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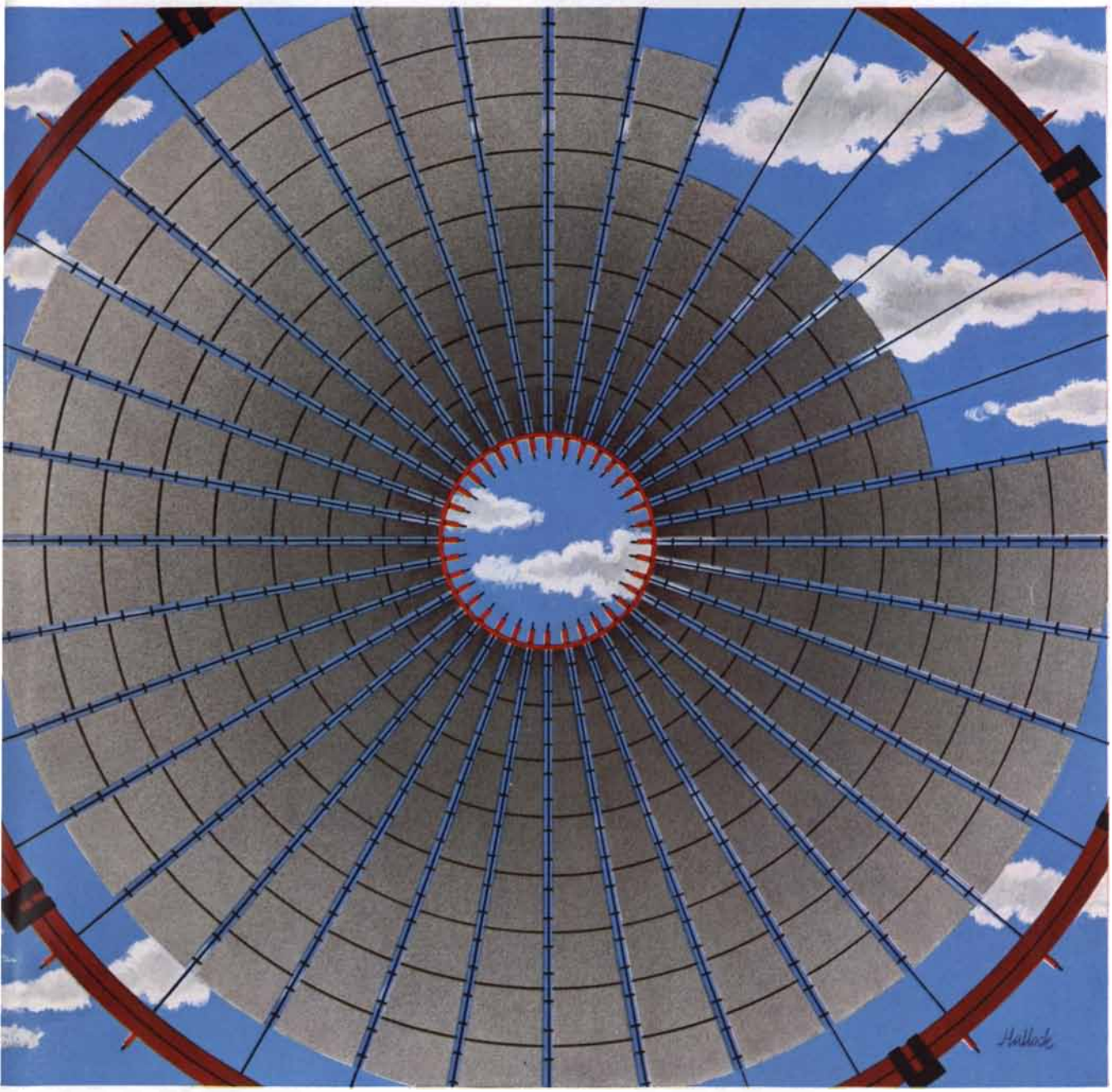

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July 1958

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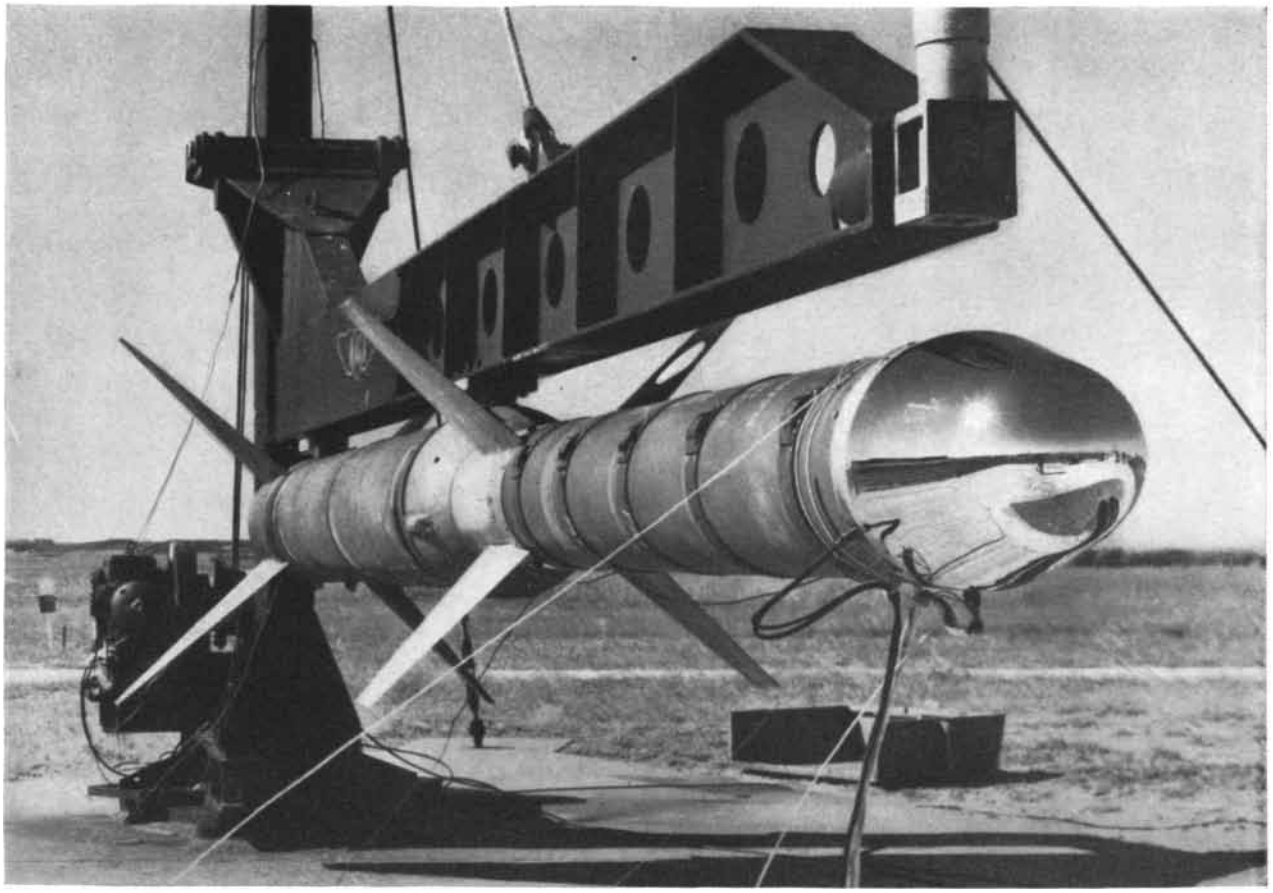

EXPERIMENTAL MISSILE is used by NACA researchers to study high temperatures at speeds up to Mach 5. The nose cone is spun Inconel alloy, polished down to a 2 micro-inch finish at the tip. *Photo courtesy of Aviation Week.*

The search to keep a missile's nose from becoming its "Achilles' heel"

Intercontinental ballistic missiles are designed to plunge back into the earth's dense atmosphere at speeds in the neighborhood of Mach 10.

Temperatures in the thin boundary layer of air surrounding it are measured in *thousands of degrees Fahrenheit.*

How do you keep the nose from melting?

A sharp, needle-point nose reduces aerodynamic drag. But it doesn't help dissipate heat. A blunt nose shape does considerably better, even though it causes a high pressure drag, and creates intense heat in the shock wave. One explanation for the good showing of the blunt shape is that heat follows the wave—and just sort of "slides off" the nose.

