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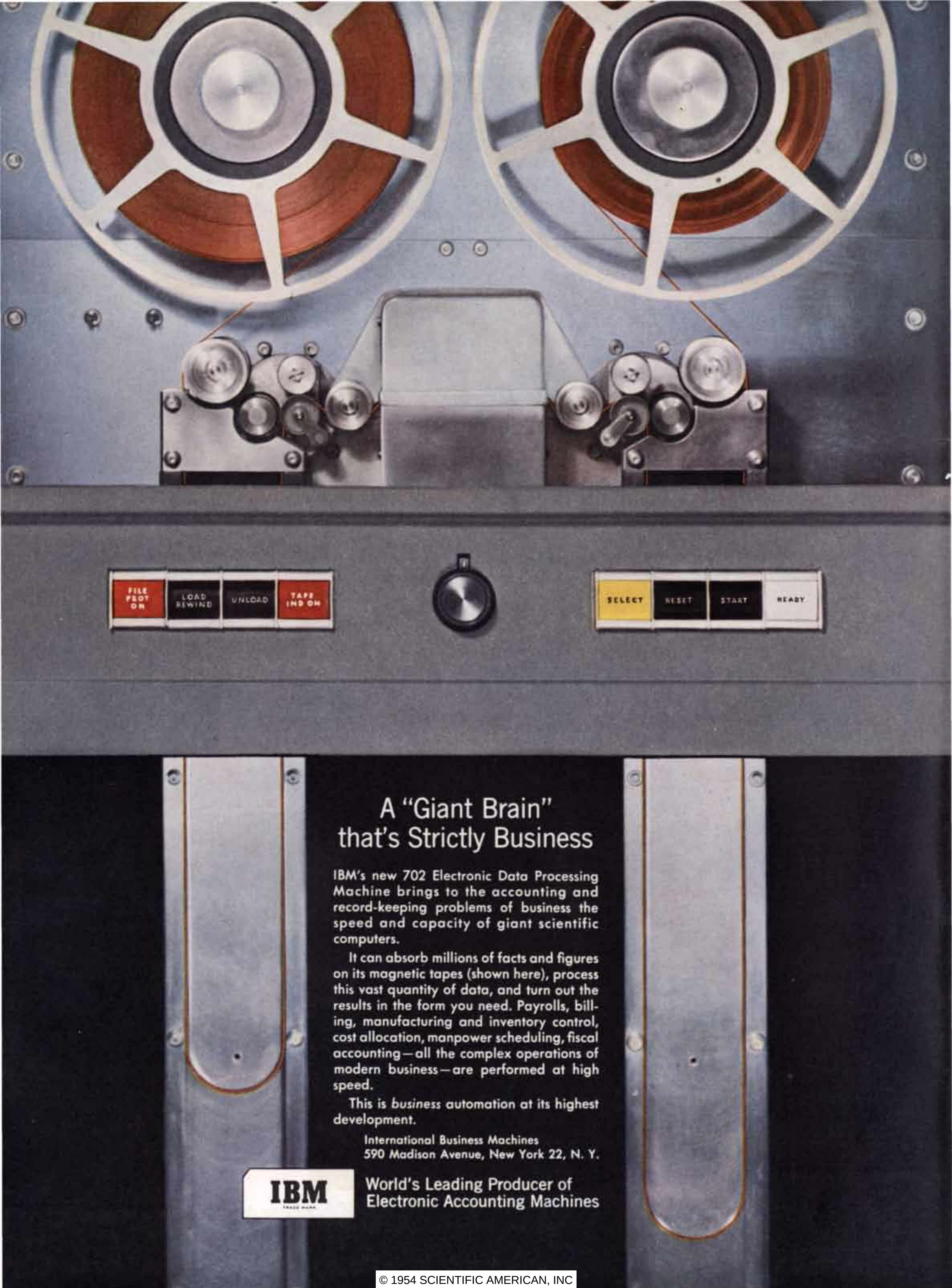
August 1954



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LETTERS

Sirs:

The article on William Rowan Hamilton by Sir Edmund Whittaker [SCIENTIFIC AMERICAN, May] impels me to make several comments.

It is clear that the history of science, as indeed the history of all facets of human accomplishment, is essentially the biographies of the men who did it. When narrated by a skillful and eloquent writer, and by one who sees clearly the place of each achievement in the larger scheme of things, there is nothing so stirring to read. Sir Edmund Whittaker is such a writer. By virtue of his own majestic competence he weaves from the vast array of detail a whole cloth which is poetry to read.

In connection with the commutative law (of algebra), the following elementary exercise may aid some readers in discovering for themselves, in an experimental way, that $a+b$ need not equal $b+a$.

Take any unsymmetric object, a man's hat, say. (Or even a lady's hat!) Hold it in any position with both hands and imagine three mutually perpendicular axes to pass through it. Now rotate the hat through 90 degrees, first about one axis, then about another, then about the third. Note well the position of the hat before the rotations and after. Now repeat the rotations but change the order in which they are done. The final position of the hat is different. It is seen that $a+b+c$ is not equal to $b+c+a$!

Lastly, in spite of the many beautiful and suggestive results brought forward by Hamilton in his development of the algebra and calculus of quaternions, the quaternionic scheme failed to meet in an entirely satisfactory way the requirements of mathematical physicists. It may safely be said that only two ideas of any substantial consequence in the whole scheme of quaternions have remained with us. These ideas are embraced in the two terms, *curl* and *divergence*. When a quaternion is produced in a certain way, as by operating on a certain kind of function, the vector part of this quaternion is now called the curl; the scalar part is the negative of what is now called the divergence. These two ideas play important roles in mathematical physics.

JULIUS SUMNER MILLER

El Camino College
El Camino College, Calif.

Sirs:

I have read the elegant article by Dr. Edward L. Ginzton [SCIENTIFIC AMERICAN, March] with more than ordinary interest. The underlying principle of the klystron—velocity modulation and bunching of electrons—is recognized to be the first vacuum-tube microwave generator, *i.e.*, the retarding-field or positive-grid oscillator. As far back as 1929 I invented and investigated a double-grid version of such a retarding-field tube (German patent 539,192) which is a forerunner of the reflex klystron.

At the end of his paper Dr. Ginzton expresses doubt as to the ability of the mighty midget of modern electronics, the transistor, to produce microwaves. His prediction seems premature because in the meantime not only have "internal oscillations" been discovered in transistors without the aid of external resonance systems, but also higher modes of those internal oscillations run up to ultrahigh frequencies and the lower end of the microwave region. Naturally the minute transistors of today cannot compete with huge klystrons; but it must be kept in mind that the transistor is still in its infancy while the klystron is the product of decades of tube development. After the discovery of the internal transistor oscillations—the dual form of Barkhausen's electron oscillations—there are no theoretical and practical reasons why we cannot have, in a reasonable time, microwave transistors

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Can You Use The "Grain That Stops Lightning"?

CRYSTOLON* silicon carbide (SiC), electrochemically produced from silica sand and coke, is produced by Norton in many forms. One of these forms, E-179 CRYSTOLON grain, is known as "lightning arrestor grain" because of its carefully controlled electrical properties — obtained by specially controlled furnacing techniques, which lower its surge impedance.

In Commercial Lightning Arrestors

E-179 CRYSTOLON grain has the particularly useful property of acting as an insulator at low voltages and as a conductor at high voltages. This "valving" action, analogous to pressure-controlled valves in a fluid system, is provided in the arrestor circuit by a spark gap in series with an E-179 grain unit, loose or molded into blocks. The number of series used varies according to the arrestor's voltage rating.

The non-linear behavior of E-179 CRYSTOLON grain may be expressed in terms of voltage and current by the equation:

$$V = AI^n$$

where A is a constant for a given sample, and n, the exponent, is approximately 0.1 for E-179. For a material where the exponent n = 1, the equation becomes Ohm's Law: $V = IR$. The value of A is controlled by the method of manufacture. The exponent is constant over a wide range of surge impedance.

Ceramic Non-Ohmic Resistors

in the form of block, disc or rod are composed of a fired mixture consisting principally of a ceramic bond and E-179 CRYSTOLON grain. The nature of this crystalline silicon carbide determines the finished characteristics of the resistors. Both the nominal grain size and actual distribution of grain size around the nominal are factors which must be controlled.

E-179 CRYSTOLON grain is available in grit sizes from 60 to 240, inclusive, manufactured to customers' specifications, with impedance values measured for every lot of grain in each grain size.

Besides the applications mentioned, other uses for this special CRYSTOLON grain are: spark plug resistors, railroad blocks and discs, voltage control devices and varistors for telephones.

Regular CRYSTOLON Grains

share the common characteristics of great mechanical strength and resistance to heat shock. And in refractory applications the high thermal conductivity of CRYSTOLON material — 8 to 10 times that of ordinary fireclay — is a distinct advantage.

CRYSTOLON silicon carbide dissociates without melting at the extreme temperature of 4170°F. It is an acid refractory and at elevated temperatures resists all slags except those high in alkalies. Other characteristics include: maximum operating temperature — 2800°F; specific gravity — 3.20; bulk density — 98 lbs. per cu. ft.; hardness (Knoop) — 2500; crystal structure — hexagonal system, hemahedral class. A typical chemical analysis shows:

SiC	98.13%
Free SiO_2	.50
Fe	.25
Al	.25
Free C	.20
CaO	.15
Si	.50
MgO	.02

Regular CRYSTOLON material is used for: metallurgical additions; as a source of silicon for silicon tetrachloride base silicones; for electrical heating elements; and for refractory cements and shapes for industrial furnaces which utilize its high thermal conductivity, high hot strength and good thermal shock resistance.

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include ALUNDUM* fused alumina, MAGNORITE* fused magnesium oxide, NORBIDE* boron carbide, Fused Stabilized Zirconia and many others, including a number still undergoing research and development.

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For Your Own Applications or Developments

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H. E. HOLLMANN

U. S. Naval Air Missile Test Center
Point Mugu, Calif.

Sirs:

After reading James E. McDonald's "The Shape of Raindrops" in the February issue of Scientific American I feel constrained to come to the defense of my colleagues the cartoonists. The article reveals the inability of workers in the physical sciences to appreciate the purposes of workers in the social sciences.

The purpose of physical science might be described as the investigation of laws by which objects may be moved. The purpose of social science might be described as the investigation of laws by which people may be moved. A physical scientist creates a model of a raindrop in order to learn about the motion of that complex of objects which we call "weather." The cartoonist creates a model of a raindrop in order to learn about the motion of that complex object which we call a person when affected by the weather!

In other words, the cartoonist's raindrop is an accurate representation of what the average man thinks is hitting him and making him wet and miserable as he charges down the street with his dripping hatbrim pulled down to his eyes looking for a bar where he can wait until the downpour is over. Since the wretched man's eyes are not stroboscopic and he does not carry a high-speed flash around with him, what he sees are not bun-shaped globules floating gently around, but a series of streaks ending in a wet splash. To this his imagination adds the picture of a detaching drop—the only time in the history of a drop of water when his miserably inadequate retina is able to register a clear picture of it—and he thinks he sees a streamlined "teardrop."

I am afraid the feeling of wetness, etc., which it is the duty of the cartoonist to convey, would not be adequately indicated by a man surrounded by miniature hamburger buns, however "true" such a picture might be to the Martian with stroboscopic vision!

ARCHER TORREY

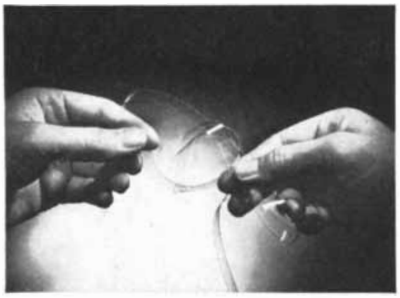
Vicar
Saint John's Mission
Athol, Mass.

CORNING GLASS BULLETIN

FOR PEOPLE WHO MAKE THINGS

Ribbon glass by the yard. Here's a glass that's a thousandth of an inch thin and in small widths it's flexible as—well, a ribbon. You can twist it, roll it, wrap it around your arm without cracking it. It comes in any length you want—inches, yards, miles.

Actually ribbon glass isn't a single glass. We can make it of several different compositions according to what you need it for. Originally we developed it to take the place of mica in electronic capacitors of which there are several in your radio and TV sets and in any other piece of electronic equipment you can name. As mica is formed in layers, it is subject to cleavage in the plane parallel to lamination; ribbon glass being homogenous is easily workable. This is just one advantage of this glass in capacitors.



Medical scientists have found a quite different use for ribbon glass—as microscope slide covers. These are the wafer-like pieces of glass that are used to cover blood smears and the like for examination under the microscope. In this case ribbon glass can be made clearer, flatter and more free of bubbles and striae than previously made glasses.

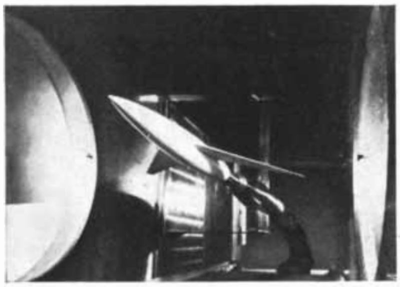
▶ Seems as if this unique stuff should be good for a *lot* of things, but *what* (other than electrical and laboratorial) probably lies in the laps of imaginative designers. Would you like us to send you a little strip to play with?

Two tons—on the nose! If you called for them, we could, with reasonable speed, provide you with a king-size pair of glasses. The lenses alone would weigh in at a hefty two tons.

Since it's no mean feat to balance "specs" like that on your nose, we don't have too much call for them. Still, we have filled one order and are prepared to fill another any time they're needed. You might be interested in this little story, not as a prospect for such outsized eye-wear, but because it might suggest a new approach to some design or manufacturing problem of your own.

Our aerodynamic friends find wind tunnels valuable instruments in developing new and better products. Naturally, to make the most of said wind tunnels, it's necessary to see and photograph what's going on inside. That's what led us to build the windows you see in the picture below. Weighing nearly a ton each, these giant disks are of finest optical quality—a very necessary feature since the scientists and engineers must make precise observations through them. More remarkable still is the fact that these optically perfect pieces of glass withstand the enormous forces built up by air moving at nearly *twice the speed of sound.*

▶ If heretofore you've looked on glass as a somewhat fragile material of limited use, these windows to the supersonic world may give you food for thought. However, we like to admit that, despite the unique quality of these panes, they are just one of countless special-application products devised by Corning engineers working with customers' problem children. So, even if aeroplanes or ranting winds aren't your responsibility, talking over *your* problem with the men at Corning could very well lead to a profitable solution.



In defense of light. Throwing light on a subject is often easy—*keeping* it there may be something else again.

A good, if unusual, case in point is made by a manufacturer of our acquaintance who makes shot blasting equipment for cleaning metal castings. Unfortunately the shot which cleaned the castings also played havoc with the light bulbs in the equipment. For a while it looked like a choice between constantly replacing shattered bulbs or working in the dark—neither offering a satisfactory solution.

The big question—could the castings be cleaned while being seen? Turns out the answer was YES. Corning was able to develop a special glass globe to shield the light bulbs from the metallic barrage. Made of clean PYREX brand glass No. 7740, these half-inch thick, abrasion-resistant globes let through plenty of light and, by saving bulbs from speedy annihilation, earn their keep over and over again.

▶ If by chance some production problem centers your interest on protecting light bulbs perhaps we have the specifications, solution and can quote prices. On the other hand, if our little story serves only to give you an idea of what a rugged material glass really can be, we encourage you to refresh your memory on some of its other useful attributes, which you will find described quite lucidly in our Bulletin IZ-1, "Glass—its increasing importance in product design." We'd be delighted to send you a copy.

Frankly, we're being amazed continually (almost) by the ingeniousness of people who come up with ideas we'd never in all time think of for putting glass to work. We've worked with hundreds of folks and we'd like to work with you, if you have a stubborn materials problem that glass might eliminate. We've got research experience, application experience, production experience, and plenty of facilities. It'd be a pleasure to put them to work for you on any likely problem or product.

Corning means research in Glass

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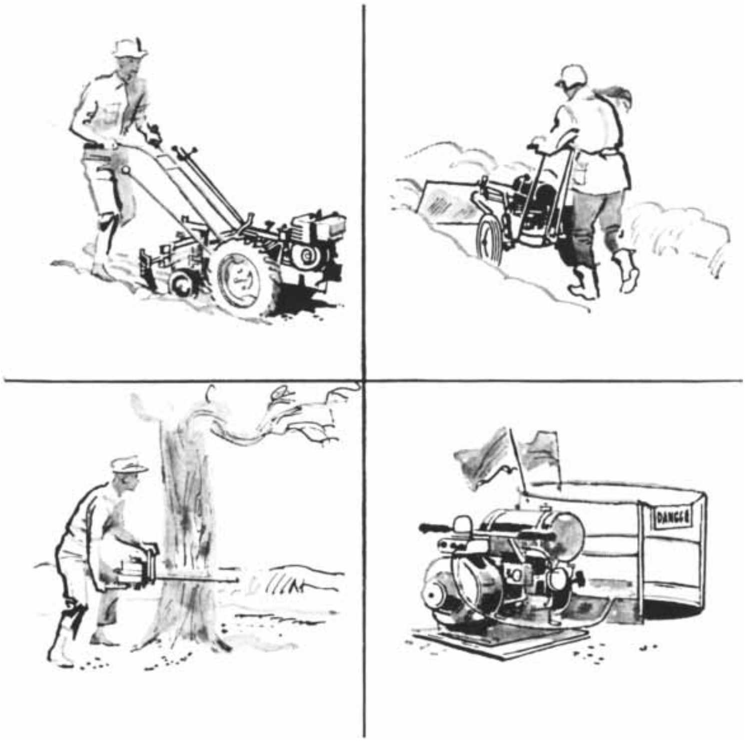
Just a Glimpse

The foregoing is just one part of the entire Bendix operation. Our twenty-six divisions research, develop and manufacture about a thousand different products for scores of different industries. Better known components used by the automotive field are power brakes, power steering, Stromberg* and Zenith* carburetors, Bendix* radio, complete braking systems, brake blocks and lining, electric fuel pumps and the famous Bendix* starter drive.

Military, air line, business and private planes use all kinds of Bendix equipment: complete radio communications systems, automatic pilots and many other gyro-controlled instruments, fuel injection, landing gear, brakes, ignition systems, telemetering equipment, jet engine



controls, aircraft pumps, air-borne starters, storm detecting air-borne radar . . . and much other equipment.

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brake blocks, brake lining, synthetic resins.

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electronic tubes; dynamotors, inverters.

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50 AND 100 YEARS AGO

AUGUST, 1904: "Prof. G. H. Darwin suggests in *Nature* that previous estimates of the sun's age will have to be modified, as the result of the discovery of a new source of energy in the disintegration of the atoms of radio-active substances. Lord Kelvin's well-known estimate of 100 million years was arrived at on the assumption that the energy emitted by the sun was derived from gravitation by the concentration of its mass. Prof. Darwin estimates that the energy derivable from this source is 2.7×10^7 calories. If the sun were made of a radio-active material of the same strength as radium, it would be capable of emitting 10^9 million calories without reference to gravitation. The geologist's estimate of the age of the earth has always been so much greater than that of the physicist, that they have generally been looked upon as irreconcilable. The multiplication of the physical estimate by 20 would bring it into very close agreement with the geological estimate. The presence of helium in the sun points to the existence of radium in its mass, so that there is much to be said in favor of Prof. Darwin's hypothesis."

"It is gratifying to learn that science has at length discovered the real cause of 'caisson disease'—the terrible scourge which is the dread of engineers where submarine or tunneling operations have to be carried on under a pressure greatly exceeding that of the normal atmosphere. Profs. Hill and Macleod have shown that the various symptoms displayed by victims of caisson disease are produced by the effervescence of the blood in the small blood vessels consequent on the escape of the excess of air which exposure to pressure has forced into solution, and which subsequently effervesces like the gas in a freshly opened bottle of sparkling wine. This escape of air from the blood vessels obstructs the circulation in the parts nearest them, and the nature of the bad symptoms displayed depends on the position of the blood vessels in which most air happens to be absorbed at the time, and in which effervescence is most readily effected."

"H. Zahn has vainly endeavored to observe the N-rays discovered by Blondlot. He says that the latter's experiments as described by him have been repeated in several quarters, but so far without success. He himself employed a method which he claims to be more sensitive, as well as more objective, than that of Blondlot. The author does not go so far as to deny the existence of the N-rays, but points out that their discoverer has not described his experiments with sufficient detail, and that the rays can certainly not be so easily observed as he alleges."

"The results of some trials made by the French Automobile Club to ascertain the distances at which motor cars can be stopped when running at various speeds are likely to upset the popular impression formed by many motorists that a car can be brought to a standstill in its own length from a speed of 30 miles an hour. The trials in question were conducted in the Bois de Boulogne, and while they show that motor cars can stop more quickly than horses, yet they required a distance of 10 feet in which to come to rest when traveling at a speed of 7½ miles an hour. At a speed of 16 miles an hour, 33⅓ feet were required to stop in, and 60 feet at a speed of 25 miles an hour."

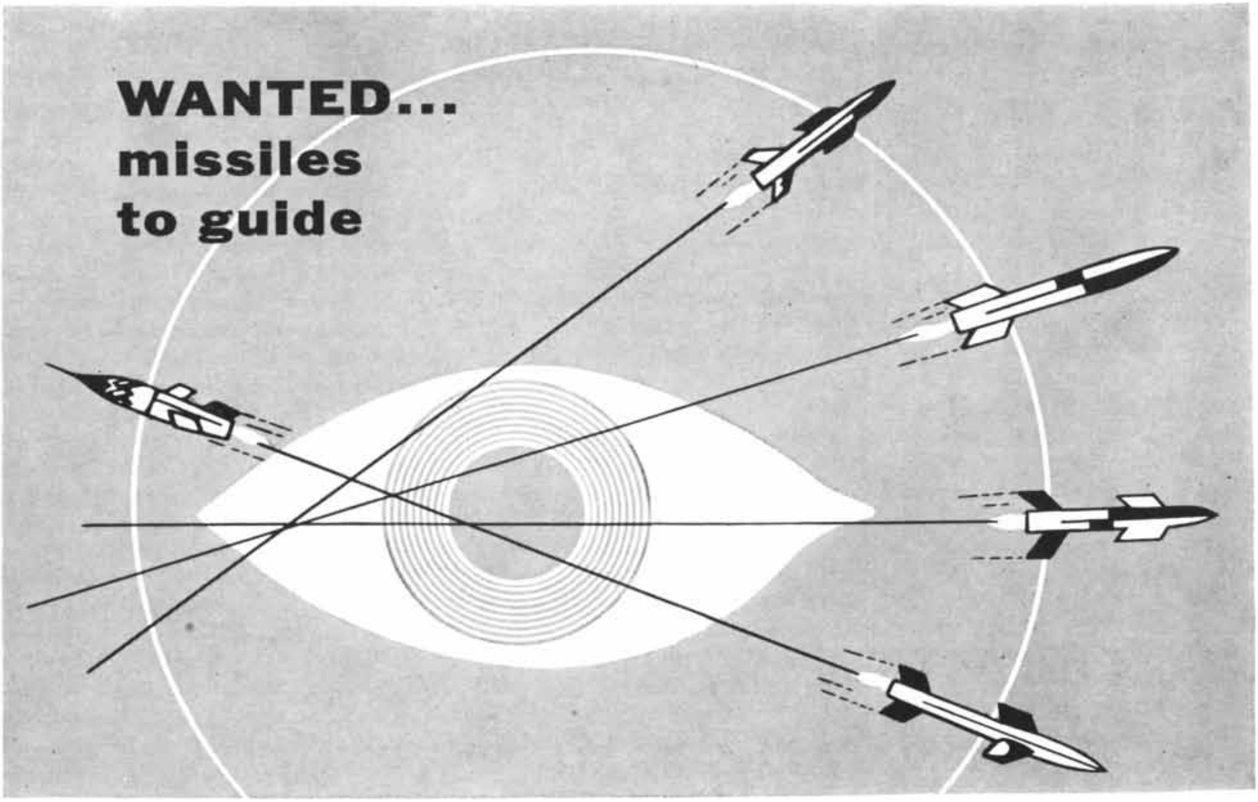
AUGUST, 1854: "No project of the present day is of more importance than the union of the Old and New Worlds by the lightning railroad—the telegraph. We understand that a company, having this object in view, has been organized in New York, and from the high standing, wealth, and experience of some of its members, we expect that the word *fail* will form no part of their vocabulary. Peter Cooper, Esq., is President, and Professor Morse is Vice President; T. P. Shaffner of Washington, Secretary of the American Telegraph Association, being one of the most active directors."

"The following from the *United States Economist* will open the eyes of thousands of our people to the growing importance of certain products made at home which the great majority of our people suppose are made in England:—

'The manufacture of many articles of hardware has lately been introduced into this country, and firmly established. Many of our heavy articles are unapproachable by the English imported goods. For instance, our Eagle anvil, with its cast-steel face, is firmer and more durable than the English anvil, of wrought iron. The American chain vise is an improvement unknown there. The augers made here are far in advance of the English ideas of progress, and so of many other articles. Five years ago masons' trowels were all imported; now $30,000 worth of trowels, confessedly superior to the English, are made by one manufacturer.' "

"A report has been submitted to the U. S. Senate by Senator Fish, on the subject of 'Health on Board of Emigrant Ships.' From the statistics presented it appears that while some ships from Liverpool had not a death on board the whole voyage, others had between 70 and 80. The disease is attributed to bad ventilation, and we conceive that the report has struck the true nail on the head. It is our opinion that the inhalation of impure air is the cause of nine-tenths of all the diseases in the world."

"It is well known to our readers that application was made to have the patent of Col. Colt, for revolving firearms, extended by special act of Congress, and that, while the bill to meet his case was before the House of Representatives on July 8, the Hon. Mr. Clingman, of North Carolina, rose up and stated that 'from extraordinary means resorted to he had no doubt very large sums of money had been offered to gentlemen to induce them either to vote for the Bill or absent themselves.' Mr. Clingman demanded the appointment of a committee to investigate the subject. A majority of that Committee has made a partial report. They concede that the evidence does not show that money was offered to members for their aid in this case, to influence their votes, but they say that 'the money has been used, as the evidence shows, in paying the costs and charges incurred in getting up costly and extravagant entertainments, to which ladies and members of Congress and others were invited, with a view of furthering the success of this measure. The ladies having been first duly impressed with the importance of Colt's pistol extension by presents of Parisian gloves, are invited to these entertainments, and the evidence shows that while there members are appealed to by them to favor this particular measure.' "



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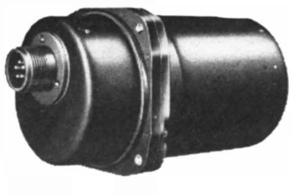
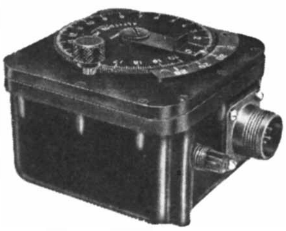


SYNCHROTEL TRANSMITTERS

for the remote electrical transmission of data such as true airspeed, indicated airspeed, absolute pressure, log absolute pressure, differential pressure, log differential pressure, altitude and Mach number.



PRESSURE MONITORS

to provide control signals which are functions of altitude, absolute pressure, differential pressure, etc.

To control a guided missile effectively and absolutely is a challenging problem with which hundreds of engineers are grappling every day.

The solution depends upon the efficiency and the reliability of the controlling parts.

For over 25 years Kollsman has been making precision aircraft instruments and equipment used on military and commercial aircraft throughout the world. The talents and skills needed for success in this special and challenging field are equally necessary in the design and manufacture of precision controls for missiles.

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THE AUTHORS

WILLIAM W. COOPER and ABRAHAM CHARNES ("Linear Programming") are at the Graduate School of Industrial Administration of the Carnegie Institute of Technology. Cooper is primarily an economist, Charnes primarily a mathematician, but they combine both fields in their teaching and research. Cooper is president of the Institute of Management Sciences, which is concerned with applying scientific analysis in business. The Institute was formed to provide a center in which findings developed in 'operations research' could be generalized. Cooper, a University of Chicago graduate, has been exploring a field of mathematical economics known as "the theory of the firm." His interest in this topic was deepened by his wartime investigation into intra-firm behavior for the Air Force. Charnes, who holds a Ph.D. in mathematics from the University of Illinois, did operations research in submarine warfare.

PETER F. SALISBURY ("Artificial Internal Organs") is a research associate with the Institute for Medical Research at Cedars of Lebanon Hospital in Los Angeles. He took an M.D. at the Medical School in Rome, an M.A. in biochemistry at Cambridge University and a Ph.D. in physiology at the University of Minnesota. His studies at Cambridge and in Minnesota were in the permeability of membranes. His interest in artificial organs was aroused in 1941 when he saw a young girl dying of mercury poisoning and decided it should be possible to save such a patient if a temporary replacement could be found for the kidneys. Ever since, he has designed, made and tested artificial internal organs.

JAMES A. FORD ("The History of a Peruvian Valley") is associate curator of North American archaeology at the American Museum of Natural History. He drifted into archaeology at the age of 16, when he started spending his summers excavating and collecting for the Department of Archives and History of his native state of Mississippi. During World War II he spent alternate periods as an observer of arctic survival problems in central Alaska and the Aleutians and as senior design specialist in Washington, working out models of new equipment for the Army. He received his Ph.D. in anthropology from Columbia University in 1948, after having spent a year in Peru as a Guggenheim Foundation fellow.

GEORGE WALD ("The Origin of Life") is one of the world's leading authorities on the chemistry of vision—a field of research which he has pursued with tenacity and increasingly rewarding discovery for some 20 years (see his article "Eye and Camera"; SCIENTIFIC AMERICAN, August, 1950). A native New Yorker, he successively considered careers in engineering, law and medicine but finally found what he wanted in science—"a way of life that would always run far ahead of my capacities." It was as a graduate student at Columbia University under Selig Hecht, "a superb scientist and a great personality," that Wald developed his interest in vision. He went to Germany on a National Research Council fellowship, discovered vitamin A in the retina while working in Otto Warburg's laboratory in Berlin and obtained a first view of the design of the rhodopsin cycle in rod vision in Otto Meyerhof's laboratory at Heidelberg. He spent a second year of his fellowship at the University of Chicago, joined the Harvard University biology department in 1934 and has been there ever since, at present as professor of biology. He received the Eli Lilly prize of the American Chemical Society in 1939 for his fundamental work in biochemistry, and the Lasker award of the American Public Health Association in 1953.

SAMUEL TOLANSKY ("A Topographic Microscope") is a specialist in two rather distantly related fields: interferometry and the study of line spectra. An Englishman born in Newcastle upon Tyne, he is professor of physics and director of the physics laboratories at Royal Holloway College, University of London. From wartime experience in the use of interferometers in nuclear spectroscopy he went on to develop methods of applying interferometry to the exploration of surface features of structures on a molecular scale. His wife is a painter, and Tolansky maintains an interest in folklore as well as in art.

JOSEPH BERNSTEIN ("Tsunamis") was plunged into the subject of tidal waves only recently, when he took a job as oceanographer with the U. S. Navy Hydrographic Office after a very different career. He had been a social worker and expert on labor relations—Brooklyn field office supervisor of the U. S. Department of Labor Wage and Hour Division. But he has an M.A. in zoology from Columbia University and has long

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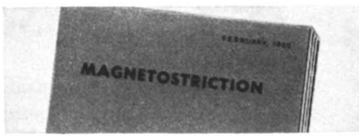

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been a writer and reader in many fields of science; when recent appropriations cuts eliminated his Department of Labor job, he was delighted at the opportunity to turn to oceanography.

OLIVER P. PEARSON ("Shrews") is, by a coincidence, one of two contributors to this issue who have done field research in Peru. Pearson led the Gardner-Peruvian Expedition of 1939-1940, in the course of which he studied the life histories of Peruvian mammals. In 1947, after receiving his Ph.D. from Harvard, he joined the Museum of Vertebrate Zoology at the University of California, where he is assistant professor of zoology and assistant curator of mammals. He was drawn to zoology by the influence of a teacher at Swarthmore College, Robert Enders, and he claims that after 15 years he is "still coasting on the impetus received from Enders." He has previously appeared in these pages as the author of "The Metabolism of Hummingbirds" in the issue of January, 1953.

JOSEPH J. CORNISH III ("The Boundary Layer") has been interested in aeronautics ever since he built model airplanes as a schoolboy in his native New Orleans. After service as navigator in a transport squadron in World War II he took his B.S. in mechanical engineering at Louisiana State University. He holds an M.S. in aeronautical engineering from the graduate school of Mississippi State College, where he is now studying the effects of boundary-layer control under a contract sponsored by the Office of Naval Research. Having made his childhood hobby his profession, he has now adopted a new hobby: building computing machines and robots.

MAX BLACK, who reviews Pierre Duhem's *The Aim and Structure of Physical Theory* in this issue, is professor of philosophy at Cornell University. A graduate of Queens College at the University of Cambridge, he started out as a mathematician. However, the turbulence Bertrand Russell and Ludwig Wittgenstein had caused in the flow of ideas at Cambridge soon drew him into logic and the philosophy of science. Shortly after taking his Ph.D. at the University of London he came to the U. S., of which he became a citizen in 1948. As a logician he has confounded probability by writing two abstruse books—*The Nature of Mathematics* and *Critical Thinking*—which reached second editions. His latest book, *Problems of Analysis*, came out last May.

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THE COVER

The photographs on the cover show the personal treasures of ancient Peruvian chieftains (*see page 28*). These objects may now be seen in the traveling exhibition of the Museum of Modern Art: "Ancient Art of the Andes." At the left is a small wooden scepter representing a man seated atop a jaguar. At top center is a gold earring inlaid with turquoise and mother-of-pearl. At bottom center is a piece of shell inlaid with turquoise; it represents a jaguar god. At upper right is a black stone pendant inlaid with turquoise. At lower right is a bronze personal decoration inlaid with turquoise. The earring and the black stone pendant are from the private collection of Rafael Larco Hoyle in Chiclín, Peru. The other objects are from the private collection of Norbert Mayrock in Santiago, Chile.

THE ILLUSTRATIONS

Cover photographs by Nickolas Muray

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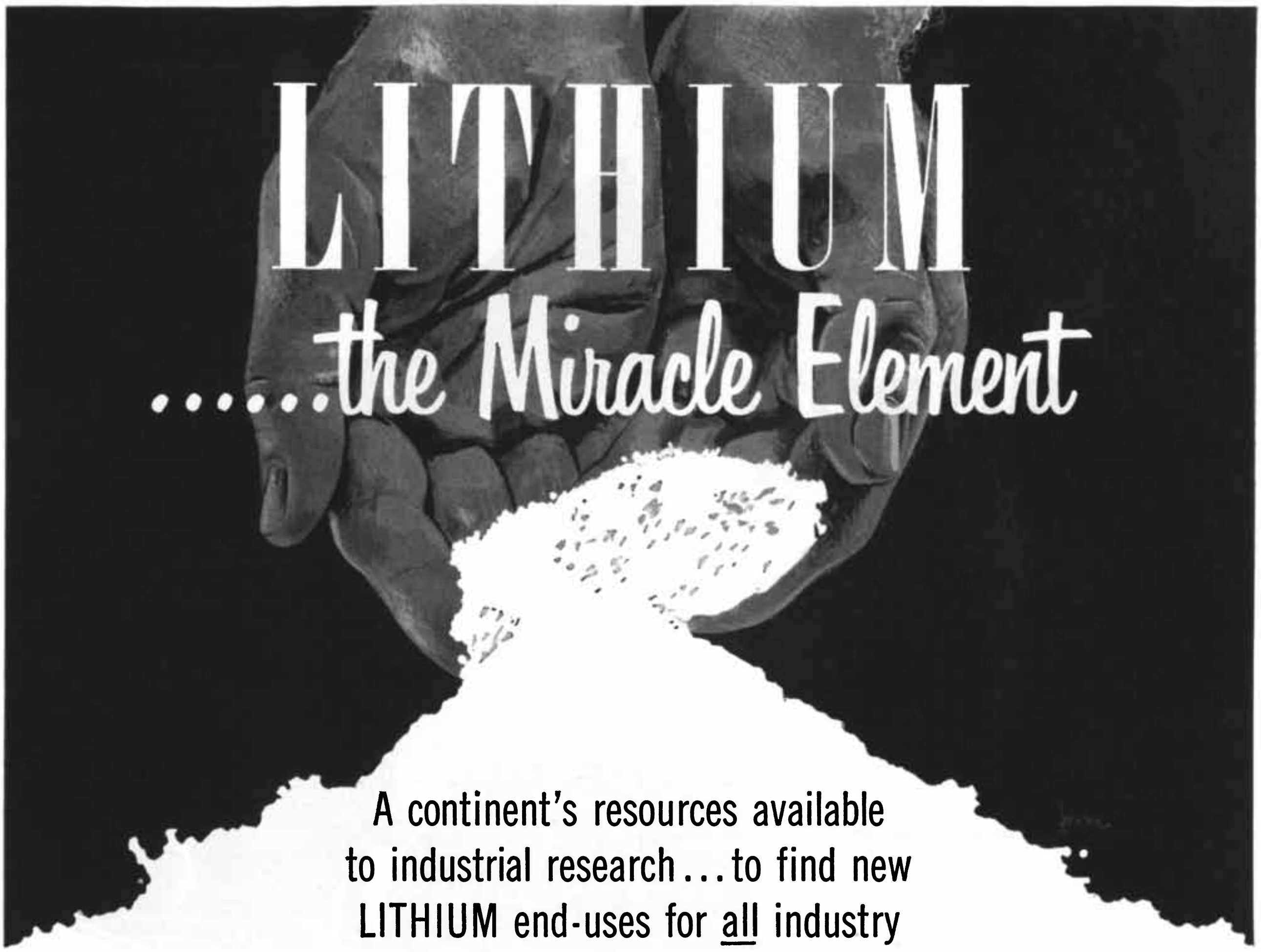

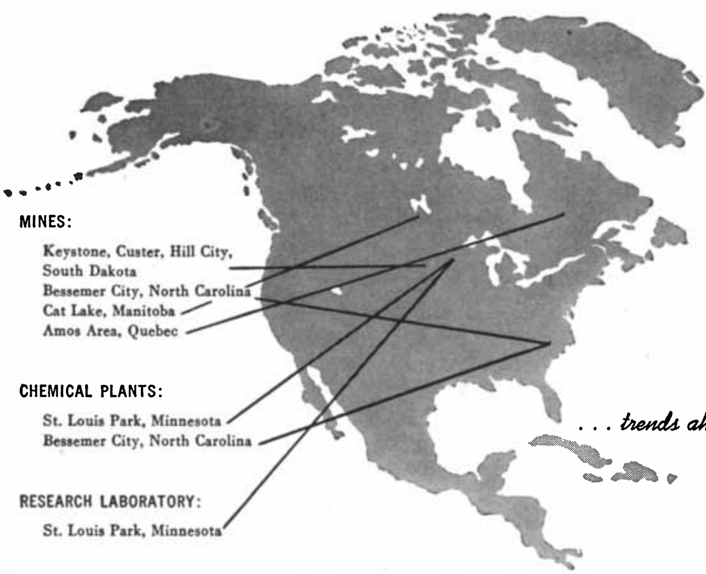

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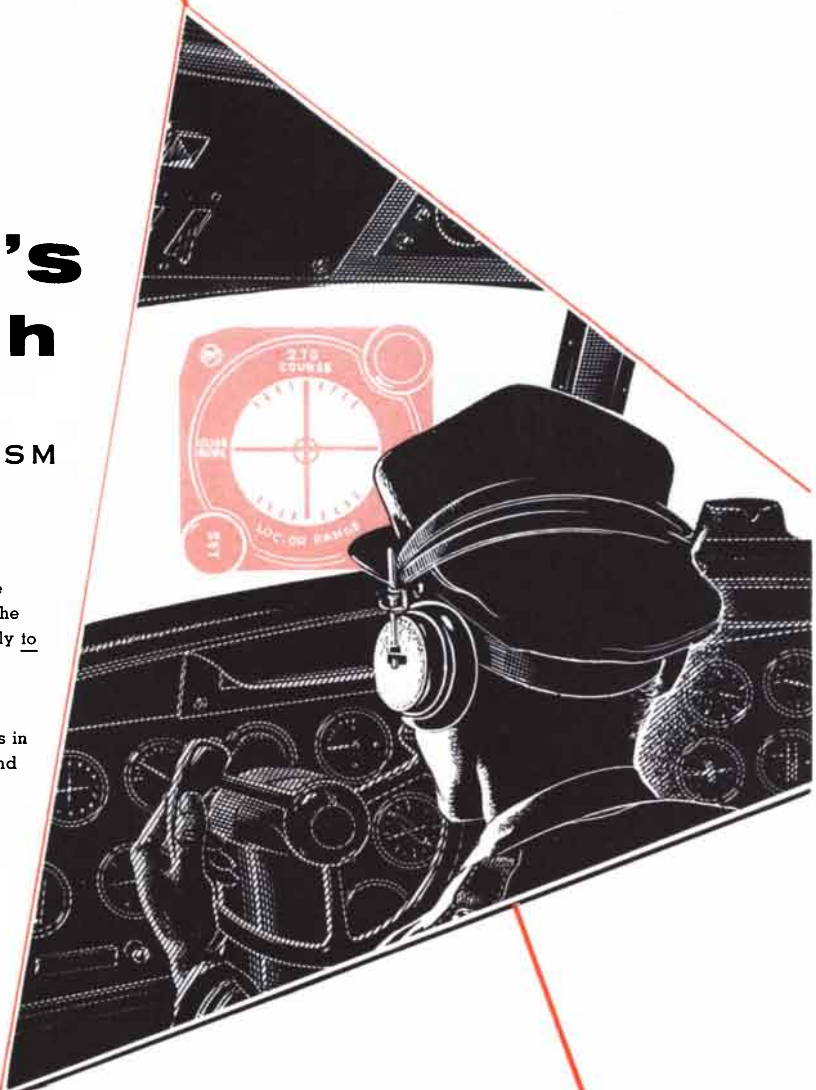

