of pieces of string of arbitrary lengths. Players take turns cutting a one-inch segment from any piece of string. The segment can be cut from the end or it can be cut, with two snips, from the interior. In the second case it will leave two pieces of string where there was one before. A one-inch piece can, of course, be taken without any snipping. The person who gets the last one-inch piece wins.

String lengths need not be rational. In the top illustration on the opposite page a game begins with four strings of lengths 1, pi, the square root of 30 and the square root of 50. Who has the win if both sides play rationally? This seems at first an enormously difficult question, but with the proper insight it is absurdly easy. To work on the problem rule four straight lines of about the required lengths. As each one-inch segment is erased the remaining lines are labeled with correct lengths.

The game can also be played with closed loops of string. Suppose it begins with seven such loops, each with a length greater than two inches. Without knowing any of the actual lengths, which player has the win? Approached in the right way, this is even easier to answer than the previous question.

Our final game, called the "game of the hamstrung squad car," is taken from Rufus Isaacs' book *Differential Games* (Wiley, 1965). Devotees of recreational mathematics may recall that Isaacs provided the excellent illustrations for the late James R. Newman's popular *Mathematics and the Imagination,* but among mathematicians Isaacs is best known as an operations-research expert. He is now at the Center for Naval Analyses in Washington. Last year his book shared the Lanchester Prize, given annually by the Operations Research Society of America for outstanding contributions in the field. The book is filled with original methods of solving difficult conflict games of the kind often encountered in military situations, particularly games that have to do with pursuit and capture. Some of these games are discussed in simpler, discrete ver-



Marienbad starting pattern for nim or kayles

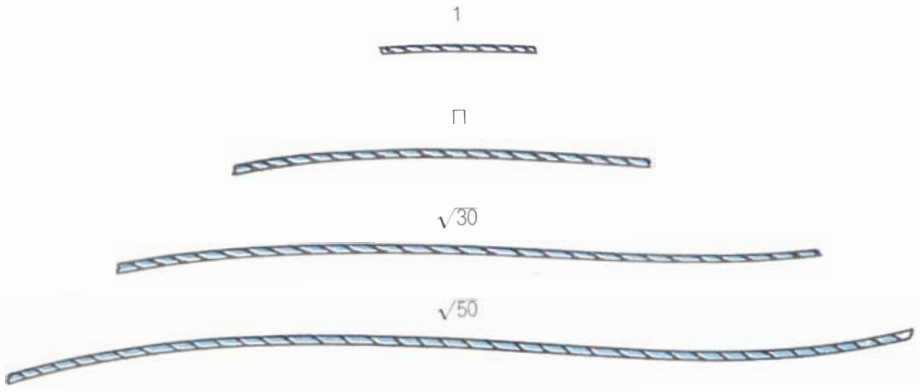
sions that have great recreational interest.

One of the book's key games, completely solved by Isaacs, is what he calls the "homicidal-chauffeur game." Imagine a homicidal chauffeur at the wheel of a car he is driving on an infinite plane. He moves at a fixed speed. He can shift the position of his steering wheel instantaneously, but the degree to which he can turn the front wheels is limited. Also on the infinite plane is a lone pedestrian. He can move in any direction at any instant. His speed too is constant, but less than the car's speed. Under what conditions can the car (assumed to be a positive area surrounding the driver) always catch (touch) the pedestrian? Under what conditions can the pedestrian escape permanently? How can the pursuer minimize the time it takes to run down his quarry when this is possible?

Fortunately we shall not be concerned with these difficult questions but with the simpler and somewhat similar game Isaacs calls the "hamstrung squad car." Imagine a city of infinite extent, with streets that form a regular square lattice. A squad car is at one intersection. At another is a carful of criminals. The squad car moves twice as fast as the criminals' car but is hamstrung by having to observe municipal traffic rules that prohibit left turns and U-turns, so that it can only go straight ahead or turn right at each intersection; the criminals' car does not observe these restrictions, so that at each intersection it can move in any of the four directions.

For the quantized game, intersections are replaced by the squares of an infinite checkerboard. The squad car is a counter with a vector arrow painted on it to indicate the direction in which it is moving. The criminals' car is an unmarked counter. Players take turns, the squad car making the first move. All moves are like rook moves in chess: up, down, left or right but never diagonally. The criminals move one square at a time. The squad car moves two squares, always in a straight line, either in the direction it has been traveling or after making a right turn. (It cannot go one square, turn right and then go another.) It "captures" the criminals if it lands on the square occupied by them or on a square that is adjacent orthogonally or diagonally.

These rules are illustrated on the next page. The squad car can move to squares *A* or *B* on its first move. From *A* it can then move to *C* or *D;* from *B*, to *E*



Hénon's string game

or *F*. After each move it should be turned (if necessary) so that its arrow shows the direction in which it was last moving. The criminals can move to squares *W, X, Y* or *Z*. If the squad car were on *F* and the criminals were on the same square or on any of the eight shaded squares surrounding it, they would be considered caught.

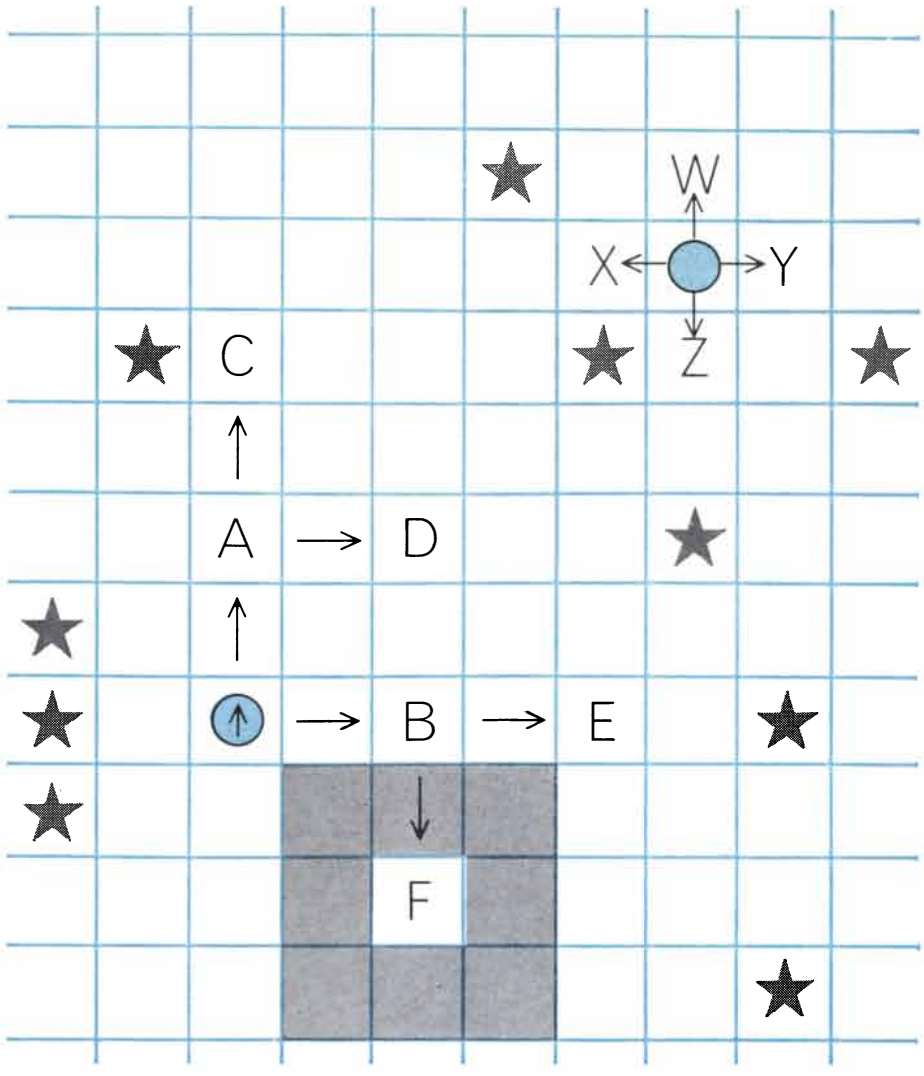
From what starting positions can the criminals be captured? Isaacs shows that surrounding the squad car's initial square there is an asymmetrical, compact area of exactly 69 squares each

NUMBER IN ROW	K NUMBER	NUMBER IN ROW	K NUMBER	NUMBER IN ROW	K NUMBER
1	1	31	10	61	1
2	10	32	1	62	10
3	11	33	1000	63	1000
4	1	34	110	64	1
5	100	35	111	65	100
6	11	36	100	66	111
7	10	37	1	67	10
8	1	38	10	68	1
9	100	39	111	69	1000
10	10	40	1	70	110
11	110	41	100		
12	100	42	111		
13	1	43	10		
14	10	44	1		
15	111	45	1000		
16	1	46	10		
17	100	47	111		
18	11	48	100		
19	10	49	1		
20	1	50	10		
21	100	51	1000		
22	110	52	1		
23	111	53	100		
24	100	54	111		
25	1	55	10		
26	10	56	1		
27	1000	57	100		
28	101	58	10		
29	100	59	111		
30	111	60	100		

NUMBERS OVER 70

REMAINDER	K NUMBER
0	100
1	1
2	10
3	1000
4	1
5	100
6	111
7	10
8	1
9	1000
10	10
11	111

Binary k *numbers for playing kayles*



Isaacs' "hamstrung squad car" game

of which is a fatal starting spot for the criminals. If they start on any square outside this area they can (assuming an unbounded board) always escape permanently.

The reader is urged to draw a large checkerboard of, say, 50 squares by 50 (or find a room with a suitable floor pattern), choose a starting position near the center for the squad car and see if he can identify the 69 fatal squares. Until the game is fully analyzed it can provide much amusement. The player moving the criminals' car can choose his starting spot and then see if he can win by reaching the border before he is caught. Playing the game long enough will eventually outline the fatal area, but there is a simpler way by which it can be delineated quickly and each of its squares given a number indicating the number of squad car moves required for the capture if both sides play rationally.

For readers not inclined to make a complete analysis here is a simpler problem. Assume that the squad car starts from the position shown in the illustration. The criminals may start from any of the 10 starred squares. From all but one of these starred positions they can escape permanently. Which is the fatal starred square, and in how many moves will the criminals be caught if they start from that square and both sides make their best moves? These and the other questions will be answered in the next issue.

The acrostic sonnet given last month is by Edgar Allan Poe. He called it "An Enigma." The lady's name, Sarah Anna Lewis, is read by taking the first letter of the first line, the second letter of the second line and so on through the 14 lines. The poem is not so well known as Poe's other acrostic, "A Valentine," in which another lady's name is similarly concealed. In J. A. Lindon's poem the first line is repeated not only by the first words of the eight lines but also by the *n*th words of the *n*th lines.

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THE AMATEUR SCIENTIST

How to make holograms and experiment with them or with ready-made holograms

Conducted by C. L. Stong

A few of the many amateurs who made the helium-neon laser described in this department in September, 1964, and December, 1965, have now taken up holography: the photographic technique of recording light waves in mid-flight and in effect reconstructing them later so that they continue onward unchanged. If the recorded waves are reflected by an object, the reconstructed waves enable an observer to see the object in three dimensions, as though he were viewing it through a window. The reconstructed scene appears in three dimensions, with full perspective and all the effects of parallax. For example, background details that may be obscured behind a feature in the foreground can be brought into view simply by moving the head to one side or the other. Similarly, the eyes must be refocused when attention is shifted from objects in the foreground to those in the background [see "Photography by Laser," by Emmet N. Leith and Juris Upatnieks; SCIENTIFIC AMERICAN, June, 1965].

It is now possible for amateurs to buy a hologram and to perform some interesting experiments with it, a subject to which we shall return. Sylvain M. Heumann of South San Francisco, Calif., is one of those who do their own holography. Discussing both the principles and the procedures he uses for making holograms at home, Heumann writes:

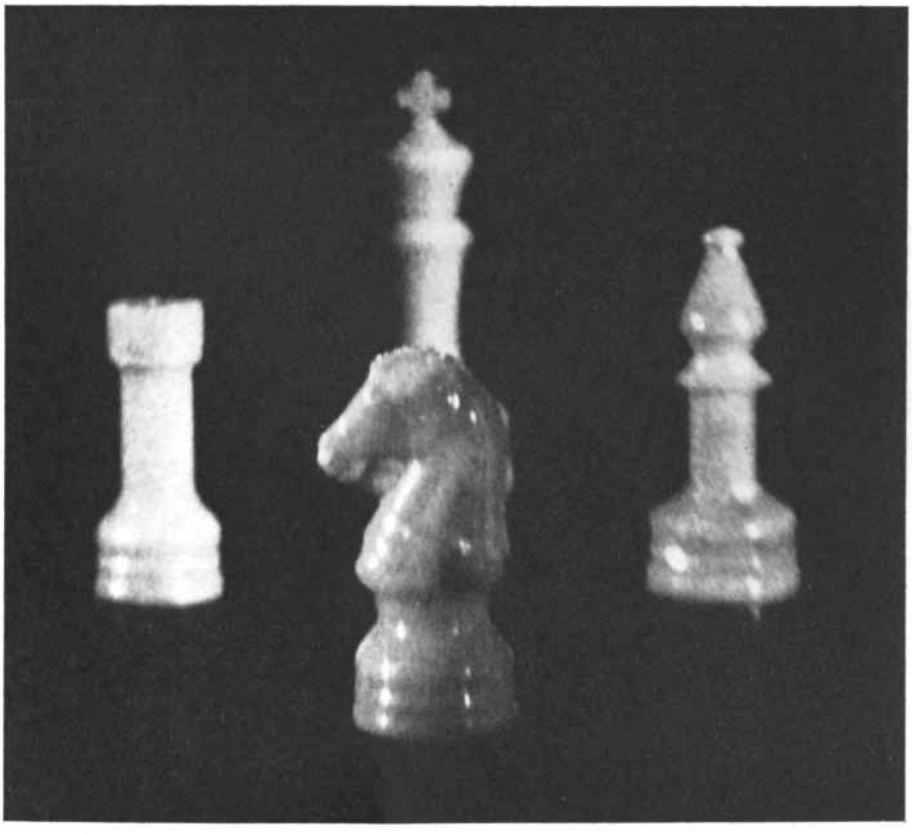
"In principle holograms should be easy to make. In practice they are not.