For experimental purposes, scientists need a nose material that can be spun into a great variety of shapes . . . one that maintains structural integrity far up the temperature scale. And those are among the reasons they often select high-strength, heat-resisting Inconel* nickel-chromium alloy . . .

The National Advisory Committee for Aeronautics, for example, began using Inconel alloy for tests after a several-year-long investigation of materials suitable for use at high Mach numbers and high temperatures.

Of course, much is still to be learned about the mechanics of aerodynamic heating and its applications to the design of hypervelocity aircraft and missiles. But the tests are indicating how the problems can be solved. And advances such as those being made daily by NACA's research are rapidly leading to perfection of "The Ultimate Weapon," the device that may well prevent war among men.

Do you have a metal problem? One that involves high temperatures . . . low temperatures . . . corrosion . . . stress . . . fatigue or some other troublesome factor? Inconel alloy or another of the many Inco Nickel Alloys may be just the metal you've been searching for. Our new booklet, "A Review of Nickel-Base Alloys for Aeronautical Applications," is yours for the asking. *Registered trademark

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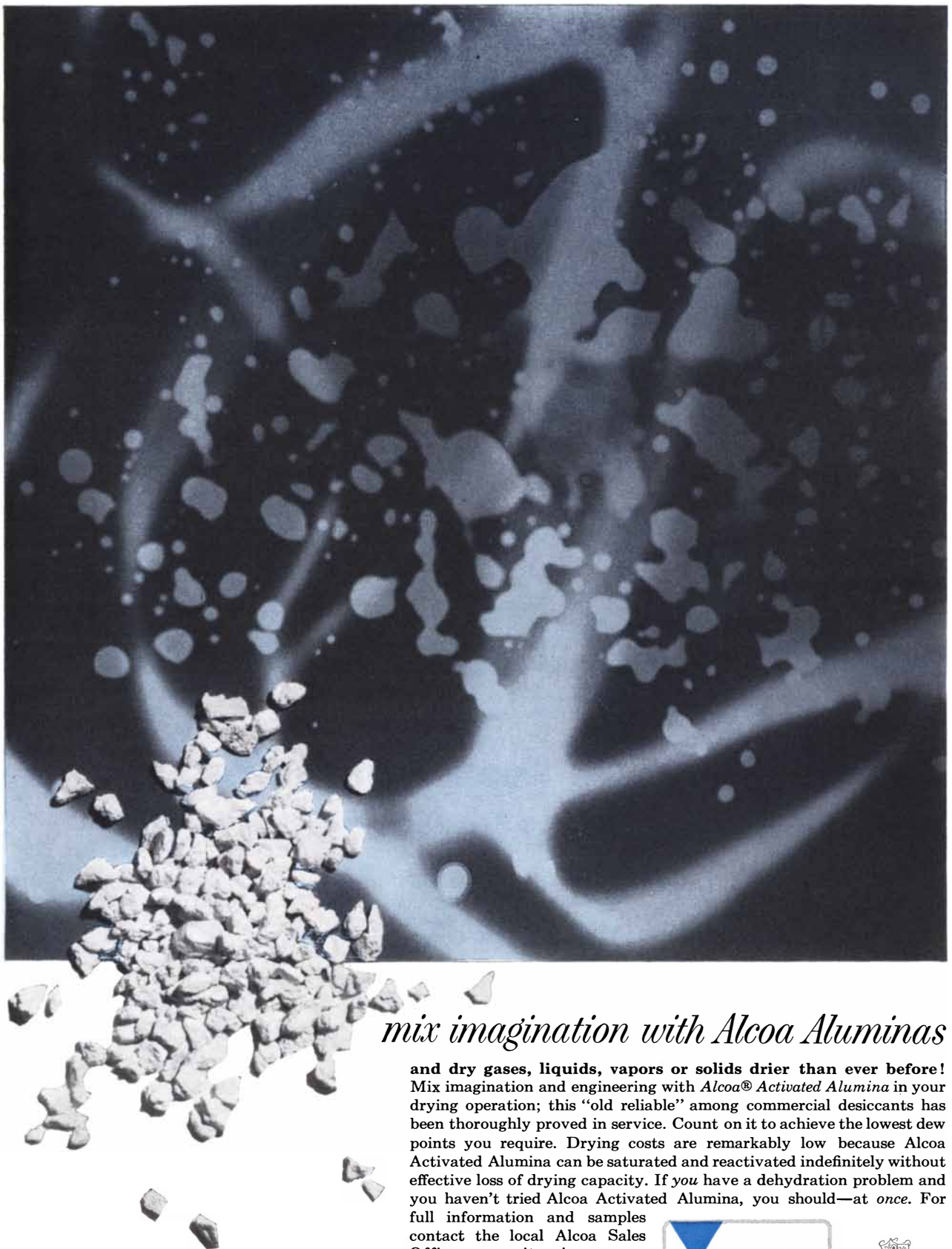

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and dry gases, liquids, vapors or solids drier than ever before! Mix imagination and engineering with *Alcoa® Activated Alumina* in your drying operation; this "old reliable" among commercial desiccants has been thoroughly proved in service. Count on it to achieve the lowest dew points you require. Drying costs are remarkably low because Alcoa Activated Alumina can be saturated and reactivated indefinitely without effective loss of drying capacity. If *you* have a dehydration problem and you haven't tried Alcoa Activated Alumina, you should—at *once*. For full information and samples contact the local Alcoa Sales Office or write ALUMINUM COMPANY OF AMERICA, CHEMICALS DIVISION, 706-G Alcoa Building, Pittsburgh 19, Pa.

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ARTICLES

DEPARTMENTS

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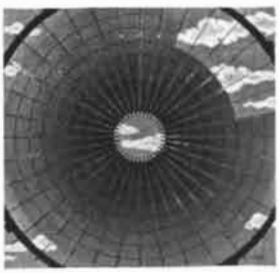

THE COVER

The cover shows the bottom of a half-finished roof made of prestressed concrete (*see page 25*). The gray sectors are slabs of concrete suspended from a web of steel cables. When all the slabs are in place, weights are placed on them to stretch the cables. The spaces between the slabs are then filled with concrete. When the concrete has set, the weights are removed so that the cables compress the whole structure. The roof, designed by Mario G. Salvadori, was built by a group of Columbia University architecture and engineering students under direction of Bruno Funaro.

THE ILLUSTRATIONS

Cover by Robert Hallock

Page	Source
25	Hamilton Wright
26-28	Bunji Tagawa
30	Preload Company, Inc. (*top*); U. S. Geodetic Survey (*bottom*)
31	Preload Company, Inc., (*top*); Hamilton Wright (*bottom*)
32-34	Royal Canadian Air Force
35	Bunji Tagawa
36-37	Bunji Tagawa (*top*), U. S. Geological Survey (*bottom left*), Royal Canadian Air Force (*bottom right*)
38	Dominion Observatory
39	Bunji Tagawa
40-44	John Langley Howard
59-60	Eric Mose
69	René Martin
76	J. Desmond Clark
78	Bunji Tagawa
80	Eric Mose
82	Northern Rhodesia Information Department
85	Woods Hole Oceanographic Institution
86-90	James Egleson
94	Eric Mose
95	National Institute for Medical Research
96-106	Alex Semenoick
108-114	Roger Hayward