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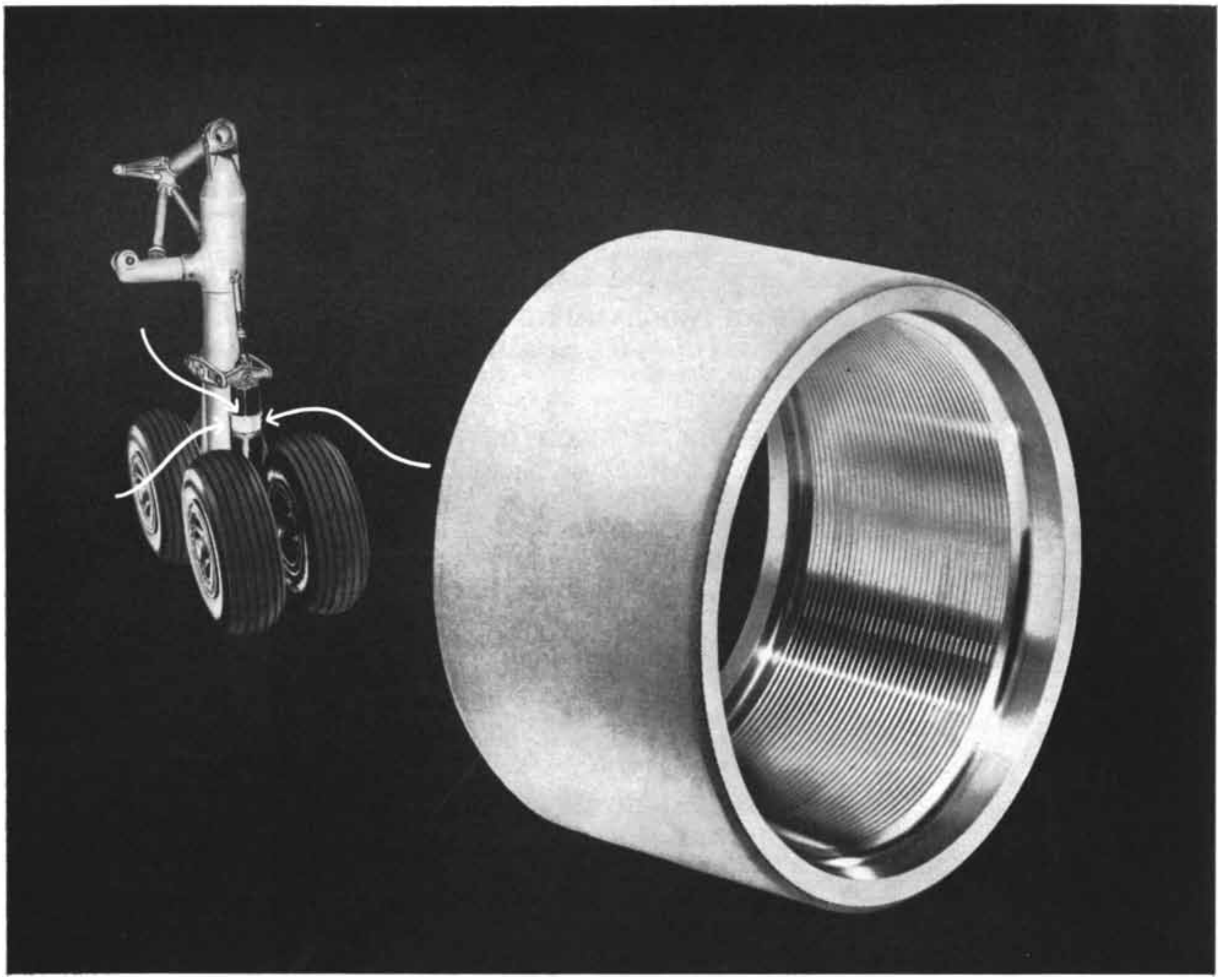


SCIENTIFIC AMERICAN

AUGUST, 1954 VOL. 191, NO. 2

Linear Programming

Like the theory of games, it is a method of pure mathematics that can be applied to human affairs. It is used to calculate the best possible solution to a problem that involves a number of variables

by William W. Cooper and Abraham Charnes

Imagine that you are manufacturing a product at a number of factories and must freight it to markets in many different parts of the country. How would you go about calculating the pattern of shipments that would deliver the goods from your many warehouses to the many markets at the lowest possible freight cost?

By common sense and trial and error you might readily work out a reasonable schedule. But even a non-mathematician can see that to find the best solution among the infinite number of possible solutions would be a far more formidable problem.

We shall describe in this article a recently developed technique in applied mathematics which makes it possible to solve such problems in a relatively short time by means of simple computations. The theory of linear programming was developed by John von Neumann, G. B. Dantzig, T. C. Koopmans and a few other mathematicians, statisticians and economists. It was first applied as an operating tool by Marshall Wood and his staff in the Air Force's Project SCOOP (Scientific Computation of Optimum Programs). One of its applications was in the Berlin air lift. As a result of work by the Air Force group and others in linear programming and related developments, such as the theory of games, statistical decision theory and input-output analysis, truly scientific methods of analysis are now being applied to many problems in business and logistics which used to be considered beyond the scope of such analyses. In this article we shall confine ourselves to linear programming and explain the principle with a sample problem.

Linear programming derived its name from the fact that the typical problems with which it deals are stated mathematically in the form of linear equations. (Actually "linear" is too narrow a name for the technique, for it may be applied to nonlinear problems as well.) In essence it is a method for considering a number of variables simultaneously and calculating the best possible solution of a given problem within the stated limitations. Any manufacturer will at once appreciate that this is a precise statement of his own problem. In deciding what particular items to manufacture, and in what quantities, he must take into account a great complex of factors: the capacities of his machines, the cost and salability of the various items, and so on. To make matters worse, each subdivision of his problem has its own complexities; for instance, he may have to choose among several possible processes for making a particular item. And all the factors and decisions may interlock and react upon one another in unexpected ways. In the circumstances, the best that any management can hope to achieve is a reasonably workable compromise. With linear programming, however, it becomes possible to locate definitely the optimum solutions among all the available ones, both in the realm of over-all policy and in departmental detail.

To illustrate the method let us take a highly simplified hypothetical case. We have a factory that can make two products, which for simplicity's sake we shall name "widgets" and "gadgets." The factory has three machines—one "bounder" and two "rounders." The same machines can be used to make widgets or gadgets. Each product must first be roughed out on the bounder and then rounded on one of the rounders. There are two possible processes for making each product: We can use the bounder and rounder No. 1 or the bounder and rounder No. 2 for either a widget or a gadget. Let us name the respective processes for the widget One and Two, and for the gadget Three and Four. The key variables are the times involved. To make a widget by Process One requires .002 of an hour on the bounder and .003 of an hour on rounder 1; by Process Two, .002 of an hour on the bounder and .004 of an hour on rounder 2. A gadget by Process Three takes .005 of an hour on the bounder and .008 of an hour on rounder 1; by Process Four, .005 of an hour on the bounder and .010 of an hour on rounder 2. Finally, we know that the capacities of the machines for the period we are considering (say six months) are 1,000 hours of operation on the bounder, 600 hours on rounder 1 and 800 hours on rounder 2.

All this information is summarized

at the top of the opposite page. A production superintendent might call this a flow chart; we can think of it as a model which specifies conditions, or constraints, that will govern any production decision we must make. Now it is readily apparent that we can translate these facts into an algebraic model. If we let x_1 represent the unknown number of widgets to be made by Process One, x_2 the number of widgets by Process Two, and x_3 and x_4 the numbers of gadgets to be made by Processes Three and Four, we can write all the information in an algebraic table [*middle of opposite page*]. The inequality sign before the numbers representing hours of capacity on the machines is the well-known symbol meaning "no more than." What this table means is simply that we can make no more widgets and/or gadgets than the capacities of the respective machines will allow. But with the conditions stated in this form, we are now in a position to consider the variables simultaneously and to calculate solutions which will satisfy the constraints. A solution will be called a linear program; linearity here refers to the fact that the available capacity on each machine is used up *in proportion to* the number of items run through it.

It is important to note here that the unknowns x_1, x_2, x_3 or x_4 may be zero but none of them can be a negative number. Of course it is obvious that we cannot produce a minus number of products. But in mathematics the exclusion of negative values must be carefully noted. In fact, the successful development of the theory of linear programming required extensive study of the effects that this restriction would have on traditional methods of solving and analyzing equations.

Having stated the constraints, we can proceed to find the best production schedule attainable within these limitations. What we mean by "best" will of course depend on what criterion we choose to apply. We might decide to seek the schedule that would produce the largest possible number of items, or the one that would use the greatest possible amount of the machines' available running time. But ordinarily the objective would be the greatest possible profit. Let us assume that the profit on each widget produced by Process One is 85 cents, on each widget by Process Two 70 cents, on each gadget by Process Three \$1.60, and on each gadget by Process Four \$1.30. We then get this equation: Total Profit $= .85x_1 + .70x_2 + 1.60x_3 + 1.30x_4$.

From this information we could calculate the number of each item we should produce to realize the largest possible total profit within the machines' capacity. (Be it noted that gadgets, though yielding a larger per unit profit, should not necessarily pre-empt the machines, for widgets take less time to produce.)

The problem as so far outlined, however, is much too simple to represent an actual situation. To come closer to a real problem we should at least introduce a sales factor. Let us suppose, therefore, that our factory has orders for 450,000 widgets. Elementary arithmetic will show that our present machine capacity cannot turn them out within the time limit. We have enough capacity on the bounder for 500,000 widgets (1,000 hours divided by .002 of an hour per widget) but our two rounders combined could finish no more than 400,000. We must obtain more rounder capacity, and this may be done by authorizing overtime on one or both of the rounders. Suppose, then, we arrange for 200 hours of overtime on the faster of our two rounders (.003 of an hour per widget). Because of higher labor costs for overtime, the profit per widget will be reduced from the usual 85 cents to 60 cents during the overtime period, and if we should use any of the overtime capacity for making gadgets, the unit profit on them will drop from \$1.60 to \$1.40.

The constraints governing this expansion of the problem are summarized in the algebraic table above (the new symbols x'_1 and x'_3 represent the number of widgets and of gadgets, respectively, to be turned out on rounder 1 during the overtime period). Given the unit profit figures, we are now prepared to calculate the most profitable possible employment of the machines.

The answer can be computed by one of several methods. The most general, devised by Dantzig, is called the simplex method. Certain special methods which are more efficient for the kind of problem being considered here were developed by the authors of this article. These systems, though too involved and lengthy to be explained in detail here, require only simple arithmetical operations which can easily be carried out by clerks or commercially available computers. The simplex method starts from zero use of the machines' capacity, and the computation proceeds by a series of specified steps, each of which advances closer to the ultimate answer.

The answer in this case is that we should produce no gadgets but should make 466,667 widgets, finishing 200,000 on rounder 1 at straight time, another 200,000 on rounder 2 at straight time and the remaining 66,667 at overtime on rounder 1. The total profit will be \$350,000. Our system of calculation tells us that it is not possible to devise a production schedule which will yield a larger total profit within our restrictions.

It is possible that there may be other programs which would provide as much (but no more) profit. If there are, the analyst can quickly find them. He can also determine the second best or third best program, and so on. Thus the method is not only powerful but also flexible; it can offer management a range of choices based on different considerations. Furthermore, linear programming methods can be extended to analyze the effects of any change in the restrictions—an improvement in efficiency, an increase or reduction in cost, an increase in capacity. These methods employ a "dual theorem," whereby a maximizing problem (such as the maximization of profits in the case we have been considering) is viewed as the reverse of a related minimizing problem. In this case the minimizing problem is concerned with the worth of the machine capacities. Using the same set of facts and calculations, it is possible to show precisely how much more profitable it is to employ overtime on rounder 1 than on rounder 2. If the overtime on rounder 1 were increased to 300 hours instead of 200 hours, the maximum profit would be \$370,000 instead of \$350,000. But an increase of overtime from 300 to 301 hours would be worthless, for at that point the possible rounder output would exceed the capacity of the bounder.

In short, linear programming may be applied not only to finding the best program within given restrictions but also to assessing the advisability of changing the restrictions themselves.

The hypothetical problem outlined in this article was simplified to illustrate some of the basic elements of the technique. In any real-life problem the factors at play are both more numerous and more difficult to identify. It is as important to locate the truly pertinent factors as it is to construct the correct mathematical model for dealing with them. The application of linear programming is full of pitfalls. To evaluate the various features of a problem and determine which should be included in the model requires understanding collaboration between the mathematical analyst and the operations people actually working at the job.

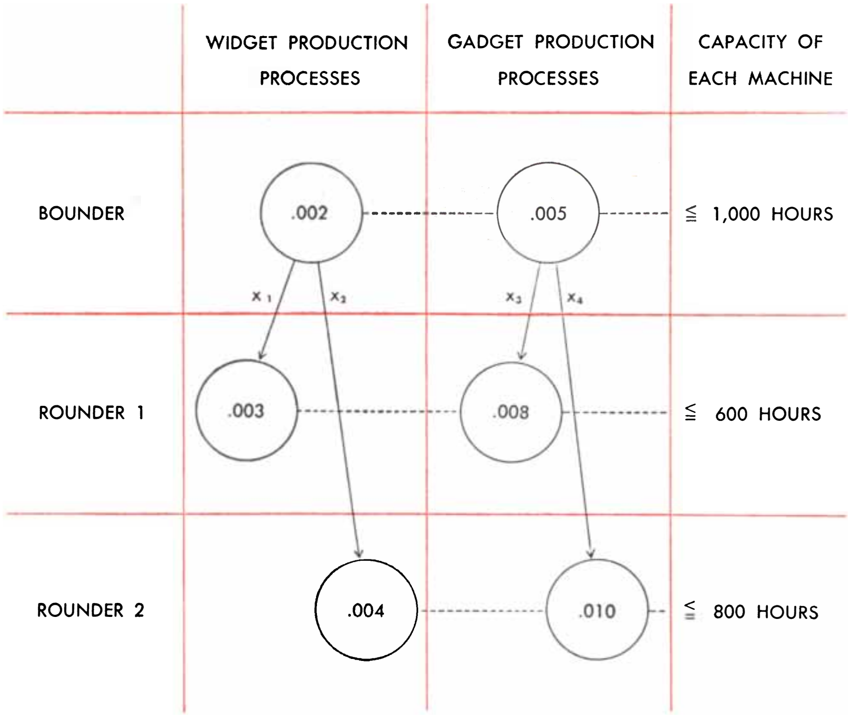
The range of problems to which linear programming may be applied is very wide. As we have already indicated, the Air Force has employed it in problems of logistics. In industry the method is solving problems not only in production but even in such matters as devising the most effective salary pattern for executives—a pattern which will not only meet competition for their services from outside but will also avoid inconsistencies within the company.

Through the dual theorem, linear programming has been related to the theory of games; it is thereby enabled to take probabilities as well as known restrictions into account. It also has fundamental, though indirect, connections with statistical decision theory, which the late Abraham Wald related to the theory of games shortly before his recent death in an airplane crash. All three of these disciplines are contributing to one another's progress. Indeed, our own chief interest in linear programming is to develop generalizations which will enlarge the scope of the technique.

It has been highly satisfying to us to see how often research on a particular problem has led to methods of much more general application, sometimes in altogether unexpected fields. For instance, the work we did in adapting linear programming to the problem of the executives' salary schedule opened a new path for studying the field of statistical regression and correlation analysis. Similarly, an investigation of certain problems in economic measurement and management science has paved the way for new approaches in totally unrelated fields of work in engineering and physics, such as plasticity and elasticity.

As research on these new tools of scientific analysis continues, we can expect to find many new uses for them. But what is perhaps most remarkable is the great and continuing revolution that science and technology have wrought in mathematics. As the mathematician and writer Eric Temple Bell has said in his book *The Development of Mathematics*:

"As the sciences . . . became more and more exact, they made constantly increasing demands on mathematical inventiveness, and were mainly responsible for a large part of the enormous expansion of all mathematics since 1637. Again, as industry and invention became increasingly scientific after the industrial revolution of the late 18th and early 19th centuries, they too stimulated mathematical creation. . . . The time curve of mathematical productivity [shoots up] with ever greater rapidity. . . ."



GRAPHIC MODEL depicts the restrictions on production of "widgets" and "gadgets" by three machines: one "bounder" and two "rounders." The numbers in the circles indicate the fraction of an hour required for each machine to perform its function on each part.

BOUNDER	$.002x_1$	+	$.002x_2$	+	$.005x_3$	+	$.005x_4$	≦ 1,000 HOURS
ROUNDER 1	$.003x_1$	+			$.008x_3$			≦ 600 HOURS
ROUNDER 2			$.004x_2$	+			$.010x_4$	≦ 800 HOURS

ALGEBRAIC MODEL of the same conditions represents as x_1, x_2, x_3 and x_4 the numbers of items produced by the processes indicated by arrows in the graphic model. The blank spaces in each column can be disregarded because they represent zero in each case.

BOUNDER	$.002x_1 + .002x_2 + .002x'_1 + .005x_3 + .005x_4 + .005x'_3$	≦ 1,000 HOURS
ROUNDER 1	$.003x_1 + .008x_3$	≦ 600 HOURS
ROUNDER 2	$.004x_2 + .010x_4$	≦ 800 HOURS
ROUNDER 1 (OVERTIME)	$.003x'_1 + .008x'_3$	≦ 200 HOURS
CONTRACT	$x_1 + x_2 + x'_1$	≧ 450,000 WIDGETS

COMPLETED MODEL is based on the assumption of additional capacity for one of the machines. This is overtime on rounder 1. Now two new processes are introduced: x'_1 and x'_3. The sign before 450,000 widgets means at least this number must be produced.

Artificial Internal Organs

The artificial kidney has been widely used when the natural organs are temporarily unable to do their work. Now several machines are being developed to replace the heart and lungs

by Peter F. Salisbury

Ever since men began to understand the workings of the human body it has been the dream of physicians to replace degenerated or sick organs with young and healthy ones. In 1628, the same year that William Harvey's work on the circulation of the blood appeared, an Italian doctor named Giovanni Colle wrote: "If a man in his old age had but the eye of an adolescent, would he not see like the adolescent? Would he not feel and reason like a youth if he had the heart and brain of a youth? Likewise, if he obtained the blood of a youth he would live like the youth."

Alas, successful transplantation of healthy organs from one person to another seems even more remote in the 20th century than it did in the 17th. It is not so much that the surgery is difficult, but we have learned that the tissues of every human being are unique.

Mammalian tissue is endowed with a large number of antigenic factors, which may be combined in millions of different ways; this is the biochemical basis of individuality. Because of the biochemical differences among individuals, even as simple a tissue as skin tends to atrophy when transplanted; it will not "take" permanently. Until the biological and immunological factors which affect survival of transplanted tissues are known, the transplantation of entire organs will not be possible.

Physicians long ago realized that if they could not provide the body with new "spare parts," they might accomplish some benefit by supplying a sick patient with healthy blood. Apparently the first cross transfusion ever attempted was performed in 1492 on the person of Pope Innocent VIII. The experiment, using three boys as donors, ended in disaster for all concerned—and the Pope's physician, Abraham Meyre, fled for his life. The physician must have been prompted to his experiment by some notion about the magical powers of blood, for nothing was then known about its qualities or functions. He was obviously, however, a man far ahead of his time. Since the blood is the transport system that circulates nourishing substances, building materials and waste products to and from the tissues of the body, the task of the internal organs is essentially the chemical modification of blood. When the blood of a sick person is passed through the circulatory system of a healthy donor of the same blood group, the donor's organs will make all the needed modifications automatically and perfectly.

A technique of cross transfusion which can be applied in human beings was developed in 1948 in the author's laboratory at the Cedars of Lebanon Hospital in Los Angeles. Cross transfusions have been carried out successfully in some 200 known cases in various countries. Giuseppe Vecchietti of Italy has used it to treat patients seriously ill of kidney disease and toxemia of pregnancy. Clarence W. Lillehei and Morley Cohen of the University of Minnesota have employed it to take the place of the patient's heart and lungs during heart surgery.

Although the therapeutic possibilities of cross transfusion are tremendous, the process is not yet without danger. Modern medicine has returned to the dream of replacing sick organs with healthy ones, albeit in artificial form. Thanks to the new materials made available by technology, it has become possible to create machines which can perform the functions of some of the natural internal organs.

The organs with which we may become concerned are the heart, lungs, liver and kidneys. Except for the heart, which is a pump, all these organs have much the same general kind of function: to maintain the body's balance of vital substances. They remove waste products and supply proper proportions of oxygen, sugar, minerals, hormones, proteins and so on to the blood. What an artificial internal organ machine must do is remove blood from the body, pump it through the machine circuits, add or remove specific substances and then conduct it back into the patient's circulation.

The mechanical problem of circulation at once confronts us with difficulties. We have first the problem of coupling the blood vessels to the artificial organ. When, as in an artificial kidney, the blood flow need not be large, plastic tubes inserted into the arteries or veins will suffice. But when the blood has to be circulated at a rapid rate, the flaccid walls of the great veins may collapse and block the intake openings of the tubes. In operations on the heart the entire flow of blood from the veins must be bypassed around it, and in the case of a human adult this means that more than a gallon of blood must be withdrawn every minute. The problem of preventing the blockage of the tube openings has been solved by the invention of special catheters with arches or coaxial tubes to hold the vein walls open.

Next there is the matter of the tubes themselves. The natural blood vessels have a lining which inhibits clotting and does not react with the blood cells or the plasma proteins. But almost any material that we may use to line the tubing and walls of our machine will act on the blood in some way and tend to denature its proteins. The best lining material that has been found so far is a nonwettable substance such as silicone coating or certain plastics. Human blood has been circulated through such a system as many as 60 times without harm. But chemists are still searching for a better lining material.

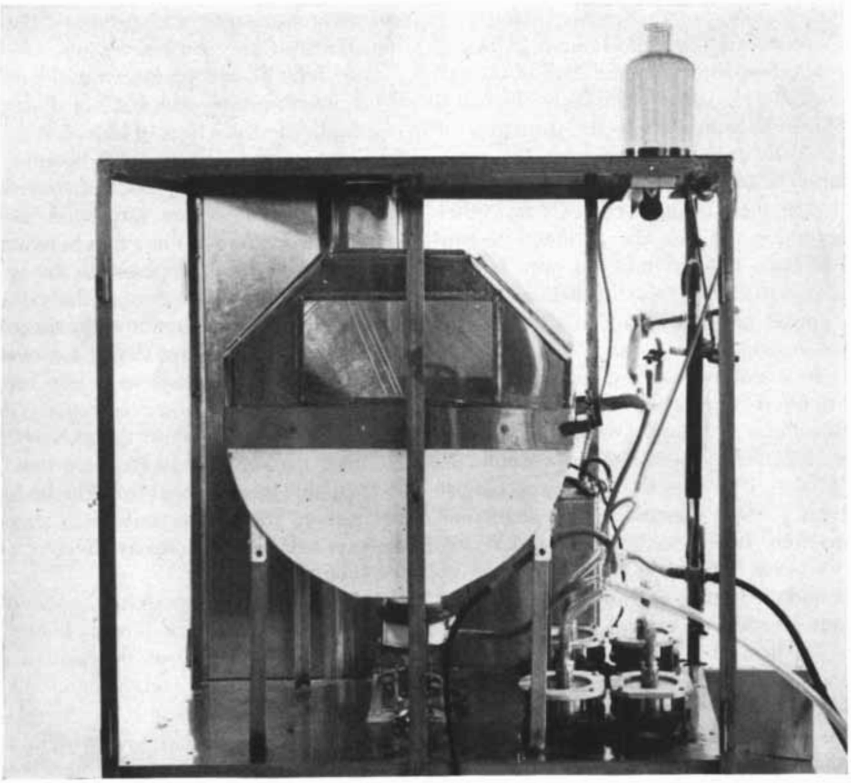
To keep blood flowing we must prevent it from clotting. Ordinarily it would clot within a few minutes after it left the body; this means that we must add heparin or some other anticoagulant when it enters the machine. We must also make the blood circuit as short and smooth as possible, for excessive turbulence of flow would injure the cells and platelets, and any blind alleys or recesses where the blood stagnated would promote clotting.

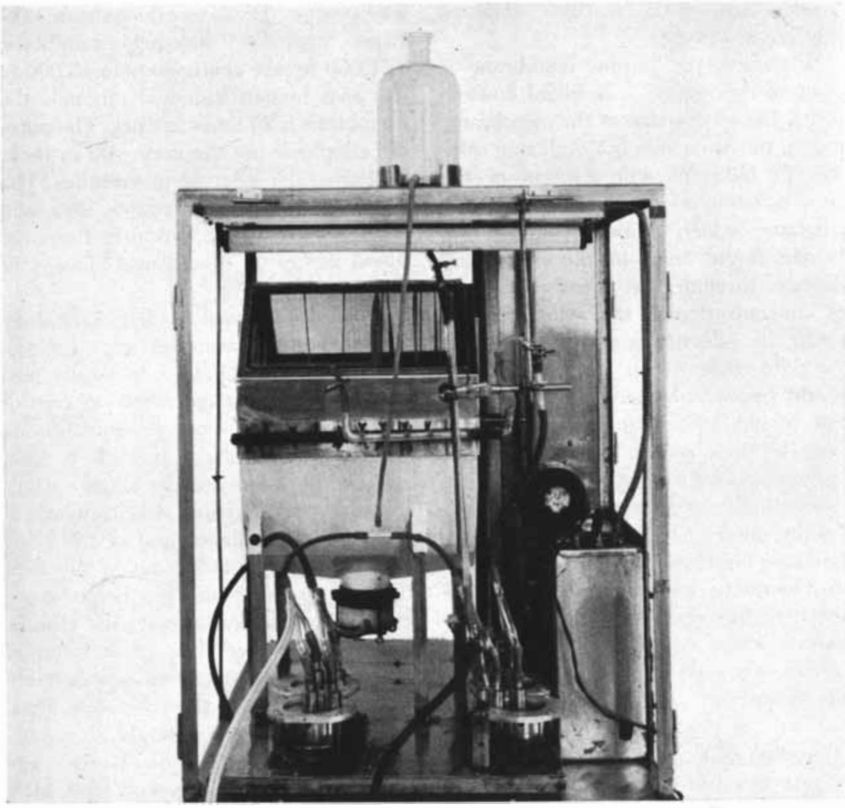
The requirements for the pump that drives the blood through the machine are especially finicky. The pump should not crush the blood cells or denature the proteins, should be sealed to keep out microbes in the air, should have no recesses where the blood might stagnate, should be made of easily cleaned or sterilized plastic or siliconed materials, should not create too much turbulence and should interpose no moving parts such as valves into the bloodstream. It is easy to see that a pump with these specifications cannot be simple. The one instrument that satisfies all the criteria is a pump invented by Vecchietti. A modification of it has been developed at the Cedars of Lebanon Hospital.

Blood that has passed through conduits and pumps and been subjected to rapid fluctuations in pressure often contains emboli—small gas bubbles or cell clumps. Various bubble traps and filters have been designed to eliminate these hazards before the blood is reinjected into the patient. Relatively large bubbles are easily removed in a widened section where the flow slows down enough to allow the bubbles to rise to the surface. But the very small bubbles of the so-called "oxygen mist" are more difficult. They can be eliminated by baffles coated with antifoam or in a "flowing film" trap in which the blood is drawn out in a thin film and flows down an inclined plane, where the small bubbles rise to the surface. As for the emboli, they can largely be prevented by the use of sufficient anticoagulant.

So much for the general features of these machines; now let us look at the two types that have been most fully developed—the artificial kidney and the artificial heart-lung.

The kidney has many functions, of which the task of eliminating waste ma-





EXPERIMENTAL HEART-LUNG MACHINE was designed by Clarence Dennis and Karl E. Karlson of the State University of New York College of Medicine. Here it is shown from two sides. The heart is the four cylinders at the bottom of the machine. The lung is a system of rotating screens in the large tank near the top of the machine. The blood is oxygenated as it flows over the screens in a thin film. At the top is a bottle to handle overflow. Other experimental heart-lung machines have been built by Leland C. Clark of Antioch College, by John H. Gibbon, Jr., of Jefferson Medical College, by Salisbury and by others.

terials is only one. Besides taking care of waste disposal, the human kidney is concerned with the regulation of the salt and water balance in the body, the metabolism of amino acids, the formation of red cells in the bone marrow, the regulation of blood pressure, the transformation of short-chain fatty acids and other activities. So far the artificial kidney has been able to take on only two of the natural organ's functions—waste disposal and regulation of the salt and water balance.

In a natural kidney, waste products are filtered out of the blood by means of membranes through which some substances diffuse while others do not. As early as 1912 the U. S. pharmacologist John J. Abel constructed an ingenious machine which imitated these filtering functions. He made the membrane of collodion tubing and for his anticoagulant he used an extract from the heads of leeches. Abel demonstrated that urea and other waste products would diffuse from the blood through the pores of the membrane into the salt fluid surrounding it. This observation forms the basis for the artificial kidney; the actual development of the machine involved only engineering.

Nowadays the porous membrane is made of cellophane. The blood flows in a thin film on one side of the membrane, and on the other side is a dialyzing solution (a balanced salt solution of the same osmotic pressure). Any diffusible substance which is more concentrated in one liquid than in the other will migrate through the membrane until its concentration is the same in each liquid. By selecting a dialyzing fluid of the right composition, one can remove or add various substances to the blood at will, within limits (*e.g.*, the plasma proteins, the hemoglobin molecule, viruses and bacteria are too large to pass through a cellophane membrane). Blood from a healthy donor may itself be used as the dialyzing fluid: since normal blood is the most perfectly balanced dialyzing solution possible and contains many substances which might be of benefit to a patient, we may yet hear more of this possibility.

The first man to build an artificial kidney suitable for use in human patients was W. J. Kolff of the Netherlands. He made it during the German occupation, when the plastic materials, stainless steels and other items we now take for granted were not available to him. In spite of these handicaps he was able to perfect his machine and to use it with encouraging results in treating sick people. His machine consists essentially of a long tube of cellophane wound on a drum which rotates in a bath of dialyzing fluid. The Kolff type of kidney is still the most widely used. In 1950, however, Leonard T. Skeggs and Jack R. Leonards of Ohio developed an improved machine. The blood flows in a film between two sheets of thin cellophane in the opposite direction to the flow of dialyzing solution on the opposite side of the sheets. Its great advantages are that it removes excessive water as well as waste materials and that the observer can see at a glance how much fluid the body has absorbed from the machine or how much the machine has removed from the body. Per unit of membrane surface, a sheet dialyzer can be five times as effective as the tube dialyzer.

It is interesting to compare the size of these machines with the human kidney. A man's kidney is about the size of a fist; the two kidneys weigh about 300 grams. On the other hand, the Skeggs-Leonards artificial kidney, which is comparatively compact as such machines go, takes up eight cubic feet and weighs 200 pounds. However, it has about the same area of filtering membrane (21,000 square centimeters to 18,000 in the two human kidneys), though the membrane is 25 times as thick. The pores of cellophane are the same size as those in glomerular filtering membranes. The artificial kidney can remove urea and certain other waste products from the blood as fast as the natural kidneys or faster.

The clinical use of the artificial kidney is no longer considered experimental. With a good machine it is usually possible to "wash out" 60 to 80 per cent of the accumulated waste products in one six-hour run. It is also possible to treat successfully edema of the lungs, various forms of poisoning and derangements of the acid-base balance and of the body salts. Hemodialysis has saved the lives of many patients and has helped keep comfortable many others with chronic but not fatal renal damage. It is one of the most gratifying experiences in medical practice to see the revival of a patient who has been brought in unconscious, twitching convulsively and vomiting uncontrollably and who, after a run on the artificial kidney, sits up in bed and asks for breakfast the next morning.

The artificial kidney cannot cure kidney disease—but it can buy time, during which the body may repair itself. Ordinarily a person who cannot excrete urine will die within 14 days. One boy who was in this condition was kept alive by an artificial kidney for 82 days.

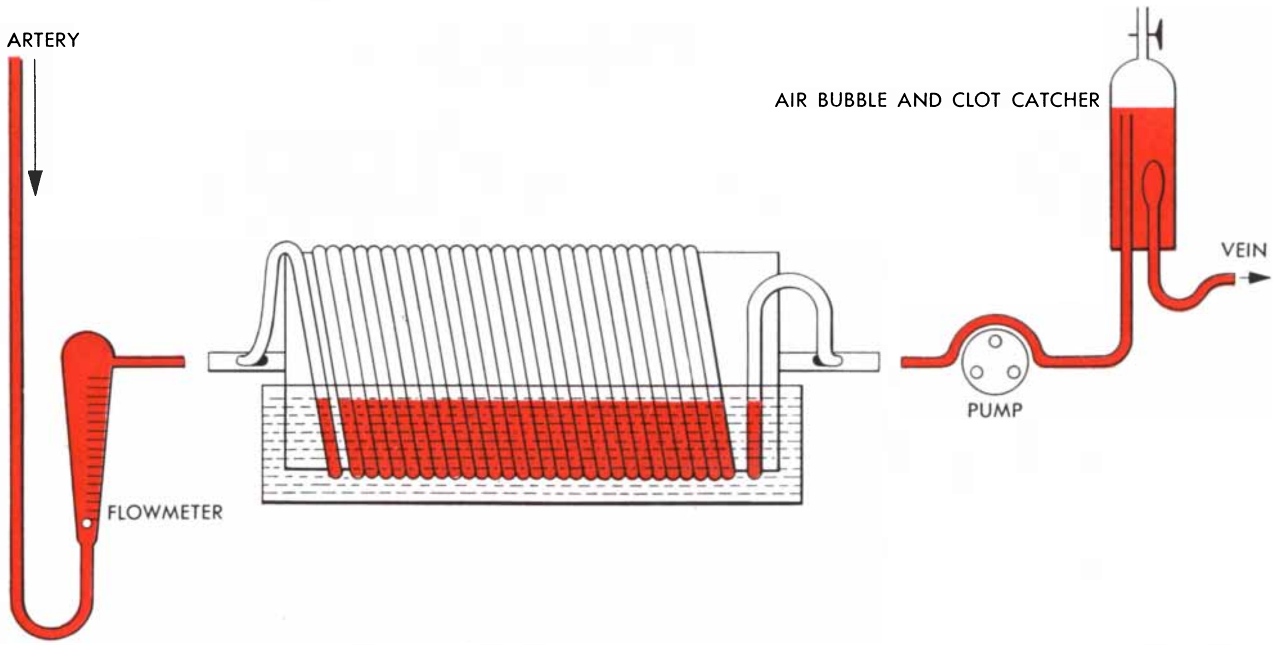
The artificial heart-lung machine is currently exciting much interest because it seems that we are on the threshold of great developments in this field. The reason these two organs must be combined in one machine is obvious: a blood-pumping machine alone would be of no value because the blood must be supplied with oxygen and relieved of carbon dioxide (functions normally performed by the lungs) before it can be pumped into the arteries.

The main problem has been to develop an adequate lung mechanism. To add oxygen and remove carbon dioxide rapidly enough when we are dealing with large volumes of blood (up to about a gallon per minute), the blood must be exposed to the gas atmosphere as a very thin film—no more than about half a millimeter thick. The task of an artificial lung is to spread out from one to five liters of blood per minute in a film covering two to 10 square meters, to expose this film to the oxygen atmosphere under sterile conditions and to collect the oxygenated blood.

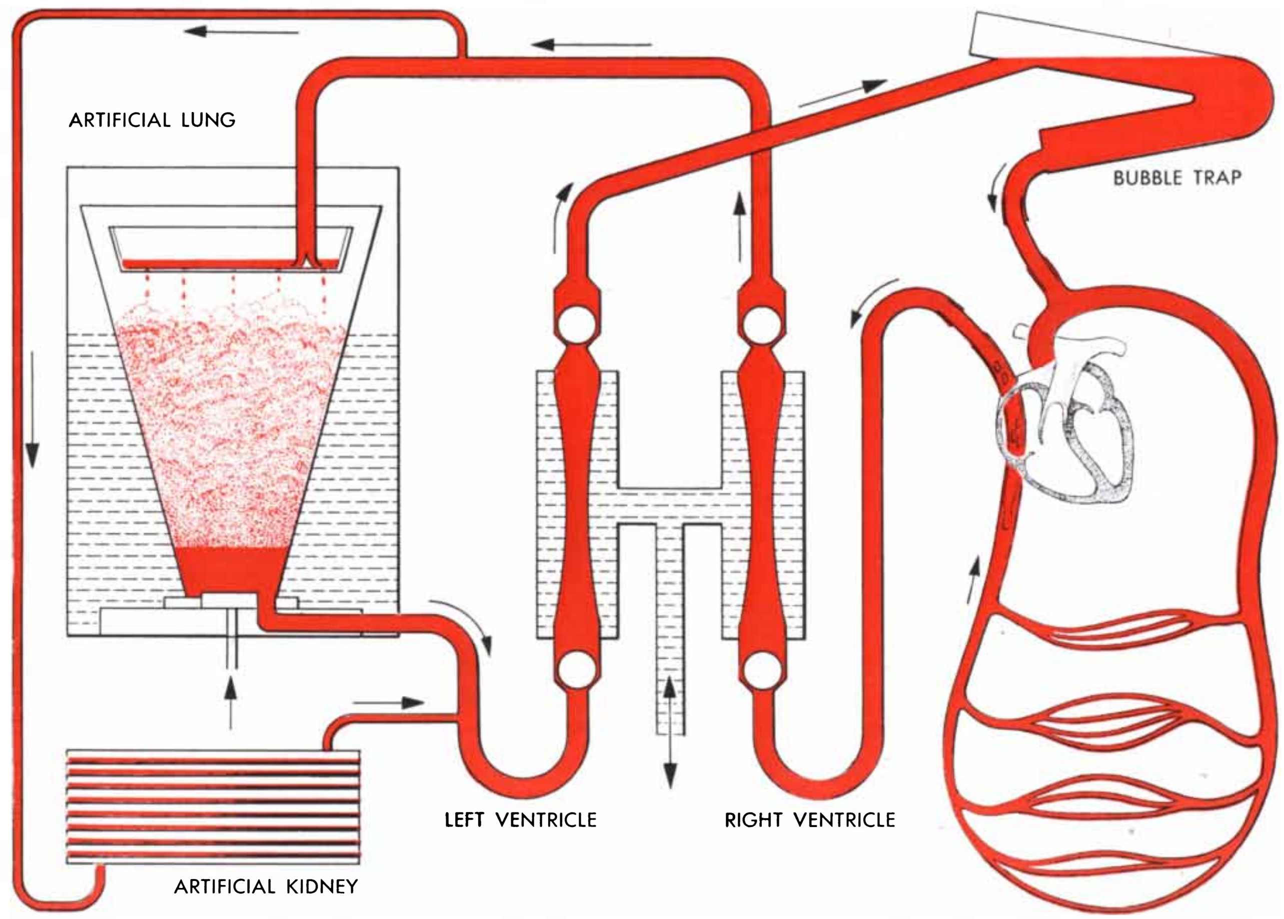
Investigators have tried the most varied approaches to this problem: rotating cylinders; rotating disks or rings partly immersed in a bath of blood; the spreading of blood in a film on the inside of cups or over screens, membranes or in rotating spiral tubes; the dispersal of oxygen directly into the blood in the form of bubbles. The best artificial lung now available drops blood on a cushion of blood-oxygen foam, where the blood rivulets film out between the gas bubbles. This principle, introduced by Russell A. Waud of the University of Western Ontario, does away with wettable surfaces and promises an artificial lung which can be used for long periods.