"The object to be recorded is placed on a solid platform and flooded with light from a laser. Light reflected by the object falls on a photographic plate that faces the object. The plate is simultaneously flooded by a second set of rays, called the reference beam, that is reflected by a mirror. The reference waves travel on a path that bypasses the object. After adequate exposure the plate is developed.

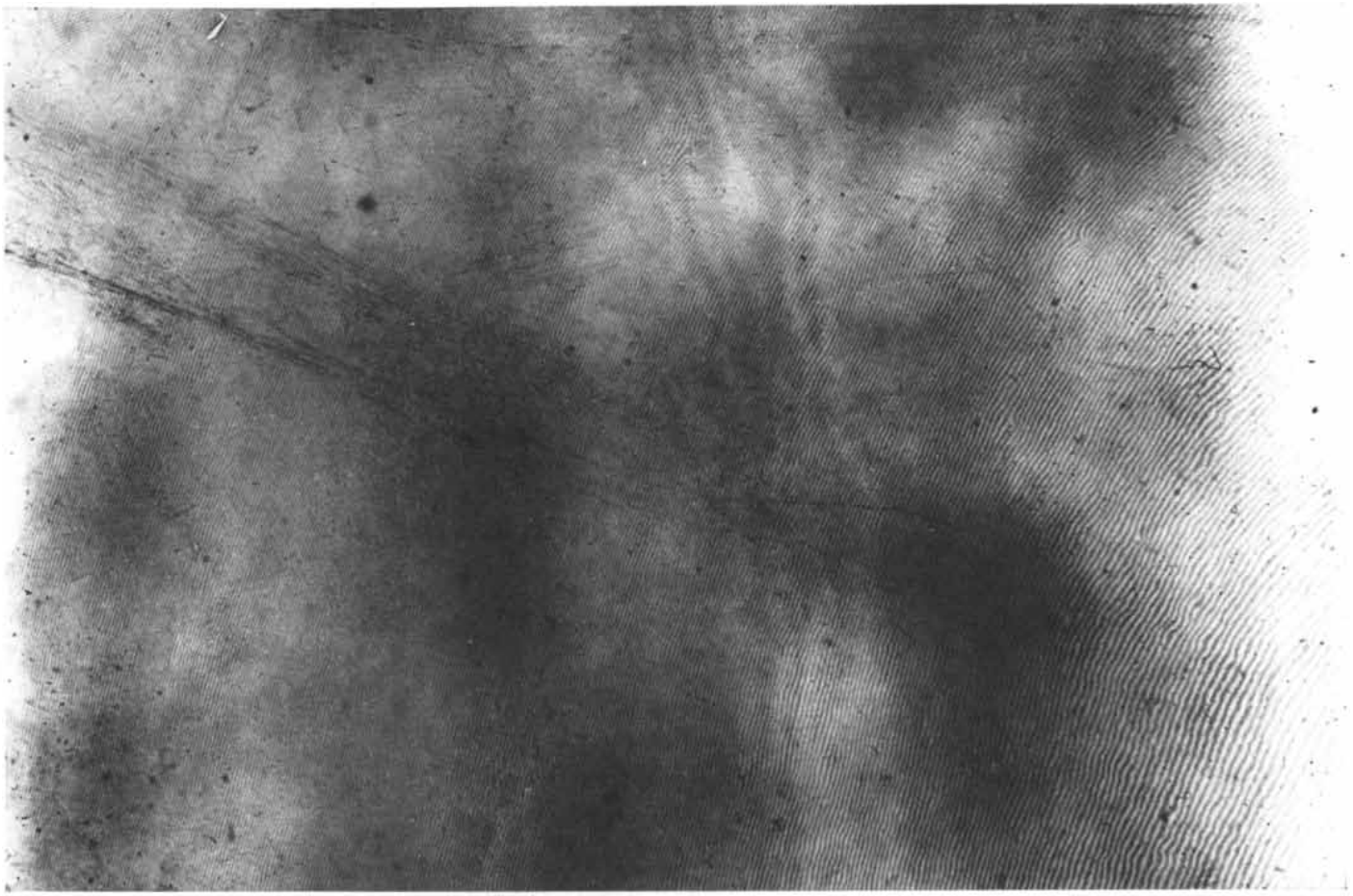
"No lens is used to form an image, and no image appears on the completed plate. Instead the emulsion records an abstract pattern of fine lines and whorls that may be roughly likened to a thumbprint. If rays of colored light are now directed through the hologram along the path of the reference beam, a new set of rays emerges from the back of the hologram. The new waves are in every respect identical with those that were reflected by the object. A viewer who sees them for the first time is likely to think he is being tricked, because the object looks so real.

"If the exposure were made with ordinary light, the photographic plate would merely blacken. Every part of the plate receives light from every point on the object and from the mirror. Laser light, however, is coherent: the waves are identical in length, and they proceed in step. At some points on the photographic plate the crests of waves reflected by the object coincide with the crests of waves in the reference beam. The two waves reinforce each other and expose the photographic emulsion at that point. At other places the crests of waves reflected by the object coincide with the valleys of waves in the reference beam. They cancel, so that the plate receives less exposure. Such interference effects vary at all points on the plate, depending on the shape and surface texture of the object.

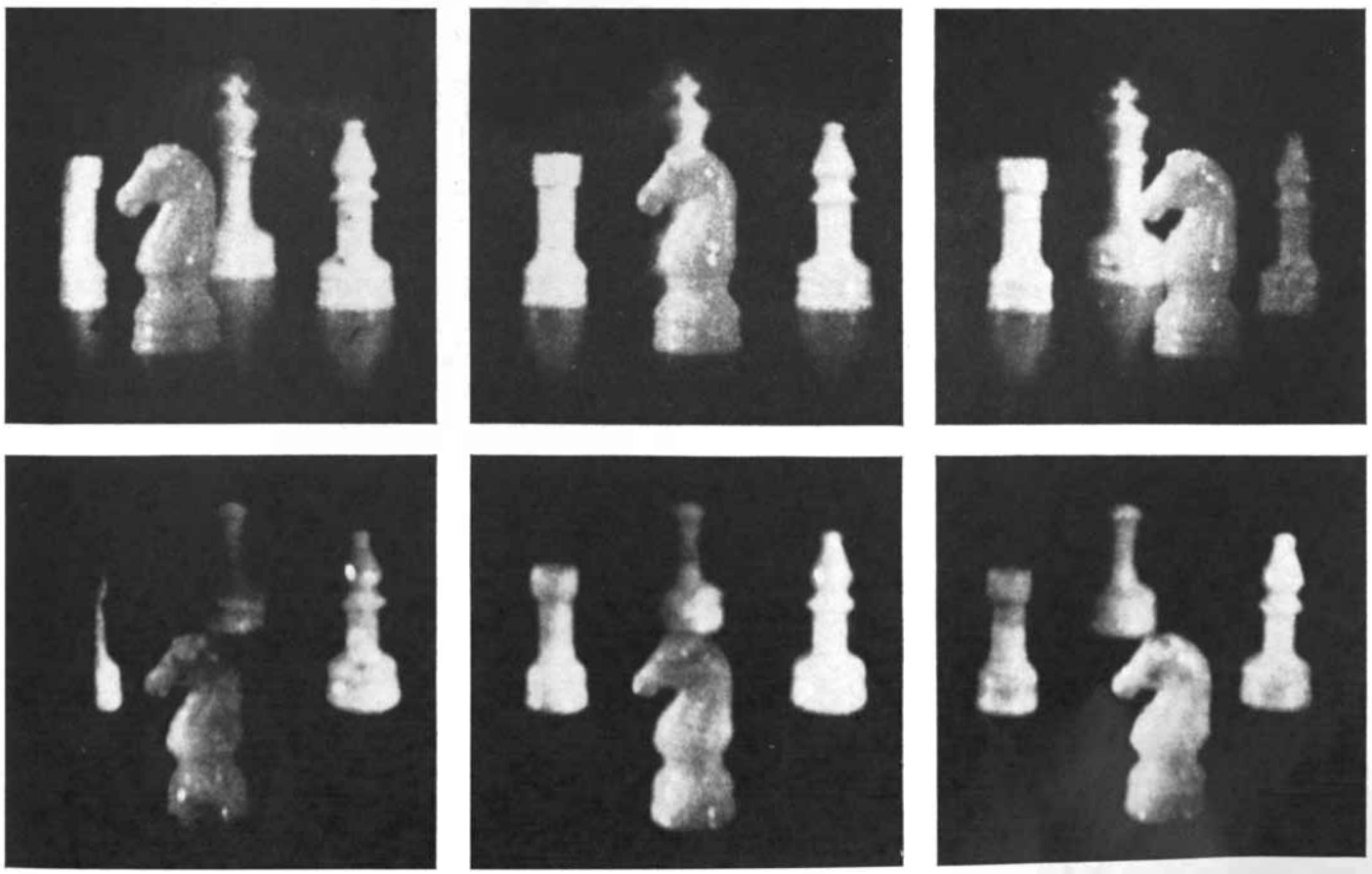
"The pattern of fine lines in a hologram has the property of diffracting, or bending, light rays. The diffraction is greater with close spacing than with



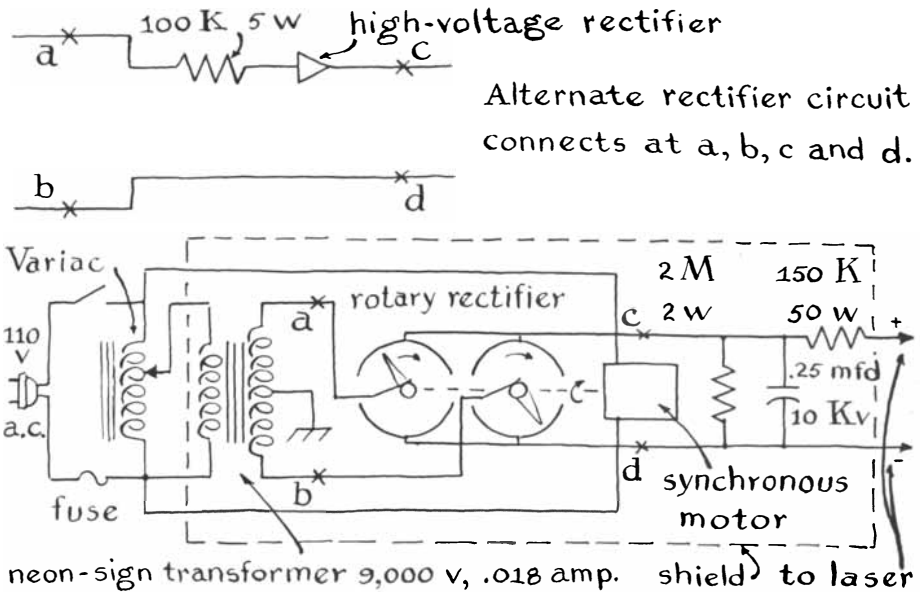
Reconstruction of entire hologram at top of opposite page



