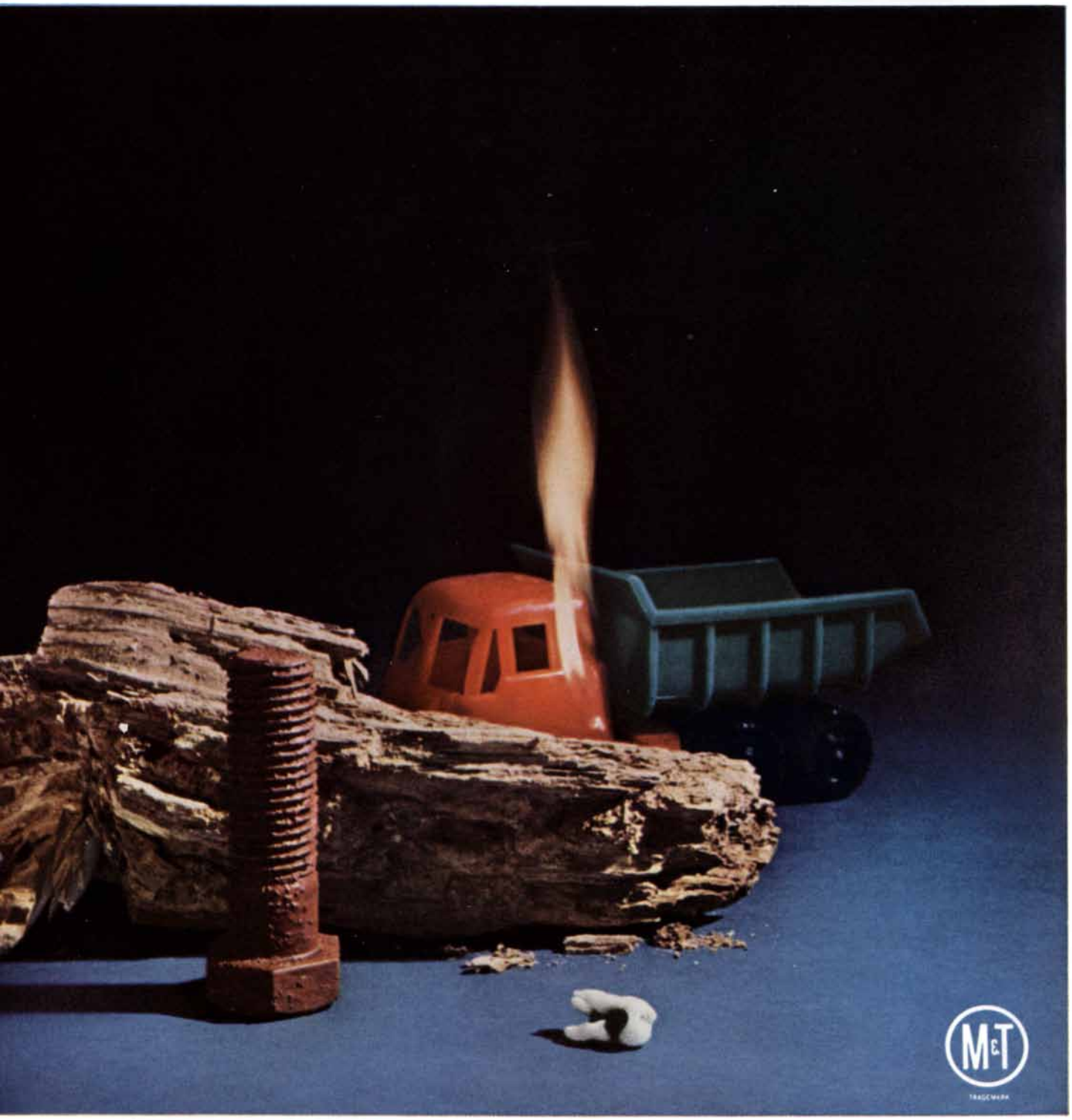
SCIENTIFIC AMERICAN

CHANCE

SIXTY CENTS

October 1965



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Established 1845 **SCIENTIFIC AMERICAN** October 1965 Volume 213 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover illustrates the theme of the article entitled "Chance" (*page 44*). Among the matters discussed by the author are some aspects of coin-flipping, including the nature of an "unbiased" coin and the question of whether or not a run of heads increases the likelihood that tails will come up on the next flip. In the painting the artist has portrayed a fanciful coin-flipping experiment that is yielding a most unlikely result: all the pennies that have landed on the table have come up heads.

THE ILLUSTRATIONS

Cover painting by Stanley Meltzoff

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LETTERS

Sirs:

It was with the greatest interest that I read "High-Speed Tube Transportation," by L. K. Edwards, in the August issue of *Scientific American*. I hope that this system can soon be put to the large-scale test it appears to deserve.

One question arose. The author states: "Even the longitudinal stresses turn out to be primarily tension rather than compression, since the train will be accelerated by low pressure in front of it and decelerated by low pressure behind it." This will have to be explained a little more fully for me, since I have been trained to believe that a vacuum does no pulling of its own accord but merely represents a lack of force to balance the pushing of the outside atmosphere. In other words, I would expect *high* pressure behind the car to accelerate it rather than *low* pressure in front. This should produce a longitudinal compression, rather than a tension, in the car.

FLOYD A. HUMMEL, JR.

Urbana, Ill.

Sirs:

L. K. Edwards' article "High-Speed Tube Transportation" fascinated me. His proposals seem as sensible as they are brilliant.

There is only one thing I don't understand: How can the tubes float in water (as illustrated on page 32) on the upper slopes of the gravity-vacuum system outlined on page 39? In seeking its own level, wouldn't the water flow from the end sections near ground level and flood the middle section 3,000 feet below the surface (illustration on page 38)?

A. KENT MACDOUGALL

New York, N.Y.

Sirs:

Mr. Hummel brings up an issue that disturbed a number of readers. This is a somewhat tricky point. It is easy to overlook the effect of air inside the train, which of course is at atmospheric pressure. As the vehicle is entering the tube, there is no differential pressure, and therefore no longitudinal force, at the rear of the train. At the front bulkhead, however, there is a differential pressure of nearly one atmosphere, producing the 70-ton force that *pulls* the train into the tube. Later, with low pressure both ahead and behind and with speed essentially constant, the shell of each car feels a 70-ton longitudinal tension. Finally, as the vehicle emerges from the tube, the 70-ton force is found at the rear bulkhead, pulling the train to a stop. Thus, as stated in the article, longitudinal stresses are primarily tension rather than compression.

Mr. MacDougall's concern was also shared by others. The flotation is specifically proposed for the level stretches of the Corridor run; fortunately this is where speeds are highest. In sloping areas, as stated near the top of page 39, one answer is to hang the entire tube on springs. Pairs of conventional coil springs every three feet would provide the requisite support and softness. Alternatively, where there is moderate slope, we might incorporate flexible dams to produce a gentle "stair step" in the water level. If the spacing is as close as 25 to 50 feet, I believe there will not be significant loss of smoothness or structural integrity.

L. K. EDWARDS

Palo Alto, Calif.

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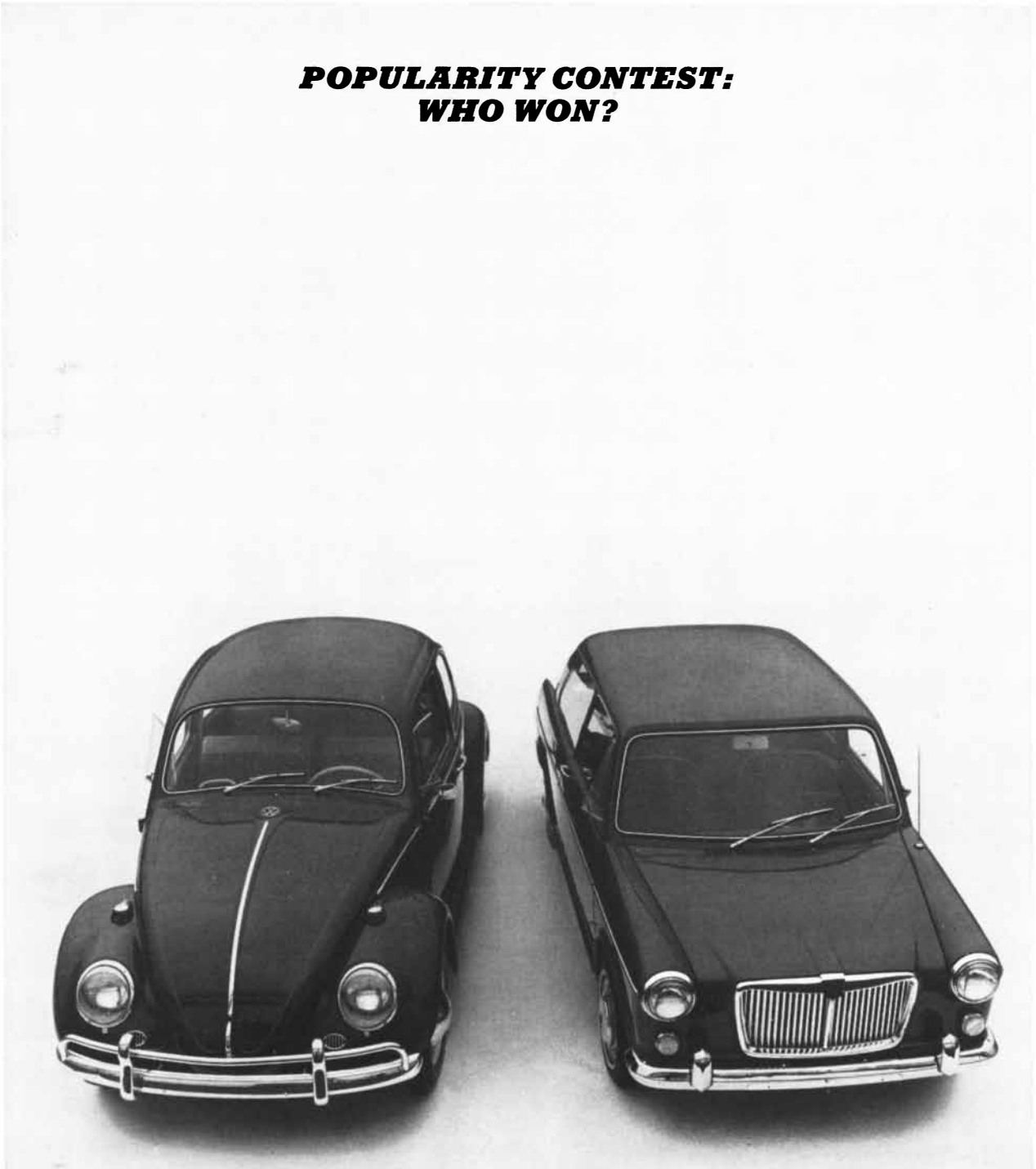

Who else!

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Congratulations, you lusty, close-fisted 18%.

As for you, VW, wait 'til next year.

MG

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1915: "The month just ended has been one of the most eventful of the war, and later developments may show it to be one of the most decisive, possibly marking a turn in the tide of victory which for five months has flowed so strongly in favor of the Teutons. It has been a week full of surprises, following each other with such rapidity as to leave us almost bewildered. At the outset we were anxiously awaiting the outcome of the German turning movement at Vilna, which threatened to capture or destroy a large fraction of the Russian army, when our attention was suddenly diverted from this field by developments in the Balkans. This was surprise number one, to be followed almost immediately by surprise number two, when we learned that the Russian Vilna army had escaped and that the Germans were fighting a furious and apparently successful battle for the possession of Dvinsk and the extreme northern section of the Russian line. For a day or so interest was divided between this struggle and the Balkans, when the greatest surprise of all came with the powerful offensive operations of the Allies in the west from the North Sea to near Verdun. Decidedly the Allies must be given most, if not all, of the points in this round of the 'great fight.' "

"The subject of drug addiction in the U.S. has been much discussed since the Harrison law went into effect, and many exaggerated and misleading statements in regard to it have been published. A timely paper by M. I. Wilbert of the U.S. Public Health Service on 'The Number and Kind of Drug Addicts' has recently appeared in *Public Health Reports.* It was generally predicted that the result of the enforcement of the Federal anti-narcotic law would be the besieging of hospitals by drug addicts and a crime wave of national scope, accompanied by a trail of suicide and death. Although hospital reports clearly show an effect of the enforcement of the law, these dire predictions have by no means been verified. After a careful review of various evidence, including especially statistics as to the total amount of narcotic drugs available for all purposes, legitimate and otherwise, Mr. Wilbert concludes that the estimate made by the committee of the American Pharmaceutical Association some years ago that the drug addicts in this country do not number more than 200,000 is approximately correct even at the present time."

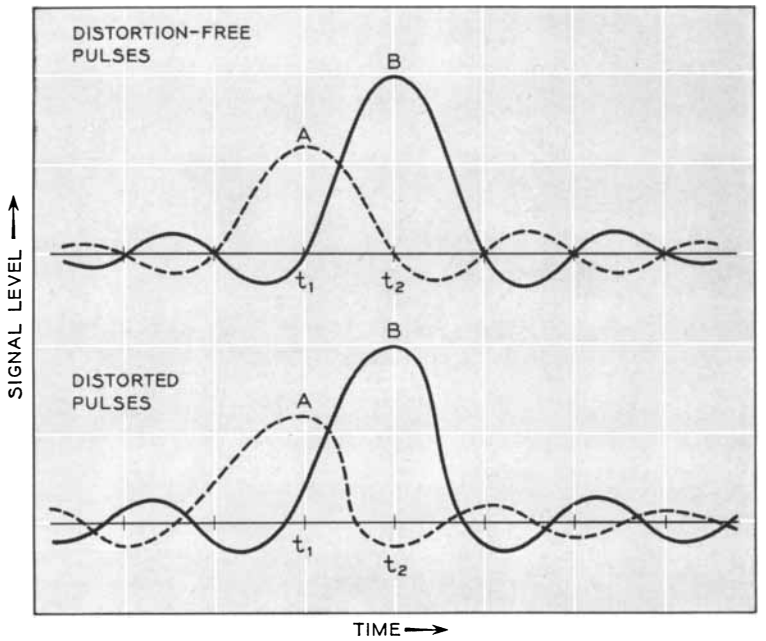
"Germany has abundant supplies of potatoes, beetroots and turnips—materials containing carbohydrates. Albuminous fodder, however, is scarce and before the war had to be largely imported. An invention recently made in Berlin, we have just learned, provides a nourishing yeast containing more than 50 per cent albumen, prepared from sugar and ammonium sulphate. The sugar is bound to an inorganic base; in order to supply the albumen, the sugar is 'fertilized' with ammonia, potash and magnesia in the form of their salts, after which some yeast is introduced and a strong air current applied. The yeast then absorbs the sugar and the 'fertilizer,' thus resulting in the formation of a highly albuminous yeast."

"The possibility of devising an electrical machine for solving numerical equations to any degree has recently been suggested by a French author. Essentially the machine will consist of a collection of various electromagnetic machines connected in cascade, the armature circuit of one machine being used in the excitation circuit of the next and so on. It has been demonstrated by a commentator on the suggestion that by the connection of transformers in cascade it would be possible to solve not only algebraic equations but linear differential equations with constant coefficients as well."

"The great war will be decided on the Western front, either in France and Flanders or on or within the German frontier. There has been much talk of this war as being a war of exhaustion. If it should prove to be that, it will be an exhaustion not of munition, not of economic resources, but of men. The vast scale on which this war is being fought prevents its being decided by any one great decisive action—the campaign against Russia by Germany has proved that. The great nations engaged in this war have such vast resources back of them that all talk of defeat through exhaustion is absurd. Defeat will come through lack of men to put into the line. When the fighting line thins out beyond a certain minimum with which it can be held, the enemy will break through, communications will be cut and the whole line of an embattled nation will be thrown back in defeat. The Allies realize this, and they are fighting their fight on this basis. The Central Powers have enormous numbers of men. True, but the Allied powers have a vastly greater number—and the fighting of the war has proved that there is very little to choose in point of bravery between the opposed forces. Hence the inevitable sequel: the collapse sooner or later, and rather later than sooner, of the Central Powers for lack of men to put in the fighting line."

OCTOBER, 1865: "Twenty years have passed since this paper commenced its existence. As we look back on that time it seems short, but what great events are crowded into its span! With the possible exception of the period of the first French Revolution—from 1789 to 1809—there is no equal portion of history that marks so great a progress in those arts which ameliorate the physical condition of mankind, in those labors by which our intellectual nature is informed and developed, in those struggles which carry forward the political emancipation and elevation of the race and in those discoveries by which our knowledge of the universe is enlarged. With the record of this marvelous progress in all departments of life our pages in the past have been enriched, and in view of the constantly accelerated march of invention, discovery and improvement it may be reasonably hoped that they will be not less opulent in the future. Considering, however, the unimaginable character of past discoveries, who will venture even to dream of the nature of those which may come forth in the years that are before us?"

"We are informed that the flying machine which has been in process of construction in Jersey City, and which has been incorrectly called the Government machine (the Government had nothing to do with it), has been completed and tried. It of course failed, as everybody of any judgment knew that it would. They were not able to get it off the ground."



Report from
BELL LABORATORIES

Concept of the data-distortion problem in simplified form: Two data pulses at top are undistorted because their "tails" all pass through zero signal level at sampling times t_1, t_2, etc. Thus, receiving circuit "looking" at the signal at time t_2 would "see" signal energy from pulse B only. Distorted pulses at bottom, however, have tails which do not pass through zero at sampling times. In this case, receiver at time t_2 will see energy from both pulse A and pulse B and might register a false signal level. Such distortion must be reduced to a minimum to achieve high data transmission rates.

AUTOMATIC EQUALIZER MINIMIZES DATA DISTORTION

A communication signal arriving at its destination is never a perfect replica of the original. There is always some distortion, and if this distortion exceeds acceptable limits, it must be reduced by a process known as equalization.

Equalization increases the rate at which data pulses can be transmitted. Ideally, the equalization should also adapt rapidly to changing transmission characteristics, which are caused by varying temperature, humidity and other factors. Otherwise, distortion may cause receiving circuits to register false values for the data pulses (see above drawing).

To solve this problem a new data equalizer promising increased data rates—up to a threefold increase on voice-telephone channels—has been devised at Bell Telephone Laboratories. With this new equalizer, test pulses cause a series of adjustments to be made in the settings of equalizer attenuators. These adjustments, impossible to perform rapidly by hand, are performed automatically by control circuitry. As a result, the equalizer quickly reaches a condition of minimum data distortion. Later, when the transmission characteristics of the line change, the equalizer automatically adapts to the changes by making additional adjustments that keep the attenuators at their optimum settings.

Experimental automatic data equalizer devised at Bell Laboratories. Control section consists of the circuit packages; the package being inspected is one of 12 attenuators, the settings of which determine the degree of distortion-correction of the equalizer.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

"Steepest descent" minimization

The new data equalizer was made possible by a discovery by R. W. Lucky at Bell Laboratories that a technique of minimizing mathematical functions is applicable to the problem of data equalization. Known as the "steepest descent" technique, it is analogous to a hiker desiring to climb down a hill in minimum time. In the equalizer application, it was shown that the steepest descent technique results in the true minimum, and not a local or relative minimum of the function. It was also shown that an equalizer based on this technique could be built with simple control circuitry. An experimental model of the equalizer (see photo) uses a 12-tap delay line in a transversal filter with an adjustable attenuator at each tap. The control circuitry extracts information from each test pulse, and for each pulse adjusts all attenuators by small steps, each step calculated to reduce distortion in the direction toward the minimum.

THE AUTHORS

ALFRED CHAMPAGNAT ("Protein from Petroleum") is manager of the Société Internationale de Recherche BP, a French adjunct of the British Petroleum Company. Born in Marseilles and educated at the University of Strasbourg, he spent many years with the Société Française des Pétroles BP, first as a research chemist and then as research director. His interest in the biosynthesis of proteins from petroleum and in problems of protein deficiency began several years ago with an investigation his research group made of the possibilities of petroleum microbiology. In 1964 Champagnat was made a chevalier of the French Legion of Honor.

C. ANDREW L. BASSETT ("Electrical Effects in Bone") is associate professor of orthopedic surgery at the Columbia University College of Physicians and Surgeons and attending orthopedic surgeon at Presbyterian Hospital in New York. Bassett, who was born in Maryland, took his medical training at Columbia-Presbyterian; he received an M.D. there in 1948 and a D.Sc. in medicine in 1955. His various professional activities outside his teaching and hospital work include service this year as chairman of the Committee on Scientific Investigation of the American Academy of Orthopedic Surgery. Bassett has been given awards for work in spinal-cord regeneration and in peripheral nerve-graft preservation and transplantation. Early in September he began a year's leave of absence, which he is spending at the Strangeways Laboratories in Cambridge, England, "probing some ultrastructural aspects of bone formation in tissue culture."

EDWARD ANDERS ("Diamonds in Meteorites") is professor of chemistry at the University of Chicago. He was born in Latvia and educated at the University of Munich and Columbia University, obtaining master's and doctor's degrees from Columbia in 1951 and 1954 respectively. In 1955, after teaching for a year at the University of Illinois, he joined the Enrico Fermi Institute for Nuclear Studies at the University of Chicago. "I spent the first seven years of my scientific career on a wholly unsuccessful search for technetium (element 43) in nature," he writes. "After this wild-goose chase I began to work on meteorites. Among my present research interests I should list in first place mass spectrometric studies of the organic compounds in carbonaceous chondrites. Next I would list our work on chemical fractionations in meteorites. A third area is the identification of meteorite parent bodies."

A. J. AYER ("Chance") is Wykeham Professor of Logic at the University of Oxford. He has held that position since 1959; for 13 years before going to Oxford he was Grote Professor of the Philosophy of Mind and Logic at the University of London. A graduate of Eton and Oxford, Ayer began his teaching career in 1932 as a lecturer in philosophy at Christ Church College of the University of Oxford. During World War II he enlisted in the Welsh Guards, receiving an officer's commission the same year. Among the books that Ayer has written are *Language, Truth and Logic, The Foundations of Empirical Knowledge, The Problem of Knowledge* and *The Concept of a Person.*

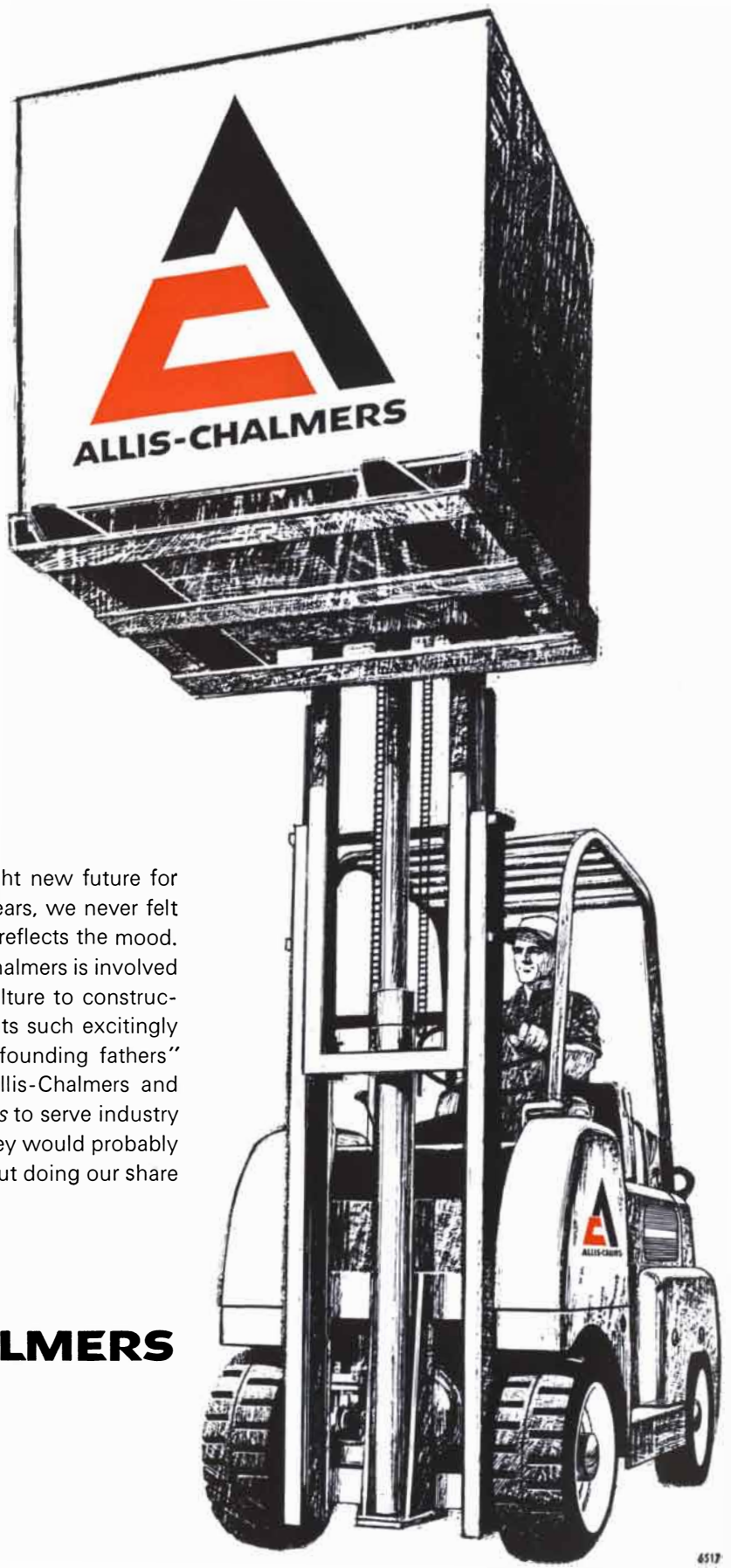
R. D. PARKS ("Quantum Effects in Superconductors") is associate professor of physics and Alfred P. Sloan research fellow at the University of Rochester. A graduate of Kansas State University, he obtained master's and doctor's degrees from Stanford University in 1958 and 1961 respectively. He joined the faculty of the University of Rochester in 1962 after a year as a National Science Foundation postdoctoral research fellow at Stanford.

EDWARD P. LANNING ("Early Man in Peru") is associate professor of anthropology at Columbia University. He did fieldwork along the entire Peruvian coast from 1956 to 1958, excavating a number of sites and presenting the results as a doctoral thesis at the University of California at Berkeley, where he received a Ph.D. in 1960. For the next year he was senior museum anthropologist at the Robert H. Lowie Museum of Anthropology of the University of California. From 1961 to 1963 he was lecturer in archaeology at the University of San Marcos in Peru while doing the research he describes in his current article. Lanning writes: "Perhaps the most interesting aspect of the research to me was the discovery that the archaeologist can gather kinds of evidence on the history of climate that are not available to the climatologist, as well as contributing a precision of dating that is usually impossible to other disciplines dealing with the history of climate."

LOWELL E. HOKIN and MABEL R. HOKIN ("The Chemistry of Cell Membranes") are respectively professor of physiological chemistry and research associate at the University of Wisconsin. Lowell Hokin, a native of Illinois, studied medicine at the University of Louisville and the University of Illinois, obtaining an M.D. in 1948. After his internship he studied biochemistry at the University of Sheffield, receiving a Ph.D. in 1952. Mabel Hokin, a native of Sheffield, received a Ph.D. in physiology at the University of Sheffield in 1952. Since their marriage the authors have worked as a research team, first at McGill University and, since 1957, at the University of Wisconsin. Lowell Hokin is currently studying the chemical characteristics of the protein component of the sodium-transport lipoprotein and continuing to investigate some aspects of the role of phospholipids in transport. Mabel Hokin is continuing her studies of the function of phospholipids in transport-triggering mechanisms.

RICHARD J. ANDREW ("The Origins of Facial Expressions") is an investigator in the School of Biological Studies at the University of Sussex, having recently taken up his duties there after six years in the department of biology at Yale University. Born in England, Andrew took honors in zoology at the University of Cambridge. "My approach to behavior," he writes, "has therefore been that of a biologist rather than a psychologist." Andrew's early research interest was in the courtship, fighting and preflight displays of several kinds of closely related small birds. "My interest in primate displays was first aroused by wondering why human beings laugh and how laughter evolved —and finding that philosophical and psychological answers, which abound, all seem very unsatisfactory. Of late I have become convinced that it is in the development of behavior that the real clues concerning the true nature of the motivational structure underlying aggression, sex, fear and so on will be found."

ANATOL RAPOPORT, who in this issue reviews *The Natural History of Aggression,* a symposium edited by J. D. Carthy and F. J. Ebling, is professor of mathematical biology at the University of Michigan.



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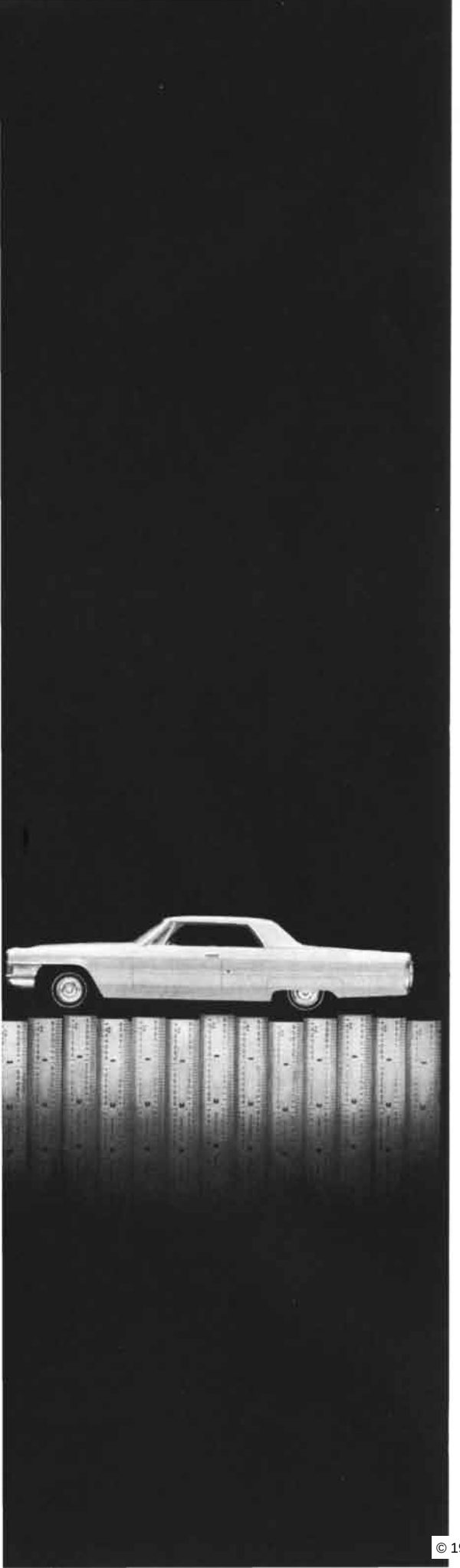

One of a series briefly describing GM's research in depth

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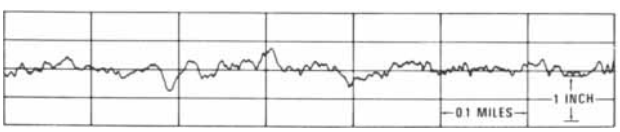
In addition to aiding state highway departments, the Profilometer has also helped airport authorities quickly determine runway surface conditions and is being used to measure profiles of railroad rails. It can show irregularities having wavelengths up to 1,000 feet.

Research travels many roads . . . sometimes building the tools to gather information, analyze it, and suggest its uses. It all helps General Motors to find a better way.

General Motors Research Laboratories

Warren, Michigan



GM Research oscillograph trace of concrete highway profile.

Established 1845 SCIENTIFIC AMERICAN October 1965 Volume 213 Number 4

Protein from Petroleum

Certain microorganisms thrive on hydrocarbons. In growing they synthesize proteins rich in amino acids that plant foods lack. Protein from petroleum may help solve the world's food problem

by Alfred Champagnat

The title of this article may suggest science fiction, but it is a statement of fact. In a pilot plant at Lavera in France substantial amounts of high-grade protein are being produced by microorganisms growing on a diet consisting mainly of petroleum hydrocarbons. This unusual concept, tested by a research team of the Société Française des Pétroles BP, has proved so successful that there is good reason to believe petroleum will become an important food resource for the earth's growing population.

Why turn to petroleum to solve the food problem? After all, the store of petroleum in the earth is limited, and at the rate it is being burned for fuel it will be used up before many more decades have passed. Before considering the ways and means of producing food from petroleum, it is well to survey the rationale of such a program and see if it would be worthwhile.

To begin with, it is now quite clear that the world nutrition problem is essentially a question of proteins. At present roughly half of the people in the world have a poorly balanced diet that retards normal growth. The main lack in their diet is animal protein; they live principally on grains and tubers, which may supply enough calories but which contain inferior proteins lacking certain essential amino acids that are present only in animal proteins. The peoples of Europe and North America, with a favorable climate and the development of animal husbandry, have usually been able to enjoy a diet based largely on meat and fish. Not so the inhabitants of the earth's tropical regions. As the undernourished countries grow in population, the inadequacy of their diet, and particularly the protein deficiency, is becoming more pronounced. Kwashiorkor, the protein-deficiency disease, is on the increase among the children of these countries. In general, it can be said that protein poverty is one of the principal factors holding back the underdeveloped areas.

By the year 2000 the present world population of three billion is expected to have more than doubled, to above six billion. The protein problem then will be worldwide. In 1958 the total world production of animal proteins was about 20 million tons, of which 14 million were consumed by the less than one billion population of the advanced countries and six million by the two billion inhabitants of the underdeveloped countries. In the year 2000, to feed properly the expected world population of some 6.3 billion the production of high-quality protein should be trebled, to at least 60 million tons per year.

How is this to be done? The British economist Colin G. Clark has estimated that with intensive cultivation of all the earth's arable land 10 billion persons could be fed adequately. Such a program would call, however, for prodigies of effort, investment and political discipline that seem unrealistic to expect in the short time that remains before the world food problem will become desperate.

Let us examine our present conventional sources of protein. The primary source is plant life, which by utilizing the carbon in the carbon dioxide of the air manufactures organic substances, including proteins. Now, a nonruminant mammal such as man can assimilate proteins directly from plants by eating grains and certain roots and tubers. The proteins of the most common vegetable foods, however, lack some of the essential amino acids. The cereal grains, for example, generally lack the amino acid lysine, and frequently they are poor in methionine and tryptophan. It is the missing amino acids that make most vegetable proteins inferior in quality from the standpoint of human nutrition. Of the 20-odd amino acids required by the human body, man must get 11 in his food because his body does not synthesize them. There are, of course, plant products that contain well-balanced proteins with most of the essential amino acids; among these are soybeans, chick-peas and meal made from the oilseeds of certain plants. These are important potential staples for protein nutrition, but they have not yet been developed into major foods.

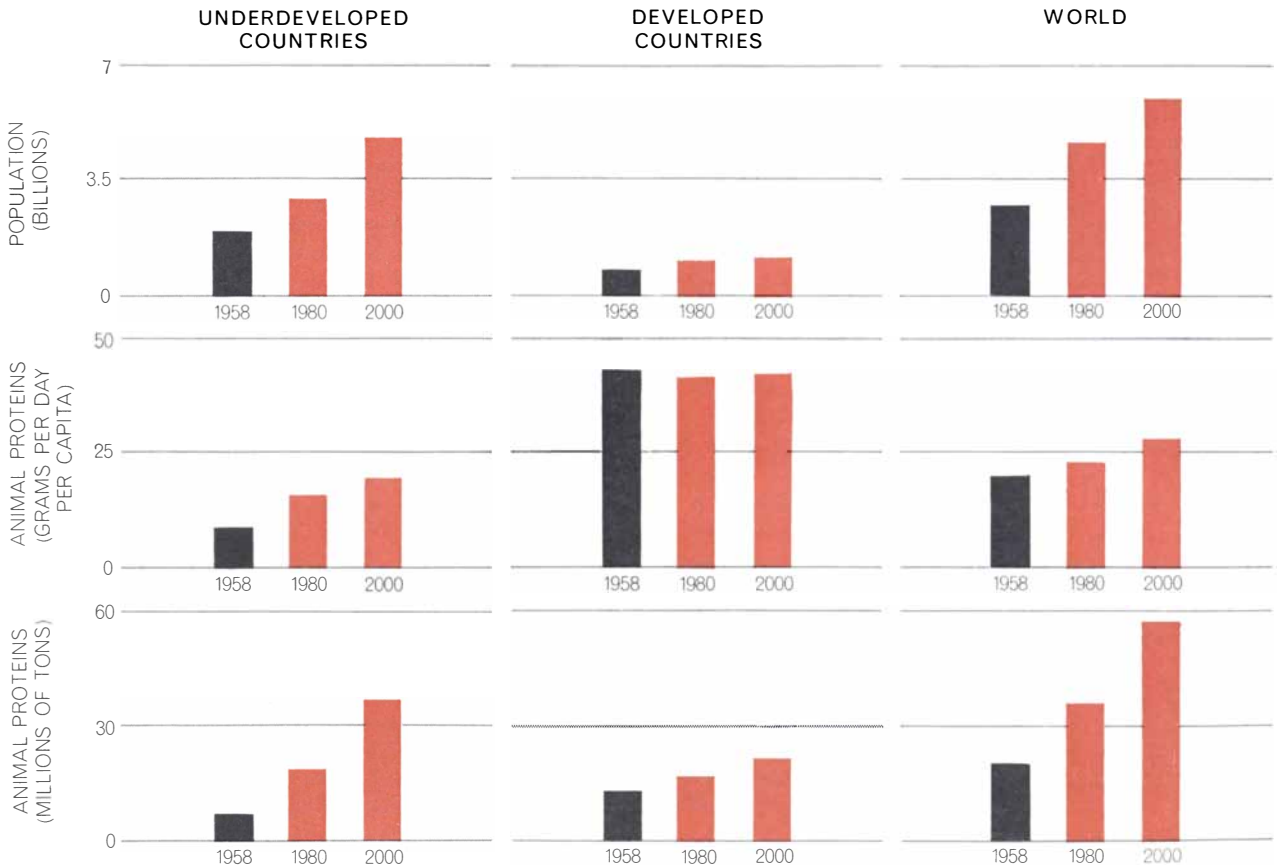
The meat of ruminant animals, which with the help of intestinal bacteria convert vegetable food into proteins con-

taining a full stock of amino acids, is man's main present means of maintaining a balanced diet. As the human population multiplies, however, there is a growing recognition that raising animals is a highly expensive way of producing food: pound for pound it is much less efficient than raising plant crops. It takes seven calories of plant carbohydrate to produce one calorie of beef protein, and even in the more efficient procedure of chicken raising the yield is one calorie of chicken protein from 3.5 calories of feed. In the Tropics the problem of producing meat protein is compounded by tropical insects and diseases. At best, even in favorable climates, the production of protein through agriculture must be accounted costly when one considers the required investment of labor, machinery and fertilizers and the uncertainties of weather, soil and water supply.

Some of the same considerations apply when we contemplate increasing our harvest of protein from the ocean. The rich fishing grounds of the cold seas could be exploited more fully than they have been, but the fish life is not unlimited. In the warm seas of the Tropics, where phosphorus, nitrogen and plankton are less abundant, the fish life is sparser. Some authors have proposed harvesting the protein-rich plankton of the oceans for human food, but it must be remembered that if the plankton is removed on a large scale, the fish population will decline. The cultivation of fish in freshwater lakes and ponds, providing the fish with food rations in much the same way that land is enriched with fertilizer, is a promising method of producing more protein in the Tropics, but it certainly could not completely fill the gap for the populations of these regions.

In the long run man will have to organize all the earth's land and sea resources for the most efficient production of living organic matter, because that is the only way he can assure himself of a continuing, expanding food supply. It will take a great deal of time and progress in technology and social wisdom, however, for mankind to establish any such comprehensive control on a worldwide basis. In the meantime, what about the immediate future—the next 35 years, during which the world population seems bound to double? It seems as if the human race must find some quick means of multiplying its supply of protein. This is the necessary and sufficient reason for giving serious thought to the possibilities in petroleum—the large store of organic material that mankind has, so to speak, in the bank.

The production of protein by microorganisms from carbon-containing compounds is not, of course, a new idea. For many years the growing of yeast for animal food and even human foods has been an appreciable, although small, industry. The yeast fungi are grown on carbohydrates (most commonly molasses), and they produce vitamins and pro-



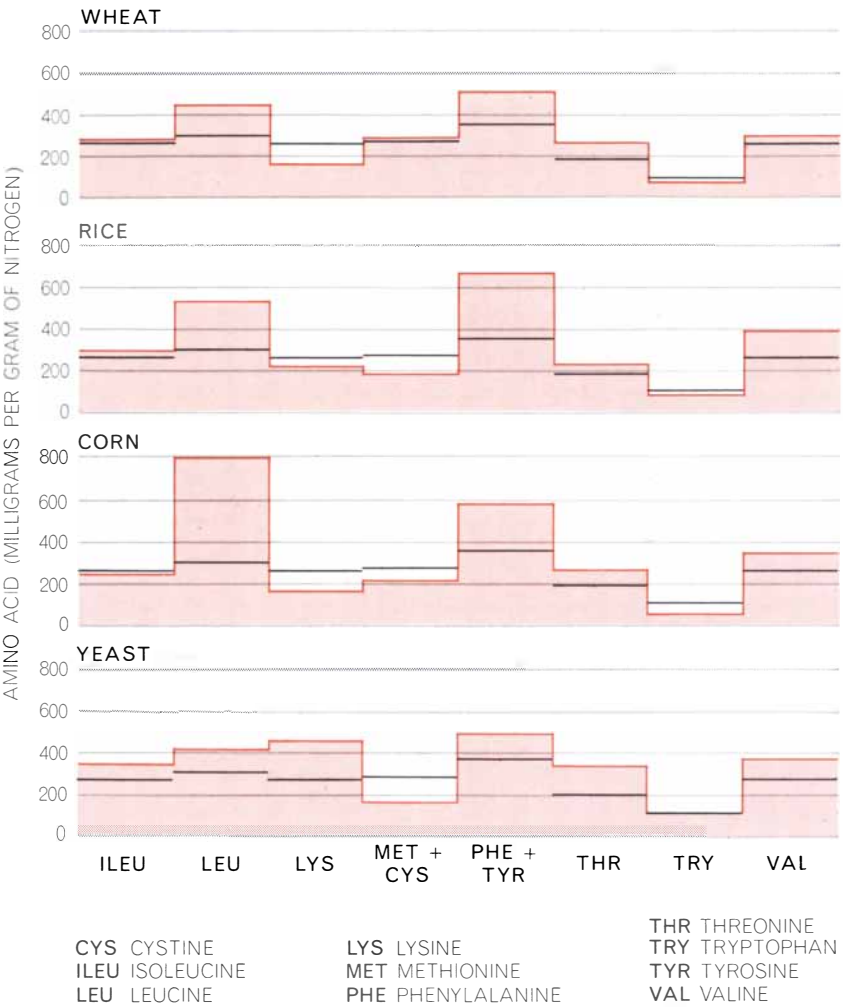
WORLD NUTRITION PROBLEM is essentially a question of proteins. The top row of charts shows the trend of the world's population. The next row shows the amount of animal protein available per capita in 1958 and the goals considered desirable for 1980 and 2000. The bottom row shows the supply of animal protein required to meet these goals for the increasing population. The underdeveloped countries include those in the Far East, Near East, Africa and Latin America (excluding the countries in the Río de la Plata region). The developed countries include those in Europe, North America, Oceania (Australia and New Zealand) and the Río de la Plata region. Data for the graphs were drawn from the report "The World's Hunger and Future Needs in Food Supplies," prepared in 1961 by P. V. Sukhatme for the Food and Agriculture Organization (FAO) of the United Nations.

teins comparable to those of animals. This method of protein production has a number of attractive aspects. The organisms grow very rapidly, doubling their weight every five hours or less, which is several thousand times faster than farm animals synthesize protein. The microorganisms can be grown in tanks: they require no soil or sunlight or rainfall or assistance from human labor. The fungi also afford the special but important advantage that, because they belong to the plant kingdom, their "meat" (that is, protein) is not outlawed by religious or traditional taboos anywhere in the world.

A question arose: Could hydrocarbons, instead of carbohydrates, serve as the basic medium for the growth of microorganisms? It has been known for a long time that molds commonly grow on petroleum. They are found in the bottom of oil tanks, in refinery equipment, in oil-impregnated soils and even under the tarry surfaces of roads. In 1952 a German biologist, Felix Just, reported that in the laboratory he had succeeded in growing yeast on pure hydrocarbons of the paraffinic family (distinguished by their waxy content).

It was this report that launched our research group at Lavera on its project. We enlisted financial and other support from the British Petroleum Company and obtained expert counsel on the fundamental microbiological problems from the bacteriologist Jacques Senez of the Centre National de Recherche Scientifique. We set out to explore the techniques that would be necessary for the large-scale cultivation of yeasts on petroleum fractions.

Let us consider first the basic mechanics of the process. When yeast is grown on sugar, the medium for the fermentation usually consists of the carbohydrate in a water solution, soluble mineral and organic compounds containing nitrogen, phosphorus and potassium and additions of certain trace elements and growth vitamins. A flow of air is bubbled through the liquid to provide oxygen and maintain a good mixture of the materials throughout the fermentation vessel. The temperature and acidity also are carefully controlled for maximal reproduction of the yeast cells. Eventually the cells are harvested by centrifuging or filtering them out of the medium. The cells are then washed and dried and thus become available in solid form as a food stock containing about 50 percent protein. With flavoring added, this stock has been used as a basis for a variety of prepared foods, from soups to ice cream.



PROTEIN-DEFICIENT GRAINS make up a large part of the diet of roughly half the people in the world. The grains supply enough calories but contain inferior proteins that lack certain essential amino acids present only in animal proteins. The three cereal grains shown here, for example, generally lack the amino acid lysine, and frequently they are poor in methionine and tryptophan as well. In each case the daily amino acid requirement of an average human (formulated by the FAO Committee on Protein Requirement) is indicated by the black line. The amino acid content of a typical yeast is shown at bottom.

The growing of yeasts on petroleum instead of sugar introduces certain complications. One is the insolubility of hydrocarbons in water. The oily hydrocarbons can be mixed in the watery medium only in suspension, and to keep the oil droplets well dispersed throughout the medium it must be stirred strongly. This is relatively easy to do in a laboratory apparatus but presents formidable difficulties on a large scale.

A second major difficulty is the greater need for oxygen. Whereas sugar molecules contain about 50 percent oxygen, hydrocarbon molecules have no oxygen. Consequently the oxygen supply delivered to the organisms by the bubbling of air through the medium must be at least three times greater on a hydrocarbon substrate than on a sugary substrate. Moreover, because this results in a threefold increase in the cells' output of heat, a cooling system is required to control the temperature of the medium. These disadvantages are offset, however, by an important advantage. Because all of the oxygen required by the cells is supplied by the air, their consumption of the carbon-supplying substrate is correspondingly reduced. The rate of production of yeast is twice as great on hydrocarbons as it is on sugar: under favorable conditions a kilogram of hydrocarbon will produce a kilogram of yeast, whereas a kilogram of sugar yields only half a kilogram of yeast.

Along with studies of adaptations of the culture process that had to be made to grow yeasts on petroleum went a search for the most suitable raw ma-

terials. The Lavera laboratory set out to determine if microorganisms could be grown efficiently on fractions from crude petroleum rather than on the pure, synthesized hydrocarbons that Just had used. It was known that some aromatic hydrocarbons were hostile to the growth of microorganisms; hence a mixture containing the various classes of hydrocarbons (paraffins, isoparaffins, naphthenes and aromatics) was ruled out. As had been expected, the most productive fractions proved to be paraffinic ones, which include kerosene and certain gas oils. At present the favored fraction on which the yeasts are being grown is a gas oil, a fraction between kerosene and lubricating oil.

This particular food for microorganisms yields an important dividend beyond protein. The organisms feed mainly on the wax in the paraffinic oil; thus they deparaffinize the oil. With the wax removed, the oil is more fluid and becomes usable as No. 2 fuel oil, suitable for diesel engines and domestic heating. This by-product would be especially significant in Europe, where No. 2 fuel oil is in great demand for these uses. (In the U.S. most of the heavily paraffinic gas oil is converted into gasoline.)

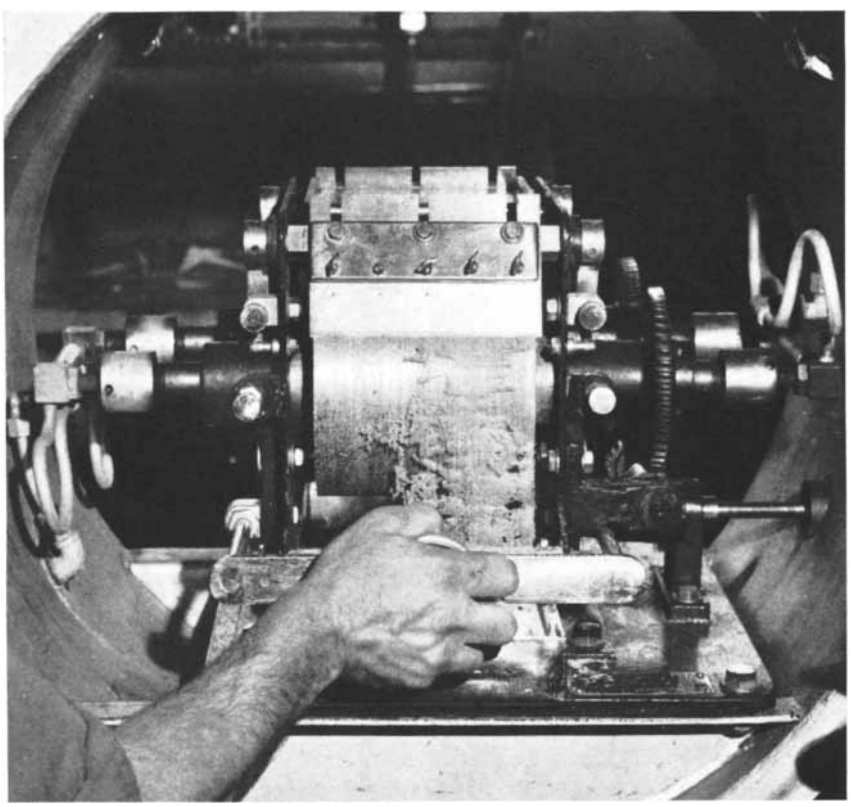
In addition to the selection of the best food for the organisms there is the matter of selection of the organisms themselves. As in wine making, some yeasts are better than others when it comes to the making of proteins. No doubt it will be found that for each petroleum fraction there is a species of microorganism most efficient in turning it into protein. The species of organisms also differ in the kinds of proteins they produce. By selection and genetic breeding of the organisms it will be possible to make proteins to order. Our laboratory has studied only a few species of organisms so far, but it is already clear that the range of possibilities for creating proteins is wide—much wider than through agriculture or animal husbandry. For further inspiration there is the example of what has been achieved within the past decade by research on the abilities of microorganisms to produce antibiotics and other drugs in almost endless variety.

On a sizable pilot scale the development center at Lavera is now producing protein from petroleum around the clock, improving the process as the work proceeds. The medium is similar to that for the growing of yeasts on sugar, except that oil is substituted for the sugar. Nitrogen is added to the medium in the form of ammonia salts; phosphorus and potassium are supplied in the form of general fertilizers; trace elements and growth vitamins are added. The product of the organisms feeding on this medium is more than 50 percent protein.

The proteins produced by the fermentation of petroleum differ in no essential respect from those made by any other natural process—whether by beef cattle, poultry, fishes, plants or yeasts growing on sugar. They are rich in *B* vitamins and in a well-balanced variety of amino acids; in particular, they have a high content of lysine, which makes them a useful complement to the lysine-poor cereals. In experiments on rats it has been found that they have a digestibility of 85 to 90 percent. There is no reason to believe there is anything bizarre about the biological matter that has been grown on petroleum. Because of the strangeness of the source, however, a long and costly program of tests is being carried out on experimental animals to determine the nutritional value of the petroleum-based protein and its freedom from toxicity. Once it has passed these tests, we plan to incorporate it in food products designed for commercial production and to submit these products to international organizations for them to test.

When the yeasts grown on petroleum have been dried and purified, the concentrate is in the form of a powder or whitish flakes with no pronounced odor or taste; it has less odor than yeast grown on sugar. Like concentrated protein from meat, fish, yeast or soybeans, the protein from petroleum can be transformed into many different foods. Its first use is likely to be in feeds for livestock. We have prepared a number of sophisticated versions of the food, ranging from tasty meat concentrates to fermented fish sauces of strong aroma that are highly esteemed in Asia. We have also considered ways of packaging it as a pure, concentrated protein, like powdered skim milk.

The British Petroleum Company, which operates in several countries, has now thrown its full weight behind the development of petroleum fermentation as a food resource. In addition to the semi-industrial development center at Lavera it is supporting a laboratory for fundamental research in the Paris area and a research and development center at Grangemouth in Scotland. The company has also acquired land in Nigeria for an experimental farm where it hopes to examine, under tropical field condi-



DRIED YEAST CELLS are shown emerging from the laboratory drum dryer at the Lavera refinery of the Société Française des Pétroles BP in France. The yeasts were grown on petroleum and have been dried and purified; the concentrate, in the form of pale flakes with no pronounced odor or taste, contains more than 50 percent high-quality protein.

tions, the effects of rearing animals on diets consisting primarily of locally grown feed supplemented by protein from petroleum. British Petroleum is not alone; large organizations in several other countries are now taking up the same field of research.

It is easy to illustrate the potential importance of this movement with a few figures. We have calculated that with an outlay of some 40 million tons of petroleum (a small fraction of the 1.25 billion tons of crude oil produced in 1962) 20 million tons of pure protein could be produced per year. This alone would double the present total annual production of protein. For comparison with other possible sources, consider sea fishing, which also might produce a quick increase in yield. At present it brings in some 40 million tons of fish a year, representing about six million tons of pure protein. By tremendous efforts the catch might be increased to a maximum of 100 million tons of fish a year (any larger take would endanger the reproduction of fish), which amounts to 15 million tons of protein. This does not come up to the potential yield from petroleum, and it would be a more difficult effort.

Petroleum is relatively cheap and stable in price. It can easily be transported anywhere in the world by tankers. There are more than 700 refineries, distributed in almost all countries, that could set up units that would produce protein and at the same time deparaffinize crude oil. The oil industry is highly organized and flexible, as it has shown in turning quickly to the manufacture of a great variety of chemical products from petroleum. The production of protein would widen the diversification of the industry and thus further strengthen its foundations. The industry therefore has strong reason to take an active interest in this new development.

One must recognize that this fossil liquid petroleum will not last forever. Yet food is certainly as important to man as fuel. To burn all or nearly all of the petroleum and fail to allot even a small portion of it to producing food, if that proves practicable, would be a serious mistake. Protein from petroleum, although not a total or permanent solution to the world food problem, nevertheless deserves our most serious efforts because of its high promise and the great needs of the near future. It will require a large investment of research and money, but the studies so far indicate that it would pay high returns to mankind in health and peace.

LARGE PILOT PLANT at the Lavera refinery is now producing protein from petroleum on a scale permitting engineering studies. With an outlay of some 40 million tons of petroleum the world's refineries could produce 20 million tons of pure protein per year.

ELECTRICAL EFFECTS IN BONE

When bone is mechanically deformed, it generates a small electric current. This suggests that the changes that occur in living bone when it is under mechanical stress are mediated by electric fields

by C. Andrew L. Bassett

The most striking characteristics of bone are its solidity and strength. In performing operations on bone the surgeon saws it, drills it, places screws in it, nails it and otherwise treats it like wood. Before the advent of materials such as steel and plastics men used it in a wide variety of tools, weapons and art objects, largely because it was hard and durable. Yet in the living organism bone has another feature that seems the opposite of durability: it is remarkably changeable.

Living bone adapts its structure to changes in mechanical load; like the proverbial twig, as bone is bent, so grows the bone. This property of bone was concisely stated in 1892 by the German anatomist Julius Wolff. In its modern form Wolff's law can be phrased: "The form of the bone being given, the bone elements place or displace themselves in the direction of the functional pressure and increase or decrease their mass to reflect the amount of functional pressure." In other words, bone not only alters its orientation in response to mechanical stress but also gains or loses substance.

How is bone able to achieve these changes? Its capacity is perhaps even more impressive in view of the fact that it is largely composed of hard mineral crystals. Here, however, is a clue to a possible mechanism by which bone shapes itself. Many crystals are piezoelectric; that is, when they are subjected to mechanical stress, they produce an electric current. It seems likely that such electrical effects play an important role in the behavior of bone—even though it now appears that the mineral crystals of bone may be only secondarily involved in them.

Let us consider the behavior of bone in a little more detail. In a child any long bone, such as the thighbone, can be fractured completely and yet can heal even when the two sides of the break are not precisely aligned [*see illustration on page 20*]. After the fracture a mass of reparative tissue grows across the break, setting the stage for osteogenesis: the formation of new bone. The reparative tissue—which may contain cartilage, connective tissue and fibers of new bone—is called a callus. The new bone is formed by specialized cells known as osteoblasts; at the same time it is trimmed and shaped by bone-destroying cells, the osteoclasts. (A third type of cell—the osteocyte—is found inside the bone in the tiny spaces called lacunae, where it serves to maintain normal bone tissue.) After the healed bone has been in use for a year or two, the site of the fracture will probably be impossible to distinguish on an X-ray plate.

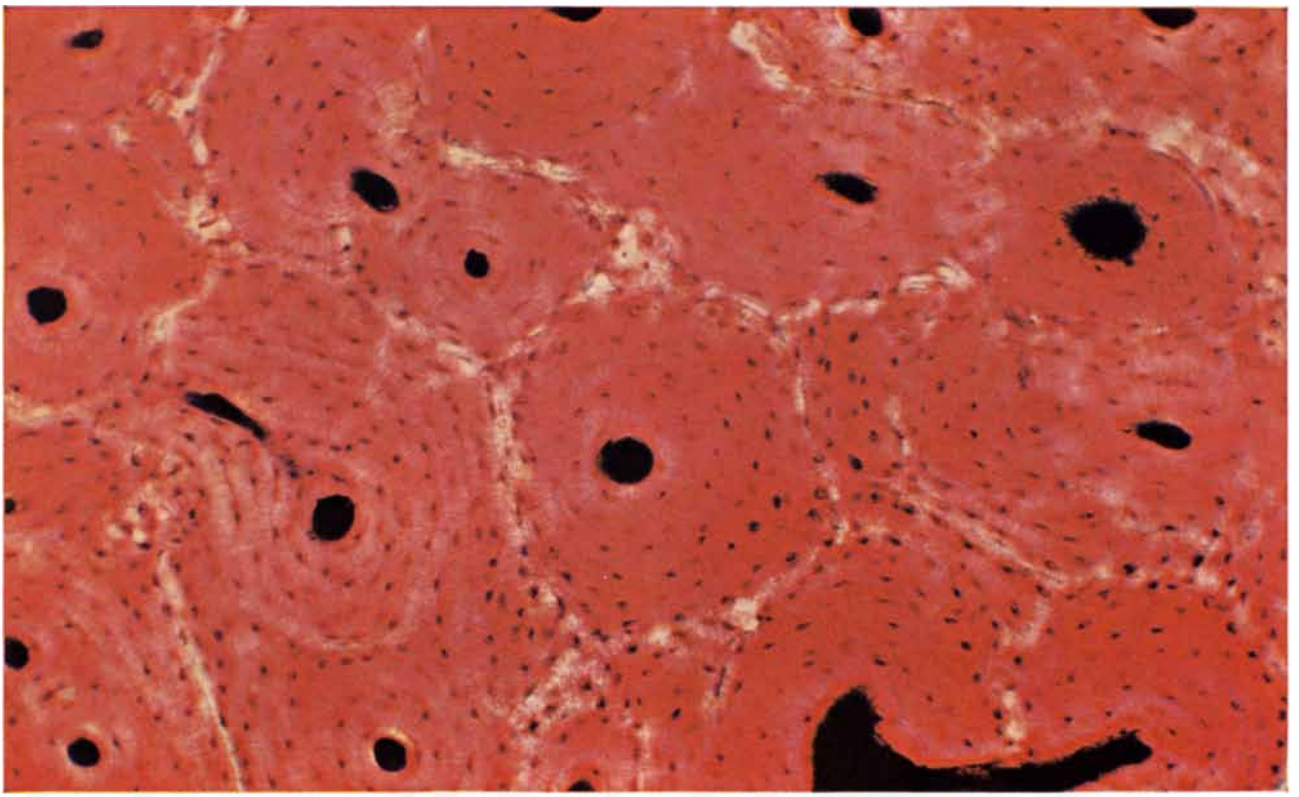
The question is: What is the nature of the stimulus that induces the formation and destruction of bone exactly where these processes are needed? Or, to put the question in a more general form, what is the signal for change in bone? A number of laboratories have undertaken to look into the matter, among them our Orthopedic Research Laboratories at the Columbia University College of Physicians and Surgeons and those of E. Fukada at the Institute of Physical and Chemical Research in Tokyo and I. Yasuda at the Second Red Cross Hospital in Kyoto.

A concept basic to such investigations, as it is to many other investigations in modern biology, is that of negative-feedback control. Here the negative-feedback control system consists of (1) a signal from the environment, (2) a transducer to convert the signal into a meaningful biological response and (3) the response itself. Usually the system also involves (4) a second transducer to translate the response into (5) activity that will correct or stop the original environmental signal. This circular feedback system is said to be negative when it damps the effect of an excessive signal, as opposed to enhancing the effect.