A reliable heart-lung machine would be of great value not only in heart surgery but also for treating coronary occlusions, heart failure, shock, pulmonary edema and other critical conditions. An auxiliary circulation could take over part of the heart's work, allowing it to rest for a while and heal. For this purpose we would not need as large a machine as for heart surgery.

One may confidently predict that the next few years will see artificial heart-lung machines which can be used in human patients for days at a time. Permanent artificial organs—the old dream—are a problem which we must leave to future generations.



ARTIFICIAL KIDNEY designed by W. J. Kolff consists mainly of a rotating drum (*center*) wrapped with cellophane tubing. The bottom of the drum is immersed in salt solution. As the blood flows through the tubing, the urea in it filters through the cellophane into the salt solution. Before the blood is returned to the body, any bubbles or clots that have formed in it are removed.



HEART-LUNG-KIDNEY MACHINE built by Salisbury oxygenates blood by dropping it into a constantly renewed froth of blood and oxygen in the large cone at the left. The heart consists of two rubber tubes (*center*) which are regularly squeezed by an increase in the pressure of the water around them. Part of the blood is cycled through a kidney which consists of a series of permeable sheets.

The History of a Peruvian Valley

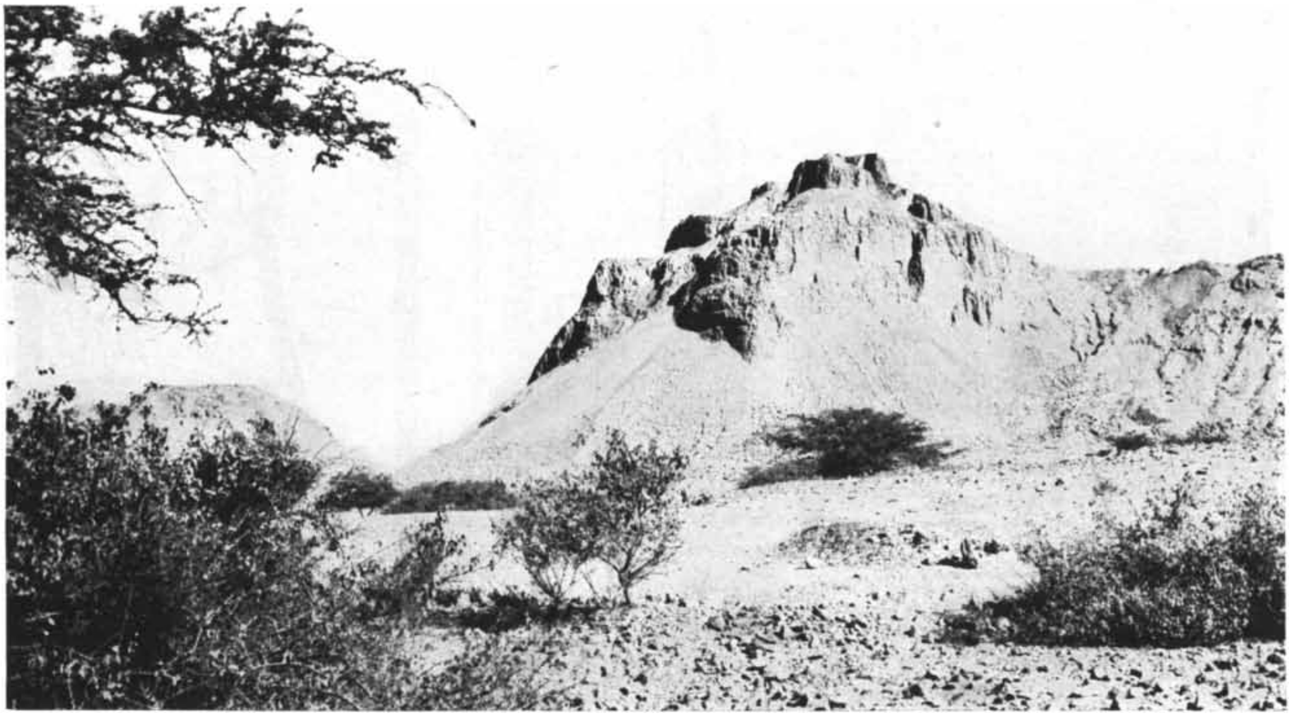
For 4,500 years the tides of civilization and conquest have flowed across the Virú Valley. An account of how its history was reconstructed by an intensive archaeological expedition

by James A. Ford

From the foothills of the high Andes facing the coast of northern Peru a river named Virú flows down a gently sloping valley into the Pacific Ocean. This little valley, some 20 miles long and nine miles wide at its broadest, where it fronts the sea, is typical of the many valleys that slice across the narrow coastal plain between the mountains and the sea in northern Peru. In that otherwise arid land, the small irrigated valleys have been oases of human settlement for thousands of years. Each valley has its own life and history—a history perhaps as old as the settlements where civilization began in the ancient Mediterranean world.

Today the Virú Valley is a rather conventional farming community of 8,000 people with a mixed Indian and Spanish culture, now beginning to be affected by the impact of the jeep and the juke box. Only some half-buried ruins suggest its more powerful and abundant past. The Virú Valley, indeed, was once as rich and fertile as the valley of the ancient Nile—a proud builder of great temples, fortifications and the wealth of empire.

Partly because of the glamor of the Incas, partly because of the gold buried in its prehistoric tombs, Peru has been a diggers' paradise ever since the Spanish adventurers discovered it. In our century serious archaeologists have collected and carefully studied Peruvian artifacts going back for thousands of



BRICK FORTIFICATION towers above the floor of the Virú Valley. Known as the Castillo de Tomaval, this imposing adobe structure was built during the Gallinazo period of about A.D. 100 to 800 and used during the Mochica period of about A.D. 800 to 1000.

years. But the finds were not systematically related to one another; some of the interpretations of them were clearly wrong. Several years ago the time seemed ripe to attempt an orderly retracing of Peru's prehistory. To organize and relate the known facts and to fill gaps in the history, a group of archaeologists decided to make a concentrated investigation of the history of a single valley, and they chose to study the Virú.

The day when the archaeologist, preferably equipped with beard and beautiful daughter, set off on solo expeditions has long passed. Nowadays archaeologists almost always work in teams, usually under the direction of an institution. Our group was a team of specialists from various institutions organized on a cooperative basis. We undertook to carry out in one season a program which would have taken a single investigator many years. Ten scientists made up our party—seven archaeologists, two ethnologists and a geographer. Coming together from eight different institutions, they formed an expedition under the auspices of the Institute of Andean Research, a scientists' "holding company" set up many years ago for just such cooperative projects.

The geographer was Webster McBryde of the Smithsonian Institution; the ethnologists were Allan R. Holmberg of Cornell University and Jorge C. Muelle of the Institute of Ethnology in Lima; and the archaeologists were Junius B. Bird of the American Museum of Natural History, William Duncan Strong of Columbia University, Clifford Evans, Jr. (now of the U. S. National Museum), Donald Collier of the Chicago Natural History Museum, Wendell C. Bennett of Yale University, Gordon R. Willey, then of the Smithsonian Institution, and the writer.

The group divided the investigation into a number of assignments—the geography of the valley and present use of the land, the culture of the present inhabitants, the various periods in the valley's history, the evolution of its pottery, the ancient building sites and so on. During its single season of field work (1946) the survey party systematically examined more than 300 sites.

The several investigators have already published separate reports on their work; this article will outline the integrated history of the valley as we were able to reconstruct it from the artifacts and the remains of ancient structures.

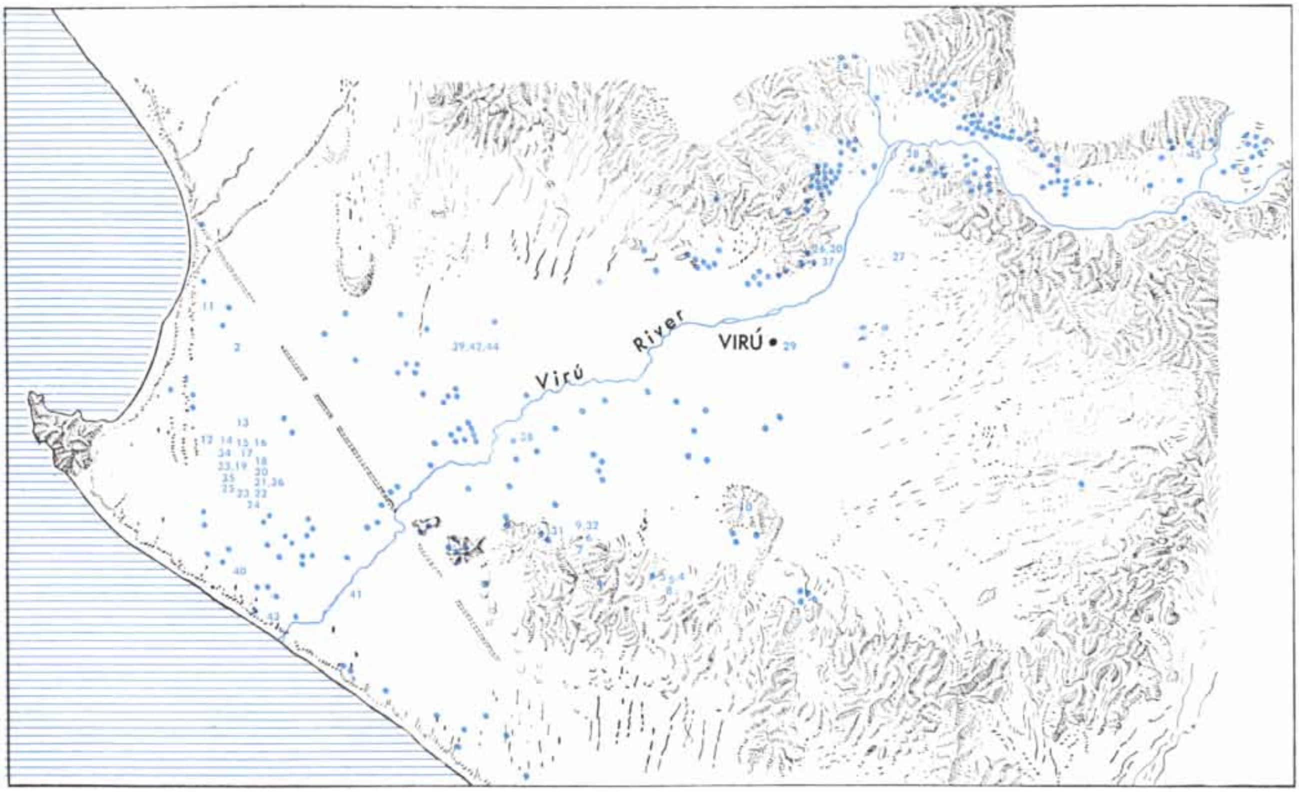
Irrigation by the river water is the dominant fact of life in the Virú Valley; it was responsible for the beginnings of social organization among the early peoples and still shapes the community pattern today. The upper part of the valley, which has first chance at the precious irrigation water, is occupied by a family-owned sugar plantation, Hacienda Tomaval. The central part is a community of small farms, centering in a village named Virú. The lower part near the sea, receiving the smallest share of irrigation water, is the property of a corporation-owned plantation, Hacienda Carmelo, which is worked by sharecroppers who raise corn and cattle.

VIRU RIVER flows into the sea in northern Peru. Chan Chan was the Chimu capital; Wari, the Tiahuanaco; Cuzco, the Inca. The Mochica capital was probably in the Chicama Valley.

Of the valley's earliest history little evidence remains. Near the sea were found three sites of human habitation which apparently belong to a period beginning about 2500 B.C. In the small mounds constituting these sites are curious underground houses with mud-plastered walls. The evidence suggests that no more than a few hundred people inhabited the valley at that time. Away from the shore the valley floor probably was covered with an almost impenetrable forest of thorn bush.

From finds in a well-preserved site of the same period in another valley north of the Virú, it was possible to learn more about these early Peruvians. They were already practicing agriculture, growing cotton, gourds, squash, beans and aji pepper. They wove cotton fabrics and made baskets; they caught fish and other food in the sea; they cooked with stones heated in the fire; they made crude stone hand axes and knives. But as yet they had no pottery.

Pottery first appears in the Virú Val-



VIRU VALLEY is 20 miles long and nine miles wide at its broadest. The sites investigated by the expedition are indicated by colored dots. The principal sites are labeled with numbers. Number 1 is Huaca Prieta, a pre-ceramic refuse mound and cemetery. Numbers 2 to 7 are Guañape middens and rock-walled houses. Numbers 8 to 11 embrace a Puerto Moorin village, a midden with an adobe building and a midden with a cemetery. Number 10 is the Bitín hilltop fortress. Numbers 12 to 28 are the chief Gallinazo sites, including middens, dwelling construction mounds, pyramids, refuse mounds and cemeteries. Number 26 is the Castillo de Tomaval (*see page 28*). Number 28 is the Castillo de Sarraque, another vast adobe fortress complex. Numbers 29 to 33 are Mochica castillos and cemeteries. Number 30 denotes the Mochica habitation of the Castillo de Tomaval. Number 31 is the main Mochica complex called Castillo de Huancaco; it is a pyramid-dwelling-administrative center with fortifications. Number 32 denotes Mochica burials in Puerto Moorin structures. Number 33 indicates the Mochica habitation of a Gallinazo pyramid. Numbers 34 to 39 are Tiahuanaco middens, cemeteries and compounds. Numbers 38 and 39 are great rectangular enclosures. Numbers 40 to 42 are Chimu compounds. Number 42 indicates the Chimu phase at 39, a compound showing vestiges of all the ceramic periods of the valley. Numbers 43 to 45 are Inca compounds. Number 44 is the Inca phase at compound 39. The dotted lines mark the course of the Tiahuanaco highway.

ley about 1200 B.C. At first it was a plain, undecorated ware of simple shapes; later it took on the more definite character of a culture known as the Chavín complex, which was spreading over all of northern Peru, probably from Central America. The central element of the Chavín complex seems to have been a religious cult featuring a ferocious-looking cat-god with prominently displayed incisor teeth. This demon was to haunt the cosmology of the ancient Peruvians for the next 2,000 years; it is elaborately depicted on their ceramics and textiles over that whole period.

The Chavín influence introduced into the Virú Valley mirrors, finger rings, elaborately carved stone objects, gold-working techniques and the custom of placing rich offerings with the bodies of the dead. It also brought an important economic asset—corn. Doubtless it was this improved food supply that gave rise to the first villages in the valley by 500 B.C. They consisted of 20 to 30 single- or two-room houses, built of stone and handmade adobe. The rooms were small and frequently had rounded corners.

The fact that most of the dwellings and communities were on the flanks of the valley, several miles away from the river, strongly suggests that the people of Virú had already begun to establish an irrigation system. In the next period, ending about A.D. 1, the irrigation system was further developed and agriculture became the economic mainstay. This was a time of rapid increase in population, as is shown by the expansion in the number and size of dwellings. Consisting of small rectangular rooms, built adjacent to one another in an unplanned fashion, the new dwellings were probably occupied by extended families or kin groups. The communities spread over the wide floor of the lower valley.

Along with this marked increase in population came the first signs of broader social organization, at least for purposes of defense. Stone-walled forts were constructed on the crests of six prominent hills along the sides of the valley. A typical one stands atop a steep-sided hill some 800 feet above the valley floor. Within the stone wall encircling the hill's almost flat top, which is about 1,200 feet long and 300 feet wide, are three platform mounds that were the sites of pyramidal temples. They show that the organization of the community had a religious as well as a military basis. The dwellings in the valley during this period tended to cluster around the forts, suggesting that the inhabitants fled to these strong points in times of danger.

In the next period, from A.D. 1 to 800, the Virú culture reached its peak. Its irrigation system was fully developed; its population rose to at least 25,000; the entire valley was brought under the control of a central government. Four great "castillos" were built at strategic localities on rocky spurs in the upper part of the valley. Each castillo consisted of a large pyramidal mound with large adjoining rooms, the whole built of sun-dried bricks. In the lower part of the valley were about a dozen similar large brick pyramids. Along the edge of the cultivated lands were adobe and rock walls to aid in repelling invaders. The Virueños no longer had to flee to distant hilltop forts for protection.

The administrative and population center appears to have been in the open lower part of the valley. Around a great brick pyramid over 80 feet high are clustered the ruins of other pyramids and enormous apartment houses, honeycombed with small, brick-walled rooms. Apparently the rooms were entered from above, for few have doors. Evidently most of the citizens of this city did not live in luxury. There were many other settlements and individual houses scattered throughout the valley. Stone was employed for construction where it was readily available.

This time of the valley's heyday is known as the Gallinazo period, after the name given to its central city. Judging from the amazing amount of labor that was expended on public works, the valley must have been very strictly organized and its inhabitants had little leisure. It is hard to see how their religion could have been much consolation to these over-organized people, for it featured a particularly ferocious-looking version of the cat demon. But it apparently offered the promise of a pleasanter afterlife, for quantities of textiles, gold ornaments and pottery were buried with the dead in extensive cemeteries located outside the irrigated areas. The burial pottery was a fine, specially made ceremonial ware, much superior to the ordinary cooking and eating pots found in the houses. It probably was made by a corps of priest-craftsmen.

During the same period a development similar to that in the Virú Valley was also taking place in the more than 20 other parallel river valleys along the desert coast of Peru [see "The Lost Cities of Peru," by Richard P. Schaedel; Scientific American, August, 1951]. By A.D. 800 they constituted a series of valley states, insulated from one another by the intervening stretches of barren desert. There were local differences in their religions, pottery, architecture and textiles.

This situation of independent neighboring states is quite familiar to students of the history of Neolithic and Bronze Age cultures in the Old World. And, just as in the Mediterranean and in

BURIAL TREASURE of a Mochica dignitary is one of few such deposits which escaped looting. Among the objects are carved staffs and pottery adorned with the portraits of kings.

Mesopotamia, waves of conquest soon began to consolidate the separate communities on the Peruvian coast. From the Chicama Valley, 50 miles north of the Virú, a warrior tribe which has been named the Mochica conquered six of the valleys, among them Virú.

Mochica administrators moved into Virú and began to build a large building at the foot of a mountain mass on the southern edge of the valley. This structure, now called Huancaco, has a brick pyramid at one end and a series of large rooms bounded by massive brick walls extending for 800 feet along the mountain. While its architecture and the sun-dried bricks of which the building is constructed are of the Mochica type, there is a hint that the conquerors were not doing all the work. North of the building was an area about half a mile square, enclosed by high brick walls, which seems to have been a concentration camp housing a labor pool made up of the defeated Virueños. The continued prevalence of Virú houseware throughout the valley shows that the population was not replaced by immigrants.

There are indications that Huancaco was never completed. In any case, the Mochica domination of Virú was soon replaced by a new conquest by mountain people coming from south central Peru. Their culture was related to that of the famous site of Tiahuanaco in Bolivia. Perhaps these mountain people learned political and military organization from the states in the coastal valleys. If so, they learned well—as well as the Vandals learned warfare from the Romans—for about A.D. 1000 they conquered the entire Peruvian coast.

CAT-GOD of terrifying mien was a principal deity worshiped in the Virú Valley, at least from Guañape into Chimu times. This example of a funerary vessel is approximately 10 inches high. It was found in a burial in the chief Gallinazo group (*see map on page 30*).

The conquest of the militaristic Mochica kingdom was probably a rather violent affair, and its effects can be seen in the history of Virú. Not only was there an abrupt change in the ceremonial pottery, but even the everyday household wares soon changed. This probably indicates that the conquerors were shifting and mixing populations. The new population elements brought to Virú black mold-made pottery of types that had been developing to the north.

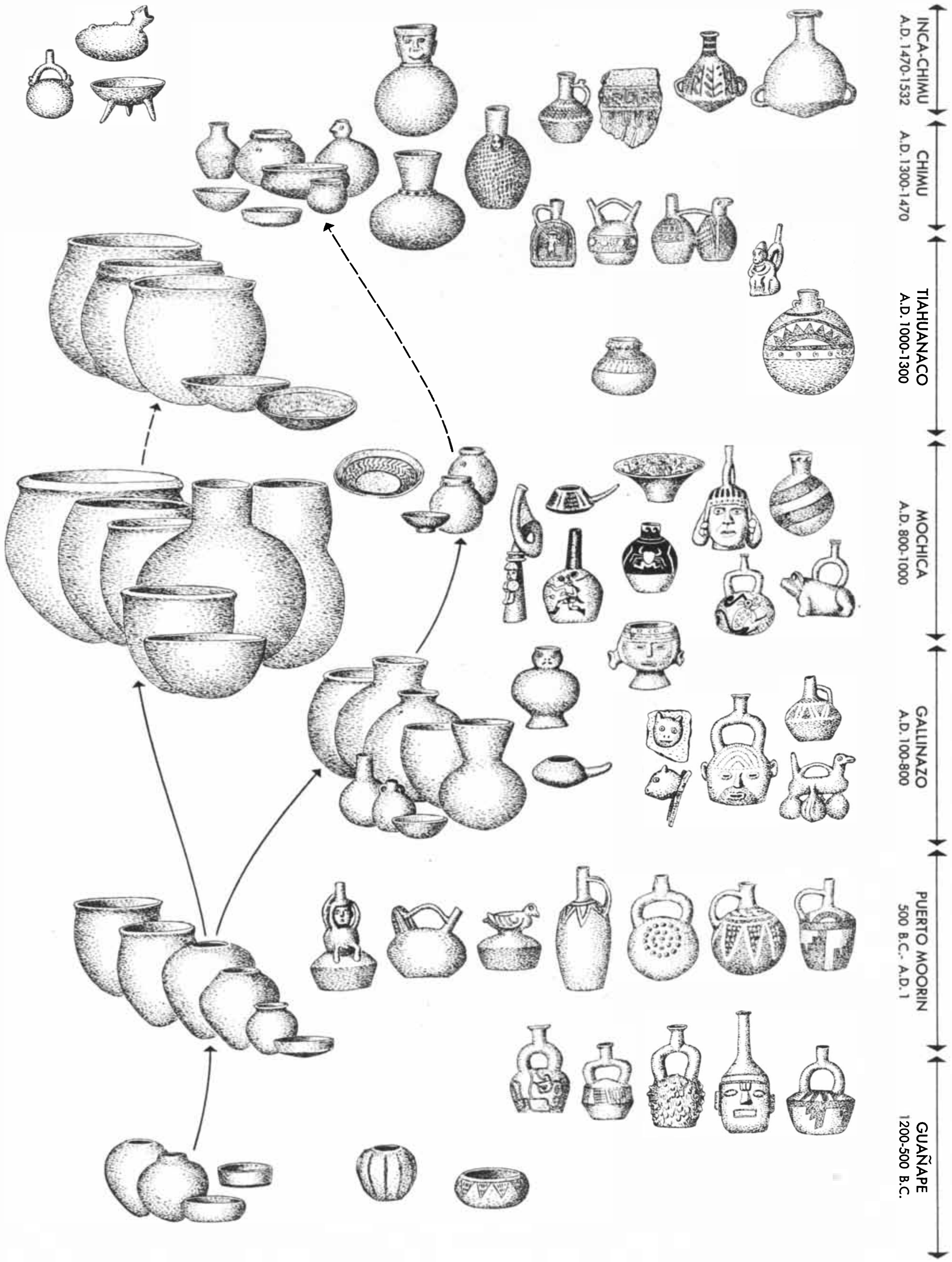
The central city, Gallinazo, had already been abandoned under the Mochica occupation. Now the new conquerors gave up the castillos and other public buildings—though they did not go so far here as they did in Chicama Valley, where they destroyed great brick pyramids over 100 feet high. In Virú they built four high-walled, rectangular compounds, not far from the beach and near the river. These compounds measured as much as 400 by 750 feet, and in them rooms were arranged in an orderly fashion.

During this period, to which the name Tomaval has been assigned, the valley continued to be irrigated over nearly all its practical area; indeed, water appears to have been brought nearer the beach than before. Apparently the population did not decline. The conquerors introduced well-planned houses of a new type featuring several small rooms, perhaps bedrooms, and a large living room. Judging from the architecture, life became a little more comfortable in Virú.

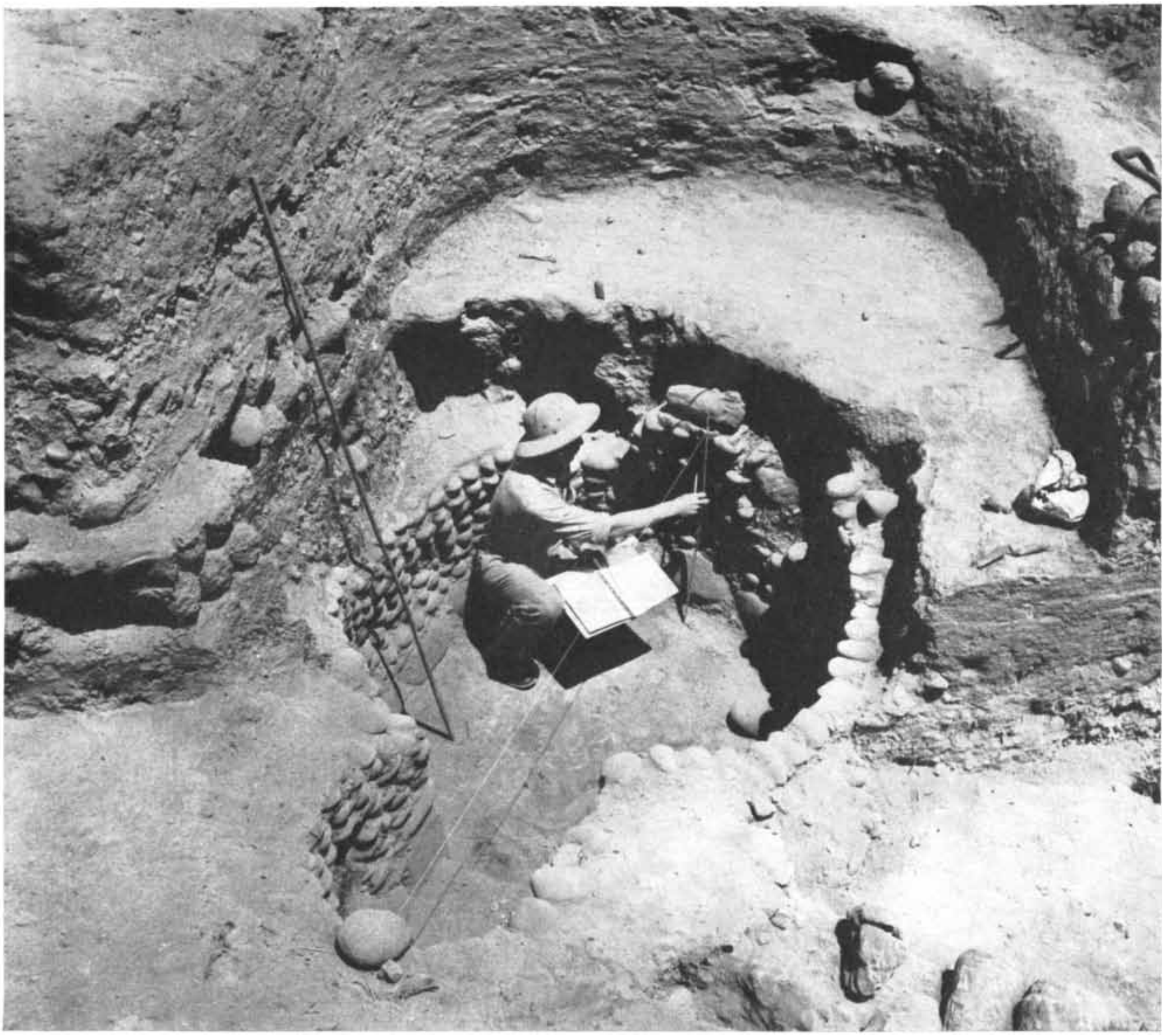
The new rulers built what was evidently a through highway connecting the valleys; it runs straight across the Virú Valley but now loses itself under the sand dunes at the valley border. Adobe walls outline the 30-foot right of way. This is the coastal highway that the Inca later used so effectively to bind their empire together.

The mountain people had learned how to conquer, but their administrative apparatus must have been defective. Their rule lasted only 300 years. About A.D. 1300 the empire fell apart, and part of it, including Virú, was regrouped into a new political unit known as the Kingdom of Chimu. The capital of this kingdom was the great city of Chan Chan in Moche Valley, the next valley north of Virú.

In the period of Chimu domination, Virú did not prosper. Its population decreased markedly; large sections of the



CERAMIC HISTORY of the Virú Valley is represented in this drawing. At the left is shown typical household pottery of successive periods, which are indicated on the vertical scale at right. Some wares tended to persist through several cultures. The more elaborate funerary pottery, shown at the right, is actually smaller in scale than the plain ware. The arrows indicate patterns of development.



DWELLING of the Guañape period was excavated in the Chicama Valley. It consisted of a deep hole, faced with stones picked up on the beach and roofed over with any available material. In its shape and narrow entrance way it resembles the igloo of the Eskimo.

irrigation system were abandoned; and people lived mainly in the upper part of the valley, where they needed only short irrigation canals. There were, however, some settlements near the beach, and they adopted a new method of obtaining water for crops: the people laboriously removed the top three feet or more of soil, from areas as large as an acre, so that plant roots could reach the ground water flowing beneath the surface.

By this time technology had greatly advanced. Excellent and intricately carved wood objects of the Chimu period have been preserved. Weaving, which has a long history on this coast, was at an amazing peak of proficiency, probably unrivaled in any other pre-machine-age culture. Spectacular garments were made of the feathers of tropical birds brought from across the Andes. Gold, silver, copper and bronze were cast and hammered into a variety of ornaments and useful tools. Pottery was mostly mold-made, and apparently was turned out in job lots by specialists. The former distinction between the sacred and household pottery had almost disappeared.

The Virú Valley continued to be a pawn in the struggle for empire on the Peruvian coast. When the Inca tribe came down from the highlands in the 15th century to begin the conquests that were to set up an empire from Chile to Ecuador, its army found the Chimu kingdom its most formidable opponent, but the invaders overran Chimu and swallowed up Virú about A.D. 1470. The valley's population dwindled further. The Inca largely took over: their pottery replaced the existing types; they built at least two strongholds atop peaks in the upper valley. Beside the river and near the beach there is a rather elaborate Inca house, with a walled courtyard enclosing a large pool, which may have been the headquarters of the Inca administrator who ruled the sadly depopulated valley.

The conquest of Peru by Pizarro's army in 1532 marked the end of this remarkable American development. It is interesting to speculate on what might have happened had the Spaniards not come. So far as Peruvian history developed before this outside interference, it paralleled in general outline the development of the Neolithic and Bronze Age states and empires of Asia Minor and the Mediterranean.

Kodak reports to laboratories on:

a new optical element . . . the most sensitive lead-sulfide photoconductive cell available

Axicons

The axicon has been invented. To the lens, the prism, and the mirror—the basic elements of optical design—there has been added the axicon. It could have been invented in 15th-century Florence, or in Restoration England for presentation at an early session of the Royal Society, but it wasn't. It was invented in no garret, but in this bright and shining factory overlooking the Genesee River in Rochester, N. Y., by John H. McLeod, a Kodak optical engineer. This is incredible.

Our times seem far too complex, our science and technology far too advanced for a man to invent anything as simple as the axicon in the sixth decade of the 20th century.

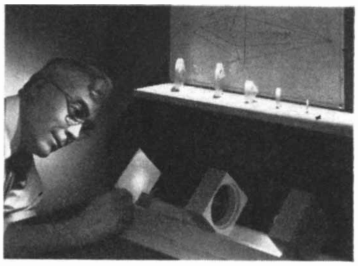
But listen to Doctor McLeod:

"A search for a universal focus lens has led to a new class of optical elements. Probably the most important of them is a glass cone. This class has the common property that a point source on the axis of revolution is imaged to a range of points along the axis. Such elements do not, therefore, have a definite focal length. The word 'axicon,' meaning axis image, has been coined to cover this type of element. [*Note: He had to coin a word. There just wasn't any existing word to serve the purpose.*] Axicons form images only of small, bright objects.

"One application is in a telescope. The usual spherical objective is replaced by a cone. This axicon telescope has no focusing movement but is in focus for targets from a foot or so to infinity. It can simultaneously view two or more targets placed along a line.

"If a light source is added to the telescope with a suitable beam splitter, it becomes an autocollimator. It can do more than an ordinary autocollimator, however, for, in addition to checking the perpendicularity of a mirror, it can simultaneously view one or more targets along the line of sight. [*He means more than "view." At a distance of 100 feet, the position of a target can be determined to .001", and even a non-technical executive has done it. In angle, this means an accuracy of 1/5 second.*]

"A useful form of axicon is a reflecting cone. It will return an image of a point source back to the source over a range of distances depending on the cone design. This form may



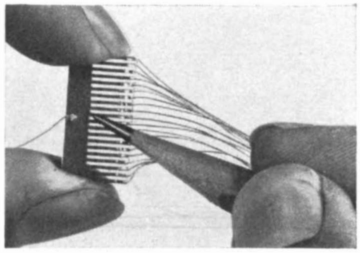
be used for the precision checking of lathe beds and the like, or for checking the flatness of surface plates."

If you would like to use a line of light in space as a tool, get in touch with Eastman Kodak Company, Special Products Sales Division, Rochester 4, N. Y.

Ektron detectors

We are going to stop being coy about it and come right out and say that a certain manufacturer of materials for "chemical photography" whose name appears at the bottom of this page is now also manufacturing the most convenient device for the *electrical* detection of radiant energy.

It is called the *Kodak Ektron Detector*. It is the most sensitive lead sulfide photoconductive cell presently available. Its response to a 2500 K tungsten light source is about the same as that of a red-sensitive gas-filled phototube of comparable sensitive area under comparable conditions. But vibration doesn't bother it, for it consists merely of a prepared surface, operating right out in the open. Even more important, the sensitive surface can be of any size or shape. On the glass slip, in line with the pencil point, the 20 little dots you see here are individual photoconductive cells.



So far you've read only half the story, possibly the less significant half. Though the *Kodak Ektron Detector* competes with the phototube and photomultiplier on their home grounds in the visible spectrum, it reaches its maximum sensitivity at 2μ in the infrared. At 2.7μ, operating at room temperature, it gives a hundred times the response of a good laboratory bolometer. All in all, the useful response extends from 0.3μ in the ultraviolet to 3.5μ in the infrared. Usable frequency response is from steady illumination to 5,000 radiation pulses per second.

Two of the biggest vistas:

1. Rugged, low-cost switching in which light replaces moving parts. Better yet, forget about visible light and operate your source cool enough to last just short of forever.
2. Simple automatic control for the process industries, based on the characteristic near-infrared absorbance bands of your process liquid, gas, or solid. (Even manufacturers of laboratory spectrophotometers have been turning to *Kodak Ektron Detectors* because where else can they get such high gain out to 3.5μ?)

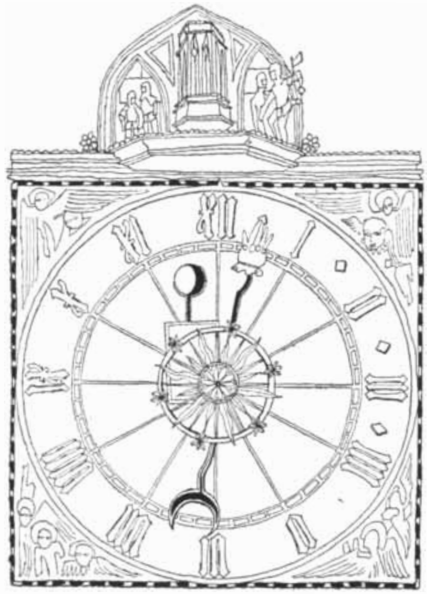
This thing is more than a gleam in our eye. We are in production and can accept orders today. You transact your business with a man named W. F. Swann at Eastman Kodak Company, Rochester 4, N. Y. He can tell you about the various structural types of Kodak Ektron Detectors, *the many sizes and shapes in which we make them, and the story on matched sets and multiple-detector units. Figure from $14 to $24 apiece for the various standard* Kodak Ektron Detectors *you'll need for working out your ideas. We can talk later about quantity prices.*

Prices quoted are subject to change without notice.

This is one of a series of reports on the many products and services with which the Eastman Kodak Company and its divisions are . . . *serving laboratories everywhere*

Kodak
TRADE-MARK

SCIENCE AND



Verdict

The Oppenheimer case last month officially became a closed incident. By a four to one vote the Atomic Energy Commission, like the special Gray board, held J. Robert Oppenheimer to be a security risk and unemployable for any further atomic work in the national defense.

In the Commission, as in the Gray board, the dissent came from the scientist member of the jury. Henry D. Smyth asserted in his dissenting opinion that Oppenheimer's continued employment would "not endanger the common defense and security" but on the contrary would "continue to strengthen the U. S." His opinion presented in sharp focus the disagreement between scientists and the national Administration over the present security system.

The AEC majority ruling against Oppenheimer was based upon a somewhat different emphasis from that of the Gray board majority. The Commission dismissed the criticism of Oppenheimer's lack of enthusiasm for making the H-bomb, asserting that he was "entitled to his opinion." The four members who condemned him—Lewis L. Strauss, Eugene M. Zuckert, Joseph Campbell and Thomas E. Murray—based their decision on what they said were "fundamental defects in his character," and on his Communist associations, which they found "have extended far beyond the tolerable limits of prudence and self-restraint" expected of a man in his position. Murray added that he considered Oppenheimer "disloyal"—defining loyalty as "exact fidelity" to the "security regulations." The Commissioners cited six instances of untruths told by Oppenheimer—the Chevalier incident, the Lomanitz, Lambert, Peters and Weinberg cases and the Seaborg letter incident. They added that "the catalogue does not end with these six examples."

In his dissent Commissioner Smyth insisted that "the only question being determined by the Atomic Energy Commission is whether there is a possibility that Dr. Oppenheimer will intentionally or unintentionally reveal secret information to persons who should not have it. To me this is what is meant within our security system by the term 'security risk.' . . . In my opinion the most important evidence in this record is the fact that there is no indication that Dr. Oppenheimer has ever divulged any secret information. . . . The Gray board reported . . . that Dr. Oppenheimer 'seems to have had a high degree of discretion reflecting an unusual ability to keep to himself vital secrets.' "

Reviewing the majority's citations of untruthfulness, with detailed examination of the testimony, Smyth found the instances "thin" and "singularly unimpressive" as attempts to impugn Oppenheimer's character. The Chevalier incident, he agreed, was "inexcusable," but it was 11 years old and Oppenheimer had amply expiated it. Smyth contradicted the majority's assertion that there were other instances besides the six cited. He said: "Any implication that these are illustrations only and that further substantial evidence exists in the investigative files to support these charges is unfounded." The whole record, he concluded, "destroys any pattern of suspicious conduct or catalogue of falsehoods and evasions, and leaves a picture of Dr. Oppenheimer as an able, imaginative human being with normal human weaknesses and failings. In my opinion the conclusion drawn by the majority from the evidence is so extreme as to endanger the security system."