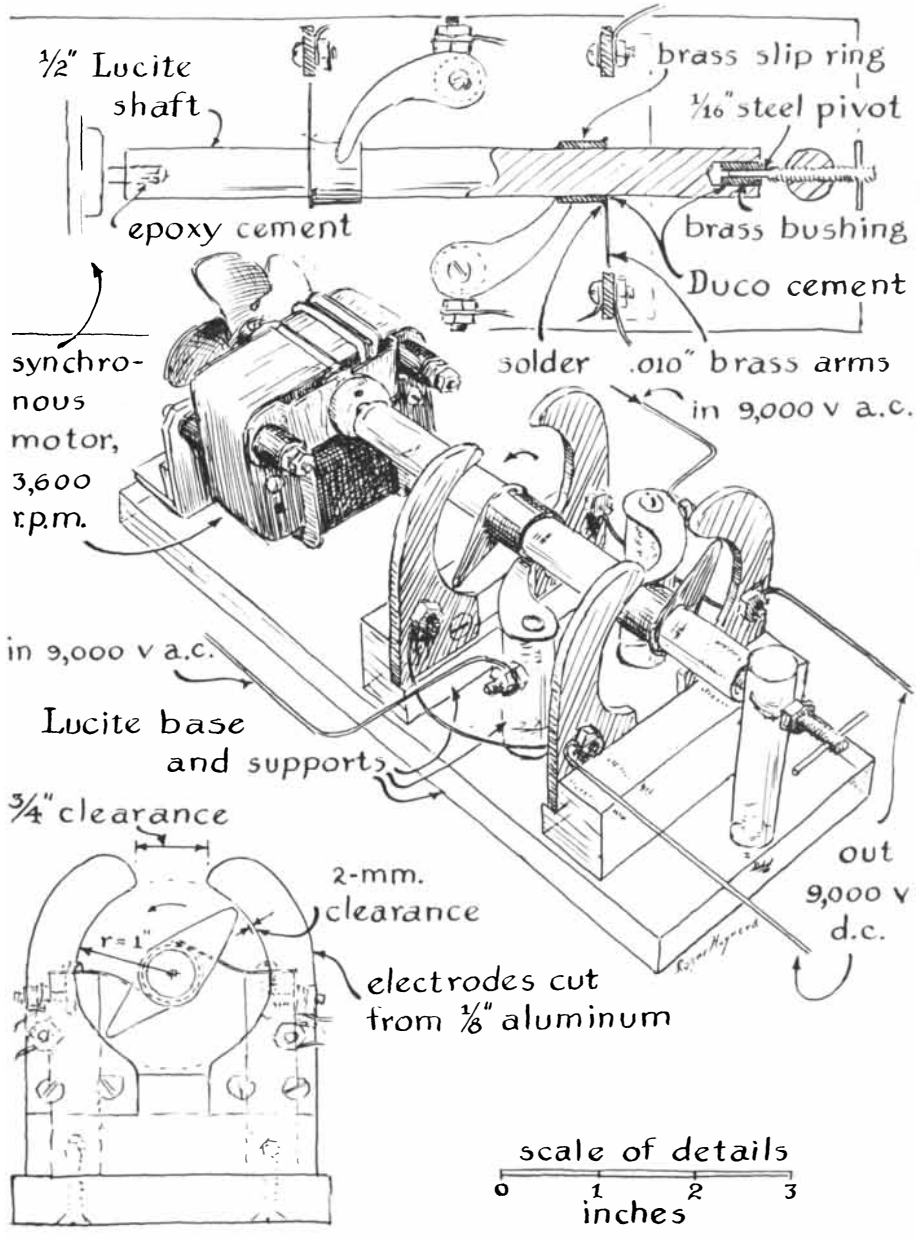
Hologram made with a laser built by an amateur



Perspectives obtained by reconstructing corresponding segments of the hologram



Alternative rectifier circuits



The synchronous-switch rectifier

narrow spacing. Advantage is taken of this effect in the hologram to reconstruct the light waves that were reflected by the object. Rays that enter the hologram from the same direction as the reference beam are bent and scattered precisely enough to match those that were reflected by the object. In effect they duplicate the object rays. The light used for reconstructing the object rays should be coherent, but remarkable realism can be achieved with ordinary colored light emitted from a pinhole source.

"The structure of the hologram involves dimensions that are determined by the wavelength of light and the angle made between the object beam and the reference beam. Normally the plate must record many thousands of lines per inch, a resolving power that greatly exceeds that of ordinary photographic plates. Indeed, the ultrafine structure of the pattern explains why the hologram can record more information than an ordinary photograph. It also helps to explain why holograms are difficult to make at home. During exposure the photographic plate must remain motionless with respect to the relative positions of the mirror and the object. Any relative movement between the three in excess of a few millionths of an inch causes the lines to blur; hence the quality of the reconstructed waves will be seriously degraded.

"For best results the photographic plate must be capable of recording about 60,000 lines per inch. Emulsions capable of this high resolution are comparatively insensitive. Those I use are rated at an ASA speed of only .003, in contrast with ordinary black and white film, which is rated from 400 up. The problems of making holograms, then, consist in devising rigid structures for supporting the apparatus, insulating the apparatus against vibration and maximizing the available light to minimize the exposure interval.

"The first requirement for making holograms is a laser. Mine was built at home. The apparatus described previously in this department will work splendidly if it is modified to develop somewhat more power and to generate light waves of a single frequency. The output power can be increased substantially by operating the laser on direct current, a requirement that is simple to meet. A string of two or more silicon rectifiers, such as type CR210, can be connected in one lead of the neon-sign transformer as indicated by the accompanying illustration [*top of this page*]. The resulting unidirectional current is smoothed by connecting a capacitor

across the output of the rectifiers. The circuit must also include two resistors, one for limiting the current in the rectifiers and the second to compensate for the negative resistance of the laser tube. High-voltage rectifiers are expensive. The experimenter who has more time than money can substitute a synchronous rotary switch.

"The switch consists of an insulating shaft that carries two switch arms spaced 180 degrees apart. Each arm passes close to but does not touch an opposing pair of semicircular electrodes [*see bottom illustration on opposite page*]. In the case of 60-cycle operation the switch arm rotates synchronously at 3,600 revolutions per minute. It is driven by a Barber-Coleman synchronous motor, type KYAJ622–328. The motor is available from the Edmund Scientific Co., 101 East Gloucester Pike, Barrington, N.J. 08007. The base of the switch and the supports for the electrodes can be made of Lucite or any comparable insulating material.

"Alternating current is connected to the switch arms through brushes made of brass shim stock that ride on brass slip rings. The slip rings make a snug fit with the shaft. Other essential mechanical details are evident in the illustration. The inner diameter of the semicircular electrodes must be at least two inches, and opposing electrodes must be spaced at least three-quarters of an inch apart. All the other dimensions can differ from those shown.

"When the synchronous switch is in operation, the blades must stand midway between the opposing semicircular electrodes at the beginning of each cycle. They must complete half of a revolution at the end of each alternation of current. In other words, the switch must operate in phase with the alternating current.

"To set the switch arms in phase, connect one output lead of the neon-sign transformer to the brush of one switch arm and connect the other output lead of the transformer to one of the semicircular electrodes. Apply power to the neon-sign transformer from a variable-voltage transformer, such as a Variac. Connect the motor to the power line. When the motor comes up to full speed and is running synchronously, gradually apply power to the neon-sign transformer and observe the gap between the switch arm and the electrode. When the voltage has been increased sufficiently, sparks will bridge the gap.

"Note the point on the semicircular gap where the sparks first appear. Perhaps they will begin approximately halfway around the electrode. If so, shut off the power, stop the motor and rotate the switch arm 90 degrees on its shaft. Reenergize the apparatus and again observe the gap. Doubtless the sparks will now fill the entire arc of the semicircular electrode. Should the sparks originate at greater or lesser angles around the semicircular electrode, adjust the angular position of the switch arm on its shaft by an appropriate amount.

"After the switch arm has been positioned so that the sparks fill the complete arc of the electrode, fix it to the shaft with a dab of quick-drying cement. Then rotate the remaining switch arm 180 degrees from this position and similarly cement it to the shaft. Adjacent semicircular electrodes are interconnected. When an alternating-current source is connected to the rotating switch arms, unidirectional current can be drawn from leads connected to opposing semicircular electrodes.

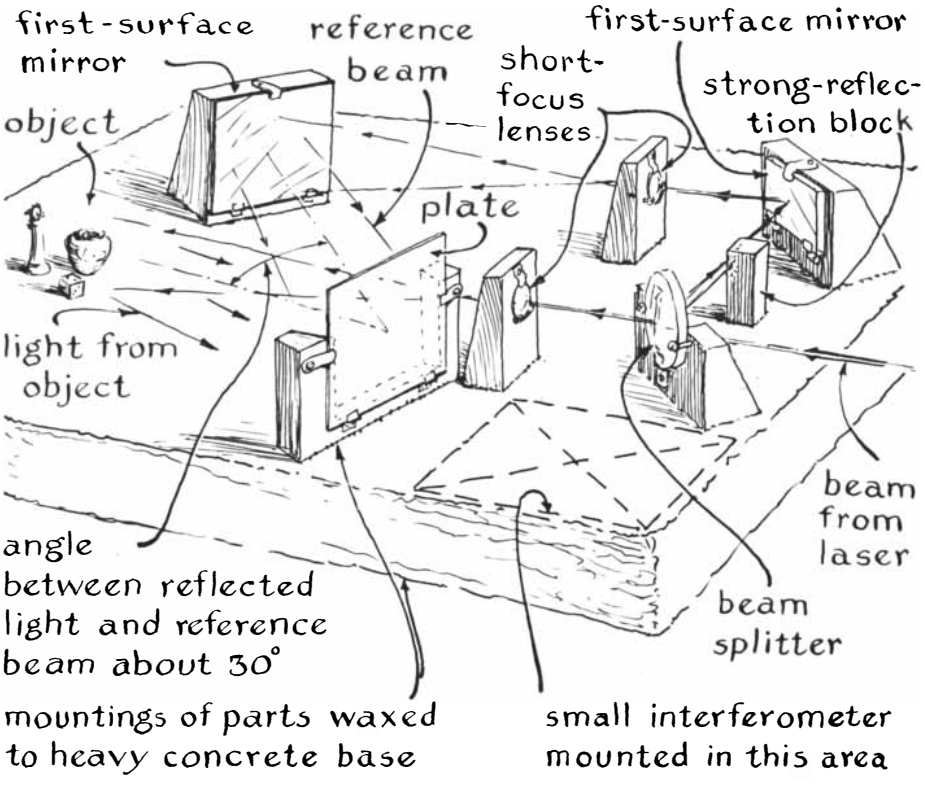
"The switch functions as a full-wave rectifier and can replace the costly diodes. The switch requires no current-limiting resistor. A capacitor of about .25 microfarad should be connected across the output of the switch, however, and a resistor must be inserted in one lead between the capacitor and the laser to compensate for the negative resistance of the laser tube.

"Conduction between the switch arms and the semicircular electrodes is established through the spark. For this reason the switch unfortunately acts as a copious generator of electromagnetic noise at frequencies close to all television channels. In order to prevent the radiation of this noise, the switch, the neon-sign transformer, the capacitor and the resistor must be installed in a grounded metal cabinet.

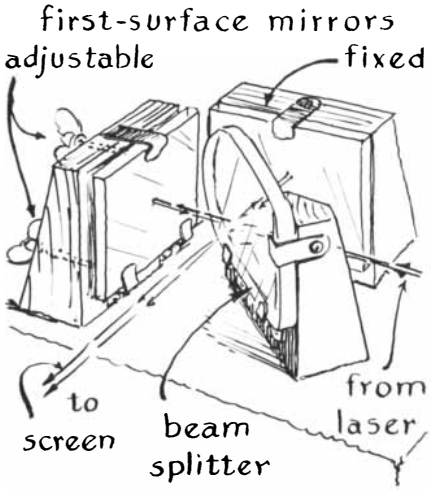
"In some cases it may also be necessary to insert choke coils and bypass capacitors in the alternating-current power line and the direct-current output leads. The choke coils and bypass capacitors should be potted in grounded metal containers and installed in the cabinet. The cost of the complete synchronous rectifier should not exceed $20. Warning: The high voltage is lethal. Handle it accordingly.

"To make certain that the laser will generate coherent light of a single frequency (that it will operate in the so-called TEM_{00} mode), the resonator should consist of one mirror of spherical figure and one flat mirror. The flat mirror can be bought from Henry Prescott, 116 Main Street, Northfield, Mass. 02118. The laser described previously in this department was equipped with a pair of mirrors of spherical figure. Either one of these can be replaced with the flat mirror.

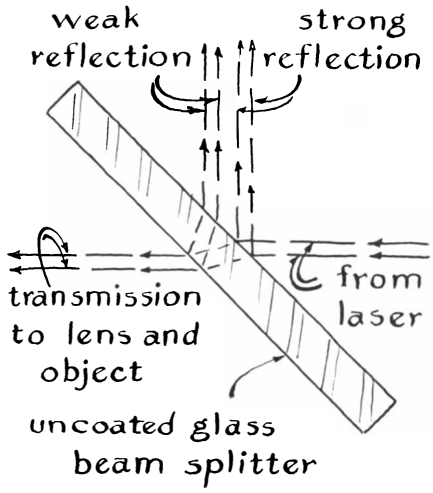
"To make the modification, align the two spherical mirrors so that the laser functions normally. Remove one mirror



Optical train for making holograms



Arrangement of interferometer



Details of the beam splitter

and replace it with the flat mirror, which can be aligned by inserting a microscope slide between it and the adjacent Brewster window at an angle of about 45 degrees, shining a small light on the slide and manipulating the adjustment screws while looking through the spherical mirror and down the capillary tube. When the reflected light reaches maximum intensity, the flat mirror is in proper adjustment.

"The adjustment can also be made by the method described in this department in December, 1965. Occasionally a small additional adjustment is necessary. It is made by applying direct current to the tube and rocking the adjustment screws back and forth slightly until the beam appears. Direct the beam onto a white screen and observe the pattern. If it consists of an array of two or more spots, adjust the screws until the spots merge into a single disk of uniform intensity. Incidentally, the laser may not develop maximum intensity when adjusted for TEM_{00} mode, but more intense multimode beams cannot be used for making holograms.

"The desired disk-shaped spot of light may contain a number of interference fringes and circles. Such spurious effects usually represent diffraction patterns that are caused by dust or by imperfections in the mirrors. The beam can be cleaned up by passing the light through a pinhole about .0005 inch in diameter. The pinhole must be located at the focus of the two lenses that will be used to spread the beam into a pair of broad cones. A good pinhole can be made by pressing a sharp needle into a sheet of aluminum foil backed by a piece of plate glass. The pierced foil can be mounted on a ring of cardboard for clamping into position in the optical train. Finally, the power of the laser can be further increased 10 to 25 percent by placing a series of reasonably strong horseshoe magnets every inch or so along the laser tube. The magnetic fields reduce the tendency of the laser to generate infrared waves and therefore concentrate the output at the desired wavelength of 6,328 angstrom units.