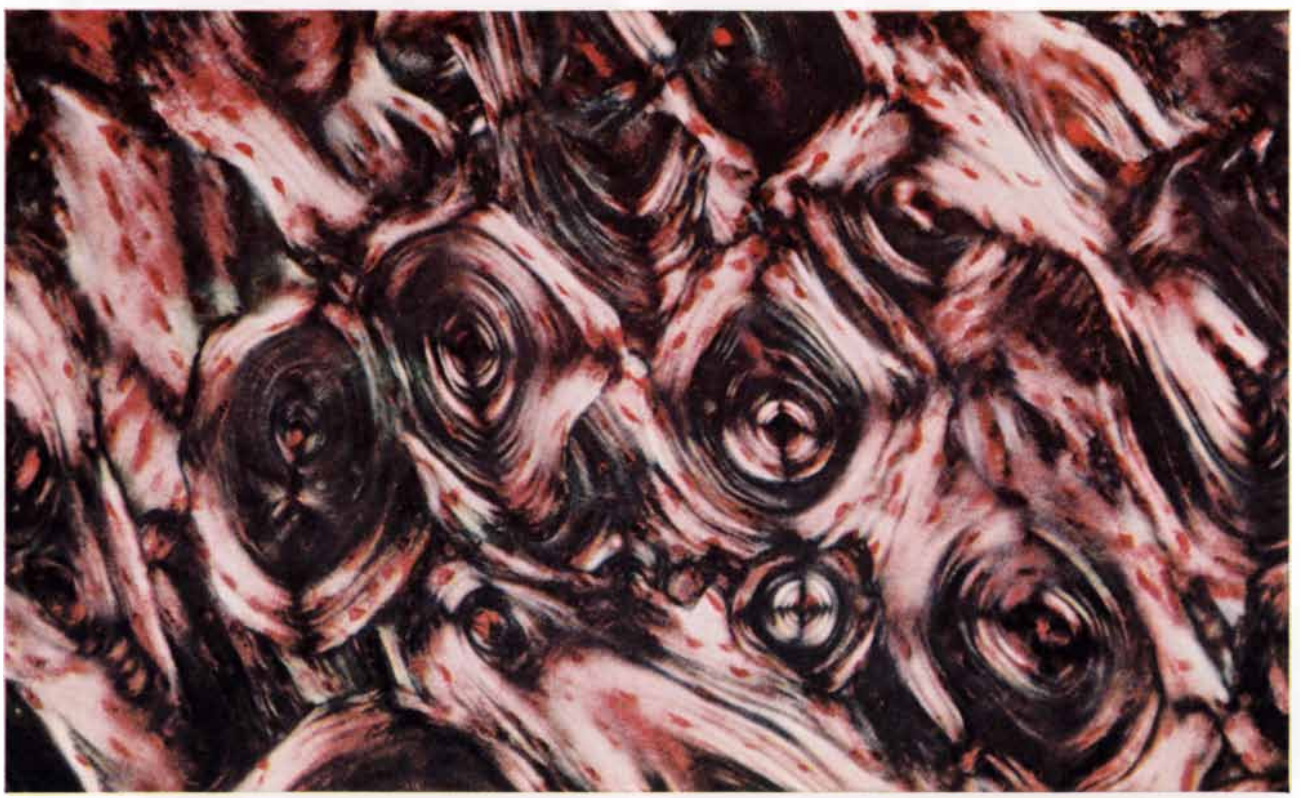
It had been known that a negative-feedback system appears to control another activity of bone: supplying calcium to the blood. Franklin C. McLean of the University of Chicago had pointed out that when the level of calcium ions in the blood plasma fell below a certain point, this gave rise to a signal for the parathyroid glands to secrete greater quantities of hormone. The parathyroid hormone activates the osteoclasts to destroy a certain amount of bone and release calcium to the plasma, thereby eliminating the cause of the original signal [see "Bone," by Frank'in C. McLean; SCIENTIFIC AMERICAN, February, 1955].

It now appears that the phenomenon summarized by Wolff's law also represents a negative-feedback system. In this case the environmental signal and the final correcting response were known: a deforming force results in a change in bone structure needed to resist the force. The mechanisms by which one led to the other, however, seemed quite mysterious until the transducers were identified.

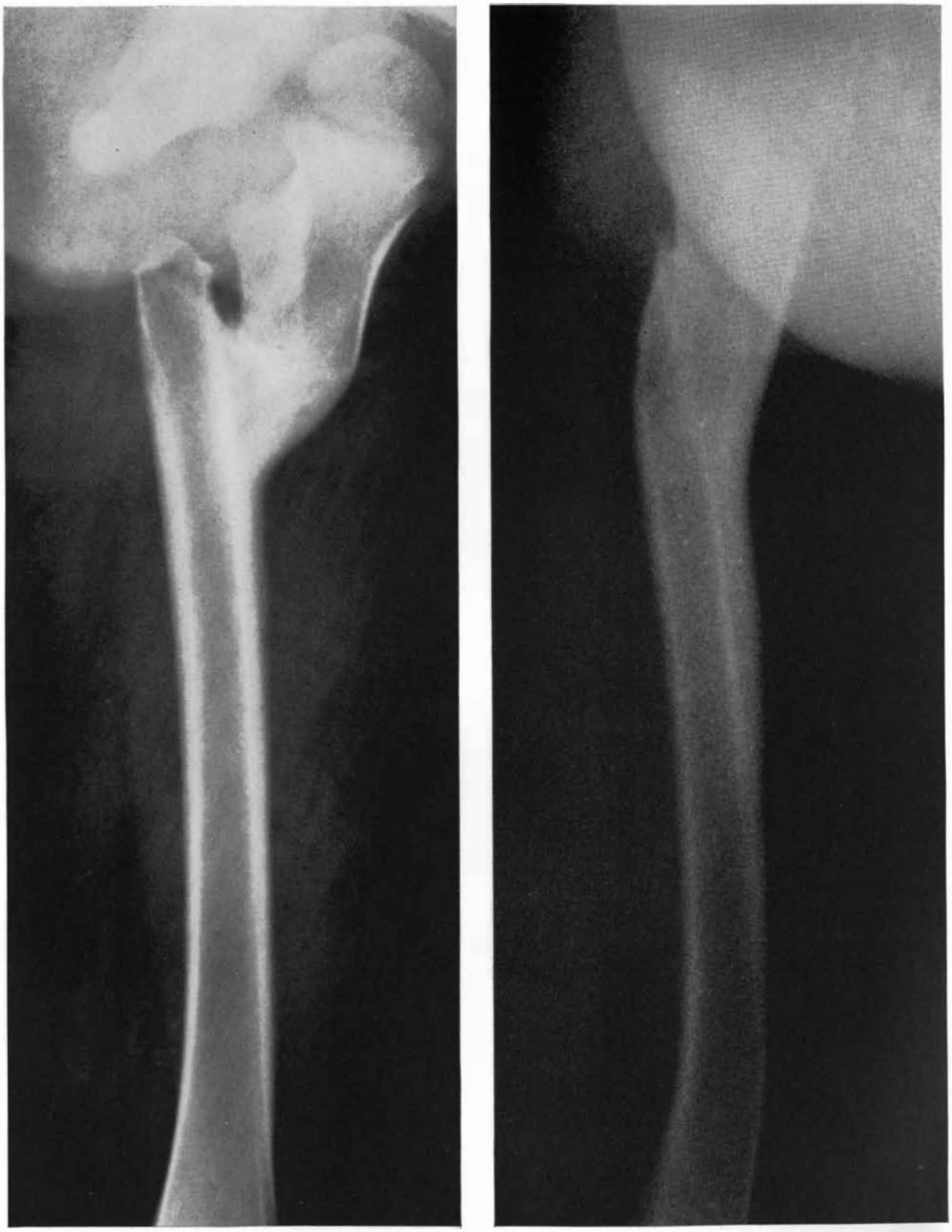
The mineral crystals of bone are embedded in an organic matrix; they account for roughly two-thirds of bone by weight. The structure of the bone crystals closely resembles the structure of fluorapatite, a mineral found in rocks. In the bone crystal, however, the positions of the fluorine atoms in fluorapatite are occupied by hydroxyl groups (OH); accordingly the bone crystal is called hydroxyapatite. The organic ma-



PHOTOMICROGRAPH OF BONE enlarges some 80 diameters the roughly cylindrical units called osteons. Here the osteons are seen end on; each one is represented by a yellowish outline. The large dark spot in the middle of each unit is a canal traversed by blood vessels. The smaller dark spots arrayed in circles around the canals are cavities that contain the specialized cells of bone.



POLARIZED-LIGHT MICROGRAPH made at the same magnification indicates that bone is highly crystalline. This is shown by the rings around each canal and also by the dark cross pattern, which is characteristic of certain crystals viewed in polarized light. The rings are made up of crystals of the mineral hydroxyapatite embedded in a crystalline matrix of the protein collagen. The rings are alternately light and dark because the orientation of the crystalline material changes, alternately passing light and blocking it.



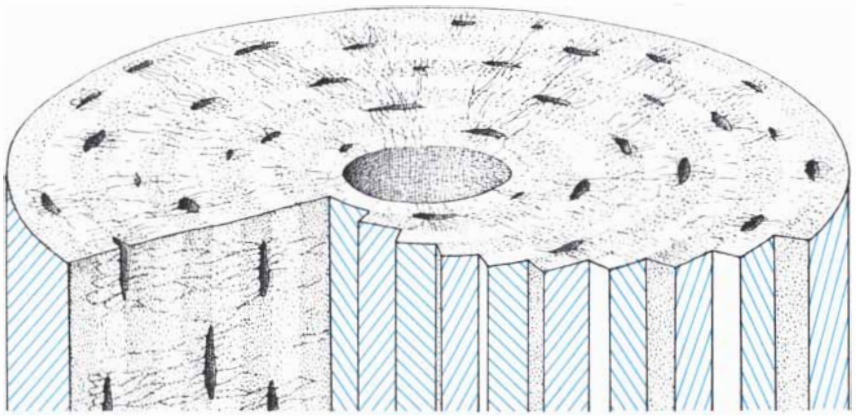
CHANGEABILITY OF BONE is exemplified by the healing of a fracture, depicted in these two X-ray plates. Fractured thighbone of a two-year-old boy appears in plate at left, made in August, 1963, four months after the break occurred. Upper part of bone had been broken off toward right; it was not set, although a cast was placed around the leg to prevent further damage. Callus of connective tissue, cartilage and new bone extends across the fracture gap. In plate at right, made in October, 1964, a year and a half after fracture occurred, the bone has healed and the site of fracture is scarcely apparent. Special cells are trimming the rough edges, and the healed bone is gaining a mass and orientation appropriate to resist normal stresses to which it is exposed.

trix in which the hydroxyapatite is deposited is composed mainly of the protein collagen, and it too is in a crystalline state: its long-chain helical molecules lie side by side in an array that forms a regular hexagonal pattern when it is viewed from the end. Thus bone is made up of at least two crystalline systems.

The fact that bone is so highly crystalline suggested to several investigators that it might be piezoelectric—that it generates an electric current when it is mechanically deformed. In 1953 Yasuda demonstrated that it was indeed piezoelectric; similar observations were made in our laboratory in 1956 and 1957. Later in 1957 Fukada and Yasuda (who were then working together) published a detailed study of bone's piezoelectric properties. They also discovered that dry collagen would develop an electric charge when it was stressed or bent, and this led them to propose that the source of piezoelectricity in bone was collagen.

No evidence has yet been advanced to suggest that hydroxyapatite crystals are primarily involved in the piezoelectricity of bone. There are, however, at least two other systems in bone that may give rise to electric charge. First, the organic matrix in which hydroxyapatite crystals are embedded contains not only collagen but also hyaluronic acid, a long-chain molecule of the class known as mucopolysaccharides; recently it has been found that when certain members of this class of molecules are deformed, a separation of the electric charges in them occurs. Second, work by R. O. Becker at Syracuse University suggests that the interface between collagen and hydroxyapatite is a semiconductor junction of the *p-n* type: a junction between two crystals in which the relative availability of electrons is different. Crystalline collagen tends to have an abundance of electrons; crystals of hydroxyapatite, a lack of them. Bending a *p-n* junction between the two would generate an electric potential. In short, electricity theoretically could be generated in bone in any or all of three ways: a stress on or bending of collagen fibers, a bending of mucopolysaccharide molecules and a stress on the collagen-hydroxyapatite interface.

Becker, together with C. H. Bachman, has analyzed the electrical properties of bone in an effort to determine which of the mechanisms actually operates. His studies indicate that these properties are not simple enough to be explained by the usual piezoelectric effects encountered in one kind of crystal. His view is disputed by, among others, Morris H. Shamos and Leroy S. Lavine of New York University, who believe that collagen alone is probably the main source of stress-induced potentials. The investigations in our laboratory, however, tend to substantiate Becker's view in that they suggest that the source of electricity is a multitude of tiny junctions between collagen and hydroxyapatite.



STRUCTURE OF OSTEON is shown in three dimensions. In the middle is the canal that contains the blood vessels; it is connected by much finer canals to cavities that contain osteocytes, the cells that maintain the bone tissue. The concentric layers are composed mainly of hydroxyapatite embedded in variously oriented fibers of collagen (*colored lines*).

In a series of experiments designed to clarify the matter, strips of bone of various widths were gradually deformed while the electricity generated in response was measured. At a certain point, known as the plastic range, the bone will not completely spring back from its deformed position. We observed that, until the plastic range was reached, bone strips of all widths generated electricity roughly in direct proportion to the amount of deformation they had undergone. Thereafter the rate of increase of electrical output dropped—most markedly in the thicker specimens, which reach the plastic range after significantly less deformation.

When we chemically removed the hydroxyapatite from the specimens, however, the amount of electricity generated by deformation was much less. This suggests that collagen alone cannot be the main source of electric charge. In this connection it is useful to regard bone as a two-phase material, one phase being hydroxyapatite and the other collagen. (Actually bone is a three-phase material if we include the substances that appear to cement the hydroxyapatite crystals together.) In such materials, a nonbiological example of which is fiber glass, a strong but brittle substance is embedded in a weaker but more flexible one; the combined substances have a greater strength for their weight than either substance alone [see "Two-Phase Materials," by Games Slayter; SCIENTIFIC AMERICAN, January, 1962]. In bone, of course, hydroxyapatite is the stronger material and collagen the more flexible, and bone's modulus of elasticity lies between that of the mineral and that of the protein. Accordingly collagen probably cannot be flexed enough to give rise to the observed potentials. A significant stress would be likely to develop, however, at the junction between the collagen and the hydroxyapatite when bone is deformed.

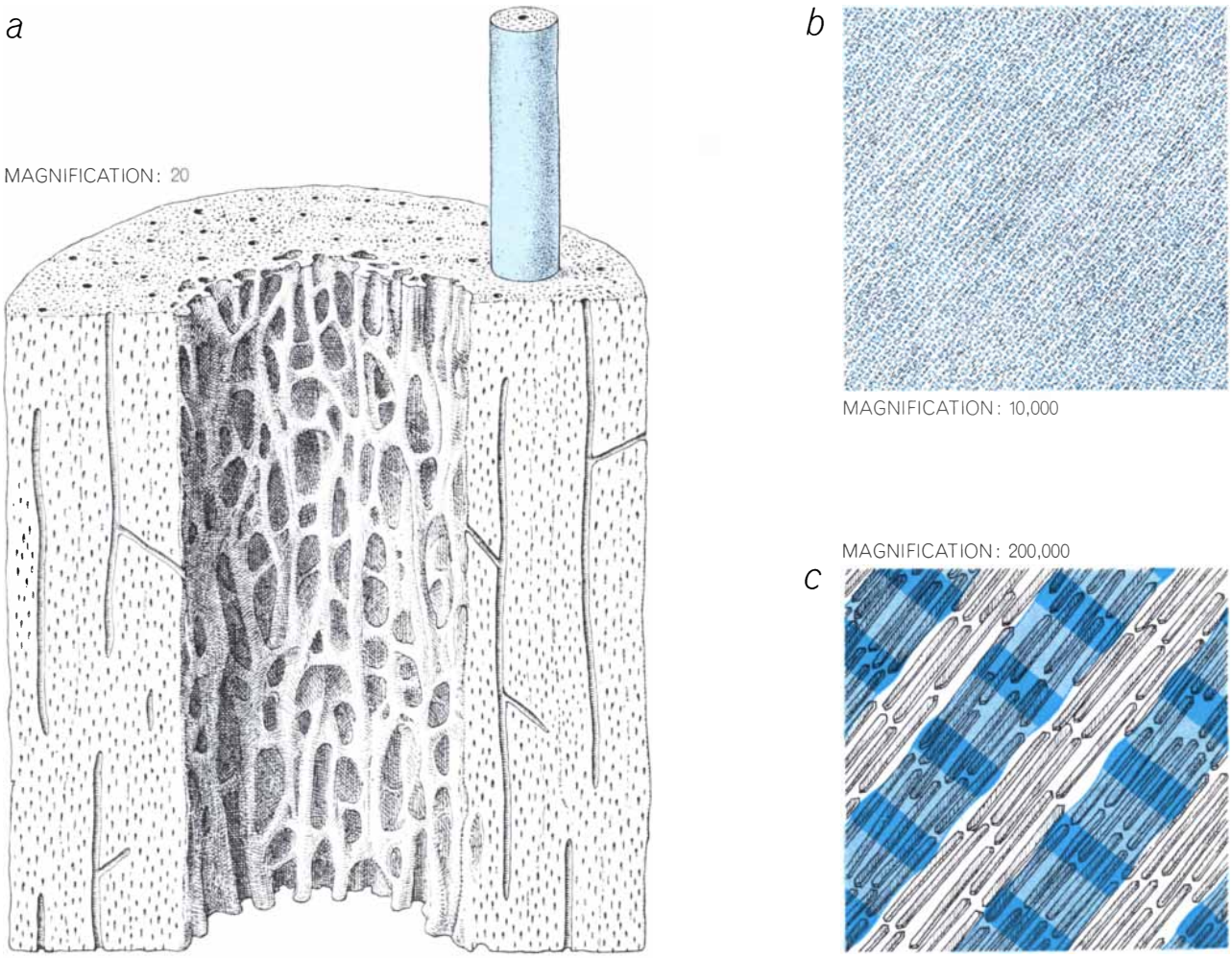
Now let us consider the role electrical effects are likely to play in the feedback system that regulates change in bone. Four of the five elements in our generalized negative-feedback system can be identified. The initial environmental signal is a deforming force. It activates a large number of piezoelectric transducers, which generate electric potentials proportional to the applied force. In order to change the architecture of bone so that in time it can resist the force, the potentials must stimulate a second transducer mechanism. If the original force is compressive, that is, if it is directed along the axis of an existing bone structure, the change may involve only an increase in mass; if the force acts at an angle to the axis, giving rise to shear, the modifications will involve realignment. In 1962 Becker and I postulated that electric potentials not only affect the activity of bone cells directly but also influence the pattern in which large molecules such as collagen come to-

gether. Our investigations since then have generally confirmed these postulates. We have found that formation of bone in living animals can be influenced by weak, artificially induced direct currents and that the alignment of collagen molecules in solution outside the body can be influenced in much the same way.

When drops of collagen in solution were subjected in our laboratory to a current comparable to that calculated for living bone responding to deformation, in from one to five minutes a band of collagen formed at right angles to the direction of the electric field (and near the negative electrode). The collagen molecules in this band could be made to form fibers by the addition of salts of the appropriate ionic concentration. Once the fibers had formed they remained stationary after the current had been shut off; they were found to be parallel to one another and perpendicular to the lines of force of the electric field in which they had developed. The bands formed more rapidly when we used an intermittent current rather than a continuous one. Although it was not surprising that the electrically charged molecules of collagen migrated in an electric field, it was most interesting that they moved so rapidly and formed such an orderly pattern under the influence of currents as small as those we were using.

On the basis of these results in vitro it seemed possible that molecules with a net electric charge could migrate and align themselves under the influence of currents of the magnitude found in vivo. Such behavior may have far-reaching biological significance. If the long-chain molecules manufactured by living cells are piezoelectric, they may possess an automatic control mechanism when they are outside the cell. When they are deformed, they may produce an electric charge that can selectively attract, repel or align charged molecules and ions in their immediate vicinity.

Here the precise nature of the electrical signal produced in living bone is of central importance. For example, if the signal is a wave with positive and negative phases of equal amplitude, an electrically charged molecule would merely move back and forth as the wave passed. There is an exception to this statement: if, as one phase of the wave passes, the molecule is chemically linked with another, it may not be able to move back when the second phase passes. On the other hand, the signal may not be a wave with two equal and opposite phases; one of the two phases may be dominant or there may be only one phase. In that case it would not be necessary to invoke the exception in



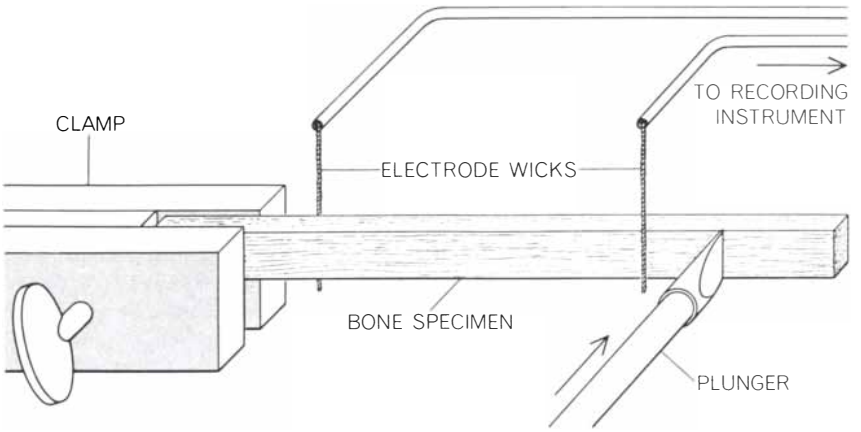
FINE STRUCTURE OF BONE is illustrated on three levels of magnification. At left (*a*) is a section of bone depicted without its inner marrow. Haversian canals oriented on the long axis are the main branches of the circulatory network in bone. One osteon is shown extending from bone to emphasize its unit structure. At top right (*b*) section of osteon is shown to consist of collagen fibers (*color*) and hydroxyapatite crystals (*gray*). At bottom right (*c*) juxtaposition of collagen and hydroxyapatite is rendered in detail.

order to show that the signal can move a molecule in one direction to form bone.

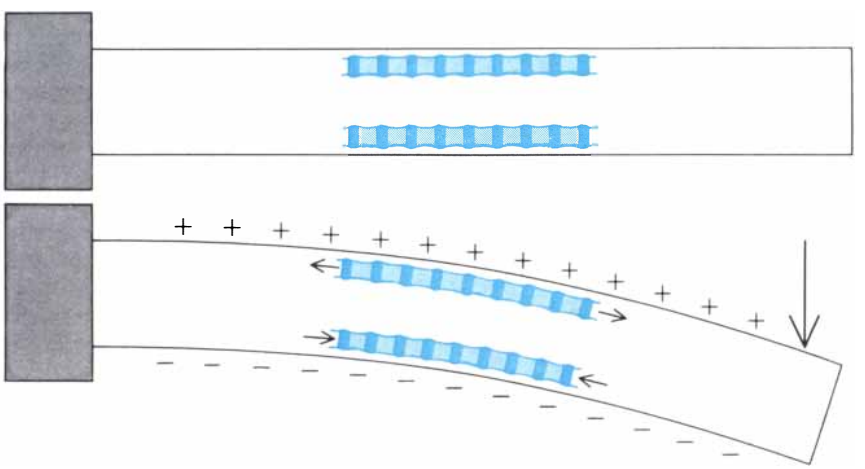
What must the electrical signal actually achieve to build bone? The fundamental structural unit of bone is the osteon: a cylinder with a central canal traversed by blood vessels. Around the canal are concentric lamellae, or thin layers, of hydroxyapatite within and around highly organized bundles of collagen fibers; the lamellae are penetrated by smaller canals [*see illustration on opposite page*]. The regularity of this repeating unit implies that its construction involves a very precise control system. Such a system must obviously do more than simply influence molecules to move into position; it must also organize the activity of such cells as the osteoblasts and the osteoclasts. This idea is not farfetched; there appears to be a close relation between the electrical characteristics of the living cell and its external electrical environment.

In our laboratory we have shown that the nature of the electrical pulses obtained from bone varies significantly with the rate, magnitude and duration of its deformation. The orientation of osteons, lamellae, canals or mineralized bundles of collagen with respect to the direction of the applied force can also affect the character of the pulse. Moreover, it is likely that the relative degree of mineralization or hydration in various parts of the bone will affect its electrical behavior. The actual generators of electricity are so small that it is not possible to measure their individual activity; the pulses recorded in these studies must therefore represent the summation of billions of individual events occurring within the specimen under investigation.

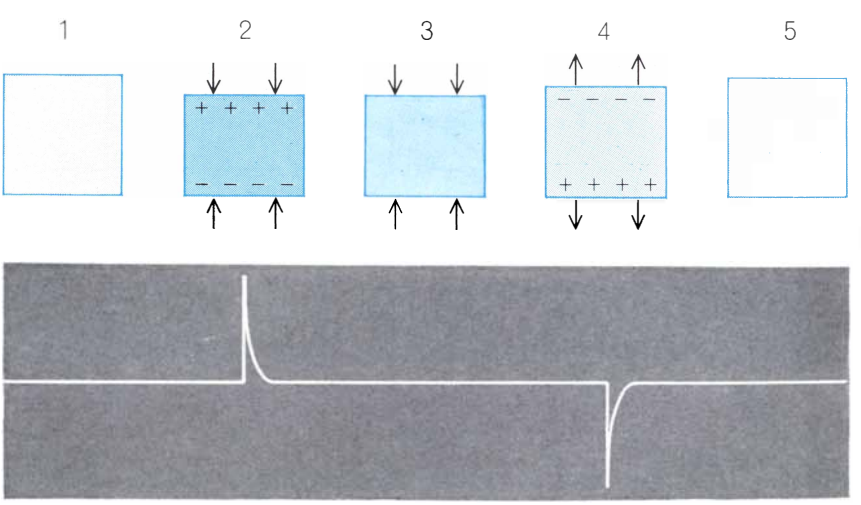
Even though these considerations influence such characteristics of the electrical signal as magnitude and decay time, we have found in our laboratory a uniformity in one feature of the pulses obtained by deformation: their polarity. Regions under compression, which tend to be concave, are usually negatively charged; regions under tension, which tend to be convex, are usually positively charged. It is known both clinically and experimentally that a concave region of bone will be built up and a convex region torn down. This observation led to the prediction that electrically negative regions are associated with the building up of bone and the positive regions with its tearing down. With this prediction in mind we



DEFORMATION EXPERIMENT to measure the current produced when bone is bent is diagrammed. A thin, moist strip of bone is placed in an insulated clamp at one end and bent by an insulated plunger at the other. Two electrode wicks are attached to bone, one on each side, an inch apart. Current generated in the bone is recorded on an oscilloscope.



POSSIBLE EFFECT OF DEFORMATION on bone is depicted. In strip at top collagen fibers are represented in normal alignment. Strip at bottom is bent so that collagen fibers stretch on one side, are compressed on the other. As a result shear stresses develop between adjacent strands of collagen and opposite charges build up on opposite sides of the unit.



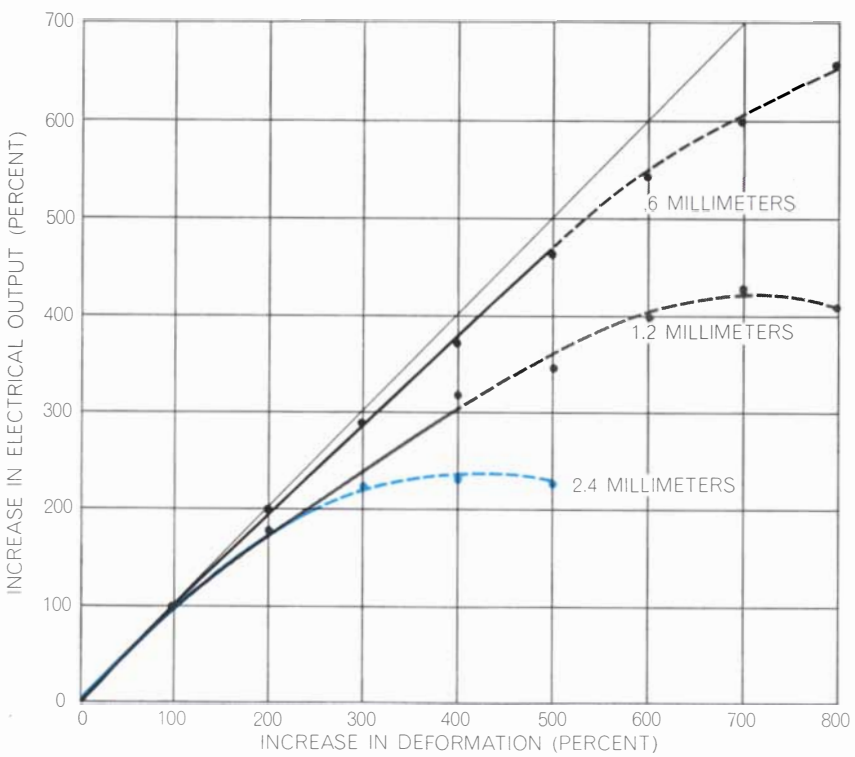
PIEZOELECTRIC EFFECT caused by stress on bone is illustrated. Each rectangle represents a piezoelectric crystal which, when compressed (*2*), produces an electric charge that tends to "leak" (*3*). When stress is removed (*4*), crystal resumes its original shape and charge is reversed. These steps give rise to oscilloscope trace of shape shown at bottom.

observed the effects on living bone of artificially induced continuous direct currents. We implanted a small, painless battery pack in the thigh of each of several dogs so that two platinum electrodes projected into the marrow space. For purposes of experimental control we inserted inactive batteries in some of the dogs; these dogs developed small masses of new bone at the point where each inactive electrode projected into the marrow space. In those dogs carrying active batteries a larger mass of new bone formed only around the negative electrode. Similar results have been reported by Yasuda in Japan. Surprisingly in our experiments there was no erosion of bone around the positive electrode.

How can this partial refutation of our prediction be explained? The dogs were active after the electrodes were inserted, and strong stresses were probably developed in the region of both holes in the bone. Such concentrations of stress might have caused an increased electrical activity of the bone itself that overrode the local effects of the artificial positive electrode. On the other hand, a simple connection between positive charge and bone destruction may not exist. The experiment nonetheless demonstrated that bone growth is enhanced in regions of negative charge. The effect of artificial continuous currents did not, however, establish a conclusive link between stress-induced potentials and the activity of bone cells.

All the evidence so far indicates that the intermittent electrical signals measured on bone surfaces have two phases; that is, the signal first has one polarity and then the other. It thus seems reasonable to ask: Can a cell discriminate between the positive and the negative phases of the signal and act accordingly? Or does it react to the greater or lesser electrical activity produced by greater or lesser stress? Although concrete answers are not yet available, one can put forward a working hypothesis. Such a hypothesis should explain how bone cells can simultaneously specialize as osteoblasts and osteoclasts even when they are only a few thousandths of a millimeter apart.

Generally speaking, to detect a difference in electric potential means to measure the relative availability of electrons or certain ions. One might put forward the hypothesis that bone destruction results when electrical activity is diminished or nonexistent. This line of reasoning can lead in any one of several directions, but here I shall take up only one of them.

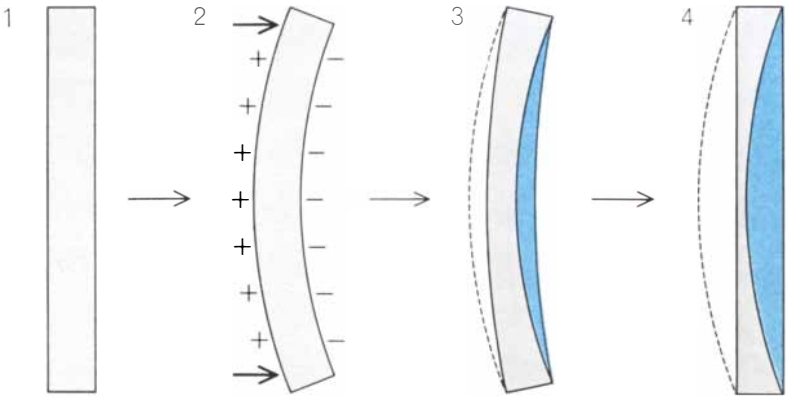


ELECTRICITY GENERATED BY DEFORMATION of bone is graphed by plotting increase of electrical output in percent (*vertical axis*) against the increase in deformation in percent (*horizontal axis*) for bone strips of several widths. The straight line represents an ideal linear, or one-to-one, relation. Broken lines indicate that bone strips have been deformed to the plastic range, that is, the point beyond which the strips will not spring back to normal. In this range there occurs a diminution in the rate of increase of electrical output.

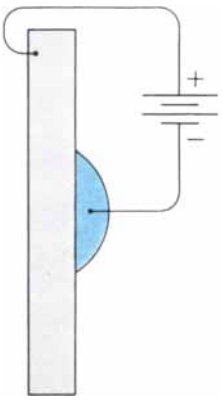
Tissues are nourished by the movement of fluids, and bone is no exception. Obviously, however, the movement of fluids through bone presents difficulties. Bone is almost incompressible under normal loads, so that fluids cannot be "massaged" back and forth. The tiny canals in the bone through which the fluids must move account for only 3 percent of the area in a cross section of bone tissue. Furthermore, many of the bone-tending osteocytes are situated at relatively large distances from blood vessels. In view of the inefficiency of this supply line, it might be expected that most osteocytes would be on the brink of starvation for nutrients or oxygen. Under the stimulus of minor, normal deformations of the skeleton, however, an alternating electrical signal could act as a pump to promote the ebb and flow of ions and charged molecules. If such a pumping system exists (and if it does not, the nutrition of bone cells remains a mystery), it may depend on the junctions between hydroxyapatite and collagen. There are approximately a billion of these possible generators of electricity around each osteocyte.

If the generation of current were increased above normal levels in a given region, cells in the region might be activated to produce bone and stabilize the region. Conversely, diminished electrical activity might result in the death of osteocytes by starvation. It should be emphasized that the potentials generated by stress apparently do not require the presence of living cells. Bone in the body that has lost its living tissue may continue to generate potentials if it is intermittently deformed; thus it may escape destruction by osteoclasts.

If osteoclasts appear in regions where the electrical signal is diminished or absent, it should be possible to find a common electrical link between the factors known to cause bone destruction. For example, although it has been said that bone destruction requires a local increase in the number of blood vessels, it is not clear whether the increase occurs before the destruction or after it. If, as one investigator believes, the increase in the volume and rate of blood flow called active hyperemia causes



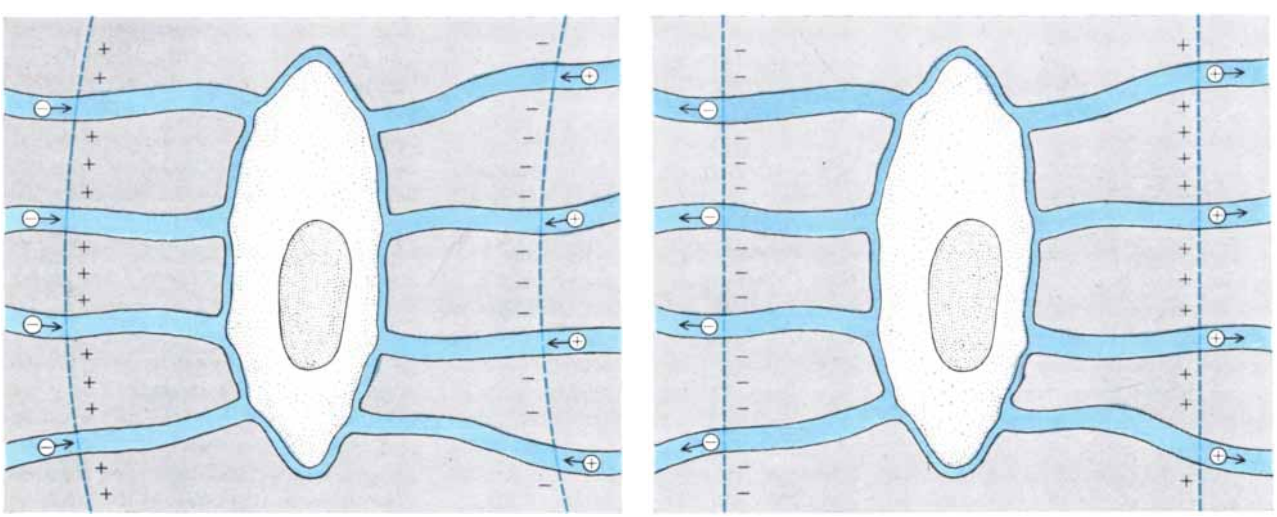
NEGATIVE CHARGE AND BONE GROWTH were associated by observing normal response of bone to deformation. When negative charge builds up on concave side (*2*), new bone forms to fill it and old bone is removed from convex side (*3 and 4*) to straighten it.



ELECTRIC CURRENT applied to undeformed bone caused growth in area of negative charge, no loss in area of positive.

bone destruction, it might do so by providing more oxygen molecules to act as electron "sinks." Furthermore, arteries are positively charged on the outside and negatively charged on the inside. It is therefore conceivable that the erosion of bone by the abnormal enlargement of an artery may be electrically mediated, because the larger vessel could conduct away more electrons. Finally, a recent observation that the hormone of the parathyroid glands influences the electrical conductivity of cell membranes lends support to the idea that bone destruction is controlled by electrical effects.

It appears more than likely, then, that changes in the orientation and mass of bone are controlled by stress-generated electric potentials, even though it is far from clear exactly how these potentials achieve their effects. If this is true, electrical effects are obviously important not only in situations such as a broken bone but also in many other pathological conditions affecting the skeleton. Bone may function as an exquisitely sensitive piezoelectric gauge, responding to the slightest jar or deformation. There are several sources of normal mechanical input for the skeleton. The cardiovascular system provides a continual deforming force by means of hydrostatic pressures in the blood vessels, and possibly through the recoil of the heart. Gravity causes direct distortion of the skeleton, and it stimulates the tone of the muscles that must stabilize the body against gravity; the intermittent pull of these muscles also deforms the bone. When a voluntary muscle action—such as a stride—is taken, additional mechanical stress is developed; with each step the shock from the impact is transmitted throughout the skeletal system. These sources of mechanical stress have some relevance to space travel. The astronaut who is subjected to prolonged periods of weightlessness loses the major portion of mechanical stimuli to bone, and must therefore expect his bones to lose mass at a more rapid rate than those of a person who must remain in bed or otherwise inactive for a protracted period. On the other hand, cardiovascular activity may suffice to provide the minimal stress that produces a threshold electric signal in bone—the signal that keeps the feedback system in operation.



ELECTRICAL EFFECT ON BONE CELLS is outlined according to a hypothesis suggested by the author. A slight stress on bone (*left*) might generate an electric charge that attracts or repels electrically charged molecules and ions in the blood plasma bathing the osteocytes. Removal of stress (*right*) would cause reversal of charge and an opposite effect on charged particles. This electrical pumping system would explain how nutrients in the blood are passed through tiny canals to osteocytes deep within the bone.

DIAMONDS IN METEORITES

Many of the meteoritic fragments around Arizona's Meteor Crater (and also three other meteorites) contain bits of diamond. These inclusions provide information on the history of the meteorites

by Edward Anders

On the morning of September 10, 1886, the peasants of the Siberian village of Novo-Urei were working in their fields when suddenly the hazy sky was brilliantly illuminated. A few seconds later several deafening blasts were heard and two fireballs were seen to fall from the sky. When the peasants had recovered from their fright, they searched their fields and finally discovered two heavy black stones. The larger one, weighing about four pounds, was subsequently acquired by the Mineralogical Institute in St. Petersburg. The smaller one was broken up and eaten by the superstitious peasants.

It is not known what effect the meteorite had on the peasants' teeth, but when the mineralogists M. Yerofeyev and P. Lachinov tried to grind up a piece of the stone for analysis, their agate mortar was deeply gouged. They soon established the cause. The meteorite contained nearly 1 percent of diamond.

At once a search was begun for other diamond-bearing meteorites. Today, 79 years after the Siberian discovery, only four well-authenticated examples are known. One is of course the Novo-Urei meteorite, and two others are similar stony meteorites that had fallen several years earlier in India. One, a six-pound stone, turned up among the possessions of the Raja of Goalpara; the other, a 10-ounce stone, fell near the village of Dyalpur. These three diamond-bearing meteorites are known as ureilites.

The fourth example—an iron meteorite rather than a stony one—is the most spectacular of all. It is represented by thousands of fragments of the meteorite that produced Meteor Crater in northern Arizona. This crater, about 1,300 meters (4,250 feet) across and 175 meters (575 feet) deep, was evidently created by an iron-nickel object with a mass of close to two million tons. Because of the extremely sparse rainfall in Arizona, the crater has suffered very little erosion in the 20,000 years or so since its creation [*see illustration on opposite page*]. Following the custom that meteorites are named for the post office nearest the site of discovery, the object that produced Meteor Crater is known as the Canyon Diablo meteorite.

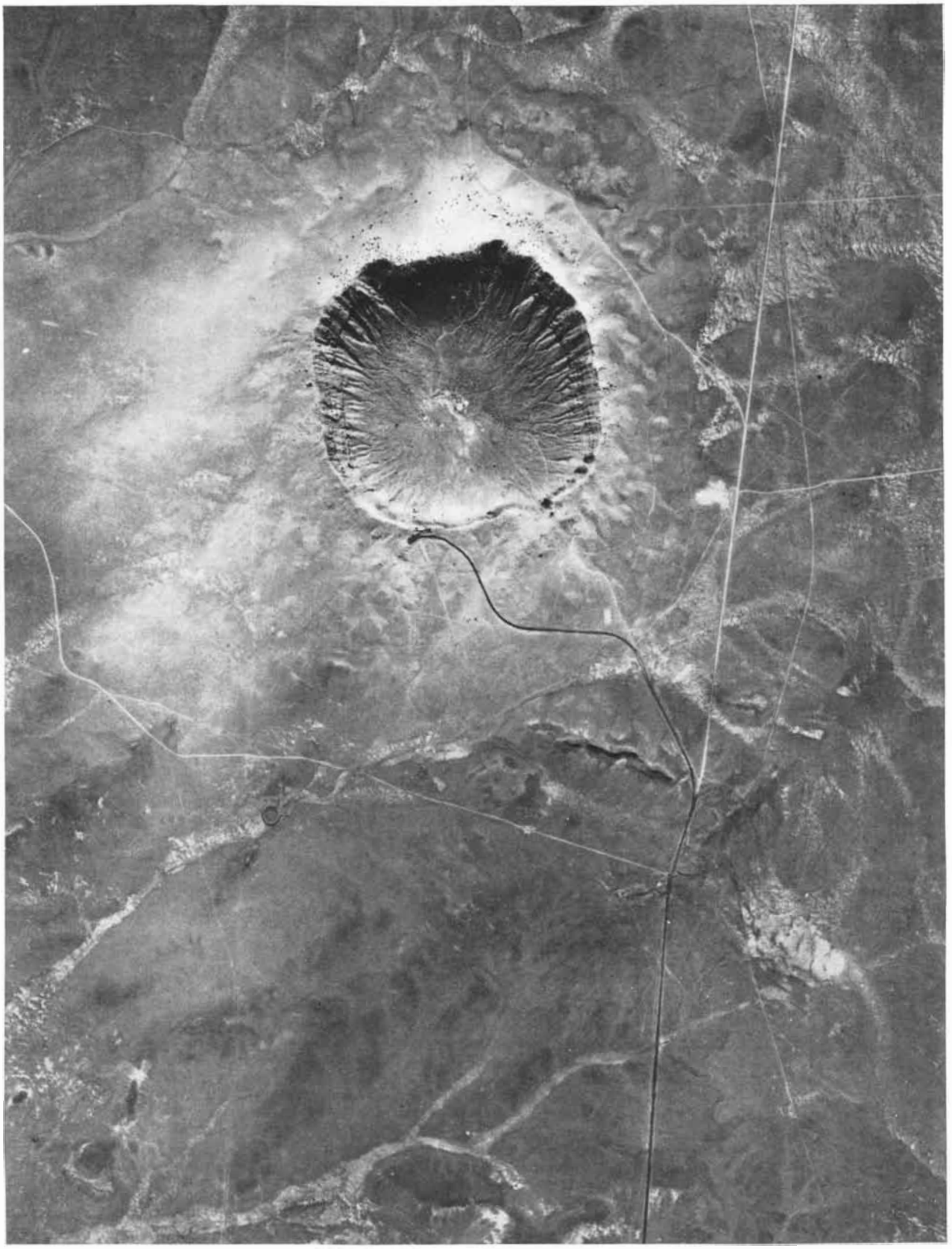
It is obviously a matter of considerable interest to know whether the diamonds in the Canyon Diablo fragments were present in the meteorite before it collided with the earth or were created by the impact. If they were already present, one might argue that they were produced by great pressure inside a massive body, perhaps a body as large as a planet. On the other hand, if one holds that the diamonds were produced by impact, one still has to decide whether the impact occurred in space or on the earth. In this article I shall describe the evidence that makes it possible to choose among the three alternatives.

Although it is now generally accepted that the Arizona crater was made by a meteorite, a contrary view was once strongly held. Shortly after Meteor Crater was discovered in 1891, G. K. Gilbert, an eminent geologist of the day, declared it to be of volcanic origin rather than meteoritic. This verdict was all the more remarkable because Gilbert had just completed a classic study of the surface of the moon in which he clearly favored a meteoritic origin for the lunar craters. Gilbert's opinion carried great weight, and for many years the sole proponent of the impact origin of Meteor Crater was the mining engineer D. M. Barringer.

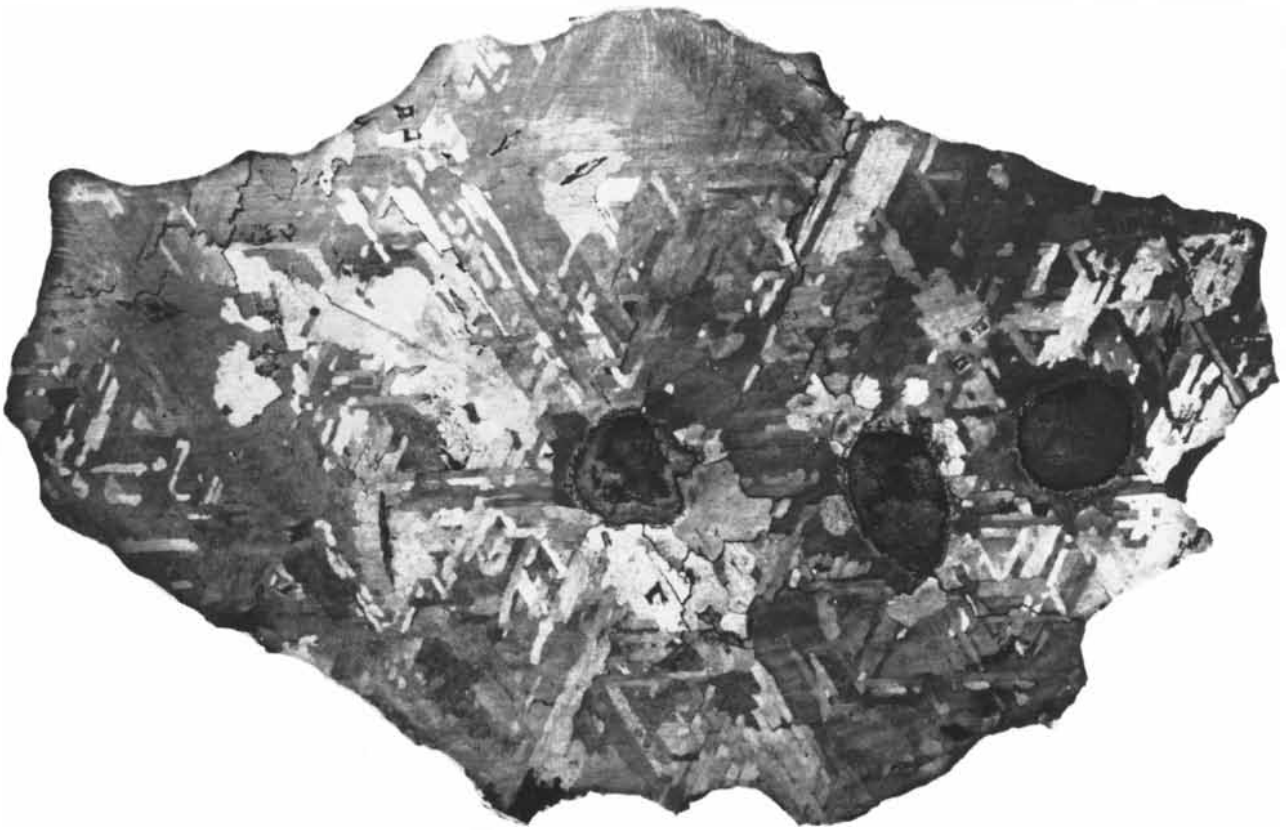
Barringer was so firmly convinced that an immense meteorite had produced Meteor Crater that he bought the site, formed a mining company and began drilling to locate the iron-nickel mass he felt sure had buried itself not far below the surface. Gradually it became evident that Barringer's search was doomed to failure.

To have produced such a huge crater the meteorite must have been so massive that its speed would have been reduced scarcely at all as it ripped through the earth's atmosphere. This implies, in turn, that it must have struck the earth with at least escape velocity: the velocity needed to free a body from the earth's gravitational field (11.3 kilometers per second, or about 25,000 miles per hour). At this velocity the kinetic energy of a meteorite is more than 15 times greater than the explosive energy of an equal mass of TNT. Thus a two-million-ton meteorite would have had the explosive force of a 30-megaton hydrogen bomb. The Canyon Diablo meteorite itself could hardly have survived the impact. Detailed theoretical analyses of the crater-formation process have been published by several investigators, most recently by Ernst J. Öpik of the Armagh Observatory in Northern Ireland, Eugene M. Shoemaker of the U.S. Geological Survey and R. L. Bjork of the Rand Corporation.

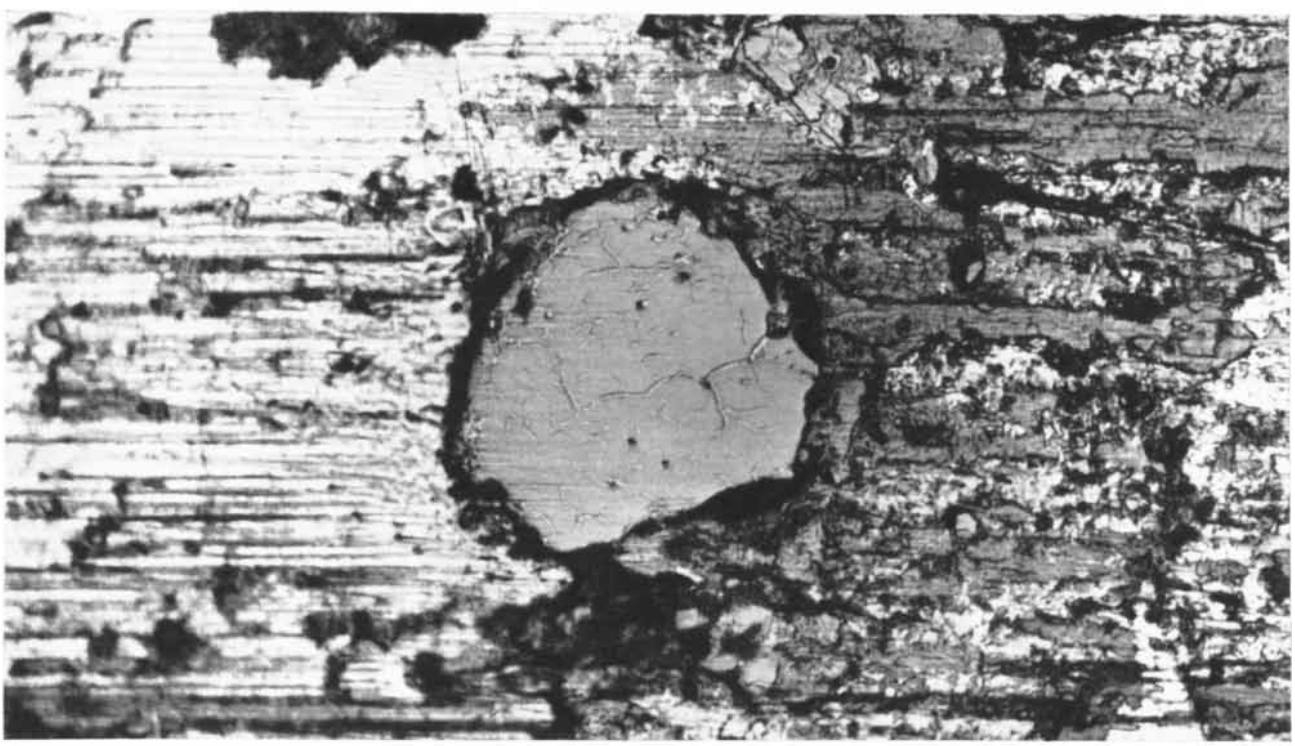
The mineralogists who had discovered the meteoritic diamonds were disappointed in their appearance. The great majority are tiny, black and opaque, and even the few translucent ones lack recognizable crystal faces [*see bottom illustration on page 28*]. This in itself is puzzling; most of the other constituents of iron meteorites take the form of single crystals, larger and more nearly perfect than any found on earth. Why are the diamonds an exception?



METEOR CRATER in Arizona is believed to have been produced about 20,000 years ago by an iron-nickel body, known as the Canyon Diablo meteorite, that may have weighed two million tons. The crater, seen here in a vertical aerial photograph, is about 4,250 feet in diameter and 575 feet deep. Gullies in the crater wall are the result of erosion by rainwater. White material outside the crater is limestone and sandstone ejected by the impact; the black specks are trees. A paved road leads to the northern rim (*bottom*). Almost all of the meteorite was vaporized by the impact, which released the energy equivalent of a 30-megaton hydrogen bomb.



TYPICAL CANYON DIABLO FRAGMENT displays a characteristic "Widmanstätten" pattern when polished and etched with acid. This pattern consists of broad bars of nickel-poor alpha iron separated by thin plates of nickel-rich gamma iron (*here barely visible*) arranged along the planes of an octahedron. "Alpha" and "gamma" designate particular atomic configurations of iron that are stable respectively at low and high temperatures (*see illustration on opposite page*). The three large inclusions consist of iron sulfide mixed with a small amount of graphite. This photograph of a 13-inch cross section was made at the Smithsonian Institution.



DIAMOND-BEARING FRAGMENT of the Canyon Diablo meteorite is enlarged 375 diameters in this photomicrograph made by A. El Goresy of the Max Planck Institute for Nuclear Physics in Heidelberg. The diamond is the gray mass in the center of the picture.

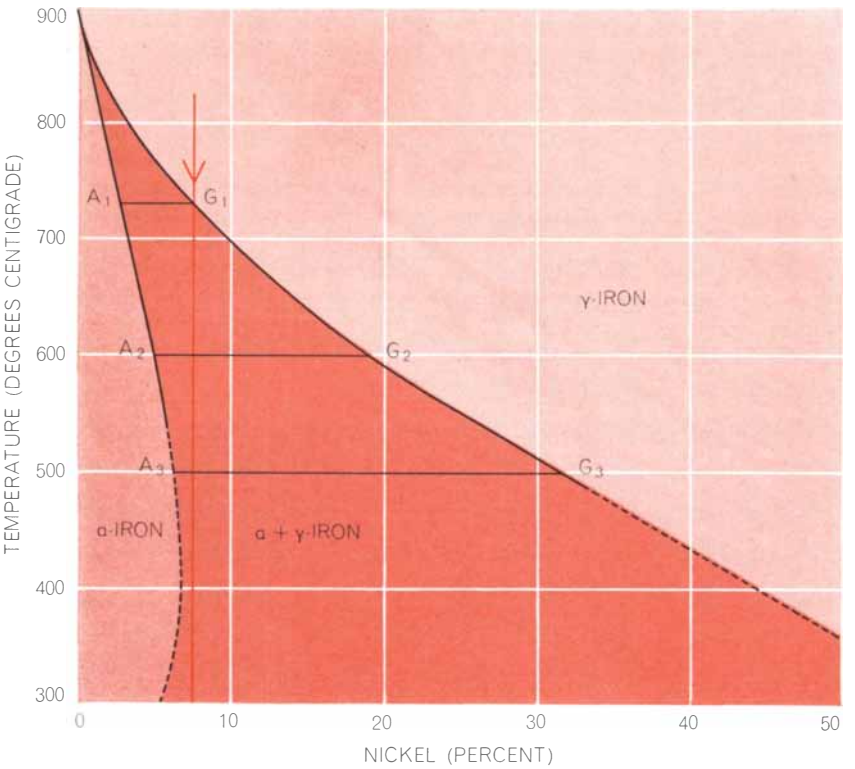
For 70 years the meteoritic diamonds remained a mystery. Finally in 1956 Harold C. Urey, who was then at the University of Chicago, pointed out that the diamonds should provide an exceedingly informative clue to the history of meteorites. Urey, who had pioneered in the application of chemical principles to the origin of the solar system, observed that in order to form diamond from graphite considerable pressure is needed. If the graphite is at room temperature, the theoretical pressure required is at least 16 kilobars, or about 16,000 atmospheres. (One kilobar is 987 atmospheres; one atmosphere is 14.7 pounds per square inch.) If the temperature is raised to about 700 degrees centigrade, a pressure of at least 31 kilobars is needed to form crystals of diamond or to preserve crystals that have already been formed. Urey concluded that the meteorites had once passed through a high-pressure stage.

The obvious source of pressure is gravitational pressure inside a large celestial body. A simple calculation shows that the body would have to be as large as the moon if pressures greater than 16 kilobars are to prevail in an appreciable fraction of its interior. Urey therefore proposed that most, and perhaps all, meteorites had once existed in parent bodies at least the size of the moon.

This was a provocative idea, since it seemed to support Heinrich Olbers' hypothesis of a century ago that the asteroids are the debris of a small planet. On closer examination, however, Urey's proposal was found to create more problems than it solved. For example, most iron meteorites have a characteristic structure consisting of two iron-nickel alloys—alpha iron and gamma iron—that reveal the temperature history of the metal. The alpha form has a body-centered-cubic crystal structure, composed of subunits in which eight atoms of iron form a cube with a ninth atom in the center. In the gamma, or face-centered-cubic, form the cube is empty but there is an atom of iron in the center of each face. When an iron meteorite containing alpha and gamma iron is polished and etched, it commonly shows the so-called Widmanstätten figures, a characteristic pattern named after its discoverer, A. B. Widmanstätten [*see top illustration on opposite page*]. The pattern appears because the two alloys differ in nickel content and therefore are attacked at different rates by the etching acid.

Metallurgical studies of iron-nickel alloys show that alpha iron is the stable form at low temperatures and gamma iron the stable form at temperatures above 600 to 900 degrees C., depending on the amount of nickel present. Thus for a typical meteoritic alloy of about 7.5 percent nickel, the Widmanstätten figures must have originated by slow cooling through a temperature range from 700 to 400 degrees [*see illustration above*]. The difficulty this presents to Urey's idea is that a moon-sized body that had once been molten would not cool to 700 degrees, let alone 400 degrees, in the entire age of the solar system.

Urey tried to solve this problem by invoking special assumptions, but there were further difficulties. First, a moon-sized body appears to be extremely resistant to disruption; it would not break up even if it were to collide with another body of similar size. Second, the mass of the bodies in the asteroid belt between the orbits of Mars and Jupiter, which is the source of most or all meteorites, is only about a tenth of a lunar mass; it seems most doubtful that the belt ever contained an order of magnitude more material. Finally, most properties of meteorites point to a low-pressure history.



IRON-NICKEL PHASE DIAGRAM shows the relation among crystal structure, nickel content and temperature. In alpha (α) iron the basic structural unit is a cube with an iron atom in each corner and one in the center. In gamma (γ) iron the cube is empty but there is an iron atom in the center of each face. The cooling path of an alloy containing 7.5 percent nickel is represented by the vertical line. On reaching 730 degrees centigrade the homogeneous gamma phase becomes unstable and tends to re-form into a mixture of alpha and gamma phases with the nickel content indicated by A_1-G_1. On further cooling, both alloy fractions become richer in nickel (A_2-G_2, A_3-G_3). Eventually the diffusion rate of nickel becomes so low that the transformation is arrested. The diagram is based on the work of J. I. Goldstein and R. E. Ogilvie of the Massachusetts Institute of Technology.