The day after the AEC decision Oppenheimer's colleagues at the Institute for Advanced Study, of which he is director, affirmed their "complete confidence in his loyalty to the U. S., his discretion in guarding its secrets and his deep concern for its safety, strength and welfare." Earlier the scientific staff at Los Alamos, the American Physical Society, the Federation of American Scientists and many other groups had sup-

THE CITIZEN

ported Oppenheimer and questioned the security system under which he was found unworthy to serve his country.

When Oppenheimer received the AEC verdict, he said that he would not appeal it to President Eisenhower, that he would continue his studies and work at the Institute. He said:

"Dr. Smyth's fair and considered statement, made with full knowledge of the facts, says what needs to be said. Without commenting on the security system which has brought all this about, I do have a further word to say. Our country is fortunate in its scientists—in their high skill and their devotion. I know that they will work faithfully to preserve and strengthen this country. I hope that the fruit of their work will be used with humanity, with wisdom and with courage. I know that their counsel, when sought, will be given honestly and freely. I hope that it will be heard."

Smoking and Mortality

New evidence of a connection between cigarette smoking and higher death rates was reported on both sides of the Atlantic last month. Surveys conducted by the American Cancer Society and by two British physicians showed that cancer and coronary disease claim many more victims among smokers than among abstainers.

In the U. S. study 187,766 men between the ages of 50 and 70 were observed for two and a half years. Among those who smoked a pack a day or more, 745 died during the period. In a comparable group of non-smokers there would have been 319 fewer deaths. Cancer killed 161 of the heavy smokers—98 more than the expectation for non-smokers. Coronary disease killed 344 smokers, 163 above the expectation for non-smokers. In the age range from 50 to 59 the smokers' death rate from all causes was more than 60 per cent higher than that among non-smokers; from 60 to 64 it was 102 per cent higher; over 65, it was 30 per cent higher. Lung cancer was five to 15 times as prevalent among heavy smokers as among those who have never smoked regularly. But smokers had a higher death rate from other types of cancer as well.

The figures were disclosed at a meeting of the American Medical Association by E. Cuyler Hammond and Daniel

Horn, statisticians in charge of the ACS study. They had not expected to make a report so soon, but they found the smokers' death rates so alarming that they decided to publish the preliminary results. Hammond and Horn said that they personally had stopped smoking cigarettes.

Charles Cameron, medical director of the ACS, commented that the smoking picture was "admittedly grim," but said that a cause-and-effect relation has not yet been proved. He also suggested that smokers console themselves by viewing the situation in terms of expectations. At age 50, he pointed out, a non-smoker has about one chance in 100 of dying in the next 18 months. For a heavy smoker the risk rises to one chance in 50.

The British report, published in the *British Medical Journal*, was based on a canvass of 40,000 physicians by Richard Doll and A. Bradford Hill. Among doctors over 35, non-smokers had an annual death rate of 3.89 per thousand, whereas those who smoked 25 cigarettes or more per day had a death rate of 5.15 per thousand. Of 789 doctors who died in a 29-month period, 36 had lung cancer. All 36 were smokers. Doll and Hill also noted an increase in coronary thrombosis among the smokers.

Kalinga Award

Waldemar Kaempffert, science editor of the New York *Times*, is the 1954 winner of the Kalinga Prize for science writing. The award of 1,000 pounds sterling is given by the United Nations Educational, Scientific and Cultural Organizations. Previous winners were Louis de Broglie, French physicist, and Julian Huxley, British biologist.

Kaempffert, who has been with the *Times* since 1927, has written several books on science. He is a former managing editor of Scientific American and former editor of *Popular Science Monthly*.

Impasse as Before

A new set of disarmament proposals has been put forward by the Western powers and rejected by the Soviet Union, it was announced last month. Great Britain, France and the U. S. had proposed a five-step program which would begin with an immediate ban on the use of nuclear weapons except against aggressors and would end with limitation of conventional arms and destruction of all nuclear or other total weapons.

The U. S. proposed that the control organization be called the United Nations Disarmament and Atomic Development Authority. The authority would be charged not only with monitoring the disarmament process, but also with undertaking research and development in peacetime uses of atomic energy.

Representatives of the U.S.S.R. were reported standing pat on their old position: insistence upon an unconditional immediate outlawry of atomic weapons. The Soviet delegate at the talks in London read into the record V. M. Molotov's reply to President Eisenhower's atomic pool proposal of last December. The reply: By "sanctioning" the manufacture of atomic weapons the plan "would play into the hands of aggressive forces."

Science and Selective Service

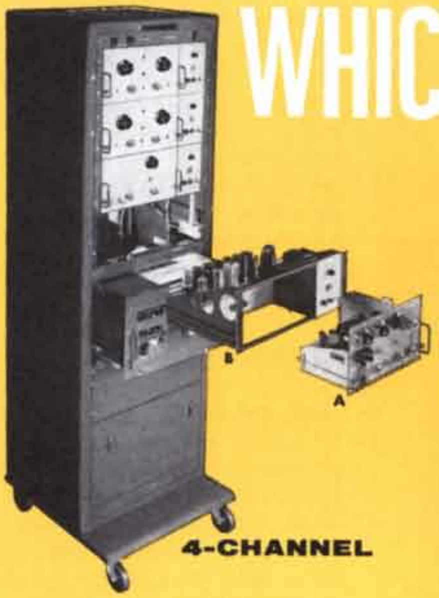
In recent months 8 per cent of all inductees into the armed forces have been practicing scientists and engineers or college seniors who majored in science. Howard A. Meyerhoff, executive director of the Scientific Manpower Commission, adds that the new enrollments in graduate science study dropped almost 4,000 in the past year and 3,500 graduate students had their training interrupted by induction. Only 10,663 received advanced degrees in science and engineering last year.

Meyerhoff's concern over selective service policy for scientists has been echoed recently by other professional groups. The Engineering Manpower Commission estimates that there is a shortage of 35,000 to 40,000 engineers and the shortage is increasing. In a letter to the director of Selective Service, the American Chemical Society recently pointed out that, despite such shortages, scientific deferments are being sharply cut. One state director of Selective Service, the letter said, recently informed his boards that the only scientific personnel to be considered for extended deferment are those making atomic weapons or airplanes to carry them.

Sky Map

The most exhaustive survey of the heavens ever undertaken is about to bear fruit. The National Geographic Society and the Palomar Observatory have announced that the first volume of their photographic sky atlas, covering their Schmidt-camera survey of the sky, will be published next year. When completed the atlas will comprise 879 sections, covering all of the heavens that can be seen from Palomar—about three fourths of the celestial sphere. Each section, photo-

WHICH "150" fits *your* oscillographic recording need?



4-CHANNEL

Sanborn "150" Recording Systems that put to use the original design concept of amplifier interchangeability (illustrated at the left) start with either a four-channel or two-channel standard Basic Assembly, to which the user adds whatever selection or combination of preamplifiers (A) are needed for his recording problem. The standard Basic Assemblies comprise a metal Cabinet, Recorder, and a built-in Driver Amplifier and Power Supply (B) for EACH channel. Presently available Preamplifiers are: AC-DC, Carrier, DC Coupling, Servo Monitor, Log-Audio, and Low Level Chopper.

Advantages common to ALL Sanborn Recorders are: inkless recording (by heated stylus) on plastic coated strip chart paper, and in true rectangular coordinates . . . high torque galvanometer movement . . . time and code markers . . . numerous paper travel speeds.

As a graphic example of the design idea that has brought new versatility to industrial recording, a Carrier Preamplifier (A) is shown above in position to plug into a Driver Amplifier in framework with Power Supply (B) which are normally already in place in the Basic Cabinet Assembly.

The identical design principles of the four-channel system are provided in the two-channel, the only difference being the number of channels.

2-CHANNEL

"150"

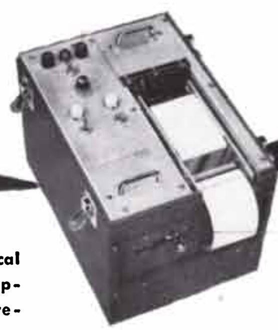
COMPLETE FOUR-CHANNEL SYSTEM FOR USE WITH ANALOG COMPUTERS

This "150" system consists of a Cabinet Assembly, a four-channel Recorder, and *two* dual channel DC Amplifiers. Each amplifier is complete with a common power supply. Each measures and records two separate single-ended signals, at sensitivities between one and one hundred volts per centimeter. The *two*-channel version of this system will comprise Cabinet, *two*-channel Recorder, and *one* dual channel amplifier.

"150"

SINGLE-CHANNEL RECORDER

A compact, lightweight unit for use when only one channel is required — provides permanent, inkless recording in *true* rectangular co-ordinates; *five* paper speeds (5, 10, 25, 50, 100 mm/sec.); *extra* stylus for either manual or remote timing and coding marks. Designed for simple, patch cord connection to *any* of the several "150" preamplifiers (plus driver amplifier and power supply), available soon in portable metal cases.



Ask, also, for a copy of the *Right Angle* — a Sanborn publication devoted to oscillographic recording in industry.

Catalog and technical data on all "150" equipment available on request.

SANBORN COMPANY
Industrial Division
CAMBRIDGE 39, MASS.

graphed with both red and blue plates, will show a portion of the sky about as big as the bowl of the Big Dipper and extending to a depth of 500 million light-years. The pictures are being made by Palomar's 48-inch Schmidt telescope.

Begun in 1949, the mapping project will be finished in 1956. The atlas is to be published in three or four volumes, one appearing each year. The price per set will be between $1,600 and $2,000. Anyone who wants a copy must order it from the Mount Wilson and Palomar Observatories by October 1 of this year.

Irradiated Plastics

Among potential applications of high-energy radiation, one of the more promising is the treatment of plastics. These substances are extremely sensitive to all types of radiation, and, unlike most materials, are frequently improved rather than damaged by its effects. A recent article in *Nucleonics* by A. Charlesby of the British Atomic Energy Research Establishment reviews the current research in the field and indicates some of the industrial possibilities.

At the molecular level, a plastic material made up of long-chain polymers is like a bundle of sticks held together by comparatively small forces. Such a material is soft, soluble and has a low melting point, because the molecular chains readily slide past one another and are easily pulled apart. If stronger and more permanent attachments can be set up laterally between the chains, the substance becomes more rigid and much more resistant to solvents and to high temperatures.

To set up these attachments or "crosslinks" means establishing chemical bonds between core atoms (usually carbon) of different chains. Vulcanization of rubber, for example, is a process for producing crosslinks. Radiation, Charlesby points out, is an efficient way of crosslinking many materials. Electrons, neutrons or gamma rays knock out some of the atoms that normally surround the central atoms of the chains and thus furnish points where two adjacent chains can combine chemically. A few such combinations per molecule are enough to make a big difference in the physical properties of the material. A single fast neutron, Charlesby says, can produce as many as 5,000 crosslinks in a piece of polyethylene. Radiation will convert ordinary polyethylene from a wax-like material to a clear, hard substance which resists temperatures up to 200 degrees centigrade and is virtually insoluble. Irradiated polyethylene is

now being used to make plastic bottles that can be sterilized.

Other polymers such as polystyrene, rubber, nylon, polyvinyl acetate and gutta-percha can be treated in the same way as polyethylene, with similar effects on their properties. Charlesby makes a rough estimate that the cost of radiation treatment with reactor fission products might be as low as five cents per pound of material processed.

Types

A person who dislikes Jews is likely to consider them ambitious, intelligent, aggressive, shrewd, materialistic, efficient and mercenary. The same person, however, will assign these very attributes to Americans in general and to himself in particular. In Jews he finds the qualities distasteful; in the other groups, on the whole, admirable. These are some of the findings of two social psychologists, Gerhart Saenger and Samuel Flowerman, who are doing research on the relation of stereotypes to prejudicial attitudes. They report their study in the journal *Human Relations*.

Saenger and Flowerman take issue with the view that prejudice arises from an uncritical acceptance of a stereotyped, and false, picture of the disliked group. Polling 449 U. S. college students, the psychologists found that the picture of the "typical Jew" is surprisingly like that of the typical American or the typical businessman. Similarly the typical Italian, whom many of the students also disliked, is similar to the typical woman—emotional, artistic, passionate, impulsive and so on.

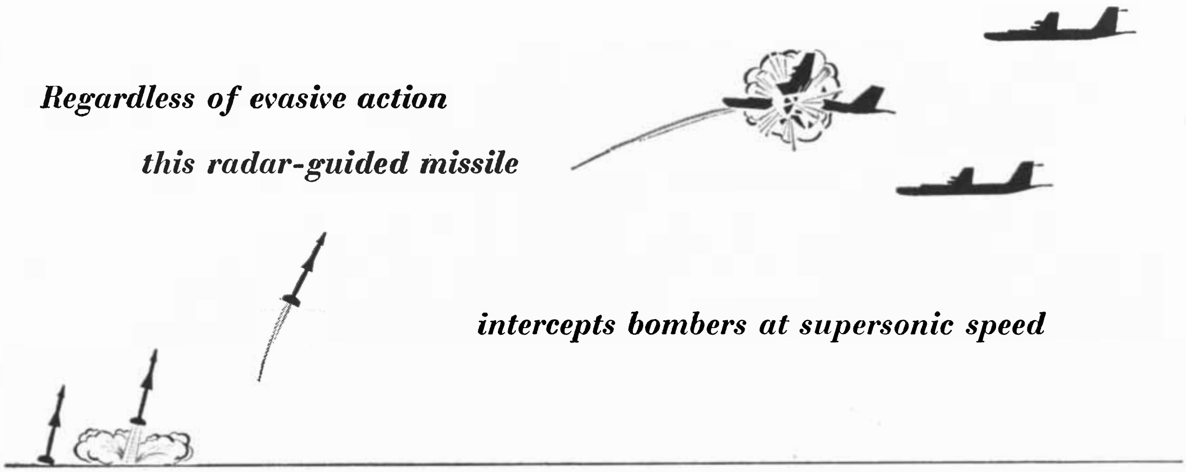
These results, the authors point out, contradict the ethnocentric theory of prejudice—*i.e.*, that people dislike groups whom they believe to be different from themselves. Indeed, the anti-Semitic students, who in general have "authoritarian" personalities, are likely to impute traits such as aggressiveness and materialism to themselves as well as to Jews, and they admire these qualities more than do unprejudiced, democratic personalities.

To show a prejudiced person that his stereotypes are unreal, say Saenger and Flowerman, merely deprives him of the rationalization for his attitudes. This may engender guilt feelings and increase hostility. The authors suggest that if the prejudiced individual can be shown that it is a common tendency to view liked and disliked groups in the same stereotyped way, he may be led to examine his own attitudes more critically and realistically.

Regardless of evasive action

this radar-guided missile

intercepts bombers at supersonic speed



Nike—product of teamwork

Now going into service as part of our nation's air defense system, the Army's *Nike* has already brought down high-flying, radio-controlled bombers during simulated attack.

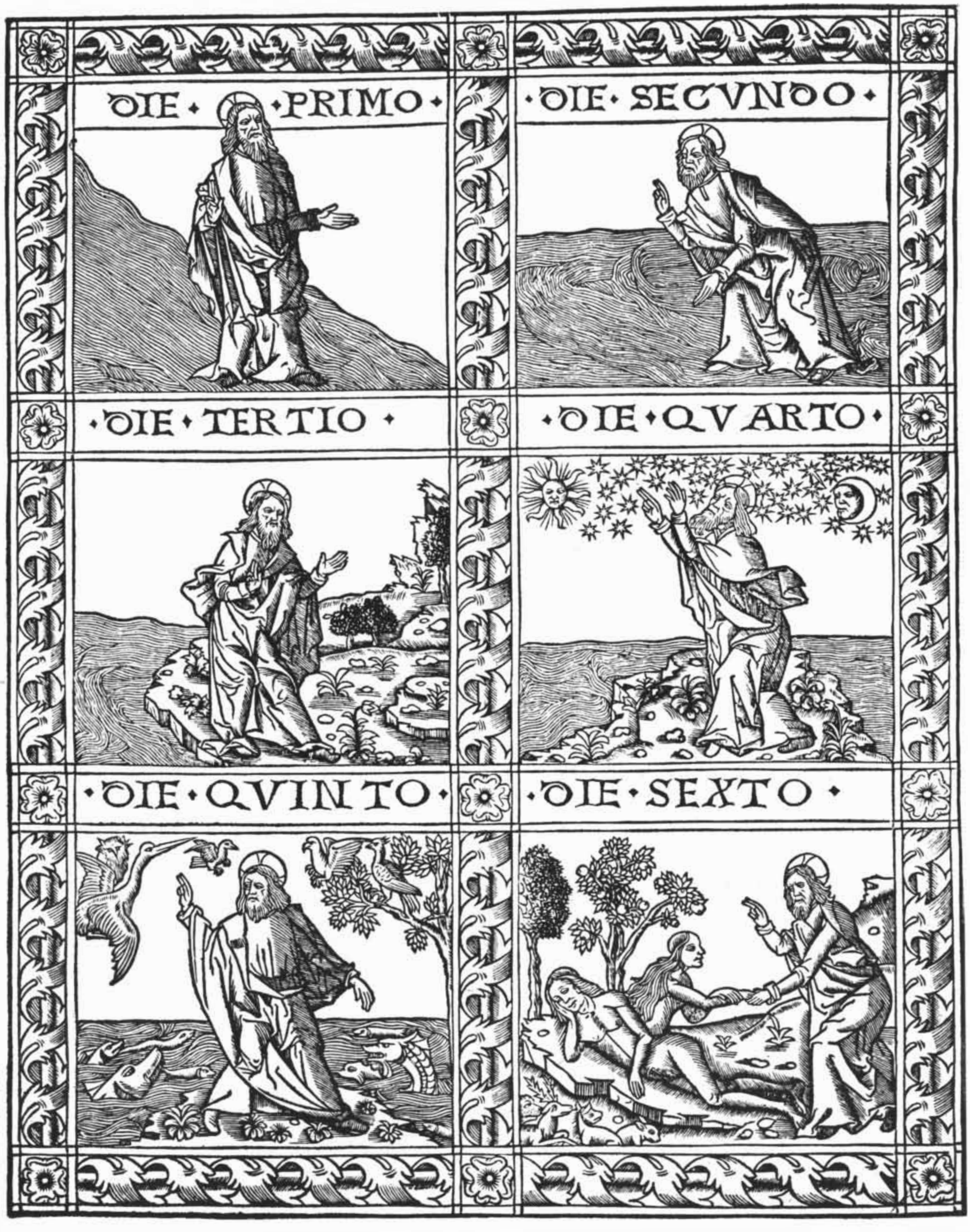
The Team chosen by U. S. Army Ordnance Corps to develop and build this vital defense weapon consists of Bell Telephone Laboratories, Western Electric Company, and Douglas.

The Nike missile, now in volume production, is directed by a guidance system which keeps it "on target" despite any evasive action. At the micro-second of intercept, Nike's warhead explodes. The target is destroyed. Highly mobile, the entire system can be moved by air, used with troops in the field, or to replace anti-aircraft guns in defense of fixed installations.

Selection of Douglas to design the Nike airframe recognizes leadership in missile engineering. Selection to build the missile in volume recognizes another Douglas "plus" — manufacturing dependability.

Enlist to fly in the U. S. Air Force

Depend on *DOUGLAS* **First in Aviation**



BIBLICAL ACCOUNT of the origin of life is part of the Creation, here illustrated in a 16th-century Bible printed in Lyons. On the first day (*die primo*) God created heaven and the earth. On the second day (*die secundo*) He separated the firmament and the waters. On the third day (*die tertio*) He made the dry land and plants. On the fourth day (*die quarto*) He made the sun, the moon and the stars. On the fifth day (*die quinto*) He made the birds and the fishes. On the sixth day (*die sexto*) He made the land animals and man. In this account there is no theological conflict with spontaneous generation. According to *Genesis* God, rather than creating the animals and plants directly, bade the earth and waters bring them forth. One theological view is that they retain this capacity.

THE ORIGIN OF LIFE

How did living matter first arise on the earth? As natural scientists learn more about nature they are returning to a hypothesis their predecessors gave up almost a century ago: spontaneous generation

by George Wald

About a century ago the question, How did life begin?, which has interested men throughout their history, reached an impasse. Up to that time two answers had been offered: one that life had been created supernaturally, the other that it arises continually from the nonliving. The first explanation lay outside science; the second was now shown to be untenable. For a time scientists felt some discomfort in having no answer at all. Then they stopped asking the question.

Recently ways have been found again to consider the origin of life as a scientific problem—as an event within the order of nature. In part this is the result of new information. But a theory never rises of itself, however rich and secure the facts. It is an act of creation. Our present ideas in this realm were first brought together in a clear and defensible argument by the Russian biochemist A. I. Oparin in a book called *The Origin of Life*, published in 1936. Much can be added now to Oparin's discussion, yet it provides the foundation upon which all of us who are interested in this subject have built.

The attempt to understand how life originated raises a wide variety of scientific questions, which lead in many and diverse directions and should end by casting light into many obscure corners. At the center of the enterprise lies the hope not only of explaining a great past event—important as that should be—but of showing that the explanation is workable. If we can indeed come to understand how a living organism arises from the nonliving, we should be able to construct one—only of the simplest description, to be sure, but still recognizably alive. This is so remote a possibility now that one scarcely dares to acknowledge it; but it is there nevertheless.

One answer to the problem of how life originated is that it was created. This is an understandable confusion of nature with technology. Men are used to making things; it is a ready thought that those things not made by men were made by a superhuman being. Most of the cultures we know contain mythical accounts of a supernatural creation of life. Our own tradition provides such an account in the opening chapters of *Genesis*. There we are told that beginning on the third day of the Creation, God brought forth living creatures—first plants, then fishes and birds, then land animals and finally man.

Spontaneous Generation

The more rational elements of society, however, tended to take a more naturalistic view of the matter. One had only to accept the evidence of one's senses to know that life arises regularly from the nonliving: worms from mud, maggots from decaying meat, mice from refuse of various kinds. This is the view that came to be called spontaneous generation. Few scientists doubted it. Aristotle, Newton, William Harvey, Descartes, van Helmont, all accepted spontaneous generation without serious question. Indeed, even the theologians—witness the English Jesuit John Turberville Needham—could subscribe to this view, for *Genesis* tells us, not that God created plants and most animals directly, but that He bade the earth and waters to bring them forth; since this directive was never rescinded, there is nothing heretical in believing that the process has continued.

But step by step, in a great controversy that spread over two centuries, this belief was whittled away until nothing remained of it. First the Italian Francesco Redi showed in the 17th century that meat placed under a screen, so that flies cannot lay their eggs on it, never develops maggots. Then in the following century the Italian abbé Lazzaro Spallanzani showed that a nutritive broth, sealed off from the air while boiling, never develops microorganisms, and hence never rots. Needham objected that by too much boiling Spallanzani had rendered the broth, and still more the air above it, incompatible with life. Spallanzani could defend his broth; when he broke the seal of his flasks, allowing new air to rush in, the broth promptly began to rot. He could find no way, however, to show that the air in the sealed flask had not been vitiated. This problem finally was solved by Louis Pasteur in 1860, with a simple modification of Spallanzani's experiment. Pasteur too used a flask containing boiling broth, but instead of sealing off the neck he drew it out in a long, S-shaped curve with its end open to the air. While molecules of air could pass back and forth freely, the heavier particles of dust, bacteria and molds in the atmosphere were trapped on the walls of the curved neck and only rarely reached the broth. In such a flask the broth seldom was contaminated; usually it remained clear and sterile indefinitely.

This was only one of Pasteur's experiments. It is no easy matter to deal with so deeply ingrained and common-sense a belief as that in spontaneous generation. One can ask for nothing better in such a pass than a noisy and stubborn opponent, and this Pasteur had in the naturalist Félix Pouchet, whose arguments before the French Academy of Sciences drove Pasteur to more and more rigorous experiments. When he had finished, nothing remained of the belief in spontaneous generation.

We tell this story to beginning students of biology as though it represents a triumph of reason over mysticism. In fact it is very nearly the opposite. The reasonable view was to believe in spontaneous generation; the only alternative, to believe in a single, primary act of supernatural creation. There is no third position. For this reason many scientists a century ago chose to regard the belief in spontaneous generation as a "philosophical necessity." It is a symptom of the philosophical poverty of our time that this necessity is no longer appreciated. Most modern biologists, having reviewed with satisfaction the downfall of the spontaneous generation hypothesis, yet unwilling to accept the alternative belief in special creation, are left with nothing.

I think a scientist has no choice but to approach the origin of life through a hypothesis of spontaneous generation. What the controversy reviewed above showed to be untenable is only the belief that living organisms arise spontaneously under present conditions. We have now to face a somewhat different problem: how organisms may have arisen spontaneously under different conditions in some former period, granted that they do so no longer.

The Task

To make an organism demands the right substances in the right proportions and in the right arrangement. We do not think that anything more is needed—but that is problem enough.

The substances are water, certain salts—as it happens, those found in the ocean—and carbon compounds. The latter are called *organic* compounds because they scarcely occur except as products of living organisms.

Organic compounds consist for the most part of four types of atoms: carbon, oxygen, nitrogen and hydrogen. These four atoms together constitute about 99 per cent of living material, for hydrogen and oxygen also form water. The organic compounds found in organisms fall mainly into four great classes: carbohydrates, fats, proteins and nucleic acids. The illustrations on this and the next three pages give some notion of their composition and degrees of complexity. The fats are simplest, each consisting of three fatty acids joined to glycerol. The starches and glycogens are made of sugar units strung together to form long straight and branched chains. In general only one type of sugar appears in a single starch or glycogen; these molecules are large, but still relatively simple. The principal function of carbohydrates and fats in the organism is to serve as fuel—as a source of energy.

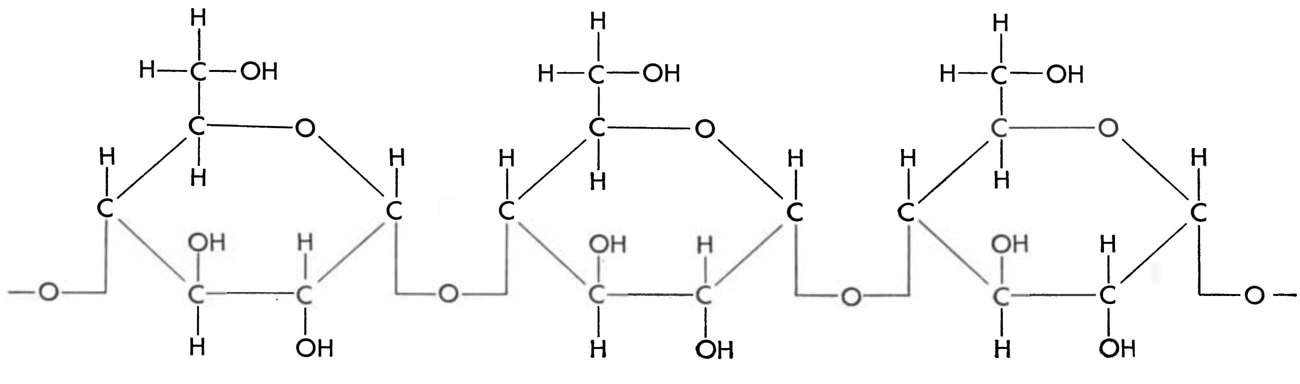
The nucleic acids introduce a further level of complexity. They are very large structures, composed of aggregates of at least four types of unit—the nucleotides—brought together in a great variety of proportions and sequences. An almost endless variety of different nucleic acids is possible, and specific differences among them are believed to be of the highest importance. Indeed, these structures are thought by many to be the main constituents of the genes, the bearers of hereditary constitution.

Variety and specificity, however, are most characteristic of the proteins, which include the largest and most complex molecules known. The units of which their structure is built are about 25 different amino acids. These are strung together in chains hundreds to thousands of units long, in different proportions, in all types of sequence, and with the greatest variety of branching and folding. A virtually infinite number of different proteins is possible. Organisms seem to exploit this potentiality, for no two species of living organism, animal or plant, possess the same proteins.

Organic molecules therefore form a large and formidable array, endless in variety and of the most bewildering complexity. One cannot think of having organisms without them. This is precisely the trouble, for to understand how organisms originated we must first of all explain how such complicated molecules could come into being. And that is only the beginning. To make an organism requires not only a tremendous variety of these substances, in adequate amounts and proper proportions, but also just the right arrangement of them. Structure here is as important as composition—and what a complication of structure! The most complex machine man has devised—say an electronic brain—is child's play compared with the simplest of living organisms. The especially trying thing is that complexity here involves such small dimensions. It is on the molecular level; it consists of a detailed fitting of molecule to molecule such as no chemist can attempt.

The Possible and Impossible

One has only to contemplate the magnitude of this task to concede that the spontaneous generation of a living organism is impossible. Yet here we are—as a result, I believe, of spontaneous generation. It will help to digress for a mo-



CARBOHYDRATES comprise one of the four principal kinds of carbon compound found in living matter. This structural formula represents part of a characteristic carbohydrate. It is a polysaccharide consisting of six-carbon sugar units, three of which are shown.

ment to ask what one means by "impossible."

With every event one can associate a probability—the chance that it will occur. This is always a fraction, the proportion of times the event occurs in a large number of trials. Sometimes the probability is apparent even without trial. A coin has two faces; the probability of tossing a head is therefore 1/2. A die has six faces; the probability of throwing a deuce is 1/6. When one has no means of estimating the probability beforehand, it must be determined by counting the fraction of successes in a large number of trials.

Our everyday concept of what is impossible, possible or certain derives from our experience: the number of trials that may be encompassed within the space of a human lifetime, or at most within recorded human history. In this colloquial, practical sense I concede the spontaneous origin of life to be "impossible." It is impossible as we judge events in the scale of human experience.

We shall see that this is not a very meaningful concession. For one thing, the time with which our problem is concerned is geological time, and the whole extent of human history is trivial in the balance. We shall have more to say of this later.

But even within the bounds of our own time there is a serious flaw in our judgment of what is possible. It sounds impressive to say that an event has never been observed in the whole of human history. We should tend to regard such an event as at least "practically" impossible, whatever probability is assigned to it on abstract grounds. When we look a little further into such a statement, however, it proves to be almost meaningless. For men are apt to reject reports of very improbable occurrences. Persons of good judgment think it safer to distrust the alleged observer of such an event than to believe him. The result is that events which are merely very extraordinary acquire the reputation of never having occurred at all. Thus the highly improbable is made to appear impossible.

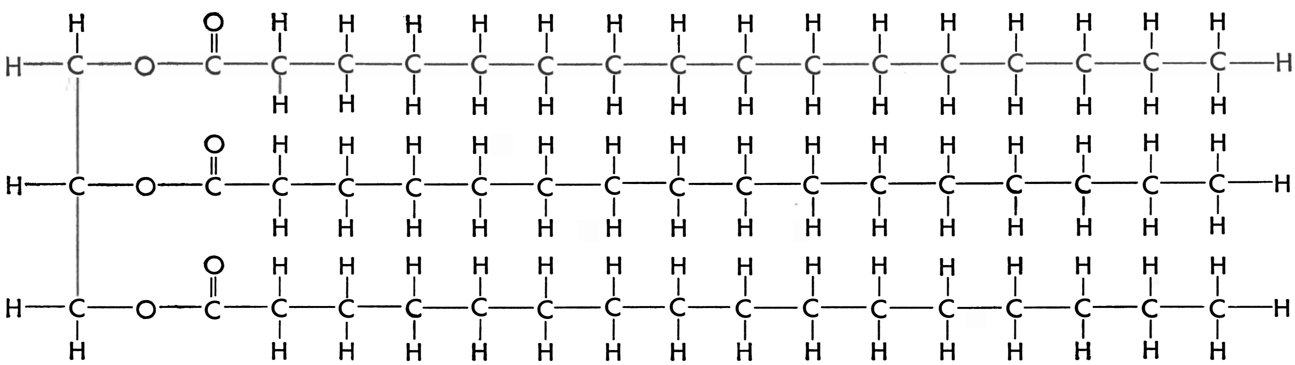
To give an example: Every physicist knows that there is a very small probability, which is easily computed, that the table upon which I am writing will suddenly and spontaneously rise into the air. The event requires no more than that the molecules of which the table is composed, ordinarily in random motion in all directions, should happen by chance to move in the same direction. Every physicist concedes this possibility; but try telling one that you have seen it happen. Recently I asked a friend, a Nobel laureate in physics, what he would say if I told him that. He laughed and said that he would regard it as more probable that I was mistaken than that the event had actually occurred.

We see therefore that it does not mean much to say that a very improbable event has never been observed. There is a conspiracy to suppress such observations, not among scientists alone, but among all judicious persons, who have learned to be skeptical even of what they see, let alone of what they are told. If one group is more skeptical than others, it is perhaps lawyers, who have the harshest experience of the unreliability of human evidence. Least skeptical of all are the scientists, who, cautious as they are, know very well what strange things are possible.

A final aspect of our problem is very important. When we consider the spontaneous origin of a living organism, this is not an event that need happen again and again. It is perhaps enough for it to happen once. The probability with which we are concerned is of a special kind; it is the probability that an event occur *at least once*. To this type of probability a fundamentally important thing happens as one increases the number of trials. However improbable the event in a single trial, it becomes increasingly probable as the trials are multiplied. Eventually the event becomes virtually inevitable. For instance, the chance that a coin will not fall head up in a single toss is 1/2. The chance that no head will appear in a series of tosses is $1/2 \times 1/2 \times 1/2 \ldots$ as many times over as the number of tosses. In 10 tosses the chance that no head will appear is therefore 1/2 multiplied by itself 10 times, or 1/1,000. Consequently the chance that a head will appear at least once in 10 tosses is 999/1,000. Ten trials have converted what started as a modest probability to a near certainty.

The same effect can be achieved with any probability, however small, by multiplying sufficiently the number of trials. Consider a reasonably improbable event, the chance of which is 1/1,000. The chance that this will not occur in one trial is 999/1,000. The chance that it won't occur in 1,000 trials is 999/1,000 multiplied together 1,000 times. This fraction comes out to be 37/100. The chance that it will happen at least once in 1,000 trials is therefore one minus this number—63/100—a little better than three chances out of five. One thousand trials have transformed this from a highly improbable to a highly probable event. In 10,000 trials the chance that this event will occur at least once comes out to be 19,999/20,000. It is now almost inevitable.

It makes no important change in the argument if we assess the probability that an event occur at least two, three, four or some other small number of



FATS are a second kind of carbon compound found in living matter. This formula represents the whole molecule of palmitin, one of the commonest fats. The molecule consists of glycerol (*11 atoms at the far left*) and fatty acids (*hydrocarbon chains at the right*).

times rather than at least once. It simply means that more trials are needed to achieve any degree of certainty we wish. Otherwise everything is the same.

In such a problem as the spontaneous origin of life we have no way of assessing probabilities beforehand, or even of deciding what we mean by a trial. The origin of a living organism is undoubtedly a stepwise phenomenon, each step with its own probability and its own conditions of trial. Of one thing we can be sure, however: whatever constitutes a trial, more such trials occur the longer the interval of time.

The important point is that since the origin of life belongs in the category of at-least-once phenomena, time is on its side. However improbable we regard this event, or any of the steps which it involves, given enough time it will almost certainly happen at least once. And for life as we know it, with its capacity for growth and reproduction, once may be enough.

Time is in fact the hero of the plot. The time with which we have to deal is of the order of two billion years. What we regard as impossible on the basis of human experience is meaningless here. Given so much time, the "impossible" becomes possible, the possible probable, and the probable virtually certain. One has only to wait: time itself performs the miracles.

Organic Molecules

This brings the argument back to its first stage: the origin of organic compounds. Until a century and a quarter ago the only known source of these substances was the stuff of living organisms. Students of chemistry are usually told that when, in 1828, Friedrich Wöhler synthesized the first organic compound, urea, he proved that organic compounds do not require living organisms to make them. Of course it showed nothing of the kind. Organic chemists are alive; Wöhler merely showed that they can make organic compounds externally as well as internally. It is still true that with almost negligible exceptions all the organic matter we know is the product of living organisms.

The almost negligible exceptions, however, are very important for our argument. It is now recognized that a constant, slow production of organic molecules occurs without the agency of living things. Certain geological phenomena yield simple organic compounds. So, for example, volcanic eruptions bring metal carbides to the surface of the earth, where they react with water vapor to yield simple compounds of carbon and hydrogen. The familiar type of such a reaction is the process used in old-style bicycle lamps in which acetylene is made by mixing iron carbide with water.

Recently Harold Urey, Nobel laureate in chemistry, has become interested in the degree to which electrical discharges in the upper atmosphere may promote the formation of organic compounds. One of his students, S. L. Miller, performed the simple experiment of circulating a mixture of water vapor, methane (CH_4), ammonia (NH_3) and hydrogen—all gases believed to have been present in the early atmosphere of the earth—continuously for a week over an electric spark. The circulation was maintained by boiling the water in one limb of the apparatus and condensing it in the other. At the end of the week the water was analyzed by the delicate method of paper chromatography. It was found to have acquired a mixture of amino acids! Glycine and alanine, the simplest amino acids and the most prevalent in proteins, were definitely identified in the solution, and there were indications it contained aspartic acid and two others. The yield was surprisingly high. This amazing result changes at a stroke our ideas of the probability of the spontaneous formation of amino acids.

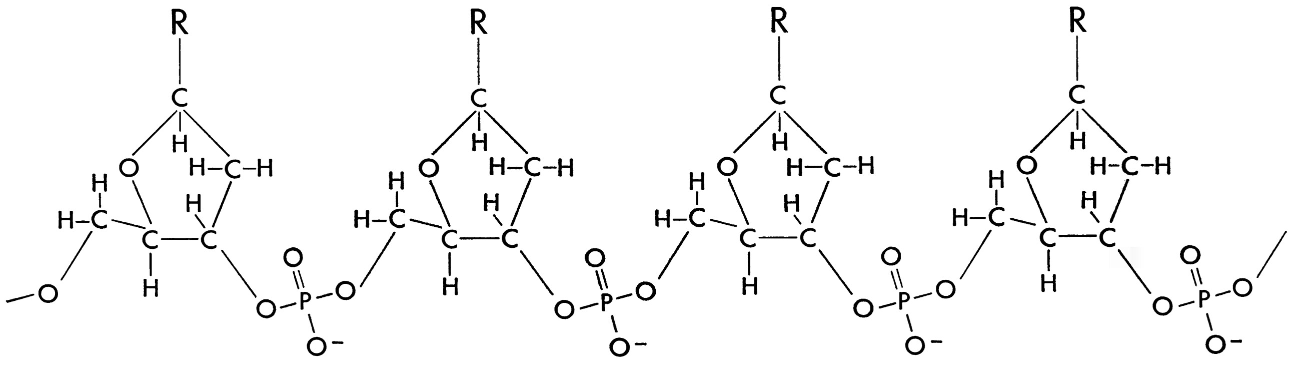
A final consideration, however, seems to me more important than all the special processes to which one might appeal for organic syntheses in inanimate nature.

It has already been said that to have organic molecules one ordinarily needs organisms. The synthesis of organic substances, like almost everything else that happens in organisms, is governed by the special class of proteins called enzymes—the organic catalysts which greatly accelerate chemical reactions in the body. Since an enzyme is not used up but is returned at the end of the process, a small amount of enzyme can promote an enormous transformation of material.

Enzymes play such a dominant role in the chemistry of life that it is exceedingly difficult to imagine the synthesis of living material without their help. This poses a dilemma, for enzymes themselves are proteins, and hence among the most complex organic components of the cell. One is asking, in effect, for an apparatus which is the unique property of cells in order to form the first cell.

This is not, however, an insuperable difficulty. An enzyme, after all, is only a catalyst; it can do no more than change the *rate* of a chemical reaction. It cannot make anything happen that would not have happened, though more slowly, in its absence. Every process that is catalyzed by an enzyme, and every product of such a process, would occur without the enzyme. The only difference is one of rate.

Once again the essence of the argument is time. What takes only a few moments in the presence of an enzyme or other catalyst may take days, months or years in its absence; but given time, the end result is the same.



NUCLEIC ACIDS are a third kind of carbon compound. This is part of desoxyribonucleic acid, the backbone of which is five-carbon sugars alternating with phosphoric acid. The letter R is any one of four nitrogenous bases, two purines and two pyrimidines.