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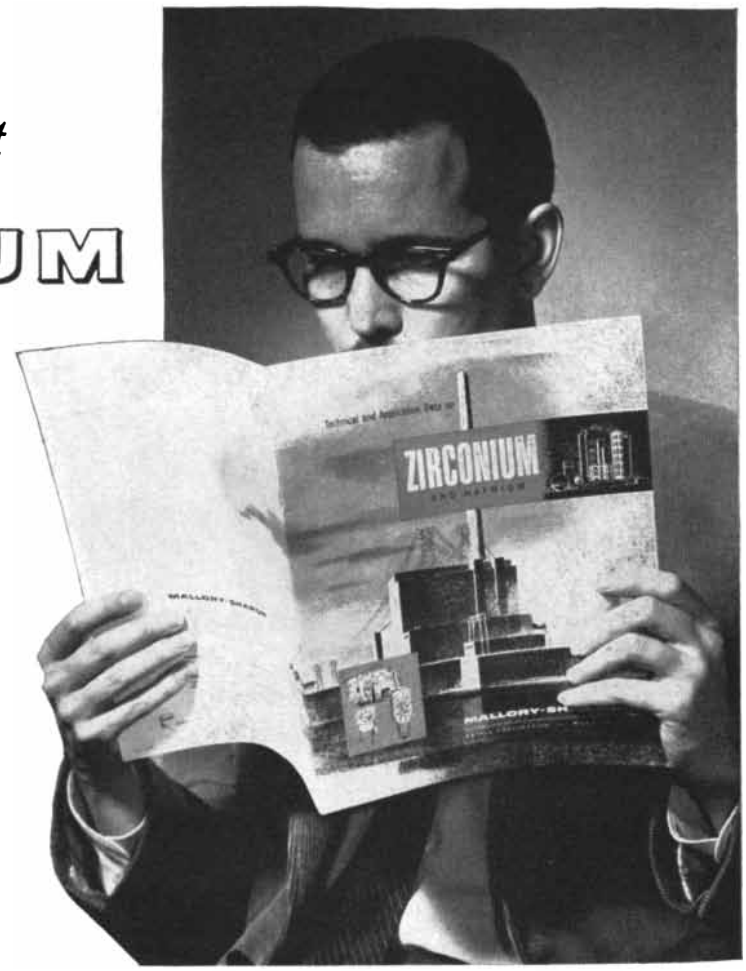
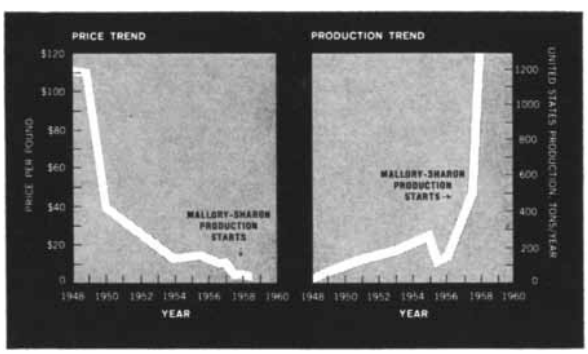
Mallory-Sharon's integrated production facilities ... from raw materials through finished mill products ... mean *greater availability* and *lower costs*.

We're ready *now* to help you explore practical commercial uses for zirconium. Write us for technical information, or engineering assistance on specific applications.

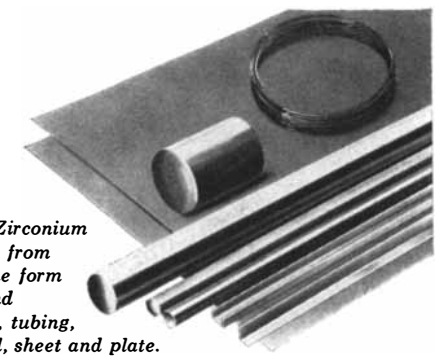


For technical facts — *Write for new 16-page booklet, giving technical and application data on zirconium ... its excellent corrosion resistance to most acids, alkalies and combinations of these media ... its remarkable nuclear properties.*

For availability — *As Mallory-Sharon's large, modern, sponge plant reaches full production this year, zirconium becomes readily available for all commercial applications.*



For lower prices — *Greater availability will definitely be reflected in lower prices. In many cases, the improved performance of zirconium parts much more than offsets their higher material cost.*



For mill products — *Zirconium is now available from Mallory-Sharon in the form of rounds, bars and billets, wire, tubing, strip, foil, sheet and plate. Quality and properties are carefully controlled at every stage of production.*

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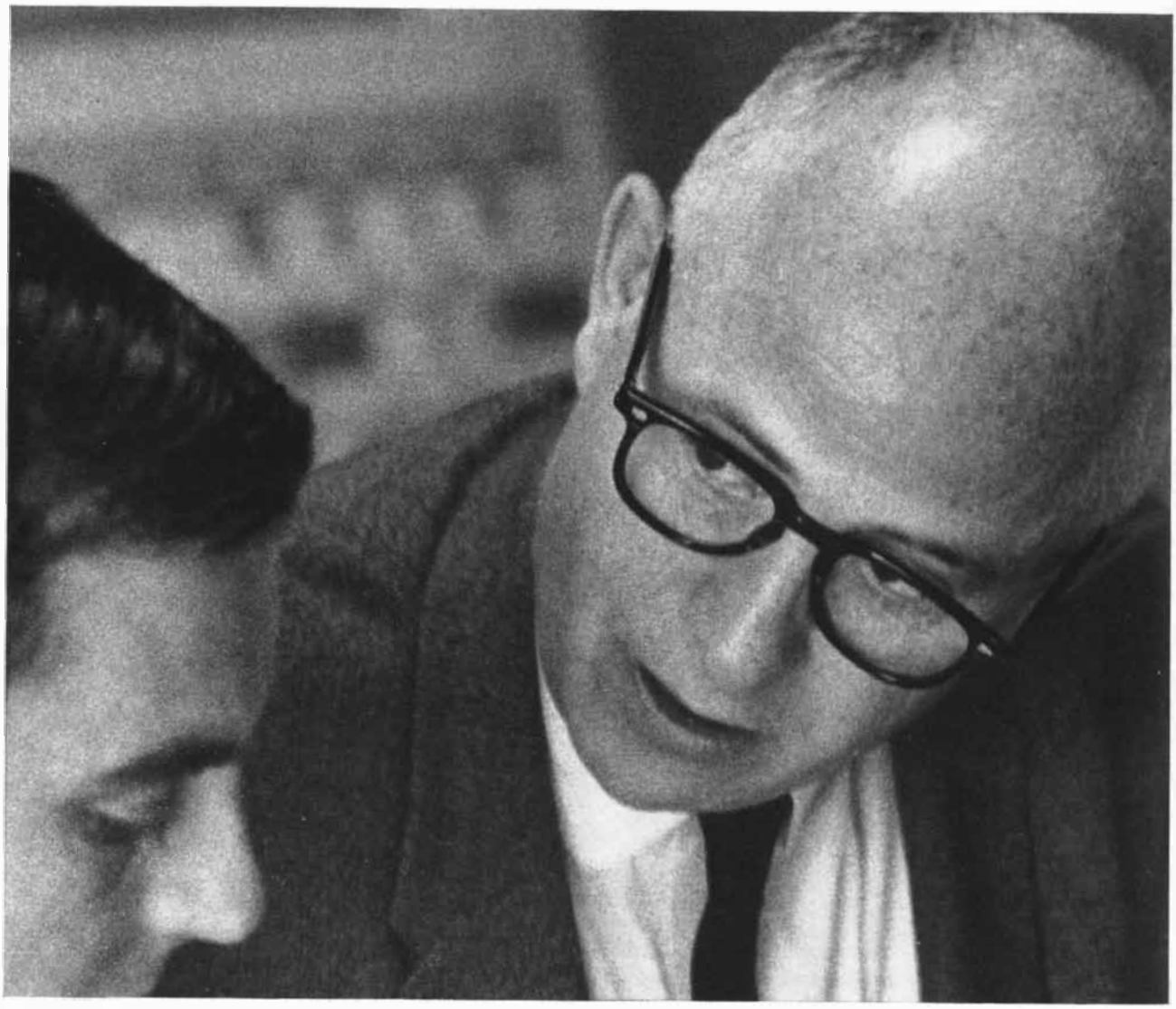
CREATING A NEW WORLD WITH ELECTRONICS... NO. 6

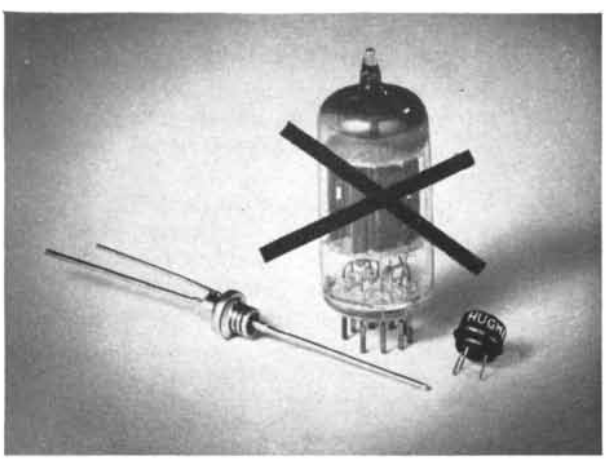
Why all this talk about



transistors?