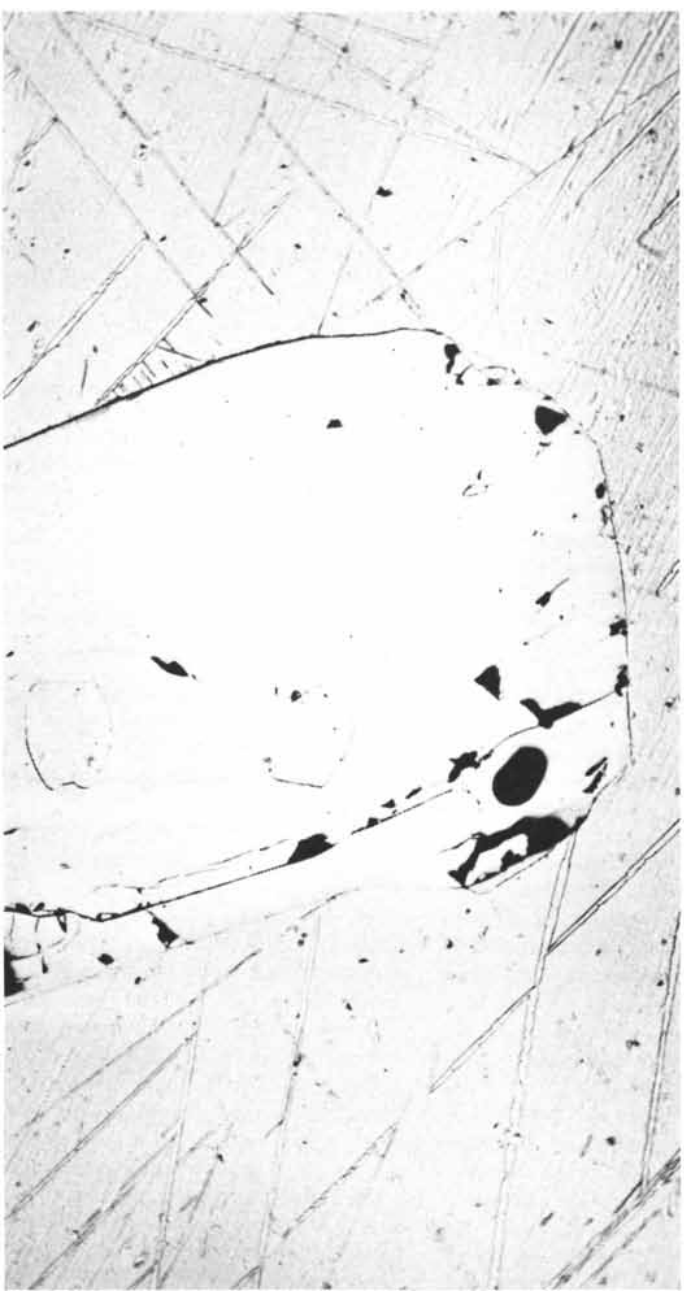
The year after Urey presented his hypothesis a rather different point of view was put forward by H. H. Nininger in his book *Arizona's Meteorite Crater*. It had been known that only a fraction of all the Canyon Diablo meteorite fragments contained diamonds. Moreover, the presence of diamonds seemed to be unpredictable. One investigator would dissolve a small fragment in acid and obtain a copious residue of diamonds; another would dissolve a much larger fragment and find none. Nininger too had believed that the distribution was random and unpredictable, until he realized that all 40 of the diamond-bearing meteorites he had discovered had come from the *rim* of the crater. None was from the surrounding plains, where most of the

Canyon Diablo fragments had been found. Soon Nininger had turned up another important clue: the Widmanstätten pattern was quite distinct in the plains specimens but usually very faint in specimens found on the rim. This suggested that the rim specimens had been strongly reheated late in their history. A survey of an additional 550 meteorites fully confirmed these differences.

Nininger concluded that such correlations could not be accidental. He therefore proposed that the diamonds had been formed during the impact that produced the crater.

I did not learn of Nininger's interesting ideas until two years after their publication, when I visited him in 1959 in Sedona, Ariz. Since his evidence was impressive, I decided to look into the matter more closely. Nininger lent me eight of his diamond-bearing samples, and when I returned to the University of Chicago, Michael E. Lipschutz and I examined them under the microscope. To help interpret our observations we were fortunate in obtaining the advice of an expert metallurgist: Cyril S. Smith, who is now at the Massachusetts Institute of Technology.

There was no doubt that the diamond-bearing meteorites had been intensely reheated. In normal iron meteorites most of the metal is present as a single large crystal of alpha iron containing about 7 percent nickel [*see illustration at left below*]. In the diamond-bearing samples the alpha iron was no longer smooth and monocrystal-

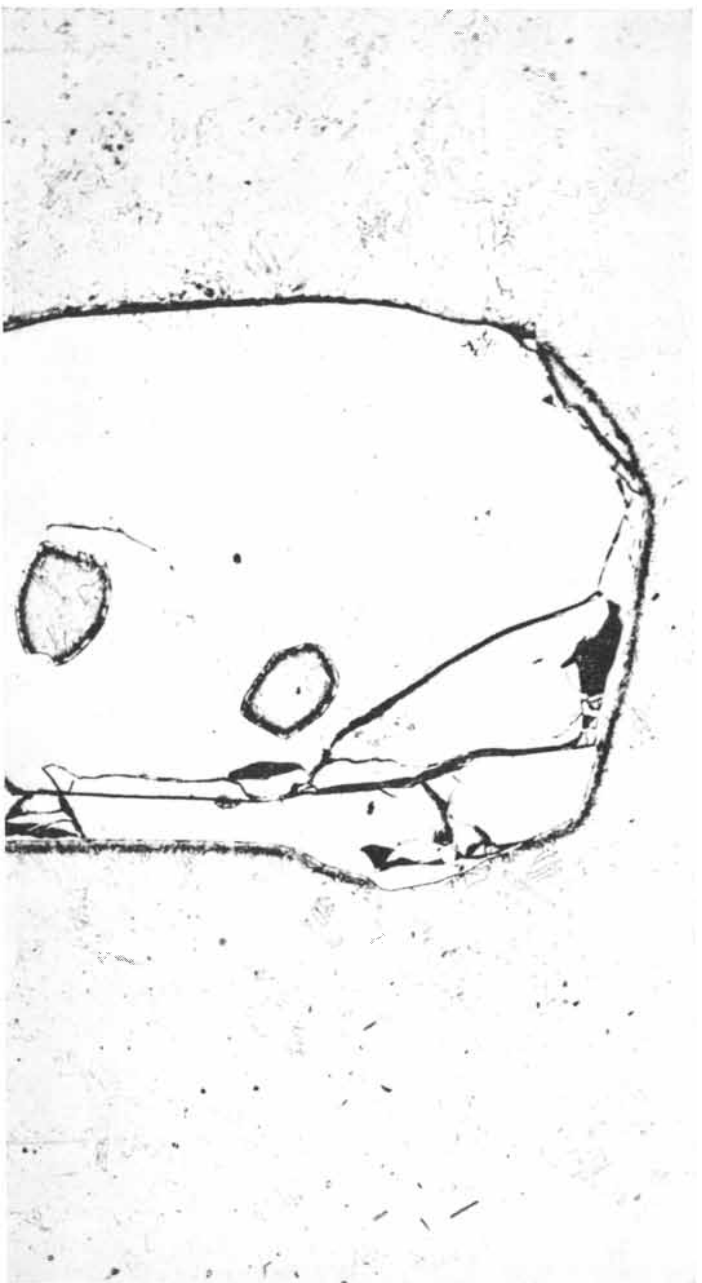


SHOCKING causes changes in the microstructure of meteorites. A photomicrograph of a normal iron meteorite enlarged 170 diameters (*left*) shows a single crystal of alpha iron containing fine parallel lines known as Neumann bands. They could have been produced by gentle collisions when the meteorite was still in orbit. The central mass with a fine black outline is iron carbide. In a heavily shocked, diamond-bearing Canyon Diablo meteorite (*middle*) the alpha iron is in the form of many small crystals. A fuzzy darkened area around the iron carbide shows that carbon diffused into the metal while it was in the gamma state and rapid cooling con-

line; it had become a jumble of small crystals [*see illustration at right on opposite page*]. Such a transformation can be brought about at will, simply by heating an iron meteorite to 740 degrees or higher. At this temperature body-centered alpha iron with 7 percent nickel changes to face-centered gamma iron. When the sample is cooled, the alpha iron reappears, but now it is no longer in the form of a single large crystal; because of defects or stresses in the crystal lattice the alpha iron reemerges in the form of many small crystals [*see illustration at left below*]. This polycrystallinity largely masks the Widmanstätten pattern.

There was other evidence of reheating. Canyon Diablo meteorites contain a considerable amount of iron carbide in the form of thin plates. Under the microscope the plates appear as nearly white, sharply bounded areas. In meteorites containing diamonds, however, a fuzzy dark border can be seen at the interface between the carbide and the alpha iron [*see illustration at right on opposite page*]. Carbon is almost insoluble in alpha iron but is slightly soluble in gamma iron. Evidently the dark border represents carbon that had diffused into the surrounding metal after it had been reheated and was temporarily in the gamma state. The diffusion process stops as soon as the temperature drops below 740 degrees, when the metal reverts to the alpha phase.

The appearance of the diffusion border provides a clue to the cooling time.



verted the iron and carbon in the diffusion zone to martensite. The third specimen (*right*) was obtained by heating sample at far left to 850 degrees for 15 seconds and quenching it quickly. Features shown in the shocked specimens have been reproduced: alpha iron is now polycrystalline and martensite has appeared.

MODERATELY SHOCKED METEORITE, also a Canyon Diablo specimen, contains evidence that the alpha iron was once converted to the denser epsilon form by shock pressures that briefly exceeded 130 kilobars (about 130,000 atmospheres). The evidence is the fine-grained, dark appearance of the alpha-iron crystals.

DEGREE OF SHOCK	PLAINS (PERCENT)	RIM (PERCENT)	DIAMOND-BEARING (PERCENT)
LIGHT	86	0	0
MODERATE	14	28	29
HEAVY	0	72	71

CLASSIFICATION OF 61 CANYON DIABLO SPECIMENS was made by comparing their structure with that of meteorites subjected to a graded series of laboratory shocks. Canyon Diablo fragments deemed to be lightly shocked had been found only on the plains, heavily shocked specimens only on the rim of the crater. A few moderately shocked specimens had been found in both locations. All 15 diamond-bearing specimens turned out to be either moderately or heavily shocked, and all but one had been found on the rim.

If the cooling time is long, the diffusion border will contain a distinctive mixture of alpha iron and iron carbide known as pearlite. If the cooling time is short—a few minutes, say—the diffusion border will contain austenite (an iron-carbon alloy with a face-centered-cubic structure). If the cooling time is still shorter—two minutes or less—the diffusion border will contain martensite (an iron-carbon alloy with a distorted body-centered-cubic structure). Since most reheated meteorites contain martensite, it is clear that the cooling times must have been quite short.

It was easy to prove that the heat effects were not due to some trivial cause, such as a close approach to the sun or accidental heating in a campfire. Frequently the meteorites show evidence of steep temperature gradients, suggestive of exceedingly short heating times. In some cases, moreover, the temperature gradients are "inverted," indicating that the inside of the meteorite had once been hotter than the outside. In one meteorite the interior had reached a temperature of more than 1,100 degrees (as shown by the presence of a characteristic structure produced only on melting) and the surrounding metal seems to have remained below 700 degrees (judging from the presence of unrecrystallized alpha iron). No conventional heat source could produce such inverted temperature gradients. The observed effects, however, could be neatly explained if the meteorites had at some time been subjected to a shock wave.

When a large iron meteorite smashes into the earth at cosmic velocity, the front surface of the meteorite is sharply compressed, and this deformation is transmitted as a high-velocity shock wave to the rear of the metallic mass. As the shock front passes, the metal in its path is compressed and intensely heated. In a matter of milliseconds the shock front is reflected from the meteorite's rear face as a rarefaction wave. The material behind such a wave would be decompressed, but it would not return to its original temperature. Its new temperature would depend on the shock pressure as well as on its density and compressibility. In a body as irregularly shaped as a meteorite, complex temperature and pressure profiles can arise from the interaction of primary shocks and their reflections from surfaces and crystal boundaries. Steep temperature gradients should be the rule rather than the exception.

That this shock event occurred when the Canyon Diablo meteorite struck the earth and not at some earlier time in outer space is proved by the evidence for rapid cooling found in many of the specimens. Laboratory experiments and theoretical calculations show that cooling times as short as two minutes could be attained only by isolated meteorite fragments, not by material located inside a two-million-ton object.

Lipschutz presented our findings at a meeting of the American Chemical Society in Cleveland in April, 1960. His talk, I am sorry to say, aroused deep apathy. Fortunately for us, however, Shoemaker and his U.S. Geological Survey colleagues E. C. T. Chao and B. M. Madsen were making an independent study of Meteor Crater, looking for evidence of a shock wave in the sandstone layer below the crater floor. Three months after our Cleveland paper they reported finding that the sandstone contained coesite, a high-pressure modification of silica. This mineral, previously unknown in nature, had been made artificially in 1953 by Loring Coes, Jr., of the Norton Company. Because coesite can be formed only by pressures greater than 20 kilobars, Chao and his associates proposed that it be used as a diagnostic mineral for distinguishing between meteoritic and volcanic craters.

The discovery of coesite made people somewhat more receptive to our hypothesis of shock-induced phase transformations in meteorite fragments. The intellectual climate became almost balmy a year later, in June, 1961, when Paul S. DeCarli of the Stanford Research Institute and John C. Jamieson of the University of Chicago announced that they had succeeded in converting graphite into diamond by using the shock wave from a small explosive charge. Late in 1959 I had told Jamieson of our meteorite findings. He realized more clearly than I did at the time that the mechanism involved in diamond formation was the simple solid-state conversion of graphite by shock. A few years earlier, of course, the General Electric Company had announced a method of making diamonds from graphite and other carbonaceous materials by subjecting them to a pressure of more than 45 kilobars and a temperature above 1,000 degrees for several minutes. Efforts to produce diamonds by shock methods, however, had failed until DeCarli and Jamieson turned the trick. They succeeded by using graphite of rhombohedral crystal structure rather than of the familiar hexagonal structure. It had been pointed out several years earlier by Dame Kathleen Lonsdale of the University of London that of the two forms the rhombohedral form was closer to diamond in atomic structure.

It seemed evident that the shock of striking the earth had created the diamonds in the Canyon Diablo meteorites. But what about the diamonds in the three stony meteorites: Novo-Urei, Goalpara and Dyalpur? Here the explanation had to be different. All three ureilites were small and so must have been slowed down to a velocity of less than 200 meters per second in passing through the earth's atmosphere. An impact at this velocity could never generate the shock wave needed to produce diamonds.

These meteorites, however, must have suffered at least one additional impact in their history: the one that shattered their parent body in outer space. Perhaps the diamonds were made at that time. Like the Canyon Diablo diamonds, the ureilite diamonds are not single crystals; they are made up of

millions of tiny crystalline regions called crystallites and closely resemble the shock-produced diamonds of DeCarli and Jamieson. Lipschutz (who is now at Purdue University) has also found that the crystallites in each diamond grain of the ureilites are not randomly oriented with respect to one another but show a preferred spatial orientation, in common with shock-produced diamonds. This, together with other evidence of shock in the ureilites, has led us to postulate that their diamonds too were shock-created.

The shock hypothesis was seriously challenged last year by N. L. Carter and G. C. Kennedy of the University of California at Los Angeles. They believed they had found a diamond-bearing Canyon Diablo meteorite that showed no evidence of shock. One such example would suffice to demolish the shock hypothesis, which demands a perfect correlation between diamonds and shock. On closer examination, however, the specimen in question revealed substantial evidence of shock pressures exceeding 400 kilobars. Thus there seems to be no exception to the correlation between diamonds and shock. By late 1963 the number of diamond-bearing Canyon Diablo fragments discovered by Nininger had risen to 120. All showed evidence of severe shock.

Much more remained to be learned about the Canyon Diablo meteorite. We had only vague notions about the pressures actually reached by the various fragments. To establish a quantitative scale of shock effects we selected nine pieces of a particular iron meteorite (known as the Odessa meteorite) that showed little evidence of shock and subjected them to laboratory shocks at pressures ranging from 200 to 1,000 kilobars. (The shock experiments were performed by DeCarli and by N. L. Coleburn of the Naval Ordnance Laboratory.) Using these nine meteorites as calibration standards, Lipschutz and Betty Nielsen classified 61 Canyon Diablo fragments from known locations according to shock intensity. The results showed a division into three categories.

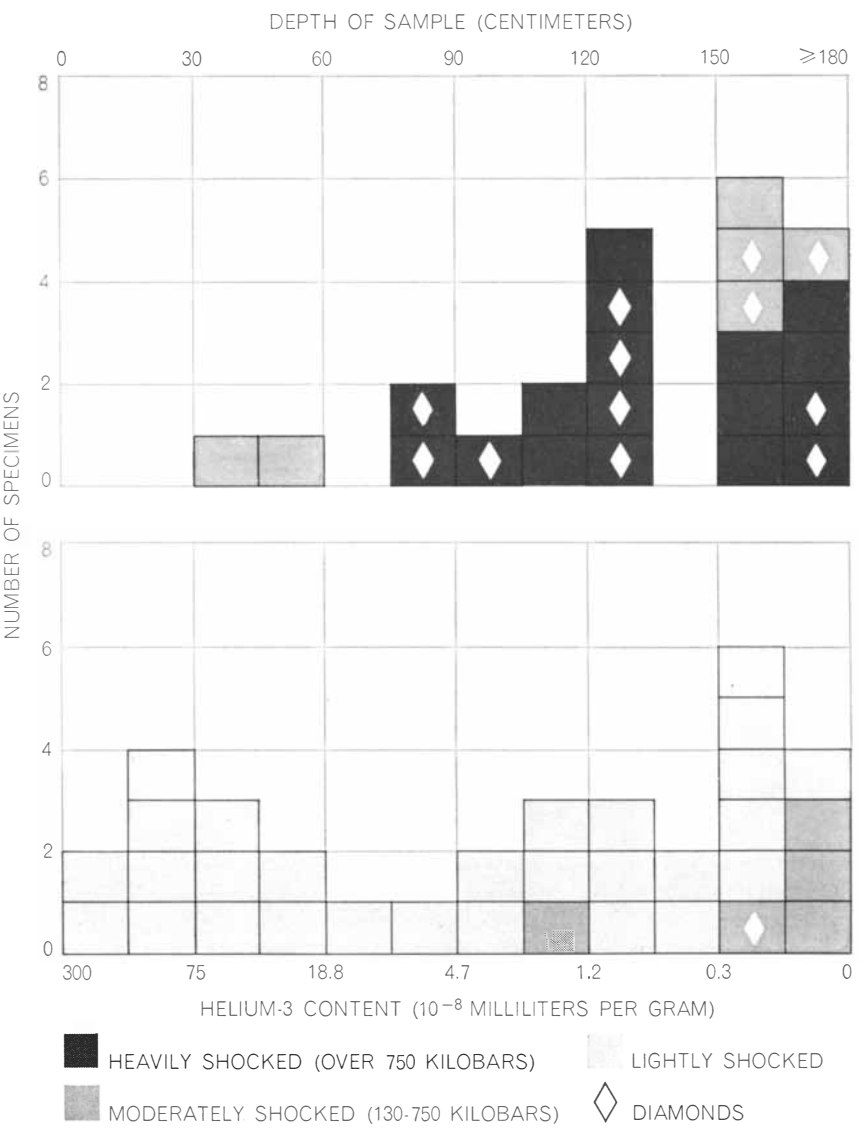
The first contained heavily shocked meteorites in which the alpha iron had recrystallized throughout the specimen. Comparison with artificially shocked meteorites showed that this change required a pressure of at least 750 kilobars.

The second group consisted of moderately shocked meteorites in which the alpha iron had recrystallized only in a few isolated spots. These specimens also gave a peculiar pattern on etching that showed that the metal had once been converted briefly to the densest form of iron known: epsilon iron, whose threshold of formation is 130 kilobars [*see illustration at right on page 31*]. The presence of epsilon iron in meteorite samples indicates moderate temperatures and a pressure ranging from 130 to 750 kilobars.

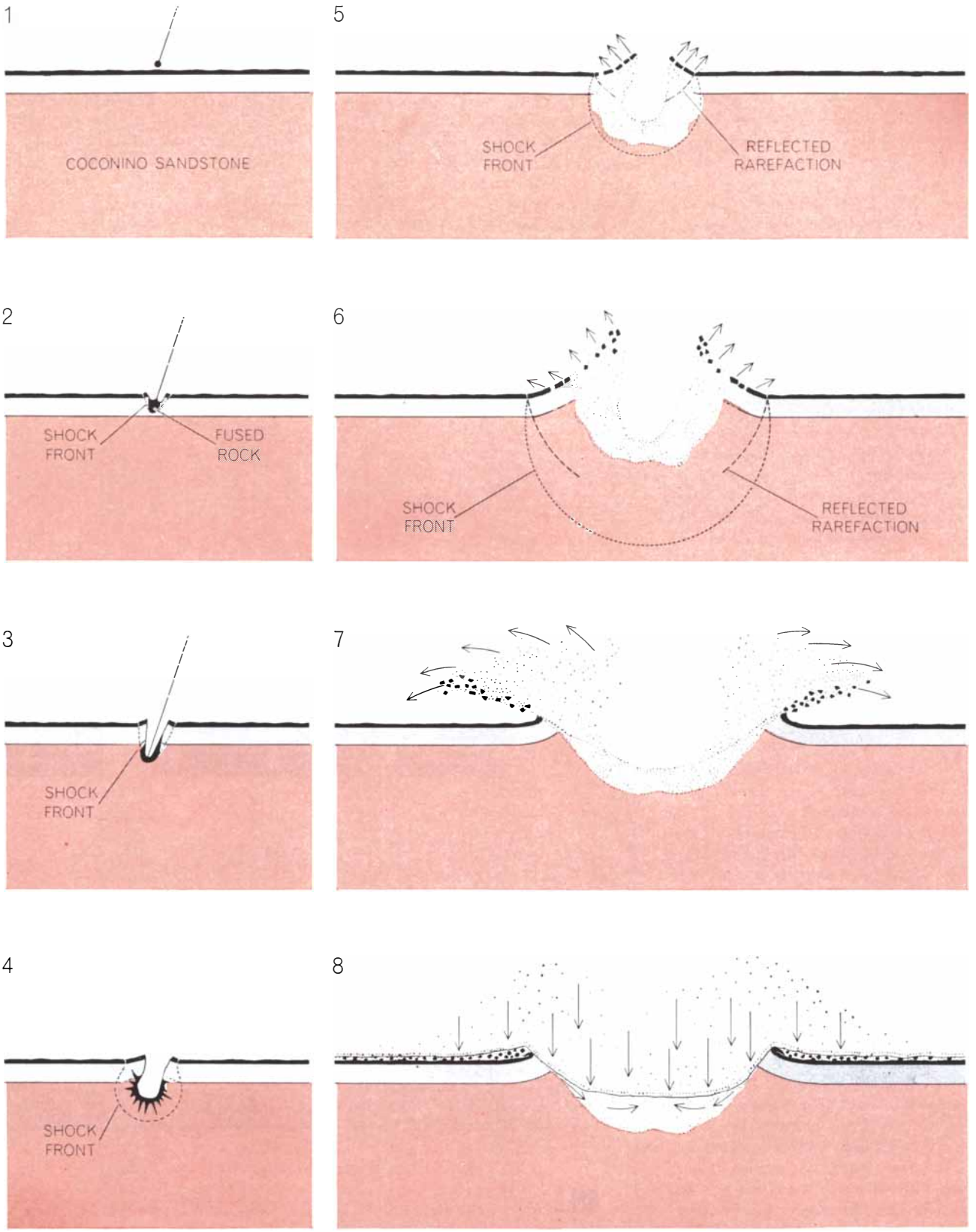
The third category consisted of lightly shocked meteorites. In these the epsilon structure was absent, implying that shock pressures had not reached 130 kilobars.

All 15 diamond-bearing fragments were either moderately or heavily shocked. We also found a good correlation between shock effects and location, although the distinction between rim and plains specimens was not quite as sharp as Nininger had originally supposed. Strongly shocked meteorites were found only on the rim and lightly shocked ones only on the plains. But moderately shocked specimens were found in both locations [*see illustration on opposite page*].

One novelty turned up in this study: a diamond-bearing plains specimen. It showed signs of moderate to severe shock and so was no embarrassment to the shock hypothesis. Although the hypothesis requires that the correlation between diamonds and shock be perfect, it does not require that the correlation



LOCATION OF FRAGMENT IN ORIGINAL METEORITE can be inferred from its content of helium 3, produced by cosmic rays while the meteorite was still in orbit around the sun. The more deeply buried the sample, the lower its helium-3 content. The top diagram shows that all rim specimens had been moderately to heavily shocked and that 18 out of 23 had evidently been buried at depths greater than a meter. The bottom diagram shows shock and depth data for 33 plains specimens. Note that one plains specimen contains diamond.



IMPACT OF CANYON DIABLO METEORITE is depicted in this sequence of eight diagrams based on a study by Eugene M. Shoemaker of the U.S. Geological Survey. In *1* the meteorite approaches the ground at about 15 kilometers per second. In *2* most of the energy has been transferred to compressed fused rock ahead of the meteorite. The initial shock wave has passed through the meteorite and has been reflected back as a rarefaction wave. In *3* the meteorite has become the liner of a transient cavity. In *4* the cavity expands as fused rock and meteoritic material are shot out of the cavity behind the shock front. In *5* shock is reflected as a rarefaction wave from the surface of the ground and momentum is trapped in material above the cavity. In *6* the material behind the rarefaction wave is thrown out to various distances along ballistic trajectories. In *7* ejection of material continues; the ultimate diameter of the crater is defined. In *8* crater-wall material slumps and fragments thrown to great heights shower down to form a layer of mixed debris.

between diamonds and distance from the crater also be perfect.

Now it had become possible to say something about the conditions under which the diamonds in the Canyon Diablo meteorite had formed. Most, if not all, of the diamond-bearing specimens had evidently been shocked to more than 600 kilobars. According to data from Francis P. Bundy of the General Electric Company, graphite shocked to a pressure of more than 600 kilobars will melt. Presumably the shock wave created by the impact of the Canyon Diablo meteorite transformed graphite particles into droplets of liquid carbon; when subsequently decompressed, the droplets froze into small crystals of diamond. In less strongly shocked specimens graphite may have been transformed directly into diamond by a rearrangement of atoms in the solid state.

Dieter Heymann of the University of Chicago has recently been trying to learn something about the original location of the rim and plains specimens within the Canyon Diablo object. As I have noted, the major part of the two-million-ton projectile vaporized on impact. Only a tiny fraction, some 30 tons, has so far been recovered in the form of isolated fragments. Although most pieces of the jigsaw puzzle are thus missing, a clue exists that allows at least a partial reconstruction of the puzzle.

At some time in its cosmic history the Canyon Diablo object was presumably part of a larger body. When this body broke up, the surface of the Canyon Diablo fragment, perhaps 60 to 80 meters in diameter, was exposed to cosmic ray bombardment. Under this bombardment iron and nickel atoms in the meteorite were transmuted into a variety of lighter elements. The amounts actually transformed were exceedingly small: on the order of one atom in 10 million in a period of a billion years. Among these lighter elements, however, are certain rare isotopes of the noble gases: helium 3, neon 21 and argon 38. Modern mass spectrometers can detect such gases when they are present to the extent of less than a billionth of a milliliter in a gram of sample [see "The Age of the Elements in the Solar System," by John H. Reynolds; SCIENTIFIC AMERICAN, November, 1960].

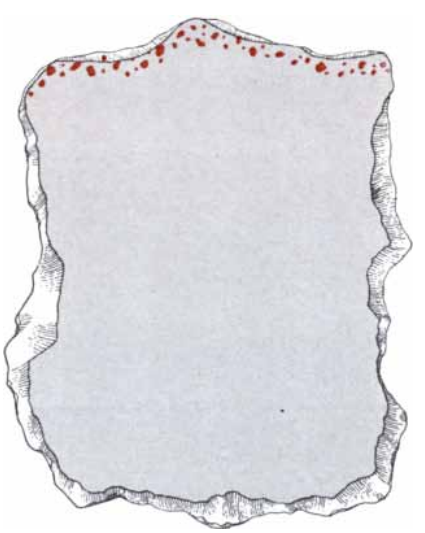
None of the gases had initially been present in the meteorite. The amount of helium 3 in a given specimen therefore depends on only two variables: the duration of the cosmic ray bombardment and the depth to which the specimen was buried below the surface of the meteorite. The depth enters the picture because cosmic rays are absorbed by the meteorite; thus the flux of cosmic rays and the production of helium 3 decrease with increasing depth. In an iron meteorite the decrease amounts to about a factor of two for each 15 centimeters. If the duration of cosmic ray bombardment is known, the depth can be inferred from the helium-3 content.

By using known relations among noble-gas isotope ratios Heymann was able to determine the bombardment ages of a number of Canyon Diablo fragments. Surprisingly not one but two dates were found: 540 million years and 170 million years. This was consistent with earlier results obtained by H. Wänke and E. Vilcsek of the Max Planck Institute for Chemistry in Mainz. They found that some large iron meteorites had apparently broken up more than once before they hit the earth, with the result that some of their material that had once been shielded deep in the meteorite had later been exposed to bombardment by cosmic rays. Canyon Diablo appears to have suffered one such secondary collision 170 million years ago, after the initial collision that expelled it from its parent body 540 million years ago. Quite recently Wänke and Vilcsek found a Canyon Diablo fragment bearing evidence of a third collision 15 million years ago.

It seems that the collision that took place in the asteroid belt 540 million years ago was a major cataclysm that has been showering debris on the earth ever since. H. Voshage and H. Hintenberger, also of the Max Planck Institute for Chemistry, have shown that more than half of all iron meteorites found on the earth have exposure ages between 500 million and 600 million years. Heymann, in turn, finds that most of the so-called hypersthene chondrites, which comprise more than half of the stony meteorites, suffered intense shock and reheating about 520 million years ago. Perhaps these two events are related and refer to the breakup of one or two sizable asteroids. Calculation indicates that the disrupted body must have had a diameter of at least 80 kilometers and a mass of some 10^{15} tons.

It may be possible in a few years to locate somewhere in the sky the remains of the parent body of the Canyon Diablo meteorite. Among the asteroids some 30 "families" with similar orbital elements have been recognized; it is plausible that each family represents the debris resulting from the breakup of a single large asteroid. One would like to know if the meteorites currently bombarding the earth can be traced to any of these families. Information on this point may become available in the next few years. R. E. McCrosky of the Smithsonian Astrophysical Observatory has recently set up a network of meteor cameras in the plains states. If a meteor trail is recorded by two or more cameras, its orbit can be computed with good accuracy. If the meteorite that produced the trail can subsequently be located on the ground, its age can be measured. With luck, it may be possible to link meteorites from the collision of 500 million years ago to a specific family of asteroids in the sky. Four asteroid families that cross the orbit of Mars are prime candidates.

Let us now return to the Canyon Diablo meteorite. After determining the exposure times of a number of specimens, Heymann was able to relate helium-3 content to the depth at which the specimen was located in the Canyon Diablo body before its impact with the earth. He then tried to correlate this depth with the degree of shock and with the place where the specimen had been collected—on the rim or on the plains [*see illustration on page 33*]. Heymann found that most of the rim specimens had apparently been located



CANYON DIABLO BODY may have looked something like this. The two-million-ton mass of iron-nickel alloy was perhaps 60 to 80 meters in diameter. Only a fraction of the material (*color*) in the last two meters or so escaped vaporization as the object struck the earth. The material in this rear face may have weighed 50,000 tons, of which perhaps 2,000 tons can be accounted for in assorted debris: iron-nickel fragments, "shale balls" and other oxidation products.

at a depth of more than a meter in the Canyon Diablo body and that about half of the plains specimens had been closer to the meteorite's surface. In general, the more deeply the specimen had been buried, the more intensely it had been shocked. The final correlation is this: The most deeply buried fragments experienced the most shock, the shock produced diamonds and for some reason the heavily shocked specimens were ejected with low velocity, so that they landed only on the rim.

It is also evident that the surviving fragments are not random samples of the 60-to-80-meter projectile; nearly all of them come from the outermost two meters of the object. Öpik has argued that only material from the rear face of the projectile stood a chance of survival; the rest was either vaporized or pulverized. Heymann's results certainly support this view. Even of the rearmost two meters only a small fraction survived the impact in the form of solid fragments. If "shale balls" and other oxidation products are counted with the meteorites, the total mass of ejected solid fragments may have been as much as 2,000 tons. The two-meter layer from which these fragments came, however, represented at least 50,000 tons. Thus only 4 percent of this layer, or .1 percent of the entire meteorite, survived [*see illustration on preceding page*].

Probably only material from a few favored locations on the meteorite—corners, edges or humps—was able to escape intact. Two of the samples studied by Heymann had abnormally high noble-gas ratios, which may imply that they came from more strongly irradiated projections of some kind.

It is difficult to predict the ejection pattern from first principles, but Bjork has attempted the task for an idealized Canyon Diablo meteorite of cylindrical shape. During the early stages of the impact the topmost layers of the meteorite were presumably thrown off; these fragments were apparently thrown farthest and fell on the plains. Later, when deeper and more strongly shocked layers had presumably been exposed, ejection velocities would have dropped considerably; material thrown off then may have fallen on the rim.

Bjork's calculations also suggest that the entire meteorite was shocked to about 10,000 kilobars and should have vaporized without leaving a trace of solid fragments. What allowed fragments to survive was the irregular shape of the meteorite. Shock waves are reflected from free surfaces as rarefaction waves, and in an irregularly shaped body the interaction of such rarefaction waves with one another and with the shock front can lead to a pressure-temperature distribution of bewildering complexity. Presumably a few regions near the rear surface escaped destruction because of the fortuitous cancellation of primary and reflected shocks.

One can be somewhat more definite than this about the early history of the Canyon Diablo object, or its parent body. At a very early stage, dated at about 4.55 billion years ago by studies of radioactivity, a melting process separated the iron-nickel alloy from the silicate material with which it was originally associated. The slow cooling that produced the Widmanstätten pattern in the metal apparently developed in the next .5 billion to 1.5 billion years. John A. Wood of the University of Chicago has deduced from the distribution of nickel in microscopic plates of gamma iron that the meteorite cooled through the temperature range from 700 to 400 degrees at a rate of about one degree per million years. Such a cooling rate would be expected of an asteroid that was between 250 and 500 kilometers in diameter. This would make its diameter between a third and two-thirds that of the largest known asteroid: Ceres.

The story of Meteor Crater and the meteorite that made it is typical of current research in this field. The investigator striving to reconstruct the history of meteorites from a few fragmentary clues faces problems similar to those of the archaeologist and the paleontologist. His task is more difficult because the conditions that meteorites encountered during their long history often lie outside the realm of human experience. The example of meteoritic diamonds certainly illustrates this point. Similar problems will face us when the first samples of the moon and other planets are returned to the earth. Meteorites can teach us some valuable lessons in preparation for that day.

OBLIQUE VIEW OF METEOR CRATER gives a more vivid impression of its great size than the vertical view on page 27. Dark objects along the rim in the left foreground are trees. Bordering the rim at right are boulders that were ejected at the time of impact.

Kodak advertises its new Q-System for print reproduction

To manage so that all the details get themselves attended to and everything runs smoothly is the most valuable of skills. Engineers will putter forever and scientists will never quit stargazing unless skillfully managed.

Quantity production of high speed engineering drawing intermediates would help take up some slack from the meandering time line between a decision for action and the delivery of tangible fruit.

This calls for the new KODAK Q-System.

In the exposing section of the department's diazo machine something new called KODAGRAPH Q Paper is exposed to the original drawing. The original drawing is then returned to its repository or its creator, and the Q Paper is fed to the new KODAK Auto-Processor. Twenty seconds later it comes back out ready for as many trips through the diazo machine as there are prints needed. All this happens in roomlight. The new machine takes an hour to install, requires no plumbing or venting.

Have the right person get in touch with Eastman Kodak Company, Industrial Reprography, Rochester, N. Y. 14650. Some organizations need the Q-System as much for the salvage of nearly lost handiwork as for prudence in safeguarding fresh drawings.

Kodak advertises a newly invented Q-switch dye for infrared lasers

Engineers find what will work and how to put it together with other things that also work so that the combination solves a problem demonstrably better than it has been solved before. Defining the problem in the first place is usually also their task, as is giving the boys in the front office the feeling of having done it all themselves—with the aid of science.

Q is the quality of a tuned circuit. In 1889 Lord Kelvin (late founding director of Kodak Ltd.) defined a "q" for the Institution of Electrical Engineers of London in his presidential "Address on Ether, Electricity, and Ponderable Matter." He was groping to relate frequency to a-c "resistance." Later engineers used cavity resonators as tuned circuits. Still later ones ran the frequencies in their cavity resonators up into the optical range—with the aid of one of Einstein's theories. Those are lasers. By making high-class neodymium-doped glass for these lasers, we have shifted the frequency of interest down a bit from the visible to 1.06μ in the infrared, which has its advantages.

Then some engineers saw that if the onset of good resonance could be delayed until a larger proportion of the ions attained the condition where they could be stimulated to emit as Einstein predicted, output power would rise. In short, the Q of the cavity should be spoiled and then suddenly restored. Various complicated arrangements to this end were devised.

Then some physicists with an engineering attitude and a knowledge of photochemistry stepped in and proposed interposing a dye that exhibits optical saturation. This means that its opacity suddenly drops when the energy-absorbing mechanism in the dye molecule gets temporarily swamped. The Q-switch dye ought to have a narrow absorption band split clean down the middle by the 1.06μ laser line.

The dye industry, broadly considered, can prosper without taking on such strange assignments. We, in distinction, have had a team of engineer-like chemists puttering for the past 40 years with dye molecules as though they were mousetraps, in hopes that the attainment of better ones would have the well-known consequences predicted by Ralph Waldo Emerson. When handed the strange assignment, they smiled.

We are pleased to announce EASTMAN *Q-Switch Solution 9740. It is supplied as 100 ml of chlorobenzene solution. The measured absorption coefficient at 1.06μ is given on the package that safeguards it against ambient ultraviolet which would reduce the coefficient. We ship with $\alpha = 25 \pm 1$ cm^{-1}. The $100 kit includes a supply of solvent with which the coefficient can be cut. The way we have seen this particular dye drop its coefficient at the right nanosecond and get it back again undiminished in 500 trials by 1- to 5-megawatt pulses coursing through it and the prospects for service at much higher power levels and for reliable periodic pulsing through the self-restoring properties of this liquid Q-switch all encourage us to hope that interested engineers will send for a data sheet on* EASTMAN *Q-Switch Solution to Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company). To accompany the request with a valid purchase order for the kit wouldn't hurt.*

Price subject to change without notice.

Kodak advertises D.Q.E., a simple concept that may help locate the boundary of the universe

Science is pleased to lend aid. Patience is the strength of scientists. They need it not only for understanding nature but for dealing with the men of decision and action. Scientists no longer shun affluence. They face a major peril: that they will forget the supreme importance of stargazing and thereby become useless.

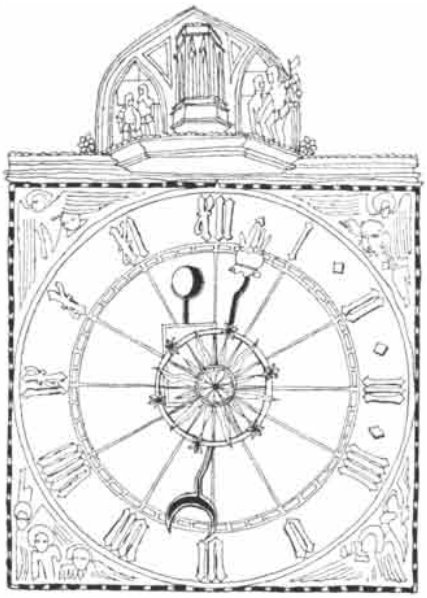
Quanta from quasars must not be wasted. Quasars were first called quasi-stellar sources when the radio astronomers picked them up. Now, not many months later, the challenging problem is to tell them apart from the faintest stars on photographic plates. They are really intrinsically very different, being billions instead of millions of light years distant, as are the galaxies. Now astronomers are developing techniques for finding them among all the faint stars that are only thousands of light years away. Quasars are drawing plenty of big-telescope time. They are receding at nearly the speed of light. They must be out by the "shock wave" from the original big bang of creation. Space itself may have meaning only to this boundary and be a figment of the intellect beyond it.

Those who regard such matters as important have to argue quantum economics and telescope-time economics, which are related. In their world the big questions are: How long do I have to count quanta to pick up the difference between those from my quasar and those from radiative processes in the night sky, including scatter from the well-lit motel on the other side of the mountain? How long can I count quanta without

unjustly depriving my colleague of his quanta-counting time? The second question calls for administrative talent, the first for an understanding of D.Q.E., detective quantum efficiency.

This is a figure of merit that relates through simple algebra photographic graininess, contrast, speed, and the size of the star image rendered by the telescope. This same D.Q.E. is the square of the ratio of output signal/noise to input signal/noise—for any quantum detector, photographic or otherwise. To avoid inevitable loss of rigor in the present verbal environment, we'd rather not go into further detail here. Suffice it to say that 1) the viewpoint shows how an emulsion of lower sensitivity *improves* quasar-finding power if properly designed for the purpose; 2) that we have made such emulsions experimentally with gratifying results; 3) that pure scientists will not for long be the only ones using photographic products built by the D.Q.E. principle.

For a proper exposition of D.Q.E. send to Eastman Kodak Company, Special Applications, Rochester, N. Y. 14650, for a reprint from Journal of the Optical Society of America *for August '65.*



SCIENCE ANI

The Importance of Cities

Congress has passed a bill to establish a U.S. Department of Housing and Urban Development, the head of which will be the 11th member of the Cabinet. The creation of the new department promises to make the interaction of cities and the Federal Government more direct than it has been in the past. It will enable the Government to deal with the problems of individual cities as such rather than as problems of states, of urban blocs or of other inappropriate political entities.

The head of the new department will supervise and coordinate the activities of all Federal agencies whose programs are primarily devoted to urban affairs. The largest agency of this kind is the Housing and Home Finance Agency; the others include agencies promoting urban renewal, community planning, mass transportation and the improvement of public facilities in cities. In the future the outlay of funds to such programs will be channeled through the Department of Housing and Urban Development. The new department will also underwrite research on the economic, social and technological problems of cities.

Gilt-Edged Neutrinos

Nine years after the first detection of artificially produced neutrinos, the first naturally produced neutrinos have been detected in a laboratory 10,492 feet below ground in a gold mine near Johannesburg. The laboratory was built under the direction of Frederick Reines of the Case Institute of Technology and J. P. F. Sellschop of the University of Witwatersrand. Reines collaborated with Clyde L. Cowan, Jr., in the 1956 discovery of the first neutrinos.

The neutrinos of 1956 were actually antineutrinos produced in a large nuclear reactor operated by the Atomic Energy Commission, which is also sponsoring the current experiment. The present neutrinos were presumably created when cosmic rays struck the earth's atmosphere; seven have been counted since the first neutrino event was recorded on February 23. Without difficulty the neutrinos penetrated the two miles of rock above the laboratory near Johannesburg and, after interacting with atomic nuclei in the rock, gave rise to mu mesons. (The overwhelming majority of such neutrinos, of course, pass straight through the earth without doing anything.) The mu mesons were detected with the aid of 36 liquid-filled scintillation counters that line the two walls of a horizontal tunnel for a distance of about 110 feet. The 36 counters contain 4,400 gallons of mineral oil in which a scintillating substance is suspended. Two light-sensitive photomultiplier tubes are located at the end of each counter and report the tiny flashes of light produced by the passage of high-speed subatomic particles. Only particles that pass through two counters on opposite sides of the tunnel are counted as mu mesons that may have been produced by neutrinos. Many mu mesons created in the atmosphere by cosmic rays also pass through the tunnel, but because they are traveling vertically single mu mesons can produce scintillations on only one side of the tunnel.

The tunnel was specially constructed by the East Rand Proprietary Mines as an extension of one of its own workings. Associated with Reines and Sellschop in the experiment were Marshall F. Crouch, Thomas L. Jenkins, William R. Kropp, August A. Hruschka, Bruce M. Shoffner, Henry S. Gurr and Gary R. Smith of the Case Institute and Basil Meyer of the University of Witwatersrand. Several other groups have also been searching for natural neutrinos in underground laboratories. A joint Indian-Japanese-British team working in

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the Kolar goldfields in southern India reported observing one neutrino event about a month after the first East Rand observation.

Powerful Paper

The paper on which this magazine (and most U.S. magazines and newspapers) is printed contains a powerful compound that may serve as a precise means of controlling certain harmful insects. The discovery of the compound solved a baffling biological mystery that recently confronted Carroll M. Williams and Karel Sláma at Harvard University; the mystery and its solution are described in *Proceedings of the National Academy of Sciences.*

Sláma and Williams found that the European bug *Pyrrhocoris apterus,* which had been raised successfully in Sláma's laboratory in Czechoslovakia for 10 years, invariably died without reaching sexual maturity when raised at Harvard. Instead of metamorphosing into normal adults, the bugs continued to grow as larvae or molted into adult-like forms preserving many larval characteristics.

It was evident, Sláma and Williams write, that at Harvard "the bugs had access to some unknown source of juvenile hormone," the hormone that promotes larval growth of insects but must be absent for the larvae to undergo metamorphosis to adulthood. "An audit of the culture conditions at Harvard versus Prague suggested 15 differences. By systematic study 14 were eliminated. The source of juvenile hormone activity was finally tracked down to exposure of the bugs to a certain paper towel... which had been placed in the rearing jars." Several other types of paper towel and tissue had the same effect on the bug. "Indeed, pieces of American newspapers and journals (*The New York Times, The Wall Street Journal, The Boston Globe, Science* and *Scientific American*) showed extremely high juvenile hormone activity when placed in contact with *Pyrrhocoris.* The London *Times* and *Nature* were inactive, and so were other paper materials of European or Japanese manufacture."

On further investigation Sláma and Williams found that the active material came mainly from "the indigenous

American pulp tree, the balsam fir." They were also "astonished to find that our most active extracts were without any detectable effects" on various other insects. "What this implies is that molecules with juvenile hormone activity for one species of insect are not necessarily active on other species," and that in turn implies "that the hormonally active material may be effective in the selective destruction" of certain insect pests. "Additional studies are under way to clarify the chemistry of the active material and to define the types of insects sensitive to this particular variant of juvenile hormone."

The Other Side of the Moon (Cont.)

The second series of photographs of the far side of the moon, made by the Soviet spacecraft *Zond 3*, has confirmed the fact that it differs markedly in appearance from the near side. Whereas the visible side is dominated by large, dark maria, or "seas," the hidden side has few, if any, maria. It consists largely of crater-strewn "highlands" (*see illustration below*).

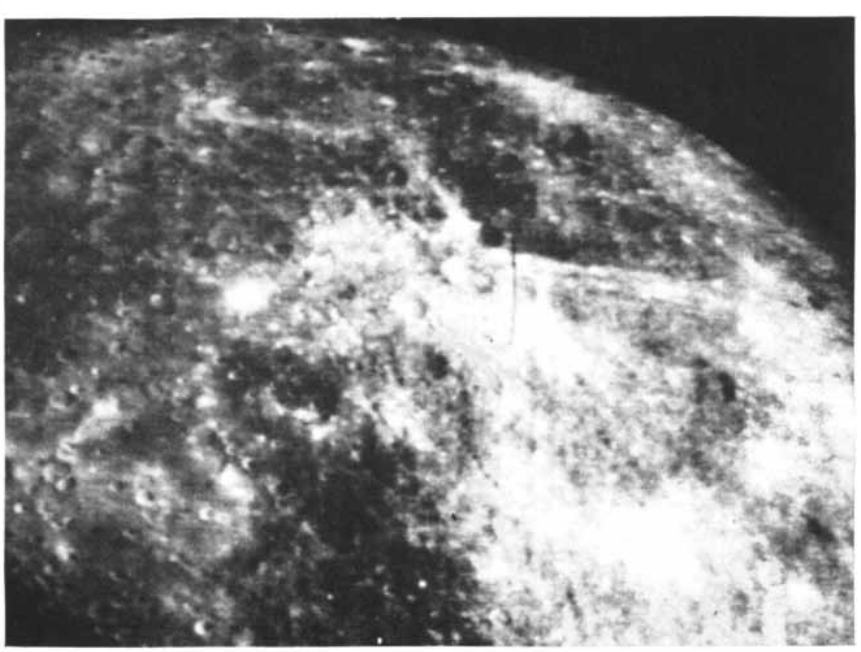
Some students of lunar geography think the difference in topography is significant. "Clearly the moon is telling us something," said one. Others believe that it simply represents a chance distribution of events that happened to give rise to a few enormous craters on one side of the moon and none on the other. The craters subsequently filled with a lava-like material and took on the appearance associated with maria.

The latest photographs of the back of the moon were taken over a period of 68 minutes on July 20, when *Zond 3* approached to within less than 6,000 miles of its target. The pictures were recorded on photographic film and developed automatically. Nine days later, when the earth presented a favorable target for *Zond 3*'s narrow-beam directional antenna, the pictures were scanned electronically and relayed to a Soviet tracking station. The television scanning system provided 1,100 horizontal lines per frame and 860 dots per line.

Two-Quantum Maser

A maser that operates only when the stimulating radiation arrives as a packet containing two quanta, instead of the usual single quantum, makes it possible to amplify simultaneously at two frequency levels instead of one. This new type of maser operation was observed for the first time by Norman S. Shiren of the International Business Machines Corporation.

The possibility of obtaining two-quantum emission in an optical maser, or laser, had been discussed a year ago by three other IBM workers: P. P. Sorokin, N. Braslau and R. L. Garwin. They pointed out that several advantages would accrue from such a mode of operation: amplification at two frequencies, the use of a wide combination of frequencies, rapid buildup of a giant pulse at one frequency if the other frequency were primed with energy in



Albert Einstein crater and ray systems on the back of the moon as photographed by Zond 3

the form of a high density of photons. The Soviet physicist Aleksandr M. Prokhorov, who shared the 1964 Nobel prize in physics for his contributions to the maser, had independently discussed the possibility of a two-quantum laser. Two-quantum processes, although not applied to masers or lasers, had been investigated theoretically as early as 1931 by Maria Goeppert Mayer, now at the University of California at San Diego.

In the ordinary one-quantum maser an atom that has been raised to a particular excited state is stimulated to return to a lower state when struck by a photon whose energy exactly matches the energy that would be emitted if the atom were to drop to the lower state spontaneously. In the two-quantum maser, stimulation is provided by two photons, represented by input signals of two different frequencies, that together carry the energy needed to match that of the transition between the atom's two states of excitation. It does not matter how the total energy is divided between the two photons; both input signals are amplified.

In the particular device used by Shiren one of the input signals was electromagnetic and the other mechanical, in the form of an ultrasonic vibration. The active material is a crystal of magnesium oxide containing ions of iron or nickel. With the maser immersed in liquid helium, these ions are pumped to a high energy state. When stimulated to return to a lower state, the ions emit one quantum of electromagnetic energy and one quantum of vibrational energy whose frequencies match those of the original electromagnetic and ultrasonic signals. The IBM workers believe it should be possible to build a two-quantum laser that will operate on two input signals that are both electromagnetic.

Molecular Memory of Dawn

Individual nerve cells removed from a mollusk seem to "remember" the time of daybreak and the fortnightly time of particularly high tides. These two pieces of information are presumably important in the mollusk's feeding and reproductive habits. The evidence that the information is stored in individual nerve cells is reported by Felix Strumwasser of the California Institute of Technology.

The mollusk used in the experiments is the sea hare, a sluglike creature six to nine inches long that lives along rockbound coasts. Its extremely large nerve cells, up to half a millimeter in

diameter, make it useful in studies of electrophysiology. The cells employed in the Cal Tech experiments are from the main ganglion in the sea hare's midsection; the ganglion is concerned with feeding, respiration, excretion, reproduction and the ejection of an inky fluid used for concealment.

Strumwasser "trained" sea hares by putting them in a tank that provided 12 hours of light followed by 12 hours of darkness. The sea hares were exposed to this cycle for several days. Then the ganglion associated with feeding was removed and placed in a constant-temperature bath of seawater. By inserting microelectrodes in individual cells Strumwasser could record when the cells produced a nerve impulse.

The "resting" rate of the cells was a few impulses per minute. But periodically, at a time coinciding with the time when the tank lights had been switched on during the training period, the impulse rate shot up to about 40 counts per minute and remained elevated for about three hours. The rate then fell to the resting level until the following "dawn," when the rate increased again. After about 48 hours the isolated nerve cells stopped working, presumably for lack of nutrition. Some of the cells in the ganglion studied by Strumwasser increased their firing rates every 12 hours, as if they remembered evening as well as dawn.

A subtler and at first more puzzling impulse cycle was detected by analyzing the firing peaks of nerve cells of several sea hares covering a two-week period. These peaks did not coincide with either dawn or evening. Strumwasser finally observed that this cycle corresponded to the period of highest tides that occur fortnightly in the sea hare's original home. The memory of this lunar tidal cycle had not been destroyed by the laboratory training cycle.

Strumwasser has preliminary evidence that the firing patterns are related in some way to the production of ribonucleic acid (RNA), giant molecules formed within the cell on templates of deoxyribonucleic acid (DNA). A number of workers have proposed that RNA molecules can encode an organism's environmental experience in analogy with the way DNA encodes the sum total of its genetic history.

Coolest Stars

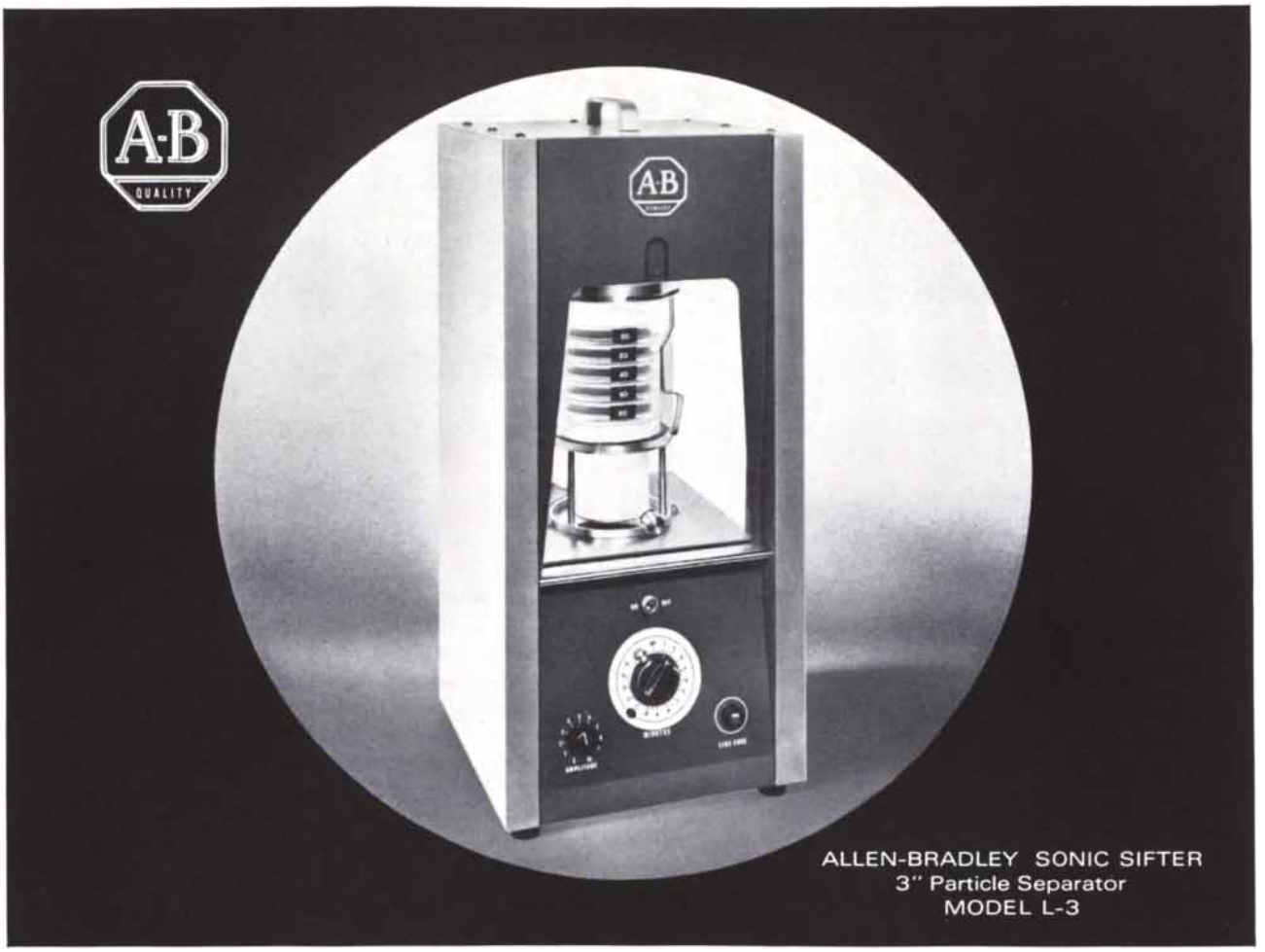
Two stars cooler than any previously known have been found by infrared astronomers of the California Institute of Technology. The surface temperature of one is about 1,200 degrees Fahrenheit and of the other only 800 degrees, which is about the surface temperature of Venus. Both objects, however, are presumed to be genuine stars with interior temperatures high enough to sustain nuclear reactions.

The stars were discovered at the Mount Wilson Observatory with the aid of a new telescope that has a 62-inch aluminized plastic mirror and a speed of $f/1$; in other words, its focal length is equal to its aperture. Light gathered by the mirror is focused on an array of liquid-nitrogen-cooled detectors that measure infrared radiation in two ranges, between .68 and .92 micron and between 2.01 and 2.41 microns (see "Infrared Astronomy," by Bruce C. Murray and James A. Westphal; SCIENTIFIC AMERICAN, August). The new telescope is being used in an infrared sky survey being carried out under the direction of Gerry Neugebauer and Robert B. Leighton. They and D. E. Martz, now at Pacific Union College, have reported the discovery of the cool stars in a recent issue of *The Astrophysical Journal*.

The two cool stars—the cooler one in the constellation Cygnus and the warmer in Taurus—appear as barely visible objects of the 16th magnitude in photographs made with large optical telescopes. The 800-degree temperature of the Cygnus object has been confirmed at the University of Arizona by Harold L. Johnson, Frank Low and David Steinmetz, who made measurements at six different infrared wavelengths.

Like ordinary incandescent light bulbs, the two stars radiate more energy in the infrared spectrum than in the visible spectrum. But whereas a 100-watt bulb yields about 2 percent of its energy as visible light and 5 percent as radiation in the two narrow infrared regions studied by the Cal Tech workers, the comparable figures for the two cool stars are about .01 percent as visible light and 10 percent as infrared radiation in the two regions measured.

"We do not know where in the stellar evolutionary scale such red stars appear," Leighton says. "We don't know whether they are young or old." Nor is their size known. If they are nearby, they could be classed as red dwarfs. If they are far out in the galaxy, they could have diameters as large as a billion miles, or more than 1,000 times that of the sun. Neugebauer and Leighton believe there may be several thousand cool stars within range of their 62-inch infrared telescope.



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CHANCE

The word has many definitions, not all of which apply to the word probability. The vagueness of the concept persistently contributes to errors in its application

by A. J. Ayer

The word "chance" is commonly used in several different senses. One of the things I hope to accomplish in this article is to disentangle them. In some of these senses, although not in all, "chance" is a synonym for "probability." Thus such statements as that the chance of throwing double-six with a pair of true dice is one in 36, that there is a slightly better than even chance that any given unborn infant will be a boy, and that there is now very little chance that Britain will join the Common Market can all be regarded as expressing judgments of probability.

It is to be noted, however, that each of these examples illustrates a different kind of judgment of probability. The first is an example of what is often called a judgment of a priori probability: it relates to the mathematical calculus of chances. The second is an example of a statistical judgment: it estimates the actual frequency with which some property is distributed among the members of a given class. The third is an example of what, for want of a better expression, I describe as a judgment of credibility: it evaluates the degree of confidence we are entitled to have in the truth of some proposition or in the occurrence of some particular event.

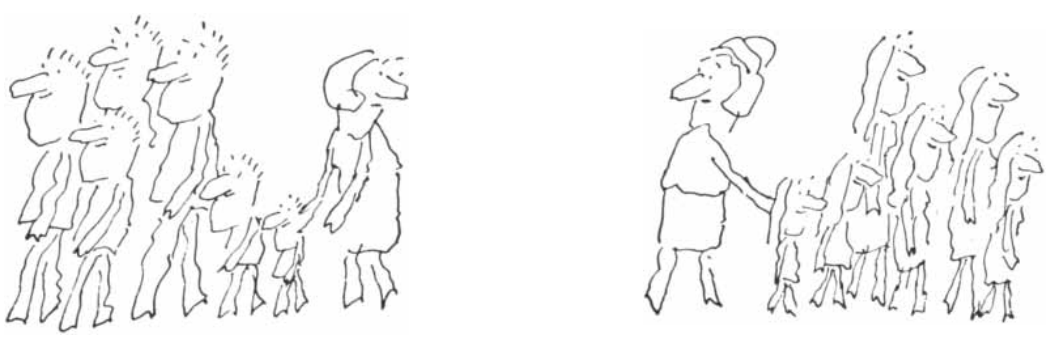
Although any of these judgments of probability can correctly be expressed as an estimate of chances, it is with judgments of the first type that the concept of chance is most closely associated. Thus it is characteristic of what are known as games of chance that their results are substantially in accordance with the a priori probabilities. Our first problem, then, is to try to make clear exactly what this implies.

The Calculus of Chances

In dealing with this problem, the most important point to bear in mind is that the calculus of chances is a branch of pure mathematics. Hence the propositions it sets forth are necessarily true. This point tends to be obscured by the fact that statements such as "The chance of throwing heads with an unbiased penny is a half" are open to more than one interpretation. An unbiased penny (or a true die) could be defined in physical terms as one that was constructed of such and such materials and had its center of gravity in such and such a place. In that case these statements would be statistical; their truth would depend on the actual frequency with which the results in question were obtained with coins or dice that met these physical stipulations.