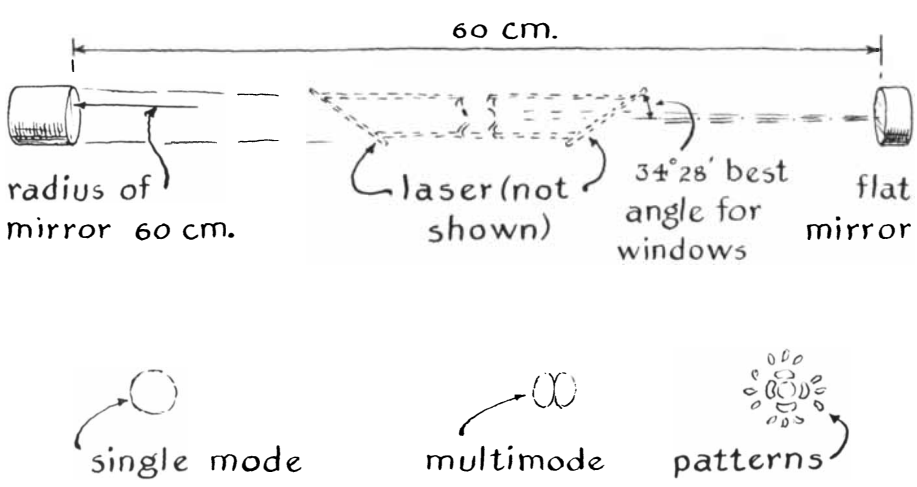
"In addition to the laser, the experimenter will require the following equipment: a heavy table that is insulated against vibration; four first-surface mirrors; two lenses for spreading the laser beam; two beam splitters, and a supply of high-resolution photographic plates together with chemicals for their development. All these materials, except the table and the chemicals, can be bought from the Edmund Scientific Co.

"My table consists of a granite surface plate mounted on dense polyfoam. It weighs 100 pounds. The polyfoam rests on the cement floor of my basement. Another amateur who goes in for holograms uses a stack of concrete blocks of the type sold by dealers in gardening supplies. Each block is two feet square and two inches thick. Six blocks are cemented together with roofing tar and placed on a foot-thick stack of old newspapers. The assembled table weighs 500 pounds. The heavier the table the better. It cannot be insulated too well.

"To check the stability of the table you will require a small interferometer consisting of a beam splitter (Edmund catalogue No. 578) and two first-surface mirrors (Edmund catalogue No. 40,040). These components can be secured to one corner of the table by wax, blocks of wood or rigid fixtures such as machinist's vises [*see illustration at top left on this page*]. Direct the rays of the laser into the beam splitter and adjust the position of the components until the two beams superpose on a screen that can be permanently mounted on a distant wall.

"The superposed beams will make a small spot of light on the screen. Enlarge the spot by inserting a lens with a focal length of 10 to 50 millimeters in the beam at a point within a few inches of the apparatus. Interference fringes will appear in the enlarged spot. They must show no perceptible movement. If they do, add mass to your table and improve the insulation. During the hologram exposure the fringes must show no movement. Street traffic and other sources of vibration can present a problem. In some regions exposures can be made only during the early hours of the morning when traffic is at a minimum.

"Once the table has become stable you can assemble the optical train of the holograph apparatus [*see illustration on preceding page*]. You will require a piece of thick glass for the beam splitter (Edmund catalogue No. 2,183), a large front-surface mirror (Edmund catalogue No. 40,043), a small first-surface mirror



Laser resonator used in making holograms

(Edmund catalogue No. 40,040) and two simple lenses of good optical quality, any convenient aperture and a focal length of about 17 millimeters. The lenses need not be achromatic. The mounting supports can be improvised according to the tastes and resources of the experimenter. Again, stability is the essential requirement.

"The subject to be photographed should consist of small objects that will stand still. Chessmen are a good example. The available light from a homemade laser limits the size of the scene to about one square foot if the exposure is to be kept within a five-minute interval. The photographic plate should be placed vertically, facing the subject at a distance of about 10 inches. First, however, place a piece of white cardboard in the position the plate will occupy. The cardboard should match the size of the plate.

"Darken the room, direct the rays of the laser into the beam splitter and adjust the lens of the appropriate beam to floodlight the object. (The laser does not have to be on the stable table.) Block off this beam and adjust the lens and mirrors so that the second beam, as reflected by the small and large mirrors, floods the cardboard screen. If the diagram [*page 125*] has been followed carefully, the distance from the beam splitter to the object to the cardboard screen will be approximately equal to the distance from the beam splitter to the small mirror, large mirror and cardboard. In no case should an inequality exceed half of the length of the laser. If scattered light from the laser tube is perceptible on the screen, enclose the laser in an opaque housing.

"The two beams that now fall on the screen must be adjusted for relative intensity. The beam from the mirror should be two to three times brighter than the rays reflected to the screen by the object. The brightness is difficult to estimate, but it is not too critical. If the reference beam seems too bright, try shifting the position of the lens so that it picks up the rays that are reflected by the second surface of the beam splitter. If the beam still seems too bright, move the lens closer to the splitter or insert a neutral-density filter in the beam at the point where it is reflected from the beam splitter. If a filter is so used, place it exactly at right angles to the axis of the beam; otherwise light will be reflected back and forth internally between the glass surfaces and will introduce unwanted interference effects.

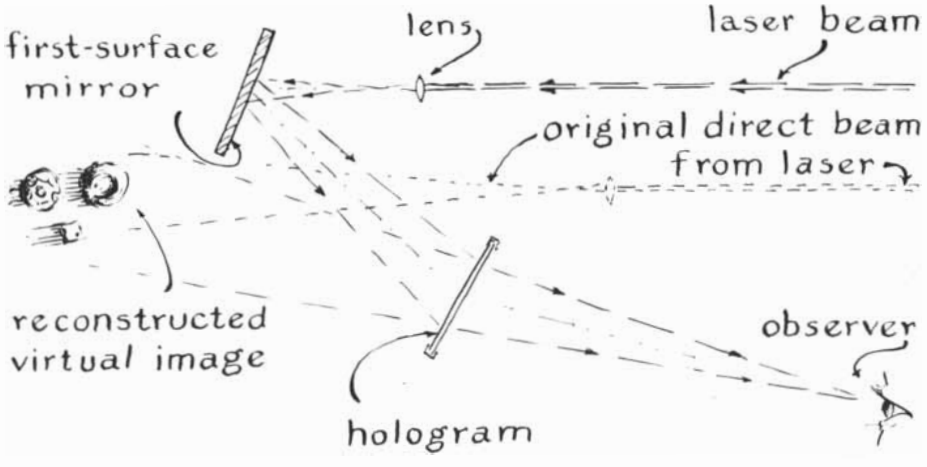
"The angle made at the photographic plate between rays from the object and those of the reference beam should not exceed 30 degrees. The spacing of the lines in the hologram varies inversely with the size of this angle and becomes so narrow at angles approaching 90 degrees that problems arise. Now replace the cardboard screen with the photographic plate. The emulsion side should face the object. (The emulsion side of a plate can be determined by the fact that it will stick to your lip.) The best emulsion for holograms is the Eastman Kodak Company's 649F, which comes in the form of four-inch by five-inch glass plates, packed 36 to a box. The plates are fairly expensive. They can be obtained from the Edmund company in smaller quantities. Other emulsions of lower resolving power can be made to work by using a narrow angle between the reference beam and the object beam. This arrangement generates somewhat broader fringes, which are better for such emulsions, but the adjustment is difficult and I do not recommend it to the beginner.

"Just before making the exposure, direct the laser beam into the interferometer and examine the fringes for movement. If they appear solid, switch the rays to the hologram beam splitter and make the exposure. A dim safelight can be used if it is kept at least 15 feet from the plate. The exposure time is a matter of trial and error. If the object is colored and not more than three inches in diameter, a laser output of five milliwatts should make an exposure of optimum density in about three minutes. If the plates are stored in a refrigerator, allow at least 30 minutes for them to reach room temperature before use. The Eastman Kodak Company recommends that 649F plates be developed for five minutes at 67 degrees Fahrenheit in Eastman H. R. P. developer. Thereafter the plates are fixed, washed and dried.

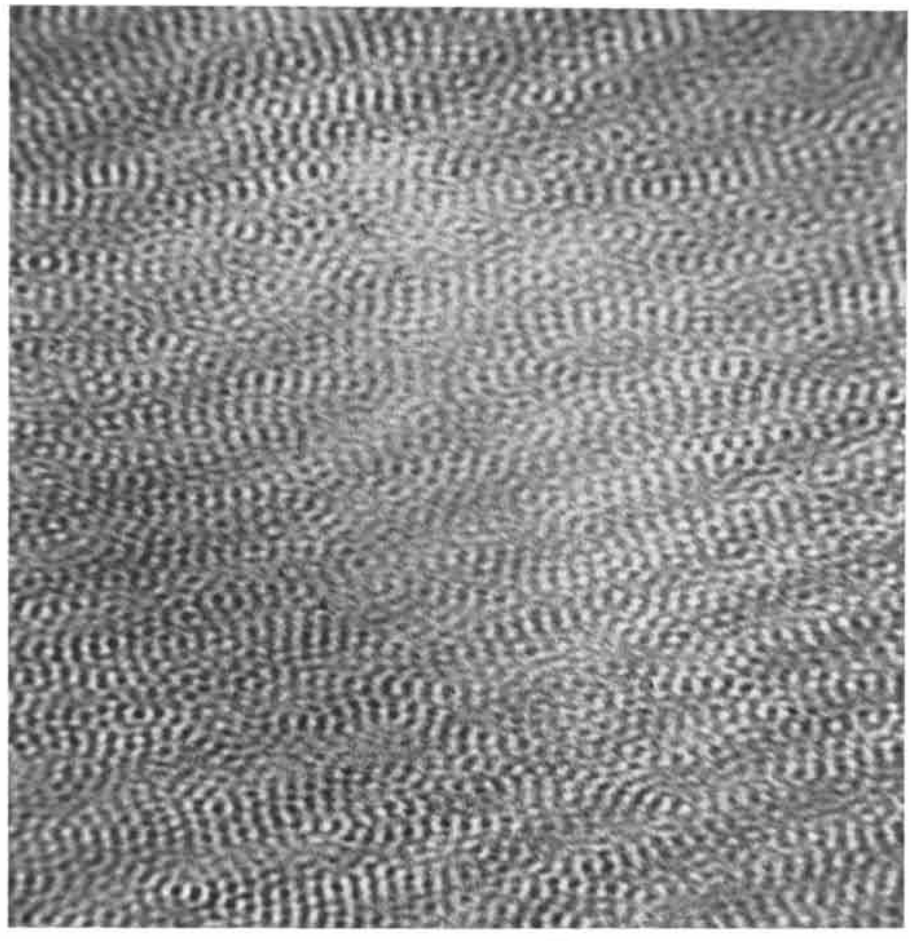
"The dried hologram can be inspected immediately for an image. Place the plate in the diverged beam of the laser at the angle of the reference beam. You should then see the object. Rotate the plate from side to side to find the angle that yields maximum brightness. Alternatively you can inspect the hologram by placing a filter of almost any color in the slide holder of a 35-millimeter projector and fitting a pinhole mask over the front surface of the projection lens. You can even use a flashlight of the penlight type if it is fitted with a self-focused bulb. When inspected by flashlight, the hologram will be fuzzy and the image will appear in the colors of the rainbow.

"If no image can be found, the probability is high that something moved during the exposure. Examine the plate under a microscope at a magnification of about 600 diameters. The pattern should consist of fine, crisscrossed lines. If these lines are not seen, some part of the apparatus certainly moved during the exposure. If the emulsion is much darker or lighter than a conventional photographic transparency, appropriately increase or decrease the exposure during the next try. If the object has poor contrast, increase or decrease the intensity of the reference beam.

"You do not have to make a hologram to have fun with these fascinating playthings. Relatively inexpensive holograms on film can now be bought, with a viewing filter, from the Edmund company. A number of engrossing experiments can be done with them. Try photographing the reconstructed light. You will discover that either the focus must be altered for recording sharp images of foreground and background objects or the lens must be stopped down to increase the depth of the field. Try making photographs of



Optical arrangement for reconstructing hologram rays



Segment of a hologram enlarged 150 diameters

various areas of the hologram. Each portion, however small, will reproduce the entire scene—yet the information contained by each area differs from that of other areas. The principal difference involves the effects of parallax: the relative displacement of objects as seen from various points of view. In addition, each area makes a contribution to the resolution of the entire plate. Features of the scene appear in sharpest focus when the reconstructed rays from the full plate are intercepted by the eyes. It is this property of the hologram that accounts for the fact that blemished plates can yield good results. Clear photographs of objects can be made from holograms that are dust-pocked or scratched—imperfections that would ruin a conventional photographic negative.