The tiny transistor is a frequent topic of conversation these days. Consumers are talking about, *and buying,* transistorized radios, hearing aids and other products. Manufacturers are developing new ways to reduce costs with transistorized automation systems. Industrial designers are transistorizing old products to give them new sales appeal and make them more efficient.

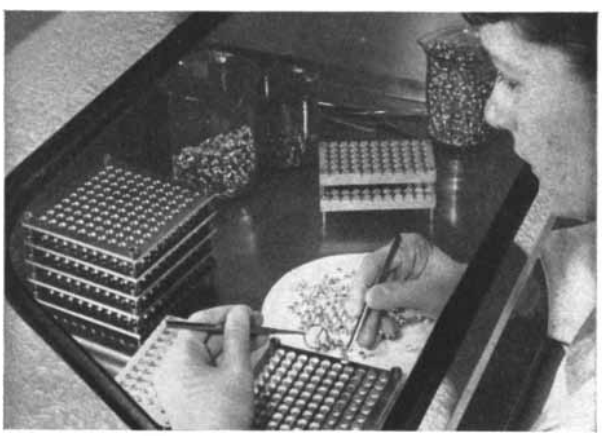
The transistor does its job much better than a vacuum tube many times its size—uses less power, generates almost no heat, and can withstand for long periods of time, shock and vibration that would shatter a vacuum tube in *seconds.*



Either of these small HUGHES *transistors amplifies as much electrical current as the much larger power vacuum tube.*

Hughes transistors were developed to the strict standards and requirements of advanced computers, weapons systems and missiles. Because of that heritage, HUGHES coaxially packaged transistors have a much wider range of application for commercial uses than ordinary transistors. They are more efficient, will withstand more abuse, and are readily adapted to machine assembly methods.

We're mighty proud of HUGHES transistors—which are made to the same strict standards as all HUGHES products. HUGHES transistors are subjected to dozens of test-inspections during manufacture. Reliability is not only *designed* into HUGHES products—it's the "religion" of everybody who works at HUGHES.



Final assembly of HUGHES *transistors at the new semiconductor manufacturing plant takes place under a glass hood that keeps out dust and moisture.*

We will welcome an opportunity to demonstrate to your engineers why HUGHES transistors are the best in the industry. And perhaps our wide commercial and military experience in the design of electronic systems and components can help improve your product and profit picture. Please write:

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LETTERS

Sirs:

The article by Walter C. Michels in your April issue will delight the hearts of many physics teachers who in the past quarter-century have been caught between the muddleheaded educationists, with their emphasis on adjustment, and the functional boys who saw in high-school physics nothing more than a parade of gadgets.

The program described is very similar to the one we put into effect at Belmont High School in Los Angeles during the 1930s and early 1940s. In that dreadful period, when the perverters of John Dewey were riding high, our emphasis on fundamentals and the interrelation of the different fields of physics and mathematics certainly seems to have been effective, judged by the number of our students who went on into scientific work. Of course they might have done so anyway; teachers and doctors are always taking credit for the normal processes of nature. But at least we did not retard them.

Excellent as Dr. Michels's basic plan is, there is one field in which it could be expanded, and one attitude to which, I believe, sharp exception could be taken.

An excellent case is made for the need of a broad scientific background for every citizen who expects to function intelligently in the modern world. No thoughtful person can take exception to

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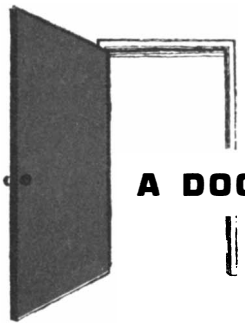

A DOOR IS OPENED TO NEW DEVELOPMENTS IN POLYETHYLENE...MISSILES...FOREST FARMING

A new concept of plastics manufacture—slush molding with A-C polyethylene. (Decoys shown are from mold above.)

Polyethylene, as we all know, is pretty versatile stuff. By varying its molecular weight, it can be made soft and fluid—or so hard that even its manufacturer doesn't know what to do with it! (More about this from us in future articles.) Right now, a word about the low-molecular types, of especial interest to molders and textile people.

Slush molding: Molders are well aware of the advantages of this process—low pressures, short runs, inexpensive molds. But they may not be as aware as they should be of the advantages of polyethylene for slush molding. Here's an entirely new material for the process—one which "gives the properties without the problems." A mixture of A-C polyethylene with conventional types permits viscosity control. Polyethylene and slush molding are opening up a whole new concept of plastics manufacture—from small toys to 50-ounce parts—all with fine detail and warm "lifelike" feel.

Textile finishes: Polyethylene is now emulsifiable—and that's good news for the textile industry, already the largest consumer of chemicals. A-C polyethylene emulsions can be used either by themselves or with other finishes to impart a variety of desirable characteristics to both natural and synthetic fibers, such as soft "hand," and better wearing qualities through increased tear strength and abrasion resistance. *Send the coupon for our latest bulletins on these polyethylene developments.*

REPORT ON ROCKET PROPELLANTS. A few years from now, if somebody tells you his vacation is going to be "out of this world," he may mean it quite literally. He may be planning a jaunt to Mars—or the moon. Chances are he'll go "by rocket." And what will make the rocket go? That's a question which is absorbing the attention of many of our rocket-minded citizenry today—and for purposes far more pressing than space travel.

Nitrogen Tetroxide may prove to be one of the answers. It's certainly worth a long look into. N_2O_4 offers some decided advantages over liquid oxygen and hydrogen peroxide as an oxidizer. Compared to liquid oxygen, for instance, it is strikingly better on a density basis (1.45 vs. 1.14). It gives 12% greater range and is far easier to handle, needing no refrigeration. More than an oxidizer, its energy content contributes thrust as well. Availability? Sources are now adequate and potential availability is practically unlimited. The cost is slightly greater, but all things considered, it may be cheaper to use—as a first-stage, dependable oxidizer.

Of course, there's nothing exactly "new" about Nitrogen Tetroxide as a chemical. It became available in pilot plant quantities 'way back in the early 1940's. Today's demands for the ideal rocket propellant give it new and pertinent interest. *A new bulletin is available. Check coupon below.*

NEW FOREST-FARMING BIBLIOGRAPHY. "Forest Fertilization," a 300-page bibliography, with abstracts, on the use of fertilizers and soil amendments in forestry, has been published by the State University College of Forestry, Syracuse University. This book, first of its kind, is the result of a two-year study sponsored by Allied's Nitrogen Division. It is now available to the public at a $3.00 cost-of-printing charge. Also available, and without charge, are two booklets translated from German and Japanese sources describing fertilization practices in those countries. *Send coupon for any or all.*

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- ☐ "Forest Fertilization" ($3.00 enclosed)
- ☐ German-Japanese booklets

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this basic premise. But what of the historical development of the subject and the profound sociological effects that have followed major scientific developments? Are we to leave the interpretation of these developments to the scientific illiterates of social studies? Perish the thought! Besides it would not hurt us science teachers to give some earnest thought to historical perspective and social consequences.

The sad part of Dr. Michels's article is his implication that our economy cannot afford enough qualified physics teachers to maintain an adequate classroom program, and therefore must resort to money-saving gadgets such as canned and televised lectures.

This attitude is completely unjustified both from a standpoint of psychology and economics. The most firmly established educational principle is that the learning process progresses best when a competent teacher is in close personal communication with a moderate-sized group.

Economically there is still less justification for this abject surrender to traditional American niggardliness toward the intellectual. It has been quite thoroughly demonstrated that the American economy can support anything that the American people want. Our problem as teachers is to convince that great amorphous mass that education is almost if not quite as valuable as alcohol, tobacco or automobile tail-fins.

THEODORE F. WHITEHEAD

Metropolitan High School
Los Angeles, Calif.

Sirs:

I enjoyed the article on the bathyscaph in your April number. I am puzzled, though, as to why neither in the article nor in the bibliography is there any mention of the basic source of information on the bathyscaph in print.

This was a book done by Auguste Piccard which Oxford University Press published in 1956 under the title *Earth, Sky and Sea.* In justice to Mr. Piccard's literary endeavors and to the translators, and for what is still the most current and complete account of the character and achievement of the bathyscaph, it would have been a service to have called attention to the book's existence.