More commonly, however, what is understood by a true die or an unbiased penny is simply one that yields results matching the a priori probabilities. When our examples are interpreted in this way, they turn into statements of elementary arithmetic. It being presupposed that a penny has two faces, and that when it is tossed it will come down with one or the other of them uppermost, to say that if it is an unbiased penny there is an even chance of its coming up heads is to say no more than that one is the half of two.

Not all our computations of chances are as simple as this, but the principle remains the same. For instance, when it is said that the odds against throwing heads with an unbiased penny three times in succession are seven to one, what is meant is that of all the possible ordered triplets of the numbers 1 and 2—such as 121, 211, 212 and so forth—the sequence 111 is just one out of eight. If we generalize this and say that the odds against throwing heads n times in succession are $2^n - 1$ to 1,



There are no laws of chance in the sense that the laws dictate the pattern of events

what we are saying is that of all the possible ordered n-tuplets of the numbers 1 and 2, the sequence of n 1's is one out of a total of 2^n possibilities.

Now, clearly the value of $1 : 2^n$ diminishes as n increases, and this is what is meant by saying that a long run of consecutive heads or tails or a long run of either red or black at roulette is highly improbable. Whatever the initial fraction representing the chance of a given result for any given turn, the chance of obtaining this result n times in succession will be represented by this fraction raised to the power of n, always provided that the successive turns are independent of each other. This is again a proposition of simple arithmetic. The only empirical assumption being made is that a game like roulette is in fact a game of chance—in other words, that it is possible to construct and operate an object such as a roulette wheel in such a way that the calculus of chances is approximately satisfied by the results.

In applying the calculus to gambling games of this kind the assumption that the turns are independent must be given particular attention. Otherwise one might find oneself committing the celebrated Monte Carlo fallacy, which in this instance can be described as the tendency to think that a run of heads in coin-flipping or of red in roulette increases the likelihood that tails or black will come up on the next turn. As we have just seen, the chances of throwing n successive heads with an unbiased coin or of having a run of n red numbers at roulette are very small if n is at all large; for example, the odds against a series of as few as 10 heads are more than 1,000 to one. Gamblers are tempted to infer from this fact that if n is a large number by these standards and heads have come up $n - 1$ times in succession, the odds against its coming up again the nth time must also be large. Hence a roulette player who has watched red come up nine times in succession will bet heavily on black.

The reasoning, however, is fallacious. The very calculation that makes a long run of red improbable is based on the premise that each spin of the wheel is independent of every other, so that the probability of red—or in the case of the coin the probability of heads —is the same in each instance, no matter what the results of the preceding spins or tosses have been. Even if a million tosses of an unbiased coin had yielded heads on every occasion, the odds against which are astronomical, the chance that it would come up tails on the next toss is still no better than a half.

Many people find this conclusion difficult to accept, because they do not realize that these estimates of chances are no more than the enumeration of abstract possibilities. To say that the odds against a million successive heads are astronomical is merely to say that if we were to list all the possible million-term sequences of heads and tails, the sequence consisting of heads a million times over is just one out of an astronomically large number of alternatives. To say that the odds against heads coming up on the million-and-first occasion are still no more than $1 : 2$ is to say, quite correctly, that one is no less than the half of two.

It will be objected that if we put ourselves in the position of a gambler who has to place his bets, it is not really so clear that the Monte Carlo fallacy is fallacious. If the coin he is tossing is unbiased, it follows by definition that it comes up tails as often as it comes up heads. So if at some stage in the series of tosses a long run of either face of the coin disturbs the balance, the other face will come up more often in order to restore it. Surely, then, the rational course for the gambler to pursue would be to note the relative frequencies with which the two faces have appeared and to support whichever of them has any leeway to make up.

The answer to this assertion is that it would indeed be the right policy if the gambler were justified in making the assumption that there was some finite number of tosses, some number that he could in principle specify, within which equality would be reached. That proposition, however, cannot be derived from the calculus of chances or even from the assumption that the coin is unbiased. If the gambler could know that the coin was unbiased, in the sense here in question, then he would know that any imbalance in the relative frequency of heads and tails would be corrected if the series of tosses were sufficiently continued. As long as no limit is set to the number of further tosses allowed for this end to be reached, however, he can draw no conclusion about the way he ought to bet. All he can say is that if the existing ratio of heads to tails is $m : n$, then the result of the next toss will be to change it either to $m + 1 : n + 1$ or to $m : n + 1$. No matter what numbers m and n may be, and however much one exceeds the other, only these two abstract possibilities exist.

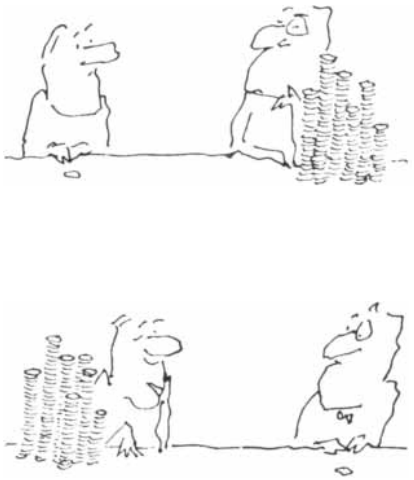
The odds are based on imaginary coins

As far as the calculus of chances goes, there is nothing to choose between them.

An example that may bring this point out more clearly is that of drawing cards from an ordinary pack. Since the number of red and the number of black cards are equal and finite, it is obvious that the greater the preponderance of red cards that have been drawn, the greater is the chance that the next card will be black, provided that when a card is drawn it is not replaced. If, on the other hand, it is replaced, then it is as if the game started afresh with each drawing, so that no matter how large the preponderance of red cards has been, the chance that the next card to be drawn will be black remains even. The Monte Carlo fallacy may then be said to consist in treating the game in which the cards are replaced after being drawn as though it were on a level with the game in which they are not replaced.

It must be remembered, however, that to talk about chance in this way is not in itself to say anything about what is actually likely to happen; it is not to make a judgment of credibility. In actual practice the roulette player who observed that red numbers came up very much more often than black might well conclude that the wheel was biased or that the croupier had discovered some means of spinning it unfairly. Then it would be rational for him to regard the odds on each occasion as being in favor of red.

Whatever view he takes, he has to rely on some empirical assumption, because to suppose that the wheel is true (in the sense that its operations satisfy the calculus of chances) is as much an empirical assumption as to suppose that it is biased. These assumptions are empirical because they are concerned with the way in which some physical object actually behaves. The question is



Deviations from probability may change

whether or not some particular roulette wheel, coin, die, pack of cards or whatever it may be is constructed and manipulated in such a way that any one of a number of equally possible alternatives is realized about as often as any other. In the cases where the results have shown themselves to be unequal—in the sense that one side of the coin, one face of the die, some group of numbers or some distribution of the cards has been particularly favored—it is a matter of predicting whether this bias will continue or whether it will be corrected. This is a question not of abstract mathematics but of fact.

It is true that if there is no limit in theory to the duration of the game, the hypothesis that it is fair can never be strictly refuted. No matter how large the deviations have been found to be, it remains conceivable that they will subsequently be corrected—or at least that they would be corrected if the game were sufficiently continued. Although there is never any logical inconsistency in holding to this assumption, there may come a point at which it ceases to be credible.

Applications of the Calculus

It should be clear by now that no conclusions about any matter of fact can be derived solely from the calculus of chances. There are no such things as the laws of chance in the sense in which a law dictates some pattern of events. In themselves the propositions of the calculus are mathematical truisms. What we can learn from them is that if we assume that certain ratios hold with respect to the distribution of some property, then we are committed to the conclusion that certain other ratios hold as well. If each of a pair of dice has six faces, and in each case the faces are respectively numbered one to six, and in each case when the die is thrown any one face comes uppermost as often as any other, then the sum of the numbers that come up when both dice are thrown will be eight on five occasions out of 36. In other words, the chances of making a point of eight with a single throw of two dice are a little worse than seven to one against.

These other words, however, are misleading, because the proposition in question is merely a proposition about numbers. The references to dice, coins, packs of cards or roulette wheels that occur in expositions of the theory of probability are entirely adventitious. These objects are dummies whose only function is to adorn the mathematical theory with concrete illustrations. The proof that they are dummies is that they exercise no control over the propositions they serve to illustrate. The question is whether they measure up to the theory, not whether the theory measures up to them.

Suppose that someone has brought himself to doubt that the odds against making a point of eight with a pair of dice are more than seven to one, and has decided to test the question by experiment. Suppose further that after recording the results of many thousands of throws he finds that the proportion of times in which his pair of dice has yielded a total of eight is as high as one in five. What has he proved? Perhaps no more than that his dice are biased; at most that tossing dice is not an affair of chance in the way that it has been taken to be, but certainly nothing that has any bearing on the theory of probability.

The fact that the propositions of the calculus of chances are not empirically testable does not, of course, entail that they have no factual application. What we require in order to be able to apply them successfully is to discover a set of possible states of affairs that satisfy the following conditions: (1) that they be finite in number, (2) that they be mutually exclusive, (3) that they be logically equal, in a sense that I shall explain, and (4) that they occur with at least approximately equal frequency. When all these conditions are satisfied, the respective states of affairs may be said to be equally probable.

What I mean by saying that the states of affairs in question must be logically equal is that each state has to be treated as a unity on a level with each of the others. This treatment does not preclude their being complex, in the sense of embracing a number of alternatives. If any member of the set is represented as a disjunction of such alternatives, however, we must not allow these disjuncts themselves to rank as members of the set. Otherwise we shall find ourselves falling into contradiction.

For example, it has been held by some writers that in a case where we have no evidence either for or against a given proposition, we are entitled to assume that it is equally likely to be true or false. Suppose, then, that I am playing a game of drawing marbles from a bag and that, relying on this principle, I take it to be an even chance that the first one to be drawn will be blue. This would be a foolish assumption to bet on, but it would not be contradictory as long as I treat not-blue as a single color on a level with blue. If, however, I follow the natural course of breaking down not-blue into a disjunction of other colors—and if, by parity of reasoning, I also take it to be an even chance that the first marble to be drawn will be black, an even chance that it will be red, an even chance that it will be green and so forth—then I am involved in contradiction. If there are more than two possibilities, it is impossible that each of them should have an even chance of being realized. This is again a question of simple arithmetic. One is not the half of any number higher than two.

To avoid contradictions of this sort, we have to decide at the outset what possibilities we are going to regard as logically equal and then adhere consistently to our decision. As Rudolf Carnap of the University of California at Los Angeles has shown in his *Logical Foundations of Probability,* such decisions can be taken on purely semantic grounds. We can construct a language with a limited number of primitive predicates and the power to refer to some finite number of individuals; we can then decide, in a more or less arbitrary fashion, that certain states of affairs, which are describable by these means, are to be counted as equally probable, and we can select our logical operators in such a way that the probability of any possible state of affairs within the selected universe of discourse can be calculated on this basis. This procedure, however, has an unduly narrow application; moreover, there is no reason to suppose that our judgments of equal probability will conform to anything that actually happens.

On the other hand, if we follow a more liberal course by relying on *ad hoc* estimates of what it seems fair to regard as equal possibilities, we shall come on situations in which what appear to be equally reasonable decisions will lead to incompatible results. I borrow a simple example from an article by J. L. Watling of University College London. Suppose "we are following a man along a road and reach a place where the road divides into three, two paths climbing the hillside, one lying in the valley." Knowing nothing but that the man, now out of sight, will take one of the three paths, how are we to estimate the probability that he will take the path lying in the valley? If we follow the classical procedure of assigning equal probability to equal possibilities, and if we regard it as equally possible that the man will take any one of the three paths, we shall have to conclude that the chance of his taking the valley path is one in three. But we might just as well regard it as equally possible that he will go into the valley or into the hills, and in that case it would follow that the chance of his taking the valley path was one in two. These conclusions are mutually incompatible, but in default of further information there is nothing to choose between them.

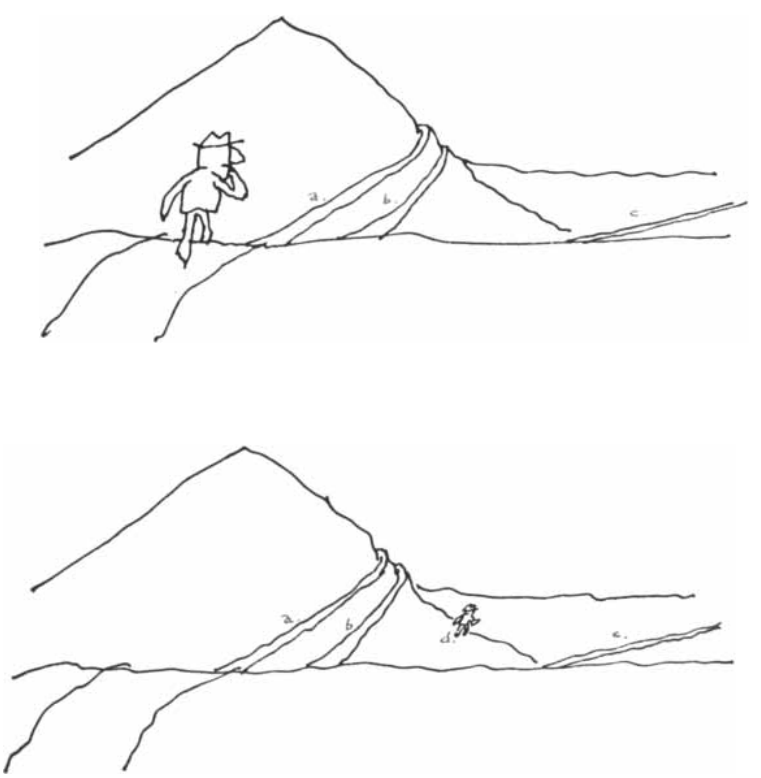
Watling takes this situation as a proof that "the classical interpretation" of probability is inconsistent. I should prefer to say in cases of this kind that it was inoperative. The calculus of chances is not inconsistent in itself. As long as we have a consistent rule for deciding what states of affairs are to count as equally possible, the calculus can be consistently applied. If its application is to be of any use to us, however—in the way of helping us to win our bets on what will actually happen—we cannot allow the assignment of initial probabilities simply to depend on an arbitrary decision. In the example chosen, if we really knew nothing more than that the man would take one of the three paths, we should have no right to assume either that it was equally likely that he would take any one of the three or that it was equally likely that he would go into the valley or into the hills. Before we could make any such assumptions, we should have to have something further to go on than the mere arithmetical fact that one is the half of two or the third part of three. We should need some factual information such as the man's habits in order to supply the calculus of chances with a foothold in reality. In general, we cannot assume that any two states of affairs are equally probable unless we have reason to believe that they occur with equal frequency. But pure mathematics cannot tell us anything about actual frequencies, and neither can semantics. We must rely on empirical evidence.

The upshot of this argument is that when we come to apply the calculus of chances, our judgments of probability undergo a change of character: they become statistical judgments. To say that there is one chance in eight that a true coin will come up heads on each of three successive tosses may, as we have seen, be just a colorful way of expressing an arithmetical truism, but to say the same applies to the penny that I have in my hand is to make the empirical statement that if it were tossed on a fairly large number of occasions and the results were set out in groups of three, the sequence heads-heads-heads would be found to occur on the average once in eight times. This is, indeed, a consequence of the more general assumption that in a sufficiently long series of tosses with this penny each of the possible sequences of a given length would occur on the average as often as any other.

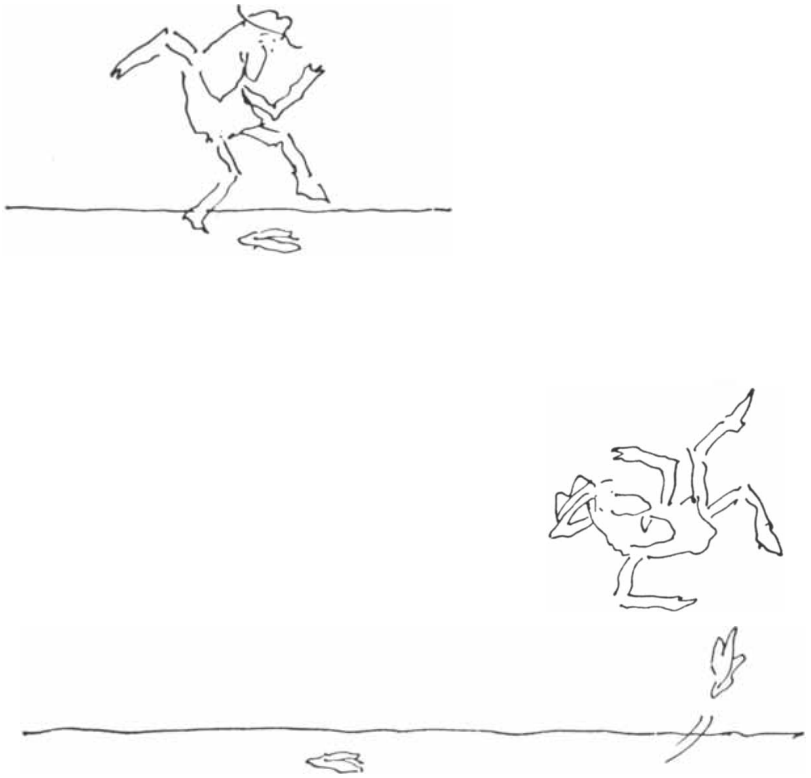
Here, however, we are faced with the difficulty that unless some limit is set to the length of the sequence within which this equality is to be realized, the empirical evidence in favor of such an assumption is bound to be incomplete. Even if a limit were to be set, so that we could in principle run through all the members of the series to which our judgment of probability refers, it is only as long as we have not done this that a judgment of this kind is of any interest to us. When we already know that a given event has occurred or that it has failed to occur, we do not speculate about its chances. The point of collecting statistics is to extrapolate them.

Samples and Classes

In other words, we normally examine only a sample of the total class of events in which we are interested; if we find that the property about which we are inquiring is distributed in a certain proportion among the members of this sample, we infer that it would be distributed in much the same proportion among the members of a further sample or throughout the class as a whole. Admittedly if we were to toss our penny 50 times, say, and found that heads came up in the ratio of three to two, we should not feel ourselves bound to regard this as a typical sample. In default of physical evidence that the penny was biased, we might rather expect that if the series of tosses were continued, the balance would be re-



What is the probability that the man will take one of three paths?



Confidence that one has beaten the odds may be misplaced

dressed. But the reason for this expectation would be that we were influenced by our knowledge that pennies physically similar to this one had been found to come up heads about as often as they came up tails. In so thinking we should be drawing on a wider range of statistics, but we should still be going beyond our evidence. We should in fact be making a deduction from a general hypothesis about the distribution of heads and tails—a hypothesis that had been derived from our knowledge of their distribution in a reasonably large sample.

The question is how such a procedure can be justified. The usual answer is that inferences from the character of a sample to the character of the total class or population from which the sample is drawn are logically justified (provided that the sample is large enough) by the law of large numbers. I shall not go into the mathematical formulation and proof of this law, which is to be found in the standard textbooks. What it comes to is that if a proportion $m : n$ of the members of some class possess the property P and we select from this class all possible samples of a given size, it must be true of the majority of these samples that the proportion in which P is distributed among their members also lies in the neighborhood of $m : n$. Moreover, as the size of the samples increases, so does the extent of the concentration around $m : n$, with the result that if the samples are made large enough, the frequency with which P occurs in practically all of them will differ only negligibly from the frequency with which it occurs in the parent class.

A common way of expressing this fact is to say that it is very highly probable that the distribution of a property throughout a given class is almost exactly reflected in any large sample drawn from that class; and since if A matches B it must also be true that B matches A, it will follow that if a property is distributed in such and such a proportion among the members of a large sample (A), there is a very high probability that it is distributed in approximately the same proportion among the members of the class (B) from which the sample has been drawn. It is in this way that the law of large numbers is thought to justify this familiar type of inference.

There is, however, a point to be made here that is rather too often overlooked. When one speaks in this context of its being highly probable that what is true of a large sample is also true of the parent class, this judgment of probability belongs to the first of my three types. It is not a judgment of credibility but a judgment that relates merely to the distribution of logical possibilities. What one is saying in fact is that among all possible samples of the size in question the number of those that roughly match the parent class is very much greater than the number of those that do not. It follows that if our sample is seriously deceptive with respect to the incidence of some property in the class from which it is drawn, it is highly untypical. This is all that follows. Even to say that the sample is untypical does not mean that it deviates from most of the samples that are actually drawn but only that it deviates from the vast majority of possible samples. This is the most that can be extracted from the law of large numbers.

But is it really likely that our sampling of nature should be untypical? The trouble with this question is that it smuggles in a judgment of credibility, for which no basis has yet been assigned. If we make suitable assumptions about the constitution of the universe, we can supply ourselves with premises from which to deduce that our sampling is fair. The premises will themselves need to be justified, however, and I do not see how this can be done except by an appeal to our experience. Then, as David Hume saw, we are landed in a circle, because this appeal to our experience makes use of the very assumptions we are attempting to justify. I am strongly inclined to think that this circle is unavoidable, but to develop this argument would lead me into the heart of the problem of induction, which I shall not attempt to penetrate here.

A Valid Application

I have tried to show that although there is nothing wrong with the law of large numbers in itself, the support it gives to arguments from inverse probability—the reasoning that a large sample is unlikely to deviate in character from its parent class—is much more precarious than has commonly been supposed. There is, however, one set of cases in which an argument of this type can be applied with complete safety. These are the cases in which the class that concerns us is finite and the unexamined portion of it is relatively very small. Suppose we know the total number of births within a given area throughout a given period but our statistics on their sex distribution are not quite complete. Then let the fraction of the class for which this information is lacking be comparatively small, say less than 3 percent. In that case, whatever the proportion of male births in our sample may be, we can be sure

that the proportion in the whole class does not differ from it much, just because there are not enough unexamined instances to make any substantial difference. By supposing all of the births in the unexamined instances to be male or all of them female, we can establish the fairly narrow limits within which the correct answer for the whole class must lie.

We now find, however, that the very security of this conclusion robs it of any interest. It tells us no more than we know already. The prospective father who wants to know whether his child is more likely to be a boy or a girl learns nothing at all to his purpose from the information that the available statistics are such that the proportion of boys among the children born or about to be born within the relevant period is bound to be more than 50 percent. All he learns is that the figures have now reached a stage where it is not going to make any appreciable difference to the final percentage which his child is. Not only can he deduce nothing about the sex of his own child—since judgments of probability, in the sense of frequency, refer to classes and not to individuals—but also he can deduce nothing about the frequency of male births in the subclass of so-far-unexamined cases to which his child belongs.

In fact, the ratio of male to female births has been found to be fairly constant, so that if the statistics had shown that slightly more female children had been born so far in the course of the year, the prospective father, knowing that there was normally a slight preponderance of males, might be encouraged to expect that his child would be a boy as the result of a belief in what is popularly known as the law of averages. If he did argue in this way, he could easily be disappointed. What is not generally realized is that the law of averages only works deductively. If we already know, with respect to the incidence of some property in a limited series of events, what the final percentage is going to be, and if we also know what the percentage is in the part of the series that has already been traversed, we can calculate what the percentage will be in the instances still to come.

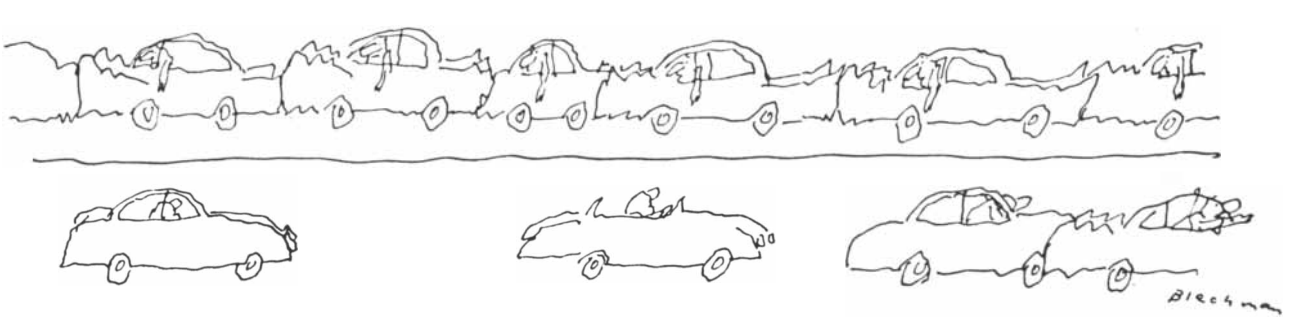
This situation, however, carries the consequence that the law of averages can only be applied with any safety when it is backed by statistical laws that are very well established. We might perhaps rely on the Mendelian laws of heredity for the assurance that if a recessive character had already appeared in a given generation among the members of a certain family of plants or animals, the character of the kind in question that would be displayed in the same generation by the remaining members of the family would be dominant. On the other hand, it would be a foolish man who argued that because the total number of automobile accidents in the current year had already risen to the average of previous years, he could drive as recklessly as he pleased, since the law of averages would keep him safe. The reason he would be foolish is not only that the incidence of automobile accidents is not known to fall under any very constant statistical laws but also that for the most part these accidents, although they may be in some measure due to common causes, are causally independent of one another. The fact that a number of accidents have occurred recently in your neighborhood does not make it any less likely that another one will occur there today—unless, perhaps, the knowledge that the accidents have occurred makes people more careful. Certainly the occurrence of another accident is not made any less likely by the law of averages.

The same reasoning applies to our example of the prospective father, in spite of the greater constancy of the birth statistics. Whatever factors may determine the sex of his child, there is no reason to believe that the sex of other children who are not his kindred but merely happen also to be born in the current year has anything to do with it. Consequently, if there has been an unusual preponderance of female births, the inference he should draw is not that there is any greater likelihood that his child will be a boy but rather that this is a year in which, for a multiplicity of reasons, the usual balance of the sexes has been altered.

Questions about Chance

We have seen that what is required for the application of the calculus of chances is a finite set of logically equal possibilities, which are fulfilled in the long run with equal frequency. It is because we suppose these conditions to be at least roughly satisfied in games played with coins, dice, cards or roulette wheels that we characterize them as games of chance. Conversely, if we play one of these games and find in a particular instance that the different possibilities are not fulfilled with anything like equal frequency, we may decide that the results are not to be ascribed to chance. Then we look for some other explanation.

It is not only in gambling games that this procedure operates. Very often, when a statistical result is said to be significant, what is meant is that it deviates from chance in the sense that it fails to accord with the a priori probabilities. A good illustration of this is to be found in the experiments that are supposed to prove the existence of extrasensory perception. A typical experiment might be conducted with a set of cards numbered one to five and another set of five cards respectively symbolizing a lion, an elephant, a pelican, a zebra and a giraffe. Both packs are shuffled; the experimenter draws a card from the numbered pack, and then he draws from the animal pack the card that corresponds in order to the number he has drawn. This procedure is repeated 100 times, the cards being replaced and the packs reshuffled after each drawing. The subject is required to say on each occasion which animal



A rise in the number of accidents does not imply that there will be a drop to maintain the statistical average

Apparent extrasensory perception in drawing cards may involve other factors

is represented by the card drawn from the animal pack.

It is assumed that if it were merely a matter of guesswork he would be right, on the average, 20 times out of 100. Sometimes, however, a subject fairly consistently gets as many as 28 right. This result is sufficiently improbable to be counted as statistically significant. It is therefore inferred that the subject's achievement cannot be put down to chance, and he is credited with extrasensory perception. (Admittedly, to talk of extrasensory perception is not to give any explanation of the subject's performance but merely to stake the claim that an explanation is called for, but this does not matter for our present purposes. Our only concern is with the meaning and implications of the statement that such things do not occur by chance.)

Let us look into this case a little more closely. Why is it assumed that if the subject had no special power of divination he would pick the right card about 20 times out of 100? The answer is that if we take every possible sequence of 100 drawings from this set of cards and every possible sequence of 100 guesses, then the proportion of cases in which the two selections match is 20 in 100. To say that it is rather improbable that as many as 28 guesses should be right is just to say that out of the total number of possible parallel sequences of 100 drawings and guesses, the proportion in which the two coincide in as many as 28 places is rather small.

It is to be noted that both these calculations are a priori. They relate to the distribution of logical possibilities and are in no way derived from the study of anything that actually happens. Why, then, should we regard it as a matter of no interest—as something only to be expected—that the series of guesses should match the series of drawings in the same proportion as the total of possible matches stands to the total of possible combinations, but think it quite extraordinary that a subject should achieve a number of matchings 8 percent higher than the a priori average? Why should it be more remarkable that the proportion of actual coincidences should deviate from the proportion of possible coincidences than that they should be in conformity with one another? What we must be assuming is that the natural thing in a card-guessing game of this kind is for every possible combination of the members of the two series to appear with equal frequency. What reason could we have for making

such an assumption antecedently to any experience? As far as I can see, none whatsoever.

If I am right about this, we are not entitled to assume that it is only a deviation from the a priori frequencies that calls for explanation. Conformity with them may equally have to be accounted for. In fact, there are many cases in which this necessity seems to be recognized. If a coin, a die or a roulette wheel yields "improbable" results, if it favors one side or area at the expense of the others, we do indeed assume that some physical bias is at work: the coin is weighted; its center of gravity has been displaced. Yet equally we think that there is a physical explanation in the case where such objects run true. It is quite an art to make dice and roulette wheels operate in such a way that each number comes up in a reasonably long run about as often as any other. There are physical reasons for this just as much as there are for the fact that one number or set of numbers comes up much more often than the others. In the sense in which chance is contrasted with design, or a chance event is one to which we do not assign a cause, it is not by chance that these operations obey the laws of chance.

Antecedently to experience, then, we have no more reason to expect that the results of tossing coins or throwing dice will conform to the a priori probabilities than that they will deviate from them. The reason we think that results that are highly improbable in this sense call for a special explanation is that they are empirically abnormal. What is significant is not the deviation from the a priori frequencies but the deviation from frequencies that have been empirically established. The special interest we take in the case where a die turns out to be biased stems from the fact that we have found by experience that most dice run true.

I believe that the same applies to the other cases in which we conclude, on purely statistical grounds, that such and such an occurrence cannot be ascribed to chance. Suppose that wherever I go in the course of a day I keep running across the same stranger. I may well conclude that this cannot be a matter of chance: the man must be following me. But my reason for this conclusion is not that our meeting so often is improbable a priori. Of course, I could argue in that way. Starting with the assumption that we are both moving within a certain limited area, I could think of this area as divided into a finite number of equal squares, like a chessboard, and then make the assumption that each of us is as likely at any moment of the day to be in any one of these squares as in any other. My reason for concluding that we were not meeting by chance would then be that out of the total number of possible paths we could severally follow, the number of those that intersected at several places was only a tiny fraction. But not only is this line of argument not necessary for me to arrive at my conclusion; in addition it rests on a premise that is entirely open to question. If the assumption that each of us is as likely to be in any one square as in any other at any given time is merely a way of stating that the squares are equal, then it is true *ex hypothesi* but is not to the purpose. If it implies that over a certain period of time we are actually to be found in any one square as often as in any other, then, in default of empirical evidence, there can be no reason for accepting it. If I nevertheless conclude that these meetings do not occur by chance, my reason will be that experience has shown me that when two people are living independently in a large city with many different venues for business and for recreation, the occasions on which their separate pursuit of their affairs leads them to be in the same place at the same time are relatively few. Here again, what needs to be particularly explained is the deviation not from an a priori frequency but from an empirically established one.

This is also, in my view, the way we should interpret the card-guessing experiments. Antecedently to experience, there is no reason to believe that the degree to which any series of guesses matches any series of drawings will or will not reflect the distribution of the logical possibilities. What is known a priori is that any card drawn will be one of five possibilities, and that any guess will also be one of five possibilities, but from this nothing at all follows about the number of matchings that will actually occur. We have to discover by experiment that certain methods of shuffling and selecting the cards do have the result that any one of them comes up about as often as any other. We have also to discover by experiment that the guesses people make are evenly distributed; or if this is not true, as for psychological reasons it may well not be in many instances, that their tendency to favor certain choices does not result in a number of matchings that is higher than the average. From these empirical premises the standard conclusions about the results that would occur by chance do follow mathematically.

But then if the results show a significant deviation, what is put in doubt is the truth of one or other of the empirical premises. The only thing that is remarkable about the subject who is credited with extrasensory perception is that he is consistently rather better at guessing cards than the ordinary run of people have shown themselves to be. The fact that he also does "better than chance" proves nothing in itself.

The same confusion is commonly found in discussions of the question whether or not the universe exists by chance. It is not, indeed, immediately clear what meaning this question could be given in terms of the a priori calculus of chances. If, however, one can make the assumptions that there is a finite number of ultimate particles in the universe and that the space in which they operate is also finite, then I suppose it could be said that the actual state of the universe is highly improbable, in the sense that the actual distribution of the particles is only one of a fantastically large number of possible distributions. In this sense, of course, any other distribution of the particles would be equally improbable, but it might be argued that their actual distribution was more improbable than some others would be, on the ground that it exhibited a greater deviation from the a priori average.

Alternatively, if we were able by what would have to be a rather arbitrary procedure to draw up a finite list of the simple properties that it was logically possible for anything to have, we might say that the actual state of the universe was improbable in the sense that the number of ways in which these properties were actually found to be com-

Misconceptions of chance are persistent

bined was only a tiny fraction of the total number of possible combinations. In neither case, however, would anything of interest follow unless we had reason to believe that some different constitution of the universe from the one that actually obtains was antecedently more likely. But what reason could there possibly be for such a belief? What meaning can be attached even to this notion of antecedent likelihood?

The most that we can say is that given the number of fundamental particles and the finitude of space, or given the number of primary properties and the range of their possible combinations, the number of possible universes in which the particles are more evenly distributed or the combinations of properties are more various is larger than the number of those in which the particles are not more evenly distributed or the combinations of properties are not more various than they are in our actual universe. But should it be supposed that a more probable universe, in this special sense, is more to be expected than the one in which we actually find ourselves? The answer is that there can be no reason at all for any supposition of this kind. The concept of a priori probability relates only to the counting of logical possibilities. How probable it is that these logical possibilities are realized in a balanced or unbalanced way can be estimated only in the light of our experience. But we can have no experience of a universe other than our own.

It is perhaps worth adding that the fact that our universe can be said to be improbable, in the senses I have just defined, does nothing at all for the traditional argument for a universe arising from design. In order to give any force to this argument, it would have to be shown that we have good reason to believe first that the universe is a teleological, or purposive, system. Secondly, it would have to be shown that it is the kind of teleological system that has been demonstrated by our experience to be usually the result of conscious planning. I take it to be sufficiently obvious that neither of these conditions is actually satisfied.

Chance, Design and Cause

We are now in a position to distinguish with some precision the various senses in which we speak of things as happening by chance. Chief among them are these five:

1. A chance event may be one that is a member of some series that conforms, in the manner we have shown to be required, with the a priori calculus of chances. (It is to be noted that this does not imply that the event is not caused, or even that it is not designed. The results of individual tosses of a coin or throws of a die are commonly not designed, but it is often the fruit of design that the series as a whole conforms to the a priori calculus.) A corollary of this usage is that when the frequency with which a certain type of event has been found to occur conforms to the a priori calculus and we meet with a significant deviation, as in the case of the card-guessing experiments, our inclination is to say that this deviation cannot be attributed to chance.

2. On the other hand, there are cases in which our reason, or one of our reasons, for saying that an event occurs by chance is just that it is a deviation from an established frequency. This is the sense, for example, in which we talk of chance mutations in biology. A similar usage occurs in historical instances where we look on the cause as incommensurate with the effect. "For want of a nail the shoe was lost, for want of a shoe the horse was lost, for want of a horse the rider was lost, for want of the rider the battle was lost, for want of the battle the kingdom was lost, and all for the want of a horseshoe nail." We say it was a mischance that the kingdom was lost because we do not ordinarily expect something so trivial as the loss of a horseshoe nail to have such far-reaching consequences. There is also the point that the loss of a nail at such and such a moment is not easily predictable, although again this is not to say that it lacked a cause.

3. When we are speaking of events brought about by human beings, or by other animals insofar as they can be regarded as purposive agents, to say that an event occurs by chance often means no more than that it was not intended by the agent or, in some cases, by anybody else. This is the sense in which "by chance" is contrasted with "by design." Again there is no implication that such events are not caused, but rather the implication that they are.

4. We talk of chance collocations of events when their concurrence is not designed and when, although we may be able to account for them severally, we have failed to establish any lawlike proposition that binds them together. The ascription of such concurrences to chance is most often made in cases where something of particular interest

follows from them or in cases where the concurrence would normally be the fruit of design. Thus if I go away on holiday and in the course of my journey keep running into friends whom I had not arranged to meet, I am struck by the coincidence, although in fact it is no more of a coincidence than my meeting anybody else. As we have seen, however, if such encounters become excessively frequent, I may begin to suspect that they are not occurring by chance. In general, to speak of events as coming together by chance does not imply that they are not connected in a lawlike way or that no law connecting them will ever be discovered, but only that no such laws figure in our accepted system of beliefs.

5. In the case of statistical generalizations it can be said to be a matter of chance which of the individuals that fall under the generalization display the property in question and which do not. Thus in the case of a law of genetics we can be confident that just one out of n individuals in the third generation will display some recessive characteristic, but we regard it as a matter of chance which one of them it will be. In microscopic physics one may accept the generalization that m out of n electrons will move from one orbit to another within a given period but regard it as a matter of chance which individuals move and which remain. This usage of chance is the only one in which it is implied that the individual events themselves, as distinct from their concurrences, have not been found capable of being brought under causal laws.

Actually, might not such events be the outcome of chance in an even stronger sense? Might it not be the case not only that we had been unable to subsume them under causal laws but also that there really were no causal laws that governed them? This is not an easy question to answer, partly because it is not clear what would count as an instance of such a chance event. One difficulty is that if no limit is set to the complexity of our hypotheses, then as long as we are dealing with a closed set of events we shall always be able to find some generalizations the hypotheses satisfy. It might be stipulated, however, that such generalizations were not to be counted as laws unless they applied to events outside the set they were already known to cover, and it might in fact turn out in certain domains that we never succeeded in making any such extrapolations. If this led us to conclude that the phenomena in question were such that attempts of this kind never would succeed, we could reasonably express the conclusion by saying that the phenomena contained an irreducible element of chance.

There are, indeed, those who maintain that this stage has already been reached in quantum physics, but this is still a matter for dispute. The ground for saying that determinism has broken down in this domain is that the determinism that was postulated in classical physics required that it be possible, at least in principle, to ascertain the position and momentum at any given instant of all the particles in the universe. This is a condition that microscopic particles do not satisfy. It can still be argued, however, that this reasoning does not logically preclude their falling into some deterministic pattern. Even so, the fact remains that such a pattern has not yet been found. Until it is found, the view that the fundamental laws of physics are not causal but only statistical would appear to hold the field.

I think there is another important sense in which chance can be held to intrude into the world. Even in a field in which causal laws are well established, there is often a certain looseness in the way they fit the facts. The phenomena that are taken as verifying the laws cover a certain range. If the phenomena are quantitative, the values actually recorded may be scattered around the values the law prescribes. These slight deviations are not held to be significant; they are ascribed to errors of observation.

"Errors of observation," however, is here a term of art. Apart from the existence of the deviations there is usually no reason to suppose that any errors have occurred. Now, I think it possible that this looseness of fit cannot be wholly eliminated; in other words, that there are limits to the precision with which the course of nature can be prospectively charted. If this were so, it might be said that anything that fell outside these limits remained in the hands of chance.

Of course this cannot be proved. Whatever limit is set, there can be no a priori reason for assuming that it will never be overstepped. The person who believes in chance, in this absolute sense, can properly do no more than issue a challenge. He points to certain features of the world and defies anyone to show that they fall entirely in every detail within the grasp of causal laws. But however long he triumphs, there remains, in yet another of the manifold senses of "chance," the chance that his challenge will eventually be met.

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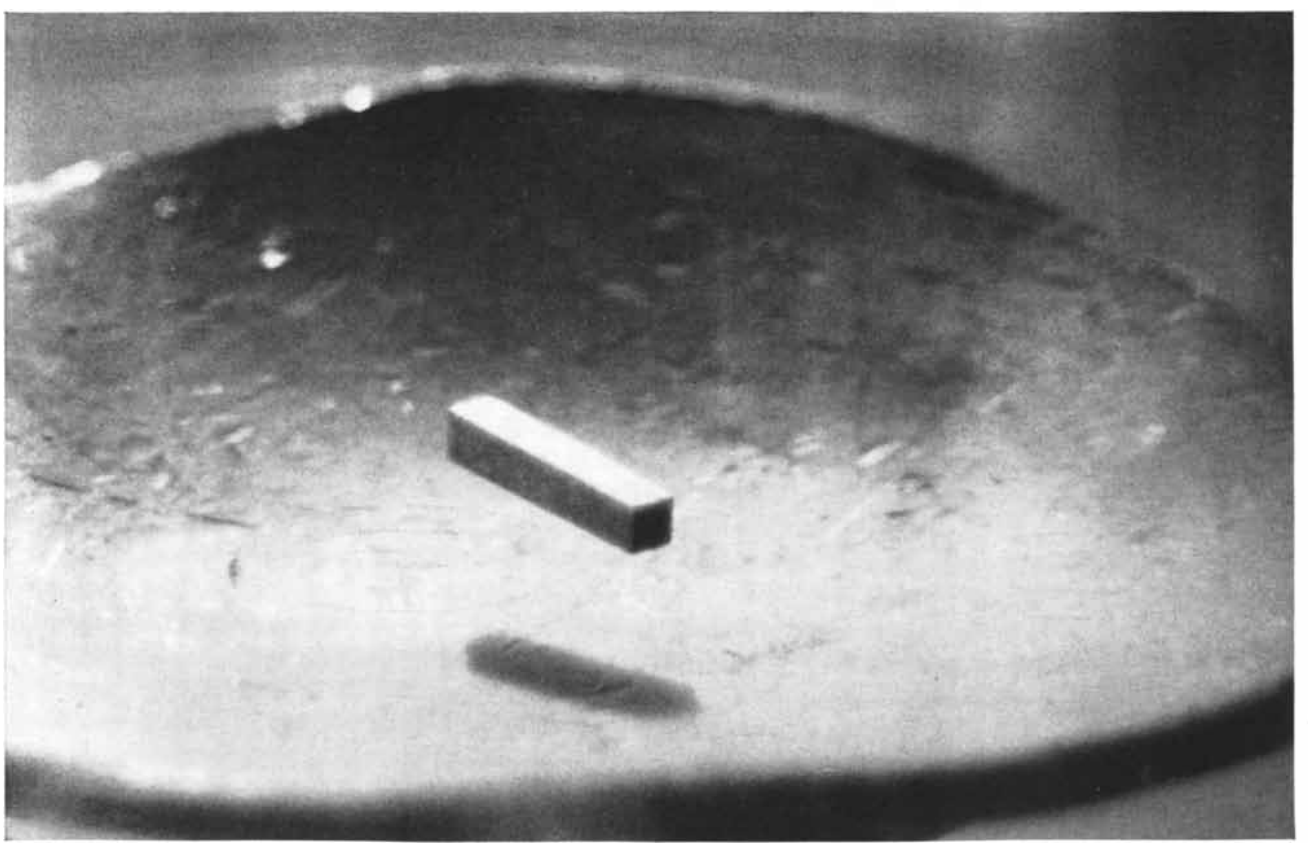
Quantum Effects in Superconductors

In a superconductor the motions of widely separated electrons are related. This leads to curious consequences when superconducting bodies of various shapes and sizes are placed in a magnetic field

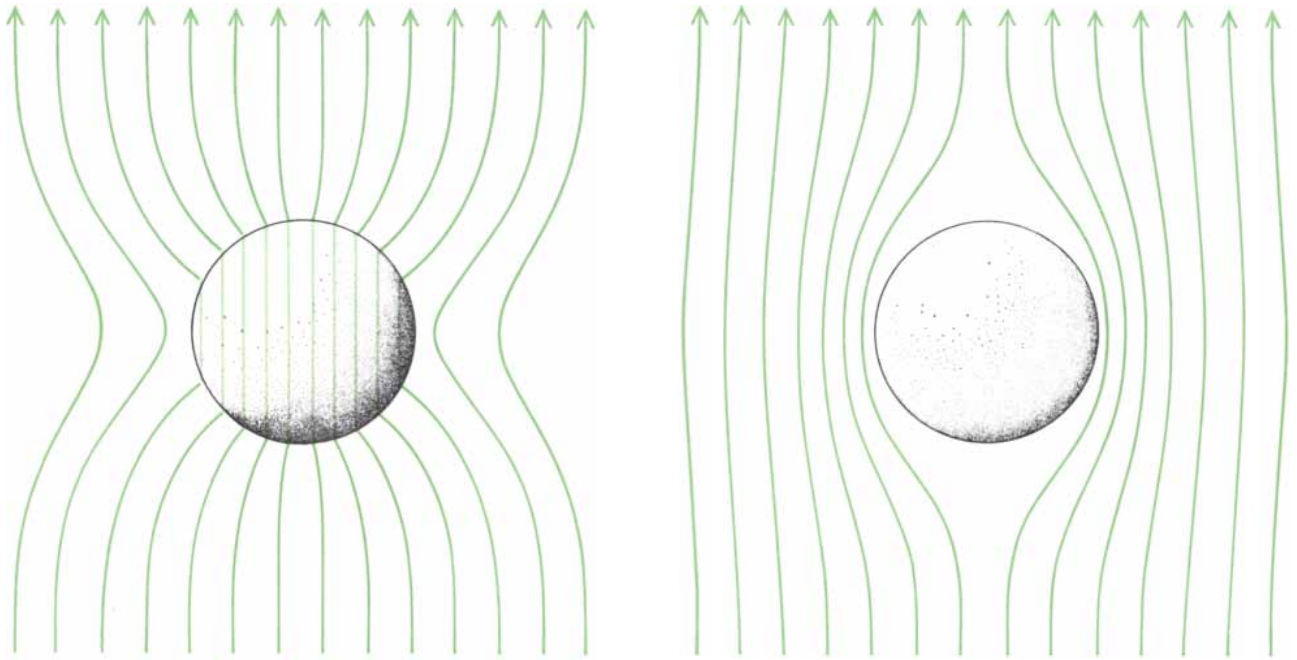
by R. D. Parks

Of the two basic properties of the superconducting state, one—the complete disappearance of resistance to an electric current in certain metals at temperatures near absolute zero—is widely known. Discovered in 1911 by the Dutch physicist Heike Kamerlingh Onnes, this property is responsible for the term "superconductivity"; it has also provided the inspiration for many of the more or less speculative schemes put forward in recent years to exploit this strange condition of matter at very low temperatures [see "Superconducting Computers," by William B. Ittner III and C. J. Kraus, SCIENTIFIC AMERICAN, July, 1961; "Superconducting Magnets," by J. E. Kunzler and Morris Tanenbaum, June, 1962, and "Superconductivity at Room Temperature," by W. A. Little, February, 1965].

The second basic property of the superconducting state is not so well known. In 1933 W. Meissner and



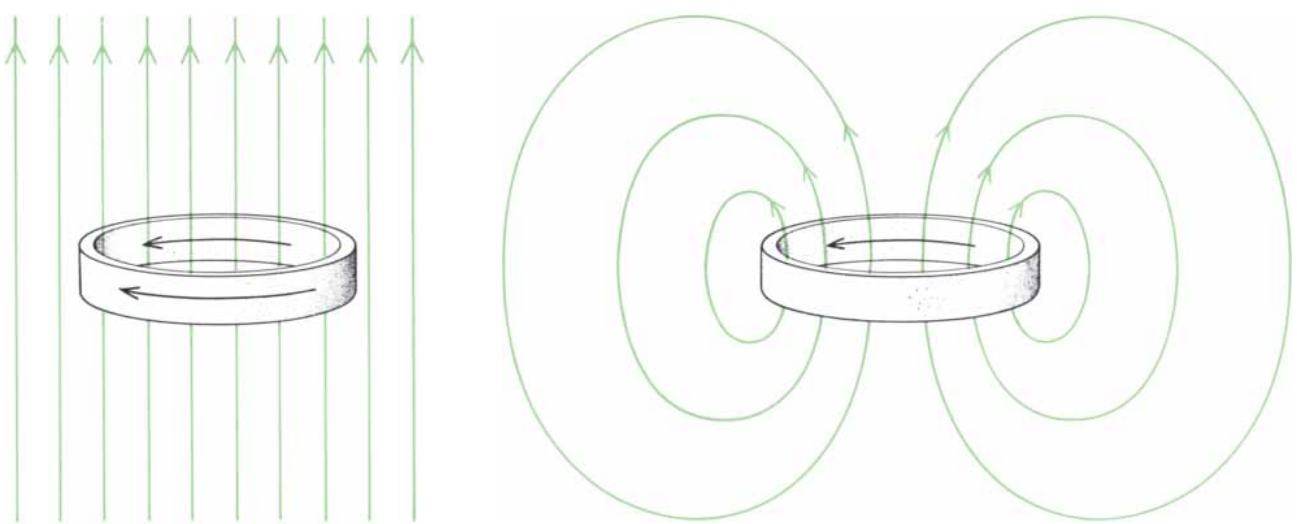
BAR MAGNET FLOATS above a concave bowl of superconducting lead in this demonstration of the Meissner effect, a basic property of the superconducting state discovered by W. Meissner and R. Oschenfeld in 1933. The magnetic field of the bar magnet sets up electric currents in a thin layer at the surface of the superconducting bowl. These currents in turn produce a magnetic field that is opposite to the field produced by the bar magnet and just large enough to cancel the field within the bowl. Thus the magnetic field of the bar magnet is completely excluded from the lead and the magnet rests on the "cushion" of its own magnetic field. In this photograph, which was made by G. W. Hughes in the laboratory of Alfred Leitner at Michigan State University, the magnet floats in air; the bottom of the lead bowl is immersed in liquid helium at 4.2 degrees Kelvin (4.2 degrees centigrade above absolute zero).



MEISSNER EFFECT in a superconductor can be viewed as the converse of the phenomenon of ferromagnetism. A ferromagnetic body (*sphere at left*) concentrates the lines of force in a magnetic field, whereas a superconducting body (*sphere at right*) pushes them out.

R. Oschenfeld discovered that in addition to its perfect conductivity a superconducting body completely expels an externally applied magnetic field. This magnetic impermeability is not a necessary corollary of perfect conductivity, which merely requires that any interior magnetic field not vary with time. In effect a superconducting body is the converse of a ferromagnetic one: an iron magnet concentrates the lines of force in a magnetic field, whereas a superconductor expels them [*see illustration above*].

The expulsion of a magnetic field by a superconductor, a property that has come to be known as the Meissner effect, is in its own right the source of many potential and realized applications. What is more, it has played an important role in the development of a theory of superconductivity that is consistent with the overall approach of modern quantum mechanics. This article describes some recent experiments that confirm a quantum-mechanical picture of superconductivity suggested



SUPERCONDUCTING RING exhibits a peculiar variation of the Meissner effect when it is placed in a magnetic field. If such a ring —made, say, of lead—is cooled from the normal conducting (or electrically resistive) state to the superconducting (or electrically nonresistive) state in the presence of a magnetic field (*left*), electric currents are set up that flow in one direction on the outside surface of the ring and in the opposite direction on the inside surface of the ring. This distribution of current effectively shields the interior of the ring from the magnetic field, but it leaves the strength of the field inside the hole of the ring unchanged and equal to the applied field. If the applied field is now turned off (*right*), the currents on the outside surface of the ring disappear, but the currents on the inside surface of the ring persist as long as the ring is kept sufficiently cold. Thus the magnetic field in which the ring was originally cooled is "trapped" in the hole of the ring as long as the ring is maintained in the superconducting state.

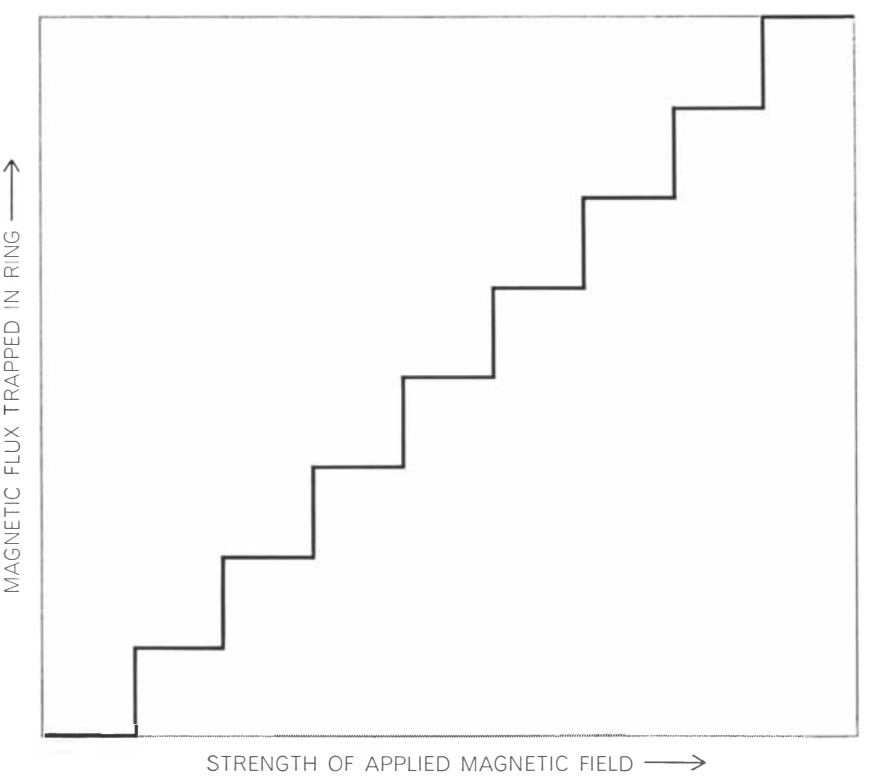
nearly 15 years ago to account for this second basic property of the superconducting state.

The Meissner effect can be explained in a general way as follows: An external field sets up electron currents in a thin layer at the surface of a superconducting body; these currents in turn produce a magnetic field that is opposite to the applied field and just large enough to cancel the applied field within the body. This general picture is inadequate, however, to deal with certain special cases involving the Meissner effect. Consider, for example, a superconducting ring [*see bottom illustration on opposite page*]. If such a ring—made, say, of lead—is cooled from the normal conducting (resistive) state to the superconducting (nonresistive) state in the presence of a magnetic field, electric currents are set up that flow in one direction on the outside surface of the ring and in the opposite direction on the inside surface. This distribution of current effectively shields the interior of the ring from the magnetic field, but it leaves the strength of the field inside the hole of the ring unchanged and equal to the applied field. If the applied field is now turned off, the currents on the outside surface of the ring disappear, but the currents on the inside surface persist as long as the ring is kept cold enough. Thus the magnetic field in which the ring was originally cooled is "trapped" in the hole as long as the ring remains in the superconducting state.

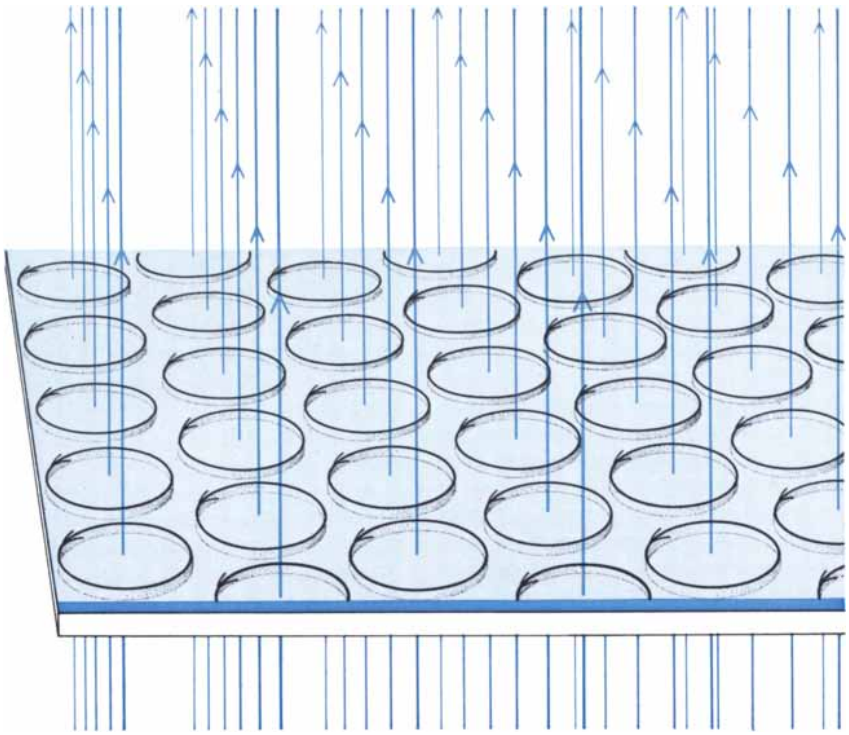
The theoretical physicist Fritz London was the first to suggest that in order to explain the Meissner effect and the persistent currents found in superconducting rings it is necessary to assume that there exists some kind of long-range correlation among the electrons in a superconductor. In a normal metal the motion of one electron appears to have little effect on the motion of another electron far away. London suggested that in a superconductor, on the other hand, one electron cannot move independently of the others; the only allowed motion of electrons is one in which many electrons move in unison. It was this idea that introduced the quantum aspect to the theoretical picture of superconductivity. In 1950, as a direct consequence of his idea, London made the revolutionary prediction that if a superconducting ring or hollow cylinder were cooled below its superconducting transition temperature in a magnetic field and then the field were turned off, the magnetic flux trapped in the hole would be found to exist only in quanta, or discrete units—regardless of the strength of the original applied field!

This was a bold prediction; although quantum effects had been predicted and observed before, they were always associated with submicroscopic systems (atoms, electrons or atomic nuclei) and never with a macroscopic system. The energy of an atom, for example, can exist only in discrete levels. To each level there corresponds a set of exactly specified orbits in which the electrons must move. In the case of a nonsuperconducting metal the language of quantum mechanics is used to describe the motion of the conduction electrons. Each electron is assigned a certain set of quantum numbers, which prescribe the exact values of the allowed energies. The electrons exist in several different quantum states, however, and can change quantum numbers as they move through the metal. In a macroscopic sample containing some billions of billions of electrons, which to a large degree move independently of one another, the quantum effects average out to zero. In a superconductor, on the other hand, the averaging process is apparently absent, and as a consequence the quantum effects can be manifested on a macroscopic scale.

At this point it must be obvious to the reader that one way to test London's concept of the superconducting state would be to measure the trapped magnetic flux in an actual superconducting ring or hollow cylinder, in order to see if the flux indeed exists only in quantized units. Oddly enough such an experiment was not even attempted until a decade after London made his prediction. One likely reason for this delay was the fact that London's prediction was not widely publicized; it appeared only as an obscure footnote in one of his books. Another reason was that even highly competent experimenters must have been easily discouraged by the extremely small size of the predicted flux quantum: only four ten-millionths of a gauss per square centimeter! This is about a millionth of the normal flux of the earth's magnetic field. To carry out an experiment using a ring or hollow cylinder with a hole one square centimeter in area would require the cancellation of the earth's magnetic field to a precision much greater than one part in a million—a



QUANTUM "STEPS" characterize the curve that relates the strength of the magnetic field in which the ring at the bottom of the opposite page was cooled to the magnetic flux trapped in the ring after the magnetic field has been turned off. According to the prediction made in 1950 by the theoretical physicist Fritz London, this magnetic flux should be found to exist only in the discrete units called quanta, regardless of the strength of the original applied magnetic field. Experiments that were performed in 1961 confirmed this prediction.



QUANTIZED VORTICES, each containing one quantum of magnetic flux, are believed to fill a superconducting film that is at a temperature just below its superconducting transition temperature and is in a perpendicular magnetic field. According to the theory put forward by the Soviet physicist A. A. Abrikosov in 1957, a vortex in its simplest description is a cylindrical core of normal metal with a very small radius (on the order of a hundred-thousandth of a centimeter), through which the magnetic flux can penetrate the superconducting film. The magnetic flux is maintained in vortex by electric currents that flow around core.

nearly inconceivable task by present standards.

With a smaller ring or cylinder, however, the magnetic field required to produce one quantum of flux is larger; it is proportional to the flux quantum divided by the area of the hole. Thus by making the ring or cylinder very small the need to cancel the earth's magnetic field so precisely is eliminated. In its place, however, appears the comparably awesome task of measuring the trapped magnetic flux in a sample of almost microscopic dimensions.

The latter obstacle was finally overcome, and in 1961 the results of two exquisite experimental tests of London's prediction were reported simultaneously. In both cases the "hollow" superconducting cylinder was prepared by depositing the superconducting metal on a fiber of nonsuperconducting material about a ten-thousandth of a centimeter in diameter. In one experiment, performed by Bascom S. Deaver, Jr., and William M. Fairbank at Stanford University, the cylinder was made of tin; in the other, performed by R. Doll and M. Näbauer at the Bayerische Akademie der Wissenschaften in Germany, the cylinder was made of lead. In both experiments the cylinder was cooled through the superconducting transition temperature in an applied magnetic field of a particular strength. The field was then turned off and the magnetic flux trapped in the hole of the cylinder was measured. This procedure was repeated for many different values of the initial magnetic field. The two experiments differed mainly in the technique used to measure the trapped magnetic flux. In the Deaver-Fairbank experiment an elaborate electronic method was used. In the Doll-Näbauer experiment a delicate optical method was used to detect the motion of the cylinder containing the trapped flux in another, weaker magnetic field; the amount of trapped flux could then be computed from the motion of the cylinder.