"The hologram is a special form of the diffraction grating, which is a flat optical surface ruled with thousands of parallel, uniformly spaced lines and used for diffracting white light into its constituent colors. Diffraction gratings transmit part of the light as a straight beam but bend and disperse other portions into bundles of rainbow colors that lie on each side of the central beam. The bundles are known as diffraction 'orders.'

"The hologram also diffracts the light into such orders. If your eye is close to the hologram, you will find a certain angle at which an apparent mirror image of the scene appears. The depth of the field in the inverted image may appear greatly exaggerated, depending on the angle between the reference beam and the object beam at which the hologram was made.

"To gain a full appreciation of the astonishing amount of information that can be compressed into the two-dimensional pattern of the hologram, examine a plate under a microscope. At 40 diameters of magnification you will find curving lines making fine patchwork designs. At 200 diameters these fine details turn out to consist of still finer features. At 1,000 diameters the structures will be resolved into an orderly pattern of relatively straight, interwoven lines that resemble the seat of a caned chair. Good holograms contain more than 25,000 such lines per inch. It is in their number, shape and density that the optical information is encoded. These paragraphs have mentioned only a few of the many new optical experiments that have been made possible by the advent of the hologram."

LASL Photograph by Bill Jack Rodgers

A View of the Pond

Randall Yoakum, a mathematician in the Test Division, watches his children set sail on Los Alamos' Ashley Pond. Randy is a member of a research group working on the physics of the ionosphere and auroral phenomena. These studies are related to anti-missile defense problems and also to the development of sensitive methods for the detection of explosions in space. Interaction of the various forms of energy released by a nuclear device with the upper atmosphere and geomagnetic field pose problems of great interest in physics and astrophysics. If you would like to share in this type of creative venture, send your resume to:

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Polymer combinations: a new technology.

Polymer blending makes possible precise control of properties. Rubber balls show effects of adding small amounts of plastic.

Uniroyal blends rubber with plastic and vice versa to create new materials with exceptional resistance to oil, ozone and abrasion.

Only a few years ago, there was a clear-cut difference between rubber and plastic. Rubber was rubber and plastic was plastic. There were few grey areas and virtually no blends of the two.

Today, however, there are many rubberlike plastics and plasticlike rubbers. In some ways, an even more interesting and useful group of compounds are the blends of rubber and plastic.

In Vietnam, a new military combat boot is lasting some 30 times as long as the previous construction which often fell apart in three weeks or less. The sole of the new boot is a rubber-plastic blend developed by Uniroyal and sold under the registered tradename "Paracril Ozo."

The same material, with varying percentages of rubber and plastic, is being used in such diverse applications as wire and cable jacketing, hose, belting and pipe insulation.

The success of the blends is due to the fact that their properties can be minutely controlled to achieve the best combination for a given application.

Paracril Ozo, for example, combines four properties seldom found in one polymer. It combines excellent oil, abrasion, and ozone resistance with good flexibility.

The nitrile rubber in Paracril Ozo is extremely oil and abrasion resistant, but relatively weak in ozone resistance, or the ability to take weathering.

The polyvinyl chloride plastic in Paracril Ozo has outstanding abrasion and ozone resistance but poor flexibility. (It is available separately under the registered tradename "Marvinol.")

Together, they perform exceptionally well. In such tough applications as jet aircraft refueling hose, Paracril Ozo stands up considerably longer than the best oil-resistant rubber used straight.

Many other promising rubber-plastic blends are under development by the polymer chemists of Uniroyal. In the future, these blends will tend to wipe out the arbitrary distinction often made between rubber and plastic.

Sole of this combat boot is an outstanding example of successful polymer blending. On the average, the boot stands up a year-and-a-half in hot, humid climate.

Oil hose is made of a blend of nitrile rubber and polyvinyl chloride plastic. This blend combines superior oil resistance and outstanding weathering ability.

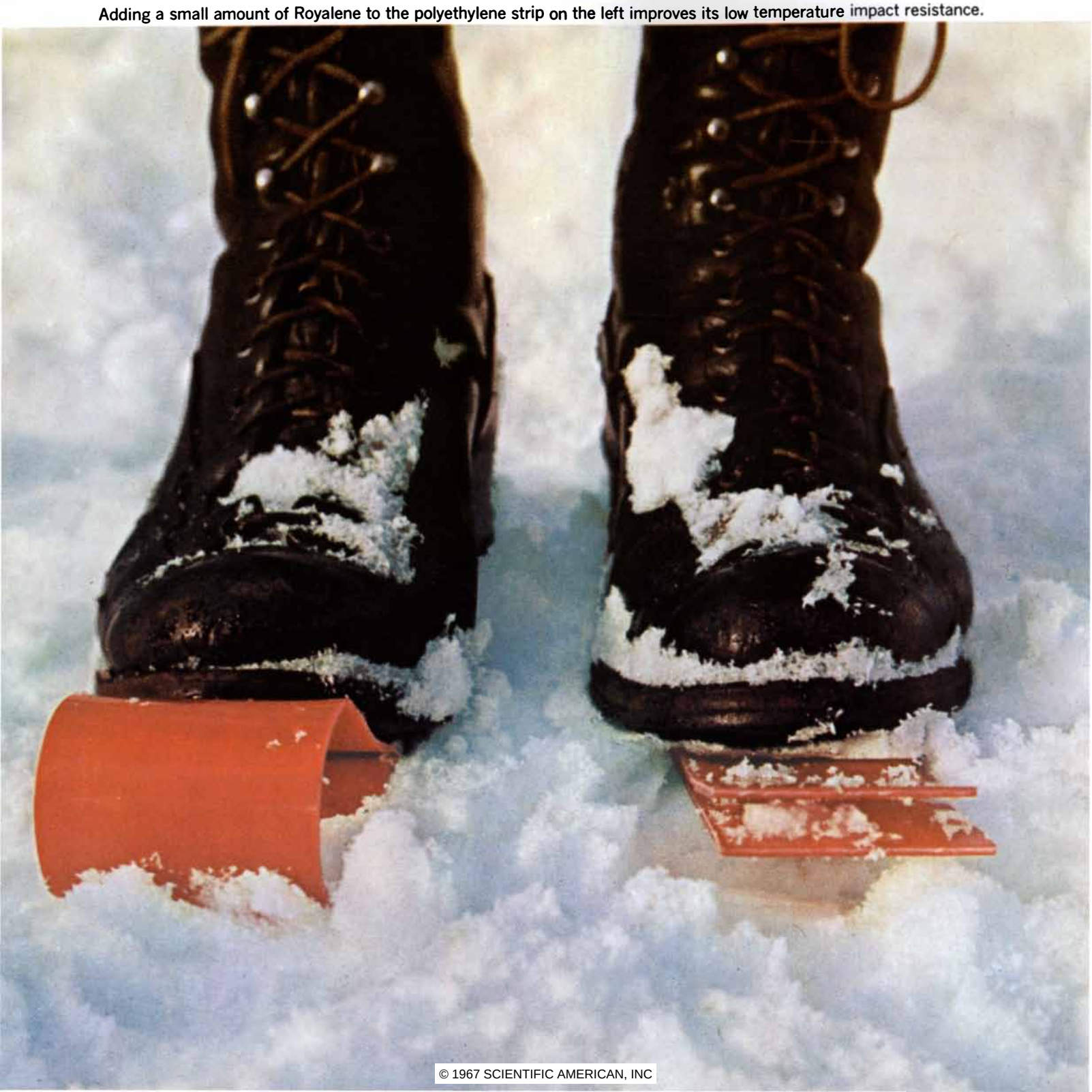
As a matter of interest, it was a Uniroyal chemist who created ABS, the first plastic made from rubber raw materials. This material, sold under the registered tradename "Kralastic," is one of the most widely used structural plastics today.

A combination of acrylonitrile, butadiene and styrene, Kralastic ABS is used in telephone housings, luggage, truck bodies and hundreds of applications.

Continued...

"Crackless Rubber" blended with plastic makes "crackless plastic."

Adding a small amount of Royalene to the polyethylene strip on the left improves its low temperature impact resistance.



Chemical Division
UNIROYAL
U.S. RUBBER

If plastic added to rubber can create a better rubber, how about adding rubber to plastic to create a better plastic?

Intrigued by the possibility of improving existing plastic materials, Uniroyal polymer chemists have explored many different combinations. One of the most promising is a combination of Uniroyal's "Crackless Rubber" with inexpensive plastics such as polyethylene. (Crackless Rubber is sold by Uniroyal under the registered tradename "Royalene.")

Adding a small amount of Royalene to polyethylene greatly improves impact resistance and low temperature properties compared with the plastic alone.

Royalene is also being blended with other rubbers. Virtually every quality whitewall tire manufactured in the United States uses a Royalene blend in the whitewall to reduce the cracking problem. The blend used is approximately 20 percent Royalene, but this is enough to solve the problem. (Royalene is 100 times more resistant to ozone attack than any other general purpose synthetic rubber. It is also highly resistant to sunlight, weathering and extremes in temperature.)

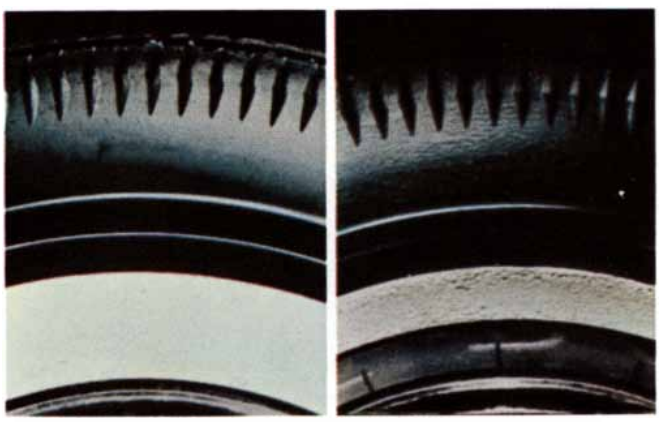
Polymer chemistry is as much an art as it is a science. Even a simple recipe based on one polymer might have ten or more other ingredients. Accelerators, curing agents, fillers, extenders, antioxidants, antiozonants.

Changing one ingredient involving less than one percent of the total can change the properties of the final compound substantially.

To obtain the optimum recipe requires much experimentation. With two basic polymers, the problem is even greater. As the largest manufacturer of chemicals for rubber and plastic, Uniroyal is in a unique position to help you.

Uniroyal's success in developing practical blends that work as well on the production line as in the laboratory is due as much to our experience with rubber chemicals as it is to the basic polymers.

If you think a plastic rubber or a rubber plastic can help you, we'd like to hear from you. Write to Uniroyal, Polymer Technical Service, Chemical Division, Naugatuck, Connecticut 06770.



Both tires were aged 18 months. The one that didn't crack contains Royalene, the "Crackless Rubber." Most whitewall and cover strips now contain Royalene.

Ingredients in a typical tire compound. Uniroyal Technical Service can help compounders determine the exact amounts of each ingredient to use to meet a specific requirement.

We think we can help you. After all, we're an inventive company and we have almost 1,500 patents to prove it. (More than half of them are concerned with polymer technology.)

Uniroyal holds more patents than any other rubber company.

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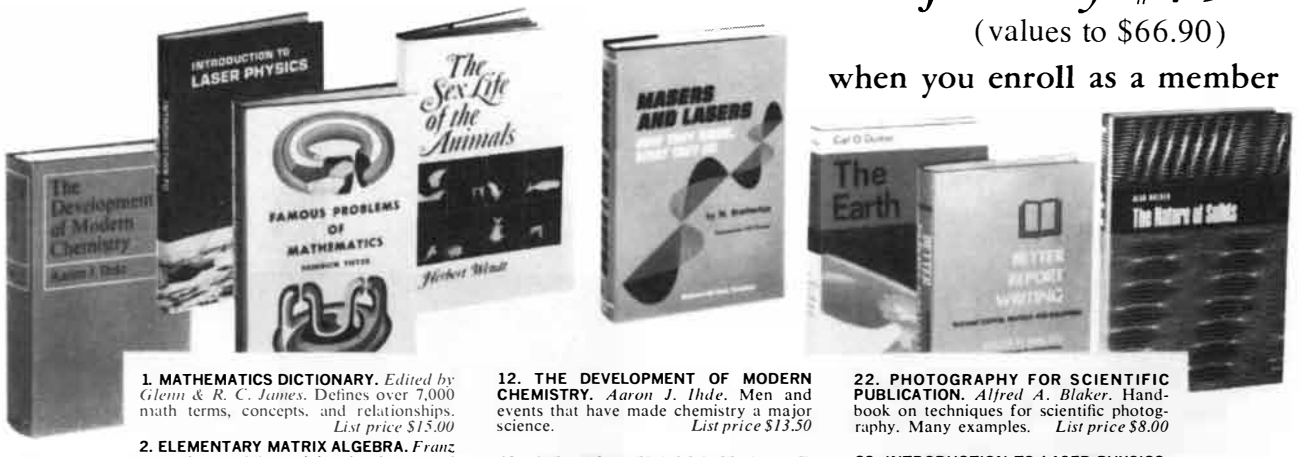

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BOOKS

On the hazards of analogies between human aggression and aggression in other animals

by S. A. Barnett

ON AGGRESSION, by Konrad Lorenz. Harcourt, Brace & World, Inc. ($5.75).

Samuel Johnson once wrote that weekly reviewers do not read books but "lay hold of a topic, and write chiefly from their own wit." He added: "Monthly reviewers are duller men, and are glad to read the books through."