Indeed, this great difficulty in conceiving of the spontaneous generation of organic compounds has its positive side. In a sense, organisms demonstrate to us what organic reactions and products are *possible*. We can be certain that, given time, all these things must occur. Every substance that has ever been found in an organism displays thereby the finite probability of its occurrence. Hence, given time, it should arise spontaneously. One has only to wait.

It will be objected at once that this is just what one cannot do. Everyone knows that these substances are highly perishable. Granted that, within long spaces of time, now a sugar molecule, now a fat, now even a protein might form spontaneously, each of these molecules should have only a transitory existence. How are they ever to accumulate; and, unless they do so, how form an organism?

We must turn the question around. What, in our experience, is known to destroy organic compounds? Primarily two agencies: decay and the attack of oxygen. But decay is the work of living organisms, and we are talking of a time before life existed. As for oxygen, this introduces a further and fundamental section of our argument.

It is generally conceded at present that the early atmosphere of our planet contained virtually no free oxygen. Almost all the earth's oxygen was bound in the form of water and metal oxides. If this were not so, it would be very difficult to imagine how organic matter could accumulate over the long stretches of time that alone might make possible the spontaneous origin of life. This is a crucial point, therefore, and the statement that the early atmosphere of the planet was virtually oxygen-free comes forward so opportunely as to raise a suspicion of special pleading. I have for this reason taken care to consult a number of geologists and astronomers on this point, and am relieved to find that it is well defended. I gather that there is a widespread though not universal consensus that this condition did exist. Apparently something similar was true also for another common component of our atmosphere—carbon dioxide. It is believed that most of the carbon on the earth during its early geological history existed as the element or in metal carbides and hydrocarbons; very little was combined with oxygen.

This situation is not without its irony. We tend usually to think that the environment plays the tune to which the organism must dance. The environment is given; the organism's problem is to adapt to it or die. It has become apparent lately, however, that some of the most important features of the physical environment are themselves the work of living organisms. Two such features have just been named. The atmosphere of our planet seems to have contained no oxygen until organisms placed it there by the process of plant photosynthesis. It is estimated that at present all the oxygen of our atmosphere is renewed by photosynthesis once in every 2,000 years, and that all the carbon dioxide passes through the process of photosynthesis once in every 300 years. In the scale of geological time, these intervals are very small indeed. We are left with the realization that all the oxygen and carbon dioxide of our planet are the products of living organisms, and have passed through living organisms over and over again.

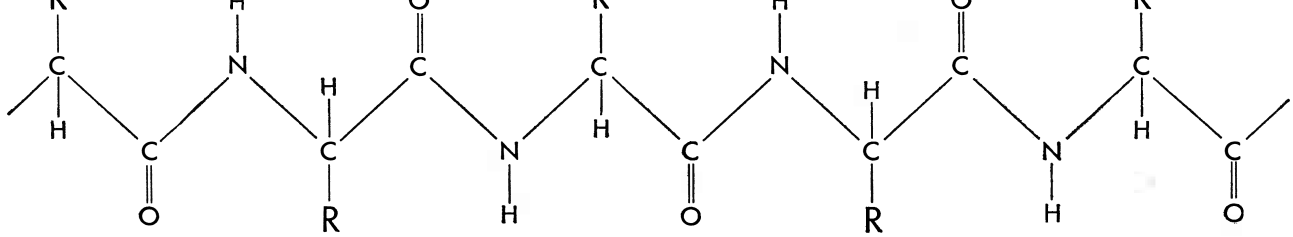
Forces of Dissolution

In the early history of our planet, when there were no organisms or any free oxygen, organic compounds should have been stable over very long periods. This is the crucial difference between the period before life existed and our own. If one were to specify a single reason why the spontaneous generation of living organisms was possible once and is so no longer, this is the reason.

We must still reckon, however, with another destructive force which is disposed of less easily. This can be called spontaneous dissolution—the counterpart of spontaneous generation. We have noted that any process catalyzed by an enzyme can occur in time without the enzyme. The trouble is that the processes which synthesize an organic substance are reversible: any chemical reaction which an enzyme may catalyze will go backward as well as forward. We have spoken as though one has only to wait to achieve syntheses of all kinds; it is truer to say that what one achieves by waiting is *equilibria* of all kinds—equilibria in which the synthesis and dissolution of substances come into balance.

In the vast majority of the processes in which we are interested the point of equilibrium lies far over toward the side of dissolution. That is to say, spontaneous dissolution is much more probable, and hence proceeds much more rapidly, than spontaneous synthesis. For example, the spontaneous union, step by step, of amino acid units to form a protein has a certain small probability, and hence might occur over a long stretch of time. But the dissolution of the protein or of an intermediate product into its component amino acids is much more probable, and hence will go ever so much more rapidly. The situation we must face is that of patient Penelope waiting for Odysseus, yet much worse: each night she undid the weaving of the preceding day, but here a night could readily undo the work of a year or a century.

How do present-day organisms manage to synthesize organic compounds against the forces of dissolution? They do so by a continuous expenditure of



PROTEINS are a fourth kind of carbon compound found in living matter. This formula represents part of a polypeptide chain, the backbone of a protein molecule. The chain is made up of amino acids. Here the letter R represents the side chains of these acids.

FILAMENTS OF COLLAGEN, a protein which is usually found in long fibrils, were dispersed by placing them in dilute acetic acid. This electron micrograph, which enlarges the filaments 75,000 times, was made by Jerome Gross of the Harvard Medical School.

energy. Indeed, living organisms commonly do better than oppose the forces of dissolution; they grow in spite of them. They do so, however, only at enormous expense to their surroundings. They need a constant supply of material and energy merely to maintain themselves, and much more of both to grow and reproduce. A living organism is an intricate machine for performing exactly this function. When, for want of fuel or through some internal failure in its mechanism, an organism stops actively synthesizing itself in opposition to the processes which continuously decompose it, it dies and rapidly disintegrates.

What we ask here is to synthesize organic molecules without such a machine. I believe this to be the most stubborn problem that confronts us—the weakest link at present in our argument. I do not think it by any means disastrous, but it calls for phenomena and forces some of which are as yet only partly understood and some probably still to be discovered.

Forces of Integration

At present we can make only a beginning with this problem. We know that it is possible on occasion to protect molecules from dissolution by precipitation or by attachment to other molecules. A wide variety of such precipitation and "trapping" reactions is used in modern chemistry and biochemistry to promote syntheses. Some molecules appear to acquire a degree of resistance to disintegration simply through their size. So, for example, the larger molecules composed of amino acids—polypeptides and proteins—seem to display much less tendency to disintegrate into their units than do smaller compounds of two or three amino acids.

Again, many organic molecules display still another type of integrating force—a spontaneous impulse toward structure formation. Certain types of fatty molecules—lecithins and cephalins—spin themselves out in water to form highly oriented and well-shaped structures—the so-called myelin figures. Proteins sometimes orient even in solution, and also may aggregate in the solid state in highly organized formations. Such spontaneous architectonic tendencies are still largely unexplored, particularly as they may occur in complex mixtures of substances, and they involve forces the strength of which has not yet been estimated.

What we are saying is that possibilities exist for opposing *intra*molecular dissolution by *inter*molecular aggregations of various kinds. The equilibrium between union and disunion of the amino acids that make up a protein is all to the advantage of disunion, but the aggregation of the protein with itself or other molecules might swing the equilibrium in the opposite direction: perhaps by removing the protein from access to the water which would be required to disintegrate it or by providing some particularly stable type of molecular association.

In such a scheme the protein appears only as a transient intermediate, an unstable way-station, which can either fall back to a mixture of its constituent amino acids or enter into the formation of a complex structural aggregate: amino acids $\leftrightarrows$ protein $\rightarrow$ aggregate.

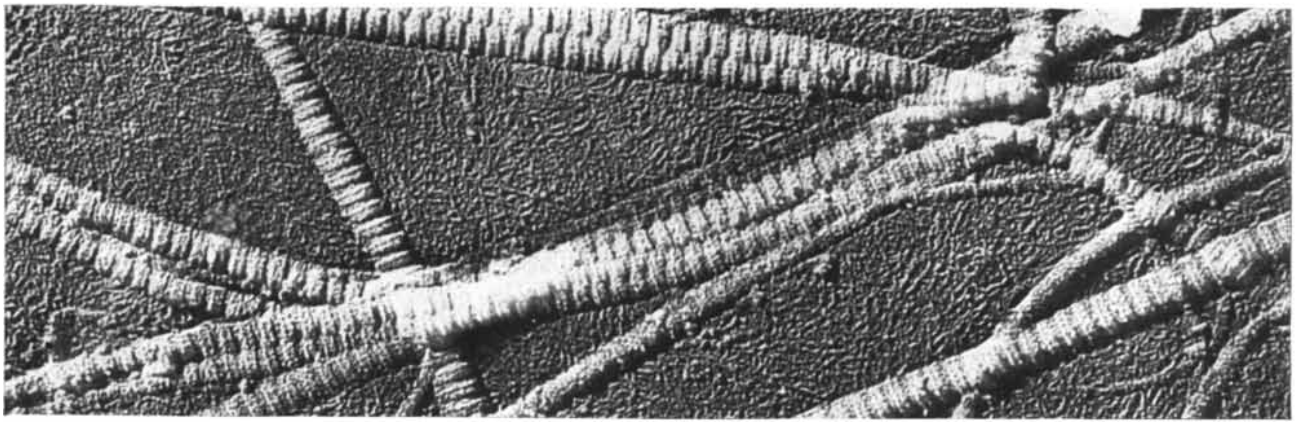
Such molecular aggregates, of various degrees of material and architectural complexity, are indispensable intermediates between molecules and organisms. We have no need to try to imagine the spontaneous formation of an organism by one grand collision of its component molecules. The whole process must be gradual. The molecules form aggregates, small and large. The aggregates add further molecules, thus growing in size and complexity. Aggregates of various kinds interact with one another to form still larger and more complex structures. In this way we imagine the ascent, not by jumps or master strokes, but gradually, piecemeal, to the first living organisms.

First Organisms

Where may this have happened? It is easiest to suppose that life first arose in the sea. Here were the necessary salts and the water. The latter is not only the principal component of organisms, but prior to their formation provided a medium which could dissolve molecules of the widest variety and ceaselessly mix and circulate them. It is this constant mixture and collision of organic molecules of every sort that constituted in large part the "trials" of our earlier discussion of probabilities.

The sea in fact gradually turned into a dilute broth, sterile and oxygen-free. In this broth molecules came together in increasing number and variety, sometimes merely to collide and separate, sometimes to react with one another to produce new combinations, sometimes to aggregate into multimolecular formations of increasing size and complexity.

What brought order into such complexes? For order is as essential here as composition. To form an organism, molecules must enter into intricate designs and connections; they must eventually form a self-repairing, self-constructing dynamic machine. For a time this problem of molecular arrangement seemed to present an almost insuperable obstacle in the way of imagining a spontaneous origin of life, or indeed the laboratory



FIBRILS OF COLLAGEN formed spontaneously out of filaments such as those shown on the opposite page when 1 per cent of sodium chloride was added to the dilute acetic acid. These long fibrils are identical in appearance with those of collagen before dispersion.

synthesis of a living organism. It is still a large and mysterious problem, but it no longer seems insuperable. The change in view has come about because we now realize that it is not altogether necessary to *bring* order into this situation; a great deal of order is implicit in the molecules themselves.

The epitome of molecular order is a crystal. In a perfect crystal the molecules display complete regularity of position and orientation in all planes of space. At the other extreme are fluids—liquids or gases—in which the molecules are in ceaseless motion and in wholly random orientations and positions.

Lately it has become clear that very little of a living cell is truly fluid. Most of it consists of molecules which have taken up various degrees of orientation with regard to one another. That is, most of the cell represents various degrees of approach to crystallinity—often, however, with very important differences from the crystals most familiar to us. Much of the cell's crystallinity involves molecules which are still in solution—so-called liquid crystals—and much of the dynamic, plastic quality of cellular structure, the capacity for constant change of shape and interchange of material, derives from this condition. Our familiar crystals, furthermore, involve only one or a very few types of molecule, while in the cell a great variety of different molecules come together in some degree of regular spacing and orientation—*i.e.*, some degree of crystallinity. We are dealing in the cell with highly mixed crystals and near-crystals, solid and liquid. The laboratory study of this type of formation has scarcely begun. Its further exploration is of the highest importance for our problem.

In a fluid such as water the molecules are in very rapid motion. Any molecules dissolved in such a medium are under a constant barrage of collisions with water molecules. This keeps small and moderately sized molecules in a constant turmoil; they are knocked about at random, colliding again and again, never holding any position or orientation for more than an instant. The larger a molecule is relative to water, the less it is disturbed by such collisions. Many protein and nucleic acid molecules are so large that even in solution their motions are very sluggish, and since they carry large numbers of electric charges distributed about their surfaces, they tend even in solution to align with respect to one another. It is so that they tend to form liquid crystals.

We have spoken above of architectonic tendencies even among some of the relatively small molecules: the lecithins and cephalins. Such molecules are insoluble in water yet possess special groups which have a high affinity for water. As a result they tend to form surface layers, in which their water-seeking groups project into the water phase, while their water-repelling portions project into the air, or into an oil phase, or unite to form an oil phase. The result is that quite spontaneously such molecules, when exposed to water, take up highly oriented positions to form surface membranes, myelin figures and other quasi-crystalline structures.

Recently several particularly striking examples have been reported of the spontaneous production of familiar types of biological structure by protein molecules. Cartilage and muscle offer some of the most intricate and regular patterns of structure to be found in organisms. A fiber from either type of tissue presents under the electron microscope a beautiful pattern of cross striations of various widths and densities, very regularly spaced. The proteins that form these structures can be coaxed into free solution and stirred into completely random orientation. Yet on precipitating, under proper conditions, the molecules realign with regard to one another to regenerate with extraordinary fidelity the original patterns of the tissues [*see illustration above*].

We have therefore a genuine basis for the view that the molecules of our oceanic broth will not only come together spontaneously to form aggregates but in doing so will spontaneously achieve various types and degrees of order. This greatly simplifies our problem. What it means is that, given the right molecules, one does not have to do everything for them; they do a great deal for themselves.

Oparin has made the ingenious suggestion that natural selection, which Darwin proposed to be the driving force of organic evolution, begins to operate at this level. He suggests that as the molecules come together to form colloidal aggregates, the latter begin to compete with one another for material. Some aggregates, by virtue of especially favorable composition or internal arrangement, acquire new molecules more rapidly than others. They eventually emerge as the dominant types. Oparin suggests further that considerations of optimal size enter at this level. A growing colloidal particle may reach a point at which it becomes unstable and breaks down into smaller particles, each of which grows and redivides. All these phenomena lie within the bounds of known processes in nonliving systems.

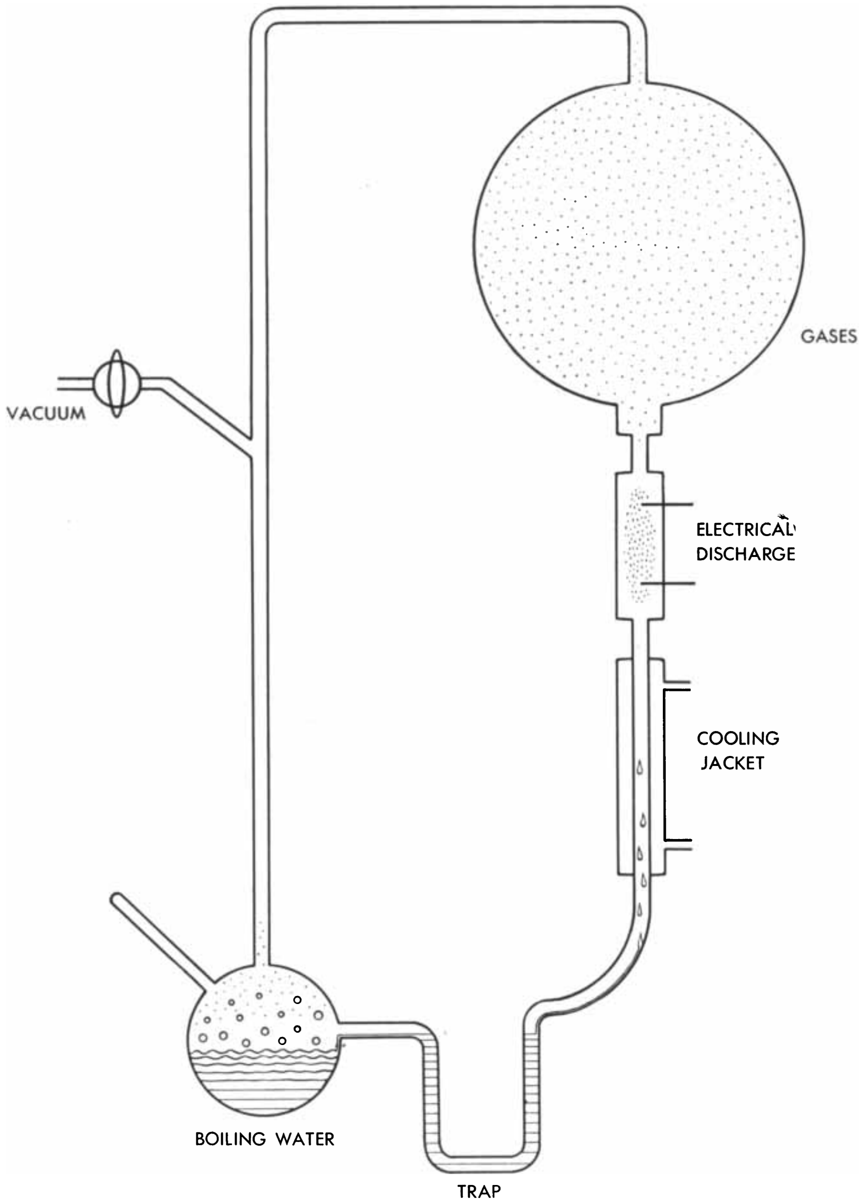
The Sources of Energy

We suppose that all these forces and factors, and others perhaps yet to be revealed, together give us eventually the first living organism. That achieved, how does the organism continue to live?

We have already noted that a living organism is a dynamic structure. It is the site of a continuous influx and outflow of matter and energy. This is the very sign of life, its cessation the best evidence of death. What is the primal organism to use as food, and how derive the energy it needs to maintain itself and grow?

For the primal organism, generated under the conditions we have described, only one answer is possible. Having arisen in an oceanic broth of organic molecules, its only recourse is to live upon them. There is only one way of doing that in the absence of oxygen. It is called fermentation: the process by which organisms derive energy by breaking organic molecules and rearranging their parts. The most familiar example of such a process is the fermentation of sugar by yeast, which yields alcohol as one of the products. Animal cells also ferment sugar, not to alcohol but to lactic acid. These are two examples from a host of known fermentations.

The yeast fermentation has the following over-all equation: $C_6H_{12}O_6 \rightarrow 2\ CO_2 + 2\ C_2H_5OH$ + energy. The result of fragmenting 180 grams of sugar into 88 grams of carbon dioxide and 92 grams of alcohol is to make available about 20,000 calories of energy for the use of the cell. The energy is all that the cell derives by this transaction; the carbon dioxide and alcohol are waste products which must be got rid of somehow if the cell is to survive.



EXPERIMENT of S. L. Miller made amino acids by circulating methane (CH_4), ammonia (NH_3), water vapor (H_2O) and hydrogen (H_2) past an electrical discharge. The amino acids collected at the bottom of apparatus and were detected by paper chromatography.

The cell, having arisen in a broth of organic compounds accumulated over the ages, must consume these molecules by fermentation in order to acquire the energy it needs to live, grow and reproduce. In doing so, it and its descendants are living on borrowed time. They are consuming their heritage, just as we in our time have nearly consumed our heritage of coal and oil. Eventually such a process must come to an end, and with that life also should have ended. It would have been necessary to start the entire development again.

Fortunately, however, the waste product carbon dioxide saved this situation. This gas entered the ocean and the atmosphere in ever-increasing quantity. Some time before the cell exhausted the supply of organic molecules, it succeeded in inventing the process of photosynthesis. This enabled it, with the energy of sunlight, to make its own organic molecules: first sugar from carbon dioxide and water, then, with ammonia and nitrates as sources of nitrogen, the entire array of organic compounds which it requires. The sugar synthesis equation is: $6\ CO_2 + 6\ H_2O$ + sunlight $\rightarrow C_6H_{12}O_6 + 6\ O_2$. Here 264 grams of carbon dioxide plus 108 grams of water plus about 700,000 calories of sunlight yield 180 grams of sugar and 192 grams of oxygen.

This is an enormous step forward. Living organisms no longer needed to depend upon the accumulation of organic matter from past ages; they could make their own. With the energy of sunlight they could accomplish the fundamental organic syntheses that provide their substance, and by fermentation they could produce what energy they needed.

Fermentation, however, is an extraordinarily inefficient source of energy. It leaves most of the energy potential of organic compounds unexploited; consequently huge amounts of organic material must be fermented to provide a modicum of energy. It produces also various poisonous waste products—alcohol, lactic acid, acetic acid, formic acid and so on. In the sea such products are readily washed away, but if organisms were ever to penetrate to the air and land, these products must prove a serious embarrassment.

One of the by-products of photosynthesis, however, is oxygen. Once this was available, organisms could invent a new way to acquire energy, many times as efficient as fermentation. This is the process of cold combustion called respiration: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + energy. The burning of 180 grams of sugar in cellular respiration yields about 700,000 calories, as compared with the approximately 20,000 calories produced by fermentation of the same quantity of sugar. This process of combustion extracts all the energy that can possibly be derived from the molecules which it consumes. With this process at its disposal, the cell can meet its energy requirements with a minimum expenditure of substance. It is a further advantage that the products of respiration—water and carbon dioxide—are innocuous and easily disposed of in any environment.

Life's Capital

It is difficult to overestimate the degree to which the invention of cellular respiration released the forces of living organisms. No organism that relies wholly upon fermentation has ever amounted to much. Even after the advent of photosynthesis, organisms could have led only a marginal existence. They could indeed produce their own organic materials, but only in quantities sufficient to survive. Fermentation is so profligate a way of life that photosynthesis could do little more than keep up with it. Respiration used the material of organisms with such enormously greater efficiency as for the first time to leave something over. Coupled with fermentation, photosynthesis made organisms self-sustaining; coupled with respiration, it provided a surplus. To use an economic analogy, photosynthesis brought organisms to the subsistence level; respiration provided them with capital. It is mainly this capital that they invested in the great enterprise of organic evolution.

The entry of oxygen into the atmosphere also liberated organisms in another sense. The sun's radiation contains ultraviolet components which no living cell can tolerate. We are sometimes told that if this radiation were to reach the earth's surface, life must cease. That is not quite true. Water absorbs ultraviolet radiation very effectively, and one must conclude that as long as these rays penetrated in quantity to the surface of the earth, life had to remain under water. With the appearance of oxygen, however, a layer of ozone formed high in the atmosphere and absorbed this radiation. Now organisms could for the first time emerge from the water and begin to populate the earth and air. Oxygen provided not only the means of obtaining adequate energy for evolution but the protective blanket of ozone which alone made possible terrestrial life.

This is really the end of our story. Yet not quite the end. Our entire concern in this argument has been to bring the origin of life within the compass of natural phenomena. It is of the essence of such phenomena to be repetitive, and hence, given time, to be inevitable.

This is by far our most significant conclusion—that life, as an orderly natural event on such a planet as ours, was inevitable. The same can be said of the whole of organic evolution. All of it lies within the order of nature, and apart from details all of it was inevitable.

Astronomers have reason to believe that a planet such as ours—of about the earth's size and temperature, and about as well-lighted—is a rare event in the universe. Indeed, filled as our story is with improbable phenomena, one of the least probable is to have had such a body as the earth to begin with. Yet though this probability is small, the universe is so large that it is conservatively estimated at least 100,000 planets like the earth exist in our galaxy alone. Some 100 million galaxies lie within the range of our most powerful telescopes, so that throughout observable space we can count apparently on the existence of at least 10 million million planets like our own.

What it means to bring the origin of life within the realm of natural phenomena is to imply that in all these places life probably exists—life as we know it. Indeed, I am convinced that there can be no way of composing and constructing living organisms which is fundamentally different from the one we know—though this is another argument, and must await another occasion. Wherever life is possible, given time, it should arise. It should then ramify into a wide array of forms, differing in detail from those we now observe (as did earlier organisms on the earth) yet including many which should look familiar to us—perhaps even men.

We are not alone in the universe, and do not bear alone the whole burden of life and what comes of it. Life is a cosmic event—so far as we know the most complex state of organization that matter has achieved in our cosmos. It has come many times, in many places—places closed off from us by impenetrable distances, probably never to be crossed even with a signal. As men we can attempt to understand it, and even somewhat to control and guide its local manifestations. On this planet that is our home, we have every reason to wish it well. Yet should we fail, all is not lost. Our kind will try again elsewhere.

A TOPOGRAPHIC MICROSCOPE

In recent years there has been a demand for methods to represent the microscopic profile of a surface. The author describes a new instrument based upon a simple extension of classical microscopy

by Samuel Tolansky

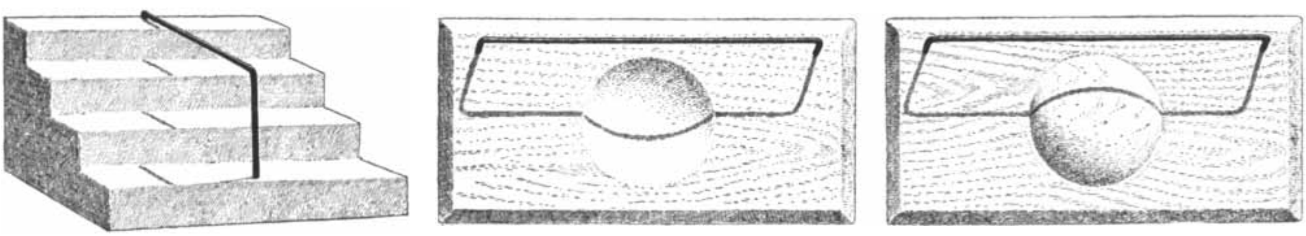
It is curious that for centuries scientists using microscopes have been content to study their subjects with precision in only one plane—the two-dimensional surface. The surface of any object one examines under the microscope has a third-dimensional aspect: what might be called its "skyline" or profile of contours as seen through a cross section of it. There are many problems in which precise information on the microtopography of a surface may be immensely useful; for instance, the growth of a crystal, the frictional wear of a surface, the finish on a metal, the evenness of an electroplated coating. Within recent years an urgent demand has emerged for a convenient technique for studying surface profiles on the micro-scale. It is the object of this article to describe a new method which I have developed.

Until recently there were only two methods of any wide applicability for high-precision measurements of surface contours. One is the so-called stylus profilometer, of which there are several variants. A fine diamond stylus is trailed across the surface like a phonograph needle, and the up-down motions are converted into electric impulses which are then amplified and recorded by a pen on a sheet of paper. The method is capable of tracing extremely small surface wavelets. It has many valuable uses, but also obvious drawbacks. On a soft material the hard diamond, even with a very small load on it, ploughs right through the surface projections; it leaves a visible scratch in a soft metal such as aluminum. Moreover, the instrument is costly, delicate and very slow, for each recording covers only a tiny region of the surface.

The second method, which I worked out some years ago, is an optical technique called multiple-beam interferometry. It produces over the surface under study a pattern of contour lines exactly analogous to a geographical contour map, but with the difference that the contours are on a scale of only one 100,000th of an inch, instead of, say, 100 feet. This method can easily detect height variations of one 10-millionth of an inch—a quantity smaller than the size of many molecules. It is inexpensive and is unsurpassed for studying the surfaces of crystals, polished metals, glasses, plastics and so on. But its main limitation is that it will work only on surfaces with smooth areas between the microtopographical prominences; it fails on a rough surface such as that of a biological material, a fiber or a corroded metal. In addition the technique requires considerable training to learn how to use it.

What was wanted was an inexpensive, fairly simple method of reasonable sensitivity which could readily be used by the large army of microscopists. To answer this need I hit upon a device which I call the "light-profile microscope." It resolves and measures topographical features down to one 100,000th of an inch—a sensitivity which is more than sufficient for many needs. And it can be used to study relatively coarse as well as very fine surfaces. During the past year a team of investigators in my laboratory at the Royal Holloway College has done a great deal of work with the light-profile microscope, and it is rapidly being adopted in many other laboratories in England.

The germ of the idea occurred to me late one sunny afternoon whilst I was descending an open-air staircase from a railway station. The sun was low, and I noticed that the shadow cast by the handrail on the steps was not a straight line but was broken into segments displaced sideways one from the other [*see illustration at left below*]. It was immediately obvious that if one knew the angle at which the light was falling and measured the displacements



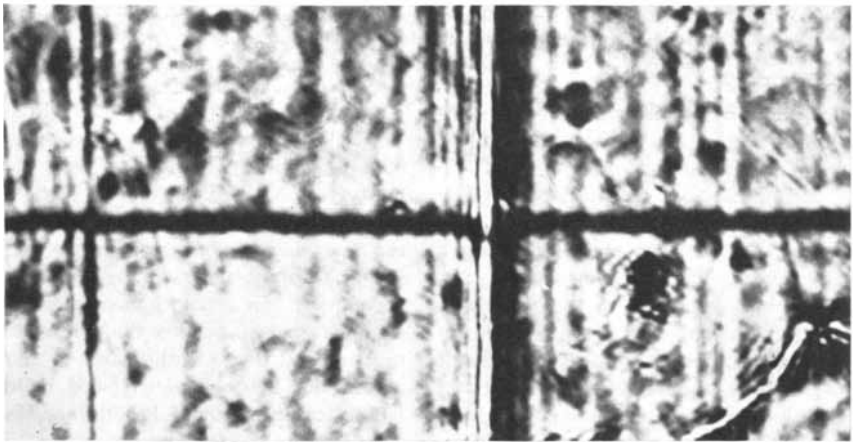
SHADOWS cast by wires represent the topography of three models in Tolansky's laboratory. If the source of the shadow is a straight line and the angle of the light is known, the heights and the hollows can be accurately measured by the displacements of the line.

of the shadow lines on the steps, then without more ado one could easily calculate the height of the steps by simple arithmetic. Indeed, one could determine the depth of any hollow or the height of any hillock from the curvature of the shadow line. It became evident that if the shadow of a straight line were cast obliquely from the side upon a wavy surface, the shadow line would wriggle along the wavy elements and reveal the profile of the surface, not only in a qualitative manner but in a way subject to exact measurement.

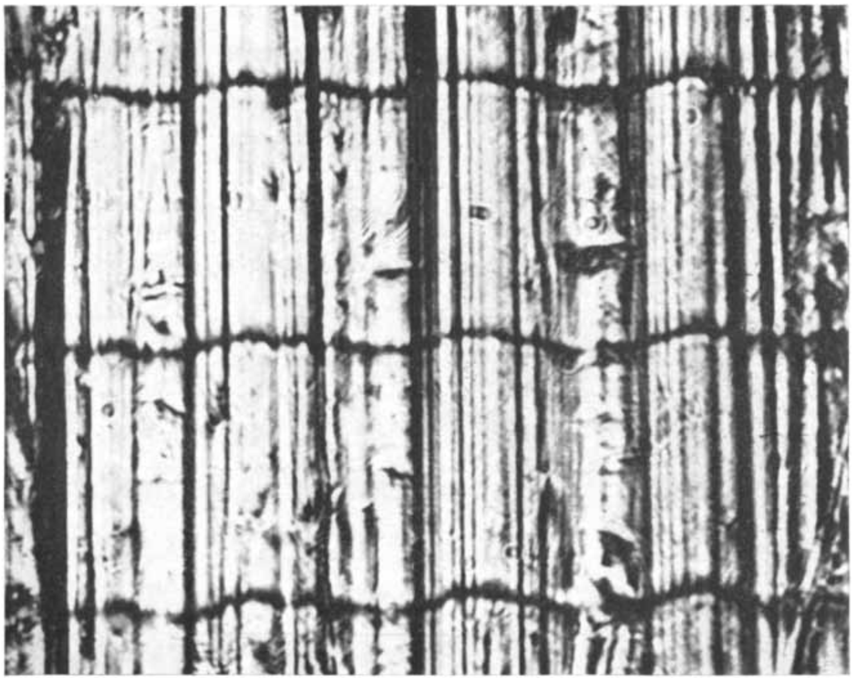
It was not difficult to apply this simple device to high-power microscopy. One arranges to cast a microscopic shadow of a straight line at a known angle on the surface under study, and the wriggling of this shadow, as seen by the same microscope that casts the shadow, gives all the necessary information. With the aid of a small scratch on a piece of glass, serving as the straight line, the technique is easily usable in any good surface-illuminating type of microscope. First it is essential to view the object by reflected light. Reflection illuminators are readily available. Secondly, the illumination must be oblique; obviously a shadow line from light directly overhead will not show contours. The best way to do this is to have the illumination come from a small mirror placed to the side of the viewing objective so as to send in an oblique pencil of light. Many commercial microscopes already have such a mirror built in as part of the illuminating equipment.

One first adjusts the microscope to view the object in focus, using the oblique illumination. So far this is standard practice. The new feature is merely the introduction of the small piece of glass with the scratch on it into the path of the illuminating beam. The opaque scratch line becomes the origin of the shadow. Now this scratch must be placed at the correct position so as to make the shadow in focus on the object under view. On practically any well-designed microscope there is nothing easier. Every such microscope has a small iris diaphragm in the path of the light beam, so placed that its image falls on the object. The purpose of this so-called field iris is to cut out scattered light by restricting the input light to cover the field of view. Since the iris is focused on the surface of the object, all that is necessary is to place the small piece of scratched glass (or a hair, a fine wire or even a broken edge of a slip of glass) close to the plane of the iris, and without more ado the light-profile

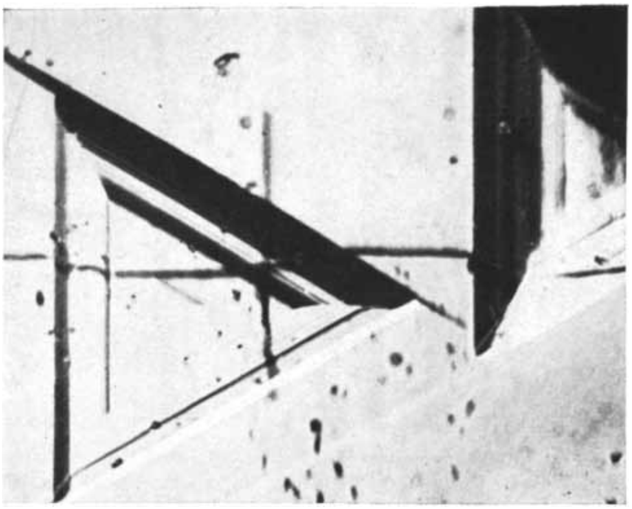
BEARING made on a boring machine was photographed by the light-profile method. The shadow line runs horizontally across the picture, indicating topography by its wiggles.



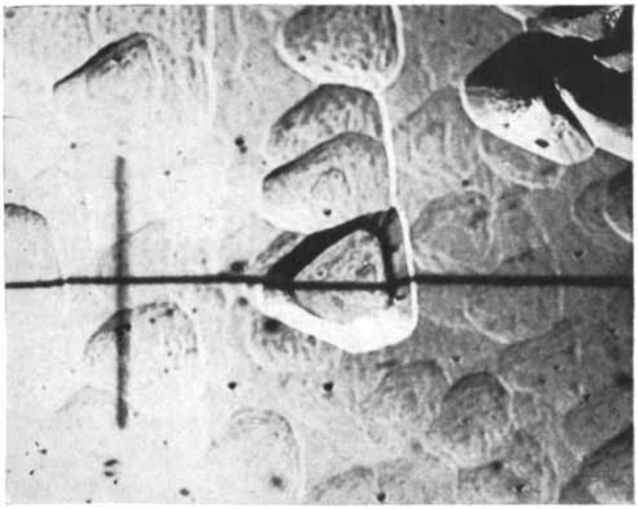
ANOTHER BEARING made on a broaching machine was photographed through the light-profile microscope. Here the shadow line is straighter, indicating a smoother surface.



MULTIPLE PROFILE of a bored bearing was made by casting three lines on it. The magnification of the photographs from which these reproductions were made is 2,000 diameters.



GROWTH TRIGONS on surface of diamond are shown by light-profile technique to be depressions. Magnification: 1,000 diameters.

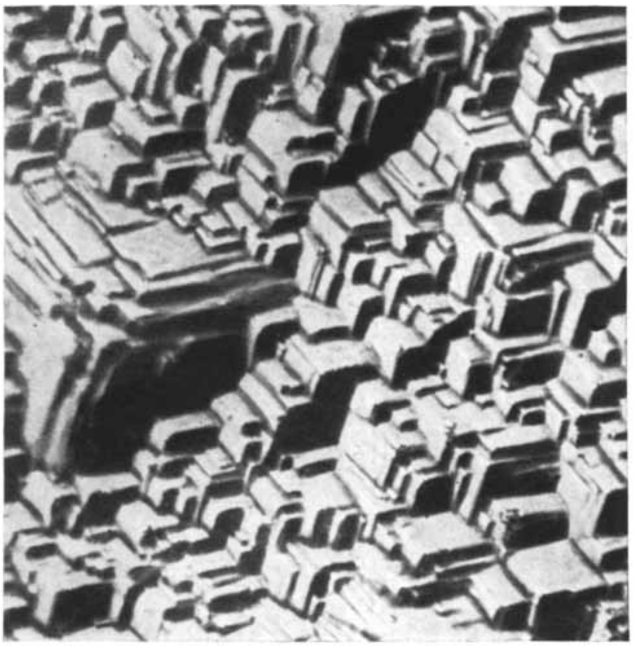


ETCH PITS on the surface of diamond differ from trigons. They are round-sided and flat-bottomed. Magnification: 1,000 diameters.

condition is established and one sees the shadow contouring the microtopography of the surface.

If one employs the highest possible effective powers with the optical microscope, say a 1/12th-inch oil-immersion objective in combination with a 20-power eyepiece, then the object is seen at a magnification of 2,000 with maximum optical resolution. It is not difficult to establish the angle of obliquity of the illumination. The degree of magnification in depth-height can then be ascertained. By the proper selection of lenses it is possible to arrange that the magnification in the up-down direction is exactly the same as that laterally. (In the step model illustrated on page 54 this happens when the angle of the light is at 45 degrees to the vertical; the sideways displacement of the shadow line then exactly equals the step height.) In the photomicrographs that accompany this article I have carefully arranged matters so that the magnification up and down is the same as that across the field of view, both being 2,000. It follows that a 1/50th-inch displacement of the shadow line at a point on the object viewed means that the height change there is one 100,000th of an inch. Actually under critically exact conditions I have been able to measure height deviations as small as five millionths of an inch.

Let us consider now a group of examples which will show the power and usefulness of this very simple device. At the outset let it be recognized that the light-profile method is applicable over a wide range of magnifications; I have used it for examining relatively coarse structures magnified only 100 times and for very fine detail magnified 4,000 times. In the photograph at the top of the preceding page the magnification was 2,000. This shows the profile of a region



ETCH FEATURES on diamond look like rectangular blocks under the conventional microscope. Magnification: 1,000 diameters.

SIMILAR FEATURES under the light-profile microscope are observed to be not rectangular blocks but triangular depressions.

on the surface of a typical automobile engine bearing. Such bearings are cylindrical shells a few inches in diameter and are produced in industry in enormous quantities not only for automobile engines but for small and large rotating engines of every kind. A primary object in the making of the bearings is to give them a very smooth, silky surface. Because the cost of polishing is prohibitive, the machining process itself must be as nearly perfect as possible.

Now the question was raised with me as to how the degree of smoothness can be assessed. It so happens that for technological reasons connected with friction, bearing surfaces are often constructed of very soft metals, for example, soft tin alloys. To drag a diamond stylus over such a soft surface to evaluate the topography is simply asking for trouble. The light-profile examination gives a completely satisfactory answer to the production engineer, and it involves no surface destruction or distortion whatsoever.