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University of Chicago Press
Chicago, Ill.

A battery of mechanized furnaces . . . automatically controlled by Honeywell instrumentation. *(Photo courtesy Motorola, Inc., Semiconductor Products Division.)*

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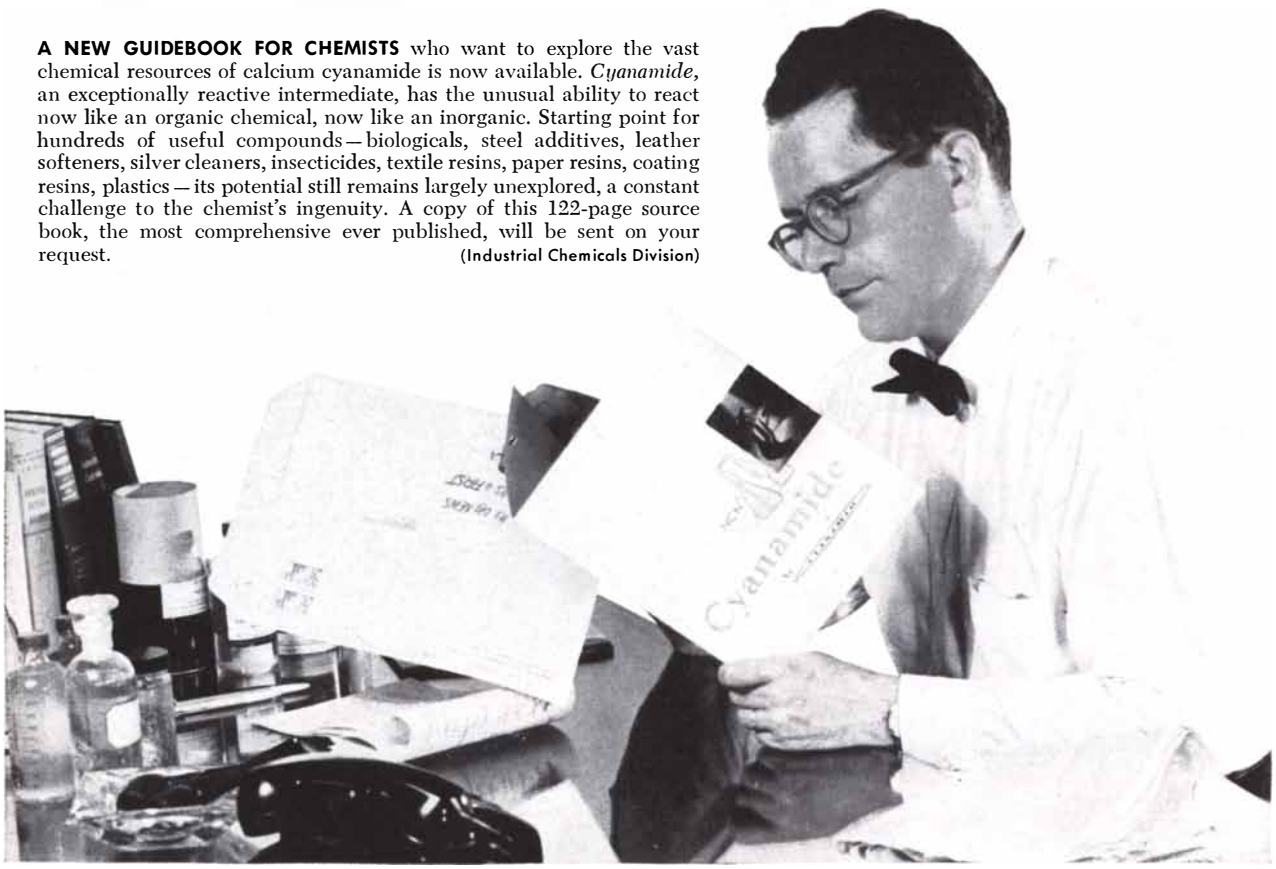
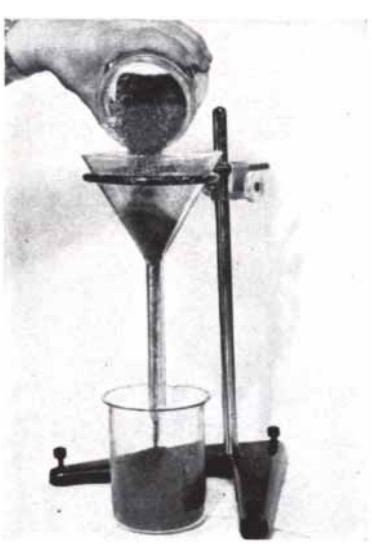
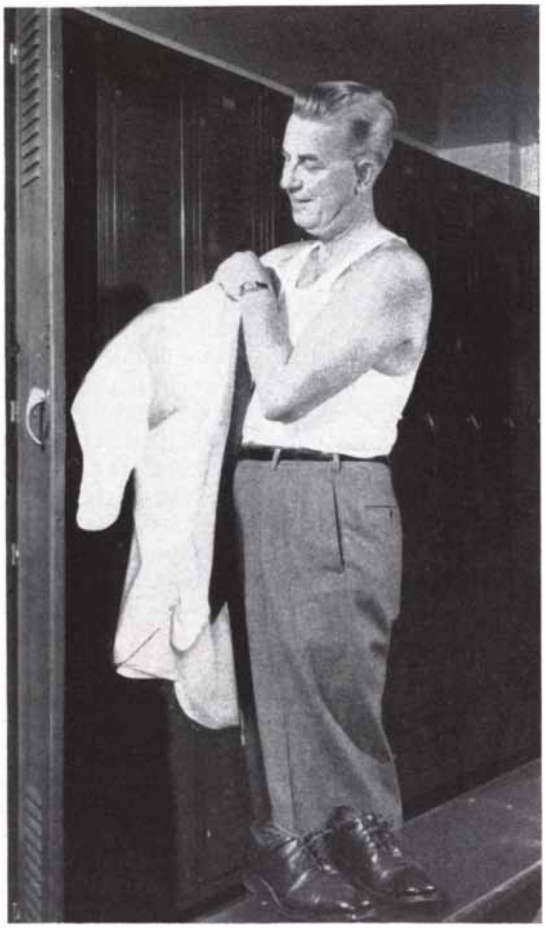
Life on the Chemical Newsfront

A NEW GUIDEBOOK FOR CHEMISTS who want to explore the vast chemical resources of calcium cyanamide is now available. *Cyanamide*, an exceptionally reactive intermediate, has the unusual ability to react now like an organic chemical, now like an inorganic. Starting point for hundreds of useful compounds—biologicals, steel additives, leather softeners, silver cleaners, insecticides, textile resins, paper resins, coating resins, plastics—its potential still remains largely unexplored, a constant challenge to the chemist's ingenuity. A copy of this 122-page source book, the most comprehensive ever published, will be sent on your request. **(Industrial Chemicals Division)**



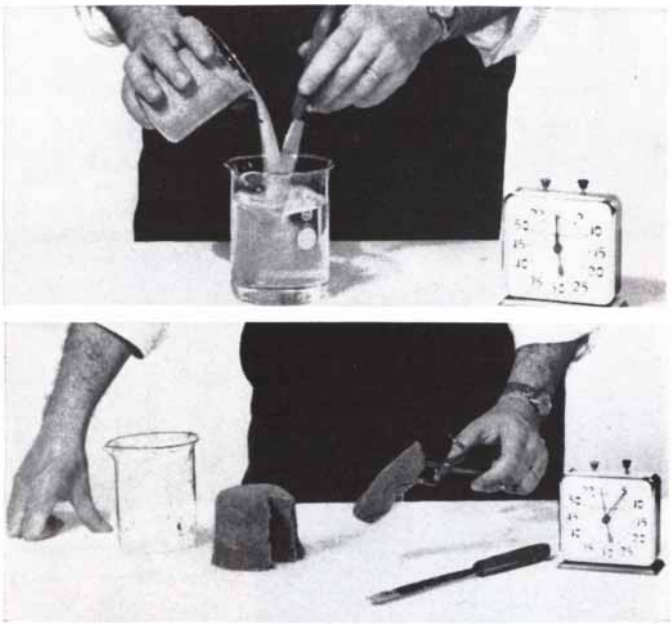


NOW DEVELOPED IN FLAKED FORM, N-cyclo-hexyl-benzothiazole-2-sulfenamide has been added to complete Cyanamid's line of rubber vulcanization accelerators. In this unique flaked form, CYDAC* *accelerator* eliminates caking often associated with currently available powders. Its free-flowing properties are of particular advantage in the automatic compounding of rubber for tire treads, footwear, heels, soles and similar products. Cyanamid's line now ranges from the very fast-curing mercaptobenzothiazole to the safest delayed-action DIBS® *accelerator*, with CYDAC falling between MBTS and NOBS* *accelerators* in processing safety. **(Organic Chemicals Division)**



FABRICS RECOVER QUICKLY FROM WRINKLES when treated with new AEROTEX* *Resin* 23, one of Cyanamid's minimum-care textile finishes. Cottons or rayons are stabilized or "set" through impregnation and curing of the resin. Even after repeated launderings, treated fabric springs back to its original position, requiring only "touch-up" ironing. Exceptional wrinkle resistance is combined with high tensile strength and resistance to discoloration from chlorine bleaches and ultraviolet rays. AEROTEX Resin 23 imparts a soft hand, and may be used with other finishes to give fabrics other desirable properties.