Johnson's comment came to mind on reading some of the early reviews of *On Aggression*. These discuss particularly the similarities that Lorenz believes exist in animal and human behavior. Joseph Alsop, writing in *The New Yorker*, detects a conflict between "the ethologists" (that is, Lorenz) on the one hand and psychoanalysts and social scientists on the other; the latter, he suggests, are unlikely to accept analogies between ourselves and other species. In contrast, Anthony Storr, a psychotherapist writing in *The Sunday Times* of London, accepts Lorenz' views on geese and men without protest. Arthur Koestler, in *The Observer*, describes these views as a "lusty gallop on a hobby horse" that it would be churlish to grudge.

Unfortunately this reviewer finds himself forced to be churlish. A book prominently reviewed by celebrated writers becomes important regardless of its intrinsic merits. The reviews mentioned (all by nonzoologists) agree on one thing: that at least Lorenz' accounts of animal behavior are authoritative and reliable. But *On Aggression* does not in fact represent the methods or opinions current in ethology (the science of animal behavior).

The main theme is stated in the introduction: "Behavioral science really knows so much about the natural history of aggression that it does become possible to make statements about the causes of much of its malfunctioning in man." First, then, let us examine the "natural history of aggression," as Lorenz describes it. In Chapter 3, entitled "What Aggression Is Good For," we are told that "we can safely assume that the most important function of intra-specific aggression is the even distribution of the animals of a particular species over an inhabitable area." But should we assume this? Lorenz does not discuss the evidence. The members of many—perhaps most—species are distributed not evenly but in quite large groups, crowds or herds. These include large hoofed mammals and ground-living apes. Of them Lorenz writes, "intra-specific aggression plays no essential part in the 'spacing out' of the species." He adds that among the herds of hoofed mammals there are no territorial boundaries.

This unsupported statement contradicts the observations of several careful workers. In 1956 William Graf described territorial behavior in the elk (*Cervus canadensis*). These animals make territorial marks by scraping the bark off trees and rubbing their faces in the scrape. Graf also refers to the similar behavior of the black-tailed deer (*Odocoileus hemionus*). In 1957 Carl B. Koford described the behavior of the vicuña (*Vicugna vicugna*), whose territorial defense depends largely on a characteristic posture in which the head and tail are held high. More recently there have been accounts of territory in the reindeer (*Rangifer tarandus*) and the Uganda cob (*Adenota kob*). Still other examples could be quoted.

Lorenz also tells us that when birds assemble in flocks outside the breeding season, they "lack aggression." This bare statement certainly needs qualification. For example, A. W. Stokes has described in great detail antagonistic behavior among blue tits (*Parus caeruleus*) at a winter feeding station. The work by Stokes is particularly important (and unusual) in that it gives *quantitative* information on the effects of various postures on the behavior of the birds toward which these signals are directed.

Further examples come in the account of the social behavior of wild rats, to which Lorenz gives a chapter. He refers to the "bloody mass battles of the brown rat" (*Rattus norvegicus*). Nothing of the kind appears in any of the detailed accounts of this species. In fact, serious clashes, when they do occur, consist of an attack by one rat on a single opponent; the latter does not fight back. Nor is there pair formation in wild rats, as Lorenz states; a female in estrus accepts males indiscriminately, and males do not fight for females. The only reference in the bibliography to work on rats is to a short paper on the interaction of "brown" and "black" rats. Encounters between these species are not bloody mass battles either.

Rats are also described as "models of social virtue," "cruel to their subordinates" and "horrible brutes." They are said to transmit by tradition knowledge of the danger of poisons. The last statement is reminiscent of the simple tales, often written by clergymen in earlier times, about animal cooperation and its moral implications. (A popular story was about the old blind rat that was guided by a younger rat by means of a twig.)

In the same passage there is a reference to a similar transmission of pathfinding, and of recognition of foods and enemies. It is not clear in just which species these abilities are supposed to exist. There are certainly traditions of food choice within monkey colonies. As for pathfinding, young animals often follow older ones of their own species, but as a rule this has nothing to do with teaching or learning a tradition. There is a deep gulf between *following*, on the one hand, and *imitation* (or learning by observation) on the other. Any discussion of tradition in other species demands a critical account of this distinction, and of the kind of evidence needed before the existence of imitation may be accepted. This is perfectly practicable even in a popular work, but it is not done.

Another passage more reminiscent of a moral tract than of ethology asks what has been learned "from the objective observation of animals" on the "ways

intra-specific aggression assists the preservation of an animal species." Among the benefits, we are told, is that the community is so organized that "a few wise males, the 'senate,' acquire the authority essential for making and carrying out decisions for the good of the community." Among some species of primates elderly males do play a special part in social life: a single, senior baboon of the genus *Papio*, for example, sometimes stops conflicts. But there is no ground for suggesting the existence of anything that can be called a senate (or legislature). Not even male apes combine to regulate the conduct of their group (although an assault by an elderly baboon may be checked by a group of younger ones).

These examples of Lorenz' method illustrate a general difficulty that all scientific writers on behavior have to face: the use of colloquial language often makes exact description difficult and rational explanation impossible. A lexical definition of "aggression," for example, is "assault." Yet the animal behavior called "aggressive" consists usually of displays (or signals) that induce the withdrawal of intruders; it does not often involve a clash. (Even when there is actual contact, under natural conditions there is hardly ever serious injury.) The displays that lead to withdrawal may be postures, noises (such as birdsong) or odors, and are often called threats. A lexical definition of "threat" is "a declaration of hostile intent." But it is difficult to give a precise meaning to a statement about what an animal *intends*. The word "threat" could be redefined as a signal that tends to induce withdrawal by a member of the same species. This at least allows the term to be used without ambiguity. An objection is that it ignores the animal's internal state. Among ourselves we think of threat as an index of anger or fear. In order to speak objectively about the counterparts of anger and fear in other species we need to know something of the physiology of the behavior observed. This entails exact descriptions of electrical, chemical and structural changes in the nervous system.

A start has been made in this difficult area, but it is not recognized by Lorenz. Instead there are many references to "instinctual urges," "aggressive impulses" and similar undefined qualities. One of the difficulties in commenting on this book is indeed that key terms are not defined; much is ambiguous or obscure for this reason alone. The progress of science has depended on the rejection of what Newton called "occult qualities." Descriptions in science are of properties that can be reliably observed: "Real is what can be measured." We no longer attribute the motion of the planets to angels; we do not "explain," or even name, the steady temperature of a mammal or a bird by an undefined "innate heat," nor do we account for disease by the presence of demons.

In one passage Lorenz refers to the uselessness of terms such as "reproductive instinct" as explanations, but he repeatedly uses them elsewhere. The human "aggressive drive" is often mentioned, but if this or any similar expression has a meaning, it is only that almost any human being *can* be provoked to violence. The crucial question is how the violence arises.

Lorenz believes that this question can be answered by studying patterns of behavior—displays, songs and so on—that are common to an entire animal species. He refers to such species-characteristic patterns as "hereditary," but this represents a confusion between heredity and development. Only differences between individuals can properly be called "hereditary." This confusion is an aspect of Lorenz' failure to take account of the *development* of behavior during the life history of each individual. It has sometimes been assumed that uniformity of behavior within a species indicates complete stability in the development of the behavior. This is now well known to be unjustified, and the concept of "innate behavior" as it appeared in ethological writings of, say, 15 years ago has been much modified.

Rhesus monkeys, *Macaca mulatta*, provide a notable example. These animals, like many others, have a "peck order," or status system, within each group; whenever (as under natural conditions) there is a settled status system, conflict is at most trivial and harmless. Such social behavior might in the past have been called "instinctive." But if young monkeys are reared without other monkeys, they fail to develop the ability to take part in a stable society. When given companions later on, they are persistently "aggressive" in the sense that they frequently attack and injure others. These celebrated observations, made by Harry F. Harlow and his colleagues, are, of all studies of animal "aggression," the most relevant to Lorenz' theme. They illustrate the importance of studying how social (and antisocial) behavior *develops*. They are not mentioned in *On Aggression*.

There is much discussion of the evolutionary origin of behavior patterns. Great emphasis is put on the "triumph ceremony" of geese and other birds. (The birds are described as if they were human beings.) This ceremony, also called an "appeasement" activity, is seen in different forms in different species. Lorenz writes: "From this gradation we can form a picture of how, in the course of phylogeny, an anger-diverting gesture of embarrassment has developed into a bond which shows a mysterious relationship to that other bond between human beings which seems to us the strongest and most beautiful on earth."

The primary hypothesis is that displays, such as those of courtship and territorial defense, have gradually evolved from other activities. For instance, birds take care of their body surfaces by preening. The displays of many species include preening-like movements, some of which show off in a striking way the characteristic feather patterns. Movements that originally had one function are supposed to have changed during evolution, so that they now have another. At the same time the structures involved have evidently become more conspicuous, sometimes by acquiring bright colors. Julian Huxley named this hypothetical process "ritualization," and Lorenz makes many confident, dogmatic assertions about it. The workers who have contributed most to its study are Niko Tinbergen and his pupils. Tinbergen has written: "Comparative description of signals [has] given us an idea of their evolutionary origin and... leads to a description of their alleged ritualization. Assuming that our reasoning has been correct, can we guess what selection pressures must have been responsible for ritualization? The paucity of experimental work on survival value renders such guesses doubly hazardous." This cautious, critical statement represents the actual position among research workers on behavior today.

There are passages in *On Aggression* about stereotyped behavior in which the development of the behavior of an individual seems to be regarded as the same as evolutionary change in behavior due to natural selection. For example, there are many rituals in human behavior that we call "superstitious," and in obsessional neurosis (induced by an unfavorable early environment) they become excessive. Lorenz writes of obsessional behavior and of the fixed action patterns of animals ("All these phenomena are related"). He states: "All human art primarily developed in the service of rituals." Characteristically, instead of discussing the difficult

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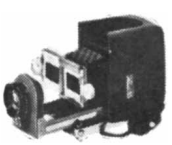

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problems raised by these proposals, he precedes the last-quoted statement with the words "There is hardly a doubt that...."

The emphasis on the stereotyped behavior of species other than man, and the neglect of behavior that can be readily altered by experience, is particularly strange when the aim is to throw light on human behavior. Man is the one species whose social behavior (except in infancy) does *not* depend on a uniform set of social signals. All our customs, including language, depend on the training we receive in our family or community. Hence arises the immense diversity of *mores* within the single species *Homo sapiens*. Yet Lorenz writes: "Human social behavior, far from being determined by reason and cultural tradition alone, is still subject to all the laws prevailing in all phylogenetically adapted instinctive behavior."

This statement is made without supporting argument—unless analogies constitute an argument. The great debate that has long ranged on this kind of question is acknowledged only in a few statements such as: "The completely erroneous view that animal and human behavior is predominantly reactive and that, even if it contains any innate elements at all, it can be altered to an unlimited extent by learning, comes from a radical misunderstanding of certain democratic principles: it is utterly at variance with these principles to admit that human beings are not born equal and that not all have equal chances of becoming ideal citizens." Yet in fact there is no school of thought that states that animal, or even human, behavior can be altered to an unlimited extent by learning, and people who work for social justice do not say that all are born equal but only that all should have equivalent opportunities to develop their abilities to the full. Lorenz may look back nostalgically to "the good old days when there was still a Habsburg monarchy and there were still domestic servants," but this does not justify him in ascribing to his opponents opinions they do not hold.

What, then, are Lorenz' proposals on the causes and treatment of "aggression" in man? What revelation has he in store for his readers? One is that there should be more international sport. This widely acceptable suggestion has often been made without benefit of ethology; it is not surprising, since (as Lorenz himself points out) sport is "specifically human." Another suggestion is that there should be more art, science and medicine—the pursuits of beauty, truth and healing; this, of course, is still more readily acceptable, since it has been a familiar notion for several thousand years. We are also urged to laugh more, and to love each other indiscriminately. The last recommendation perhaps accounts for the following sentence: "Not even the most ruthlessly daring demagogues have ever undertaken to proclaim the whole art of an enemy nation or political party as entirely worthless." It might have been more appropriate if Lorenz had reminded his younger readers of the attempt by the Nazis between 1933 and 1945 to destroy not only the German Jewish community but also the whole of Jewish culture.