Both experiments confirmed London's prediction: the trapped magnetic flux was found to be quantized [*see illustration on preceding page*]. Surprisingly, however, the measured flux quantum turned out to be only half the value predicted by London. This discrepancy has since been explained in terms of the comprehensive theory of superconductivity put forward in 1957 by John Bardeen, Leon N. Cooper and J. Robert Schrieffer, then at the University of Illinois. According to the Bardeen-Cooper-Schrieffer theory, the current carriers in a superconductor are pairs of electrons rather than single electrons as London supposed.

From the preceding discussion it should be evident that the "multiply connected" geometry of a solid with a hole in it, such as a ring or a cylinder, is important in determining the superconducting characteristics of a particular sample. This dependence on gross geometry is a direct consequence of the fact that superconductivity is a macroscopic quantum phenomenon.

What about the more common case of a "simply connected" superconductor, that is, one without a hole? It was thought for a long time that the behavior of a simply connected superconductor in a magnetic field was fairly well understood in terms of London's original theory. Recent experiments, however, have revealed a totally unexpected superconducting state never conceived of by London. This state, which occurs only in certain types of superconductor when they are exposed to a magnetic field, is characterized by the existence of electron eddies called vortices, which fill the superconducting body. These vortices are in many ways analogous to whirlpools in water. I shall now attempt to explain why, under certain conditions, it is energetically advantageous for a superconducting body to enter the vortex state.

A handy rule to follow in analyzing the behavior of any physical system is that all systems seek their lowest possible energy state. In the case of superconducting metals there exists an interaction of the electrons and the atomic nuclei that makes the energy of the superconducting state lower than that of the normal conducting state below a certain temperature. Because the system always seeks to be in the lowest possible energy state, the metal will become superconducting at this transition temperature. As the temperature is lowered below the transition temperature the difference in energy between the normal and the superconducting states increases. Now, if at some temperature below the transition temperature the magnetic field is turned on, the superconductor will expel the field. This requires energy, which must be supplied by the superconductor itself. The energy appears in the form of the kinetic energy of the moving electrons that

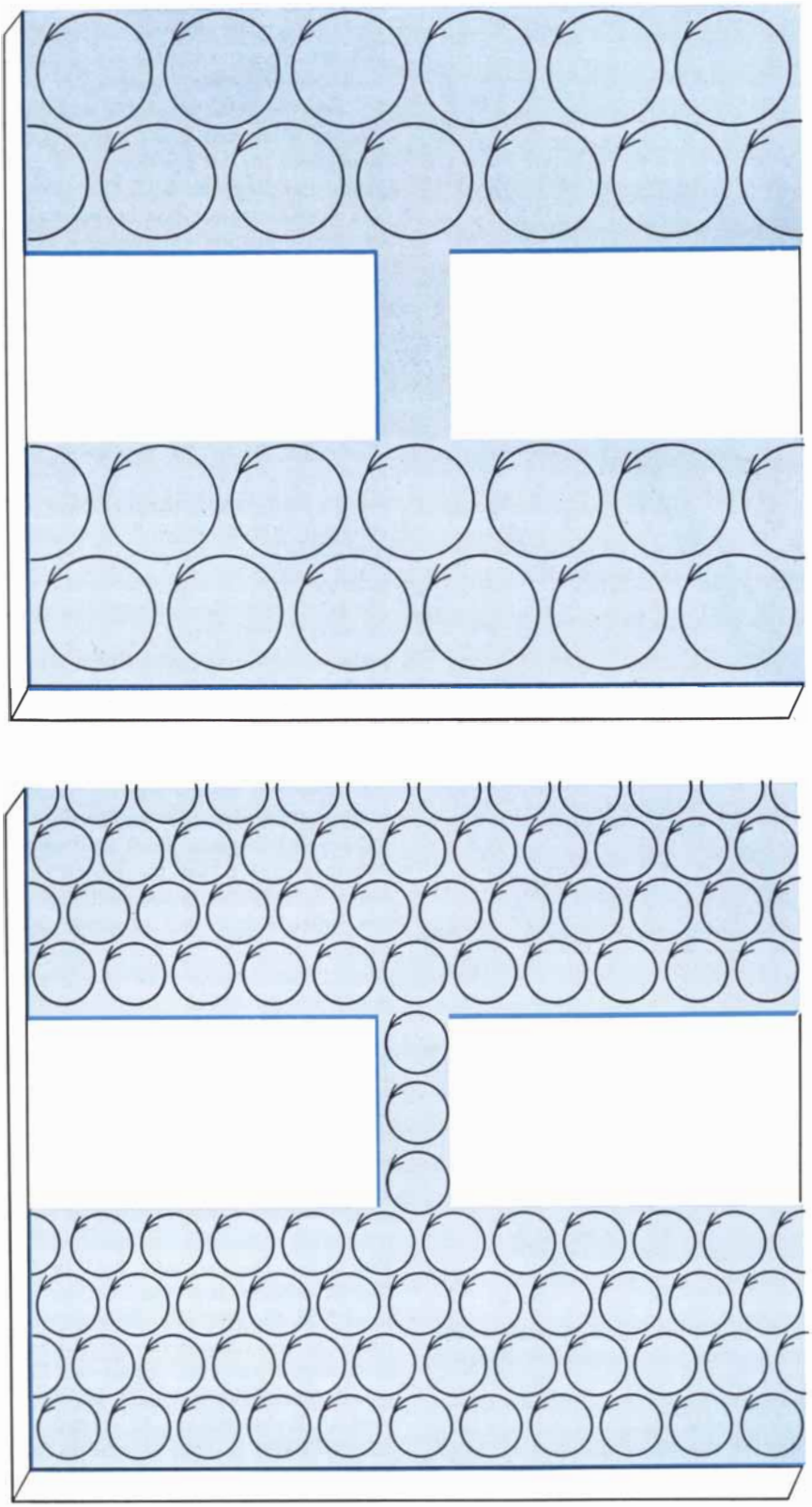
make up the surface currents required by the Meissner effect. If the strength of the magnetic field is increased, the energy required of the superconductor also increases, and at some value of the field called the critical field the energy of the superconducting state becomes higher than the energy of the normal state. When this happens, the superconductor is forced to revert to the normal state.

If there were some mechanism whereby the magnetic field could penetrate or partially penetrate the superconductor, however, the energy required of the superconductor to expel the magnetic field could be reduced, and the superconducting state could persist to a higher value of the magnetic field. In 1957 the Soviet physicist A. A. Abrikosov predicted that this is exactly what would happen for a class of superconductors that have since come to be known as Type II superconductors. These include alloys of the common superconductors (such as lead, tin and mercury), very thin superconducting films, and superconductors such as niobium that have considerably higher transition temperatures than the common superconductors.

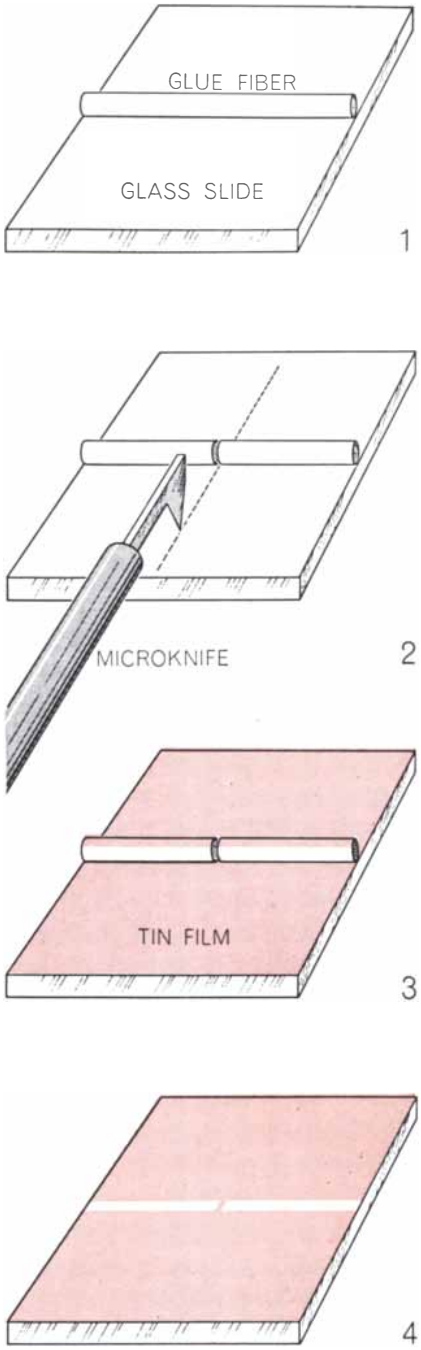
Abrikosov was able to show that in Type II superconductors in the presence of a strong magnetic field the lowest possible energy state is one in which vortices exist. According to the Abrikosov theory a vortex, in its simplest description, is a cylindrical core of normal metal with a very small radius (on the order of a hundred-thousandth of a centimeter), through which the magnetic flux can penetrate the superconductor [*see illustration on opposite page*]. The magnetic flux is sustained in a vortex by electric currents that flow around the core. Since a vortex is in effect a cylindrical hole in a superconducting body, the magnetic flux that passes through a vortex must be quantized—just as in a ring or hollow cylinder. Furthermore, it is fairly straightforward to show that it is energetically advantageous for each vortex to contain only one quantum of magnetic flux.

Since the publication of Abrikosov's theory extensive studies have been made of Type II superconductors, both in this country and abroad. The work has resulted in a wealth of experimental data that agree substantially with the predictions of the theory. Since these experiments measure the averaged behavior of billions of vortices in a macroscopic sample, however, they have provided evidence only that quantized vortices do exist in superconductors.

In order to approach the problem of



VORTEX THEORY WAS TESTED by the author and his colleagues at the University of Rochester by means of the extremely delicate experiment depicted here. A microscopic superconducting tin bridge connects two large areas of superconducting tin film. Because the size of the vortices in the film is determined by the strength of the applied perpendicular magnetic field, for a weak enough applied field (*top*) the vortices will be too large to fit into the bridge and energetically expensive Meissner currents must flow along the edges of the bridge. When the applied magnetic field is increased to the strength at which the vortices can fit into the bridge (*bottom*), the Meissner currents abruptly die away. The procedure by which the microbridge of superconducting tin is constructed is shown on the next page.



PROCEDURE by which the superconducting tin microbridge shown in the illustration on the preceding page was constructed was devised by Louis V. Surgent, Jr. First, a very thin glue fiber is laid on a glass microscope slide (*1*). The fiber is delicately cut in half, at right angles to its long axis, with a microknife (*2*). The tin is then evaporated onto the slide over the fiber (*3*). The cut fiber serves as a mask that defines the geometry of the rectangular bridge. The length of the bridge is equal to the diameter of the fiber, and the width is equal to the width of the knife cut. After the evaporation of the metal the glue fiber is dissolved with a solvent (*4*). This step leaves behind a superconducting bridge of microscopic dimensions that connects two large areas of superconducting film.

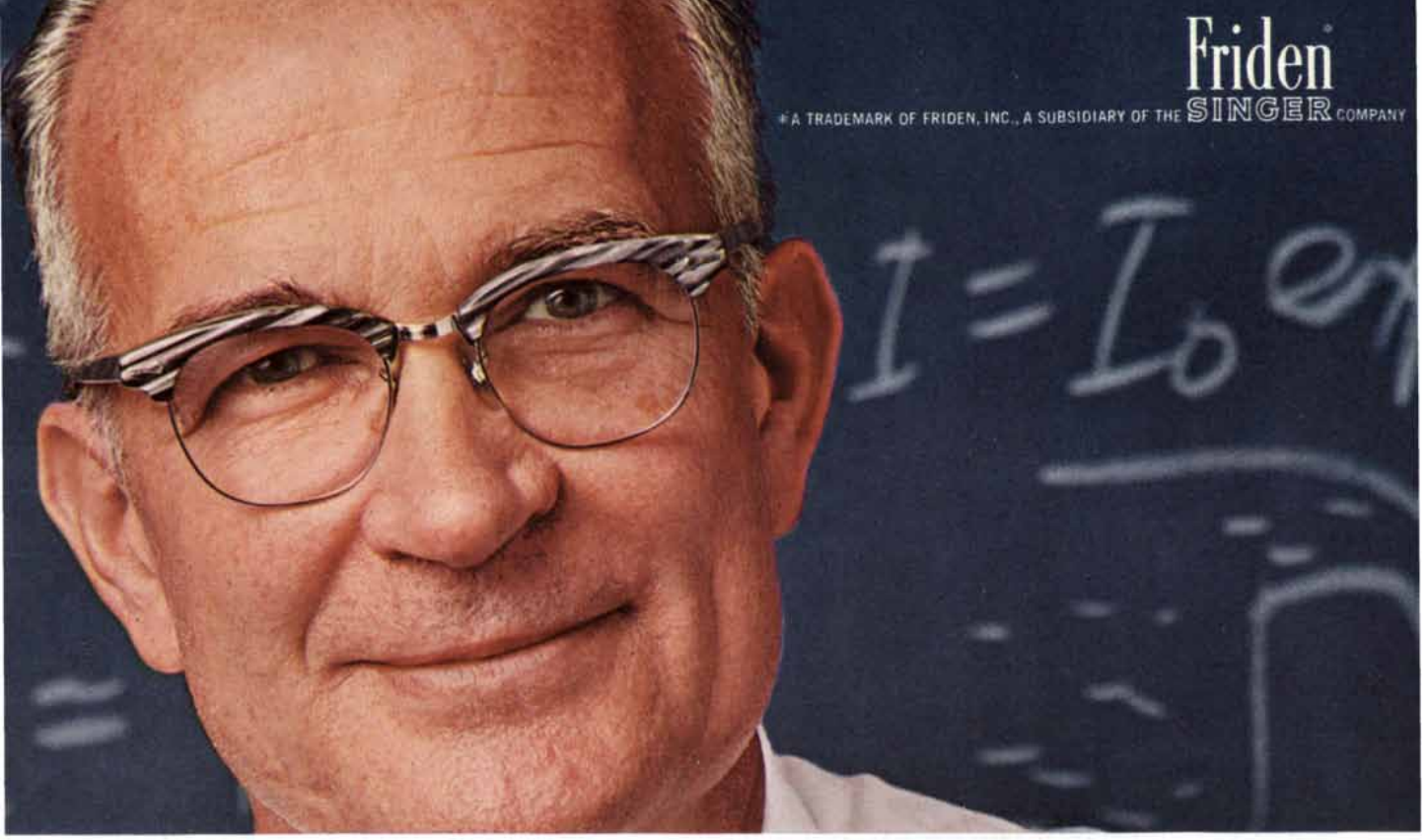
quantized vortices in a more direct way, my colleagues and I at the University of Rochester undertook a program in 1963 to study the behavior of thin superconducting films with various microscopic geometries in the presence of a perpendicular magnetic field. Our general line of reasoning can best be understood by considering first what happens in the comparatively simple case of a thin superconducting sheet of relatively large dimensions in a perpendicular field. Assuming that at a particular strength of the field there are no vortices, the Meissner effect would require that supercurrents flow at the surface of the sheet. Just below the transition temperature the Meissner currents are too weak to distort the magnetic field appreciably. In this situation the net magnetic field can be regarded as approximately uniform over the superconducting film and equal to the applied magnetic field. Nonetheless, the Meissner currents do make a small contribution to the energy of the superconducting state as a result of the kinetic energy of the moving electrons. When one calculates this energy, it turns out to be much higher than the energy of the hypothetical vortex state even for extremely small values of the applied magnetic field. One would therefore expect that the vortex state exists in thin-film superconductors in the presence of a weak magnetic field, whereas in bulk superconductors the vortex state is stable only in a very strong magnetic field.

It follows from the preceding argument that in a thin superconducting film that has been placed in a perpendicular magnetic field at a temperature just below the superconducting transition temperature, quantized vortices, each containing one quantum of magnetic flux, would fill the space of the film. Since the magnetic field in the film is uniform and equal to the applied field, the area of each vortex multiplied by the value of the applied field must equal one flux quantum. This means that if the magnetic field is increased, the vortices must decrease in size. It is still possible for the vortices to fill the space completely by crowding together, thereby making room for additional vortices of the same size to form in the film. Presumably new vortices are created at the edge of the film and move inward.

What happens in the case of a superconducting sheet of microscopic dimensions? Since the size of a vortex is determined by the strength of the applied magnetic field, in a weak enough field the vortices will be too large to fit into the sample. Thus below a certain strength of the magnetic field vortices are not allowed in the sample, and energetically expensive Meissner currents must flow along the edge of the sample. When the applied magnetic field is increased to the value at which vortices may form in the sample, the Meissner currents abruptly die away. This corresponds to a decrease in the energy of the superconducting state. Jack M. Mochel, a graduate research assistant, and I have observed this effect in microscopic samples of superconducting tin.

The samples used for our tests were prepared by the following method, devised by Louis V. Surgent, Jr., of our laboratory. First, a very thin glue fiber is laid on a glass microscope slide. The fiber is delicately cut in half, at right angles to its long axis, with a microknife. The tin is then evaporated onto the slide over the fiber. The cut fiber serves as a mask that defines the geometry of a rectangular bridge. The length of the bridge is equal to the diameter of the fiber, and the width is equal to the width of the knife cut. After the evaporation of the metal the glue fiber is dissolved with a suitable solvent. This step leaves behind a microscopic superconducting bridge connecting two large areas of superconducting film [*see bottom of illustration at left*].

The problem now is to measure in some way the energy of the superconducting state to see if there is an abrupt decrease at the value of the magnetic field at which quantized vortices can fit into the microbridge [*see illustration on preceding page*]. To do this we make use of the fact, mentioned earlier, that the sample must revert from the superconducting to the normal state when the energy associated with the Meissner effect is just equal to the difference in energy between the normal and the superconducting state. If the former energy decreases, as it should when vortices appear in the superconducting sample, this allows the sample to remain superconducting to a higher value of the applied magnetic field. Therefore the variation of the transition temperature with the magnetic field reflects the variation of the energy of the superconducting state with the magnetic field. In our experiment the transition temperature of the microbridge was measured as a function of the applied magnetic field. We found that as the magnetic field was increased from zero the transition temperature decreased; this is the normal behavior of a superconductor. As



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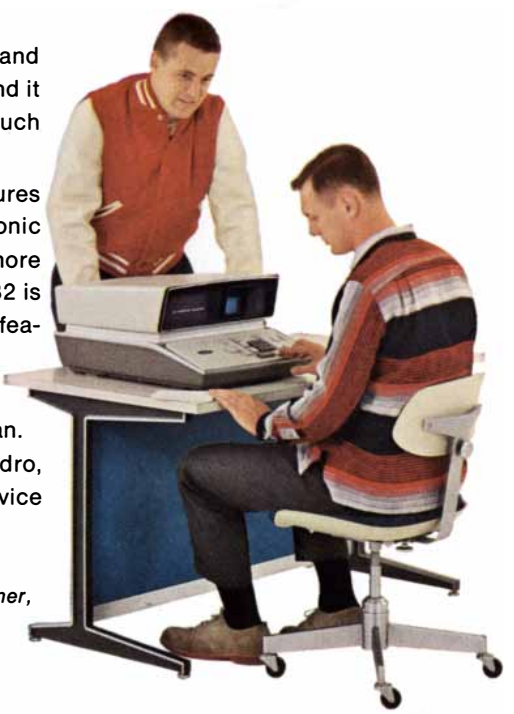

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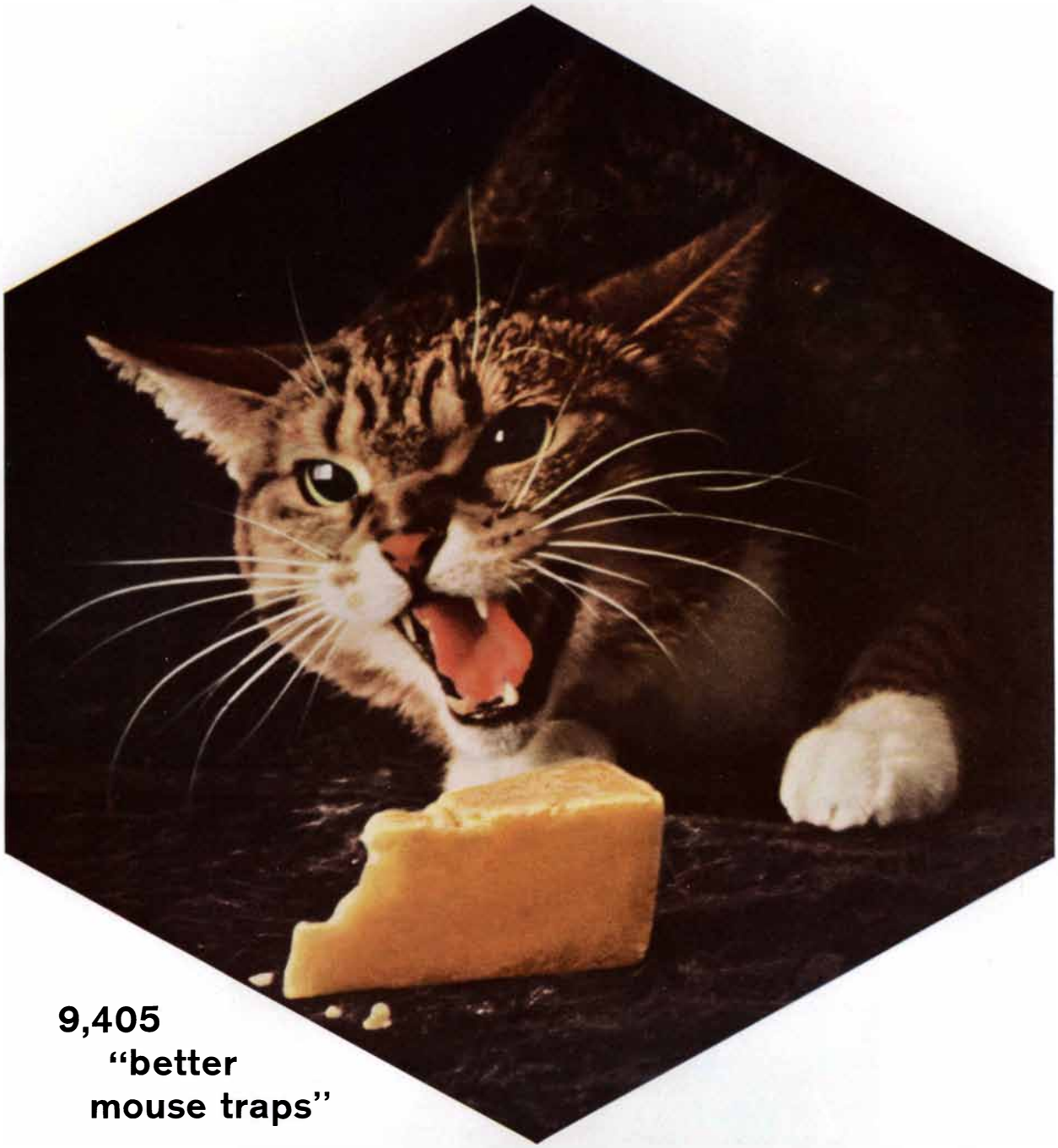

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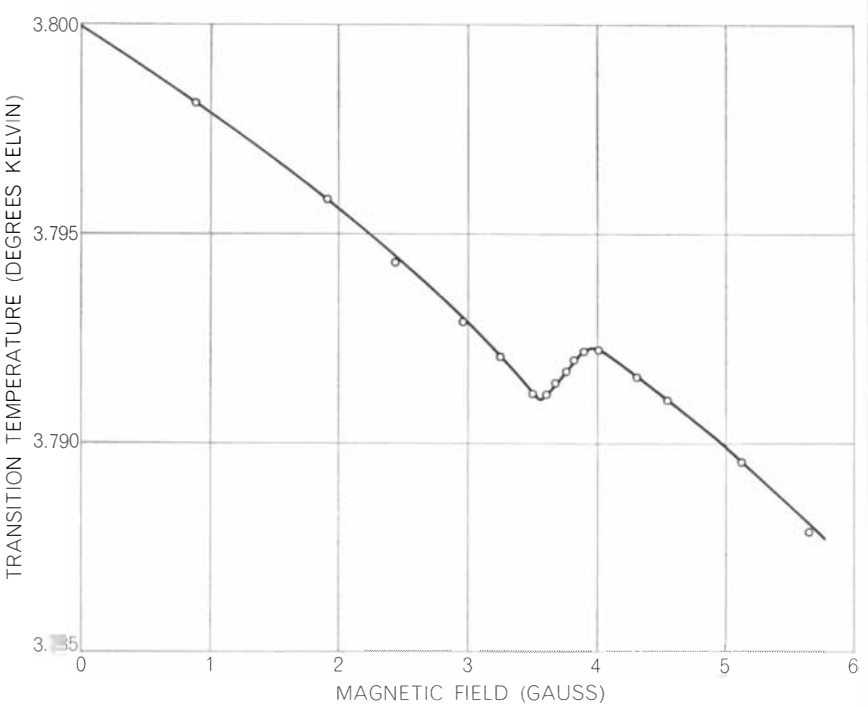
the magnetic field reached the value at which vortices containing one flux quantum could just fit into the microbridge, however, the transition temperature stopped increasing. As the magnetic field was increased above this value the transition temperature again decreased for a while with increasing field. This result appears as a kink in the curve that relates transition temperature to the strength of the applied magnetic field [*see illustration below*]. We believe that this experiment provides indisputable evidence that quantized vortices do indeed exist in superconductors.

It is interesting to compare quantized vortices in superconductors with quantized vortices in superfluid helium [see "Quantized Vortex Rings in Superfluid Helium," by F. Reif; SCIENTIFIC AMERICAN, December, 1964]. In a superconductor a vortex results from the response of electrons to an applied magnetic field. In superfluid helium a vortex results from the response of helium atoms to a rotation of the vessel containing the liquid helium. In a superconductor a vortex persists at least as long as the magnetic field is left on. In superfluid helium a vortex persists at least as long as the vessel continues to rotate. In a superconductor a vortex must contain a discrete number of flux quanta. In superfluid helium a vortex must contain a discrete number of quanta of circulation. In both cases energy calculations reveal that the favored quantum state for a given vortex is attained when the quantum number is one. In both cases the fact that vortices can persist for indefinite periods of time and are quantized can be explained only if we assume that both superconductivity and superfluidity are macroscopic quantum phenomena, as first suggested by London.

Many questions concerning vortices in superconductors still remain unanswered. How and where are vortices created in a superconductor? How do vortices move? Do vortices always exist in thin superconducting films in perpendicular magnetic fields regardless of the purity of the film or the species of the superconductor? How do vortices interact with one another and with supercurrents? The answers to these questions are currently being sought in an increasing number of low-temperature laboratories.



KINK in the curve that relates the superconducting transition temperature of the tin microbridge to the strength of the applied magnetic field was taken by the author and his colleagues as providing indisputable evidence that quantized vortices do indeed exist in superconductors. They found that as the magnetic field was increased from zero the transition temperature decreased, which is the normal behavior of a superconductor. As the magnetic field reached the value at which vortices containing one flux quantum could just fit into the microbridge, however, the transition temperature stopped decreasing. As field was increased above this value the transition temperature again decreased. The hump in the curve is attributed to the decrease in energy associated with the appearance of vortices in the microbridge.

Early Man in Peru

The peculiar climate and abundant sea life of the Peruvian coast affected the way of life there from the time of the first nomadic campers 9,000 years ago to that of the predecessors of the Incas

by Edward P. Lanning

When the Spaniards came to Peru in 1527, the region was controlled by the mountain-dwelling Incas. Before the rise of the Incas a number of independent kingdoms had flourished along the Peruvian coast. Much earlier—about 2500 B.C.—the coastal valleys had been inhabited by farmers who produced superior textiles but had not yet learned how to make pottery. Now evidence has been uncovered that the Peruvian coast nurtured a number of primitive but distinctive cultures at least as early as 8500 B.C., 5,000 years before the rise of the first cities in Mesopotamia.

These new findings not only push back the record of human occupation in Peru; they also demonstrate that the lives of both the earliest and the later coastal peoples were intimately related to the region's unusual climatic conditions and were significantly affected by long-term changes in climate, vegetation and other factors of the coastal environment. I have found numerous examples of such environmental influences in the course of surveying a coastal area of about 200 square kilometers that includes the town of Ancón and much of the lower valley of the Chillón River, just north of Lima [*see illustration on page 71*]. I conducted the survey between July, 1961, and August, 1963, while I was a Fulbright Fellow at Lima's University of San Marcos. During the second season's work I collaborated with Thomas C. Patterson of Harvard University, and we had the assistance of several students from the University of San Marcos.

Before I describe our findings, the reader will find it useful to know something of the past and present climate of the central Peruvian coast. Although the region is cool and overcast for most of the year, it is one of the world's most arid deserts. Both the aridity and the overcast are consequences of the fact that along the coast flows the Peru Current, a cool, upwelling body of water. Air masses coming in from the sea are cooled by the current; as they move across the land they are warmed and their capacity for retaining water vapor is thereby increased. Thus the coast seldom receives rain; instead its inhabitants depend on some 50 small rivers—such as the Chillón—that rise in the Andean highlands and are fed by mountain rainfall. The control the Peru Current exercises over the coastal weather persists even when the current temporarily disappears; occasionally it is replaced by a warm current known as the Niño, and even then a significant amount of rain is rare. Indeed, the region had its last rainfall in 1925.

This desert coast shows abundant evidence, however, of rain in the past: its hills are eroded by water and scarred with gullies in all stages of development. There is also evidence that the region's rivers once brought greater amounts of water down from the highlands; in the river valleys there are deposits of waterborne gravel more than 100 meters thick. Some of this deposition is recent, but most of it appears to be attributable to the effects of glaciation during Pleistocene times. When the mountain glaciers and the lower snow line of that period cooled the land, the temperature differential between coast and sea was decreased and so the possibility of rain was increased. On the other hand, bits of wood that yield radiocarbon dates of about 8500 B.C. have been found perfectly preserved by desert dryness, indicating that at the end of Pleistocene times the central Peruvian coast was nearly as dry as it is today. The geological evidence of more abundant rainfall may simply mean that at that time the years in which some rain fell were more frequent; perhaps there was rain every five or 10 years instead of every 40 or 50.

Two effects of the Peru Current were particularly important to the prehistoric inhabitants of the coast. First, fog coming in from the ocean nourishes lush patches of vegetation in the midst of the desert; these "fog meadows," called *lomas,* are greenest during the winter months, from April or May to November or December. Along the central coast the *lomas* were once far more extensive than they are now. In the area of our survey they were perhaps 10 times larger; their extent is indicated by acres of snail shells—the remains of former feeders on the vanished vegetation.

The Peru Current's second important effect is the result of the rich mineral content of its upwelling waters. The current nourishes a vast plankton population, which in turn supports an exceptionally abundant marine fauna: fishes, shellfish, shorebirds and sea mammals. This rich ocean life has been exploited systematically by man for at least 6,000 years. There were fishing villages on the northern coast of Chile as long ago as

COAST OF PERU is a mixture of beaches, arid headlands, desert hills and patchworks of irrigated farmland in the occasional river valleys. The aerial photograph on the opposite page shows a section of coast from the town of Ancón (*top*) south to the Chillón valley (*bottom*). The most recent rainfall in this area was in 1925. Some hills nonetheless bear vegetation that is watered by the winter fogs. These *lomas* zones were once far more extensive; within them the author has found a series of campsites that were first used 9,000 years ago.

4200 B.C. and on the south-central Peruvian coast by 3600 B.C.

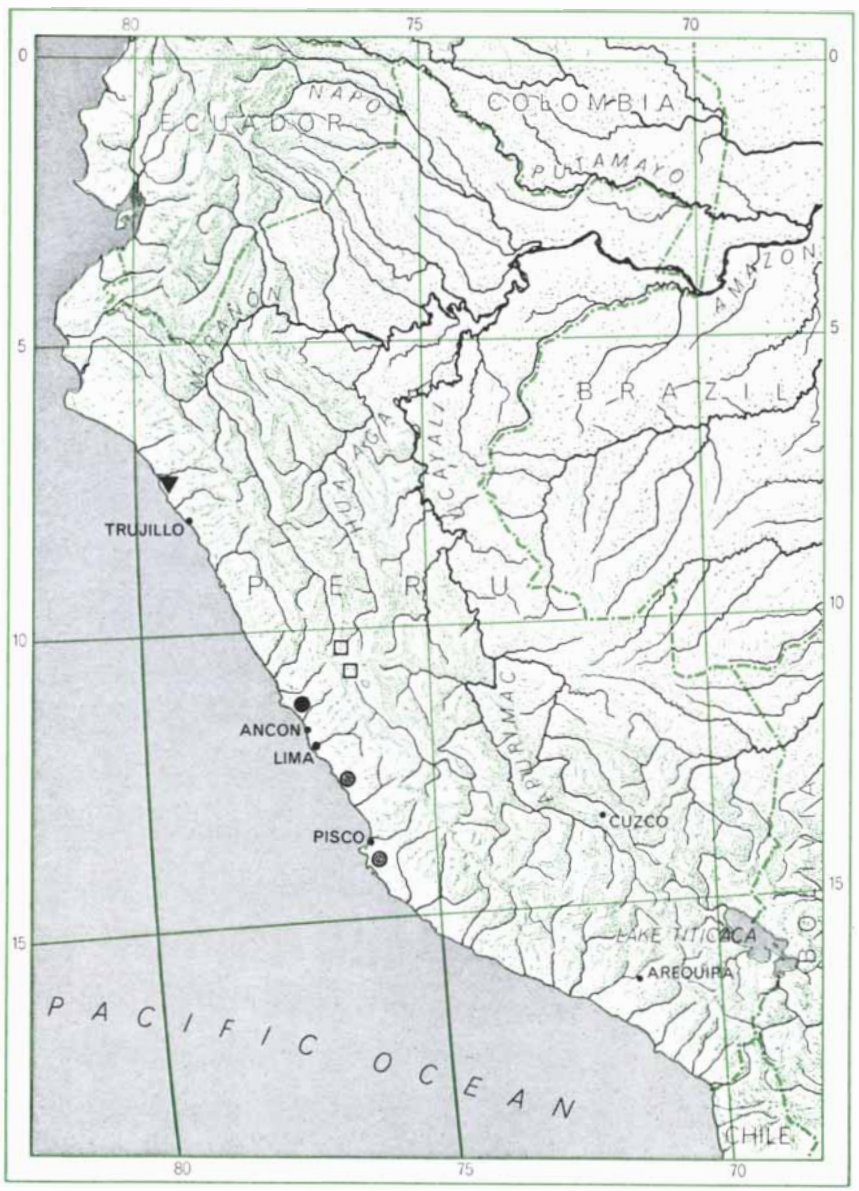
Before we began our work in the Ancón area the earliest indications of man in Peru were some sites on the northern coast where stone tools had been made about 6000 B.C. and a few highland caves that had been occupied by hunters of guanaco and Andean deer during the preceding millennium. Our survey soon turned up some 30 new sites that yielded thousands of worked stones, as well as the pieces of wood I have mentioned. Thus we know that early toolmakers visited the coast at least 10,500 years ago. We have not found any of their dwelling sites, so that although we have a good idea of the kinds of tools they made, we have no idea whatever of where and how these tools were used. In any event, this early stone industry is still being studied and it is too soon to put forward any conclusions about it.

The earliest human dwelling sites found in our survey area were located in zones formerly covered by *lomas* vegetation; they are the camps of hunter-gatherers and were probably first occupied about 7000 B.C. Since the *lomas* flourish only during the winter months, it seems safe to assume that the camps were the winter habitations of people who lived elsewhere during the summer. Summer is the rainy season in the highlands; perhaps these people migrated annually from the highlands to the fog meadows and back again.

During a period of some 4,500 years the possessors of five distinct cultures occupied these camps; each can be distinguished on the basis of changes in the inventory of artifacts [*see illustration on pages 74 and 75*]. In spite of these variations, all five cultures had many characteristics in common. Small bands of people gathered wild seeds in the *lomas* and ground them into flour with milling stones; camp refuse deposits are often packed with the seeds and stalks of wild grasses. The people also gathered potatoes, which grow wild in the *lomas*. They ate the snails that fed on the *lomas* vegetation, caught lizards and burrowing owls and hunted the deer and guanaco that came down from the highlands to graze in the *lomas* in winter months. One plant found in their refuse deposits—the bottle gourd *Lagenaria siceraria*—may possibly have been cultivated, but it could equally well have been gathered wild along the banks of the Chillón.

The tools and weapons found in the sites indicate that the winter campers were more dependent on gathering than on hunting. Hunters' tools—stone projectile points, skin scrapers, knife blades and awls for making holes in leather—are relatively rare. Heavy "core" tools, which are useful for chopping and for extracting fibers from vegetable material, are particularly abundant. So are large stone flakes struck from water-smoothed cobbles, which may have served as crude sickles; tools of this kind are found not only at the campsites but also scattered throughout the former *lomas* areas.

The earliest of the five cultures of the winter campers, known as the Arenal complex, is characterized by projectile points and skin scrapers much like the ones used by hunters in the highlands of Peru about 7000 B.C. The Arenal tools are probably of the same age, although no direct dating of the campsites belonging to the complex has yet been possible. Radiocarbon dates have been obtained, however, for the



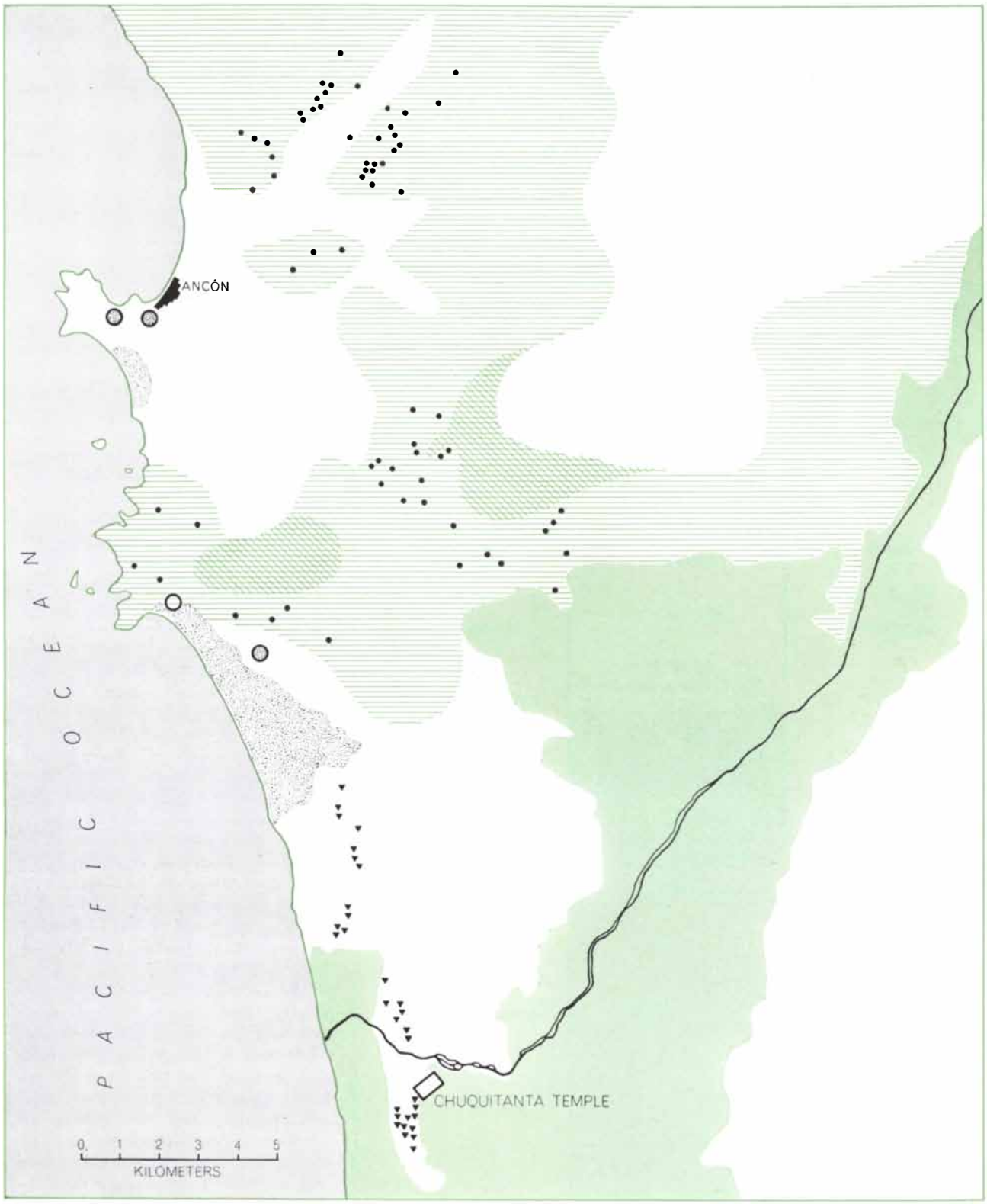
□ HUNTING CAMPS, ABOUT 8000 TO 2000 B.C.

● LOMAS CAMPS, ABOUT 5000 TO 3000 B.C.

▼ STONE WORKSHOPS, ABOUT 6000 B.C.

◉ COASTAL VILLAGES, ABOUT 4000 B.C.

EARLY SITES IN PERU, exclusive of the Ancón area, vary in kind from hunting camps in the central highlands and some stone workshops north of Trujillo to food-gatherers' campsites in the central-coast *lomas* zones and early farmer-fishermen villages on the coast.



MANY EARLY SITES in the 200-square-kilometer area the author surveyed in the vicinity of Ancón include places where stone tools were manufactured in 8500 B.C., a subsequent 4,500-year-long sequence of hunter-gatherer campsites in the area's once extensive *lomas* zone (*horizontal hatching*), and a fishing camp (*shell mound*) contemporary with the last *lomas* gatherers. Three later villages of farmer-fishermen evidently produced enough surplus food to allow the building of a ceremonial center at Chuquitanta.

two cultures that follow the Arenal: the Luz and Canario complexes. Typical Luz artifacts date from between 6000 and 5000 B.C. The "willow leaf" projectile points characteristic of the Canario complex resemble the points used by highland hunters about 6000 B.C., but radiocarbon evidence indicates that this particular stone form did not reach the coast until 5000 B.C.

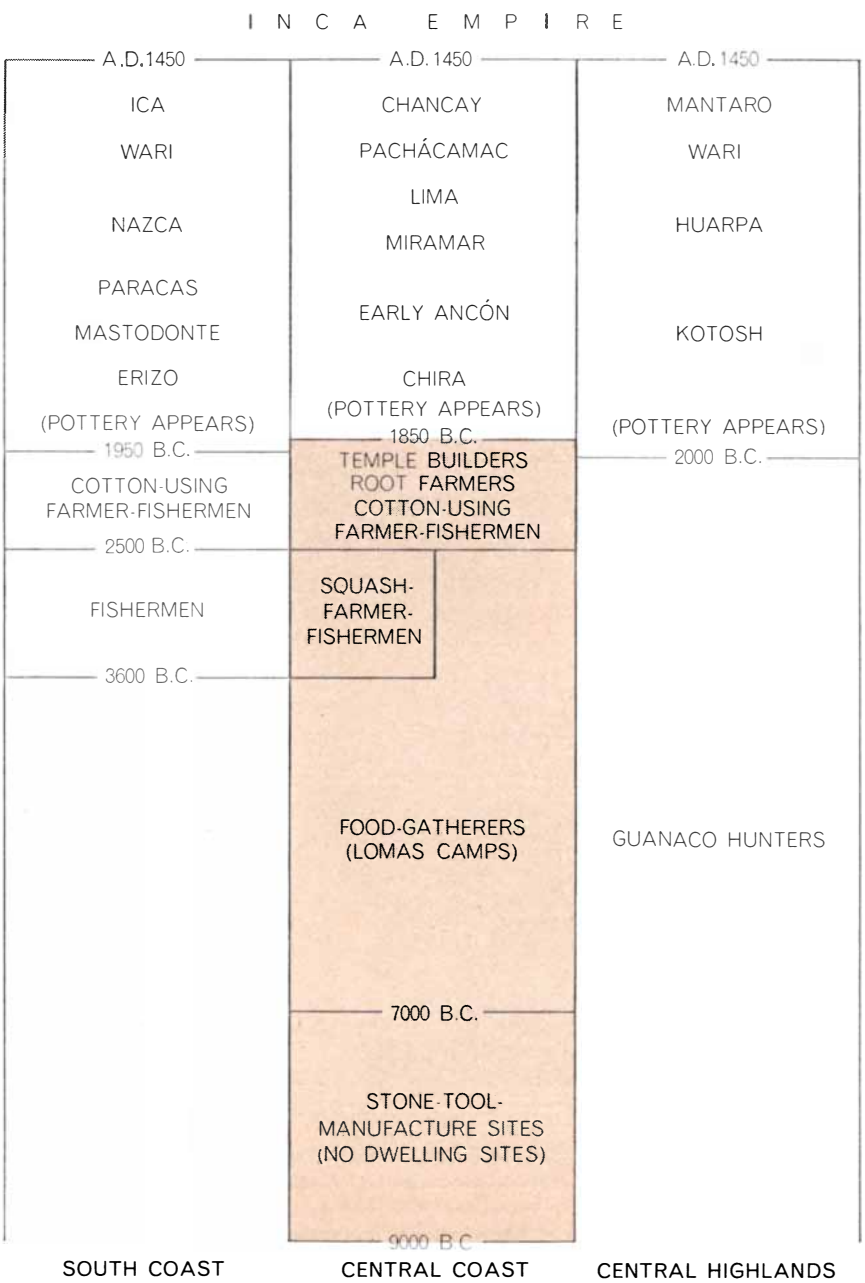
The fourth group of campsites belongs to the Corbina complex; although this culture has not been directly dated, it appears to have been in the *lomas* area between about 4200 and 3600 B.C. The fifth culture—the Encanto complex—was present between about 3600 and 2500 B.C.; the terminal date is suggested by the appearance of cultivated cotton and of twined cotton textiles, articles that are known to have reached the coast during the third millennium B.C. Support for these dates is provided by the fact that typical Encanto projectile points have been found in an early village site on the south-central Peruvian coast associated with materials yielding radiocarbon dates that range from 3600 to 2500 B.C.

During most of the 4,500-year period during which the winter campers flourished, the fog meadows were gradually drying up. Progressive desiccation of the *lomas* in area after area in the vicinity of Ancón resulted in the abandonment of campsites, although new camps were immediately established in other parts of the shrinking area. By Encanto times, however, the *lomas* were reduced to nearly their present extent and the winter campers were bringing fish, mussels and clams into camp to eke out their diet. By the end of the Encanto period the *lomas* camps were abandoned altogether.

Reconnoitering outside the area of the *lomas*, we found an ancient heap of shells, packed with other refuse, standing on a rocky point overlooking a broad beach south of Ancón known as the Playa de Ventanilla. The site—called Pampa—evidently antedates the introduction of cotton to the coast, and it is therefore probably contemporaneous with the last of the *lomas* camps. The objects found at the site—clearly the debris of casual occupation by a group of farmer-fishermen—are completely different from those found in the *lomas*. The Pampa refuse heap must represent the intrusion of a new group of people between 3600 and 2500 B.C.

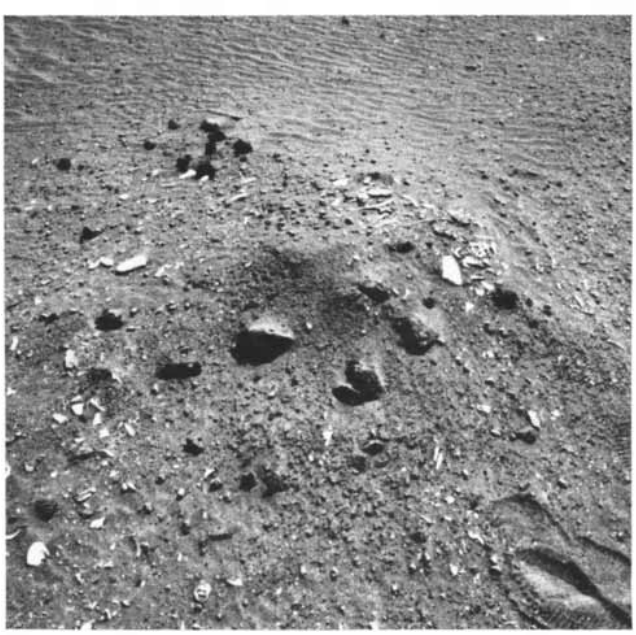
The accumulation of refuse is about six feet deep; most of the shells it contains are those of a genus of small mussel that can still be found on the tidal rocks of the coast, but there are also numerous shells of a larger bivalve, a clam that no longer inhabits these waters. The two kinds of shellfish were by no means the only foodstuffs present; in fact, the earliest inhabitants of the site lived primarily on vegetables. They evidently cultivated two species of squash (presumably their garden plots were on the banks of the Chillón, 10 kilometers to the south); they also collected wild squashes.

The lower levels of the heap contain an abundance of squash rinds and seeds and only modest remains of animal foods such as the bones of fishes, birds and sea lions. This proportion changes in the upper levels, where animal bones are abundant and the remains of squashes are correspondingly rare. Although there is no change evident from bottom to top in the artifacts made by these farmer-fishermen (for the most part shell fishhooks, sandstone files and reamers with which the hooks were made, simple stone sinkers and fishlines and lashings made of wild-plant fibers), the change in the proportions of animal and plant food suggests that the settlement gradually gave up farming in favor of fishing, hunting sea lions and snaring such shorebirds as cormorants,



INTERPLAY of prehistoric coastal and highland cultures of Peru is presented in skeleton outline. Color indicates culture sequences identified by the author in the Ancón region.

LOMAS IN DRY SEASON are bleak; the pale network of hillside tracks has been worn by goats browsing where once guanacos grazed. The trees are native mesquites and acacias; the agaves in the foreground were introduced to the region by the Spaniards.



CAMPSITE HEARTH in the *lomas* belongs to the Encanto period, when the people eked out their dwindling food supply with clams (*note shell fragments*) of a species that no longer occurs locally.

TEST SQUARE, which was dug at the fishing-village site of Punta Grande three years ago, reveals stratified layers of accumulated debris, including clamshells and the stones used for pit-baking.

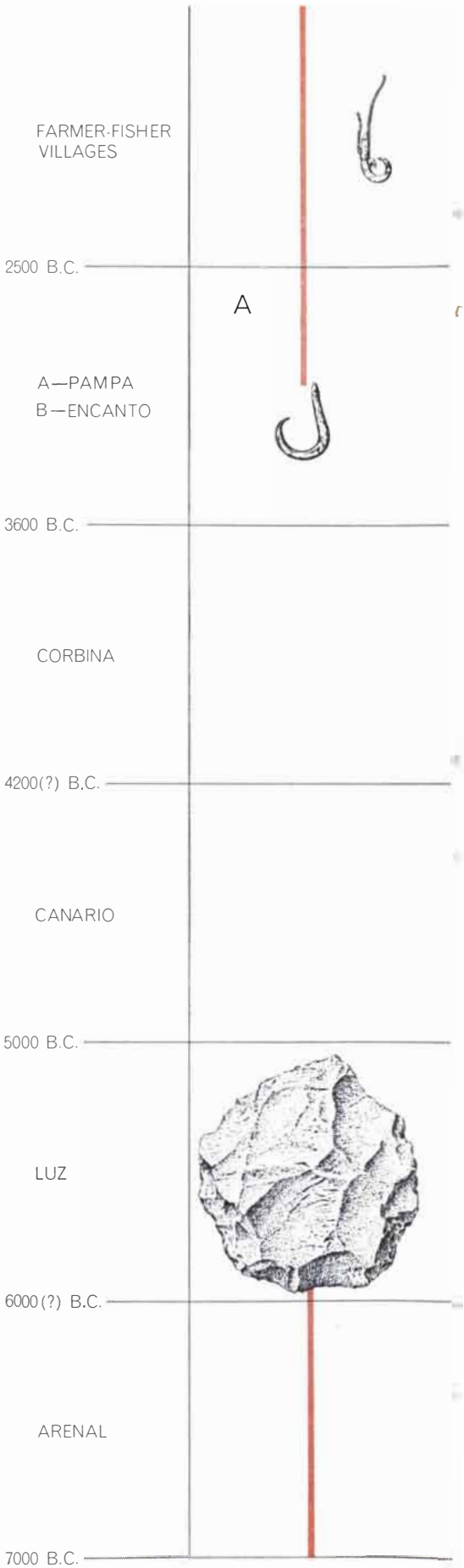
pelicans and gulls. The abandonment of farming could have been the natural result of the adoption of a new source of food and of the difficulties of cultivating riverbank fields far away from a shore campsite. It is possible, however, to interpret evidence of this kind too literally; it is equally possible that for these people squashes were a secondary source of food, grown in quantity only when the usual marine bounty temporarily failed. If this had been the case, the apparent increased emphasis on seafood in the site's upper levels would actually represent a reversion to a normal diet after a period of hunting and fishing scarcity.

The first permanent villages to be established within our survey area appear sometime in the third millennium B.C., probably about 2500 B.C. Of the three village refuse deposits we excavated, two in the steep hills near Ancón belong to the same culture. The third—at Punta Grande, about two and a half kilometers southeast of the Pampa refuse heap—is distinctly different from the others. Whether all or any of these early villages were founded by the former *lomas* campers or by the farmer-fishermen of the Pampa refuse heap is an open question. The establishment of the villages coincides with the abandonment of the desiccated *lomas;* the village refuse heaps also contain a number of *lomas* snail shells, and certain artifacts are common to the villages and the *lomas* camps. These facts suggest that the *lomas* people were the village founders. On the other hand, the presence of shell fishhooks and the large proportion of seafood remains in the villages' refuse can be taken as evidence of Pampa connections. Moreover, the introduction of cotton and a sharp increase in the varieties of cultivated foods may mean that a new group arrived on the coast at this point.

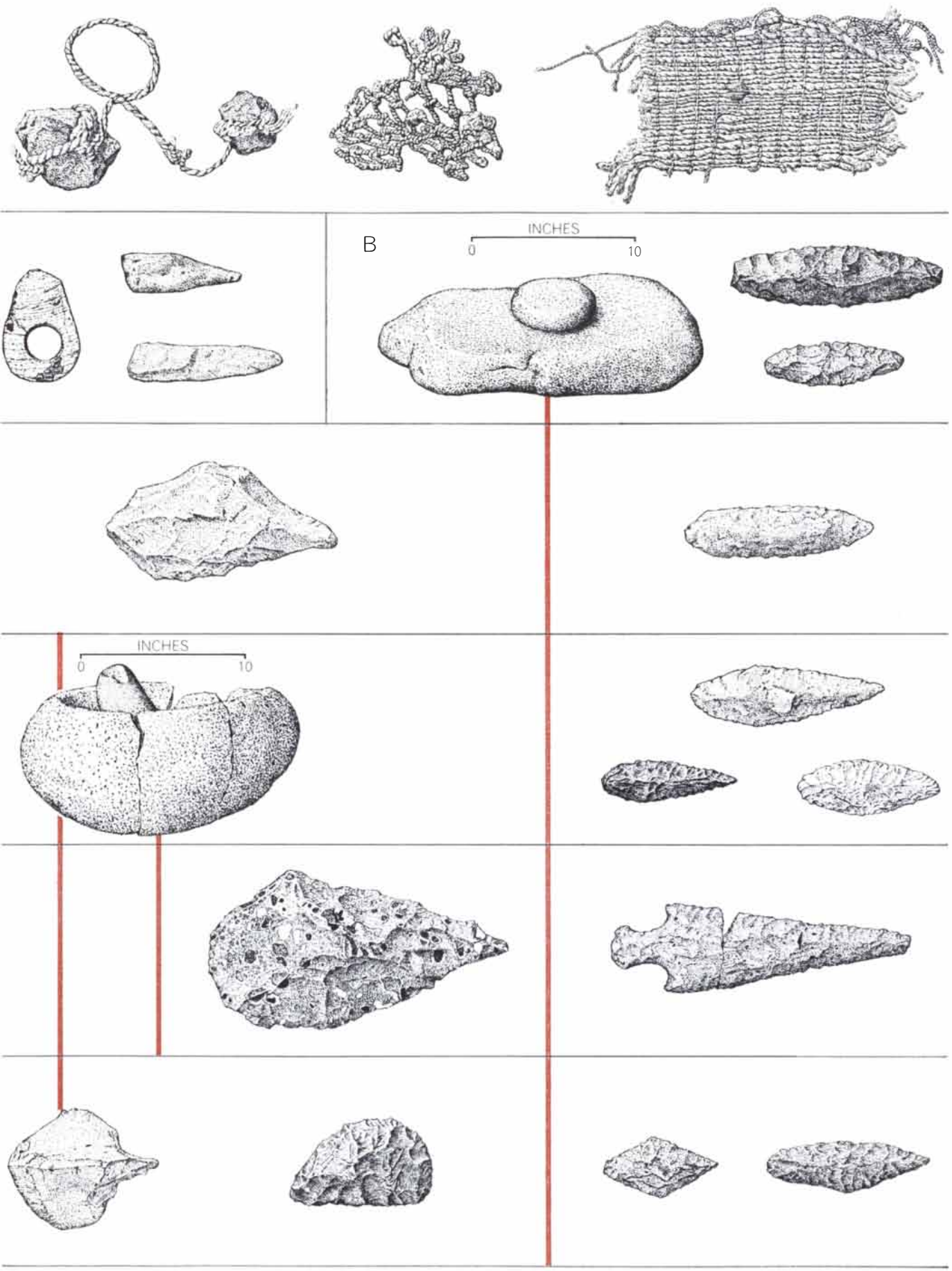
In both villages near Ancón animal foods—fish, shellfish, shorebirds and sea lions—made up the bulk of the diet. Fishhooks and other fishing gear are abundant in the refuse. Cotton and gourds were grown in large quantities, the former for the manufacture of netting and cloth and the latter for use as net floats and containers. Although plant foods are present only in small quantities and could not have bulked large in the people's diet, beans, chili peppers and guavas were grown in addition to squashes. Here, then, were villagers who fed basically on the harvest of the sea and farmed primarily to produce raw materials for their manufactured goods.

The pattern at Punta Grande, the third village site, is quite different. Fishhooks are absent; the village was on the open beach and all the fishing was evidently done with nets. Moreover, the ocean's yield does not appear to have been large: fishbones are not too common in the refuse heap, nor are the bones of birds and sea lions. The major sea harvest seems to have been clams, which were dug from the bottom of the bay. The main peculiarity of Punta Grande is its vegetable produce: a large part of the villagers' diet was composed of edible roots, many of which were probably cultivated. These include the potato (which could have been gathered wild in what remained of the *lomas*), the sweet potato, a Peruvian root known as achira and possibly two other native highland tubers. Such a root-crop assemblage suggests a highland cultivation pattern; in this period—about 2500 B.C.—none of these plants was being cultivated elsewhere on the Peruvian coast. Perhaps Punta Grande was founded by highlanders who moved down to the coast and added a little seafood to their usual vegetarian diet.

In any case, these villages and possibly others like them produced a food surplus and supported a population that was able to undertake extensive public works. A major ceremonial center—a temple complex of nine large, stone-walled structures arrayed around a central plaza—was built during this period at Chuquitanta in the lower Chillón valley [*see illustration on page 76*]. In spite of its early date, it ranks as one of the largest ceremonial centers known along the coast of central Peru. A substantial area of human habitation may once have been associated with this center, but the land around the temple buildings has been under intensive cultivation for so long that, except for a



SEVEN CULTURES of the Ancón area are distinguished by their typical implements. Colored lines indicate that the associated artifacts, such as the milling stone and mortar, are found in more than one complex. Each of the first five complexes has its own distinctive projectile points (*right*). Ocean food sources went almost unexploited until about 3600 B.C., when the last *lomas* campers began to collect seafood and the Pampa people used sandstone reamers and files to make fishhooks out of mussel shells. By 2500 B.C. farmer-fishermen in villages on the coast grew cotton and made both cloth (*top row, right*) and fishnets (*second from right*).



few stone tools typical of the period and a thin layer of refuse around some of the structures on the desert side of the valley, little has survived.

The period during which the Chuquitanta temple was built is close to the end of that part of the archaeological record for the central Peruvian coast which is characterized by the absence of pottery. When the potter's art did arrive (about 1850 B.C., according to radiocarbon indications), so did maize, the peanut and a native Andean fruit called lucuma. The subsequent arrival of a trio of domesticated animals (the llama, the alpaca and the guinea pig) and of an important tropical root crop (manioc) cannot yet be securely dated, but all were certainly present on the coast within the next few centuries.

In spite of such innovations and another great public work—the construction of a vast terraced stone structure at Ancón—there was no immediate revolutionary change in the village way of life in our survey area. It was not until after 1000 B.C. that any new settlements appeared in the Chillón valley. After that date, however, growth was rapid. Although the coastal farmer-fishermen never abandoned the shore, they were soon numerically eclipsed by an expanding population of farmers in the valley, a population that probably reached its peak about A.D. 500. By then, at least from Chicama in the north to Nazca in the south, the earlier farmer-fishermen villages were on the wane and the cultural focus of the entire region shifted from the sea to the coastal valleys, where intensive irrigation agriculture was practiced.

In this account of the Peruvian past I have isolated two environmental factors that have been important in shaping the region's history, although we must not imagine that such factors provide more than a partial explanation of the course of events. The first factor was the progressive post-Pleistocene desiccation of the *lomas;* this event quite possibly forced the formerly nomadic population of winter campers into taking up a year-round way of life on the shore. The second factor was that the newfound bounty of the sea permitted the permanent settlement of a much larger population than could have scraped a living from the *lomas,* and it even provided a surplus of food sufficient to allow the construction of ceremonial centers.