(Organic Chemicals Division)



NEED A GELLING AGENT? Gels from low viscosity systems can now be produced by AM-9* *gelling agent*. AM-9, a dry powder, forms a nonviscous solution in water. After the addition of a catalyst, the solution gels in a predetermined period of time which is controlled by the amount of catalyst used. Viscosity of the solution remains essentially that of water until just before the gel is formed, allowing the placement of the AM-9 gel almost anywhere that water can be introduced. The gel formed is insoluble in water, organic solvents and alkali. The AM-9 gel is impermeable to water and most organic solvents. The gel is resistant to fungal attack and is mechanically stable in contact with water. We will be glad to send a technical bulletin on your request.

(Market Development Department)

PHOSPHORIC ACID IS NOW ON TAP at Cyanamid's new triple superphosphate plant at Brewster, Florida. A wet process *phosphoric acid*— 54% P_2O_5— it offers the fertilizer industry an economical way to produce high analysis mixed goods using less expensive nitrogens and less sulfuric acid in processing. It will enable fertilizer manufacturers to meet farmers' constantly increasing demands for high analysis plant food. Further information is available on your request.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1908: "Nearly a score of Aero Club members and others interested in aviation made the trip to Hammondsport, N.Y., to witness the flight of the Aerial Experiment Association's third aeroplane, the *June Bug*, on the Fourth of July, for the SCIENTIFIC AMERICAN trophy. The distance to be covered was a kilometer in a straight line. The successful flight, made by Mr. Glenn H. Curtiss, was the culmination of carefully planned efforts for the winning of this trophy by the Association, a combination of inventors whose moving spirit and chief backer is Dr. Alexander Graham Bell. The speed of the machine was very nearly 40 miles per hour—39.8 to be exact. Thus it will be seen that this aeroplane, with the total weight of 650 pounds including the aviator, and with the expenditure of 25 horse-power, is capable of very nearly the same speed that the Wright brothers claim for their 1,000-pound machine with approximately the same horse-power."

"It is announced from the Hague that Prof. Kamerlingh Onnes, of the University of Leyden, who retracted lately his provisional statement that he had succeeded in liquefying helium, has now absolutely succeeded. He obtained, on July 10, 50 cubic centimeters of liquid helium, which remained in that state for 50 minutes. The boiling point of the liquid was 268 deg. C. below zero, equivalent to about 450 deg. below zero F."

"On Tuesday, July 7, the good ship *Roosevelt* started on her second voyage to the Arctic, and two days later Commander Peary left by train for Sydney, Cape Breton, where he joined the ship. From Sydney the ship will go to Hawke's Harbour, where 25 tons of whale meat will be taken on board. At Etaw the expedition will pick up the Esquimaux, upon whom reliance will be placed for the final dash by sled for the North Pole. Peary expects to reach the North Pole in the spring of 1909. If he succeeds, the news should be received in New York sometime between August 15 and September 15 of next year."

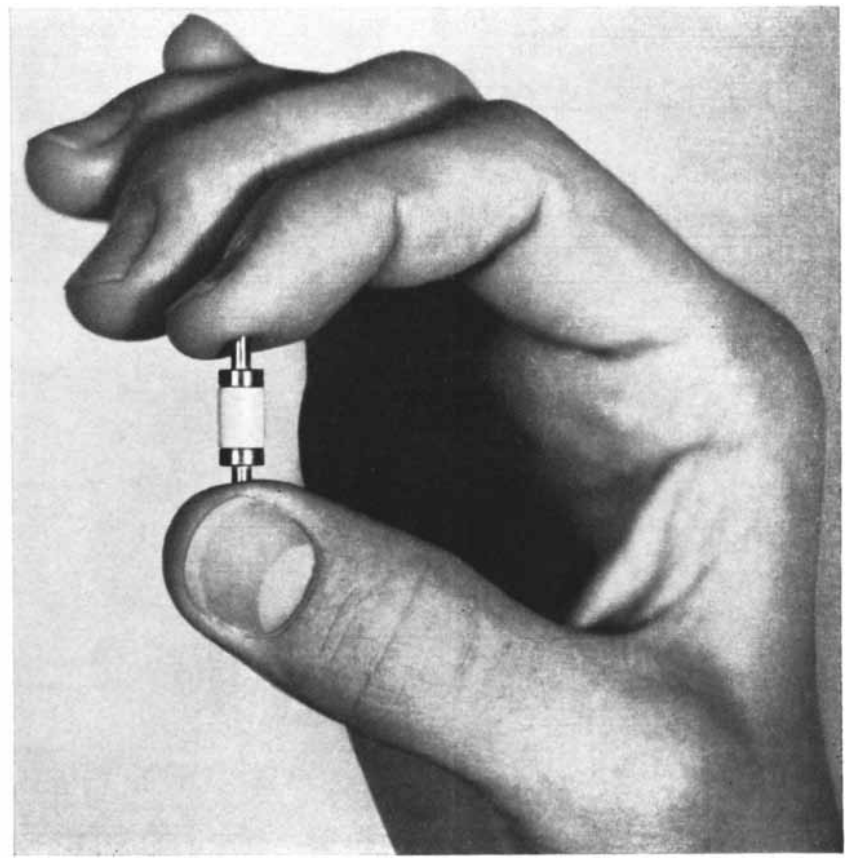
"A find of more than usual interest has been made in Egypt. Early this year excavators in the Valley of the Tombs of the Kings at Thebes, working under the direction of Mr. Theodore M. Davis of Newport, uncovered a royal burial place. Inscriptions in the shrine said that Akhnaton, Pharaoh of Egypt, had made the tomb for his mother, Queen Thiy. In a recess in the wall stood four alabaster canopic jars—jars for holding the viscera of the deceased—each with a lid exquisitely carved in the form of a feminine head. But the coffin, lavishly inlaid with rare stones and colored glass, bore the name of Akhnaton himself. Dr. G. Elliott Smith, an eminent osteologist, declared the bones to be those of a young man of about 25, powerfully built. It now seems certain that they are the bones of Queen Thiy's great son."

"The United States Navy possesses in the scout cruiser *Salem* the fastest warship in the world. In the recent government standardization trial over the measured mile course off Rockland, Me., this handsome vessel was driven at a maximum speed of 26.88 knots, and at an average speed for five runs, over the mile course, of 25.95 knots. This result is particularly gratifying because of the fact that the *Salem* is equipped with Curtis turbines, a type which is distinctly American, having been developed entirely in this country. The *Chester*, a sister ship driven by Parsons turbines, has the distinction of being the second fastest warship afloat."

"Alfred Clarke, a New Yorker by birth but a resident of Paris for a number of years, has had a vault constructed in the cellars of the Paris Opera House, in which have been placed hermetically sealed leaden casks containing talking-machine records of the voices of present-day singers as well as some orchestral pieces. The idea is to preserve these records for posterity, so that the mellow notes of Caruso and Melba may be heard by people who were born many years after the death of these artists. It was agreed that the vault might be opened after 50 years with the permission of the Ministre des Beaux-Arts."

"The fifth annual Glidden trophy tour for automobiles is over a 1,700-mile course, extending from Buffalo to Pittsburgh, thence north to Albany, N.Y., east to Boston, north to the Rangeley Lakes in Maine, and then west through

NEW DIODE SPEEDS VOICES— AT 6,000,000,000 C.P.S.