The two photomicrographs at the top of page 55 show the surface profiles of two bearings, both of similar size and material but made by different processes. The one at the top was turned on a high-precision lathe with a diamond cutting tool. The shadow line discloses a pattern on the metal that clearly reveals the shape of the cutting tool which has passed over it; it shows a regular pattern of wavelets about one 20,000th of an inch high, and a number of finer irregularities as well. The bearing in the second photograph was made with a hard carbide tool by the so-called broaching process. Its surface turned out not only to lack the wavy corrugations of a lathe-turned bearing, which was to be expected, but also to be much smoother in general, to the surprise of some engineers. The decision as to which process to use is, of course, up to the engineers; some of them argue that slight corrugations give to a bearing surface a better oil-holding ability.

A most useful feature of the light-profile method is its rapidity. One can quickly scan the contours of the object across the whole field of view of the microscope. Indeed, a rapid scanning action detects very slight ripples which might otherwise not be apparent. Inspection of an extended area can be speeded up by a simple modification, using a group of parallel scratches instead of a single one, which gives a "multiple-profile" [*see illustration at the bottom of page 55*]. The spaced shadow lines in this view of a diamond-turned bearing of aluminum show vividly how the cuts of the machine tool run along the material at about the same depth.

So much for typical technological applications. Now we shall consider how the light-profile helps on some basic scientific problems. A tremendous amount of work is being devoted today to theories of crystal growth; it has been the topic of many international conferences recently. The practical ramifications of this apparently academic subject are surprisingly far-reaching. They range from the growing of quartz crystals essential in radar equipment to the control of the size of washing-soda crystals so that they will flow out of the carton at a suitable rate. In my laboratory an active team is engaged in studies on crystal-growth problems, and each member uses the light-profile technique.

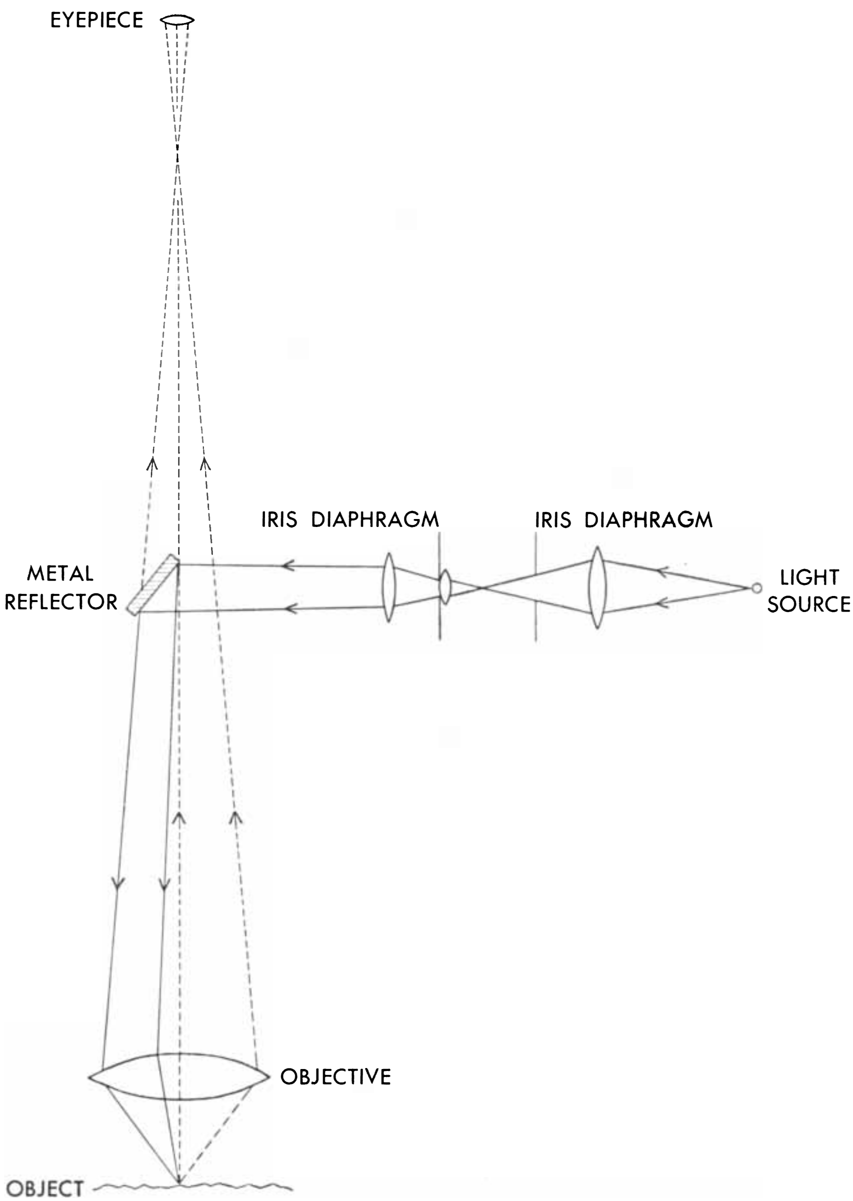
A crystal that has fascinated scientists for hundreds of years is the diamond—the hardest material known to mankind. Much remains to be learned about its wonderful properties. I have been studying diamonds by optical methods for some 10 years. No one knows how diamonds grow. One great mystery about them has been the tiny triangular depressions, called trigons, which can be seen on the faces of a diamond under the microscope. For 50 years there has been a controversy among mineralogists as to whether the trigons are connected with the diamonds' growth or are etched on them after growth. By means of measurements of the depth of these trigons I have been able to establish unequivocally that they are a manifestation of the growth mechanism.

If diamonds could be grown economically, even on a microscopic scale, the process would be of considerable industrial importance, for crushed diamond is the most powerful polishing and abrading material known. Some have claimed success in growing diamonds artificially, but others have failed under apparently identical conditions.

It happens that knowledge about crystal growth can be obtained by studying crystals in the act of dissolving or by examining the etches left on their faces by solvent action. We can etch diamonds with hot oxidizing materials or with a hot oxidizing flame. We have found that, in the early stages of etching of a natural diamond face, minute triangular-shaped pits appear. They are somewhat like growth trigons but point in opposite directions to them. The light-profile picture at the upper right on page 56 shows that the pits at first are flat-bottom craters with sloping sides. As the etching progresses, a striking block pattern appears; I describe it to my students as my "aerial diamond Manhattan skyline" [*see photograph at the lower left on page 56*]. This structure is the most unusual optical illusion I know. Although the blocks appear to the eye as rectangular piles, the light-profile [*illustration at the lower right on page 56*] shows that they are in fact nothing of the sort; they are constituted of groups of triangular pyramidal depressions, meeting to form a spurious rectangular appearance. But for the light-profile I might well have been tricked into thinking I was looking at strictly rectangular blocks.

But enough of diamonds. The whole enormous field of metal corrosion is amenable to study by light-profile methods. We are in fact actively engaged in such studies, but on a very restricted scale. One special type of corrosion under examination is the wearing away of metal contacts by electric sparks—a serious matter in telephone circuitry and in many electric systems. The light-profile technique has made it possible to measure the effect of a single spark—the shape and volume of the tiny erosion pit and the distribution of molten metal in the surrounding region.

The light-profile is a great help in certain new techniques for measuring



OPTICAL SYSTEM of the light-profile microscope introduces the line shadow by means of the mirror in the center. The shadow is cast by a scratch on the second lens from the right.

the hardness of materials. A sharply pointed diamond is pressed gently into the material under study, and the size of the microscopic impression it has made is then measured. The difficulty is that it is hard to tell how much the depression may have been reduced by elastic recovery of the material after withdrawal of the diamond. This is where the light-profile comes into the picture. It measures the precise depth and shape of the indentation, and from the known shape of the diamond (which is so hard that it itself suffers no distortion during indentation of the metal) it can at once be established whether or not there has been elastic recovery. This line of approach promises to put micro-hardness testing upon a much sounder basis than heretofore.

I could go on multiplying examples of the possibilities of this method. Perhaps one or two of the more unexpected applications might be mentioned. From the curvature of the shadow line across a narrow fiber it is possible to establish the radius of the fiber. This has been carried out for glass and for plastic fibers. Again, it is easy to measure the thickness of a very thin film of material, such as a plastic, and it is even possible to measure the line-of-sight oscillations of a vibrating system.

The applications thus far described are physical. As yet I have hardly attempted to apply the technique to the biological field. I have, however, run a profile over a human red blood corpuscle, and the depth of the lenticular portion is completely revealed by this method. There is not the slightest doubt that the thickness and shape contours of small organisms and of small fibrils or small animal or plant appendages can be measured in this way. The limitations are, of course, self-evident.

It is clear that light-profile microscopy is one more weapon, and a powerful one at that, in the armory of the microscopist. New techniques such as X-rays, electron diffraction, electron microscopy, radioactive tracers and so on have tended to overshadow the classical microscope. There is no doubt that within the last few years it has made a comeback, what with the invention of phase contrast, the development of interference methods and the more extensive use of polarization methods. I am convinced that the light-profile will take its place as one more useful microscopic technique, applicable over a wide range of magnifications for a wide range of purposes.

TSUNAMIS

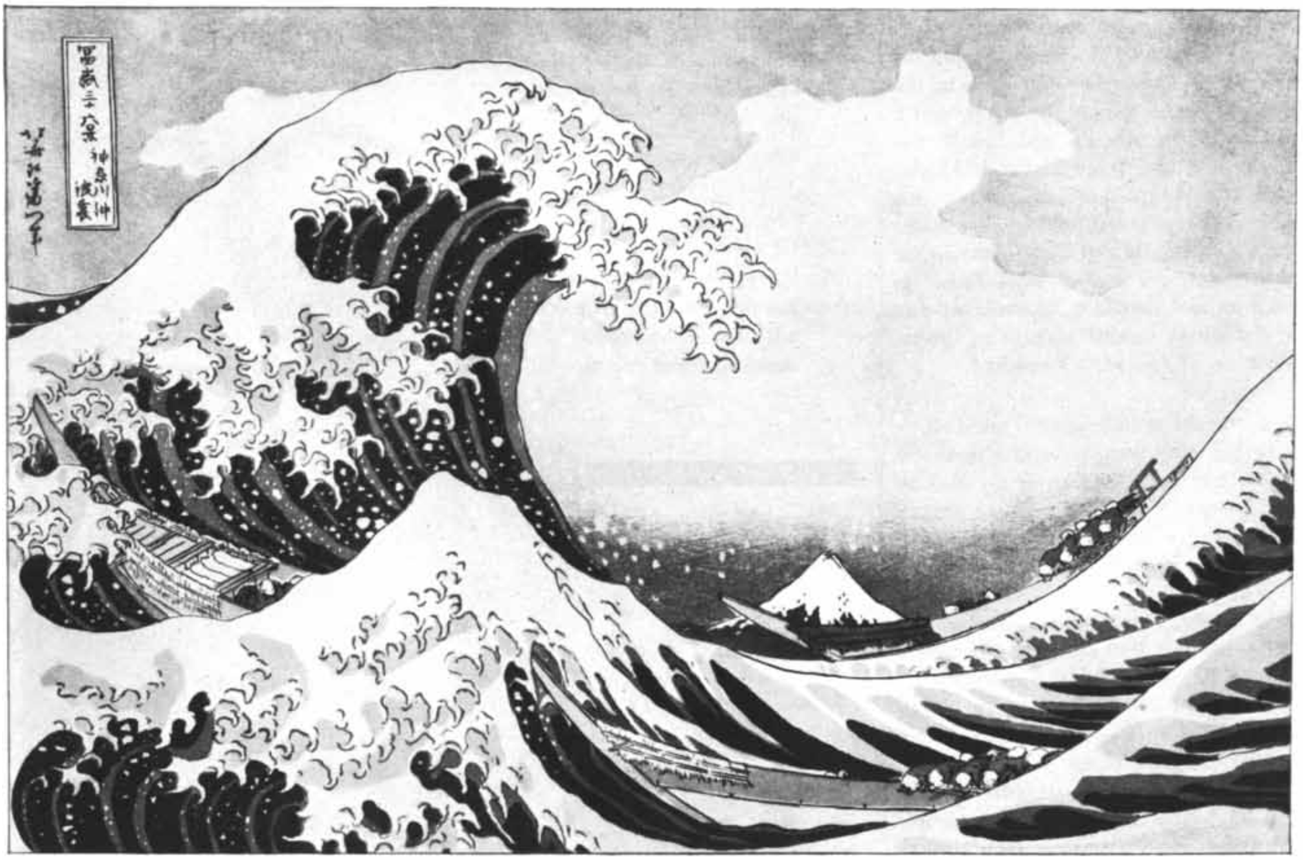
They are huge waves that crash suddenly into a coast. Often called tidal waves, they have nothing to do with tides. They are created by underwater earthquakes or volcanic explosions

by Joseph Bernstein

On the morning of April 1, 1946, residents of the Hawaiian Islands awoke to an astonishing scene. In the town of Hilo almost every house on the side of the main street facing Hilo Bay was smashed against the buildings on the other side. At the Wailuku River a steel span of the railroad bridge had been torn from its foundations and tossed 300 yards upstream. Heavy masses of coral, up to four feet wide, were strewn on the beaches. Enormous sections of rock, weighing several tons, had been wrenched from the bottom of the sea and thrown onto reefs. Houses were overturned, railroad tracks ripped from their roadbeds, coastal highways buried, beaches washed away. The waters off the islands were dotted with floating houses, debris and people. The catastrophe, stealing upon Hawaii suddenly and totally unexpectedly, cost the islands 159 lives and $25 million in property damage.

Its cause was the phenomenon commonly known as a "tidal wave," though it has nothing to do with the tidal forces of the moon or sun. More than 2,000 miles from the Hawaiian Islands, somewhere in the Aleutians, the sea bottom had shifted. The disturbance had generated waves which moved swiftly but almost imperceptibly across the ocean and piled up with fantastic force on the Hawaiian coast.

Scientists have generally adopted the name "tsunami," from the Japanese, for the misnamed tidal wave. It ranks among the most terrifying phenomena known



TSUNAMI near the coast of Japan was depicted by Hokusai, great 19th-century Japanese print maker. The title of the print (*upper left*) is approximately translated: "The crest of the great wave off Kanagawa." In the background is the smooth cone of Fujiyama.

to man and has been responsible for some of the worst disasters in human history. What made the 1946 tsunami especially notable was that a number of oceanographers happened to be in the Pacific (in connection with the Bikini atomic bomb test) and were able to observe it at first hand. It became the most thoroughly investigated tsunami in history, and from it came the development of an effective new warning system by the U. S. Coast and Geodetic Survey.

A tsunami may be started by a sea-bottom slide, an earthquake or a volcanic eruption. The most infamous of all was launched by the explosion of the island of Krakatoa in 1883; it raced across the Pacific at 300 miles an hour, devastated the coasts of Java and Sumatra with waves 100 to 130 feet high, and pounded the shore as far away as San Francisco.

The ancient Greeks recorded several catastrophic inundations by huge waves. Whether or not Plato's tale of the lost continent of Atlantis is true, skeptics concede that the myth may have some foundation in a great tsunami of ancient times. Indeed, a tremendously destructive tsunami that arose in the Arabian Sea in 1945 has even revived the interest of geologists and archaeologists in the Biblical story of the Flood.

One of the most damaging tsunamis on record followed the famous Lisbon earthquake of November 1, 1755; its waves persisted for a week and were felt as far away as the English coast. Tsunamis are rare, however, in the Atlantic Ocean; they are far more common in the Pacific. Japan has had 15 destructive ones (eight of them disastrous) since 1596. The Hawaiian Islands are struck severely an average of once every 25 years.

In 1707 an earthquake in Japan generated waves so huge that they piled into the Inland Sea; one wave swamped more than 1,000 ships and boats in Osaka Bay. A tsunami in the Hawaiian Islands in 1869 washed away an entire town (Ponoluu), leaving only two forlorn trees standing where the community had been. In 1896 a Japanese tsunami killed 27,000 people and swept away 10,000 homes.

The dimensions of these waves dwarf all our usual standards of measurement. An ordinary sea wave is rarely more than a few hundred feet long from crest to crest—no longer than 320 feet in the Atlantic or 1,000 feet in the Pacific. But a tsunami often extends more than 100 miles and sometimes as much as 600 miles from crest to crest. While a wind wave never travels at more than about 60 miles per hour, the velocity of a tsunami in the open sea must be reckoned in hundreds of miles per hour. The greater the depth of the water, the greater is the speed of the wave; Lagrange's law says that its velocity is equal to the square root of the product of the depth times the acceleration due to gravity. In the deep waters of the Pacific these waves reach a speed of 500 miles per hour.

Tsunamis are so shallow in comparison with their length that in the open ocean they are hardly detectable. Their amplitude sometimes is as little as two feet from trough to crest. Usually it is only when they approach shallow water or the shore that they build up to their terrifying heights. On the fateful day in 1896 when the great waves approached Japan, fishermen at sea noticed no unusual swells. Not until they sailed home at the end of the day, through a sea strewn with bodies and the wreckage of houses, were they aware of what had happened. The seemingly quiet ocean had crashed a wall of water from 10 to 100 feet high upon beaches crowded with bathers, drowning thousands of them and flattening villages along the shore.

The giant waves are more dangerous on flat shores than on steep ones. They usually range from 20 to 60 feet in height, but when they pour into a V-shaped inlet or harbor they may rise to mountainous proportions.

Generally the first salvo of a tsunami is a rather sharp swell, not different enough from an ordinary wave to alarm casual observers. This is followed by a tremendous suck of water away from the shore as the first great trough arrives. Reefs are left high and dry, and the beaches are covered with stranded fish. At Hilo large numbers of people ran out to inspect the amazing spectacle of the denuded beach. Many of them paid for their curiosity with their lives, for some minutes later the first giant wave roared over the shore. After an earthquake in Japan in 1793 people on the coast at Tugaru were so terrified by the extraordinary ebbing of the sea that they scurried to higher ground. When a second quake came, they dashed back to the beach, fearing that they might be buried under landslides. Just as they reached the shore, the first huge wave crashed upon them.

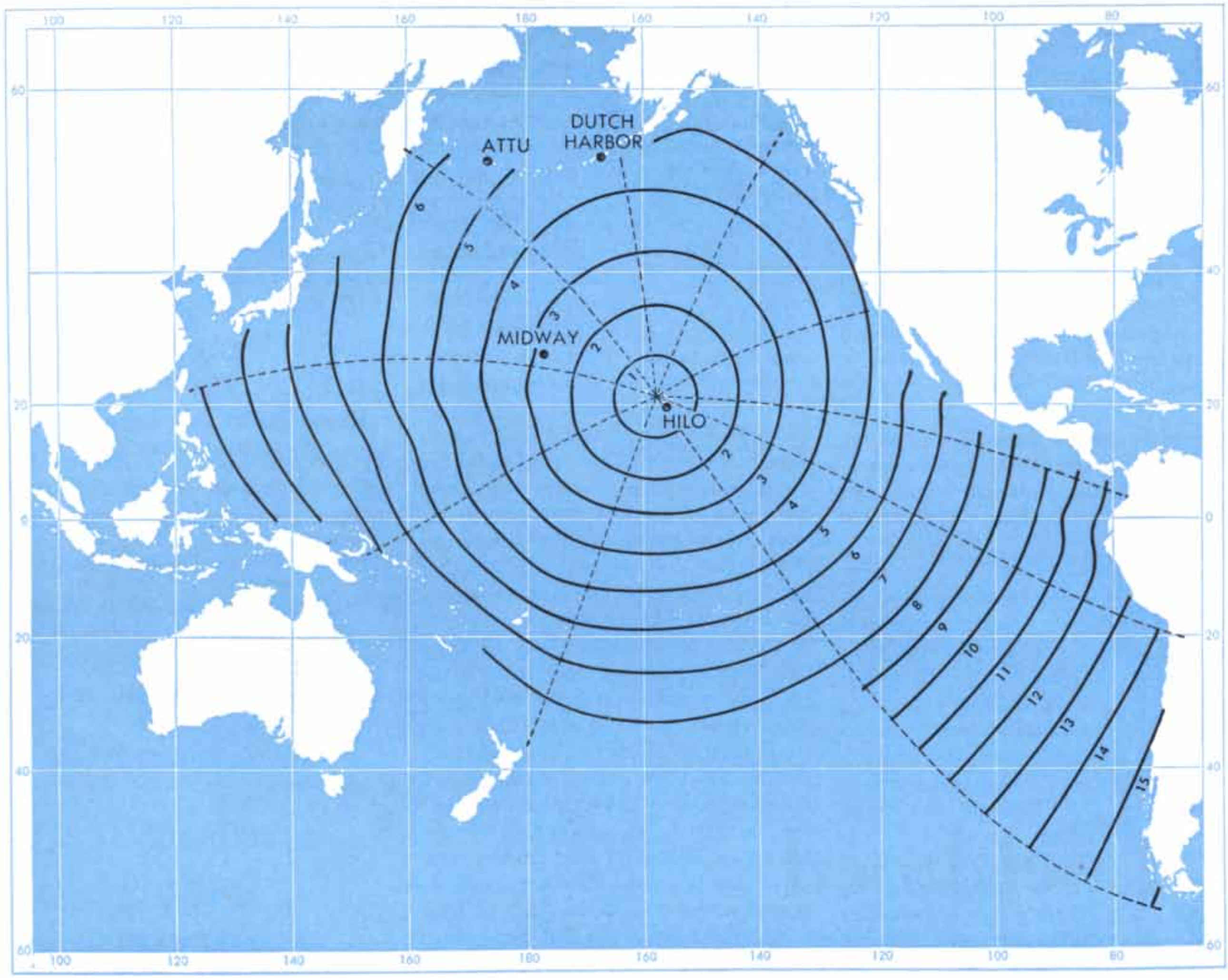
A tsunami is not a single wave but a series. The waves are separated by intervals of 15 minutes to an hour or more (because of their great length), and this has often lulled people into thinking after the first great wave has crashed that it is all over. The waves may keep coming for many hours. Usually the third to the eighth waves in the series are the biggest.

Among the observers of the 1946 tsunami at Hilo was Francis P. Shepard of the Scripps Institution of Oceanography, one of the world's foremost marine geologists. He was able to make a detailed inspection of the waves. Their onrush and retreat, he reported, was accompanied by a great hissing, roaring and rattling. The third and fourth waves seemed to be the highest. On some of the islands' beaches the waves came in gently; they were steepest on the shores facing the direction of the seaquake from which the waves had come. In Hilo Bay they were from 21 to 26 feet high. The highest waves, 55 feet, occurred at Pololu Valley.

Scientists and fishermen have occasionally seen strange by-products of the phenomenon. During a 1933 tsunami in Japan the sea glowed brilliantly at night. The luminosity of the water is now believed to have been caused by the stimulation of vast numbers of the luminescent organism *Noctiluca miliaris* by the turbulence of the sea. Japanese fishermen have sometimes observed that sardines hauled up in their nets during a tsunami have enormously swollen stomachs; the fish have swallowed vast numbers of bottom-living diatoms, raised to the surface by the disturbance. The waves of a 1923 tsunami in Sagami Bay brought to the surface and battered to death huge numbers of fishes that normally live at a depth of 3,000 feet. Gratified fishermen hauled them in by the thousands.

The tsunami-warning system developed since the 1946 disaster in Hawaii relies mainly on a simple and ingenious instrument devised by Commander C. K. Green of the Coast and Geodetic Survey staff. It consists of a series of pipes and a pressure-measuring chamber which record the rise and fall of the water surface. Ordinary water movements, such as wind waves and tides, are disregarded. But when waves with a period of between 10 and 40 minutes begin to roll over the ocean, they set in motion a corresponding oscillation in a column of mercury which closes an electric circuit. This in turn sets off an alarm, notifying the observers at the station that a tsunami is in progress. Such equipment has been installed at Hilo, Midway, Attu and Dutch Harbor. The moment the alarm goes off, information is immediately forwarded to Honolulu, which is the center of the warning system.

This center also receives prompt reports on earthquakes from four Coast Survey stations in the Pacific which are



TIME PLOT of tsunamis endangering the Hawaiian Islands may be made from this chart. When the earthquake epicenter is plotted on it, the circles indicate the time in hours for the seismic sea wave to reach Hawaii. Locations of seismic sea-wave detectors in the warning system are named on the chart. Seismographs are located in Japan, Alaska, Guam and along the coast of North and South America.

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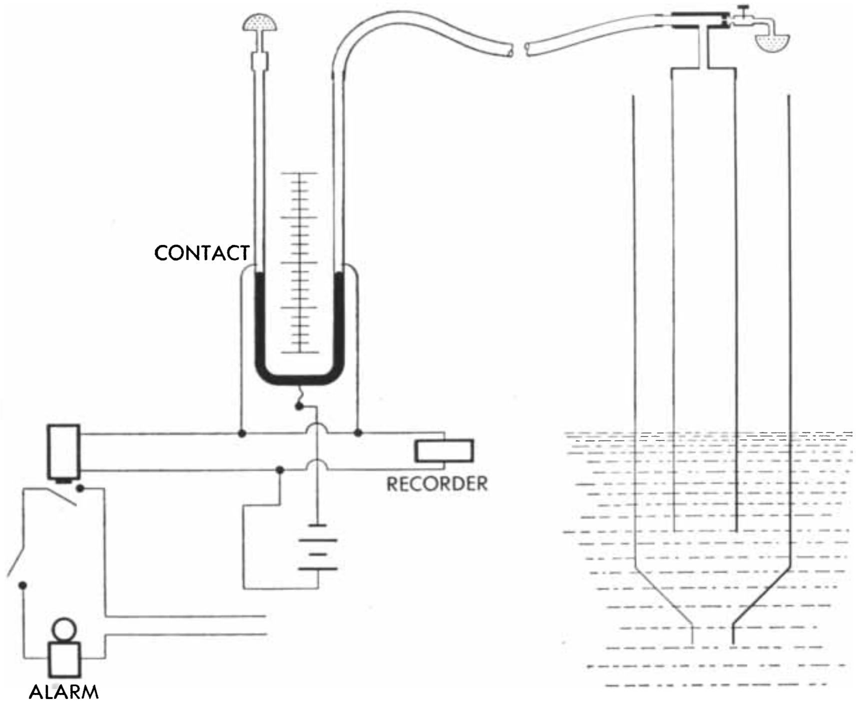

DETECTOR signals the occurrence of a seismic sea wave. An air column in the inner tube at right rises and falls with the tide. A wave of sufficient magnitude increases the air pressure until the mercury in the U-tube is forced around, closing a circuit and sounding an alarm.

equipped with seismographs. Its staff makes a preliminary determination of the epicenter of the quake and alerts tide stations near the epicenter for a tsunami. By means of charts showing wave-travel times and depths in the ocean at various locations, it is possible to estimate the rate of approach and probable time of arrival at Hawaii of a tsunami getting under way at any spot in the Pacific. The civil and military authorities are then advised of the danger, and they issue warnings and take all necessary protective steps. All of these activities are geared to a top-priority communication system, and practice tests have been held to assure that everything will work smoothly.

Since the 1946 disaster there have been 15 tsunamis in the Pacific, but only one was of any consequence. On November 4, 1952, an earthquake occurred under the sea off the Kamchatka Peninsula. At 17:07 that afternoon (Greenwich time) the shock was recorded by the seismograph alarm in Honolulu. The warning system immediately went into action. Within about an hour, with the help of reports from seismic stations in Alaska, Arizona and California, the quake's epicenter was placed at 51 degrees North latitude and 158 degrees East longitude. While accounts of the progress of the tsunami came in from various points in the Pacific (Midway reported it was covered with nine feet of water), the Hawaiian station made its calculations and notified the military services and the police that the first big wave would arrive at Honolulu at 23:30 Greenwich time.

It turned out that the waves were not so high as in 1946. They hurled a cement barge against a freighter in Honolulu Harbor, knocked down telephone lines, marooned automobiles, flooded lawns, killed six cows. But not a single human life was lost, and property damage in the Hawaiian Islands did not exceed $800,000. There is little doubt that the warning system saved lives and reduced the damage.

But it is plain that a warning system, however efficient, is not enough. In the vulnerable areas of the Pacific there should be restrictions against building homes on exposed coasts, or at least a requirement that they be either raised off the ground or anchored strongly against waves.

EDITOR'S NOTE

As indicated in the biographical note on page 12, the author of this article is employed in the U. S. Navy Hydrographic Office. The opinions or assertions contained herein are not to be construed as official or reflecting the views of the Navy Department or this Naval establishment.

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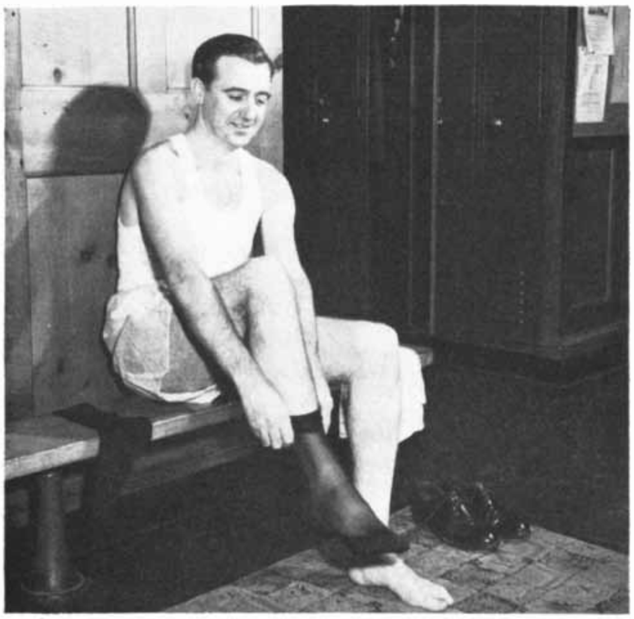

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Shrews

Although these tiny mammals are seldom seen they are remarkably common. Some weigh less than a penny, some possess a deadly venom, some are skilled underwater swimmers. All are voracious and nervous

by Oliver P. Pearson

To most people a shrew is a vexatious, scolding, turbulent woman tamed over and over again in theatrical productions since the time of Shakespeare. To a biologist a shrew is a vexatious, scolding, turbulent mammal (order of insect eaters) that has rarely submitted to taming since long before Shakespeare. Because shrews are extremely tiny, live in burrows and seldom interfere with man's interests and activities, even their unruly personality has failed to bring them to people's attention. Their obscurity is certainly not due to scarcity; in the eastern third of the U. S., for instance, probably the most abundant mammal is a certain species of shrew. More than 30 species are found in North America, and the animal makes its home on every major continent except Australia.

The American shrews resemble small moles (to which they are related) and earless mice (no relation). They have long, pointed noses, tiny eyes and velvety fur. Some of them are astonishingly small, weighing less than a penny. The shrew's plushlike fur is well-suited to its life in burrows, for no matter in which direction the animal goes its hair does not muss. Its eyes are almost hidden in its fur. It has little need of them, as a matter of fact, for it spends practically all of its time in dark tunnels or thick vegetation, where it must rely primarily on hearing (which is good despite its negligible ear lobes), on smell and on tactile stimuli, received by sensitive whiskers near the tip of its nose. Shrews move about constantly, quivering their nose nervously and sometimes keeping up a faint, thin, high-pitched twittering. Some individuals of the common short-tailed species when cornered throw their head back, open their mouth and utter a long, shrill chatter that sounds like the song of the Tennessee warbler.

The shrew's living requirements are moisture, cover and a supply of small invertebrates and seeds for food. It is so small that it can make its home in leaf-mold, grass, sphagnum or marsh plants, where it digs a tunnel or makes a leafy nest. It lives in such diverse environments as forests, meadows, bogs and salt marshes. Shrews like deciduous forests that are rich in leaf litter and rotting logs. Rolling aside one of these logs frequently discloses a shrew tunnel or nest. The little animal finds plenty of worms, grubs and insects within its tunnel and runways, but it must also scurry out at frequent intervals for nuts and seeds to fill out its diet.

So elusive are shrews that even experienced investigators seldom see them in the wild. About the only way to get a look at them is to capture them in mousetraps. Traps placed at their runways and other favorable spots will catch a fair number, but the captures give no true idea of the actual shrew population, for some of the species are trap-shy. I trapped for many years in suburban Philadelphia, using all sorts of ingenious (I thought) traps, without catching a single shrew of the species *Cryptotis parva.* Yet I discovered that barn owls were catching these little shrews in the same area. The first specimens of Cryptotis ever found in Canada were discovered (still alive) in the stomach of a milk snake. Some years ago Marcus Lyon, an Indiana mammalogist, reported that in many years of trapping he had captured only one Cryptotis in that state. But on Christmas Day, 1949, a hawk shot in Wayne County, Indiana, had in its digestive system the remains of 27 Cryptotis!

Shrews are noted for their nervous restlessness, and there is good reason for this. As the smallest living mammals, they have the highest rate of metabolism, for the "living" rate of animal tissue goes up as animal size goes down [see "The Metabolism of Hummingbirds," by Oliver P. Pearson; SCIENTIFIC AMERICAN, January, 1953]. One of the smaller species of shrew, *Sorex cinereus,* metabolizes four times as fast as a mouse per gram of tissue. To support their high rate of metabolism shrews must devour enormous quantities of food. To be impressed by the appetite of the shrew, you need only capture one and try to keep it fed. You will soon weary of any attempt to catch enough worms, grubs and insects to satiate it and will have to resort to teaching the shrew to eat dog food and ground meat. One man found that his 3.6-gram Sorex consumed in eight days more than 93 grams of food—earthworms, rolled oats, mice, sow bugs, grasshoppers, snails, fish and whatnot. The shrew ate on the average 3.3 times its own weight per day. C. Hart Merriam, a pioneer American mammalogist, once confined three Sorex under a glass tumbler. Two of them promptly attacked and devoured the third. Eight hours later only a single shrew, with slightly bulging stomach, remained. The tiny cannibal had transmuted both of its companions into a small heap of droppings and a few calories of wasted heat.

Such voracity is ordinarily directed toward small invertebrates, but *Blarina,* one of the larger shrews, frequently eats mice two or three times its own size. It readily kills big meadow mice. A. F. Shull, a member of the famous family of Midwest biologists, once found a Blarina nest made exclusively of mouse hair. Beside this nest were two freshly killed meadow mice and the body of a third half-eaten, and nearby lay several handfuls of hair in which were mixed the legs and tails of about 20 more. Shull was prompted to attempt an estimate of the predatory impact of shrews on meadow mice. Assuming that mice made up about 40 per cent of the diet of these shrews, he calculated that each shrew would consume about eight mice per month. Figuring a population of four shrews per acre, on a 100-acre farm the total number of mice consumed by shrews in a year would be 38,400!

Such "headlong" statistics are frequently full of pitfalls, but in this case may not be far misleading. Recent studies by Robert Eadie, a Cornell zoologist, support Shull's conclusions, if not his statistics. Eadie, like other collectors, had frequently been humiliated by having shrews invade his mousetraps and escape, leaving their droppings on the floor. Making the best of this frustrating discovery, he left large numbers of paper squares about to collect shrew droppings, usually hard to find. After analyzing the content of the droppings over many seasons, he concluded that Blarina shrews catch large numbers of meadow mice, even in years when the mice are scarce, and probably are important regulators of the meadow-mouse population.

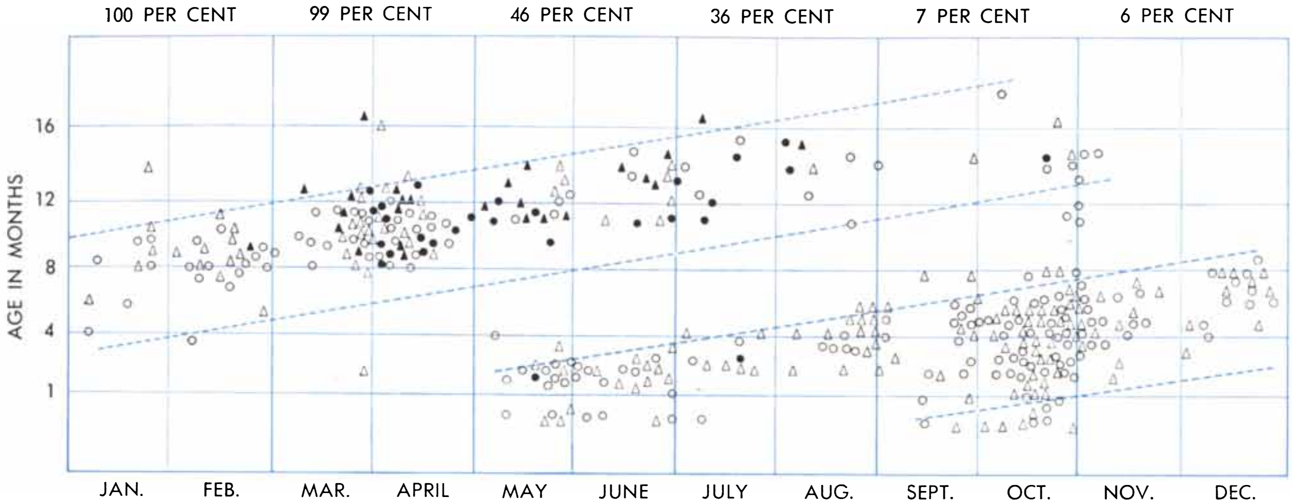
Blarina possesses a venom that helps to subdue its prey. As far as we know it is the only mammal with a poisonous bite, although some European and African shrews are suspected also. Its venom is powerful enough to kill a human being if injected into the bloodstream, but the animal lacks an effective injection mechanism. Unlike poisonous snakes, it has no hollow fangs; the poison seeps into its bite from a groove between its long lower incisor teeth. This mechanism seems to be adequate to kill a mouse but not an animal as large as a rabbit.

Nonetheless, European folklore is full of references to the toxicity of shrews and to spectacular remedies applied to people bitten or bewitched by them. One account appears in a fascinating compendium by a 17th-century clergyman named Edward Topsell, entitled *The History of Four-footed Beasts and Serpents: describing at large their true and lively Figure, their several Names, Conditions, Kinds, Virtues* (*both Natural and Medicinal*), *Countries of their Breed, their Love and Hatred to Mankind, and the wonderful work of God in their Creation, Preservation, and Destruction. Interwoven with curious variety of Historical Narrations out of Scriptures, Fathers, Philosophers, Physicians, and Poets: Illustrated with divers Hieroglyphicks and Emblems, &c., both pleasant and profitable for Students in all Faculties and Professions.* Concerning shrews the reverend wrote:

"It is a ravening Beast, feigning itself gentle and tame, but, being touched, it biteth deep, and poysoneth deadly . . . There is nothing which do more apparently explain and shew the biting of a Shrew then a certain vehement pain and grief in the creature which is so bitten, as also a pricking over the whole body, with an inflammation or burning heat going round about the place, and a fiery redness therein, in which a black push or like swelling with a watery matter, and filthy corruption doth arise, and all parts of the body which do joyn unto it seem black and blew with the marvellous great pain, anguish, and grief, which ariseth and proceedeth from the same."

In 1889 a New England naturalist, C. J. Maynard, also reported, though less vividly, the effects of a bite on the hand while he was trying to capture a Blarina shrew. His skin was slightly punctured in a number of places. Within 30 seconds he felt a burning sensation,

COMMON SHREW *Sorex personatus* attacks a large beetle. A single shrew has been observed to eat 3.3 times its own weight per day. Some shrews regularly eat mice two or three times larger than they are. In the absence of other food, shrews will eat each other.



AGE DISTRIBUTION in a wild population of short-tailed shrews sampled by trapping through the year is plotted in this chart. The circles represent females; the triangles, males. The solid circles and triangles indicate breeding individuals. At the beginning of winter only 6 per cent of the population is more than a year old. The age of the animals was estimated by the wear of their teeth.

and soon afterward shooting pains ran up his arm. The pain and swelling reached a maximum in about an hour. He could not use his hand without great suffering for three days and felt considerable discomfort for more than a week afterward. His report of the incident was published in an obscure journal at a time when Pasteur's work on rabies and "microbes" held the center of attention. Sophisticated scientists of the day attributed Maynard's symptoms to microbes and dismissed the idea that the shrew had injected a poison.