The sea could not, however, indefinitely support a growing population; I suggest as still a third environmental factor that, after all the best fishing locations along the entire Peruvian coast had been occupied by settlements of optimum size, the coastal valleys were used as new subsistence areas into which the expanding seashore population could move. Finally, a fourth environmental factor—a consequence of the characteristic topography of Peru's coastal valleys—may well have been responsible for the eventual political unification of these valley populations. The coastal valleys of Peru are narrow canyons that widen into small floodplains only within the last few miles of their journey to the sea. On each side of the floodplain the water table lies too deep to allow farming; if farmlands are to be expanded to accommodate the needs of a growing population, only irrigation can do the job. The only efficient irrigation systems are valley-wide ones that reach far upstream to collect their water. Such systems were built in all Peru's central coastal valleys. Each system must have required at least the consent, if not the active cooperation, of all the settlements in that valley.

It is therefore proposed that four environmental factors—the progressive drying up of coastal vegetation, the abundant marine life fostered by the Peru Current, a prehistoric kind of "population explosion" attendant on the exploitation of this rich food source and finally the topography of Peru's coastal valleys—played a significant role in shaping the culture patterns of the region's population for more than 8,000 years.

CEREMONIAL CENTER at Chuquitanta comprises two very large oblong structures and seven smaller buildings, all with stone walls, arrayed around a central plaza. One of the largest temples on the central coast of Peru, it is now being restored by Frédéric Engel.

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The Chemistry of Cell Membranes

The walls of the living cell consist partly of the fatty substances called phospholipids. It appears that some of these substances play an active role in the transport of other substances across the walls

by Lowell E. Hokin and Mabel R. Hokin

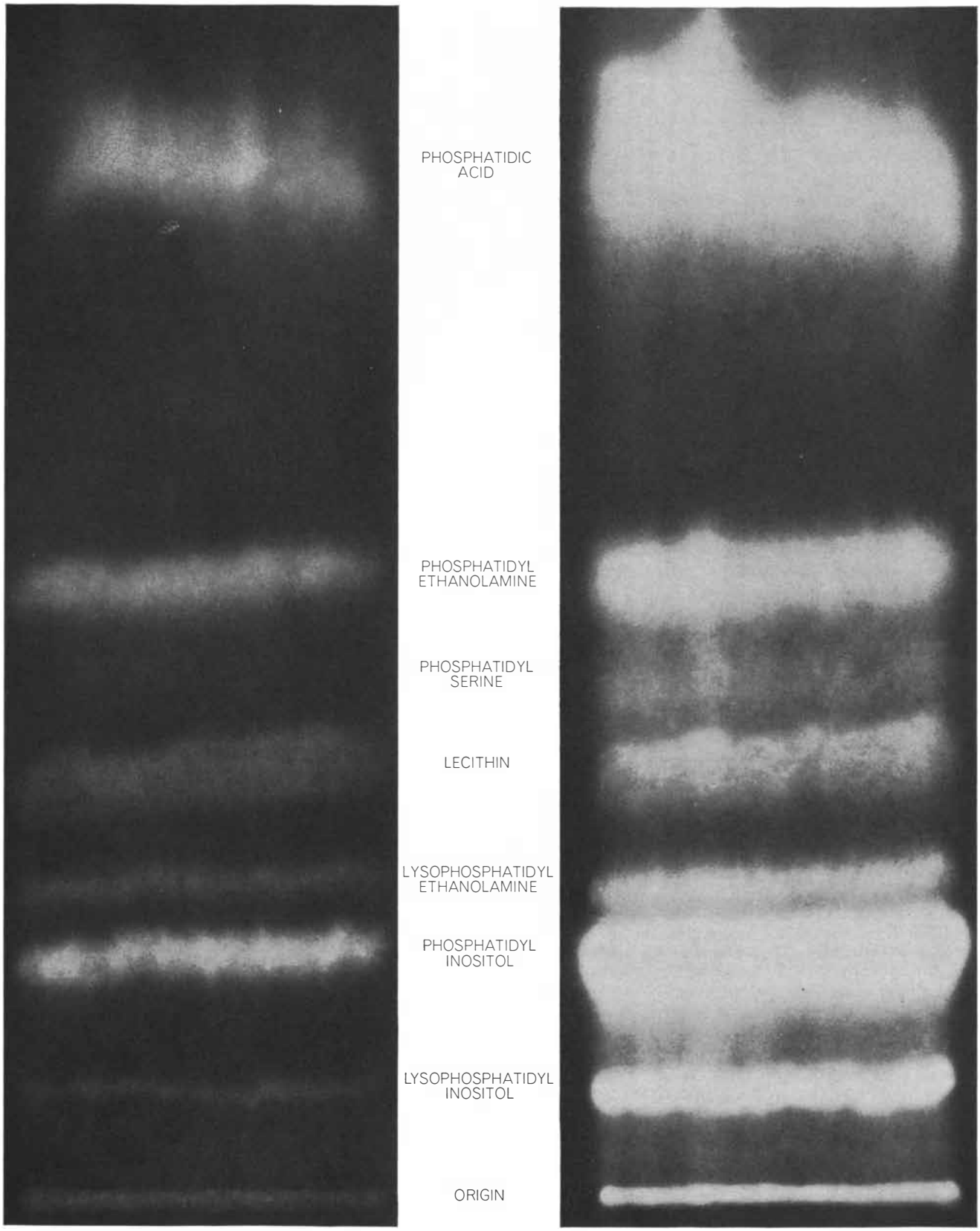
Among the vital structures without which no cell can exist are the cell membranes. These membranes are not merely the outer walls of the cell; in many cases they also form a complex system of folds within the cell, and in some cases they form closed sacs. The cell walls are selective gateways for the transport of substances into and out of the cell, and thus they control its form and activities. Biologists are increasingly impressed by the importance of the chemical machinery that operates the gates. A tremendous amount of study has been devoted to cell membranes in recent years, and much has been learned about the physical nature of the traffic across them [see "How Things Get into Cells," by Heinz Holter, SCIENTIFIC AMERICAN, September, 1961, and "Pumps in the Living Cell," by Arthur K. Solomon, SCIENTIFIC AMERICAN, August, 1962]. The chemical side of the story, however, is still largely unknown. There is little information about the basic reactions and agents involved in the membranes' handling of the transmembrane traffic.

One group of agents that appears to be very much involved has now been definitely identified. This group consists of certain phospholipids. These compounds, members of the large class of fatty substances called lipids, have long been known to be important components of the cell membranes. It used to be thought that the phospholipids served only to give the membranes physical structure and high impermeability to many substances that are held either within the cell or outside it. Now it has been discovered that they also play more dynamic roles. In studies over the past 10 years or so our laboratory in the department of physiological chemistry at the University of Wisconsin Medical School has found that, when cells are stimulated to pass materials through their membranes, there are accompanying chemical reactions among the phospholipids. The metabolic activity of phospholipids thereby revealed opens up a promising new field of investigation.

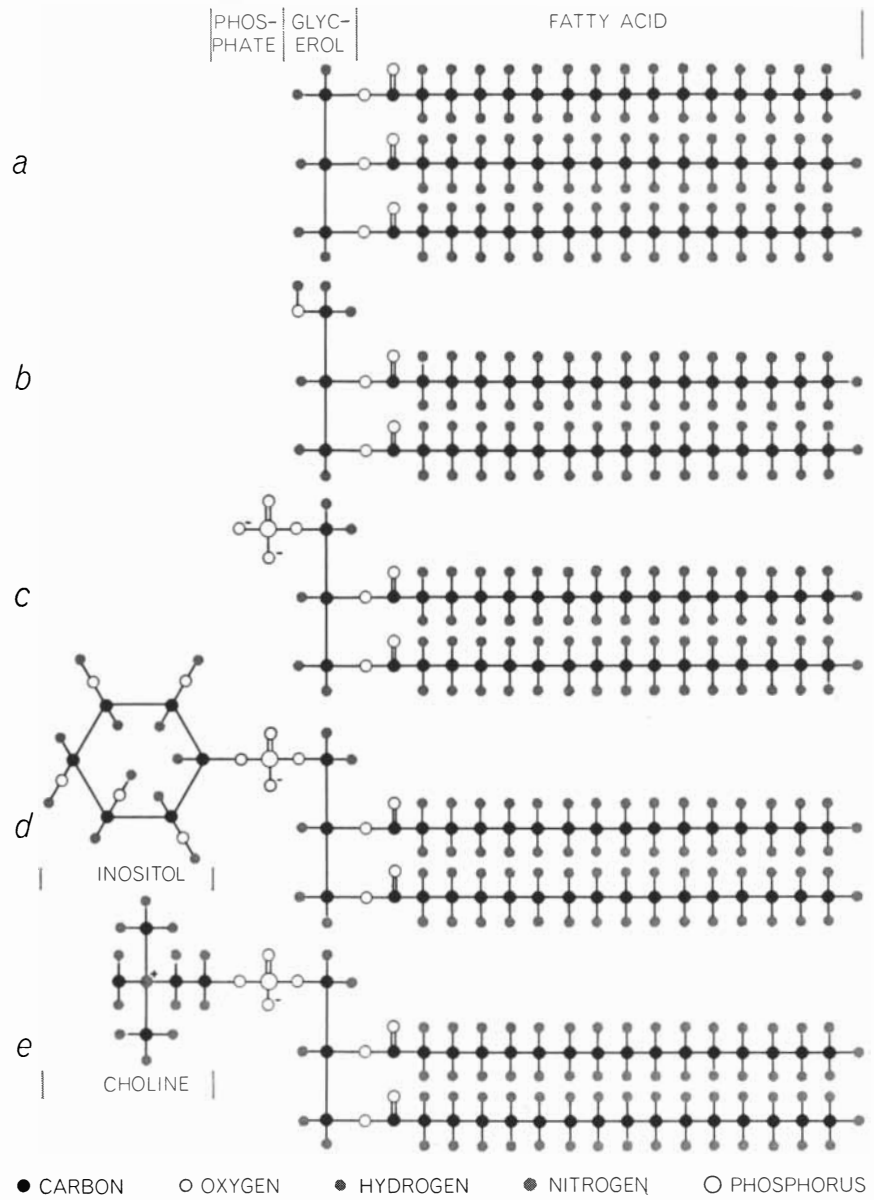
Most of the organic bulk of the living cell is made up of three classes of substances: proteins, nucleic acids and lipids. The biological functions of proteins and nucleic acids are becoming fairly well understood, but those of the lipids are not. It is known that some lipids provide energy for the cell's metabolism and that the phospholipids, which account for more than half of the total lipid content of most tissues, are located almost exclusively in the membranous components of the cell. There they form a structure that has been reasonably well established by examination with the electron microscope and by other means. A phospholipid molecule contains glycerol and phosphate, which are soluble in water, and a fatty-acid tail that is highly insoluble in water. In the cell membranes these molecules are arranged with their fatty-acid tails pointing toward each other, and their water-soluble heads, facing outward, are loosely attached to sheets of protein, so that the whole structure is sometimes called a "butter sandwich," the fatty-acid interior constituting the "butter" [*see bottom illustration on page 80*]. Embedded in the structure of the membrane is a system of enzymes—that is, protein catalysts—that conducts the membrane's chemical operations in a highly ordered way.

In physical terms there are two different processes by which substances are transported across cell membranes. In one of these processes the substance passes directly through the outer cell membrane. Glandular cells, which secrete substances at a high rate, have deep folds of membrane that give it a large surface area facilitating the transmembrane traffic. The other process involves placing the substances in what are essentially ejection capsules within the cell. The cells of the pancreas employ this system, and George E. Palade and his associates at the Rockefeller Institute have studied how it works. The pancreatic cell produces zymogens, which are precursors of digestive enzymes. For export it places the zymogens and enzymes in small sacs, or granules, enclosed by membranes [*see top illustration on page 81*]. Once the zymogen molecules have passed into a sac through its membrane they are already to all intents and purposes outside the cell. The granule travels to the cell's outer membrane and fuses with it; the fused area then opens up and spills the granule's contents into the fluid outside the cell. The process is called reverse phagocytosis, because it is similar to the opposite procedure by which a white blood cell, for instance, seizes and engulfs a foreign body.

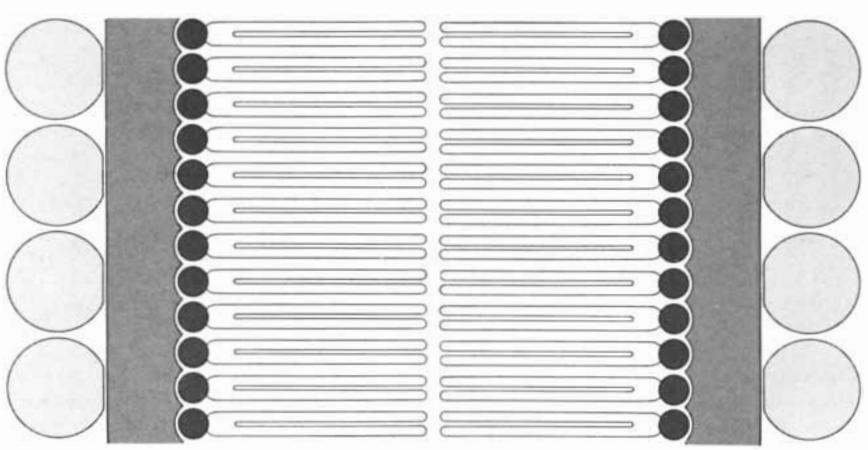
The chemical details of the transmembrane transport systems are the primary subjects of our studies. We have worked with cells of various glands —the pancreas and others. Our experiments have been based on two helpful techniques: the use of a chemical to stimulate the cells' secretion of substances through their membranes and the use of radioactive tracers to detect the activity of phospholipids in the membranes. Our principal stimulating agent is acetylcholine, a substance liberated at nerve endings that is known to trigger secretory activity by the cells



PAPER CHROMATOGRAMS indicate increased activity of phospholipids when other substances pass across the membranes of cells. The chromatograms separate the phospholipids in pancreas cells that were allowed to incorporate radioactive phosphorus; the phospholipids were thus labeled with radioactive atoms. The cells used to make the chromatogram at right were stimulated to secrete protein; those used to make the chromatogram at left were not. The solution of phospholipids extracted from each group of cells was placed at the line denoted "Origin"; as the solution moved up the paper the various phospholipids were deposited at characteristic intervals. The paper was then placed on X-ray film, which was exposed by the decay of the radioactive atoms. The bands at right are clearly more pronounced than those at left. Lysophosphatidyl ethanolamine and lysophosphatidyl inositol are extraneous products.



STRUCTURE OF FIVE LIPIDS, triglyceride (*a*), diglyceride (*b*), phosphatidic acid (*c*), phosphatidyl inositol (*d*) and phosphatidyl choline, or lecithin (*e*), is illustrated. Long groups to right are fatty acids. Names of groups to left are between short vertical brackets.



"BUTTER SANDWICH" version of membrane structure is schematically represented. Two layers of lipids, their fatty tails pointing in and their water-soluble heads pointing out, comprise the middle section. They lie between two thin sheets of protein (*medium gray bands*). These sheets of protein are thought to be coated with globular proteins (*light gray circles*).

of many glands. As for the phospholipids themselves, a brief description of their chemical nature is called for at this point.

The most familiar form of lipid, animal fat, is a triglyceride: it contains three fatty acids attached to the glycerol molecule. The phospholipids, most of which are glycerides, belong to the diglyceride family, containing only two fatty acids. In place of the third fatty acid they have a phosphate molecule, usually with an additional water-soluble molecule attached to it. In cell membranes there are five principal phospholipids of this type: phosphatidic acid, with a bare phosphate, and four others, each of which has a different group attached to the phosphate, these groups being choline, inositol, ethanolamine and serine. Choline and inositol are *B* vitamins, ethanolamine is an alcohol and serine is an amino acid. Of the various phospholipids the choline version, usually called lecithin, is by far the most abundant; in most cells it makes up more than half of the total phospholipid content [*see "e" in top illustration at left*].

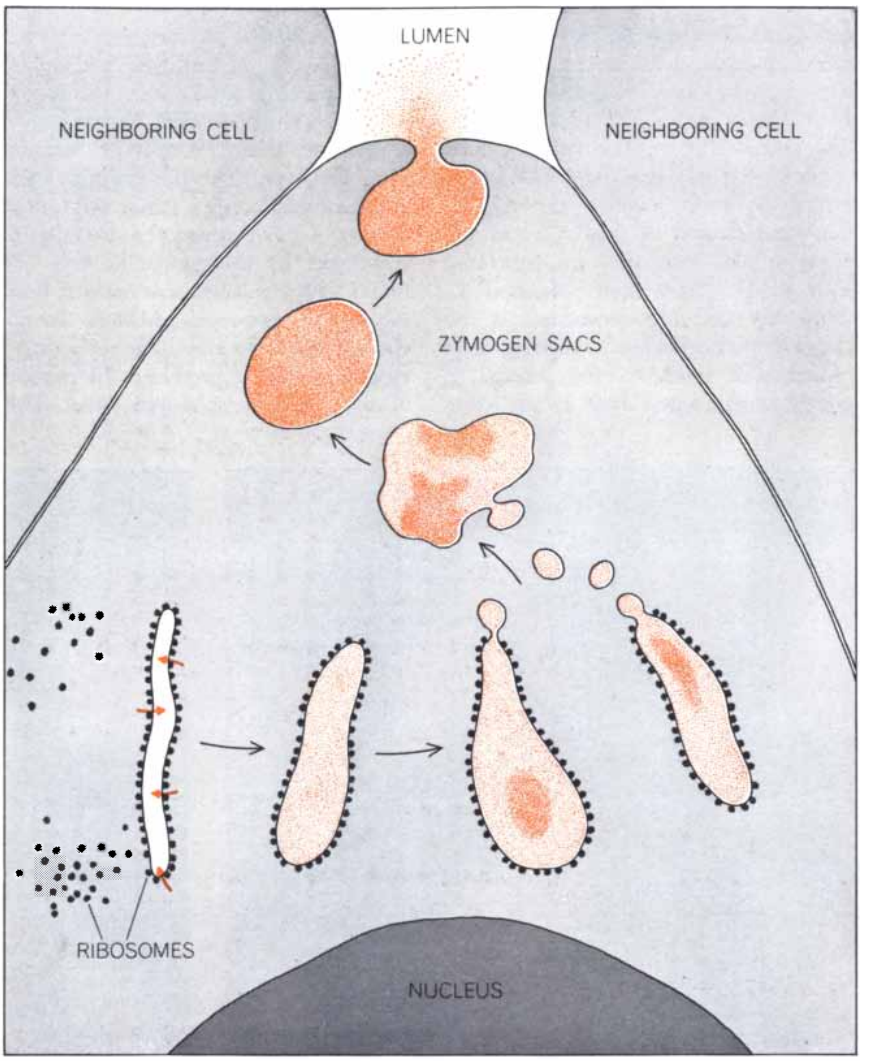
The experimental procedure in our studies is as follows. The gland to be investigated is cut into extremely thin slices (no more than a third of a millimeter thick) so that all the cells in the tissue will be exposed to easy and rapid traffic with the medium in which the cells are incubated. This medium contains a full supply of nutrients needed by the cells, with the addition of a stimulating agent (such as acetylcholine) to trigger the cells into secreting the substances they normally would in the intact animal. Also added to the medium is radioactive phosphorus, which will be incorporated in the phospholipids of the cell membranes. After the cells have been stimulated to pour forth secretions, the phospholipids are extracted from the cells and separated by paper chromatography. The amount of tracer in each phospholipid is then measured with a Geiger counter. This measurement indicates how much of each phospholipid has renewed its phosphate or been synthesized during the secretion of substances through the membranes.

The first gland we studied in detail was the pancreas. When cells of the pancreas were stimulated with acetylcholine or pancreomyzin (an intestinal hormone), they secreted the usual digestive enzymes into the nutrient medium. It was found that this secretion was accompanied by striking increases in the formation of certain phospholip-

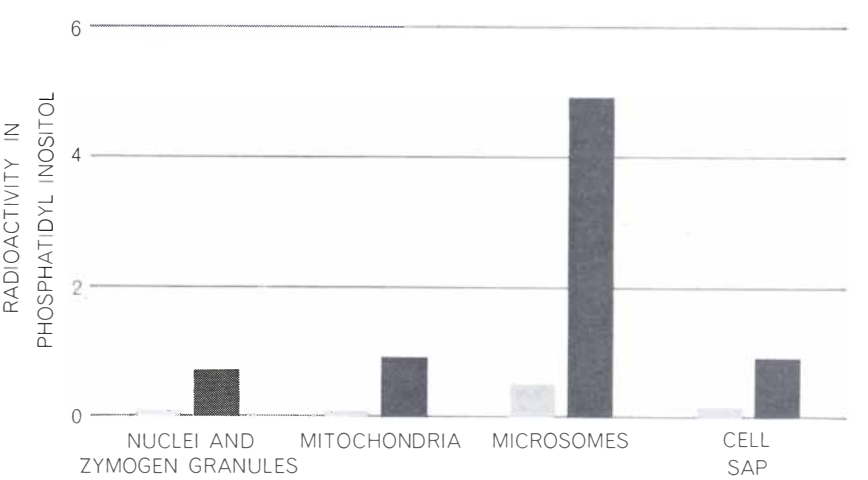
ids. Most pronounced was the increase in phosphatidyl inositol, phosphatidyl ethanolamine and phosphatidic acid; surprisingly there was no appreciable synthesis of lecithin, the principal phospholipid of the pancreatic cells. Tracer studies of the three major parts of the phosphatidyl inositol molecule—phosphate, glycerol and inositol—showed that the incorporation of all three parts was accelerated during secretion by the cell, proving that the whole molecule was being formed at an accelerated rate during secretion.

Other glands that secrete organic substances were found to behave in a similar way. A pattern emerged from these studies. In most cases the phospholipids principally affected were phosphatidyl inositol and phosphatidic acid. The magnitude of the phospholipid effect reflected the gland's capacity for secretion. For example, the pancreas, which secretes a great amount of enzyme, showed a very large phospholipid effect, and the anterior part of the pituitary, whose output is very much less than that of the pancreas, produced a small phospholipid effect.

Did the phospholipid effect actually take place in the cell membranes? This question was answered by breaking open the cells and spinning them in a centrifuge that separated the membrane material from the other structures of the cell. The radioactivity tagging the newly synthesized phospholipid was found to lie in the membranous fraction. The next question was: Did the phospholipid effect occur in some particular membrane of the cell or did it apply to the membranes in general? We investigated this by the technique of radioautography, in which a substance labeled with radioactive atoms (in this case the radioactive isotope hydrogen 3) reveals its location on a photographic emulsion [see "Autobiographies of Cells," by Renato Baserga and Walter E. Kisieleski; SCIENTIFIC AMERICAN, August, 1963]. In the cells of the pancreas there are two types of membrane: "rough," with attached granules in which enzymes are synthesized, and "smooth," covering the sacs in which the enzymes are transported to the outer membrane for ejection from the cell. These two types of membrane are in separate regions within the cell; hence radioautography can show whether radioactivity is coming from the rough membranes, from the smooth or from both. As it turned out, both types of membrane showed radioactivity signaling the phospholipid effect. This in-



SECRETION OF PROTEIN by a cell of the pancreas is depicted. Particles attached to sacs in the basal, or lower, region of cell fill them with zymogens (the precursors of digestive enzymes) and give them a rough appearance. A smooth membrane buds off, taking the zymogens toward the membrane in the apical, or upper, region of the cell. It fuses with the outer membrane by "reverse phagocytosis" and empties its contents into the space outside.

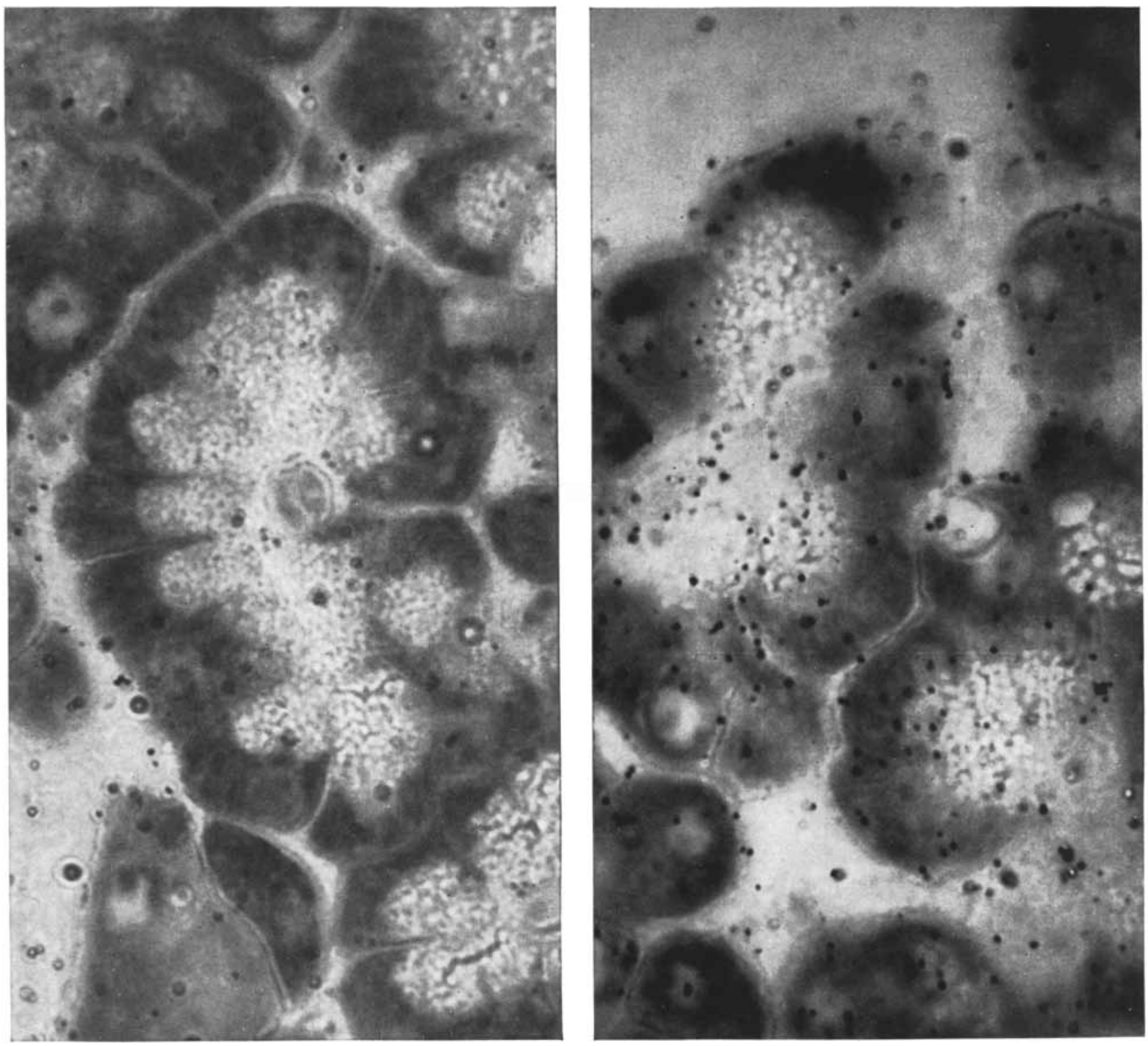


ACTIVITY OF PHOSPHOLIPIDS in various parts of the pancreas cell is graphed for cells stimulated to secrete protein (*dark bars*) and unstimulated cells (*light bars*). Cells were allowed to take up radioactive phosphorus, which they incorporate into lipids at sites of secretory activity. Cells were then disrupted and fractions containing various structures were separated by centrifuge. Microsome fraction consists of both rough and smooth membranes.

dicated that the phospholipid effect was associated with the general process of transmembrane transport rather than with a special case of such transport.

Do the phospholipids play a part in the process of reverse phagocytosis whereby the pancreatic cell discharges zymogens and enzymes through its outer membrane? A small part of the phospholipid effect may be associated with phagocytosis itself. Manfred L. Karnovsky and his co-workers at the Harvard Medical School, who have done considerable work on the process of phagocytosis, found that when white blood cells were stimulated to swallow foreign particles (of starch or polystyrene), they stepped up their production of phosphatidic acid and the phospholipids containing inositol, ethanolamine and serine. Our own experiments suggest, however, that the phospholipids are involved in only a minor way in the reverse of this process: the extrusion of substances by the pancreatic cell. We found that if calcium was omitted from the cell's incubation medium, acetylcholine failed to stimulate such extrusion, although it produced 70 percent of the usual phospholipid effect. This indicates that the phospholipids are concerned mainly with some phase of the secretory process other than the final discharge through the outer wall. The reader will recall that the zymogens in effect are already outside the cell when they have passed through the membranes into the ejection sacs.

There is little light so far on exactly how the phospholipids play their role in transmembrane transport. A biological structure that may cast considerable light has come into view, however. This helpful instrument is the salt



RADIOAUTOGRAPHS of cells from the pancreas of a rat reveal that phospholipids are active when substances are being transported across membranes. Cells at left were not stimulated to secrete protein; cells at right were. Both groups of cells were allowed to incorporate phosphatidyl inositol labeled with tritium, or radioactive hydrogen; this they did only during a period of activity. Decaying tritium leaves black dots in film. Increased number of dots at right suggests that phospholipid activity occurs during secretion. The cells form ringlike structures, with the basal (*dark*) part of each toward the outside. The even pattern of dots indicates that both the rough membranes in the basal region of each cell and the smooth membranes in the apical part (*light*) are sites of phospholipid effects.

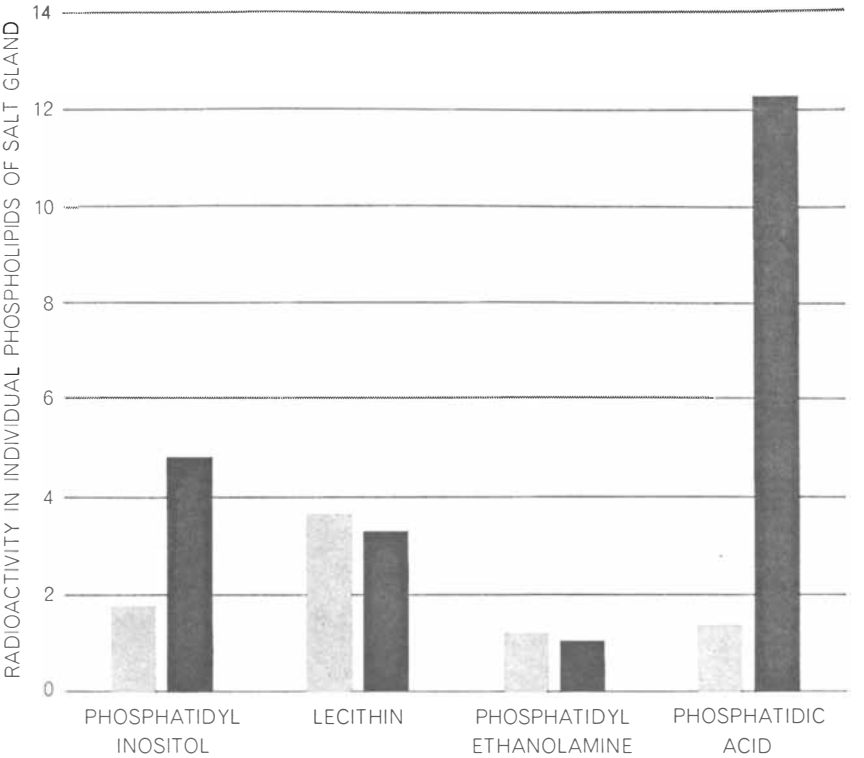
gland of aquatic birds. We have found it in many ways the most enlightening organ available for detailed study of the possible role of the phospholipids in cell membranes.

Aquatic birds employ salt glands, located above the eye sockets, to secrete into the nasal cavity the excess salt they take into their bloodstream by drinking seawater and eating marine animals [see "Salt Glands," by Knut Schmidt-Nielsen; SCIENTIFIC AMERICAN, January, 1959]. The transport of sodium ions across cell walls is, of course, one of the most essential functions of all living organisms: it serves to regulate the fluid balance between cells and their environment; it plays an important role in maintaining the excitability of muscles and nerves, and it takes part in many other processes.

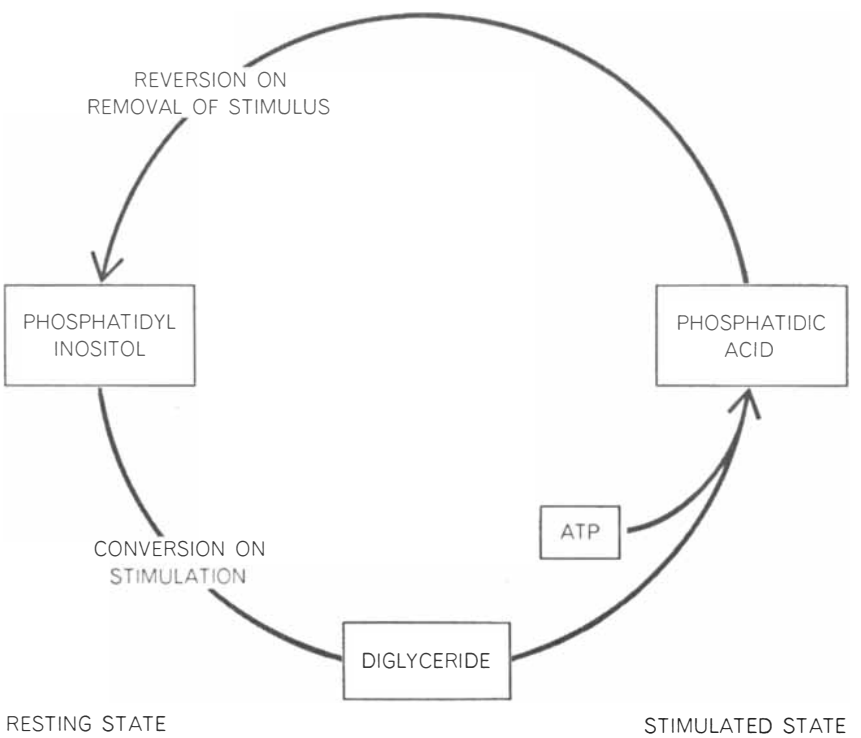
We found that in the test tube we could stimulate salt gland cells to secrete salt by injecting acetylcholine, which in the living organism is released at nerve endings in the gland and triggers it into activity. Along with the cells' secretion of salt there came an increase in their membranes' turnover of inositol and phosphate in phosphatidyl inositol and a much more striking increase in the turnover of phosphate in phosphatidic acid, as indicated by the incorporation of the appropriate labeled compounds in these phospholipids. The turnover of phosphate in phosphatidic acid was so much greater in the salt gland cells than in any other gland studied that it suggested this substance might be a special key to the transport of sodium through cell membranes.

More detailed studies of the chemical events in the membranes of the salt gland cell have shown that when the cell starts to secrete salt, part of the phosphatidyl inositol in the membranes is stripped of its phosphate and inositol group and thus is reduced simply to a diglyceride. Adenosine triphosphate (ATP) in the cell then donates a phosphate group to the diglyceride and converts it to phosphatidic acid. On the other hand, when salt secretion by the cell is stopped (by eliminating acetylcholine with the enzyme cholinesterase or inactivating it with atropine), the phosphatidic acid is converted back to phosphatidyl inositol and remains in this form while the tissue is resting.

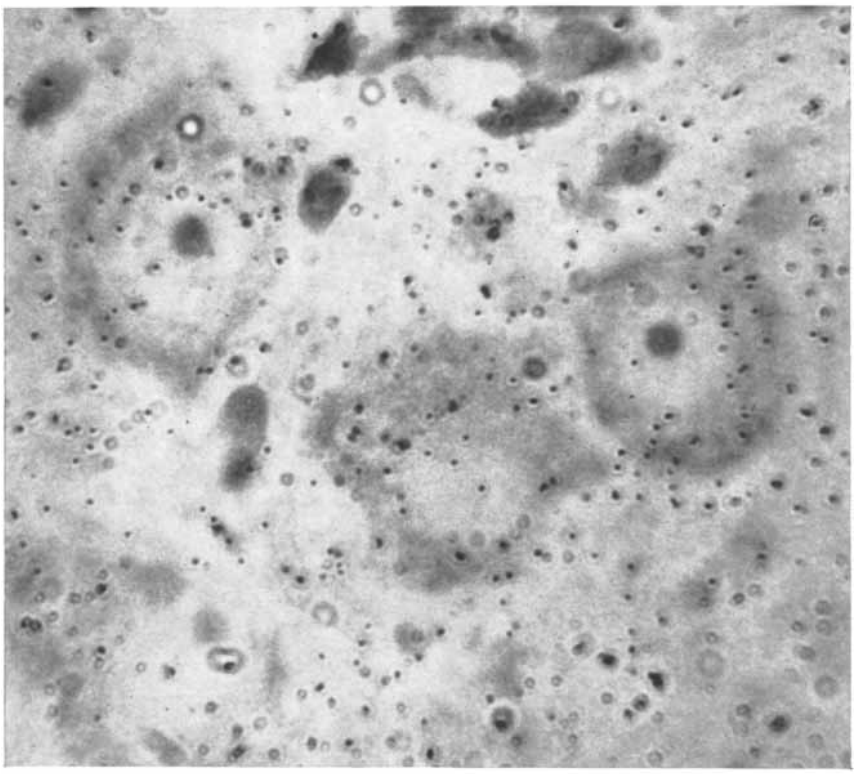
We interpret these observations to mean that the two opposite processes are mechanisms for turning the transport machine on and off. The conversion of phosphatidyl inositol to diglyc-



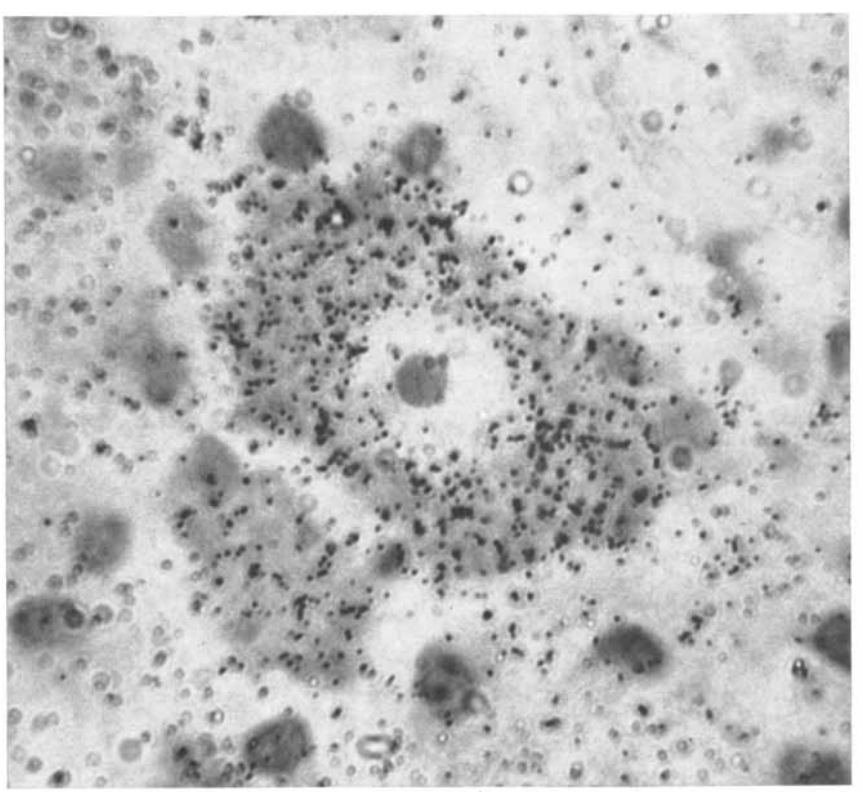
PHOSPHOLIPID EFFECT IN SALT GLAND of a goose is described in this graph. Figures are given for the turnover of individual phospholipids before the gland was stimulated to secrete salt (*light bars*) and after (*dark bars*), as indicated by the incorporation of radioactive tracers in the various compounds. The uniquely high turnover of phosphatidic acid in salt glands suggests that it may play a special role in the transport of sodium.



PHOSPHATIDIC ACID CYCLE for the salt gland is represented schematically in terms of a series of chemical reactions occurring at numerous sites on the membrane. When the cell secretes salt, some phosphatidyl inositol in the membranes is reduced to a diglyceride. Adenosine triphosphate (*ATP*) in the cell provides a phosphate group to produce phosphatidic acid. When salt secretion stops, phosphatidic acid reverts to phosphatidyl inositol.



NERVE CELLS from sympathetic ganglia of a cat appear in this radioautograph. Black dots, spread without pattern, reveal sites where radioactive tracer was incorporated into phosphatidyl inositol. No effort was made to stimulate increased phospholipid synthesis.

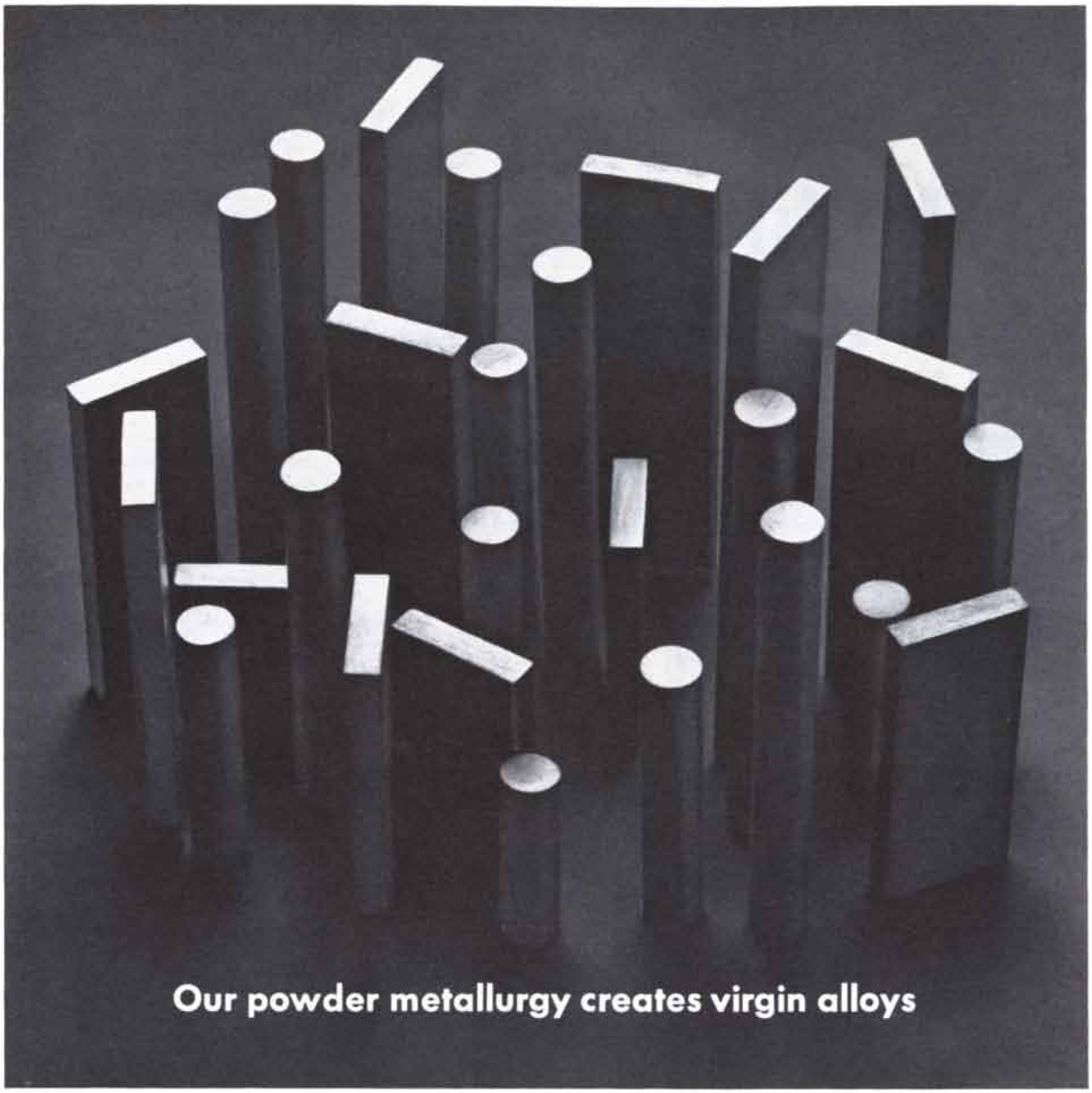


STIMULATED NERVE CELLS gain labeled phosphatidyl inositol, revealed by black dots. The stimulus was provided by acetylcholine, a substance released at the nerve synapse. It was thought that acetylcholine would serve only to stimulate phospholipid effect in the outer membrane, but radioautograph shows an effect on cytoplasm within cell.

eride and then to phosphatidic acid turns on the machine moving sodium through the membranes; the conversion of phosphatidic acid back to phosphatidyl inositol turns it off—shuts off the moving power, so to speak.

We are hopeful that further investigations with the salt gland will yield a reasonably detailed picture of just how these substances play their roles in the on-off control of the transmembrane transport of sodium. The transport process in the salt gland, however, obviously differs somewhat from that in the pancreas, judging from the tracer testimony on the phospholipids involved [*see top illustration on preceding page*]. It seems that the transport system varies in details from one type of cell to another, so that the elucidation of the phospholipids' activity in each case is a separate problem.

The kind of experimental work that has opened up these new insights into the machinery of gland cells is also beginning to yield a glimmer of new enlightenment about nerve cells. The two types of cell seem to be related by two important links: acetylcholine and phospholipids. Acetylcholine, which triggers activity in gland cells, is even better known as a stimulator of nerve cells: it is responsible for the transmission of electrical impulses across the synapse from one nerve cell to the next. Released at the nerve ending as a translation of the electrical impulse, the chemical crosses the gap to the cell body of the second nerve and excites the latter to regenerate the same impulse. The parallel between nerve cells and gland cells is even more striking with respect to phospholipids. More than 60 years ago J. W. L. Thudichum, a British physician, discovered that lipids were extremely important components of the brain cells. They account for half of the dry weight of the brain, and more than half of the brain lipid is phospholipid. Hereditary abnormalities of lipid metabolism have been found to be responsible for several severe forms of mental defect. Thudichum identified more than half a dozen lipids in the brain cells and started the elucidation of their chemical structure. The importance of his work was overlooked, however. As Irvine H. Page of the Cleveland Clinic has remarked, Thudichum "worked . . . without reward and almost without regard," and the investigation of brain lipids that he inaugurated was not followed up until some 25 years after his death. His work is



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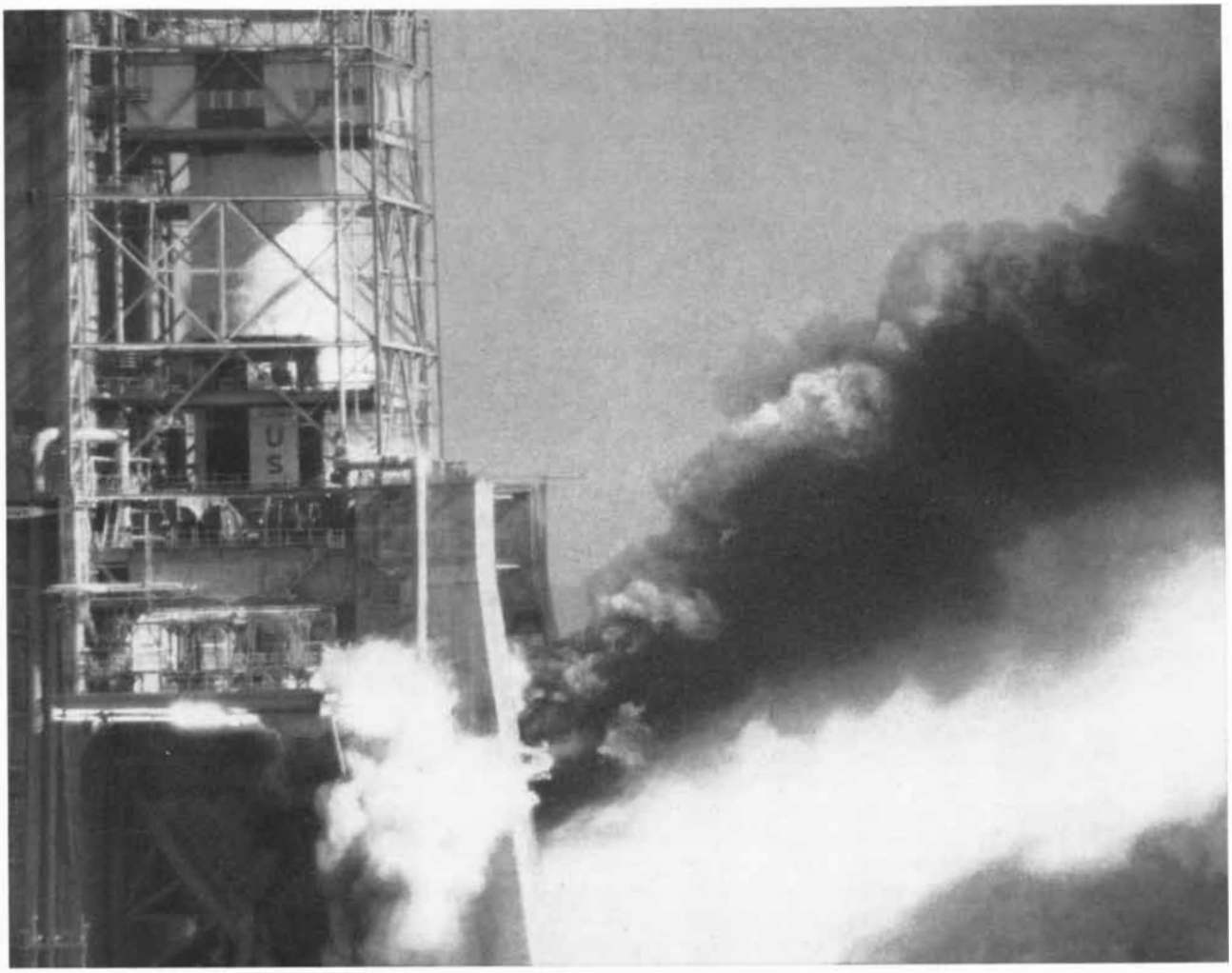
now recognized as being very significant indeed.

Several years ago we began to study slices of brain tissue by the same technique we have used on gland cells. Working with cells of the brain cortex of guinea pigs and the ganglia of cats, we found that when acetylcholine was added to the incubation medium it stimulated these cells to synthesize phosphatidyl inositol and phosphatidic acid, much as it does in gland cells. Recently Martin G. Larrabee and his collaborators at Johns Hopkins University have produced the same effects under natural conditions: they stimulated nerves electrically and found that the nerve tissue in the region of the cell body of the second nerve produced an increase of phosphatidyl inositol. They discovered further that an extract from curare, the Indian arrowhead poison and antagonist of acetylcholine, could block this effect. This was a good indication that the increased phospholipid synthesis takes place in the nerve cells beyond the synapses where the acetylcholine is released.

We have employed radioautography to locate the site of the effect more precisely. These experiments show that the stimulated synthesis of phosphatidyl inositol takes place in the cytoplasm of the cell—not in the cell's outer membrane, as one might expect. In other words, the excitation generated in a nerve cell by acetylcholine extends into the depths of the cell. The chemical reactions involved in the phosphatidyl inositol effect in ganglion cells seem to be similar to those in the pancreas. David Bodian of the Johns Hopkins University School of Medicine has recently provided evidence that "rough" membranes in the cell bodies of nerve cells may synthesize a protein that serves the needs of synaptic transmission. Since the work with the pancreas has already suggested that the phosphatidyl inositol effect is involved in transmembrane transport of protein, our current working hypothesis is that the phosphatidyl inositol effect in nerve cells plays a role in transporting protein from its site of synthesis to the synaptic region. As is the case with many working hypotheses, however, this picture may have to be changed as more experiments are done.

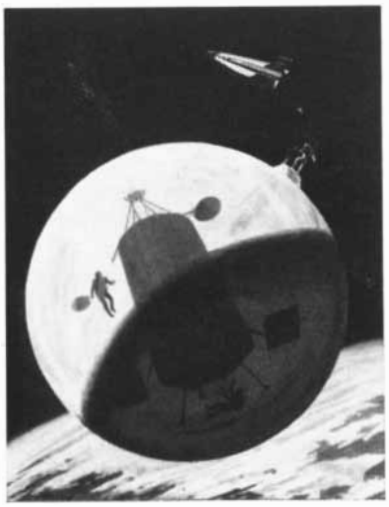
All in all the phospholipids have acquired a remarkably exciting new interest for biological investigators, and the quest for clarification of their dynamic roles in cell membranes should extend into many fields.



FIRST full-duration test firing of Saturn V's S-1C booster marked a major milestone on the way to America's first manned lunar landing. The test, conducted at NASA's Marshall Space Flight Center, generated the most force ever produced by a rocket—sufficient to create 160 million hp in flight. The Saturn V vehicle, tall as a 30-story building and weighing 3,000 tons, will launch American astronauts to the moon this decade. It will be able to put 100 tons into earth orbit, or propel several tons of instruments to Mars. Boeing holds a NASA contract to develop, build and test the S-1C booster.

Capability has many faces at Boeing

TWIN TURBINE Sea Knight, built by Boeing's Vertol Division, is U.S. Marine Corps assault transport helicopter. Tandem rotors fold in less than one minute for storage on carrier hangar decks.



SPACE BUBBLE, an inflatable balloon, suggested by U.S. Air Force and Boeing scientists, would protect astronauts while assembling platforms or repairing craft in space.

NEWEST jetliner, Boeing 737 Twinjet, will carry up to 115 passengers at 550 to 600 mph, over routes of 100 to 1100 miles. New 737 will offer more head room, more shoulder room than any other short-range jet. It has been ordered by Lufthansa, Pacific, United and Western.

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The Origins of Facial Expressions

The raised eyebrow, frown, smile, laugh and even the ability to speak may all have evolved from ancestral reflex actions that were gradually transformed into means of communication

by Richard J. Andrew

The human face is a remarkable instrument of communication. By movements of the mouth, eyes and brows it conveys, in a most sensitive way, specific emotions, thoughts or intentions that are universally understood. How did this mode of communication arise, and why have facial expressions taken the particular forms they have? Why, for instance, do two friends automatically on meeting draw the corners of their mouths back and up in what is called a smile? What was the origin of the frown? For that matter, what was the origin of speech itself? How can one account for the fact that it took the form of patterns of sound shaped by contortions of the lips and tongue, when a vocal language might just as easily have been built from a system of whistles, squeaks and grunts?

Charles Darwin, whose curiosity about evolution left no aspect of the subject unexplored, laid a foundation for the study of the evolution of facial expressions in an investigation he published in 1872 under the title *The Expression of the Emotions in Man and Animals.* Comparing the facial gestures of various primates and other mammals, Darwin concluded that their origins could be traced to primitive activities such as drawing back the lips for biting. The original acts evolved into displays that conveyed a derivative meaning (such as threat) to other animals. Darwin illustrated his interpretation with a quotation from Herbert Spencer on the threatening behavior of cats: "The destructive passions are shown in ... gnashing of the teeth and protrusion of the claws ... and these are weaker forms of the actions that accompany the killing of prey." In the course of evolution facial expressions changed in form (through changes in the facial muscles) and sometimes in meaning. Endowed, however, with the function of communication, they survived from one stage of animal evolution to the next and thus were passed along the evolutionary ladder to man.

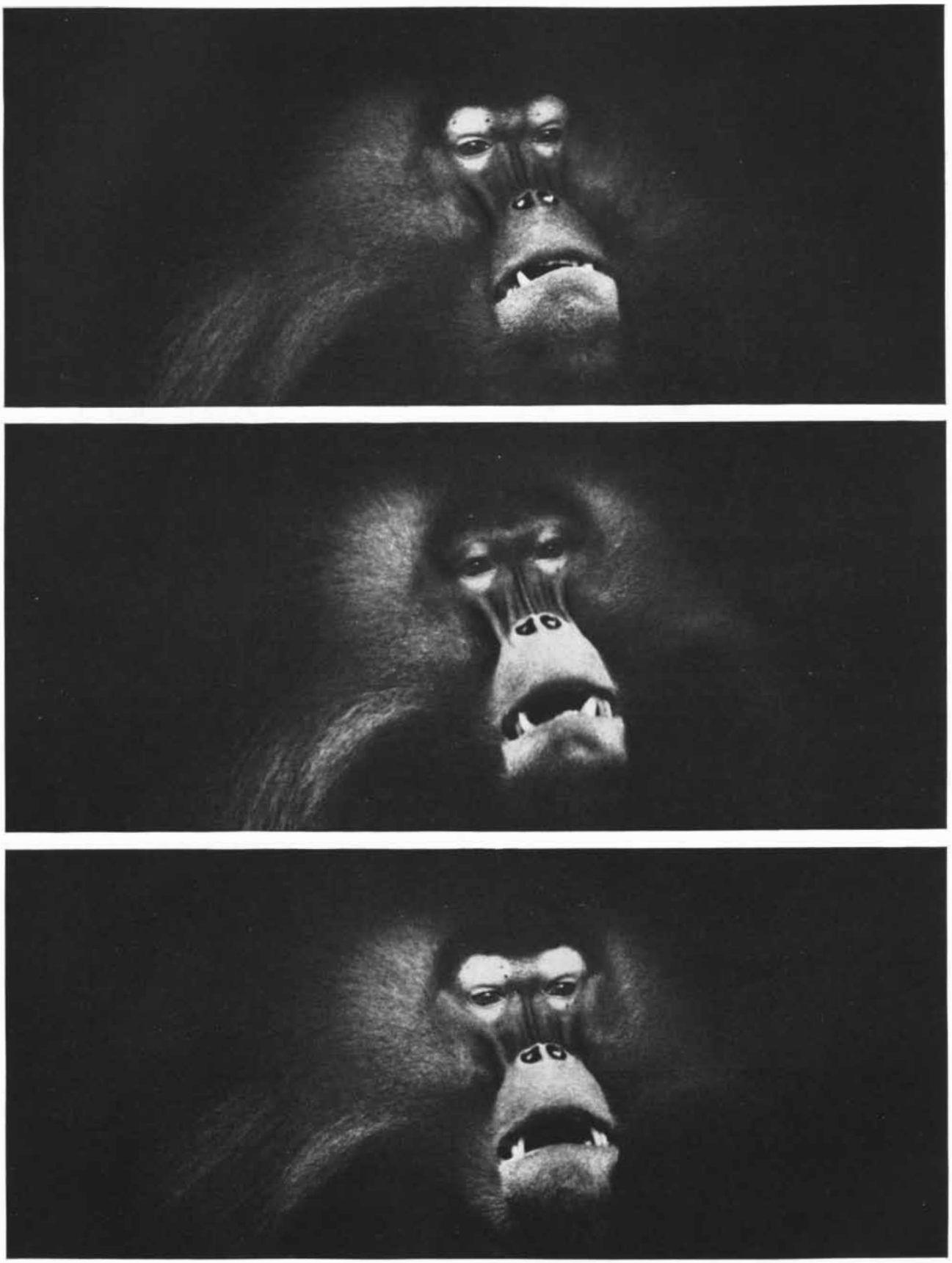
Darwin's general explanation is still considered sound. In recent years a number of anthropologists and evolutionists have revived the investigation of the evolution of facial expression as a helpful tool for studies of the development of human behavior. This inquiry, benefiting from a great deal of new information about animal displays and comparative anatomy, has begun to yield detailed answers to questions about the history of primate communication.

We shall consider the origins of several human facial expressions, culminating in human speech, but first it would be well to examine a nonhuman display that offers a particularly clear illustration of how a natural physical response is converted into an information-imparting expression.

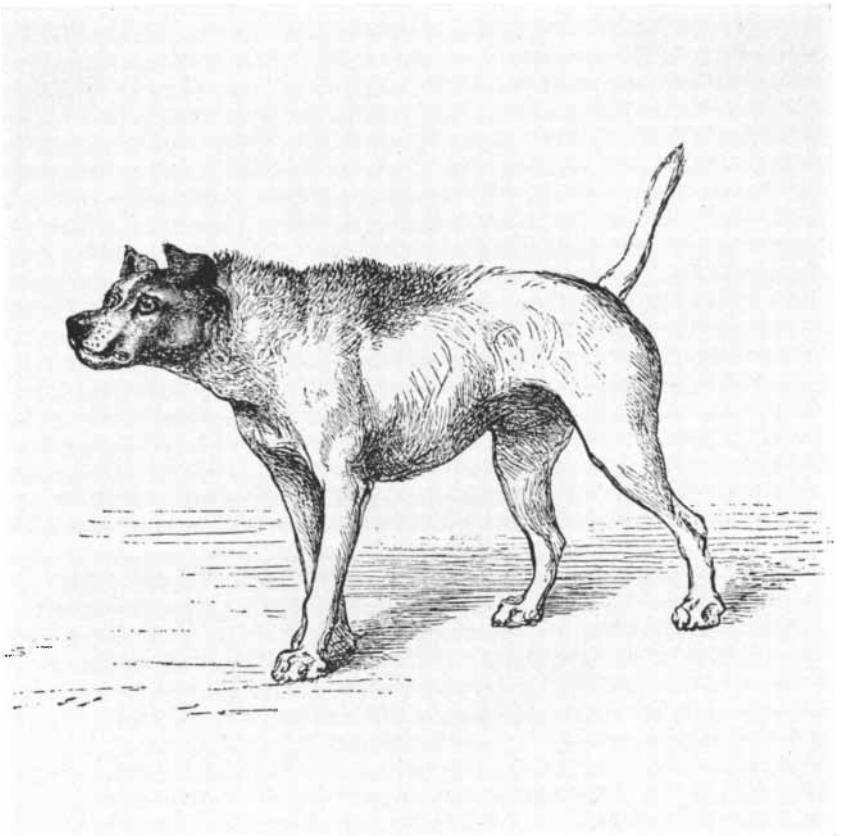
Many mammals, from mice to monkeys, flatten their ears and close or narrow their eyes when they are startled by a noise or some other sudden or noxious stimulus. This reaction is simply protective—a set of reflexes serving to reduce exposure of the sense organs to injury. Even in its primitive form, however, the flattening of the ears may convey information to other animals. Certain primates, for example, warily lay back their ears when their face approaches the face of a fellow animal (or is approached by it). The distance at which they do this depends on the degree of their sense of danger in the coming encounter. A "bush baby" of the genus *Galago,* approaching confidently to attack another animal, does not flatten its ears until it thrusts its face close to the opponent's; the animal being attacked, on the other hand, pulls in its ears while the threatening aggressor is still a considerable distance away. A male of the same genus, preparing to approach a female to attempt copulation, likewise displays its lack of confidence by flattening its ears at the very start of its approach.