How the radio art can be improved through solid state science is illustrated by a recent development at Bell Telephone Laboratories. To make voice signals travel by microwaves they must first be "converted"—caused to vibrate at billions of cycles per second. To date, it has been possible to accomplish this conversion only at the cost of appreciable loss of signal energy. Could a more efficient converter be provided?

In the field of solid state science it was known—as a laboratory curiosity—that semiconductor diodes can be made not only to convert the frequency of signals, but also to amplify them. At Bell Laboratories Dr. Arthur Uhlir, Jr., and his associates calculated that this amplifying action could be put to practical use. They proved the point by developing a junction diode converter which can deliver up to 40 times as much signal energy as previous converters.

This efficient new converter will be applied in a new Bell System microwave highway able to transmit thousands of telephone conversations and a dozen television programs simultaneously at six billion cycles per second. In other forms it is being developed, under Signal Corps contract, for radar and military communications where more efficient frequency conversion can also be used to advantage.

This development is an example of the many different ways in which Bell Laboratories works to improve your telephone service and communications at large.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

the White Mountain district, across Vermont to Saratoga. At last report the contestants had reached Boston (960 miles). Out of 30 entrants, the perfect-score cars remaining were three Pierce-Arrows, three Peerlesses, three Marmons, two Studebakers, two Hayneses, two Franklins, a Gaeth, Oldsmobile, Premier, Ranier, Reo and Thomas."

SCIENTIFIC AMERICAN

JULY, 1858: "The steamship *North Star*, from Southampton, arriving at New York July 20, brought news of the failure of the Atlantic cable. The *Niagara* and *Gorgon* met on the 28th of June, and for the third time connected the cable. They then started afresh, and, the *Niagara* having paid out over 150 miles of cable, all on board entertained the most sanguine hopes of success, when the announcement was made on the 29th at 9 p.m. that the electric current had ceased to flow. Professor Morse thinks from this result that the cable is too thick."

"The three steam fire engines lately built for the Philadelphia fire department—the *Philadelphia, Young America* and *Hope*—made a trial of their powers a few days since, in the presence of a large concourse of spectators. The result was creditable to all the machines, but the *Philadelphia* was the winner. The *Philadelphia* threw a stream through a 1½-inch nozzle a distance of 231 feet; the *Young America*, 209 feet; and the *Hope*, 212 feet."

"The steamship *Leviathan* has been re-baptized, and is now the *Great Eastern* again."

"The Dudley Observatory at Albany, not yet fairly under way, has got into trouble, and the trustees have summarily removed Mr. B. A. Gould from the post of Superintendent Astronomer, for alleged impertinence and incivility. In return, Mrs. Dudley, benefactress of the institution, has requested a majority of the trustees to resign, and the Scientific Council has also reprimanded them. Altogether it seems as if New York's quiet gubernatorial city was going to be the scene of a great disturbance, and, until the difficulty is settled, we hope that the stars will not miss their accustomed watching."

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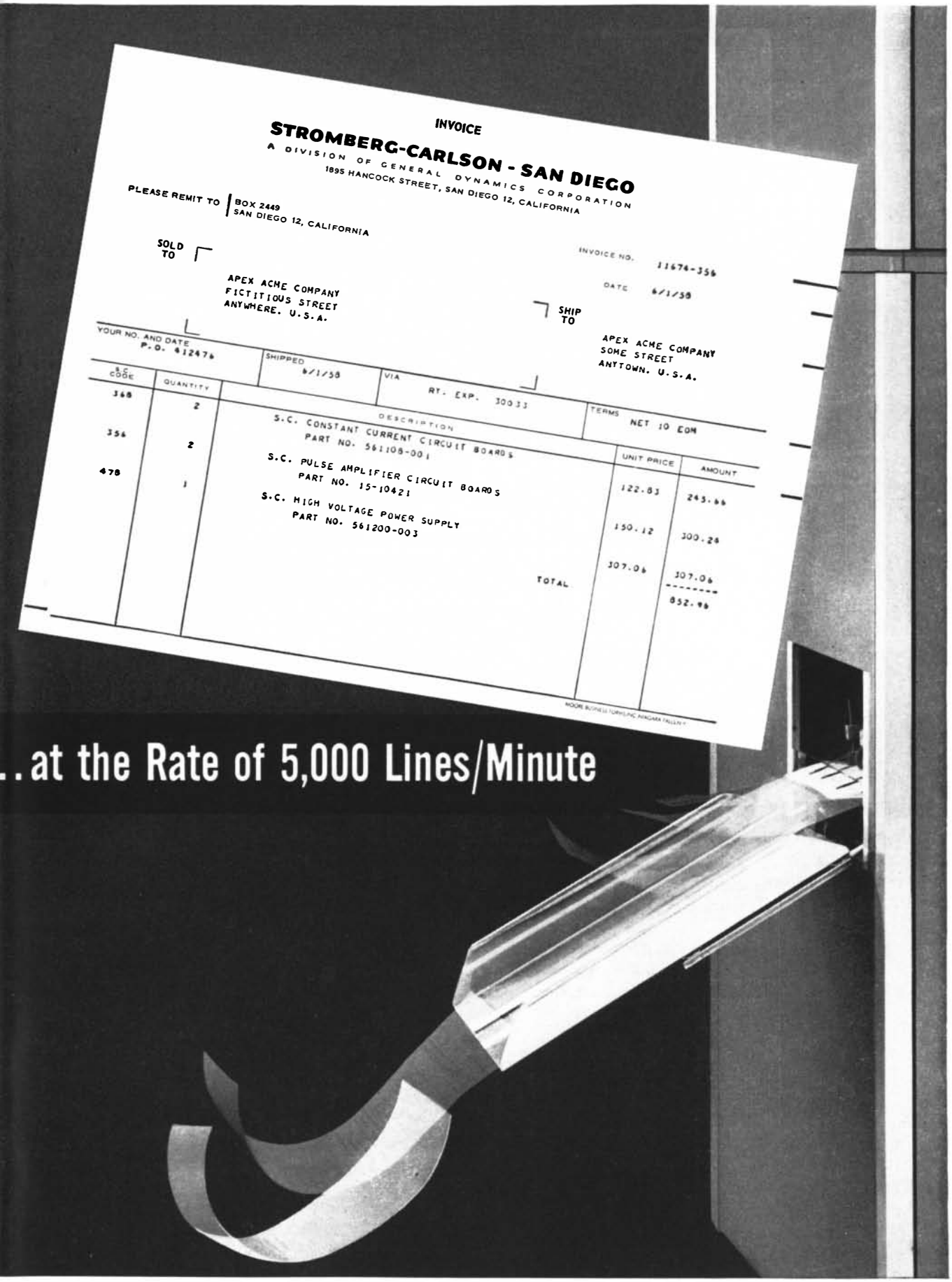