Actual proof of the toxicity of shrews came only a few years ago. In the course of a joint reconnaissance of the microscopic anatomy of the common short-tailed shrew of the eastern U. S., George Wislocki, eminent anatomist of the Harvard Medical School, pointed out to me an unusual group of cells in the microscopic tubules of the shrew's submaxillary salivary glands (below the lower jaw). It seemed worth while to test these cells as a possible source of venom. Extracts from the glands, made by grinding them in salt solution, were injected into mice. They proved highly lethal to the mice. In fact, only one 200th of the submaxillary extract from a single Blarina will kill a white mouse within a few minutes when injected into its bloodstream. The gross symptoms are labored breathing, protruding eyes and convulsions.

Some standard pharmacological tests were then applied to cats and rabbits with the help of Otto Krayer, professor of pharmacology at the Harvard Medical School. The shrew venom had a dramatic effect on the heartbeat, blood pressure and respiration of the animals. A three-pound rabbit succumbed in less than five minutes to an intravenous injection of extract from only 10 milligrams of submaxillary tissue. One shrew provides more than seven times this much venom. There seems little doubt that the venom could kill a human being if injected intravenously.

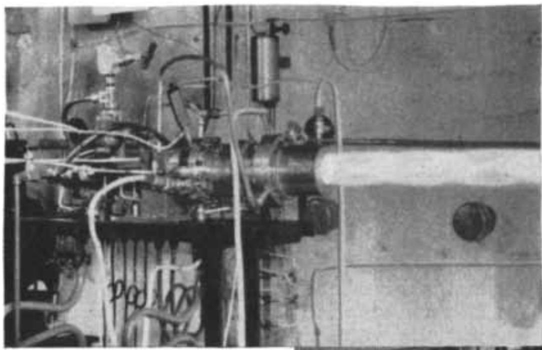
Despite their abundance shrews are not exceptionally prolific. A female of the short-tailed species, for example, has no more than two or three litters in a year—one or two in the spring and, if she survives, another in the summer. The average size of the litter is around five. Females born in the spring mature rapidly and soon can reproduce, but those born in the autumn do not reproduce until the following spring.

In captivity shrews can live more than two and a half years. In the wild, however, they age rapidly and encounter so many hazards that few live to be a year old. Among a sample of short-tailed shrews marked and released in the summer only a little more than 6 per cent survived until the following summer. And since a large number of young perish even before they are weaned or are old enough to be caught, marked and released, it is safe to say that the life expectancy of a shrew at birth is not more than a few months. Survival of the species is left to the immature, inexperienced generation that lives over the winter—a situation reminiscent of many species of insects, whose adults perish by the end of the season and entrust the preservation of the race entirely to larvae and pupae.

There has been some dispute about whether shrews die more commonly of old age or of violence. The facts that their tissues live at a rapid rate and that the uneaten bodies of dead shrews are sometimes found lying about in the woods and fields (more often than the bodies of dead mice) seem to suggest that many die of old age. However, nearly all the shrew carcasses I have found have shown clear evidence, beneath their fur, of a violent death. A record of the age distributions of samples of the shrew population trapped in various months of the year shows a high attrition among all groups, young and old, as the year goes on [*see above*].

The simplest explanation of the carcasses found in nature is that shrews are unpalatable to many predators. They have powerful scent glands in the skin. The short-tailed shrew gives forth a particularly offensive odor from oily skin glands on each side and along the midline of the belly. The odor seems to become stronger when the shrews are excited or angry. It renders shrews less palatable to foxes, cats, weasels and probably to many other animals that prey on shrews. It offers no protection against hawks or owls, however, because they have no sense of smell.

In the Blarina genus of shrews, females in the breeding stage have less well-developed scent glands than the rest of the population. This is rather surprising, because for the sake of the population those females are the most in need of protection against predators. Probably the answer is that the scent glands also serve another purpose—a social one. A wandering male shrew encountering an unscented runway or tunnel may assume that it is either vacant or occupied by a breeding female, and so not



How to watch a dozen test variables at once

INSTRUMENTATION FOR ROCKET PERFORMANCE STUDIES *utilizes this panelof Honeywell instruments at Purdue University's Rocket Testing Laboratory. Dr. Zucrow, noted leader in the field of rocket research, is shown calibrating pressure measurement to* ***ElectroniK*** *recorder during engine test. Small picture shows a typical rocket engine under test.*

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hesitate to enter. On the other hand, males are heavily scented during the breeding season. The scent, rubbing off on their burrows, may serve both to attract breeding females and as a keep-out sign to others. Birds use song in the same way, and male dogs stake territorial claims by scenting tree trunks and other objects.

One of the most interesting and unusual shrews is a water species (*Sorex palustris*) which lives along cold streams in mountainous parts of the U. S. and in Canada. It catches fish and aquatic insect larvae under water and is an excellent swimmer, propelling itself with long alternate strokes of its big hind feet plus some assistance from its front paws. On the surface it can swim at about two feet per second, and when startled or under water it appears to go much faster. It can leap at least its own body length out of the water. Streaking past a trout fisherman's feet under water, it looks like a mercury-coated mouse, for its fur traps a silvery film of air. It seldom stays under water for more than a few seconds, but even this brief holding of its breath is impressive in an animal which normally breathes several hundred times per minute.

Konrad Lorenz, in his charming book about animals, *King Solomon's Ring*, tells of a family of captive European water shrews which memorized a particular pathway in their cage. They scurried unhesitatingly along this path, like a locomotive on its track, until some minor rearrangement was made in the pathway, whereupon the shrews were thrown into confusion. At one point on the route the shrews were accustomed to jump onto a pile of small stones and then off the other side. When the stones were removed, shrews coming along the path jumped into the air at the appropriate place but landed on the floor of the cage with a disconcerting bump. Then, despite the fact that their vision is good enough to see obstructions, the shrews made their way back onto the accustomed pathway and with restored confidence repeated the pointless leap. Although this behavior appears to demonstrate gross stupidity, it should be pointed out in the shrew's favor that its remarkable path-memory normally releases its other senses for more important activities. Its substitution of habit for reason may seem unenlightened to us, but the abundance and success of shrews throughout the world are strong evidence that in the shrew's case the substitution is effective.

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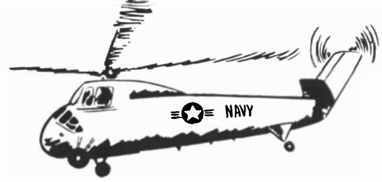

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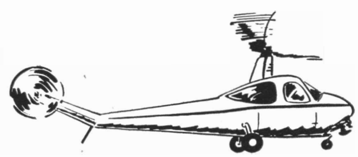

Lycoming-powered Glenview FlyRide
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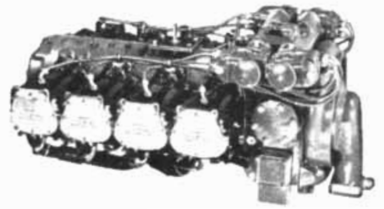

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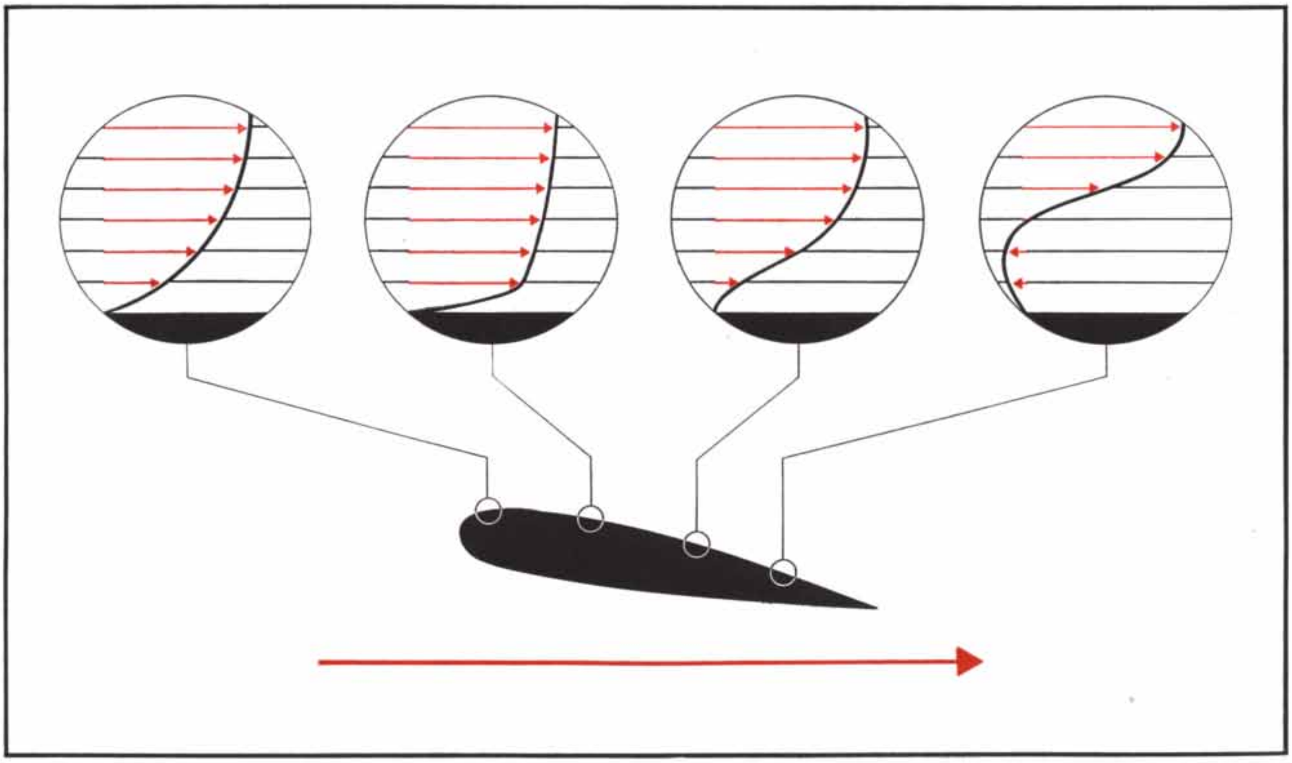
THE BOUNDARY LAYER

It is a thin region on the surface of an airplane wing where air is subject to frictional forces. By perforating the wing the thickness of the region can be controlled and flying characteristics improved

by Joseph J. Cornish III

An airplane flying through the atmosphere is sheathed with a film of air which it must drag along in its flight. A submarine gliding beneath the sea carries with it a similar mantle of water. There is nothing exotic about this phenomenon: when you pour syrup from the pitcher over your pancakes at breakfast, you can easily see the film of syrup clinging to the side of the pitcher. We are dealing with the common problem of the friction that occurs whenever a viscous fluid flows over a surface. Probably the most familiar form of the problem is the flow of water and other liquids through pipes: everyone knows that it takes powerful pumps to keep the liquid moving against the resistance of friction with the pipe walls.

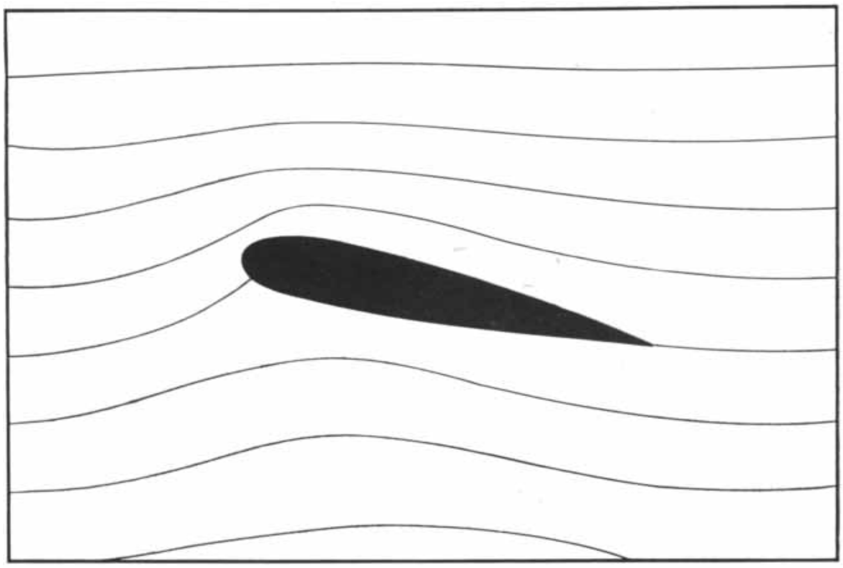
A ship trying to plow through a sea of molasses would have a rather hard time of it. The "syrup" through which an airplane flies is a good deal thinner, but air does have an appreciable viscosity. At the high speeds of modern flight, the friction effects of the air's viscosity become one of the most formidable problems in aerodynamics. Fortunately the problem is somewhat simplified by a most important discovery made in 1904 by a German physicist, Ludwig Prandtl of the University of Göttingen. He showed that all the viscosity effects are confined to a thin layer next to the surface of the moving body (or of a stationary body past which a stream of fluid moves). At the surface itself the frictional force causes the particles of the fluid to stick to the body and move



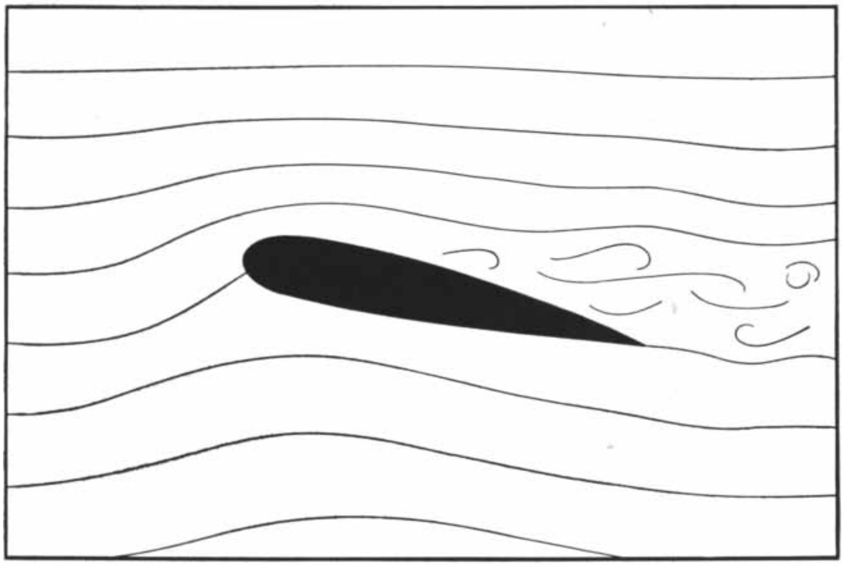
ENLARGED SECTIONS depict the profile of the boundary layer on an airfoil from which the flow separates. The relative speed of the air is represented by the length of the colored arrows. The first section shows a profile typical of laminar flow. The second section shows a turbulent boundary-layer profile. Here there is a more uniform velocity distribution because of the mixing action of turbulence. The third section shows the profile at the point of separation. The fourth shows the profile of the separated region.

with it. In other words, there the relative motion, or velocity, of the fluid and the surface is zero. Away from the surface there is an increasing difference in relative motion between the body and the fluid stream. This is simple enough to see if you press your hand on a thick book lying on a table and push horizontally: the pages closest to the table do not move, but those above slide past each other, and the distance they move increases with distance from the table.

Prandtl demonstrated that the gradients of motion between an object and a moving fluid were restricted to a thin region which he called the boundary layer. Outside this layer the surrounding fluid flows without any frictional resistance. Within the layer there is an increasing difference of velocity between the object and the fluid from the surface out to the limit of the boundary layer. In the case of a flying airplane the boundary layer of air is usually less than one inch and seldom more than a few inches thick. Aerodynamicists studying the effects of viscosity or drag can concentrate their attention on this narrow zone.



IDEAL FLUID flows smoothly around an airfoil, shown in cross section by this drawing. There is no boundary layer, and the fluid is in contact with the airfoil at all points.



REAL FLUID may pull away from the surface of the airfoil and leave a turbulent wake. The fluid in the boundary layer has suffered a loss of momentum because of viscosity.

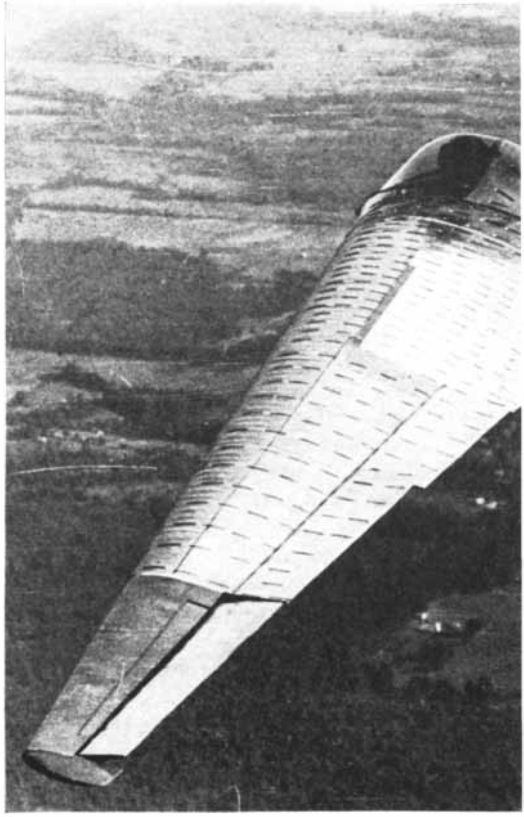
The profile of the boundary layer has been thoroughly probed with a simple instrument called the "mouse," which usually consists of a battery of the well-known pitot tubes, invented by the 18th-century Frenchman Henri Pitot to measure air speed. The velocity profiles of boundary layers under various conditions provide information for computing their characteristic thicknesses and shapes.

One important reason for close study of the boundary layer is that it has a great deal to do with an airplane's stalling and landing speed. As air flows over an airplane wing, the boundary layer grows thicker and thicker; eventually it may become thick enough to deflect the main flow of air away from the surface. If the flow separates from a large portion of the wings, they lose their lifting power and the airplane stalls. Obviously an airplane can fly no slower than its stalling speed. Thus the boundary layer dictates the lower limit of speed at which a plane can fly or land.

This same phenomenon of separation limits the top speed of helicopters. The flow of air over the rotor blades of a helicopter is much the same as the flow over the wings of a plane, and the rotors are similarly subject to flow separation and stalling. When a helicopter is flying forward, the velocity of the air over the retreating rotor blade is decreased by the forward speed. If the forward speed is high enough, the velocity over the retreating blade may be decreased to the stalling speed, in which case the rotor will no longer support the helicopter. Thus the separation caused by the boundary layer limits the speed at which the craft may fly. Surveys of the boundary layers on various types of surfaces and wings have yielded a wealth of information leading to the prevention or at least the delay of this separation.

The most direct effect of the boundary layer of course is its frictional, or shearing, force on the moving body. This force is responsible for a large part of the "drag" of modern high-speed airplanes. The drag due to friction is usually rather easy to calculate from an examination of the boundary layer if the air flow is laminar: *i.e.*, if the strata of different-velocity air in the boundary layer (analogous to the pages of a book) slide smoothly past each other. But it is much more difficult to measure when the boundary layer is turbulent.

Osborne Reynolds, the British physicist who first distinguished between laminar and turbulent flow, showed that one often passes into the other. Observe the smoke rising from a cigarette in still air. It drifts upward in smooth, continuous filaments for a distance; then the filaments begin to oscillate, and finally



FLYING-WING SAILPLANE built in Germany during World War II was photographed during a test at Mississippi State College. The upper surface of the sailplane

they erupt into boiling turbulence. This phenomenon of transition to turbulent flow very often occurs within a boundary layer after the air has moved over the surface for some distance; the smooth flow may break down into random turbulence, even when the air flow outside the thin boundary layer is still laminar.

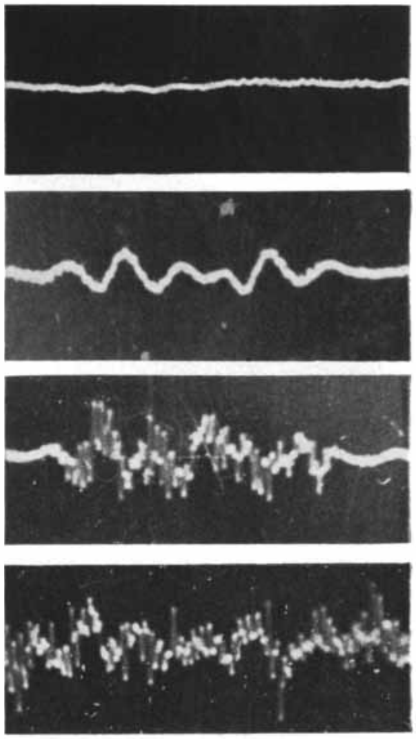
In laminar flow, friction is transmitted from layer to layer only on the molecular scale. When the flow becomes turbulent, the frictional force increases greatly, because now there is added the resistance due to the exchange of momentum between the mixed streams of different velocities. We can visualize the difference between the two kinds of friction in a simplified way by imagining a boxcar rolling down a railroad track so close to a warehouse that the car scrapes against the wall of the building. This friction may be thought of as the laminar type. Now imagine that, as the car slides past the warehouse, bundles are thrown from the boxcar into the building and from the building into the car. This passage of bundles to and fro represents the transfer of mass and resultant exchange of momentum that takes place between strata in a turbulent boundary layer.

All this makes clear why it is so im-

has been covered with tufts of nylon yarn in order to observe the regions of separated flow. The disorder of the tufts behind the pilot's canopy indicates a separated area.

portant, from the standpoint of minimizing drag, to preserve laminar flow over an airplane wing. Innumerable studies and experiments have been devoted to this subject, exploring the effects of stream velocity, surface curvature, waviness and roughness. Laminar stability is one of the most fascinating aspects of boundary-layer research.

In a brilliant theoretical analysis two students of Prandtl deduced that under certain conditions a laminar boundary layer may amplify slight disturbances that occur within it. These men, Walter Tollmien and Hermann Schlichting, reasoned that at a certain thickness and flow velocity the boundary layer would act as a spring. Any tiny impulses—arising from minute eddies in the flow or from slight roughnesses on the surface—which were received at the natural frequency of the "spring" would cause the boundary layer to oscillate more and more until its smooth flow erupted into turbulence. Tollmien and Schlichting's prediction was later confirmed experimentally by workers at the U. S. National Bureau of Standards; the oscillations are now generally known as Tollmien-Schlichting waves. It is this finding that revealed to aircraft designers the im-



OSCILLOSCOPE TRACES reveal velocity fluctuations in the boundary layer. The top photograph shows the very slight fluctuations that may occur in a boundary layer as a result of wind-tunnel turbulence. In the second photograph some of the fluctuations have been amplified to form Tollmien-Schlichting waves. The third photograph shows a burst of turbulence superimposed on the Tollmien-Schlichting oscillations. The last photograph shows the random turbulence found in a boundary layer.

portance of making airplane surfaces as smooth as possible, free from the slightest roughness or waviness. To prevent the growth of the boundary layer to too great thickness, designers streamlined all parts of the plane and made all protuberances, such as landing wheels, retractable into the body of the plane during flight.

But with the ever-increasing demand for higher top speeds, lower landing speeds and longer ranges, the boundary layer has become harder and harder to deal with. Its twin effects—frictional drag and separation of flow—continue to be the bane of the aerodynamicist.

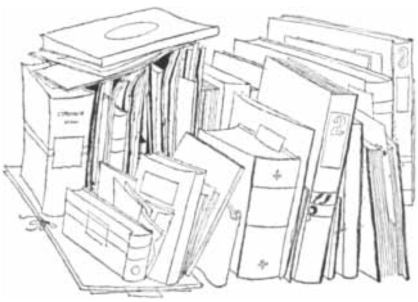
The great problem is to reduce the frictional losses in the boundary layer. Tollmien and Schlichting showed that if the boundary layer could be kept stable, it would damp out any disturbances, instead of amplifying them, and thereby keep the flow laminar.

The most exciting current development in aerodynamics is the application of an idea which actually was originally suggested by Prandtl, the father of the boundary layer. His idea was this: If the surface to which the film of air clings is made porous, the slowed air immediately next to the surface may be continuously sucked away; thus the boundary layer will be prevented from growing thicker as fast as it might otherwise. This simple idea has recently been developed by a number of investigators, among them August Raspet and Bruce Carmichael at Mississippi State College, Werner Pfenninger at the Northrop Aircraft Company and G. V. Lachmann in England. They have experimented with wings made of porous materials or perforated with small holes and slots. The air is sucked into the interior of the wing, conducted by ducts to a pump and then expelled from the airplane.

Already the idea has shown some spectacular results. At Mississippi State College a glider of 50 feet span was equipped with a wing which had been perforated with more than a million tiny holes. Suction through these holes increased the lifting ability of the glider 70 per cent and reduced its landing speed by 25 per cent. The suction system used only two horsepower. An increase in lift of course allows a plane to carry more payload, and a decrease in landing speed enables it to use a shorter runway. These improvements were accomplished solely by means of the suction system.

Control of the boundary layer may help to solve the problem of the overheating of airplanes by friction at supersonic speeds [see "The Heat Barrier," by Fritz Haber; Scientific American, December, 1953]. At the speed frontier we have now reached, airplane flight faces a seemingly insuperable dilemma: to avoid excessive frictional heating, airplanes have to climb to the thinner air of higher and higher altitudes, but unfortunately they will soon reach the limit beyond which present planes cannot climb in the rarefied air without stalling. As a way out of this predicament, it has been suggested that the wing area of the airplane be increased to give it more lift per unit of weight. This, however, would make the plane large and unwieldy. Boundary layer control by suction would help in two ways: it would reduce the heating due to friction, and it would lower the stalling speed of the airplane by preventing flow separation.

More and more aircraft designers and manufacturers are becoming interested in the benefits afforded by boundary-layer control, and research on the subject is now very active.



BOOKS

An admired French work, now available in English, about the theories of physics

by Max Black

THE AIM AND STRUCTURE OF PHYSICAL THEORY, by Pierre Duhem, translated by Philip P. Wiener. Princeton University Press ($6.00).

Duhem's book on the philosophy of science, originally published in 1906 and reprinted in 1914, is still widely read and admired in Europe. For interest, mastery of style and power to stimulate, it ranks with the writings of Claude Bernard, Emile Meyerson and Henri Poincaré. It is surprising that we should have had to wait so long for this welcome translation of his work (titled in French *La Théorie physique: son objet, sa structure*).

Like many of the best modern writers on the philosophy of science, Duhem was himself a productive scientist. When he died in 1916, at the age of 55, he had written treatises on hydrodynamics, elasticity, acoustics, electricity and magnetism, physical chemistry and thermodynamics. He was a devoted teacher of physics who yet found time to become a first-rate historian of science, working from primary sources and producing original studies of great value. His contributions to our knowledge of science in the Middle Ages are especially important. His historical writings include a history of statics, a long book on Leonardo da Vinci and a massive history of cosmological theories (*Le Système du monde: histoire des doctrines cosmologiques de Platon à Copernic*), of which five volumes had been published at his death, with four more nearly complete.

Duhem must have been a man of extraordinary energy. The charming biography of him (*Un savant français—Pierre Duhem*) by his daughter Hélène gives us a picture of a very strong character—forthright, single-minded, self-assured. He was a devout Catholic, charitable and unaffected in private life, a man of the extreme Right in politics. He knew almost by heart the Gospels, *The Imitation of Christ* and Pascal's *Pensées*. His philosophy of science is saturated with the influence of Blaise Pascal, the great 17th century mathematician and philosopher.

At the time Duhem's book first appeared, scientists with philosophical interests were revolting against the optimistic dogmatism of the 19th century. Poincaré and Ernst Mach, to name only the most eminent rebels, were denying that scientific laws and theories were reflections of an objective reality; theories, they said, were merely instruments for ordering and classifying experience. This definition of scientific theory is one of the main planks of Duhem's own philosophy of science.

By a "theory" Duhem seems to mean something more general and more abstract than a "law," although he often interchanges these two terms confusingly. At any rate, he makes a rough distinction between a generalization at the level of observation or experiment (*e.g.*, that sodium chloride combines with sulfuric acid to produce hydrochloric acid) and a higher-level abstraction (*e.g.*, the principle of conservation of energy). Let us use "law" for the first kind of generalization and "theory" for the second, though it is by no means clear that a sharp line can be drawn between "laws" and "theories"—it is a pity that Duhem ignored this point.

Now Duhem's contention is that physical "theories" must be expressed in mathematical terms and are to be regarded as artificial constructions having no direct connection with reality and, strictly speaking, incapable of being true or false. "A physical theory," he says, "is an abstract system whose aim is to *summarize* and *classify logically* a group of experimental laws without claiming to explain these laws." Theories, unlike laws, are approximate, provisional and "stripped of all objective reference." Science "is acquainted only with sensible appearances," and we must shed the illusion that in theorizing we are "tearing the veil from these sensible appearances"; theory is at best a marvelous mathematical technique for condensing and presenting in handy form our knowledge of observational regularities.

Duhem is extremely critical of his great predecessors who thought that physics provided insight into the nature of reality; Aristotle, Newton, the atomists and the Cartesians all made this serious blunder. If we think that theories *explain*, rather than summarize and classify, we inevitably become metaphysicians, he claims. And the trouble about metaphysics is that one man's self-evident truths are another's arbitrary assumptions. The properties that appear "clear and distinct" to one school will be stigmatized as "occult" by their opponents. In any case, metaphysics is an insufficient base for physics, because arbitrary hypotheses always have to be invoked to derive the specific empirical laws from the abstract and universal metaphysical principles that are supposed to explain them. (Pascal made the same point.) Duhem illustrates all this at length from his unrivaled knowledge of the history of science. The moral is that physics must be freed of all connection with metaphysics, and this can be done only if we take a modest, positivistic view of the scope and function of physical theory.

To anybody who has read other positivists of the late 19th or the early 20th century, this will be a familiar story. Mach said that a scientific theory is a "collection of as many facts as possible in a synoptical form." And Karl Pearson put the matter still more succinctly when he called scientific theory "mental shorthand." Duhem followed Mach in making much of the supposed "intellectual economy" achieved by "condensing a multitude of laws into a small number of principles."

There is certainly something attractive about this view of physical theory, especially to somebody who like Duhem was anxious to set limits to the overweening metaphysical pretensions of science. If theory is merely a mathematical device for the summarizing of laws, the problem of the relation of theory to reality disappears. And by restricting science to the organization of "sensible appearances," the way is clear for the appeal to those reasons of "the heart" of which Pascal spoke so eloquently. When science becomes humble in its metaphysical pretensions, theology can have a field day.

Duhem faithfully reflects Pascal's ambivalent attitude toward science, and, indeed, toward the use of reason in general. Admiring the achievements of physical science as he does, he is yet anxious to insist on the limitations of both the raw material and the finished product of science. Descartes was quite wrong in supposing a scientist could start from clear and self-evident ideas: what seems obvious to common sense is itself the result of "an enormous and prodigiously active association formed by the union of human minds," that is, the scientific geniuses whose discoveries have gradually become part of "the patrimony of truths common to all men." And so we have to start with generalizations which are "confused, complex and disorderly," even though endowed with direct confirmability. And when a scientist of genius brings mathematical order and clarity into this confusion, he achieves his aim only at the expense of replacing relatively intelligible concepts by symbolic abstractions which reveal nothing about the true nature of the universe. The scientist may take pride in the magnitude of his intellectual achievement, but he must be modest enough to realize that his conclusions have no bearing upon metaphysics or theology. It is significant that Duhem ended his book (in the original edition) by applying to the scientist these words of Pascal: *S'il se vante, je l'abaisse; s'il s'abaisse, je le vante* ("Does he exalt himself; I lay him low. Does he humble himself; I exalt him.") And he would surely have said amen to another of Pascal's sayings: "The last step that Reason takes is to recognize that there is an infinity of things beyond it."

Will Duhem's view of theory as a summary and classification of experiential laws survive critical examination? I think not. In order to summarize a speech, we need to know the full speech, and the summary must contain no additional matter, on pain of being rejected as defective. Now one of the most striking things about physical theory is its *predictive power:* its value to the scientist is not merely that it ties up bundles of laws already in his possession but that it leads to the promulgation and confirmation of laws which could never have been detected without its help. It is a remarkable sort of "summary" that vastly extends the scope of the original text and leads to the discovery of previously unsuspected postscripts.

The notion of "classification" is equally shaky. It is a very superficial view of theory to suppose its purpose to be merely that of grouping laws into arbitrary classes. A successful theory does bring previously disconnected laws into relation with one another, but it does so because it establishes logical connections between them. The "classification" of which Duhem speaks seems a mere by-product of the system of logical relationships which a good theory brings to light.

Duhem was aware of such difficulties. The fact that he repeatedly speaks of "logical" classifications shows awareness of the part played by theory in spinning a web of logical relationships, though he does not elaborate the point. Furthermore, his recognition of the predictive power of theory leads him in the end to a very important revision of his positivistic principles. The "classification" achieved by means of theory cannot, after all, he says, be as arbitrary as we had supposed at the outset, else it would be a miracle that we should be led to make new discoveries by its means: "If the theory is a purely artificial system . . . but fails to hint at any reflection of the real relations among the invisible realities, we shall think that such a theory will fail to confirm a new law. That, in the space left free among the drawers adjusted for other laws, the hitherto unknown law should find a drawer already made into which it may be fitted exactly would be a marvelous feat of chance."

So Duhem ends, after all, by accepting an ideal of metaphysical explanation which he at first so vehemently rejected. He has said emphatically: "In itself and by its essence, any principle of theoretical physics has no part to play in metaphysical or theological discussions." Scientific theory cannot attempt to explain objective existence. And yet he concludes by doing what he has declared illegitimate, and drawing the metaphysical inferences which he held to be out of bounds: "It is impossible for us to believe that this order and this organization [produced by theory] are not the reflected image of a real order and organization."

A theory whose formulas "correspond to real relations" Duhem calls a "*natural* classification." On his view, there is no direct way of knowing whether we already have, or are near to obtaining, a natural classification of laws; yet the predictive power of theory is an indication that we *are* approaching such a goal. For it seems, after all, that scientists will not be content to be mere organizers and classifiers of sensible appearances: "It would be unreasonable to work for the progress of physical theory if this theory were not the increasingly better defined and more precise reflection of a metaphysics; the belief in an order transcending physics is the sole justification of physical theory." This would be strange language for a positivist—and in fact Duhem was at best a half-hearted positivist who still yearned for a more penetrating insight into reality than the conventionalistic view of the nature of physical theory would permit him to profess.

I have already said that Duhem strongly emphasized the tentativeness and changeability of physical theory. But every theory provisionally accepted must have some predictive power in order to be taken seriously. How then are we to recognize the "natural classification" even if it should be in our grasp? Well, Duhem freely concedes that at any given time, including the present, the available physical theory is inevitably imperfect; it proceeds slowly by "innumerable gropings, hesitations and repentances" toward "that ideal form which would be a natural classification." And yet he dares to take the bold step of prophesying what this ideal form of theory will be like! General thermodynamics, in its mathematical abstractness and freedom from all visual models, supplies the pattern. The history of science, says Duhem, provides enough evidence to show that this is the kind of form toward which successful theory is converging. Hence, on his view, the importance of studying the history of physics: "To give the history of a physical principle is at the same time to make a logical analysis of it." The choice of the kind of theory that moves in the direction of the "ideal form" is the work of good judgment (*le bon sens*). By becoming critical historians of science we draw upon the accumulated instinctive wisdom of the whole scientific tradition, as it were, and in this way we protect ourselves against the prejudices and irrational prepossessions of the individual scientists.

I feel inclined to demur that it would be most agreeable if the history of science really did teach any lessons as clear as the ones that Duhem wished to draw from it. And when one sees him, in a remarkable passage, extrapolating into the future and discerning that the ideal physical theory toward which all good physics is asymptotically converging will reflect a refined version of the cosmology of "Aristotelian physics," one wonders whether historical study is really very effective in counteracting the student's personal bias.

The pleasure I get from rereading this rich book is due in no small part to the ironic contrast between the austere logical faith its author formally professes and the clotted prejudices that spread themselves on almost every page. Duhem had a temperamental aversion, verging upon monomania, to mechanical models of the kind that James Clerk Maxwell and J. J. Thomson favored, and one of the most amusing pages in the book is devoted to a savagely effective attack upon the bars and linkages, the sheets of glycerine, the spinning tops and rotating billiard balls, with which the dominant English physicists of the late 19th century sought to make their mathematics more intelligible to themselves and their readers. But Duhem is less than fair to the suggestive value of such models, and fails to see that there is no sound basis for preferring mathematical formulas to those that can provide a basis for visualizable analogues. If a physical theory is merely a crutch for the intellect, as he holds when he is arguing for positivism, then the structure of the theory is a matter of indifference, provided it still permits of the deduction of empirical laws. Of course, if Duhem were right in his contention that the mechanical model does no work, and is simply a concession to those who feel uncomfortable with an abstract mathematical formula, he would have a strong case against the mechanists. But for all the crudity of the earlier models, there can be little doubt that they did serve as powerful instruments of analogy in the hands of their inventors. To banish such devices would be to impoverish theoretical science—quite unnecessarily.

Duhem's bias against atomism and mechanical models shows itself entertainingly in the long section in which he expounds and elaborates Pascal's famous distinction between *l'esprit de finesse* and *l'esprit de géométrie*. It is hard to translate these labels. A man of "finesse" is broad but shallow, able to grasp many details in a single comprehensive view but unfit for prolonged abstract and rigorous thought, a good visualizer but a poor reasoner. A man of "geometry" (*e.g.*, a mathematician) is exact but narrow—methodical, clear and strict. Napoleon is said by Duhem to be a supreme example of the ample and supple temperament; Newton an equally good example of the narrow and penetrating one. (But one rather wonders about Newton's practical successes as master of the Mint and about the mediocrity of Napoleon's esthetic judgments.) In Duhem's hands this crude typology blossoms into a sweeping description of national character: The English as a people are characterized by amplitude of mind, while the French mind is "strong enough to be unafraid of abstraction and generalization." I doubt that this kind of account is any more illuminating than would be a classification of bodies into the broad-and-thin and the narrow-and-pointed. There is no doubt where Duhem's sympathies lie—he favors the mathematical mind. His chief complaint against the "English" mechanistic school of his time was its lack of order and logical cogency. But the present book is evidence that the quest for "order" and "logical cogency" can sometimes degenerate into barren dichotomies—a series of either/ors which Duhem would surely never have tolerated in his serious scientific work. It is possible to have too much "order," and there is a real danger of confusing organization and logical structure.

The final impression that the book leaves with me is that of serious incoherence in its thesis: it begins with a simple-minded positivism and ends with a mystic faith in the lessons of history. But there are plenty of good things to be found on the way—notably Duhem's sound observations on the impossibility of "crucial experiments," on how theoretical presuppositions enter into the description of experimental results and on the possibility of providing ordinal measurement for "secondary qualities." The historical sections are very good. And the impress of his strong personality holds the attention of the reader as a more consistent, less passionate argument might fail to do. Professor Wiener's translation is a good one, and the foreword to the book by Louis de Broglie (who nicely balances praise and critical reservation) is a genuine help to the reader. I think nobody seriously interested in the history or philosophy of science will want to miss reading this important book.

Short Reviews

THE MIND AND THE EYE, by Agnes Arber. Cambridge University Press ($3.00). Miss Arber, a distinguished British botanist, examines the work of the biologist and attempts to define the knowledge he is after, the kind of questions he puts to Nature, the sort of answers he can expect to get. She gives much attention to the final stage of a biologist's, or for that matter any scientist's, program, in which he must stand back "from the individual jobs to which he has set his hand, in order to see them in the context of thought in general; to criticize their presuppositions and the mode of thinking which they employ, and to discover how the intellectual and sensory elements, which they include, are interconnected." This contemplative phase is of course the crown of all previous efforts, but in these days of specialization, scientists tend to bury themselves in blueprints and details and to avoid looking up to see what their work has added to the structure of science as a whole. In their deference to the precept that a scientist must not permit his own feelings to intrude upon his inquiries, they are apt to forget that the creative power depends upon an "intense effort" in which "feeling and intuition" and free speculation play as great a part as reason and observation. "I question not my Corporeal Eye," wrote William Blake, "any more than I would Question a Window concerning a Sight. I look thro' it & not with it." Whatever we see, says Miss Arber, is seen with the mind; the mind gives meaning to what Aristotle called "immattered form." Biology, in its autonomous aspect, fulfills its function when "it offers its mite towards the ultimate fusion of metaphysical and scientific thinking." Miss Arber has for half a century reflected upon and written about the nature of science and its relation to other intellectual disciplines. *The Mind and the Eye* is an admirably written book which bears upon every page the imprint of a profoundly philosophical, sensitive mind.