Thus ear-flattening, originally only a reflex act of protection, becomes potentially a device of communication—a signal of intentions. It is a meaningful component of the animal's facial expression. (Consider, for instance, the fact that much of what we read into the expression of a dog or a horse depends on the flattening of its ears.) In the higher primates ear-flattening is less pronounced and less significant, because these animals no longer depend so much on their ears to scan the environment and hence have less ability to move their ears. They retain as a significant signal, however, retraction of the scalp, which was a part of the movement in primitive flattening of the ears. In macaques and baboons scalp retraction is much exaggerated and produces a spectacular display, such as the flattening of a topknot of hair or the pulling up of folds of brightly colored skin from under the eyebrows, which gives the animal a look of staring astonishment. Like ear-flattening, these displays carry information, but they have no element of physical protection; their sole function is communication.

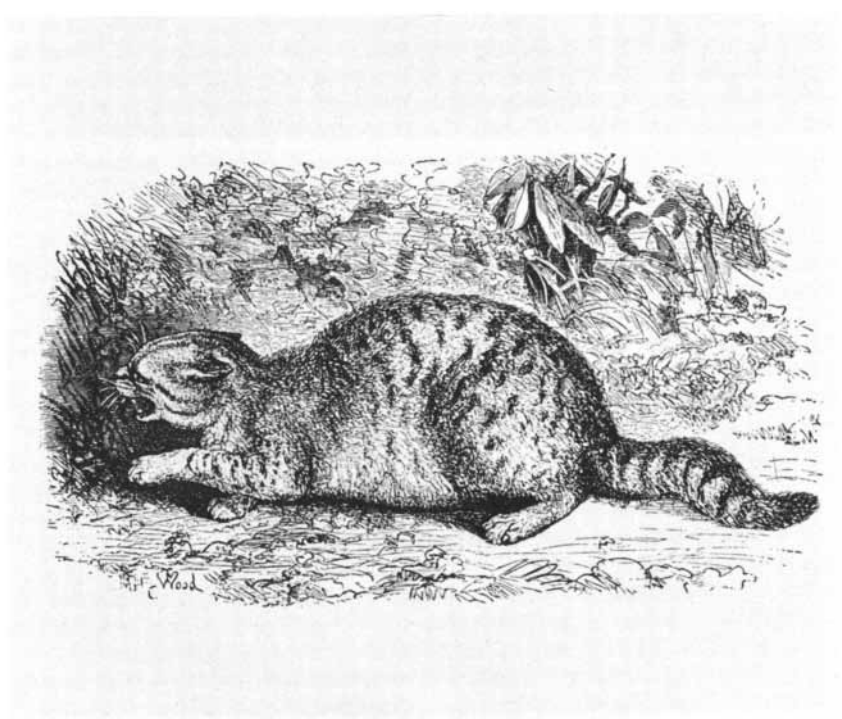
In the higher apes and in man, who have lost the ability to move their ears or retract their scalp to any significant extent, these components of expression have virtually disappeared (except in connection with the slight raising of



FACIAL DISPLAY by a gelada monkey, a close relative of the baboon, occurs when the animal retracts its scalp (*photographs at top and bottom*), thereby exposing folds of colored skin that are usually out of sight below the brow ridge (*middle photograph*). The action involves the same muscles that reflexively flatten the ears of some mammals in the event of a close approach. For many Old World monkeys, however, the reflex has become a social signal. Photographs were made at the Philadelphia Zoological Garden.



DOG'S SNARL was noted by Charles Darwin as one of the many facial expressions that are exhibited by the higher vertebrates. This illustration and the one below are taken from his study *The Expression of the Emotions in Man and Animals*, published in 1872.



CAT'S HISS is another of the animal expressions noted by Darwin, who cited an analysis by the pioneer evolutionist Herbert Spencer: "The destructive passions are shown in... [threat displays that] are weaker forms of the actions that accompany the killing of prey."

the brows as a sign of surprise). Perhaps one reason for the disappearance of scalp retraction in man is that his expressions have tended to emphasize movement in the opposite direction, that is, the drawing down, or lowering, of the eyebrows.

The point of this discussion of ear-flattening (and its associated facial movements) is that it gives a clear indication of the way in which most facial expressions originated. They are not innate expressions of pleasure, pain, anger or fear but arose in the first instance as accompaniments of functional activities or as reflex responses to stimuli (as ear-flattening was a protective response to a startling change in the environment). The expressions were perpetuated by natural selection and evolved into exaggerated displays because they had communicative value. In the course of evolution the expressions, particularly in man, came to represent not only intentions but also emotional states (although a given expression may indicate different emotions in different contexts).

Proceeding now to the origins of human expressions, we can start with the frown as a rather simple case. This expression apparently arose from the act of staring intently at an object close to the face. In that action the dog, the capuchin monkey and many other mammals with mobile faces (including man) typically lower the eyebrows. The primary function served by this movement is not clear; it may be partly protective or it may help to focus the eyes on the object. At the same time, in most mammals the direct stare is a good indication of concentrated interest and little or no fear; in fact, such interest often precedes attack. As a result the fixed stare with lowered brows has become an expression of confident (that is, unfearing) threat in monkeys, apes and man.

The history of the grin is considerably more complicated. It seems to have at least two different primitive origins. One is a protective response, like ear-flattening, to a startling stimulus. Drawing back the lips is a preliminary either to biting or to throwing out something noxious that has been taken into the mouth. A great many mammals, from the primitive opossum to the advanced primates, show this grinlike response when startled. It is a characteristic grimace under such circumstances even in man, as anyone can readily verify for himself by noting his expression when

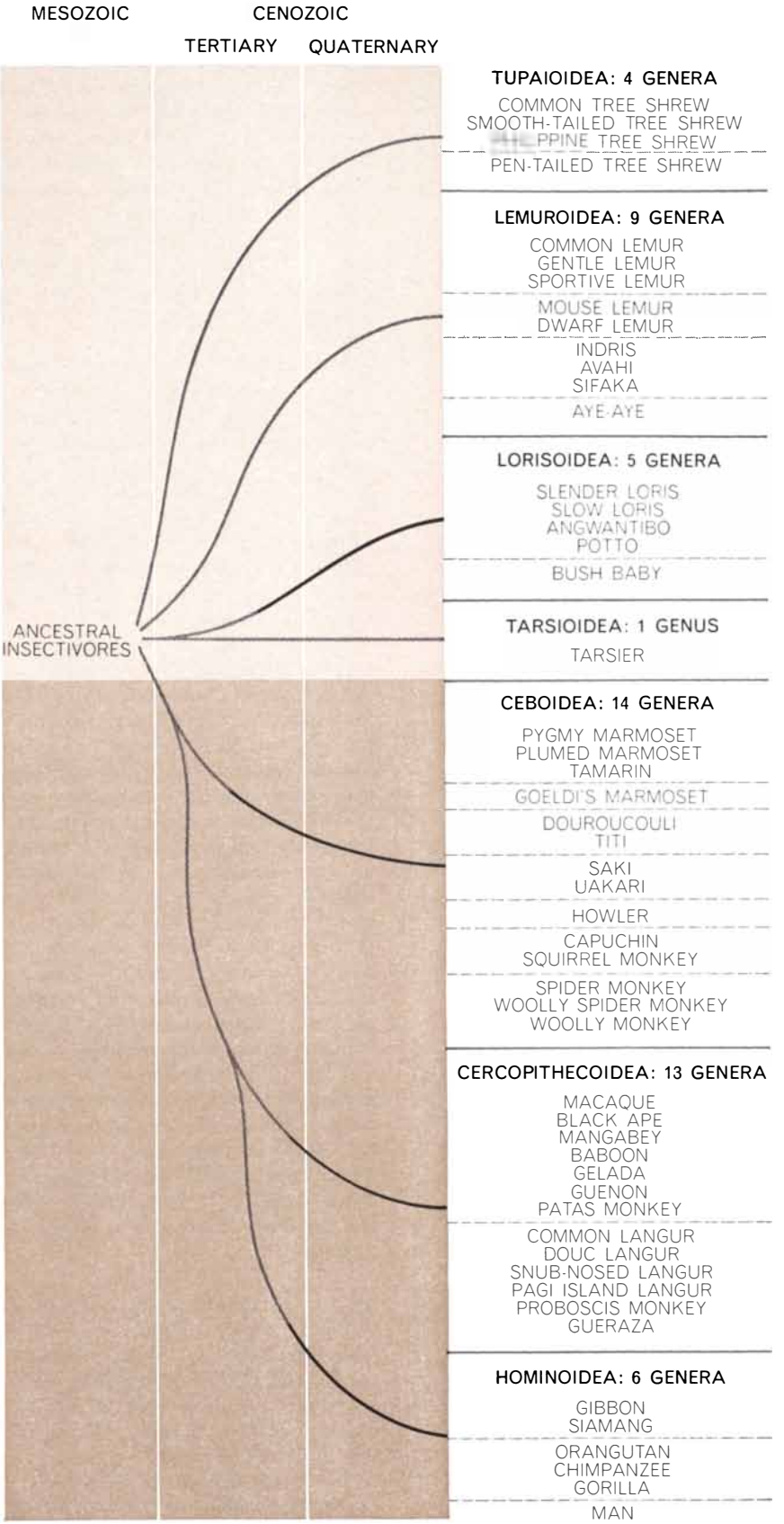
he happens to clash the gears of his car in shifting.

Another type of primitive grin is connected with high-pitched vocalization in animals. The tensing of neck muscles that accompanies a grin may serve to strengthen the neck against the vibration that accompanies vocalization. In any case, grins go with the shrill vocalizations of many species: the meow of a cat, the whinny of a horse, the clicks and crackles of lemurs, the screeching calls of monkeys, the screams of baboons and the shrieks of man (as can be seen if one watches the expressions of wailing children in a quarrel). In the social animals, including man, the grin that accompanies screaming generally signifies defensive threat. The advanced primates often omit the vocalization and show only a grin in such situations. The rhesus monkey, for example, sometimes grins in silence when it is frightened by a fellow animal.

The evolution of the primitive grin into the human smile has been traced only in part. Physically its development is rather clear: the smile is a direct descendant of the grin. The association of vocal laughter with the grin also is not difficult to explain, in view of the primitive connection between grinning and vocalization. The main problem is to explain how the smile came to be associated with pleasure.

In advanced types of monkeys, such as the baboon, grinning becomes more and more easily evoked, particularly in meetings between fellow members of a group. A subordinate macaque, for instance, will grin and retract its scalp when it catches the eye of a dominant fellow macaque some distance away. Such a grin is essentially a defensive gesture showing friendly intentions. The human smile, in many situations, has much the same meaning. When a man maintains a fixed smile in response to the verbal attacks of a superior, or when he smiles on meeting a stranger, he is behaving defensively in the same way as his fellow primates.

The smile of pleasure remains difficult to understand. Possibly the twitters and peeps of young chickens may shed some light on the subject. A chick emits these little noises in situations so much like those that cause human infants to laugh or cry that the twitter has long been interpreted as a sign of pleasure and the peep as a sign of distress. Looking into this question experimentally, I have found that the chick's twitter can be evoked not only by a pleasurable event such as the arrival of food but



PRIMATE FAMILY TREE arrays the order's 52 living genera according to their probable lines of descent. Contrasting colors indicate the split between the primitive prosimians and the more highly evolved anthropoids. The latter include the less advanced New World monkeys, the more advanced Old World monkeys and the group comprising apes and man. Some apes and Old World monkeys nearly rival man in their variety of facial expressions.

SOCIAL GREETING by a gelada monkey was recorded on motion-picture film. When an acquaintance appears, lip-smacking (*top, note protruding tongue*) rapidly turns into an exaggerated grin (*bottom*). The gesture is meant to demonstrate a lack of hostility.

also by a light touch, a sudden sound or any other conspicuous but mild stimulus that produces attention. The chick tends to move toward those stimuli that cause it to twitter and to avoid those that cause it to peep. Other workers have reported that human subjects find small changes in stimulation pleasant and large ones unpleasant. There is much experimental evidence that the higher vertebrates in general seek the stimulation of a continually changing sensory input to the central nervous system.

Thus it may be that the grin, originally a response to startling stimuli, has evolved in man into a token of pleasurable reaction to small and pleasant stimulus changes. Such a view is supported by the fact that infants show their first broad smiles on being tickled or treated to peekaboo games (in which the main point is to startle) and that the essence of all adult jokes likewise is a certain measure of surprise.

Another important human facial expression is produced by contraction of the sphincter muscle of the mouth (orbicularis oris), which may round the lips or thrust them forward in a pout. The movement probably stemmed originally from vocalization involving vigorous expulsion of air; it shows up conspicuously in a howling dog, a roaring lion or a lowing deer. In the higher animals, as lip mobility increases, the movement develops into an important visual signal. Advanced forms of the New World monkeys and the chimpanzee have a pronounced pout, as does the human child who is about to cry. In many primates the rounding of the lips, covering the teeth—which accompanies the sudden, vigorous expirations usual in threat—has become an important signal of impending attack. The human face assumes such an expression, often accompanied by a strong intake and expulsion of breath, in a display of indignation.

We come finally to the question of how human speech may have evolved from primitive facial and tongue movements. Here some suggestive ideas are offered by observation of the behavior of baboons, the most advanced of the Old World monkeys.

Among the baboons a common form of communication is lip-smacking, a display derived from movements of the lips and tongue that they use in grooming one another. Lip-smacking is a gesture of greeting, like the grin, and the baboons display this gesture much more readily than the grin. With the lip-smacking they often emit a deep grunt of friendly greeting. The point of interest is that these grunts, as modulated by the tongue and lip movements, sound much like human vowels and are produced in exactly the same way!

Of all the primates, apart from man, only the baboons are given to the deep, humanoid grunt; other monkeys and apes favor shriller calls or are less vocal and in any case do not combine grunts and lip-smacking. The baboon's deep grunt, like man's, carries overtones covering the full range of sound up to 5,000 cycles per second or more. All these overtones are capable of being amplified or filtered by changes in the resonant cavities in the animal's throat and mouth. Thus the grunts are modulated by alterations in the cavities by the lip-smacking tongue movements and by changes in the shape of the mouth.

Studies of the relation between the baboon's lip-smacking tongue movements and its grunts have been made with the aid of sound spectrograms. The lowest emphasized band of the sound (which we can call a formant because it is so like the formant of a vowel) depends mainly on the part of the mouth cavity behind the tongue, and the next two formants are controlled by the front cavity. The sound spectrogram shows that as the baboon's tongue retracts, the lowest formant rises in pitch, whereas the next two—one an overtone of the other—drop [*see bottom illustration on page 94*]. The resulting modulation of the grunt is obvious to the ear, just as is the difference between two vowels uttered by the human voice.

The grunt serves the highly social baboons as a form of language, carrying information to their fellows even when the hearers cannot see the caller's lip-smacking or other facial expression. Most commonly it seems to be an invitation to grooming, but there are indications that the baboon grunts may vary in motivation and meaning.

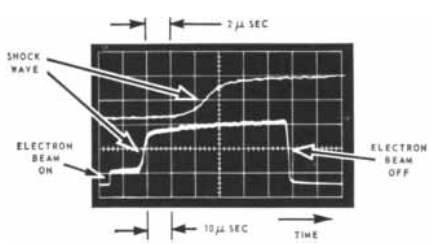
All of this suggests that human speech may have evolved from origins much like the modulated grunts of baboons. Instead of lip-smacking, tongue movements such as are used in sucking or the kind of openmouthed kiss infants often give may well have modulated the grunts of our ancestors in the human line, and these "affectionate" sounds could have led to further elaborations of vocal expression. A natural evolution such as this is far more plausible than the old theory that speech and language emerged suddenly in man at an ad-

RESEARCH REPORT

How to Dissect a Shock Wave

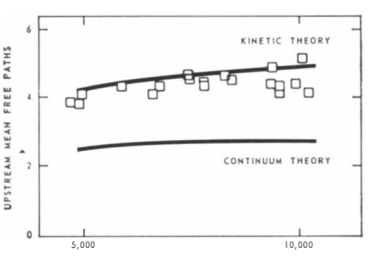
Shock waves are the essence of violence. Inside strong shock waves, a gas undergoes large changes in both its physical and chemical properties. For many purposes a shock wave can be treated as a sharp discontinuity in gas properties, but it is actually a finite region whose thickness is several times the distance a gas particle travels between collisions. The structure of this region holds the key to a number of fundamental problems in fluid mechanics and chemistry.

Detailed information on the structure of shock waves has been obtained in an elegant experiment at our laboratory.[1] The density variation through the shock is measured by the Rutherford scattering of a high-energy electron beam, the scattered beam intensity being directly proportional to the gas density. We have used this technique in our 24-inch-diameter shock tube to study strong shock waves in both monatomic and polyatomic gases. The result is a theorist's dream: an experiment whose output signal can be read directly as a plot of density against distance through the shock wave — just the information produced by the theorist's computer. And every shock is self-calibrating, since the output includes the known density in front of the shock wave.



Scattered electron beam intensity showing density variation through an argon shock wave.

A basic fluid dynamics problem: Does the Navier-Stokes continuum fluid description adequately predict shock-wave structure, or do the changes occur in so short a distance that continuum theory is no longer valid? Must we resort to the more fundamental, but more elaborate, description in terms of particle kinetic theory? Our measurements of density profiles up to shock speeds of 10,000 ft/sec in a monatomic gas (argon) clearly show that a particle description must indeed be used.



Shock thickness in argon

A basic chemistry problem: How is the kinetic energy of flowing gases redistributed by the shock wave into the translational energy mode and the internal modes of rotation, vibration and dissociation? Information about the distribution of energy can be determined from density measurements.[2] For low-speed shocks, experiments in polyatomic gases show that all the energy goes into the translation and rotation in the shock front, and is subsequently redistributed among the other modes in a relaxation zone. For higher speed shocks, such as those at reentry velocities, our measurements show that the energy sharing is so rapid that a near-equilibrium distribution of energy is reached inside the shock.

An intriguing future problem is the shock structure at meteor velocities, where the energy in the radiation field becomes comparable to the energy in the flow field.

1 *Camac, M., Avco-Everett Research Laboratory Research Report 172 (December 1963); also Phys. Fluids 7, 1076-1078 (July 1964)*

2 *Camac, M., Avco-Everett Research Laboratory Research Report 194 (October 1964)*

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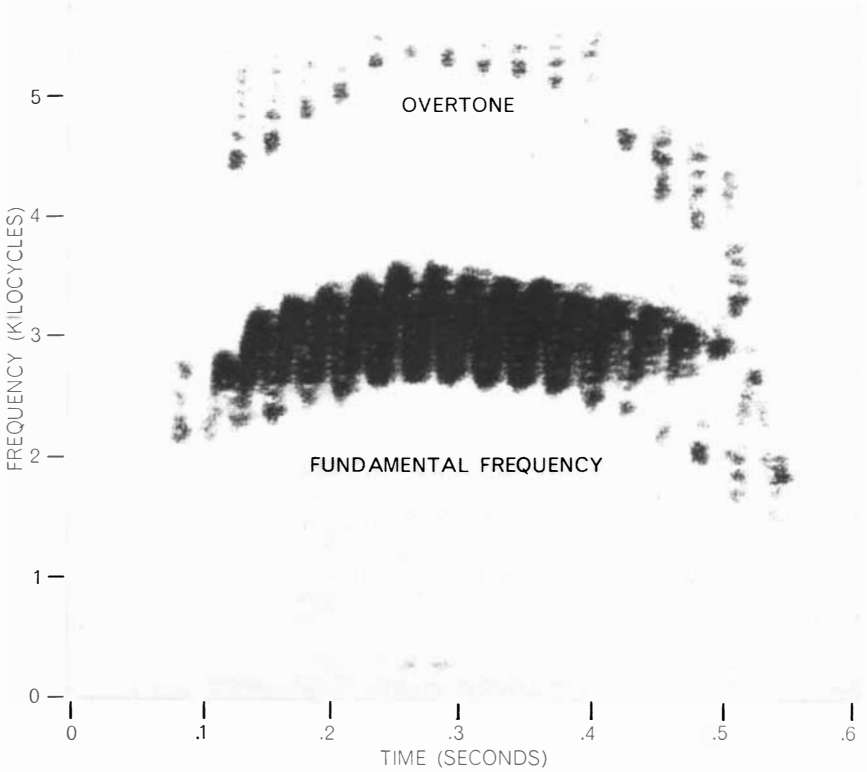
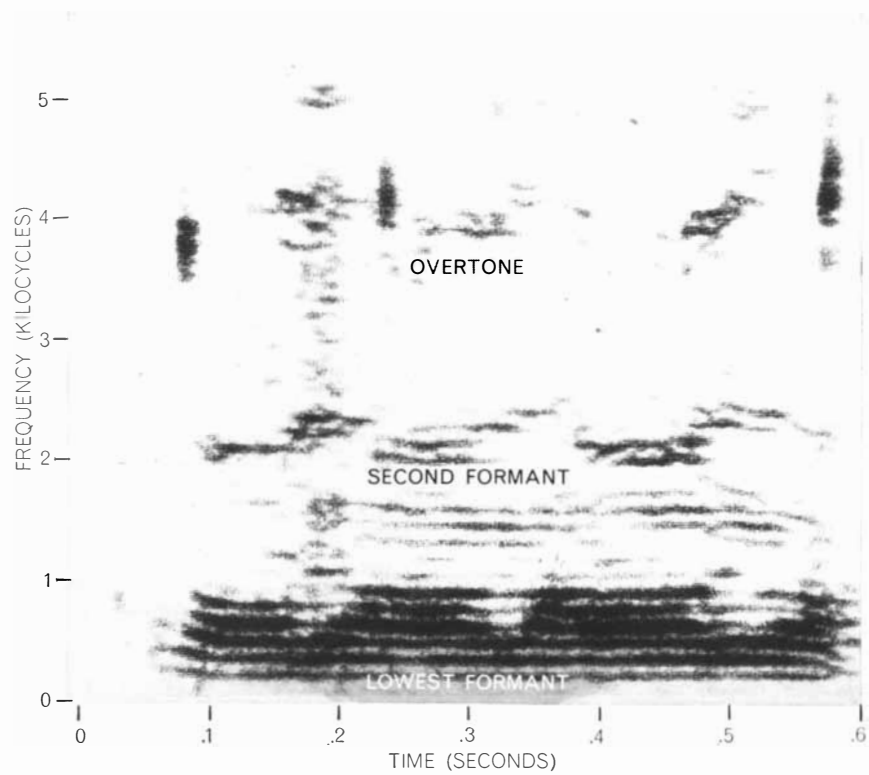


HIGH TRILL of a guenon monkey, another relative of the baboon, is reproduced in a sound spectrogram. Its fundamental frequency, between 2,000 and 3,500 cycles per second, is too high to contain any low-frequency formants such as those illustrated below. There is no evidence that the guenon's trill is modulated by motions of the animal's tongue.



LOW GRUNT of the hamadryas baboon shows a series of frequency rises in the lowest formant coinciding with drops in the second formant and its overtone. These modulations are caused by tongue retraction; a full retraction causes a click (*note overtone lines at .09, .23, .40 and .58 second*). Modulated grunts apparently serve as signals among baboons.

vanced stage of his mental development. His creation of language must have arisen gradually from an already well-developed and elaborate system of vocal displays modulated by the lips and tongue.

The remarkable similarities between the vocal displays of baboons and those of man raise a more fundamental question. What did they have in common that might explain this convergence? To begin with, it is obvious that the development of the use of displays itself depends on the extent of socialization of the animal. The relatively social wolf shows a much greater range of facial expression than the solitary bear; the brown lemur, which lives in a troop, is much more vocal than the solitary mouse lemur and dwarf lemur. One still has to explain, however, why the baboons have a more sophisticated repertory of expressive displays than other Old World monkeys, all of which are highly social. A clue can be found in the talkative baboons' way of life. The most demonstrative species are those that live together in troops on the plains. They depend on one another for protection, and the subdominant males cannot leave the troop. For these baboons mutual communication (by means of grunts and other displays) is essential, particularly to minimize fighting among themselves. On the other hand, in most societies of monkeys, including some species of baboons, the young males are free to leave the troop, and these groups may have less need of communication. It is significant that the forest-dwelling mandrill and drill baboons make far less use of grunts and conspicuous facial greeting displays than do their plains relatives.

What the plains-dwelling baboons and the plains-dwelling ancestors of man had in common, then, was a way of life that placed a premium on communication within the group. Thus it appears that the plains habitat of our ancestors may have been a prime factor in promoting not only hunting and the use of tools but also the evolution of smiling, laughter and language.

Our information on the evolution of facial and vocal expressions is still fragmentary. Nevertheless, there is now some hope that comparative studies of living species of primates, and of other mammals, will eventually enable us to understand the evolution of human behavior in the same way, if not in as much detail, that we understand the evolution of the human body.

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MATHEMATICAL GAMES

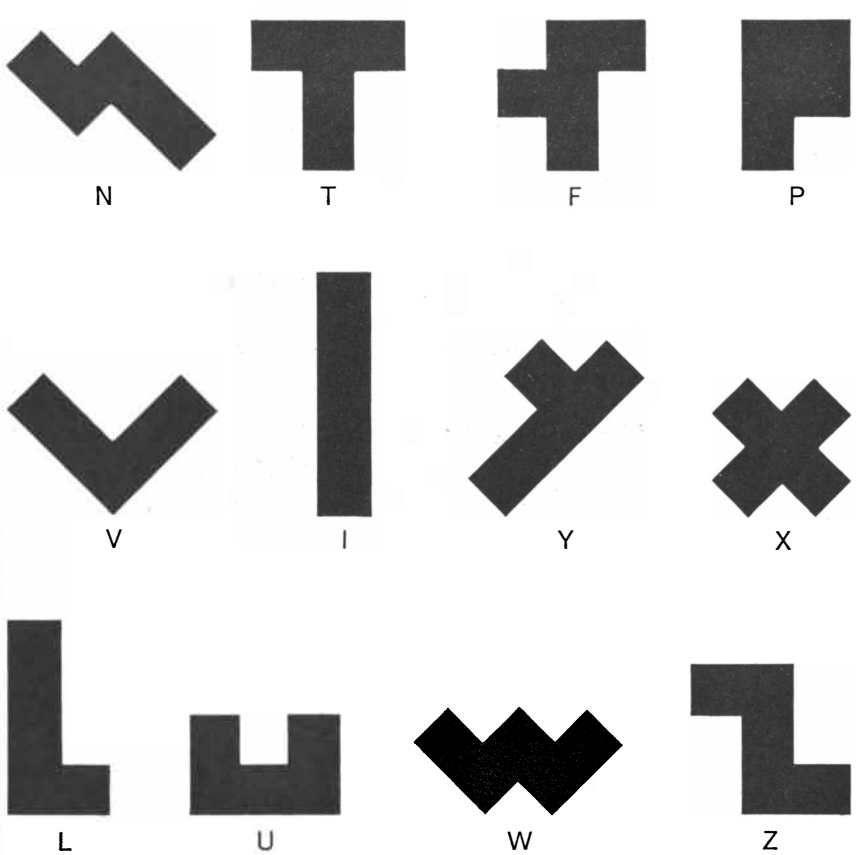
Pentominoes and polyominoes: five games and a sampling of problems

by Martin Gardner

Solomon W. Golomb's book *Polyominoes,* published earlier this year by Scribners, has stimulated worldwide interest in these figures, which are polygons formed by joining unit squares along their edges. This interest in turn has led Golomb, who teaches electrical engineering and mathematics at the University of Southern California, to devote more of his off-duty hours to exploring some of the darker corners of the field. A recent communication from him deals entirely with a series of fascinating problems, only partially solved, relating to a pentomino game he invented many years ago.

Pentominoes, which were the subject of articles in this department in December, 1957, and November, 1960, are five-square polyominoes. The 12 possible pentominoes are shown in the illustration below with Golomb's mnemonic names for them. To play the standard pentomino game you will need these 12 pieces, cut from cardboard, and a standard eight-by-eight checkerboard with squares the same size as the squares that form the pieces. If the reader has never played this game, he is urged to prepare a set of pentominoes and try it; it is one of the most unusual mathematical board games of recent years.

Two players sit across the empty



The 12 pentominoes

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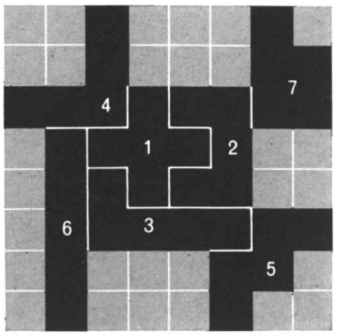


A typical standard pentomino game

board with the 12 pentominoes spread on the table beside it. The first player takes one of the pieces and places it so as to cover any five squares of the board. The second player similarly places one of the remaining 11 pieces to cover five of the remaining empty squares. Play alternates until one player is unable to move, either because no remaining piece will fit or because no pieces are left. The player who cannot play is the loser. Games are short, and of course no draw is possible. Nevertheless, great skill and insight are necessary for good play. Mathematicians are far from knowing if the first or the second player can always win if he plays correctly. "The complete analysis of the game," Golomb writes, "is just at the limit of what might be performed by the best high-speed electronic computer, given a generous allotment of computer time and a painstakingly sophisticated program." The most useful strategy, Golomb explains, is to try to split the board into separate and equal areas. There is then an excellent chance that each move by your opponent in one region can be matched by your next move in the other region. If this continues, you are sure to have the last move.

A typical game during which both players keep this strategy in mind has been constructed by Golomb and is shown in the illustration above. Player *A* puts the *X* near the center to prevent his opponent from splitting the board. Player *B* counters by fitting the *U* against the *X* (move 2)—a good move, says Golomb, because it "does not simplify the situation for the opponent or allow him to split the board." Player *A* is now equally cagey. His *L* move (move 3) continues to prevent a split. The fourth move, by *B*, is weak because it allows *A* to place the *W* (move 5) in such a way that it splits the board into two equal regions of 16 squares each. In

this case the regions are also identical in shape.

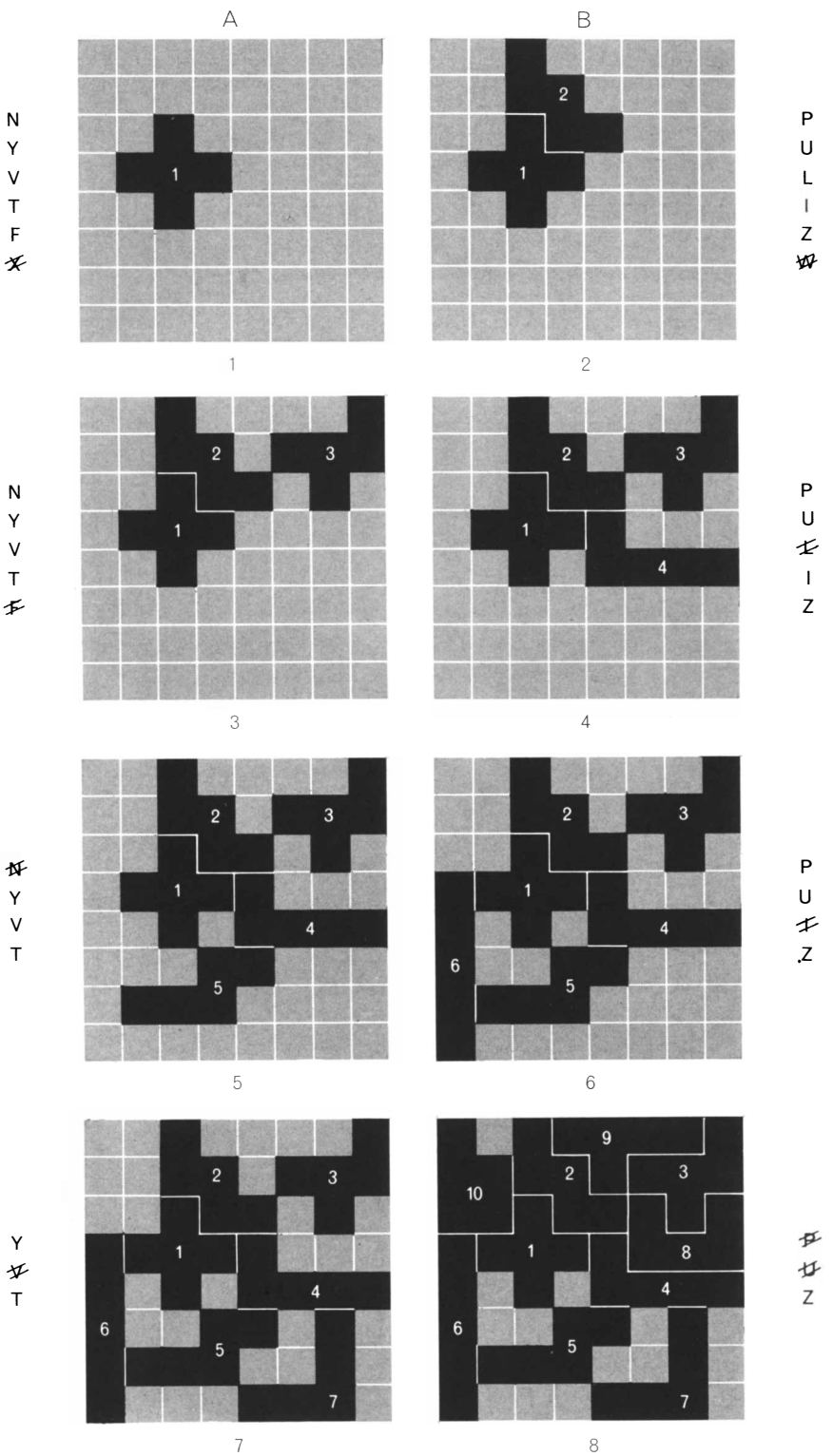
Player *B* now plays the *I* (move 6), hoping his opponent will not find a piece that fits the other region. But *A* is able to place the *P* (move 7) in such a way that he wins. Although three of the remaining regions are each large enough to hold a piece, the only three pentominoes that can fit those regions—the *I*, *P* and *U*—have already been played.

The most interesting variation of the standard game, Golomb continues, is one he calls "choose-up pentominoes." Instead of selecting a piece at each move, players alternate in choosing pieces before the game begins, until each owns six. The last to choose plays first, and the game continues as before except that each player must play only his own pieces. The strategy of this game is quite different from that of the preceding one. Instead of using the split to create a situation in which an even number of moves remain, a player tries to leave as many moves as possible for his own pieces and as few as possible for his opponent's. He does this by creating what Golomb calls "sanctuaries": regions into which only his own pieces will fit.

Golomb's comments on the typical choose-up game shown in the illustration at the right are as follows. Player *A* gets rid of the *X*, his most troublesome piece, by playing it as shown in step *1* in the illustration. (Pieces chosen by *A* and *B* are listed beside each board and shown crossed off after use.) Player *B* places his *W*, another difficult piece (step *2*). *A* now uses his *F* (step *3*) to create a sanctuary for his *Y*. *B* uses his *L* (step *4*) to make a sanctuary for his *U*. *A* plays his *N* (step *5*). *B* places his *I* (step *6*) to create a two-by-three rectangle that accommodates only two remaining pieces: his *P* and *U*. *A* then plays his *V* (step 7) but resigns when he sees that the plays must continue as shown (step *8*). The sanctuaries are filled in turn and *A* is left with a *T*-pentomino that will not fit.

If players of this game are unequal in skill, Golomb suggests that the better player give himself a handicap by letting his opponent choose first and play last. A bigger handicap allows the weaker of the two players to make the first two, or even three, choices as well as play last.

There are still other pleasant variations of the game. In "deal-out pentominoes" the names or pictures of the pieces are placed on cards. The deck is shuffled and dealt. Each player takes the pieces indicated by his cards and the game proceeds as in the choose-up form. In "partnership pentominoes" four players sit on four sides of the board and take turns playing, with opposite players forming teams. The team of the first player unable to move is the losing team. Any of the three previously described games can be played in this way. In "cutthroat pentominoes," which also applies to all three games, three or more players participate, but each is on his own. The last to play is the



A game of "choose-up pentominoes"

winner. He gets 10 points per game. The first person unable to play scores nothing and all others get five points.

Now for a sampling of the many intriguing problems suggested to Golomb by the standard game when it is played on square boards of various sizes. The board must be at least three by three to allow a first move, and of course the first player must win on the three-by-three since no second move can be made. On the four-by-four board it turns out that the second player can always win. Golomb has set out all possible first plays—excluding reflections and rotations—and a winning reply [*see illustration below*]. In every case but one the second player has a choice of winning moves. How long will it take the reader to circle the game in which the second player has only the one winning response shown?

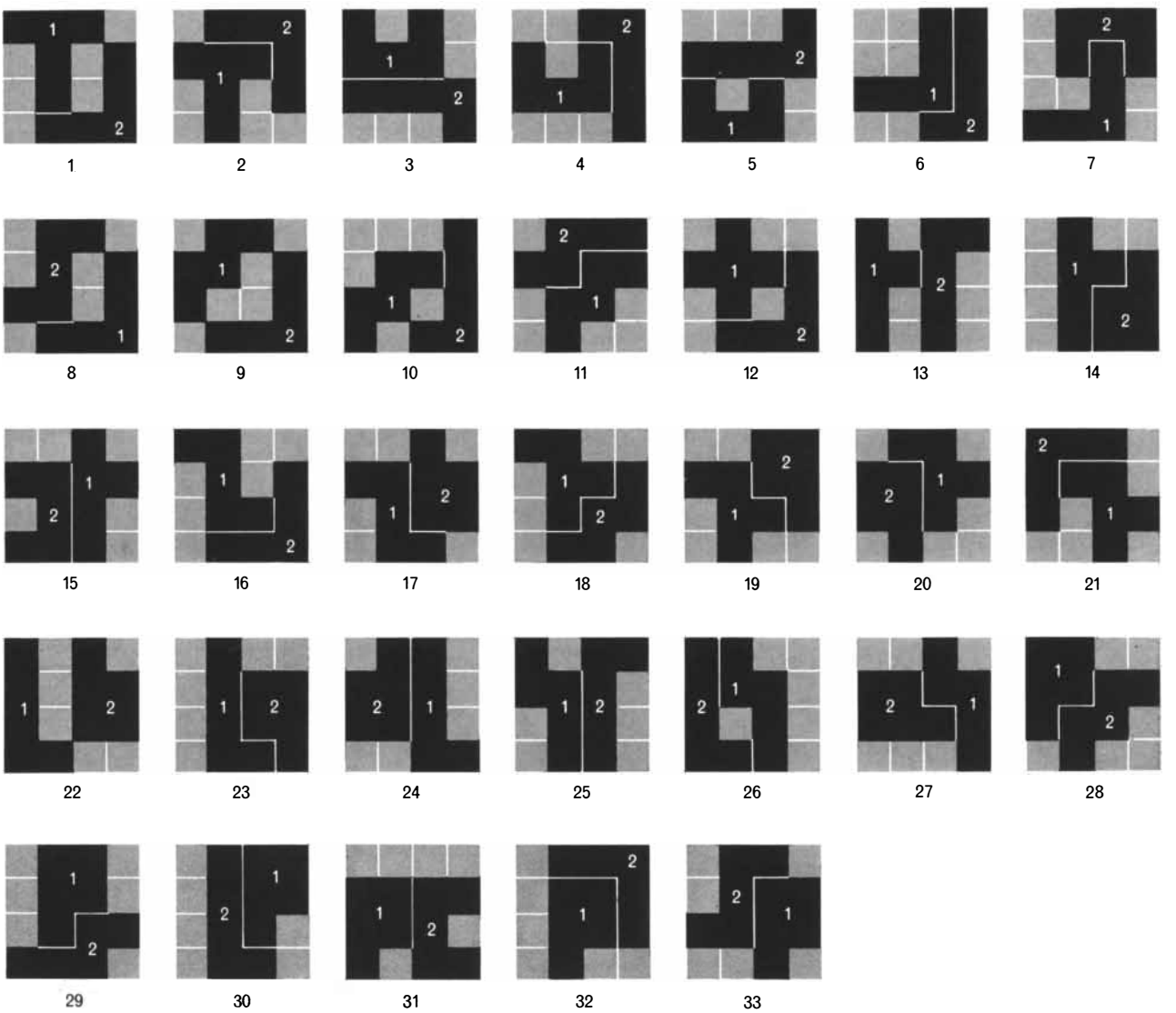
It might be supposed that the five-by-five board would be more difficult to analyze than the four-by-four, but surprisingly it is much simpler. The reason is that there is a first move that can easily be shown to lead to a victory for the first player. Can the reader discover it?

The order-six board brings an enormous jump in complexity; no one yet knows which player has the advantage. "Several promising moves have been subjected to exhaustive analysis and found to allow the second player to win," Golomb writes, "but the complete analysis will be quite lengthy, involving the correct follow-up strategies against each of a very large number of possible first moves."

Another challenging problem is that of determining the shortest possible game that can be played on squares of order-13 or less. (Beyond 13, all 12 pieces have to be played, so that the problem becomes trivial.) In other words, what is the lowest cardinal number for a subset of the 12 pentominoes that can be played on an n-by-n board in such a way that no remaining piece will fit? Examples of the shortest games known on boards through order-13 are shown in the illustration on page 102. In many cases more than one subset will yield a solution. If any reader succeeds in finding a smaller subset for any of these boards, I shall report the discovery in a later article.

The shortest game on the five-by-five board has been left blank to provide a sketching area for two easy problems. What is the shortest game that can be played on this field? What is the longest?

What about rectangular boards that



Proof of the second player's advantage on the four-by-four board

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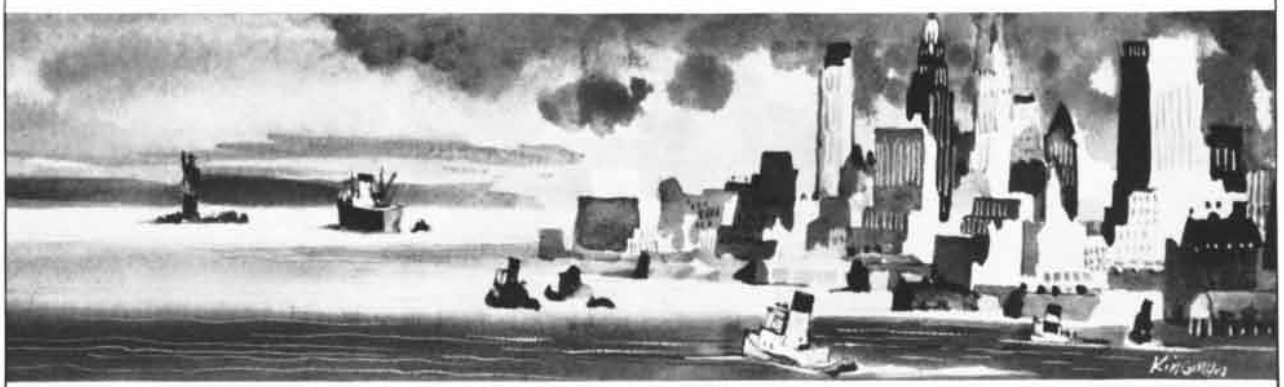

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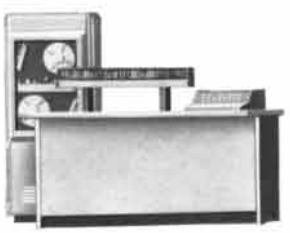

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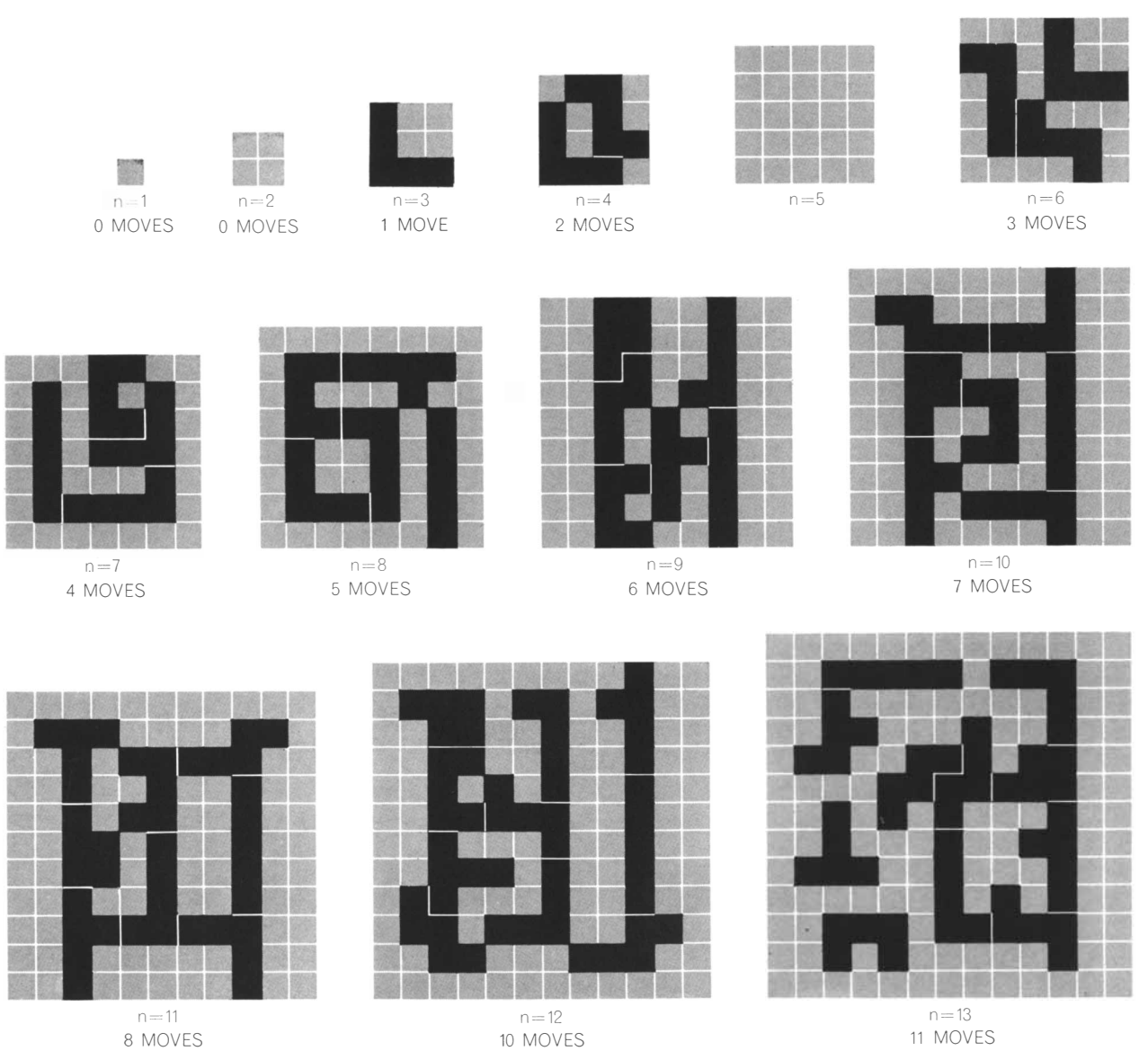
are not square? In an exhaustive analysis of all such boards with areas of 36 square units or less, Golomb found that the five-by-six board concealed the biggest surprise. The first player can always win, but only if he makes a single correct first play. Readers who find the preceding four problems too easy may enjoy struggling with this much more difficult one: What is the winning first move on the five-by-six?

A quite different type of polyomino problem—not discussed in Golomb's book and also far from fully explored—is that of determining if duplicates of a given polyomino will fit together to form a rectangle. (Asymmetric pieces may be turned over and placed either way.) If so, what is the smallest rectangle that can be so formed? If not, a proof of impossibility must be given. The problem was suggested in 1963 by David Klarner, then a graduate student in mathematics at the University of Alberta. The following year a group of high school students attending a summer institute in mathematics at the University of California at Berkeley studied the problem under the direction of their teacher, Robert Spira. They called it the "polyomino-rectification problem," using the term "rectifiable" for any polyomino that could be replicated to form a rectangle.

The monomino (one square) and domino (two squares) are obviously rectifiable since each is itself a rectangle. Both trominoes (three-square figures) are rectifiable: one is a rectangle, and two *L*-trominoes form a two-by-three rectangle. Of the five tetrominoes (four-square shapes) the straight tetromino and the square tetromino are rectangles. Two *L*-tetrominoes form a four-by-two, and the *T*-tetromino replicates to fill the four-by-four square as shown at *a* in the top illustration on page 104. The skew tetromino is not rectifiable. The proof is trivial. If it is placed to fit the upper left corner of a rectangle, it is impossible to form a top edge that terminates at a second corner, as shown at *b* and *c* in the illustration.

Similar impossibility proofs are easily found for most of the pentominoes. The reader may enjoy showing that the *T*, *U*, *V*, *W*, *X*, *Z*, *F* and *N* pentominoes are not rectifiable. The *I*, *L* and *P* are easily rectified. This leaves only the *Y*, the most difficult of the pentominoes to



Shortest games known for boards of one to 13 squares per side

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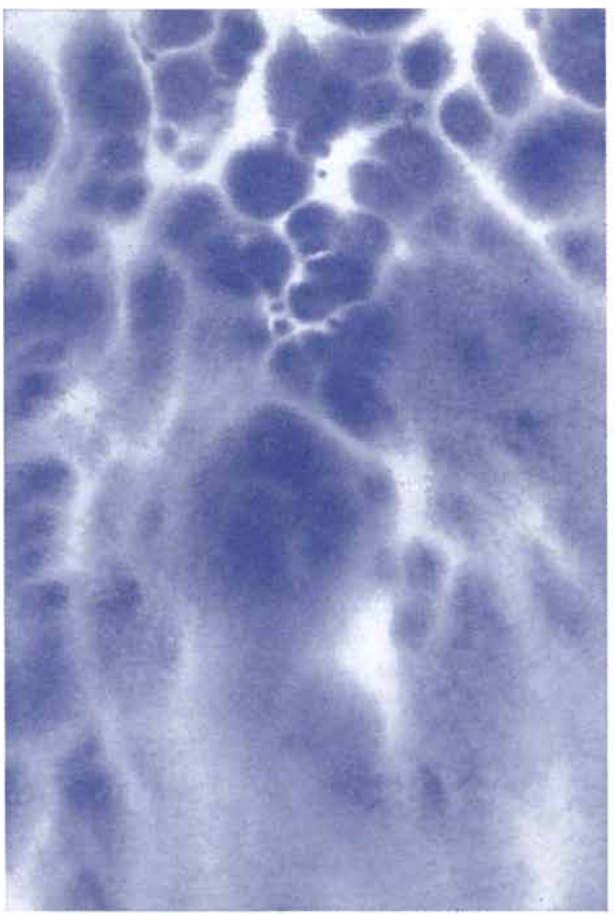

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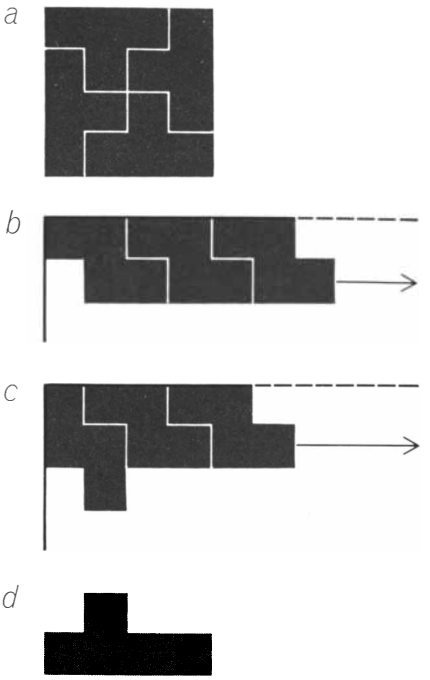


Problems in making rectangles

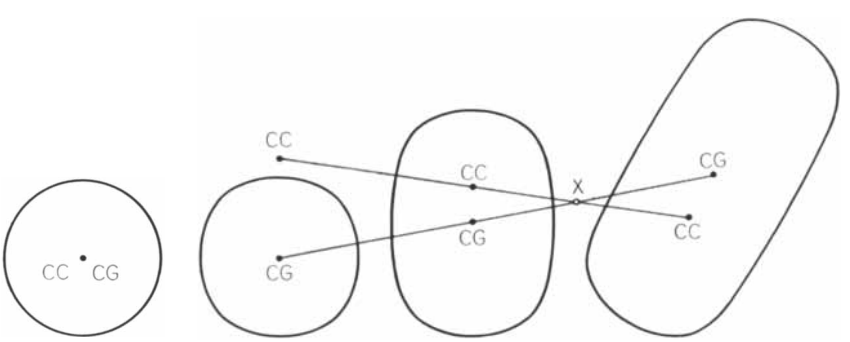
analyze. Is the *Y*-pentomino, shown at *d* in the illustration, rectifiable? If so, what is the smallest rectangle it will fill? If not, prove it. (This and the preceding problems will be answered next month.) As far as I know, the 35 hexominoes (six-square forms) have not yet been completely analyzed as to their rectifiability, although Spira's group concluded that the number of rectifiable hexominoes is either nine or 10.

Readers were asked last month to prove the existence of solid "supereggs" that would balance on their ends, for all supereggs whose formulas contained exponents higher than 2. Piet Hein's informal proof follows:

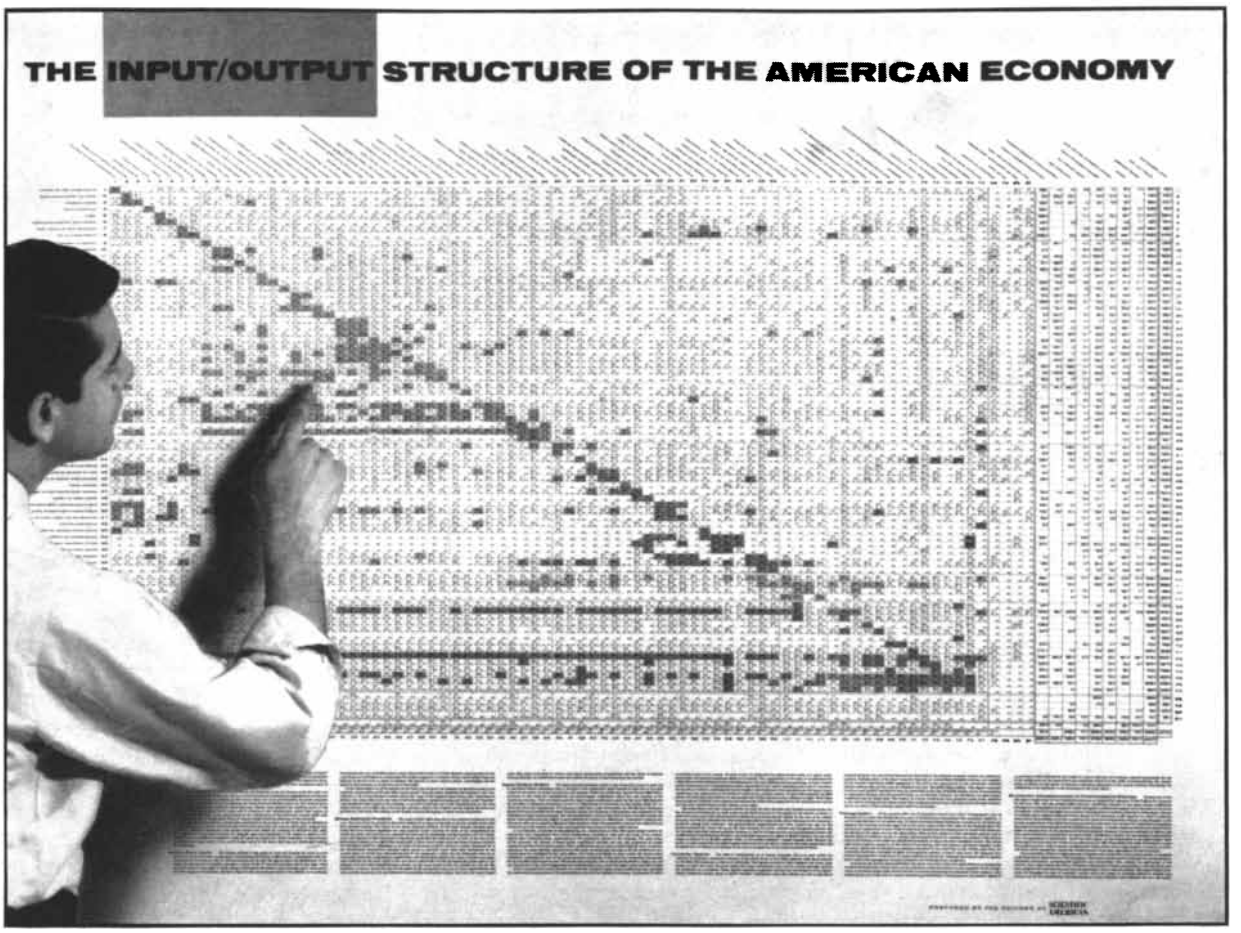
If the center of gravity, *CG*, of an egg is below the center of curvature, *CC*, of the egg's base at the central point of the base, the egg will balance. It balances because any tipping of the egg will raise the *CG*. If the *CG* is above the *CC*, the egg is unstable because the slightest tipping lowers the *CG*. To make this clear, consider first the sphere shown at the left in the illustration below. Inside the sphere the *CG* and *CC* are the same point: the center of the sphere. For any supersphere with an exponent greater than 2, as shown second from left in the illustration, the *CC* is above the *CG* because the base is less convex. The higher the exponent, the less convex the base and the higher the *CC*.

Now suppose the supersphere is stretched uniformly upward along its vertical coordinates, transforming it into a superellipsoid of rotation, or what Piet Hein calls a superegg. As it stretches, the *CC* falls and the *CG* rises. Clearly there must be a point *X* where the *CC* and the *CG* coincide. Before this crucial point is reached the superegg is stable as shown third from left in the illustration. Beyond that point the superegg is unstable (*right*). This situation applies to all supereggs, regardless of how far above 2 the exponent is in their formula. Therefore, given any exponent above 2, it is always possible to write a formula for a solid superegg with a low enough height-width ratio to allow balancing.

The higher the exponent, the greater the height-width ratio at which the egg becomes unstable. If the exponent is large, extremely tall and thin supereggs will balance. At the limit, when the exponent is infinite, the superegg becomes a cylinder with a flat, circular bottom. Readers skilled in calculus may wish to figure the critical height-width ratio at which a superegg with an exponent of 2½—Piet Hein's choice of a superegg artistically midway between an ellipsoid of rotation and a cylinder—becomes unstable.



Left to right: sphere, supersphere, stable superegg, unstable superegg



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An electrometer, a temperature-control apparatus and a simple electric motor

Conducted by C. L. Stong

The English philosopher Joseph Priestley remarked, writing to Benjamin Franklin in 1770, that "a good electrometer is one of the greatest desiderata among practical electricians to measure both the precise degree of the electrification of any body and also the exact quantity of a charge." Practical electricians still have reason to applaud Priestley's enthusiasm for the electrometer even though the instrument has been displaced in most laboratory uses by cathode-ray oscilloscopes. The electrometer remains the preferred instrument for measuring minute charges such as those induced in small insulated objects by potential differences in the atmosphere, by one insulating material rubbing against another and by the disintegration of radioactive substances.

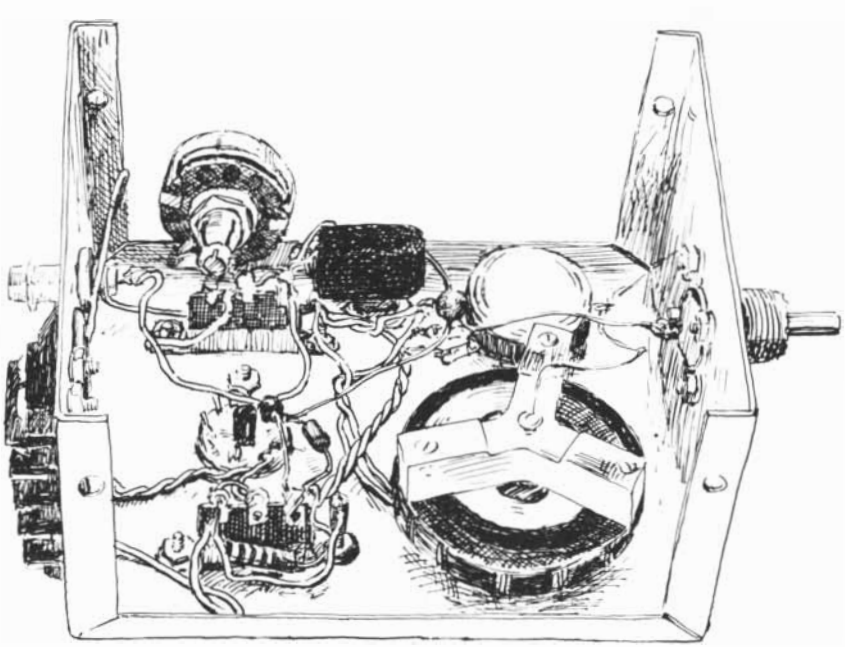
The electrometer Priestley described in his letter to Franklin had been built by a Mr. Henley of London. It consisted of "an exceedingly light rod, with a cork ball at the extremity." The rod was hinged to a somewhat thicker rod of ivory. When a charge was placed on the device, the cork ball and the thick rod repelled each other, the light rod swinging outward at an angle that depended on the strength of the charge. In this form the device was merely an electroscope. Henley converted it into an electrometer by equipping the thick rod with a semicircular scale that, in measuring the angle at which the light rod was repelled, also showed the magnitude of the charge.