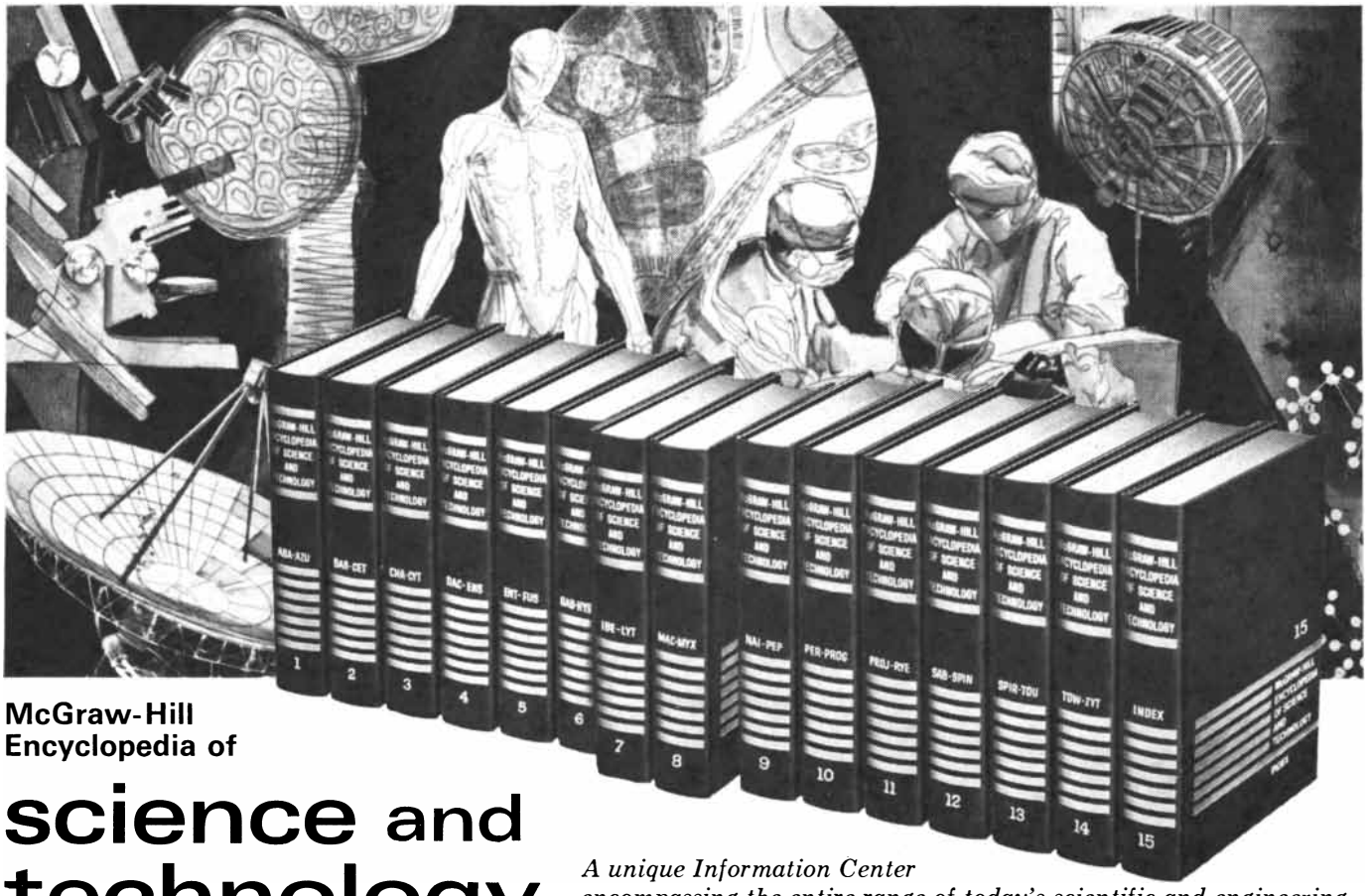
The sentence quoted strongly suggests that Lorenz lives in a private world, insulated from the real one. The same applies to his principal recommendation for further research. "I believe—and human psychologists, particularly psychoanalysts, should test this—that present-day civilized man suffers from insufficient discharge of his aggressive drive." Never mind now that "aggressive drive" is not defined. This and similar notions have been debated among medical men and psychologists for several decades and are the subject of a substantial literature. The late Karen Horney, a leader of a prominent psychiatric school that particularly emphasizes this aspect of psychopathology, has written of "the neurotic person's need for indiscriminate supremacy."

Still more to the point is the research that has been done on the developmental psychology of the bully. In the 1940's H. V. Dicks produced convincing evidence that the personalities of the brutal German soldiers who formed a substantial minority of the Reichswehr were products of families in which the father was a tyrant and the mother submerged. T. W. Adorno and his colleagues independently published a longer and celebrated work, *The Authoritarian Personality,* that extended and confirmed this analysis. On the development of "aggression" in childhood Lorenz has little to say except for a reference to "countless unbearably rude [American] children" who, he tells us, were a product of the view that children ought to be "spared all disappointments and indulged in every way."

Being a dull man, in Samuel Johnson's classification, I have "read the book through" more than once. On each reading more self-contradictions, confusions and questionable statements have emerged. How much more acceptable would have been an unpretentious account of actual behavior! It is sad that so much ability should have been misapplied in this fashion. As it is, since *On Aggression* is presented as being authoritative at least on animal behavior, it is likely to bring ethology into disrepute with critical readers, and also to mislead students and laymen. But the scope and implications of the book are far wider. It makes statements bearing on two crucial features of our existence: the growth of social behavior in children and the prevention of violence and war. These are not topics in which loose thinking can be accepted with a tolerant shrug; such work should be based on a respect for facts, for logic and for the researches of others. Instead the method of *On Aggression* is essentially antirational. This method should be repudiated by all scholars, indeed, by all responsible people.

Short Reviews

WHEAT: BOTANY, CULTIVATION, AND UTILIZATION, by R. F. Peterson. Interscience Publishers Inc. ($16). A carbonized spikelet of a hulled variety of wheat is perfectly imprinted on baked clay in material excavated in Iraq at Jarmo, a village where men already gained their strength by feeding on the seeds of wheat. That was about 6700 B.C.; today all over the world outside the Tropics men tend each year about 10^{14} individual wheat plants, mainly of the species *Triticum aestivum,* a species that itself arose in a wheat field in western Asia some 3,000 years ago. This substantial volume is a general account of wheat, taking up the plant itself, its genetics and physiology, its varieties, breeding and diseases; it gives a broad treatment of cultivation, from seed preparation to sowing, of weed and insect control, harvesting and threshing; finally it describes use, from storage, nutrient content and milling to baking, spaghetti-extrusion and international trade. The pictorial matter is fascinating: the Jarmo spikelet is here, and color photographs of grains of many varieties. The chromosome configurations of the several "species" are shown, as are the external look of the ears of almost 100 varieties. Here are the broad flatlands with the golden meadows stretching for miles, or traversed all night by a dozen combines in echelon. There are grain elevators in the Crimea and the Transvaal, and red wheat in great heaps on the ground during a bumper year in Alberta. There is a funerary model from the Old Kingdom of Egypt, showing the wheat being ground and the baker tending his fire. Next to it are modern auto-



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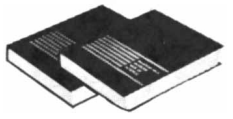

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matic ovens, producing some 100,000 loaves a day.

Most U.S. wheat is hard red winter wheat, sown in the fall, when it forms a strong root system and sends up its early-branching leaves. On the dry plains the plowman no longer encourages a layer of dust (once thought to check water loss through evaporation, a practice that itself encouraged the dust bowl) but uses a cultivator whose blades work mainly below the surface. Most fertilizer is applied at sowing time.

The next spring the field grows, with that special promising green, and the wheat grower sprays for control of broad-leaved weeds by 2,4-D and of wild oats by a specific called barban. Chinch bug, hopper, Hessian fly and their like he attacks with more sprays, even by airplane. (The crop is still not won without bloodshed: accidents to crop-dusting pilots are frequent.) He reaps and threshes all at once with the direct combine, a self-propelled machine that cuts the stems, parts grain from the chaff, stores the grain in its tank and blows the chaff and the cuttings out into the field. In 1829, even before the use of the hand cradle, one acre of wheat required 46 man-hours for harvesting, consisting in 14 for cutting by sickle, five for hand-binding, 13 for threshing with the flail, 10 for winnowing with rod and fan, and a little more. With the combine it takes half an hour. On this fact we who dwell in cities depend. By 1896 the total had already dropped to three hours; the 19th century set the pace.

Wheat seeds mainly contain starch, but their protein is important both as a nutrient and as a substance indispensable to the formation of small bubbles in the dough, which makes wheat and rye the only true bread-making grains. Heating before grinding denatures the proteins and prevents the evolution of gas. Bread eaters do not parch the grain; they probably stopped doing so, in order to turn the flatbread into the leavened, sometime in the fourth millennium B.C., a turn of events perhaps not unconnected with the spread of *T. aestivum*. Palatable bread requires only flour, water and yeast; salt is usually held essential for its savor. (It is not easy to speak of this topic without echoes of the Bible.)

The longevity of the fertile wheat seed is surprising: "By adjusting all factors to [an] optimum, it will be possible to keep wheat seed viable for as long as 100 years." The occasional assertion that wheats from ancient Egyptian storage pits and tombs has germinated is flatly denied. The authentic seeds show no germination whatever; "they are hard, dry, brittle and lifeless."

Ergot is a minor disease of wheat, although it is a major one of rye. Its black, powdery spore bodies replace entire grains in the wheat ear. We are protected statistically against the grave symptoms of ergot poisoning: the price of wheat containing even a few such bodies is lower. Dilution saves us in an era of mass production; formerly we depended on the good offices of a watchful miller. (Nowadays the ergot alkaloids are elaborately modified into LSD and supplied separately.) Our greatest competitor for the wheat is probably the stem rust, a fungus found in many races on all continents. It has a complex life cycle, requiring alternate infection of wheat or grass stems and the barberry bush. Resistant varieties of wheat are the main weapon against rust, and the task of keeping ahead of the mutating races of the rust is literally endless. Chemical control is a promising backup procedure. The major losses to stored grain come not from rats and mice but from small beetles and weevils. Such insects can develop even in very dry conditions; their respiration produces enough water vapor to promote the growth of molds and other fungi. These spread rapidly, their metabolism releasing much heat. This is the main cause of grain spoilage. The grain needs checking from time to time for moisture and temperature rise. The biology of all these events has an air of thermodynamic inevitability. The wheat is a microcosm of history, of biology, of trade, of invention.

The author of this admirable work is a specialist in cereal rusts from the Agriculture Research Station in Winnipeg. He has tried to make a book that expresses his experience and wisdom as well as library gleanings. It is a book aimed at "readers seeking a broad view" and not at specialists, nor at giving practical directions. He has fully succeeded. There is one curious lack: beer, intimately related to bread since the time of Ur, is nowhere mentioned, nor is malt whisky. Recipes and statistics are given for cakes but not for ale.

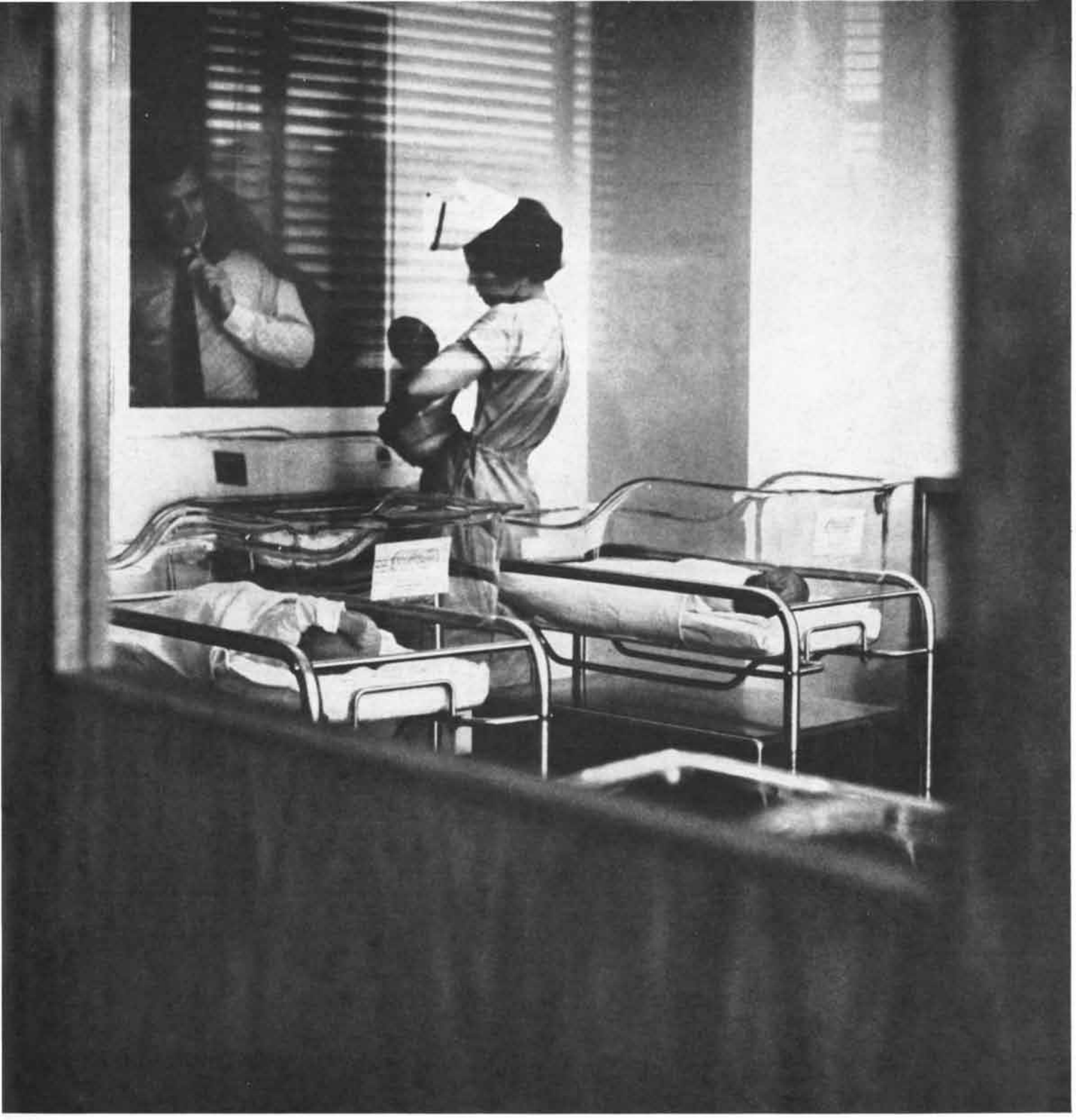
THE MIDWIFE AND THE WITCH, by Thomas R. Forbes. Yale University Press ($6.50). Every once in a while a baby enters the world with a thin membrane, a part of the amnion, covering its head. The membrane is known as a caul; it is an omen of good fortune as old as the Chaldees and as widespread as man. Leonardo was born with a caul, and of course David Copperfield. On the London docks during that terrible August of 1915, when the submarines were daily sinking the old freighters of the British merchant marine, cauls were going for two pounds sterling; they are a sovereign protection against death by drowning.