THE ANNUAL SURVEY OF PSYCHOANALYSIS, VOLUME II, edited by John Frosch. International Universities Press, Inc. ($10.00). Neither a practitioner nor a student can derive much benefit from the great annual outpouring of psychoanalytic literature. It is doubtful that any other field, except perhaps political science, produces so many words containing so little of advantage to the body, the mind or the soul. This book is a case in point. Nevertheless it does perform the useful function of telling what is going on in psychoanalysis. It digests the year's principal books on the subject and summarizes journal articles on topics ranging from the "hypnagogic phase of the development of sleep" to the application of psychoanalysis to the study of humor. (One of the papers examined is a study of the problem centering in the riddle: "Why did the moron jump off the Empire State Building? Because he wanted to make a smash hit on Broadway.") The value of the series is in showing the unimaginative quality of most of the research and in making available in convenient form the few positive accomplishments.

THE NATURAL HISTORY OF MAMMALS, by François Bourlière. Alfred A. Knopf, Inc. ($5.00). Darwin once remarked that what people are generally pleased to call the "trifling facts" about animals are the ones that "make one understand the working or economy of nature." In this authoritative and most readable volume a French medical biologist has assembled a wealth of "trifling facts" about mammals: their methods of locomotion, feeding habits, lodging places, methods of defense and protection, sexual life, developments, longevity, migrations, social life, adaptation to environment, population dynamics. Rabbits and hares eat their food twice, taking in the night's droppings in the morning—a habit which provides the animals with large amounts of B vitamins produced by bacteria in the food within the large intestine. The California sea otter, which lives chiefly on the red abalone, cracks this shellfish by rolling itself over on its back, placing a small stone on its chest and pounding the abalone on this improvised anvil. The North American pocket gopher has been known to build itself a 65-yard-long underground gallery with storerooms, sanitary rooms, secondary galleries, temporary and main exits, all within one season. You will be sorry to hear that beavers are by no means as intelligent and efficient as they are reputed to be. They are wasteful, build dams in the wrong places and keep repairing them when they don't need repair. The European bison stakes out its home territory in the following manner: It marks a tree with its horns, then urinates on the ground nearby, rolls in the urine and transfers the odor of the urine to the barked tree trunk by rubbing its back against it. This establishes a marker which is easy to find and which gives clear warning to possible trespassers. Bourlière remarks the exceptionally active sex life of the rodents: a golden hamster, for example, can copulate 175 times within a few hours. Patient observers have learned much about communication among animals, which includes a variety of olfactory signals and sign languages. The wolf speaks with its tail, using certain precise movements and seven positions which denote expressions ranging from "self-assurance" to "acute discomposure." The last chapter of Bourlière's book presents a fascinating analysis of population dynamics, with a series of remarkable hypotheses to explain the migrations of lemmings. Whether you have a serious professional interest in comparative mammalian biology or are simply interested in nature, this volume can be strongly recommended.

THE MEDUSAE OF THE BRITISH ISLES, by Frederick Stratten Russell. Cambridge University Press ($22.50). This monograph by the director of the Plymouth Laboratory of the Marine Biological Association of the United Kingdom is a magnificent work of science and of art. It describes the 90 species of translucent floating umbrellas, the medusae, ranging in size from "a pin's head to a crumpet," which may be found in the waters around the British Isles. These small jellyfish are of interest not only as biological specimens but also because they serve as "indicators of the movement of water masses in the sea" and thus provide valuable information about areas in which fish are likely to be most abundant. An outstanding feature of the book is the illustrations, which include a large number of admirable line drawings and 35 plates, 16 of which are exquisite water colors painted by the author from life. It is impossible to praise this beautiful book too highly.

LIFE IN LAKES AND RIVERS, by T. T. Macan and E. B. Worthington. Frederick A. Praeger, Inc. ($4.50). A most attractively illustrated book in the publisher's natural history series. The authors discuss the distribution, adaptability, ecology, natural history and environments of fresh-water animals and plants, the effects of pollution, and related matters. Black-and-white and color photographs give the volume a delightful country feeling.

THOMAS JEFFERSON'S FARM BOOK, edited by Edwin Morris Betts. Princeton University Press ($15.00). For 52 years Jefferson kept a running account of the many activities of his great plantations and set down a wide variety of agricultural data gleaned from his practical experience and extensive reading. Betts, who also edited Jefferson's *Garden Book,* here presents the *Farm Book* in facsimile, together with a commentary and quotations from other Jefferson papers. The book provides an absorbing record of the career of an enlightened farmer and a vivid picture of the plantation villages of 18th-century Virginia. Jefferson's landholdings totaled more than 10,000 acres. His money crops were wheat (which he milled himself) and tobacco, but he experimented also with corn, oats, barley, rye, potatoes, flax, hemp and cotton. He tried various methods of crop rotation; compared dung, marl and gypsum as fertilizers; erected elaborate structures; bred race horses and livestock; invented new farm implements; built roads, dams and canals. Like George Washington, he maintained an exchange of information with the "great promoters and publicists of the agricultural enlightenement" in this country and abroad, and while he was anxious to make profits he did not hesitate to apply methods which in his opinion would in the long run benefit the soil even if the immediate yield was thereby drastically diminished. Jefferson strove to make his farms completely self-sufficient communities and "to promote domestic crafts as an antidote to urbanization." At Monticello he had a nailery, a blacksmith's shop, a joiner's shop, a saw pit, spinning and weaving shops. His Negro slaves, whom the French philanthropist La Rochefoucauld after a visit described as "nourished, clothed and treated as well as white servants could be," were trained as cabinet makers, carpenters, cobblers, masons, bricklayers, brewers, coopers, charcoal-makers and the like. So great was Jefferson's ardor for farming that, as he wrote John Adams, it "got the better entirely of my love of study." His passion for the soil, his amazing grasp of the details of agricultural management, his "insatiable desire for improved methods," his confidence in progress—all emerge from the pages of this excellent book. Jefferson is a delight to read even when he is telling the best method of growing pumpkins.

THE BIRDS OF WEST AND EQUATORIAL AFRICA, by David A. Bannerman. Oliver and Boyd (six pounds, six shillings). This condensed version in two stout, serviceable volumes of Bannerman's classic work, the eight-volume *Birds of Tropical West Africa,* is intended to provide a guide which field naturalists and travelers can take with them without the services of an extra porter. More than 1,500 species and subspecies of birds are described in simple, nontechnical language; their habits are succinctly set forth and other principal details of natural history are given; an excellent illustrated key for identification has been taken over in its entirety from the larger work. The illustrations include 54 full-page plates, of which 30 are in color, and upwards of 400 drawings. An admirable addition to the literature of ornithology.

THE AMATEUR SCIENTIST

About various things, mainly an instrument for the very precise measurement of length

Conducted by Albert G. Ingalls

Of all measurements length is the most fundamental. Almost all physical quantities are measured by the motion of a pointer on a dial or by the distance between two objects or images. Thus length becomes the analogue of mass and time, the remaining quantities of the basic dimensional trinity. Most scientific instruments are designed to convert an unknown quantity into a convenient length, usually a few inches. A device capable of yielding a precise measure of length on the order of six inches can become one of the most useful and powerful instruments in the amateur's tool kit. With it he not only can check the accuracy of other instruments but can construct the variety of scales indispensable for gathering precise data in all branches of science.

Several months ago Roger Hayward, the versatile illustrator of this department, mentioned that he had recently built a traveling microscope and wondered if it might not hold some interest for the amateur fraternity. "This device," he wrote, "affords one of the nicest ways of measuring lengths of a few inches that I know about. The traveling microscope is just what the name implies: a microscope mounted on a carriage moved by a screw through a measured distance.

"The design of the carriage and its driving mechanism is much the same as the design of a ruling engine—but without the requirement of millionth-inch precision. At the outset let it be said that this is my first traveling microscope and I have no illusions about its perfection. Use has demonstrated that the frame could have been a bit heavier; the thrust bearing is suspect, and the ways could have been sturdier. Nevertheless, building it was fun, and no gadget in my shop has proved more useful.

"The project was really undertaken to try out a method of grinding the ways. After I had proved the method, it seemed rather a waste of time and energy not to complete the instrument. I haven't the foggiest idea of what the pitch of the screw is, and I have never been curious enough to lay hands on a standard to find out. In spite of these shortcomings the machine is capable of a precision of one part in 60,000 over a range of six inches, and with this accuracy it is possible to make fair measurements of coefficients of expansion, shrinkage of concrete and other physical properties.

"I have also made a carriage attachment which can rule scales; in fact, I used it to rule the scale of the instrument itself. A number of linear scales have been ruled with one thousandth of an inch spacing, and once I ruled a bit of grating. The rulings were half an inch long and spaced five 10,000ths of an inch apart. An indication of the instrument's precision is given by the fact that the two yellow lines of mercury are clearly resolved by this miniature grating—but the sodium lines are not.

"The traveling microscope consists of six major components: the carriage ways, the screw, bearings for the screw, the nut, the carriage and the microscope.

"The steel ways and spacer for the end plate are made from three pieces of ¾-inch stock about 10 inches long. It is important that the carriage move in a straight line without rotation, because often you want to measure objects a foot or more away. On one occasion, for example, I measured the coefficient of expansion of lucite while the sample was in an electric furnace. The measurements were taken through small windows. In such situations the mandrels (bars) that serve as ways obviously must be straight, although they need not be round.

"It occurred to me that the necessary straightness could be generated by the primitive method of wet-grinding three mandrels together in a manner analogous to the making of three flats. This time-honored method depends on the fact that if any three surfaces make perfect contact when tried in all possible combinations, all must be plane. In the case of mandrels, the method has the attractive feature that the three can be ground together in one continuous operation. The method will not assure roundness, but this is not a requirement of the ways. The sketch at the top of the opposite page shows the setup.

"It is apparent that two cylinders can lie in contact with each other along their whole length if one is barrel-shaped and the other spool-shaped. A third cylinder could not lie in contact with this pair, however. In the grinding setup it would abrade the center of the barrel-shaped member and the ends of the other. If an array of three stacked cylinders is twisted slightly, a fit is possible if all taper from the ends to thinner waists in the middle. This condition can be tested by holding two cylinders in contact up to the light. If a position can be found where light can be observed between them, then the mandrels are concave and the array was twisted during grinding. A slight adjustment of the end bearings of the grinding fixture will correct the matter.

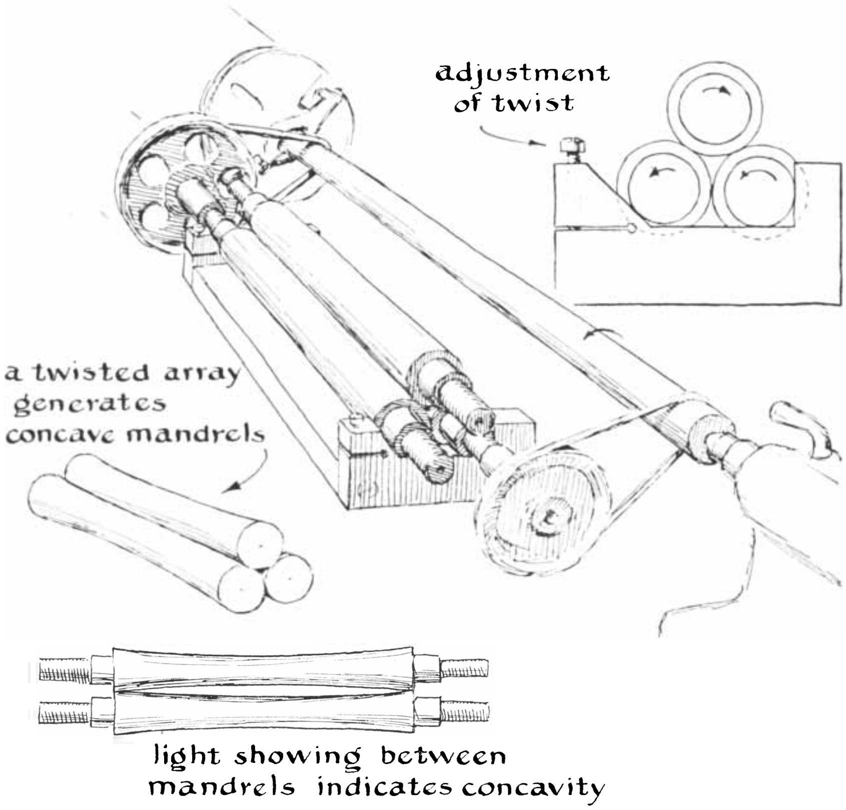
"A few evenings of grinding produced quite acceptable cylinders. The design of the bedplate and bearings of the grinding fixture is apparent in the illustration. By making the pulleys of the two lower mandrels of different sizes, I was able to get each of the three mandrels to grind on the others when they turned. The upper mandrel runs free, and grinding pressure is supplied by its weight. The assembly is belted to a rod chucked between centers in the lathe as shown. The mandrels are identical. Symmetry can therefore be maintained by exchanging and reversing the individual pieces frequently during the grinding operation.

"Separate stock is used for the screw. The ground mandrels become contaminated with carborundum, which would dull the thread-cutting tool. The screw stock is chucked between centers and carefully trued. I cut 40 threads per inch and, to assure a screw of top quality, took many fine shavings. It is desirable that each cut proceed from end to end without any interruption to sharpen tools, so that you do not have to pick up a cut in the middle of the screw. The cuts vary in depth from five thousandths to five 10,000ths of an inch. The two sides of the thread are cut with the mandrel turned end for end. This distributes errors of run which might otherwise be transmitted to the work by the lead screw of the lathe.

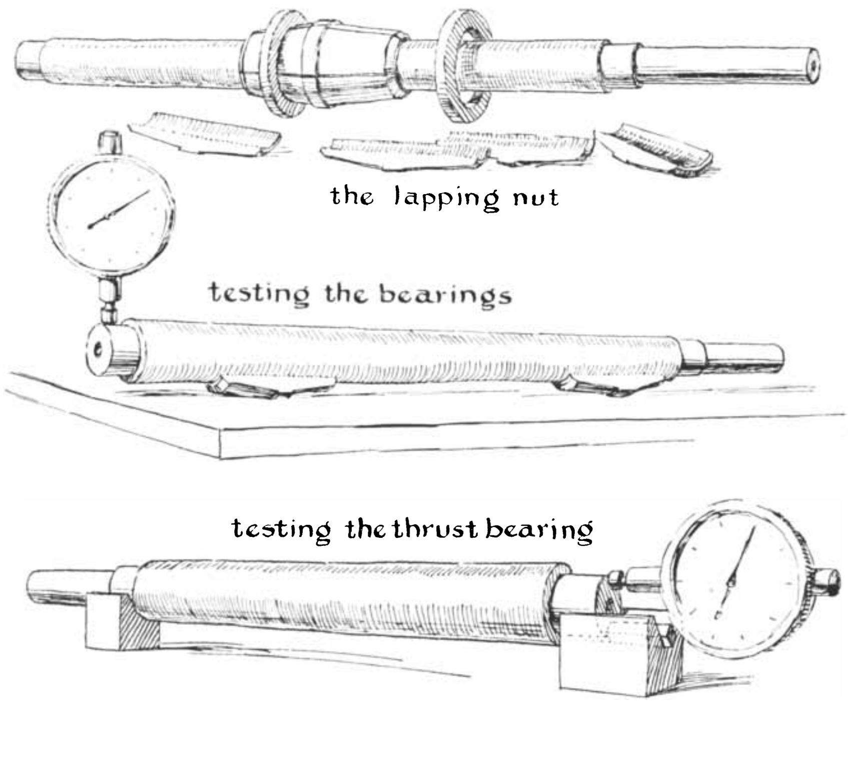
"A steel nut about three inches long [*drawing at top of illustration at lower right*] was split into four segments and used to lap the thread. As the lapping proceeded, the segments of the nut were frequently turned end for end. Measurements of the diameter of the screw (with wires and a micrometer caliper) and the disappearance of dark rings during the process of lapping were taken to indicate that a fair precision was being achieved. The outside of the nut was tapered so that steel rings could be slipped on to hold the nut segments together. Being rigid, they tended to produce a screw of uniform diameter.

"By resting the screw in parts of the lapping nut and measuring the bearing surfaces with a dial indicator [*center drawing*] I found that the axis of the finished screw no longer coincided with the axis of the bearings. This was corrected by local lapping with emery cloth on the offending surfaces. The end of the screw, which was to act as the thrust bearing, was found to be at an angle to the axis of the screw and was similarly corrected [*bottom drawing*]. Investigation later disclosed that this error originated from an error in the headstock of the lathe and demonstrated the fact that, although the flexibility of a lathe bed is small, it is sufficient when operating at this level of precision to generate and transmit errors even when the work is mounted between centers.

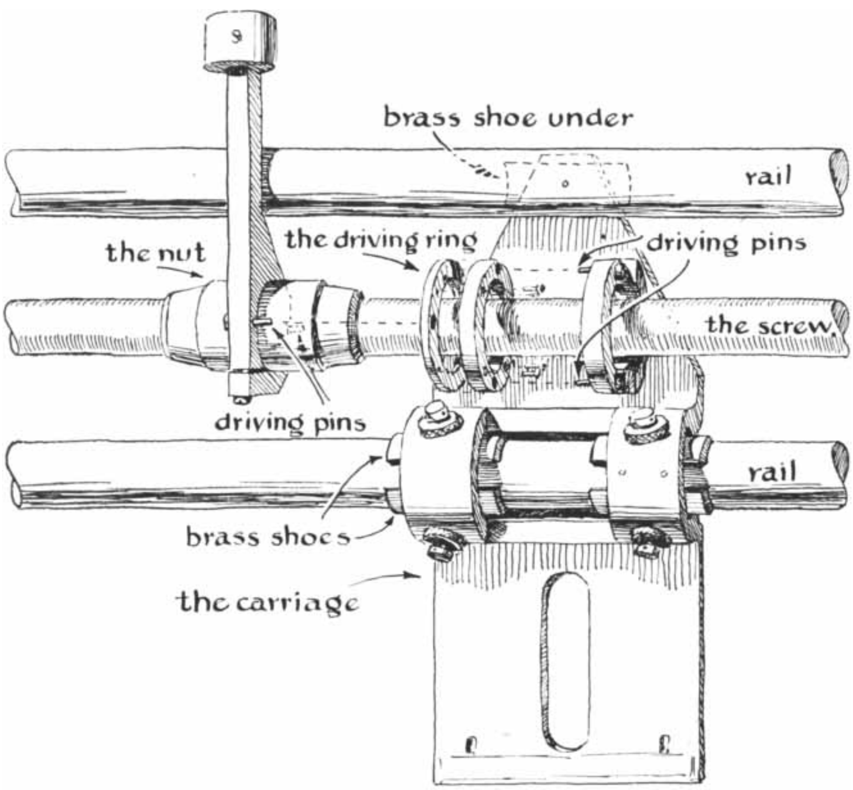
"The 'working' nut for the finished instrument was cut with a boring bar. The nut is about 2½ inches long. An arm attached to it rides on one of the cylindrical ways and prevents the nut from rotating [*drawing on next page*]. Two pins fitted into the nut, one above and the other below the screw, push the carriage through a set of rings, one of which is attached to the lower side of the carriage. The carriage ring, like the arm, is fitted with a pair of pins, but these are placed on either side of the screw at 90 degrees from those on the arm. Motion is transmitted from the tips of one set of these studs to those of the other through a floating gimbal ring. The ob-



A primitive method of generating straight mandrels



Testing the screw and the nut for a traveling microscope



The carriage assembly of a traveling microscope

ject of this arrangement is to permit the nut to wobble without affecting the smooth travel of the carriage. Drunkenness in a screw is a common defect, and the gimbal ring renders it harmless—if the ends of the studs always lie in a plane. This requirement is met by making the gimbal ring in two parts, like a pair of washers screwed together, so that the studs pass through one part and press against the other. It is as though the studs pressed against the bottom of holes drilled from opposite sides to a plane lying precisely at the midpoint of a solid ring.

"The carriage is supported by five brass shoes, four of which bear on the *top* of the front rail and the fifth on the *under* side of the back rail. This permits the carriage to extend out in front of the instrument.

"The mandrels are assembled to a pair of end plates clamped together and drilled as a unit, so that the holes will be spaced evenly and will assure parallelism of the ways. The shoulders at the ends of the mandrels make a snug fit with the end plates. After assembly, the ways are tested for twist by laying an optical flat face up on the carriage and directing a telescope at the image of an object reflected in the mirror. The image should not move up or down as the carriage crosses the ways. A twist in the ways, incidentally, introduces error only if the cross-hair in the telescope is not vertical. All three mandrels are used, two for the ways and the third, beneath the screw, as a spacer for the end plates. The back of the instrument is made of a steel plate, ⅛ inch by 2 inches, fastened to the end plates. It carries a simple leg in its center.

"The two front legs are micrometer screws. Details of the thrust bearing for the screw and the adjustable head bearing are shown on the opposite page. The sides of the thrust bearing are cut away so that it can be made a little too small to fit the end of the screw. It is merely the closed end of a leaf bearing relieved in the center and at the edge to avoid irregularities in the end of the screw. The lower bearing surfaces are on stiff members, whereas the upper one is thin enough to be limber and act as a spring to hold the screw against the lower surfaces. By too small I mean one 500th of an inch or less. The end of the screw is polished so that wobble may be studied by reflection and corrected by local polishing.

"The carriage may be fitted with almost any microscope or telescope, provided the eyepiece is equipped with cross-hairs. Experience has shown that one of the most convenient is a small telescope of ¾-inch aperture which can be focused from six inches to infinity. A second lens, an achromat of 1½-inch focal length fitted to the end, serves for objects an inch or so away.

"A handwheel with 125 divisions indicates motion of the carriage in .0002-inch units. A scale divided into .025-inch units identifies the particular turn of the screw. The instrument is completed by equipping the base with leveling screws.

"What about corrections for variations in temperature? Most measurements can be made in one setting and in a situation which avoids wide temperature swings. My home is thermostated so that it stays about 70 degrees Fahrenheit plus or minus five degrees. The temperature coefficient of steel is available from handbooks, of course, and this value plus that of the material under measurement can be taken into account. In other cases one is primarily interested in relative and not absolute measures. Temperature factors then vanish from consideration. This is true, for example, in the case of spectrum plates, where it is desired to ascertain the relative position of the lines and not their absolute distance.

"The problem of temperature really stumped me on one occasion, however, when I set out to measure the coefficient of shrinkage of two types of concrete which I planned to use in the construction of a building. I cast specimen cylinders of each type of concrete and set them on blocks behind the instrument. On each specimen, painted white, I marked two sets of ink dots about 5.75 inches apart. Each set consisted of five dots about .025 of an inch in diameter and separated by a similar distance. In projects of this kind it is interesting to make measures in sets. Averages of such sets give reproducible results within a few 100,000ths of an inch even when the individual measures vary by several 10,000ths. Readings were made at each edge of each dot—20 measures in each complete set. The average of the readings from one end subtracted from the average of those from the other end gave the dimension under study. Measures were repeated every few days, and the slow process of shrinkage over a period of 50 days was clearly recorded.

"Between measurements the cylinders were stored outside where they would be subjected to weather variations. They were brought indoors about an hour before measuring so they would reach the same temperature as the instrument. Since the humidity affects the rate of evaporation from concrete, and hence the rate of heat flow, it is anybody's guess what the temperature of the sample really was on any occasion. Two authorities provided information about the temperature coefficient of concrete: one said it was slightly higher than that of steel (about one part in a million per degree centigrade higher) and the other said it was the same amount lower than that of steel. While my measurements fluctuated fairly widely, I learned what I wanted to know: the difference between the two kinds of concrete was too small to be of consequence. I had been led to believe that one type shrank significantly more than the other.

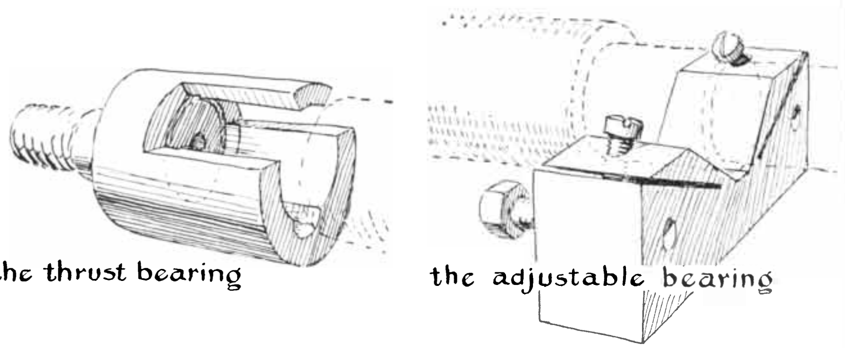
"Another useful application of the instrument is making scales. When I built the traveling microscope, I needed a six-inch scale divided into .025-inch units. The completed instrument is shown in the illustration on the next page. Its scale is etched on brass. The ruling is made with a gadget which fastens onto the carriage. It drives a scriber which rules through the slot in the carriage. A crank moves the scriber back and forth, and a cam lifts it on the return stroke. The material used for the scriber varies with the substance being ruled. For glass I use a diamond chip or shaped Carborundum (a single crystal). For lucite and other soft materials, hardened steel retains a satisfactory cutting edge. The scriber-holder slides over an adjustable cam which permits ruling long or short lines as required. The ruling device is mounted on the bench with the work on the carriage so that the turning of the crank will not jiggle the instrument. The work is advanced by turning the wheel by hand. As mentioned previously, this instrument is not designed for the production of gratings. Nevertheless it is sufficiently precise to meet most requirements of an amateur's shop."

Each August for the last 15 years the Cleveland Astronomical Society has entertained the city of Cleveland with a public telescope and star party. These parties have made Cleveland more astronomy-conscious than any other American city. James L. Russell, their organizer, says:

"We have had as many as 10,000 people in the public park where we hold them. The city turns out the park lights; we line up 35 of our homemade telescopes, and while a long line moves slowly past each telescope a professional astronomer addresses the crowd from a sound truck. After looking at the moon or a planet the people sit on the grass and watch the astronomical movies that we show, or study the celestial objects that we point out in the sky with a huge searchlight. We have so many people that it takes three evenings to run them all through. You would have to attend one of these parties to realize their magnitude."

During the rest of the year Russell leads Tuesday evening classes in telescope-making at the Cleveland Museum of Natural History, which has equipped a large laboratory for the amateurs. He says: "We have 40 people working at a time, and in the last five years they have made 350 mirrors. There is always a waiting list of about 175 applicants. It is wholesale production—the largest class in telescope making anywhere. We have 16 mirror-grinding pedestals, places for 40 people to polish mirrors at one time, a darkened place for the Foucault test, hand tools galore and machinery for making mountings—a lathe, drill press, band saws, a jig saw, sanders. Some grind or polish while others hammer and saw. It is sociable as well as astronomical. The din and dust are terrific, with 50 people in the huge room grinding, polishing, hammering, hollering and yapping their heads off, all at the same time, from five until nine. For each one who finishes the grinding stage we have 10 waiting to begin. It takes two years to work one's way to the head of the waiting line.

"Those who have made two or more mirrors, including myself, act as instructors five at a time. No one is paid; for us it is recreation and we just love it. Some bring lunches, the gal members cook them, and we grind with one hand



The thrust bearing of a traveling microscope and eat with the other. There is a rule that those who finish their mirrors must treat the entire gang to ice cream and cake, and this alone practically feeds us at most of the sessions."

The gregarious mass production of telescopes in Cleveland does not aim at perfection but primarily at making a large number of people happy with telescopes good enough for most uses. Russell is an organizer and leader. He says: "I am a lawyer, not a mechanic, and definitely not one of those who can turn out a perfect mirror, though as a beginner many years ago, using *Amateur Telescope Making*, I made 6-inch, 8-inch and 10-inch Newtonian telescopes and a Cassegrainian. Nor are many of our group scientists. While we have had chemists, physicists, physicians, engineers and many science teachers from the schools, many more are truck or taxi drivers, barbers and streetcar conductors. A large majority know neither paraboloids, hyperboloids nor other conic sections, and a few don't know the business end of a screwdriver."

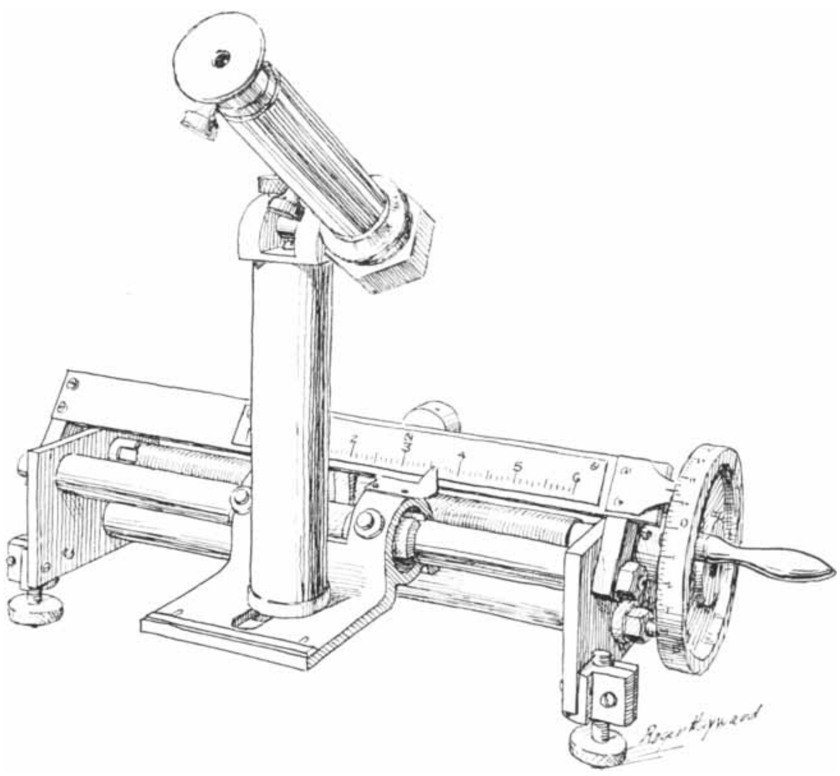
Telescope making is no longer as exclusive as it used to be. During the classic 19th-century mirror-making era in England, D. P. Barcroft has found, there were actually no more than a few dozen amateurs who made telescope mirrors. There were even fewer in the U. S. until 1926, when SCIENTIFIC AMERICAN provided a handbook on telescope making and began to publish articles on the subject in practically every issue (the number of issues has now reached 314). For years the hobby remained "snobby"—not a sport for everybody—because astronomy seemed too intellectual and mirror-making too perfectionist. Telescope making has kept its attraction for those who enjoy it as a high-precision sport in itself, but it has also come to appeal to more and more people who are curious about the universe and are not primarily interested in how meticulously accurate they can make the instrument.

"For our group," says Russell, "the trouble is that *Amateur Telescope Making* wants the mirror-maker to reach perfection. Now what does a truck driver—or a lawyer—know about paraboloids? He asks: 'Must I become a mathematician or am I making a telescope?' The major fault with all the mirror-making manuals is the tacit assumption that the aspirant with a disk of glass in his hands for the first time must achieve perfection, or else the telescope is not going to work, when the fact is that practically any mirror will work so well that the average beginning observer will not be able to distinguish the best from the worst. All the telescopes work, and their makers are tickled to death. True, under the Foucault test the mirror may not look good to an expert, but we have made a friend, the friend has made a telescope, and we have promoted interest in astronomy. A few do make really fine mirrors but ironically the payoff comes when they discover that these show no more than the one made by Joe, who has never even seen the book.

"We have found that a man or woman who consumes too much time on what seem unimportant details gets discouraged and quits, even giving the mirror the famous fireplug treatment described in the book—slam it against the nearest hydrant, brush off your hands and go home. (In fact, we keep a private hydrant handy in our laboratory.) For the first mirror, after making sure that the beginner has not even opened the book (copies of which we keep locked up) so that he does not become aware of the many pitfalls, we instruct him from the blackboard and at the bench while he works. We allow each student to proceed according to his individual ability.

"We had to abandon Pyrex, the mirror handle, the paraboloid and the pitch polishing lap. For pitch we substitute wax honeycomb foundation (HCF) used with cerium oxide. Although pitch laps give better polish and fewer zones, they are so difficult to make and to alter that we regard them as the principal bottleneck in mirror-making. They have discouraged more beginners than any one thing, or any 10 things. Although we get fewer fine mirrors with HCF, it best suits our purpose, which is to finish a mirror while the maker's enthusiasm lasts. Moreover, an HCF lap does not scratch. One could almost toss a handful of mud on one without causing scratches; sometimes, as a demonstration, I actually do toss in cigarette ashes. With 50 people milling around in our big room, stirring up dust, HCF is an ideal material. We buy it by the crate. And where it takes half an hour to perfect a pitch lap, an HCF lap takes but four minutes.

"Our objectives on the first mirror are to teach the essential technique and to produce a mirror of tolerable rather than perfect quality. We don't permit as much as a single squint with the testing apparatus until the polish is clear to the edge. Each student must also make a simple tester, take his mirror home and work there with it until he can read the Foucault shadows. Some become expert. Others who do not catch on are also unlikely to know bad images from good at the telescope eyepiece, so this problem takes care of itself. If the beginner is uncommonly apt, he may be permitted to finish on pitch. If he is uncommonly inept and begins to falter



Over-all view of the traveling microscope even with our simple technique, or is seen to be striving too hard for perfection, we tell him his mirror is good enough and to put it into use.

"At the conclusion we tell them: 'Now read *Amateur Telescope Making*, see what you did and, with its instructions and the orientation you gained by going through the work once without it, go ahead with the larger telescope you want to make.' The initial aim, however, is to complete a pilot job on mirror and mounting. Our mountings are simple and tubeless. We have the precut parts for them, since many of the beginners are not mechanics.

"Because we consider the human angle and help the beginner to bridge the gap between his capabilities and the bookworms' and wizards' book, 80 per cent finish the first telescope. Most beginners don't want to be experts; they just want a telescope, mostly to look at the moon and Jupiter, and they don't care too much if the moon is a little out of shape or Jupiter is fuzzy.

"After climbing aboard by this preliminary 'gangplank' job, some go on to build fine telescopes in our laboratory, up to 18 inches in diameter, also Cassegrainians and Schmidts. *Amateur Telescope Making* becomes their bible."

For years there have been debates about whether *Amateur Telescope Making* should be rewritten—to make it not simpler but more orderly. The suggestion always elicits strong reactions from the book's users. The iconoclastic wing demands, in the words of one: "Melt the whole thing down, stir the melt together, and pour it again as a single, coherent casting, the orderly product of a single mind at a single time." On the other hand, there is a stubborn opposing group whose view is summed up in this remark: "*ATM* has been my companion for 20 years. I like it as it is. It is not to be altered in any respect." To many who say they have read it more times than its editor (who prefers escape from optics into the history of the Dark Ages) and who insist they can rattle off its pages by heart, the idea of melting down this old bible seems almost sacrilegious.

They need not worry. While I see nothing sacred about it, if the book were rewritten it would have but one author and therefore would lose the prestige of its present galaxy of contributors. It would likewise lose Russell Porter's irreplaceable illustrations. Its present arrangement or, rather, disarrangement—the result of many additions and internal operations down through the years—

does, as has been said, forbid straightforward reading. However, it encourages enjoyable, informative browsing. In fact, the need for a book for browsing goes clear back to the original thought I had three decades ago while lying abed late one Sunday morning. The dream was to bring together as reprints in one volume all the widely scattered, obscure and fragmentary data on telescope making which, in making my own first telescope, I had been forced to mine out of the four-million-volume New York Public Library, and to make this omnium gatherum of forgotten fragments available to everyone everywhere. The book that resulted was a labor of love, performed out of working hours and with the expectation of financial loss to the publisher for the sake of a gain to the amateur. I did not at all realize in 1926 that I had hold of something which awaited only a catalyzer to start an apparently endless reaction.

Out of a feeling of moral obligation, I invite the views of the amateur telescope-making fraternity on whether they would like to see certain changes in the book; like most invited advice, it will be followed if it is liked.

Some have suggested replacing the Porter and Ellison parts of *Amateur Telescope Making* with more recent mirror-making techniques evolved by some of the graduates from the same preceptors. Leaving aside the fact that such decapitation of the book would leave meaningless 1,001 cross-references to Porter and Ellison in the rest of the book and its sequel volumes, the question arises: Just which and whose pet techniques, of which there are today as many as there are advanced amateurs, would the reader select for this apotheosis and canonization? Others have urged that the art of mirror-making should be changed to a plain-sailing science by prepared panaceas for every possible contingency in mirror-making.

Both *Amateur Telescope Making* and its much-admired companion, Allyn J. Thompson's *Making Your Own Telescope*, go into the full depth of meticulous detail for the making of the first mirror. Both imply, as Russell says, that a beginner must set his teeth to produce a perfect mirror. How many isolated beginners, haunted all through by the hobgoblin that the mirror won't work unless it is perfect, have worried themselves to a frazzle through a thousand misgivings, only to find when they completed the mirror that it worked splendidly in spite of its imperfections!

The other side of the argument is that the difficulty of telescope making is what has made it attractive to resourceful and adventuresome people, and that to reduce this endlessly intriguing, baffling and sometimes maddening art to a science, even if this were possible, would rob it of its dark allure. The books tell only half—they could not tell the rest anyway—and the happy sufferer supplies the other half of the answers out of the depths of his resourcefulness and fortitude. The work is essentially a test of character.

Yet must we be so tough, when we can more charitably serve all comers according to their individual capacities? Here is a proposal: Instead of rewriting Porter and Ellison and attempting a general rejuvenation of the venerable *ATM* (which, in case you are wondering, has suffered no loss in demand), suppose we simply add a crutch chapter based on the Russell approach for all who are panicked by paraboloids. To make space for the chapter, the present instructions for silvering mirrors and the list of astronomical groups (no longer needed because it is kept current in *Sky and Telescope*) could be dropped. The new gangplank to paradise would be placed at the end, partly from sentiment —it must not precede Porter and Ellison —and partly for practical reasons: the book is not printed from movable type but from whole-page plates, and the pagination must not be altered. The preface would direct the beginner to the optional easier approach. This, of course, would afford everyone a bonus in the form of a new opportunity to rib the editor about this "incomparable paragon of reverse sequence."

Next month I will explain in terms of physical optics why even a poor mirror can work, will describe a revised criterion for good mirrors, will show why an experienced observer still needs one, and will tell why even that criterion or the stiffer Rayleigh limit criterion is not good enough for the most expert observing, even though a beginner may not be able to detect the difference between it and any old mirror. From that explanation the reader will see that there is no intention to debase mirror-making but instead to spread out the standard—much looser for some, tighter than ever for others—to make everyone happy.

The Telescope Makers of Springfield, Vermont, with the Amateur Telescope Makers of Boston, will begin a new series of conventions of amateur astronomers at Stellafane August 21. For information communicate with James W. Gagan, Harvard College Observatory, Cambridge 38, Mass.

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Photograph by Gordon Teague

You can depend on rubber

Almost everywhere you look today you see rubber in some useful role. In fact, rubber does so many jobs better than any other material it is now used in more than 50,000 different products—and new applications are constantly being developed.

This great versatility of rubber, both natural and synthetic, is due to the ingenuity of the rubber industry in using chemicals to give its products a wide variety of qualities. For example, the properties of rubber can be varied over such a wide range that it is equally ideal for fan belts or flooring, footwear or foundation garments, tires or tubes, gaskets or gloves—everything from tiny pencil erasers to conveyer belts many miles long.

As a leading producer of chemicals, American Cyanamid Company works closely with the rubber manufacturers, helping through research and chemical development to make rubber products do old jobs better and meet exact requirements for entirely new uses. This cooperation is reflected in the increasing variety and utility of rubber products that serve you every day.

AMERICAN Cyanamid COMPANY

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