The sensitivity of the best modern electrometers far surpasses that of Henley's instrument. The modern instruments also cost more. Most of them have a special vacuum tube for sensing the charge under measurement and are priced at several hundred dollars. John L. Menke of Barnesville, Md., recently constructed an inexpensive electrometer that anyone can build at home using ordinary vacuum tubes.

Menke's instrument employs a vibrating capacitor that in effect transforms the electrostatic charge under measurement into an alternating current that can be amplified and subsequently changed back into direct current for operating a conventional milliammeter. It easily measures direct current as small as a tenth of a trillionth of an ampere—less than a billionth of the current drawn by the smallest flashlight bulb. Menke writes: "One can determine potential differences by measuring the force of attraction between the plates of a capacitor that carries the unknown charge. The only current drawn by such an instrument is the current that leaks through and over the surfaces of the insulating materials that support the plates of the capacitor. In effect the device consists of a mechanical balance for weighing the unknown charge. It is not only fragile but also insensitive to potentials of less than about 100 volts.

"Instruments of the type I constructed are known as vibrating-reed electrometers. The essential element in the instrument is a capacitor with one fixed plate. The second plate is vibrated by an electromagnet. The amount of charge the plates can store at a constant voltage changes as the spacing between the plates varies. The voltage, V, that appears across the plates of a capacitor is equal to the ratio of the charge, Q, to the capacitance, C. ($V = Q/C$.)

"When the spacing between the plates is changed, as by vibrating one of the plates, the voltage varies in step with the vibration. A charge placed on the vibrating capacitor then appears as an alternating voltage. The capacitor must be well insulated, of course, or the charge will leak off. The insulation resistance of good capacitors usually amounts to at least a billion ohms. Several kinds of plastic are readily available for constructing capacitors of this resistance, although surface leakage



Components of the vibrating-reed electrometer on chassis

may limit their performance on days of high humidity.

"For one plate of the variable capacitor of my electrometer I used the diaphragm of an ordinary magnetic earphone. The diaphragm is vibrated by connecting the solenoid of the earphone to the secondary winding of a transformer designed to heat the filament of a vacuum tube. The transformer is powered by 60-cycle house current. The second plate of the capacitor consists of a disk of flat sheet metal about the size of a 25-cent piece. The disk is soldered at the center to the end of a machine screw that fits a threaded hole in a bridge, which is flexibly attached to the case of the earphone [*see illustration on opposite page*]. The bridge is made of transparent sheet plastic.

"The screws that attach the bridge to the case of the earphone serve as adjustments for altering the plane of the disk with respect to that of the diaphragm. The screw to which the disk is attached serves as an adjustment for altering the spacing between the plates of the capacitor, as shown in the accompanying illustration [*upper illustration on this page*]. The spacing between the plates must be made as small as possible so that the variation in the capacity, and hence the change in voltage, will be as large as possible. Sharp edges on a conductor as well as burrs and dust encourage the leakage of charge and must be eliminated. To insulate the input lead that connects the fixed plate to the charge under measurement I used a conventional Teflon connector of the type designed for ultrahigh-frequency radio apparatus. An unsupported wire would be better electrically but less convenient.

"The alternating voltage that appears across the vibrating capacitor [*"C" in lower illustration on this page*] is coupled to the input capacitor of an amplifier of the cathode-follower type. The insulation resistance [*"C′" in the illustration*] of the input capacitor must be at least 1,000 megohms—a billion ohms. I used an inexpensive ceramic capacitor, rated at five trillionths of a farad (five picofarads). The capacitor is insulated for a potential of 1,000 volts.

"Several capacitors of other types were tried in the circuit, including one insulated with high-quality mica. The ceramic unit finally selected was as good as any, although individual variation among the ceramic capacitors I have is enormous. Doubtless a homemade capacitor improvised of 1/2-inch-square plates spaced 1/16 inch apart in air would be effective. The input capacitance of the assembled instrument is 13 picofarads. During operation the vibrating capacitor varies by about three picofarads.

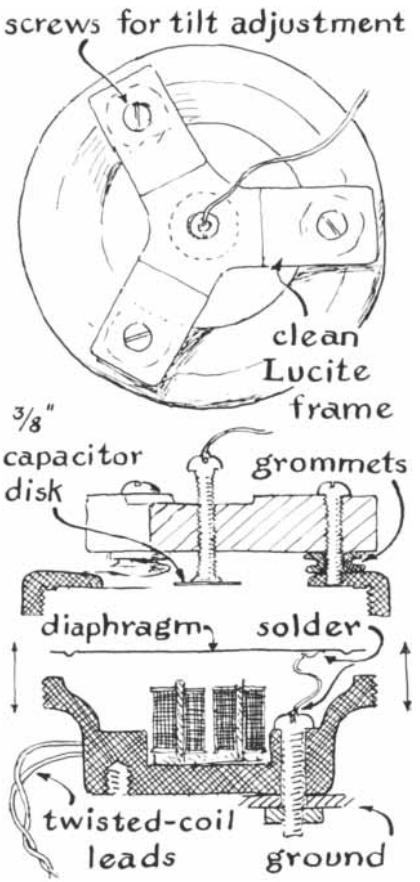
"The signal can be taken directly from the first triode section of the vacuum tube or amplified further by the second section of the tube [*see top illustration on next page*]. Either an oscilloscope or a high-impedance alternating-current voltmeter can be used for readout. It is also possible to include a vacuum-tube voltmeter circuit in the instrument and to employ a conventional milliammeter for readout.

"The use of an oscilloscope simplifies the adjustment of the vibrating capacitor, because even the slightest change in the physical position of the plates shows unmistakably in the wave form of the signal. The circuit includes an adjustment for minimizing 60-cycle hum, which is always present in the signal. The oscilloscope is also useful for monitoring this adjustment, since the hum is easily distinguished from the signal by the difference in phase of the two wave forms.

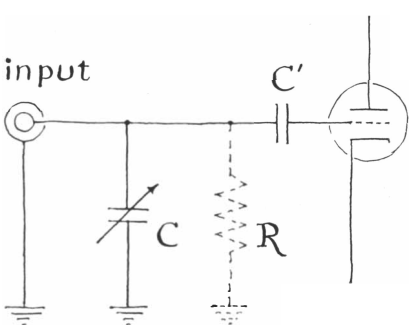
"A watch with a radium dial turned out to be a good source of charge for testing the instrument. The crystal of the watch was removed. Radium emits a variety of radiation during its chain of decay, including both beta particles (electrons) and alpha particles. The positively charged alpha particles outnumber the negatively charged beta particles. Hence a net positive charge leaves the watch, and the case acquires a net negative charge. The negative voltage increases until leakage to ground and through the air balances the charge leaving the watch. I simply hang the watch on the input terminal with an alligator clip and monitor the output voltage. The adjustment screws of the vibrating capacitor are then manipulated to produce maximum output. The balance control is again adjusted for minimum hum.

"An experimenter who constructs the instrument will be impressed by the amount of charge picked up by his body. A finger touching the input terminal produces an enormous signal that requires some time to die away. The effect is caused by alternating current induced in the body by the house wiring, by electrostatic charge generated by the friction of one's clothing and by the soles of the shoes scuffing the floor. Stray pickup from these sources can be minimized by enclosing the circuit assembly in a sealed metal box. Adjustments can then be made by inserting an insulated screwdriver through holes in the box. The operator should wear static-free clothing, such as cotton. He should also sit on a metal stool and wear a grounded metal watchband or bracelet. The instrument easily detects the voltage generated by pulling a cloth across a table 10 feet away!

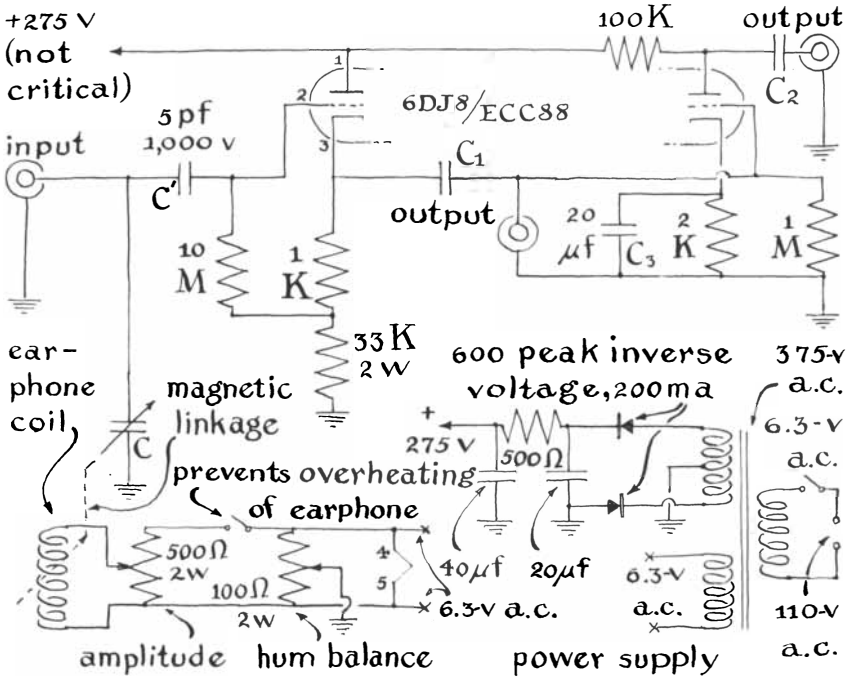
"Maximum sensitivity can be achieved and maintained by keeping scrupulously clean all insulating surfaces associated with the circuits of the vibrating capacitor and input capacitor and by sealing a desiccant inside the metal housing. Clean these surfaces with acetone, al-



Details of the vibrating capacitor



Electrometer's input circuit



Circuitry of the vibrating-reed electrometer

cohol and distilled water in that order. Repeat this procedure twice and let the parts drip dry—without wiping. Thereafter do not touch or wipe the surfaces, otherwise conducting paths will be created that will reduce the sensitivity.

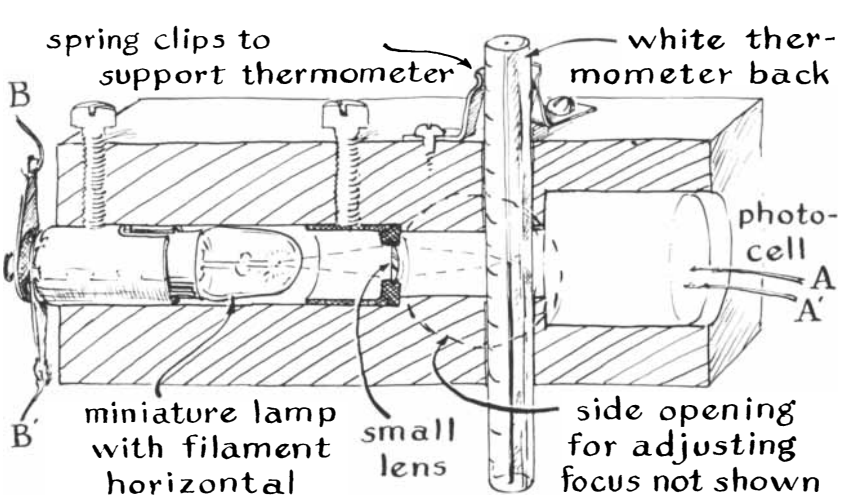
"For calibrating the instrument I had access to a source of beta rays that emitted 1,000 particles per second, producing a one-volt signal in the output. The average energy of the emitted beta particles was three million electron volts. About 100,000 charge pairs were therefore produced in the air before the average particle came to rest, because the ionization potential of air is about 30 electron volts. Since a voltage appears on the input terminal many of these charges as well as other charges naturally present in the air are collected by the terminal. The instrument is therefore sensitive to a current of about a tenth of a trillionth of an ampere at an inferred input resistance of 60 billion ohms.

"Vibrating-reed electrometers are used routinely by nuclear physicists for measuring the accumulated charge (voltage) on the plates of ionization chambers. A primitive ionization chamber can be assembled at home from a pair of insulated tin cans—a small one such as a frozen-fruit-juice container nested concentrically inside a standard No. 303 can. Circuit details are described in standard reference texts. Another application for the instrument is suggested by the precautions the experimenter must take to prevent stray pickup from influencing the output: the vibrating-reed electrometer makes a dandy burglar alarm!

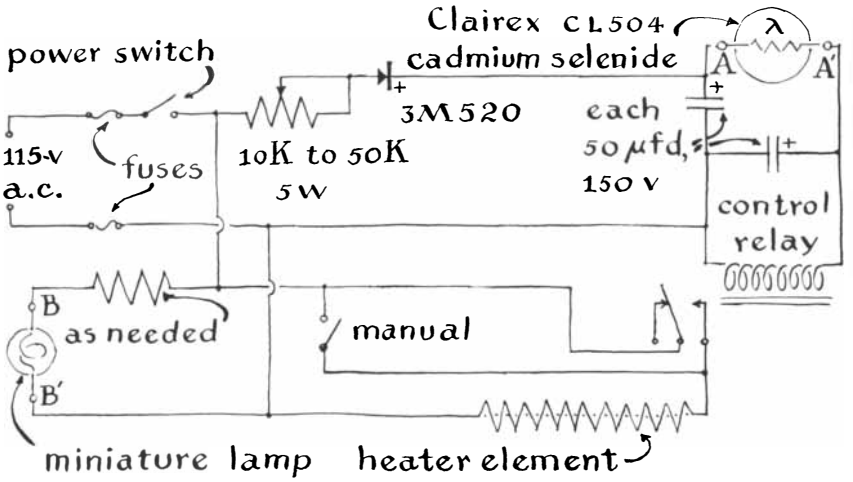
"Several improvements are possible. For example, the hum can be reduced by heating the filament of the tube by direct current. A further improvement could be made by driving the earphone at some frequency other than 60 cycles. An amplifier tuned to this higher or lower frequency would reject the 60-cycle currents induced in the input circuit by the power line and so would in effect increase the sensitivity. Heavy shielding around the earphone, and in particular around the coil, would diminish the noise induced in the input by the current that drives the earphone. The input resistance of the unit could be increased by using a two-stage amplifier of the cathode-follower type to increase the signal level. Finally, the sign of the charge under measurement must now be inferred by observing the phase of the output signal in relation to that of the current that drives the earphone. A phase-sensitive circuit could be added for displaying this information automatically."

Many experiments require the accurate measurement of minute electric currents, for which the vibrating-reed electrometer is well suited. Most such experiments also require the measurement and close control of temperature. The measurement of temperature, which is analogous to voltage, poses no problem because accurate and inexpensive thermometers are readily available. The close, automatic regulation of temperature, however, has always posed a problem for amateurs. Inexpensive thermostats of the necessary accuracy are difficult to find in most communities, and the use of thermistors involves circuit constructions that are difficult to calibrate over extended temperature ranges.

Carl Henry of Chattanooga, Tenn., has solved this problem by designing a temperature-control apparatus around an ordinary thermometer. Instead of reading the thermometer by eye and adjusting an electric heating element by hand he uses one of the new cadmium selenide photocells to monitor the thermometer and to control the heating current automatically by actuating a relay in the heating circuit. Henry writes: "Depending on the quality of



Sensing unit of the photoelectric temperature-control device



Circuitry of the temperature-control device

the thermometer, the unit can automatically control temperature within one degree. The apparatus can be built for less than $10. That price makes it, if nothing else, the most inexpensive temperature regulator now available.

"The scheme of operation is based on the interruption of a light beam by the column of mercury in a tubular thermometer. The intensity of the beam controls the output current of a cadmium selenide photocell. The operating characteristics of these new semiconducting cells differ widely from those of conventional cells with which amateur experimenters are familiar. The electrical resistance, for example, changes by a factor of a million when the incident light varies from only one to 100 footcandles. Moreover, the sensitivity to light of low intensity is impressively greater than that of conventional cells. Most of the problems encountered during attempts to use the cells in new applications arise from excessive light and stray light.

"My temperature-sensing unit consists of a miniature incandescent lamp and a lens that directs a beam of light transversely through the thermometer to the photocell [*see bottom illustration on page 108*]. The lamp, lens, thermometer and photocell are enclosed in a lightproof housing through which the thermometer slides. The position of the thermometer with respect to the housing determines the operating temperature. A small rectifier powered by 60-cycle alternating current supplies filtered direct current to the relay through the photocell, energizing both the relay and the photocell. The lamp can be energized by a transformer that operates from the power line if the voltage of the line is reasonably stable. Otherwise the lamp should be operated from a dry battery, because the photocell does not distinguish between fluctuating temperature and varying supply voltage.

"When the column of mercury does not interrupt the light beam, the photocell receives maximum illumination. Its resistance is then typically about 100 ohms. The current at this maximum illumination is about 20 milliamperes, sufficient to operate a sensitive relay. The contacts of my relay are large enough to switch the current of a 100-watt heating element. If I wanted to control a larger heater, I would insert a heavy relay in the heater circuit and operate it by the sensitive relay.

"More than one photocell must be used for controlling temperature within narrow limits. The rising column of mercury in the thermometer reduces the light to the photocell, causing the relay to open and switch off the heating element. The heated element continues to radiate for a time, however, depending on its size. As a result the temperature may rise above the level wanted. Similarly, when the mercury column drops and the relay closes, some time is required for the heating element to warm up. During this interval the temperature may drop below the desired level. At temperatures above 150 degrees Fahrenheit such overshooting is not troublesome.

"Close control at lower temperatures is achieved by equipping the thermometer with two or more photocells spaced about five degrees apart. Each photocell actuates a companion relay. The relays operate in sequence as the height of the mercury column changes and can be connected to individual heaters or wired in such a way that they sequentially short-circuit appropriate re-

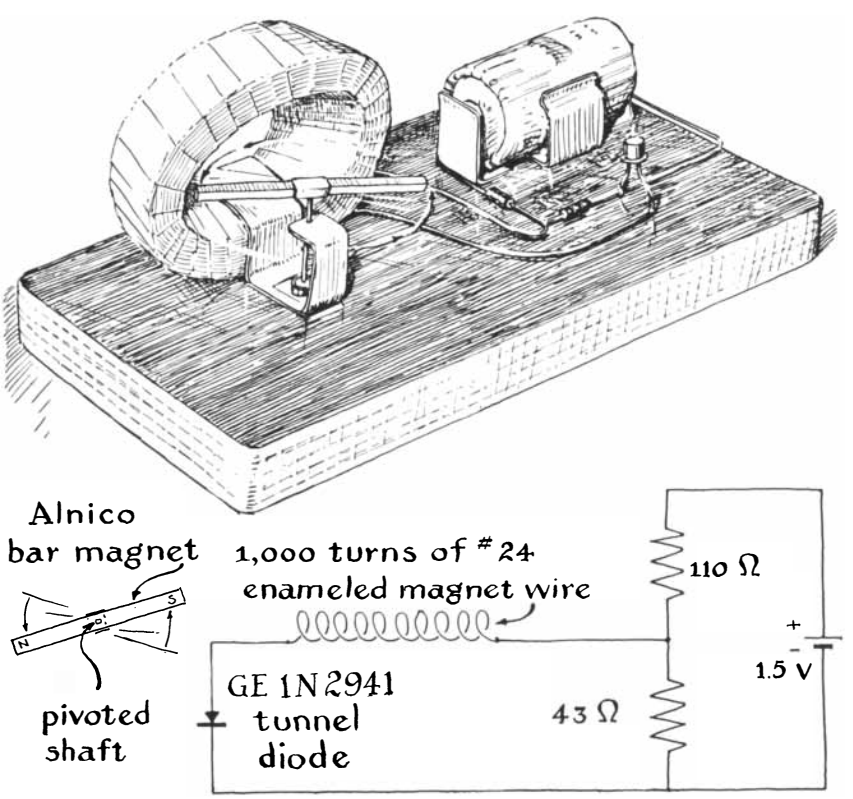
sistors that are in series with the heating element. The closest control can be achieved by using a thermometer of the expanded-scale type."

Another versatile semiconducting device, which has been largely overlooked by amateur experimenters, is the tunnel diode [see "The Amateur Scientist," March, 1963]. In a sense the function of the tunnel diode is opposite to that of the semiconducting rectifier: the diode can transform direct current into alternating current. Harry E. Stockman, professor of electrical engineering at the Lowell Technological Institute in Lowell, Mass., recently used a tunnel diode to build what is perhaps the world's simplest miniature motor—one that requires neither a commutator nor brushes. The device, which he has patented, has only three essential parts: the tunnel diode, a small coil and a bar magnet that turns on a pivoted shaft [*see illustration below*].

The motor must be started by hand. Once it is started, current induced in the coil by the magnetic field of the bar magnet causes the tunnel diode to function as an oscillator. The diode then energizes the coil with alternating current. The alternating magnetic field generated by the coil interacts with the permanent field of the magnet, causing it to rotate in synchronism with the oscillations of the tunnel diode.

The dimensions of the magnet are not critical. Alnico bar magnets about a quarter of an inch square and two inches long work well. Alnico is not easy to drill. The pivoted shaft can be cut in two, however, and the ends cemented to the magnet with epoxy resin. The coil can be wound on a wooden form of sufficient size to provide an air space for the magnet.

A pen-cell flashlight battery will drive the motor for many hours, because the unit draws only a few thousandths of a watt. I made one version of the motor that was equipped with glass pivots. It has been operating continuously on a solar battery for a year and should continue indefinitely. Incidentally, by attaching one end of the bar magnet to the shaft and suspending it vertically the magnet becomes a pendulum. Electrical noise naturally present in the circuit starts the pendulum swinging. A few millionths of a watt will keep it going. I made a pendulum that operated from a battery improvised with blotting paper sandwiched between a nickel and a penny. When the leads of the coil were attached to the coins and the paper was moistened with saliva, the pendulum promptly went into action.



The tunnel-diode motor and its circuitry

#1704

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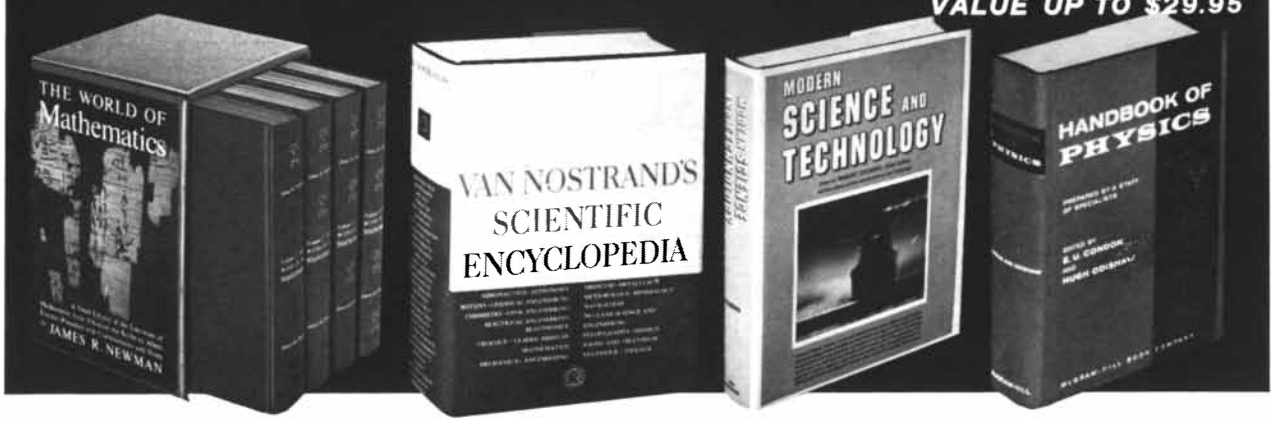

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BOOKS

Is warmaking a characteristic of human beings or of cultures?

by Anatol Rapoport

THE NATURAL HISTORY OF AGGRESSION, edited by J. D. Carthy and F. J. Ebling. Academic Press ($5).

The organization of this book suggests the intent of presenting a comparative study of aggression in the animal world, specifically among social insects (D. I. Wallis), mammals (L. Harrison Matthews), various vertebrates (Konrad Lorenz), primates (K. R. L. Hall) and human beings (Thelma Veness, Cecily de Monchaux and Derek Freeman). In addition to this comparative survey some general topics are treated from different theoretical perspectives, namely aggression between species (James Fisher), physiological aspects of aggression (Arnold Klopper), aggression and mental illness (Denis Hill) and war (Stanislav Andreski, Anthony Storr and John Burton).

The mode of discussion ranges from richly descriptive to highly speculative. In judging a book on a scientific subject by a single author or by authors working in collaboration, one can note the facts presented and the conclusions drawn and then express an opinion on the extent to which the conclusions are justified or significant. In the case of a symposium the reviewer must himself draw conclusions, and on the basis of arguments developed in different theoretical frameworks. In this book, for example, there are two sharp discontinuities in subject matter. One is the discontinuity between the concept of aggression as it pertains to nonhuman species and the concept as it pertains to human beings. The other is the discontinuity between aggression among individuals and aggression among nation-states. The breaks are so sharp that one wonders if it is at all illuminating to place phenomena so different under the same heading.

The discussions collected in the symposium are on firmest ground when they deal with aggression among nonhumans. Here the investigator can ask questions standardized in the biological sciences. What functions are served by the behavioral patterns listed under aggression? What is the genetic origin of these patterns? What are the triggering mechanisms? What are the concomitant physiological events? Some of the functions of aggression are clearly discernible, for example the defense of nesting territory and the competition for mates. The physiological basis of aggressive behavior has also been systematically investigated. Less is known about the evolution of aggression; behavioral patterns leave no fossils except when they result in artifacts.

Such is the study of aggression as a topic in natural history, and so it is presented in the first half of the book. It is obvious, however, that reviewing such studies was not the sole purpose of the symposium. One purpose clearly was to shed light on aggression as a "problem," not as a topic of natural history. The problem is that human beings are in danger of attacking one another with weapons that are capable of destroying their species. We seek enlightenment on how to cope with the problem of war, and it seems helpful to put the problem in a broader context; hence we define aggression in terms of the harm one organism or group of organisms can inflict on another and we search for instances of such situations. We hope to find features the situations have in common in order to discover their "nature," in particular conditions that are favorable or unfavorable for their occurrence. When we define war as aggression, however, the situations subsumed under the term are no longer necessarily related to one another. Accordingly a discussion of aggression is likely to lead to impasses arising simply from conflicting interpretations of the definition.

A case in point is the distinction between intraspecific and interspecific aggression. In the prologue to this volume the editors point out that predation ought not to be considered aggression. Thus "a hawk swooping on a small bird is no more aggressive than the family butcher engaged in his livelihood." This seems reasonable. But in the process of studying aggression in man we face the necessity of drawing a line between aggressive and nonaggressive killing. Is it aggression when man hunts for sport? Many psychologists will argue that it is. But what if hunting for sport is a manifestation of a predatory drive? Should not the human hunter be absolved from the charge of aggression if the hawk is? Yet Derek Freeman ("Human Aggression in Anthropological Perspective") builds his whole case (to the effect that man is by nature aggressive) on man's predatory instincts.

"The Australopithecinae," he says of the primates believed to be ancestors of man, "are an evolutionary innovation, a primate species that, becoming terrestrial, achieved an unprecedented advance by a predatory and carnivorous adaptation to their new environment, based on an upright stance and the adoption of lethal, manual weapons." If predation is not aggression, then the fact that "man has a carnivorous psychology" (S. L. Washburn, quoted by Freeman) ought not to be relevant to the problem of aggression in man. Nonetheless, Washburn says "it is easy to teach people to kill, and it is hard to develop customs which avoid killing. Many human beings enjoy seeing other human beings suffer, or enjoy the killing of animals... public beatings and tortures are common in many cultures." Freeman concludes: "These human characteristics are seen, in the light of the recent discoveries of palaeo-anthropology, to be phylogenetic; the pervasive aggression and cruelty of historic man, by which he is differentiated from other primates, is explicable, to use the words of Raymond Dart, 'only in terms of his carnivorous and cannibalistic origins.' "

Although man's carnivorous origin is clear, his "cannibalistic origins" are not. If we confine ourselves to man's "carnivorous psychology," we do not really have an adequate explanation of man's

cruelty. When one speaks of man's inhumanity to man, one usually refers to intraspecific cruelty. There is no evidence, however, that carnivores exhibit more intense intraspecific aggression than other mammals. Indeed, among the carnivores intraspecific fighting is often highly ritualized and hardly ever lethal. Wolves, for example, are "potentially so dangerous to each other that an elaborate chain of submissive reactions of increasing intensity culminating in the weaker contestant's throwing itself on its back to expose all the vulnerable parts of the body defenseless to the superior who refrains from taking the advantage presented, ensures that intraspecific fighting does not end fatally" (L. Harrison Matthews, "Overt Fighting in Mammals"). Clearly, then, attempts to explain man's inhumanity to man on the basis of his carnivorous origins fail to do the carnivores justice.

The participants in the symposium address themselves to the problem of human aggression in different ways. For example, Stanislav Andreski ("Origins of War") argues that an "innate propensity for fighting" is insufficient to explain the destructiveness of man, pointing out that the extent of damage inflicted by man on himself is made possible only by his use of weapons. This observation is of course incontrovertible, but in itself it only points up the gravity of the war problem. If man has a propensity for fighting and also a capacity for producing weapons of virtually unlimited destructive power, then the two "adaptations" coupled together can certainly ensure the extinction of man.

Andreski goes on, however, to question the "innate propensity for warmaking" (note the shift from "fighting" to "warmaking"). He points out that in order to induce warmaking a great deal of stimulation of martial ardor is needed (playing on vanity, fear of contempt, sexual desire, filial and fraternal attachment, loyalty to the group and so on). If there were an innate propensity, Andreski concludes, "such a stimulation would be unnecessary."

To these arguments Konrad Lorenz replies in a subsequent discussion: "No politician ever could make men really fight, if it were not for very archaic, instinctive reactions of the crowd on which to play." Evidence in favor of "innate propensities" might also be drawn from the circumstance that "overt expression of aggressive behavior is probably at maximal potential at the start of life" and from the intense manifestation of aggression associated with some forms of mental illness, which can be supposed to involve an impairment of inhibitory mechanisms (Denis Hill, "Aggression and Mental Illness"). In this view innate aggressive tendencies are considered to be latent under a veneer of acquired habits.

We see from these exchanges how difficult it is to put the study of aggression into a unified theoretical perspective. We see how the problem of war can confuse analysis, for example by making "fighting" and "warmaking" appear practically synonymous in spite of the fact that there may be only a remote connection between them. We say that boys fight and also that nations fight. Having identified the two manifestations of aggression, we seek mechanisms common to both types of fighting. There may or may not be such common mechanisms. Or there may once have been common mechanisms underlying both individual aggression and warmaking—mechanisms that no longer exist. Certainly a personal predilection for overt aggression is no longer the mark of the warrior. Indeed, the warrior himself is about to disappear as a component of a nation's warmaking apparatus. He seems to have been replaced by the strategist, the scientist and the technician. It is not obvious that people in these roles have greater innate propensities for fighting than other people. Yet when and if the time comes, their activities will result in more bloodshed than those of the combined hordes of Attila, Genghis Khan and Adolf Hitler.

John Burton ("The Nature of Aggression as Revealed in the Atomic Age") specifically warns against confusing the bases of behavior of individuals and of states: "One of the most common—and as I hope to show, one of the most dangerous—images is that of an international society in which nations each have the attributes of persons within a community. Abnormal psychology, games-theory, value judgments and moral responses then appear to be immediately relevant to international studies. In reality the nation-state is not of this order; if there must be an analogy (and I see no reason why there should be any), then it would be at least as appropriate to use mechanics or electronics as sociology." One could add that if analogies must be made, they should be made on the basis of inherent structural similarities. Thus the behavior of technological systems may shed more light on the behavior of states than the behavior of individuals or of small groups can.

If we keep this warning in mind, we can avoid the misunderstandings that arise when the problem of aggression is examined in a biological perspective. Indeed, the discontinuities between the behavior of man and of other animals and between the behavior of individuals and of nation-states are seen as necessary consequences of the analysis and can serve to illuminate the problem instead of obscuring it.

To begin with, the comparatively constant, situation-determined patterns of behavior in nonhuman interspecific or intraspecific aggression are reasonably explainable in terms of features established in the process of natural selection. This is in consequence of the survival value conferred on the species by certain aggressive behavior patterns provided with sufficient inhibitory checks to safeguard the species from extensive self-inflicted damage.

Once we proceed to man explanations of this kind no longer apply. The evolution of human behavior in recent millenniums cannot be ascribed to biological natural selection. For one thing, most patterns of human behavior are not transmitted to successive generations by biological mechanisms. For another, cultural evolution is so rapid (compared with biological evolution) that we cannot assume that any culture is in a state of equilibrium either internally or with respect to its environment. Whereas we can reasonably assume that a nonhuman species exists because it is "adapted," we cannot assume that any culture exists because it is adapted. Cultures are too short-lived. Possibly none of them is adapted. In answer to the question "Why, then, are they not extinct?" one can answer comfortably: "They have not had time to become extinct." It is true, as James Fisher points out ("Interspecific Aggression"), that "considering the fate of mammals in the Pleistocene period... *Homo sapiens* has done rather well." The basis for this statement is the fact that man has already existed at least 400,000 years, which is considerably longer than the average life expectancy of a mammalian species in the same general period (about 20,000 years) and even of a bird species (about 40,000 years). On the other hand, it is not safe to bet that as of now our life expectancy as a species exceeds the life expectancy of many other mammalian species.

In short, the concept of adaptation seems of little help in understanding human behavior patterns. If our species is now in a transient phase, all forms of aggressive behavior in man may well be maladaptive. The mobilization of physiological resources by the adrenal

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hormones may serve as an example. Having ceased to be useful in a civilized environment where threats cannot be dealt with either by physical combat or by flight, adrenal mobilization in response to threat or in preparation for aggression probably only harms the human organism.

Still, we cannot ignore man's biological heritage as a framework within which cultural patterns are accumulated. What is needed, then, is a theory of cultural evolution as comprehensive as the theory of biological evolution. What are the cultural analogues of mutation and selection? One would venture to guess that such a theory would be a "nonequilibrium" theory, analogous to the theory of irreversible processes in thermodynamics rather than to the classical theory that dealt with systems passing through a sequence of equilibrium states. The reason is that cultural systems cannot be explained by some natural-selection process that ensures the persistence of adaptive features and the elimination of maladaptive ones. Nevertheless, some selective process operates, since it is unlikely that cultural systems develop entirely at random. The keystone in a theory of cultural evolution would be the mechanism of selection that directs cultural change.

I suspect that a theory of cultural evolution would have to make full use of a principle unique to human psychology, namely the principle of symbolic displacement (or transformation) of drives. The full meaning of this principle has yet to emerge, but it is possible to give examples of how it may operate. Hunger is normally satisfied by the ingestion of food. Nonhumans seldom overeat to the extent of endangering their lives, but humans frequently do, possibly because with humans the ingestion of food is sometimes a symbolic act instead of a physiological necessity. Moreover, this symbolic act may assume more generalized forms, such as the compulsive acquisition of wealth or the conquest of territory. To take an example more relevant to this discussion, the aggressive drive in nonhumans manifests itself only in thrusts against enemies or rivals who present an immediate and actual threat. Man, however, by virtue of his ability to manipulate symbols, attaches the label "enemy" to entire categories of things: other animals, other people—even inanimate objects and ideas. Accordingly aggression ceases to be ruled by the situation.

The idea of symbolic displacement is central in psychoanalysis, but it has not yet been investigated by rigorous methods of observation and deduction. Perhaps on the basis of this principle the existence of an "evolutionary momentum" can be demonstrated; such a momentum might serve to explain the monstrous and maladaptive features of man's aggressive behavior without recourse to unresolvable controversies about "human nature."

If one follows the more frequently traveled paths of scientific investigation, seeking correlations among directly observable conditions or events, one naturally looks for environmental determinants of aggression. Such determinants are directly demonstrable in some animals. Lorenz remarks that "animals can be made to behave like men and massacre the fellow-members of their own species. If one crowds a dozen roe deer into a pen in a zoo, the most gory massacre is the result."

Observations of this kind suggest that environmental factors play a central role in aggressive behavior. On the other hand, it is becoming increasingly difficult to give credence to the various purely environmental factors that from time to time have been advanced as the causes of wars. Such factors may well have instigated wars at various times in man's history, but the fact that their virtual disappearance has not led to an abatement of war obviously raises doubts about their importance. At one time wars were fought for territory, for booty, for slaves. It is difficult to explain current wars in these terms. Economic factors have been persistently proposed as causes of wars. Such considerations imply a rational calculation that compares the expected gains and losses of a war. No one today argues that a nuclear war would benefit either side, yet such a war is a distinct possibility.

It is all the more surprising that similar arguments are still advanced. For example, Andreski writes: "In conditions of misery, life, whether one's own or somebody else's, is not valued, and this facilitates greatly warlike propaganda.... Moreover, when there is not enough to satisfy the elementary needs of the population, the struggle for the good things of life becomes so bitter that democratic government... becomes impossible, and despotism remains the only kind of government that can function at all. But absolute power creates the danger that a despot may push his country into war for the sake of satisfying his craving for power and glory."

Such an argument might have seemed plausible with respect to Germany 30 years ago. It scarcely applies to the U.S. today. There is less misery in the U.S. than in most other countries, less domestic despotism than in many other countries, less explicit craving for power and glory than in some other countries. Yet the U.S. is the most military-minded nation of this planet and, whatever else it may be, it is far from unaggressive.

In view of the inadequacy of clear environmental factors (crowdedness, poverty, capitalism, armament lobbies and so on) as explanations of the tendency of a country to engage in warlike acts, one is led to consider "systemic" factors, that is, internal factors inherent in the warmaking systems themselves. The lack of discussion of such considerations (they are mentioned only in passing) is a serious shortcoming of *The Natural History of Aggression*. It seems to me that it is high time to investigate the natural history of the warmaking state (*Status belligerens?*). Whether this object is properly biological is an idle question. If biologists had existed among the protozoa of bygone epochs, they would presumably have argued that metazoa were not proper objects of biological investigation. The concept of the nation-state as a quasi-organism of course goes back to antiquity. Diplomats have traditionally ascribed human patterns of behavior to nation-states. In their pronouncements states have desires and obligations; they "take a serious view," "cannot remain indifferent to," "take appropriate measures" and "pursue their interests." It is easy to dismiss these fantasies as being naïve anthropomorphism. The fact remains that they are taken seriously by men who identify themselves with nation-states. These men make decisions. As a result of these decisions thousands or millions of men engage in coordinated activity. They do so because they must. They must because they have been so conditioned. They function like elements in the nervous system of an animal. Thus the state acts in a coordinated manner, quite like an organism. From the point of view of a generalized biology the nation-state *is* essentially an organism. It behooves us to study this organism, because our lives depend on how it will act.

Short Reviews

WHERE SCIENCE AND POLITICS MEET, by Jerome B. Wiesner. McGraw-Hill Book Company ($6.95). A collection of lectures and articles by the special assistant on science and technology

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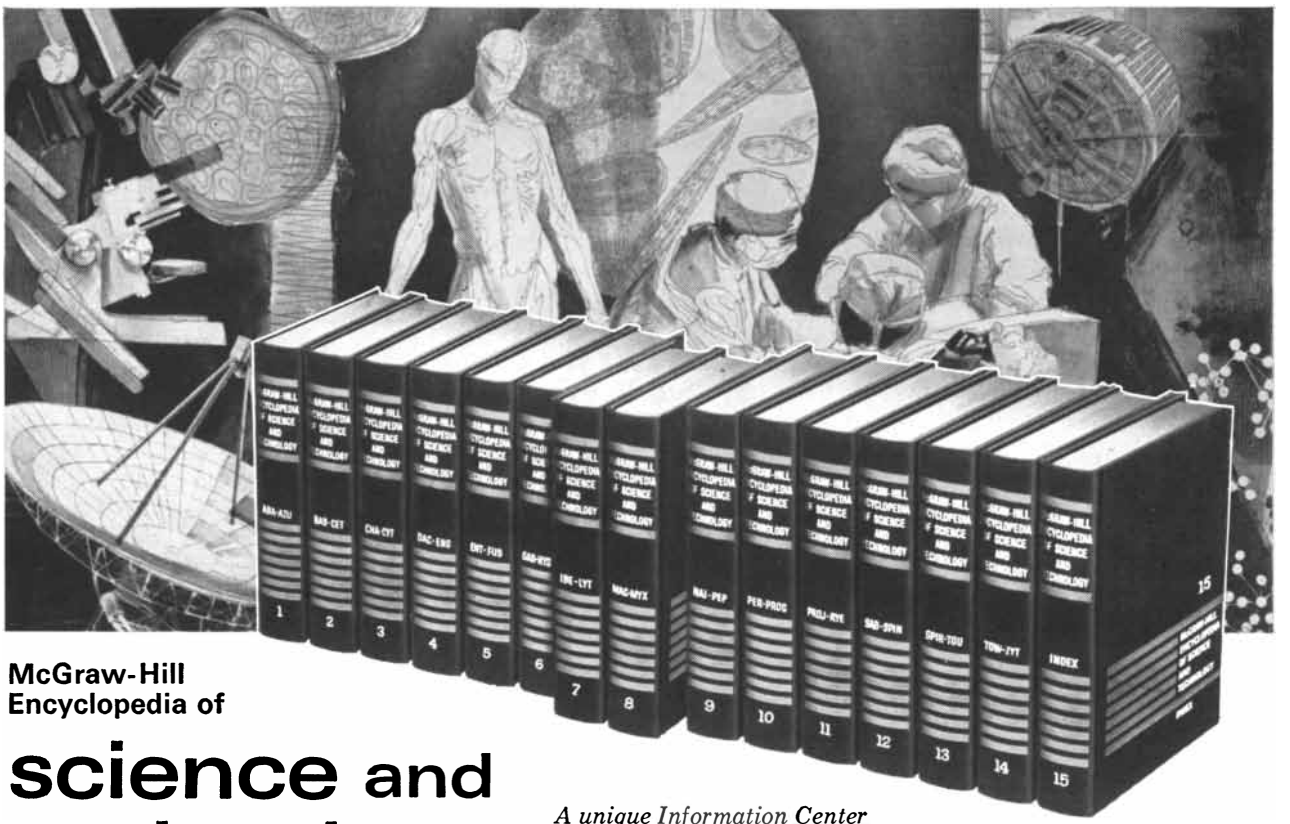

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to President Kennedy and President Johnson, all but one or two written and published during his tenure of office. They discuss topics ranging from disarmament (one of the articles on this subject, written in collaboration with Herbert F. York, appeared last year in SCIENTIFIC AMERICAN) to Federal aid to education, the main concern being a growing science that keeps bursting out of its clothes at such a rate that even a most indulgent parent finds it difficult to keep replacing and renewing the wardrobe. Wiesner has much to say that is fair and sensible about research and development needs, deficiencies in education, shortages of trained personnel, the hard problem of choice in distributing Federal subsidies, and the contributions that science and technology have made and can be expected to make to the advancement of human welfare. Of special interest are his constructive opinions on arms control, his dispassionate analysis of questions to which politicians often bring nothing better than confused thoughts, atavistic fears and jingoistic passions. But as an overall survey of the state of science today, with its heavy dependence on Federal support, which entails grave consequences to free inquiry, to balanced curricula and to the independence of schools of higher learning, the book falls short. Too often Wiesner dismisses legitimate criticisms and misgivings as ill-founded, and he fails to recognize, or at least to acknowledge, ailments that will not disappear if one pretends they do not exist. His book is worth reading for what it says and—because it reflects a myopia prevalent even among enlightened critics—for what it overlooks.

TRAVELS IN WEST AFRICA, by Mary H. Kingsley. Barnes & Noble, Inc. ($12.50). Mary Henrietta Kingsley was in every sense an eminent Victorian. As a youngish spinster she explored on her own large sections of West Africa and by her writings (this book and *West African Studies*) profoundly altered the attitudes of European colonial administrators toward their African subjects, created a scientific basis for the anthropological study of Africans and even molded the ideas that educated Africans held about themselves in the early stages of nationalist movements.

Miss Kingsley's father was an "eccentric doctor" and an amateur anthropologist who had traveled widely, and one of her uncles was the 19th-century novelist Charles Kingsley. Her childhood and upbringing instilled in her the strong urge to write and to travel. It

seemed unlikely, however, that these aspirations would be fulfilled; until the age of 30 she was obliged to take care of her parents and occupy herself fully with household chores. Then in 1892 both parents died and she found herself in possession of a legacy of £4,000 and free to do as she liked. She took a holiday in the Canary Islands and there met a number of "coasters" who were the European agents of West African trading firms. This encounter prompted her to visit the West African coast and later to make a second journey to this region in 1894.

As a sideline she collected West African fish (a task she performed so well on her first trip that the British Museum outfitted her for future expeditions), but her main purpose was to learn about the country and its peoples. No one before or since her time performed this task with so much originality and independence. No other writer, as John B. Flint remarks in his introduction to this reissue of a book first published in 1897, "so successfully evoked the transcendent beauty of the African forest, the slow tempo of the rivers, the eerie magic of African mists, or the sounds and stirrings of the African night." Wherever she went, with whomever she dealt—officials, traders, Africans—she won respect and affection. A gentle (although determined) woman, she evoked gentleness. She treated primitive people with respect, and in return they respected her. Since she herself avoided violence, none was done to her. She carried weapons but never used them. She would not participate in the slaughter of animals. Leopards, elephants, gorillas and other wild animals whose paths she crossed did not molest her. Indeed, she must have puzzled them as much as she amazes us, this "somewhat frail spinster, dressed in her usual white blouse, bonnet and woollen skirt, wander[ing] across from the Ogowé to the Rembwé with her small party of carriers, trading in the villages as she goes, noting and observing, talking and questioning." As a reporter of travels Miss Kingsley has few equals. She wrote simply and graphically; she saw things with a fresh eye and an instinct for evocative detail; she accepted people for what they were; she had a charming sense of humor arising, "as with many of the funniest things in Africa, from frustration situations."

Her theories of African personality and of what should be done to help the people help themselves are less satisfactory; as a result of her affection and respect for the people, and her unwill-

ingness to have them changed, she was inclined to turn Africa into "a kind of zoo for human beings." She thought of Africans as essentially religious and regarded it as unwise to try to Europeanize them. To her the African was a distinct kind of human being, not inferior in intelligence but wholly different from us; therefore, she argued, the attempts of missionaries to Christianize them would lead to a moral collapse because an unsuitable system of ethics was being offered to replace one that had been destroyed. Essentially her viewpoint was that of the traders: Africans were not to be educated to compete with white men but were to be given technical education as workers, plantation hands, miners and seamen. (This, as Flint points out, contradicted her view that Africans excelled in the spiritual rather than the mechanical arts.) Regardless of her prejudices and confusions, she was an altogether admirable woman. She died as unselfishly as she lived: in South Africa at the age of 37 from enteric fever while nursing fever cases during the Boer War.

MERIWETHER LEWIS, by Richard Dillon. Coward-McCann, Inc. ($6.95). A sound, readable biography of Thomas Jefferson's private secretary, who was personally selected by him to command the first overland U.S. expedition to the Pacific. With his companion William Clark, Lewis led one of the great explorations of all time, executed as flawlessly as it had been planned. No one, of course, can write about this feat without drawing heavily on Lewis and Clark's journals, diaries and letters, which are as masterly and fascinating as the expedition itself. Dillon has done this and within those limits his biography is strong. When he turns to other sources in describing Lewis' life before and after the expedition—particularly in his conjectures about Lewis' violent and tragic death—his story is much less effective. Dillon's book is certainly not without merit, but to savor the true excitement and greatness of the expedition one must turn to Reuben Gold Thwaites' edition of the original journals and Donald Jackson's *Letters of the Lewis and Clark Expedition, with Related Documents* (published in 1962 and noted in these pages), or to Bernard De Voto's popular condensation of the journals.

THE NEW PRIESTHOOD, by Ralph E. Lapp. Harper & Row Publishers ($4.95). A frequently penetrating, astringent examination of the rise to pow-

er since the first atomic bomb of a scientific elite in the U.S. While campaigning in 1912, Woodrow Wilson voiced his fear of "a government of experts." It is perhaps an overstatement to contend that these fears have been fully realized; if nothing else, there is abundant evidence that ordinary political hacks and timeservers still control most of the important valves of the Government machine. But it is equally clear that scientists have risen to positions of great political power, that they influence critical decisions far more than the experts Wilson had in mind, and that between scientists and politicians there is now a relation that is in many respects unhealthy for both science and politics. Lapp, who has had much experience in this field, describes how scientists attained their new status, explains the dangers that flow from it and suggests what might be done (including the establishment of a cabinet post for science) both to control the new priesthood and to make the best social use of science. His proposed remedies do not inspire confidence, but a good part of his indictment is as unanswerable as it is cause for concern.

LIFE, LAND AND WATER IN ANCIENT PERU, by Paul Kosok. Long Island University Press ($27.50). In 1940 the Oriental Institute of the University of Chicago published a collection of archaeological photographs from the air that remains a classic; its more than 100 plates were the result of three years of flying over the ancient ruins of Persia by Erich F. Schmidt. Now a work has appeared that does for the rich archaeological remains of Peru what Schmidt did for those of Persia. The author, the late Paul Kosok, provided a narrative concerning his surveys of Peru's numerous archaeological districts. It is illustrated with his own photographs of the people and the countryside, with his and others' photographs and sketches of prehistoric sites and artifacts and, above all, with more than 150 aerial photographs of most of Peru's famous ruins, from coastal ChanChan to the mountain city of Machu Picchu. Kosok began his work in Peru in 1939 and completed his final field season in 1950. His book was nearly finished when he died in 1959; his colleagues at Long Island University have now seen to press what was clearly a lifework.

MEETINGHOUSE AND CHURCH IN EARLY NEW ENGLAND, by Edmund W. Sinnott. McGraw-Hill Book Company ($10). The biologist Edmund

Sinnott and his photographic collaborator Jerauld A. Manter have composed an attractive survey that describes the effects of Puritan tradition on meetinghouse and church architecture and gives information on the history of the structures and their builders and on the ministers who held the pulpits. This volume is a labor of love, and the feelings that promoted it are well communicated to the reader.

ELEMENTARY LOGIC, by Willard Van Orman Quine. Harper Torchbooks ($1.60). This reviewer knows of no better introduction to modern logic than Quine's primer, which appears in this paperback in a much revised edition, fully a third of which is new. First published in 1941, it has comforted many students and general readers interested in a quick survey of the subject either as a prerequisite for some other branch of study or as a sound guide to the rudiments of formal reasoning. In explaining basic concepts, the conversion of words into symbols, the testing procedure for truth-functions and the logic of quantifiers, Quine succeeds in presenting austere matter in a manner that is inviting and even sprightly.

FROM SEMAPHORE TO SATELLITE, by Anthony R. Michaelis. International Telecommunication Union ($9.50). Published to mark the 100th anniversary of the founding in Paris of the International Telegraph Union, an event marking the beginnings of international cooperation in telecommunications, this attractive and abundantly illustrated volume gives an account of the history of long-range communications from the precursors of the telegraph and telephone through modern radio, television, radio astronomy and communication satellites. The major emphasis of the book is not so much on the scientific history of the instruments of telecommunications as it is on the international cooperation that has made possible the spectacular progress of the past 100 years.

Notes

EXPLAINING THE ATOM, by Selig Hecht. The Viking Press, Inc. ($1.45). The late Selig Hecht's admirable exposition of the principles of atomic energy, as revised and expanded by Eugene Rabinowitch, is published in a soft-cover edition.

CURIOSITIES OF LIGHT RAYS AND LIGHT WAVES, by S. Tolansky. Veneda

Publishing Company Ltd. (21 shillings). A simple introduction to certain aspects of optics: multiple reflections, color, internal reflection, interferometry, the Doppler effect, the role of light in the quantum theory and relativity.

ART & GEOMETRY: A STUDY IN SPACE INTUITIONS, by William M. Ivins, Jr. Dover Publications, Inc. ($1). A reprint of an interesting essay touching on mathematical perspectives and projective geometry, and on the relation of styles in art to advances in geometry.

PHOTOGRAPHY AND THE AMERICAN SCENE, by Robert Taft. Dover Publications, Inc. ($3). A paperback reprint of Taft's agreeable and inviting survey of American photography from 1839 to 1889, adorned by more than 300 first-rate illustrations.

THE ENGLISHNESS OF ENGLISH ART, by Nikolaus Pevsner. Penguin Books Inc ($1.95). A soft-cover reissue of Pevsner's engaging and informative Reith Lectures on the national characteristics in English painting, sculpture and architecture.

THE SCIENCE OF SOUND, by John Tyndall. Philosophical Library, Inc. ($6). A reprint of Tyndall's series of lectures on sound given in the U.S. in 1873. Tyndall, a disciple of Faraday and known for his research on the transmission of light in gases and liquids, was a popularizer of science in the best 19th-century tradition.

LECTURES ON ELEMENTARY NUMBER THEORY, by Hans Rademacher. Blaisdell Publishing Company ($6.50). Based on lectures given at Haverford College, this book by a leading mathematician is in part accessible even to beginners in the fascinating field of number theory.

THE ANATOMICAL LECTURES OF WILLIAM HARVEY, edited by Gweneth Whitteridge. The Williams and Wilkins Co. ($20.50). A scholarly edition of William Harvey's *Lectures on the Whole of Anatomy*—all that is known to remain of his anatomical writings—giving a transcription of the Latin text (based on two manuscripts in the British Museum) and a facing English translation.

A DICTIONARY OF PSYCHOLOGY, by James Drever. Penguin Books Inc ($1.25). A revised edition (by Harvey Wallerstein) of a compact, dependable reference book designed for the layman and the student. Paperback.

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

PROTEIN FROM PETROLEUM

CONSIDÉRATIONS SUR L'ÉVENTUALITÉ DE LA PRODUCTION DE PROTÉINES PAR L'INDUSTRIE DU PÉTROLE. Alfred Champagnat in *Bulletin de l'Académie Nationale de Médecine*, Vol. 147, No. 9–10, pages 182–186; March 5, 1963.

PROTEINS FROM PETROLEUM FERMENTATION—A NEW SOURCE OF FOOD. Alfred Champagnat in *Impact of Science on Society*, Vol. 14, No. 2, pages 119–133; 1964.

THE WORLD'S HUNGER AND FUTURE NEEDS IN FOOD SUPPLIES. P. V. Sukhatme in *Journal of the Royal Statistical Society*, Series A, Vol. 124, Part IV, pages 463–525; 1961.

ELECTRICAL EFFECTS IN BONE

GENERATION OF ELECTRIC POTENTIALS BY BONE IN RESPONSE TO MECHANICAL STRESS. C. Andrew L. Bassett and Robert O. Becker in *Science*, Vol. 137, No. 3535, pages 1063–1064; September 28, 1962.

MUSCLE ACTION, BONE RAREFACTION AND BONE FORMATION: AN EXPERIMENTAL STUDY. Max Geiser and Joseph Trueta in *The Journal of Bone and Joint Surgery*, Vol. 40-B, No. 2, pages 282–311; May, 1958.

PIEZOELECTRIC EFFECT IN BONE. Morris H. Shamos, Leroy S. Lavine and Michael I. Shamos in *Nature*, Vol. 197, No. 4862, page 81; January 5, 1963.

DIAMONDS IN METEORITES

FORMATION OF DIAMOND BY EXPLOSIVE SHOCK. Paul S. DeCarli and John C. Jamieson in *Science*, Vol. 133, No. 3467, pages 1821–1822; June 9, 1961.

THE RECORD IN THE METEORITES—IV: ORIGIN OF DIAMONDS IN IRON METEORITES. Michael E. Lipschutz and Edward Anders in *Geochimica et Cosmochimica Acta*, Vol. 24, Nos. 1/2, pages 83–105; June, 1961.

CHANCE

LOGICAL FOUNDATIONS OF PROBABILITY.

Rudolf Carnap. The University of Chicago Press, 1962.
PRINCIPLES OF THE THEORY OF PROBABILITY. Ernest Nagel. The University of Chicago Press, 1939.
A TREATISE ON PROBABILITY. John Maynard Keynes. Harper & Row Publishers, 1962.

QUANTUM EFFECTS IN SUPERCONDUCTORS

EXPERIMENTAL EVIDENCE FOR QUANTIZED FLUX IN SUPERCONDUCTING CYLINDERS. Bascom S. Deaver, Jr., and William M. Fairbank in *Physical Review Letters,* Vol. 7, No. 2, Section I, pages 43–46; July 15, 1961.
EXPERIMENTAL PROOF OF MAGNETIC FLUX QUANTIZATION IN A SUPERCONDUCTING RING. R. Doll and M. Näbauer in *Physical Review Letters,* Vol. 7, No. 2, Section I, pages 51–52; July 15, 1961.
QUANTIZED MAGNETIC FLUX IN SUPERCONDUCTORS. R. D. Parks in *Science,* Vol. 146, No. 3650, pages 1429–1435; December 11, 1964.
QUANTIZED VORTICES IN SUPERCONDUCTORS. R. D. Parks in *Low Temperature Physics LT9: Proceedings of the 9th International Regional Conference on Low Temperature Physics,* edited by J. G. Daunt, D. O. Edwards, F. J. Milford and M. Yaqub. Plenum Press, in press.
SUPERCONDUCTIVITY. E. A. Lynton. John Wiley & Sons, Inc., 1962.
SUPERFLUIDS, VOL. I. Fritz London. John Wiley & Sons, Inc., 1950.
VORTEX LINES IN SUPERCONDUCTORS. P. G. de Gennes in *Low Temperature Physics LT9: Proceedings of the 9th International Conference on Low Temperature Physics,* edited by J. G. Daunt, D. O. Edwards, F. J. Milford and M. Yaqub. Plenum Press, in press.

EARLY MAN IN PERU

CHANGING SETTLEMENT PATTERNS ON THE CENTRAL PERUVIAN COAST. Thomas Carl Patterson and Edward P. Lanning in *Ñawpa Pacha,* Vol. 2, pages 113–123; 1964.
NEW EVIDENCE FOR PRE-CERAMIC MAIZE ON THE COAST OF PERU. David H. Kelley and Duccio Bonavía B. in *Ñawpa Pacha,* Vol. 1, pages 39–42; 1963.
A PRE-AGRICULTURAL OCCUPATION ON THE CENTRAL COAST OF PERU. Edward P. Lanning in *American Antiquity,* Vol. 28, No. 3, pages 360–371; January, 1963.

PRECERAMIC CULTURES IN CHICAMA AND VIRÚ. Junius B. Bird in *Memoirs of the Society for American Archaeology*, No. 4, pages 21–28; April, 1948.

THE CHEMISTRY OF CELL MEMBRANES

CHANGES IN PHOSPHOLIPID METABOLISM ON STIMULATION OF PROTEIN SECRETION IN PANCREAS SLICES. Lowell E. Hokin and Mabel R. Hokin in *The Journal of Histochemistry and Cytochemistry*, Vol. 13, No. 2, pages 113–116; February, 1965.

INTERCONVERSION OF PHOSPHATIDYLINOSITOL AND PHOSPHATIDIC ACID INVOLVED IN THE RESPONSE TO ACETYLCHOLINE IN THE SALT GLAND. Mabel R. Hokin and Lowell E. Hokin in *Metabolism and Physiological Significance of Lipids*, edited by R. M. C. Dawson and Douglas N. Rhodes. John Wiley & Sons Ltd., 1964.

SYMPOSIUM ON THE PLASMA MEMBRANE. Edited by Alfred P. Fishman. *Circulation: An Official Journal of the American Heart Association*, Vol. 26, No. 5, Part II; November, 1962.

THE ORIGINS OF FACIAL EXPRESSIONS

THE CALCULATION OF VOWEL RESONANCES, AND AN ELECTRICAL VOCAL TRACT. H. K. Dunn in *The Journal of the Acoustical Society of America*, Vol. 22, No. 6, pages 740–753; November, 1950.

EVOLUTION OF FACIAL EXPRESSION. R. J. Andrew in *Science*, Vol. 142, No. 3595, pages 1034–1041; November 22, 1963.

THE EXPRESSION OF THE EMOTIONS IN MAN AND ANIMALS. Charles Darwin. University of Chicago Press, 1965.

MATHEMATICAL GAMES

POLYOMINOES. Martin Gardner in *The Scientific American Book of Mathematical Puzzles & Diversions*. Simon and Schuster, 1959.

POLYOMINOES. Solomon W. Golomb. Charles Scribner's Sons, 1965.

THE AMATEUR SCIENTIST

RADIOISOTOPE LABORATORY TECHNIQUES. R. A. Faires and B. H. Parks. Pitman Publishing Corporation, 1958.

TEMPERATURE MEASUREMENT IN ENGINEERING. H. Dean Baker, E. A. Ryder and N. H. Baker. John Wiley & Sons, Inc., 1953.

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