This learned and diverting work presents a series of essays (and a massive bibliography) about the folklore and superstition surrounding the genuine mysteries of pregnancy and birth. The tale of the caul is one; another is the endocrine disorders of aging birds. These gave rise to the true wonder of the crowing hen and its counterpart, the laying cock, with its legendary serpent offspring, the basilisk. Tests for pregnancy, means for riddling out the sex of the unborn, and eaglestone charms—stones within which a rattling small stone could be heard—are discussed with grace and erudition. The midwife, perhaps because she was so close to the beginnings of life, to inheritance and to the physical possession of the newborn, was much involved with witchcraft. The brief essay on witchcraft presented here is well informed and reveals the humane and medical leanings of its author. We are told of the brave experimenter Heinrich Marzell of Stuttgart, who in 1963 tried rubbing on himself the witches' flying ointment, a grease laden with aconite and nightshade (probably substituting, however, for the authentic fat of unbaptized infants) following a recipe by the famous Giovanni della Porta, which induced dreams and hallucinations of flight, bizarre companions and the rest of the witches' sabbath.

The most beguiling riddle is that of the Latin word square written

ROTAS
OPERA
TENET
AREPO
SATOR

Long prized as a charm against death during childbirth, this formula has been found all over Europe and Asia Minor since the fourth or fifth century. It will also put out fires and guard against mad dogs. The five Latin words have meaning, if not clarity; *sator* is "a sower," *rotas* "wheels," and so on. The cross-word *tenet*—"he holds"—and the ingenious discovery that the square can be built up from PATERNOSTER crossed on itself, plus two *A*'s and two *O*'s (the alpha and



Now a hospital climate to baby grown-ups, too.

Like most nurseries, this one has individual temperature and humidity controls. However, many other hospital rooms are cooled only by open windows and fans—rough on patients when the weather is hot and humid.

Even in other institutions and commercial establishments that have centrally-controlled cooling and heating systems, the climate can be far from satisfactory. Too cool for some, too warm for others.

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the omega), strongly suggest that it was a cryptic sign of the early Christians, like the fish. But the dates seem uncertain, and even these notions are not the only ones. SATOR is still a puzzle, as it has been for a millennium.

This is a graceful book, and the old woodcuts that illustrate it are splendid. A final chapter on the growth of the profession of midwifery in the English Renaissance is a window to sobriety and reason after the chapters of darkness. The 700 items in the bibliography include many primary sources and original papers, "in the hope," says the author, "that some readers will wish to make further explorations."

THE SIX-CORNERED SNOWFLAKE, by Johannes Kepler. Edited and translated by Cohn Hardie, with essays by L. L. Whyte and B. F. Mason. Oxford University Press ($3.40). In a merry—even joking—mood Kepler sat down, at about the same time Galileo across the Alps was using his first telescopes, to write this slender Latin essay as a New Year's gift for a learned friend who was *Reichshofrat* at the court of Rudolf II. The Latin and English texts face each other in the first 40 pages of this elegant book. According to Kepler, here was "the ideal New Year's gift... the very thing for a mathematician to give... since it comes down from heaven and looks like a star." Kepler seeks "the definite cause. ... Why always with six?" Then he proceeds by the strongest methods of the modern theorist: symmetry and analogy. The bees build on the same plan, filling space with rhombs. Pomegranate seeds, and also peas pressed tight from all sides, form the same rhomboid packings. Kepler here described for the first time the two ways of close-packing spheres: the cubic and the hexagonal. He explicitly views the forms of some solids as a consequence of the packing of identical subunits. Snowflakes, though, defeat him. They are not identical, not packed, but free. They are flat as well; even the tiny water globules he thinks comprise the flakes will not then uniquely produce the six-sided figures. Finally he recalls crystals of unusual forms, and in the end calls on chemists (*alchimisti*) and metallurgists to explain the *facultas formatrix* of the snowflake. Across three centuries B. F. Mason makes his effort. He knows a lot, and he understands a six-foldedness deep within, but of the similar branches of the snowflake he too mutters of "layers and steps ... a rhythmic character to the growth ... may explain ... the fairly regular spacing."

Kepler has not yet been given any clear answer, as L. L. Whyte proclaims in a couple of metaphysical pages. Should we not require, he asks, a simple explanation of simple observations? It is not easy to go along with this attractive view in a world that is still searching for the full story of why the apple falls. Physics makes progress where the answers—not the questions—are simple. Meanwhile the snowflake remains a quasi-symmetrical mystery. How it is made still seems beyond the clouds.

REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. United Nations ($2.50). Among other things, this report shows that the test ban *works.* A dramatic curve plots month by month since 1954 the fallout of strontium 90 on New York City. The great delayed peak coming from the last thermonuclear tests of late 1962 arrived with the spring rains of 1964, but today the level (also reduced, to be sure, by drought) is down a factor of five, back to the level of 1954. The fallout is uniformly in sharp decline by all measures. The Chinese tests so far make a negligible contribution, along with the venting accidents of underground shots.

The open biological issues remain pretty open. Genetic-risk data are still uncertain, although knowledge slowly grows. The natural background estimate is remade, and it agrees with the preceding experts' report of 1962 within 2 percent. Some chromosome anomalies are now known to be a major cause of abortion and congenital defects, but their natural cause is not securely understood. This UN committee is one of our safeguards; it deserves the gratitude of every thoughtful person.

GALAXIES AND COSMOLOGY, by Paul W. Hodge. McGraw-Hill Book Company ($4.95). This thin, handsome, graph-packed, entirely up-to-date account of the largest of all astronomical topics was written as a specialized undergraduate text, but it is an attractive work for the general reader who has learned something of the language of astronomers. Most readers will not find cosmology clarified by the succinct collection of formulas and graphs given here, but the bulk of the book sets out very well indeed the geography of galaxies, particularly of the local group, with their contents and their probable evolution. There is a minimum of mathematics. Hodge concentrates on what is seen and measured; quasars and the like, with much other speculation, earn only a mention.

Nancy and John Seletti aren't trying to save the world. Just a little piece of it.

About a mile outside the Korean village of Ku Am there are a few dozen young, still-tender mulberry trees growing on a small hill. Someday these trees and their succulent leaves will be the heart of a new village industry—a silk raising farm. That day is still many months off, but it doesn't stop the village men from making daily inspection treks up the steep hill, just in case. Just in case something miraculous has happened since yesterday. After all, it wouldn't be the first miracle to happen in Ku Am. Everyone in the village knows the story of Chang Sook, the daughter of the widow.

Ten years ago Chang Sook's chances of survival were as slim as she was. Her father had disappeared during the family's flight from North Korea. Her mother, a seamstress, worked a backbreaking day and most of the evening to earn $10 a month. Barely enough to keep them from starving.

But today that's all changed because an American couple named Seletti are sharing a little of their good fortune with a girl to whom a little means everything. Nancy, John and five-year-old Alexandra Seletti are New Yorkers. They're not fabulously wealthy as the villagers of Ku Am believe. But, they're not poor either. *Comfortable* probably describes them best. They have everything they really need, but give them ten minutes and they'll come up with ten things they want that $15 a month would buy. Luckily, they thought of Chang Sook first.

Through Save the Children Federation, the Seletti's $15 a month is doing a remarkable number of things. First, Chang Sook's immediate needs and future schooling are being taken care of. The family is getting help, too: Enough to enable Chang Sook's mother to start a small knit shop.

And with all this, there is still some money left over. This money, together with money from other sponsors, was borrowed by the village to start its precious mulberry farm. Someday silk raising will mean a permanent increase in the village's income—and permanently end the need for charity. That's what Save the Children Federation is all about. Although contributions are tax-deductible, it is not a charity. The aim is not merely to buy one child a warm coat, a new pair of shoes and a six month supply of vitamin pills. Instead, your contribution is used to give the child, the family and the village a little boost that may be all they need to start helping themselves.

Sponsors are desperately needed for children in Korea, Vietnam, Latin America, Africa and Greece. You can select the child's nationality. You will receive a photo of the child, regular reports on his progress and, if you wish, a chance to correspond.

Chang Sook writes to the Selettis. She also sends small homemade gifts to Alexandra. And she tells them of her dreams of becoming a nurse. She'll probably make it. If she does, the Seletti's investment in one girl will be repaid a thousand-fold.

The Selettis know they can't save the whole world for $15 a month. Just a small corner of it. But, maybe that is the way to save the world. If there are enough people like the Selettis. How about you?

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The radio study of external galaxies receives a brief review that is hard to match elsewhere. The methods of the optical astronomer are not paid much attention, although there is one splendidly helpful chapter on the means of measuring great distances, seen as six steps to a remote Parnassus. Beginning with the solar system, accessible to radar and to the orbital studies of Newtonian mechanics, the distances one by one fall before successive calibrations of the brightness of recognizable objects. The brightest blue stars and the clouds of ionized gas they induce work all the way up to the Virgo cluster of galaxies, 30 or 40 million light-years out. The red shift, calibrated on the Virgo galaxies, handles all the rest. The most distant objects must finally be gauged as a whole. The author has presented a taxing but rewarding book for the general reader, and a lively and unusually rich text; if the probable-error bars on most curves and, worse yet, all the references to the original papers had not been suppressed, the book would as well have been an indispensable monograph for the graduate student.

WHITE AFRICAN, by L. S. B. Leakey. Schenkman Publishing Company ($7.95). The energy, enthusiasm, directness and iconoclasm of the famous explorer of man's African past are wholly displayed in this early autobiography written when Leakey was 30 years old. He had just completed his first expedition into "Oldoway," where he had found the stone tools in Bed I, still the oldest-known artifacts of man. Here he is, a born Kenyan, "more of a Kikuyu than an Englishman in many ways," collecting obsidian flakes, running down duikers and hares, tending bees in the Kikuyu style. In school and at Cambridge he remains irrepressible, beating his big signal drum from the roof of St. Johns, and almost required to set himself his examination in the Kikuyu language. Kenya has two great books from these decades: President Kenyatta's scientific study of Kikuyu life, and the magical evocations of Isak Dinesen. Here is another worthy of the same shelf, although it is slighter than those classics.

PERSPECTIVES IN MODERN PHYSICS: ESSAYS IN HONOR OF HANS A. BETHE, edited by R. E. Marshak. Interscience Publishers Inc. ($19.50). It almost goes without saying that this volume offered as a tribute to one of the world's leading theoretical physicists has many valuable pieces on a broad range of topics in physics. Notice of a special sort is earned by

four papers that will be of particular interest to the general scientific reader: an eloquent essay on the role of physics in this century by J. Robert Oppenheimer; a fascinating personal account of 20 years of accelerator construction by Robert R. Wilson (which sounds like the logbook of one of Columbus' rival captains); a superb overview of stellar physics by E. E. Salpeter, obtaining all its central results not from computers but from insight and dimensional analysis, and a piece of highly convincing hyperengineering by Freeman J. Dyson, who lays out quite reasonably the means of refashioning galaxies from untamed forests into parks in a way that ought to nourish a whole decade of science fiction.

PRINCIPLES OF GEOCHEMISTRY, by Brian Mason. John Wiley & Sons, Inc. ($9.95). In a science where the main sources are bulky treatises crammed with dry tables, the third edition of this deft, up-to-date and clear text maintains authority without surrendering readability; this holds for the student as well as for the scientist visiting from another field. The atomic census of meteorites and of man, of seawater, alfalfa, air and coal, and how the atoms got there, form the content of the book. The thermochemistry and hydrochemistry of rocks and the cycles of elements are well described. A list of the world consumption of the elements, with sources and current prices, closes a fresh and stimulating account. Platinum, at $4 per gram, is the dearest of stable elements; the heaviest atom that is found as an invariable constituent of living forms is iodine.

THE IDENTIFICATION OF PLASTICS AND RUBBERS, by K. J. Saunders. Chapman & Hall, distributed in the U. S. by Barnes & Noble, Inc. ($2.75). Keys to wild flowers, field lists of birds—these are for a good many people companions up to the edges of science. Today we constantly touch substances that were unknown to us a generation ago. Although homes and stores are still not as rich in detail as fields and woods, it is time that people who like to know exactly where they are came to see that calling a substance a plastic is not enough to walk knowingly through the modern world. Here, then, is a first key to the domestic molecules. Rubbers snap back, thermoplastics give and thermosetting materials chip. Feel, color, burning, density and odor in the flame are clues to whatever you find. That heavy kitchen wrapping is polypropylene, and it floats easily in water.

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