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THE AUTHORS

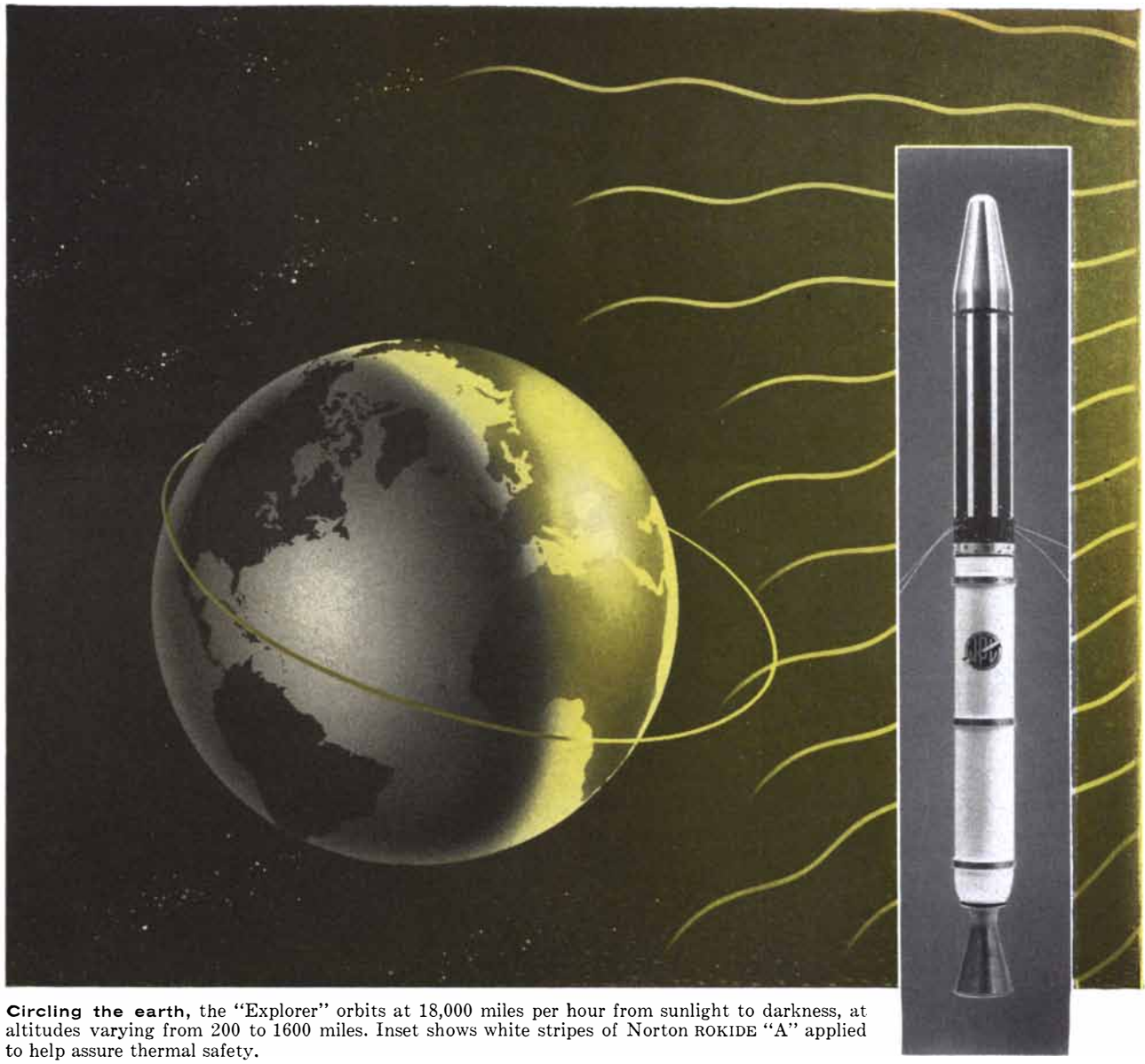
T. Y. LIN ("Prestressed Concrete") recently returned from the U.S.S.R., where he headed a U. S. delegation studying Soviet work with prestressed concrete. Born in China in 1912, Lin was educated at Chiaotung University and the University of California. From 1933 to 1946 he worked as a construction and design engineer on the Chinese Government Railway. In the latter year he emigrated to the U. S. and joined the faculty of the University of California, where he is now professor of civil engineering. Lin's interest in prestressed concrete dates from 1951, when the University was asked by the state to do research on the first bridge in California incorporating this material. The results of the investigation convinced Lin that the new technique was sound and economical. In 1953-54 he spent a year in Belgium doing advanced work in the field under a Fulbright grant. Last year he was general chairman of the World Conference on Prestressed Concrete held in San Francisco. In addition to his teaching and research at Berkeley, he is a partner in the Los Angeles firm of T. Y. Lin & Associates, consulting engineers specializing in prestressed-concrete structures.

C. S. BEALS ("Fossil Meteorite Craters") is one of Canada's most distinguished astrophysicists. Since 1946 he has served as Dominion Astronomer, directing the Dominion Observatory at Ottawa. Born in Nova Scotia in 1899, he studied physics at Acadia University, Yale University and the University of Toronto. In 1924 he went to England to study atomic spectra at the astrophysical laboratory of the Imperial College of Science and Technology. Becoming fascinated by the relationships between laboratory and stellar spectroscopy, he entered the field of astrophysics two years later at the Dominion Astrophysical Observatory in Victoria, B.C. He spent the war years studying problems of defense against poison gases. Beals is the author of more than 50 scientific papers, most of them dealing with atomic and stellar spectra and the nature of interstellar material. His concern with the latter subject led him to become interested in meteorites. As Dominion Astronomer he initiated the search for meteorite craters in Canada which has already uncovered five probable and several other possible craters, ranging in diameter from three quarters of a mile to 20 miles. He is interested in paintings and collects prints.

DONALD R. GRIFFIN ("More About Bat 'Radar' ") has been interested in natural history since boyhood, and in bats since his undergraduate days at Harvard University. A specialist in the sensory physiology of animal orientation, he has devoted a great deal of study to the radar-like echolocation systems of bats and other animals, and has written three articles for SCIENTIFIC AMERICAN on this subject. Born in Southampton, N.Y., in 1915, he was educated at Harvard and remained there during the war to do physiological research for the Government. In 1946 he joined the faculty of Cornell University. He returned to Harvard as professor of zoology in 1953. He is married and has four children; his chief hobby is sailing.

DAVID E. GREEN ("Biological Oxidation") is one of the pioneers in the field of enzyme chemistry. He first became interested in the subject in 1930, just after his graduation from New York University. As a summer student at the Marine Biological Laboratory in Woods Hole, Mass., he heard about the work being done on enzymes in England and decided to go to the University of Cambridge. After taking his Ph.D. there he remained as a research fellow for seven years, returning to the U. S. in 1941 to take charge of the enzyme laboratory of the College of Physicians and Surgeons at Columbia University. In 1948 he left Columbia to become professor of enzyme chemistry in the Institute for Enzyme Research at the University of Wisconsin; he is now co-director of the Institute and editor of *Currents in Biochemical Research*. A native New Yorker, Green acquired his hobby of figure skating on the rink at Radio City; he now practices it on Wisconsin and Minnesota lakes.

JOSEPH J. MAIO ("Predatory Fungi") originally intended to become a composer and still plays the piano and violin as a hobby. His interest in predatory plants stems from his high-school years, when he maintained a collection of Venus's-flytraps, sundews and pitcher plants. A three-year stay in a tuberculosis sanatorium made him especially aware of the activities of microorganisms, and in 1955 he received his B.S. in microbiology from the University of Washington and his M.A. two years later. As a research assistant at the University of Washington School of Medi-



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cine he is at present working on bacterial viruses. In addition to his musical diversions he enjoys oil painting.

J. DESMOND CLARK ("Early Man in Africa") was born in London in 1916. Soon after receiving his degree from the University of Cambridge he was appointed curator of the Rhodes-Livingstone Museum in Northern Rhodesia, and he has held that position for the past 20 years. He is also Secretary to the Northern Rhodesia National Monuments Commission. During the war he served in the British Army in the Somaliland and Ethiopian campaigns. In both regions he managed to combine archaeology with soldiering; he incorporated his discoveries into a book, *Prehistoric Cultures of the Horn of Africa*. Since the war his investigations of prehistoric African archaeology have centered in Northern Rhodesia and Nyasaland. Now on leave in England, he will teach this fall at the University of Chicago.

HENRY STOMMEL ("The Circulation of the Abyss") grew up in Freeport, N.Y., where he spent much of his time around small boats. Curiously, his first scientific interest was not oceanography but astrophysics. Teaching Naval R.O.T.C. courses in celestial navigation stimulated his curiosity about the sea, and since 1944 he has been with the Woods Hole Oceanographic Institution. His research interests include the large-scale ocean circulations, the Gulf Stream and oceanic turbulence. At present he is working on a project to set up permanent installations on oceanic islands for making continuous observations of the deep sea. By mooring a series of radio-telemetering buoys in the sea around an island such as Bermuda, for example, a radio monitoring station can keep watch on what is happening in the ocean over an area 1,400 miles in diameter.

F. HAWKING ("Filariasis") writes: "My first interest was classics, but as these did not seem to offer a livelihood, I turned to science, particularly medicine." Born on a farm in Yorkshire and educated at the University of Oxford and St. Bartholomew's Hospital, he had no special interest in tropical countries until 1930, when an advertisement drew him to the Liverpool School of Tropical Medicine. His first opportunity to study filariasis came in 1937, when he began two years as a Medical Research Council Fellow in Tanganyika and Nigeria. Since 1939 he has been associated with the National Institute for Medical Research in London.

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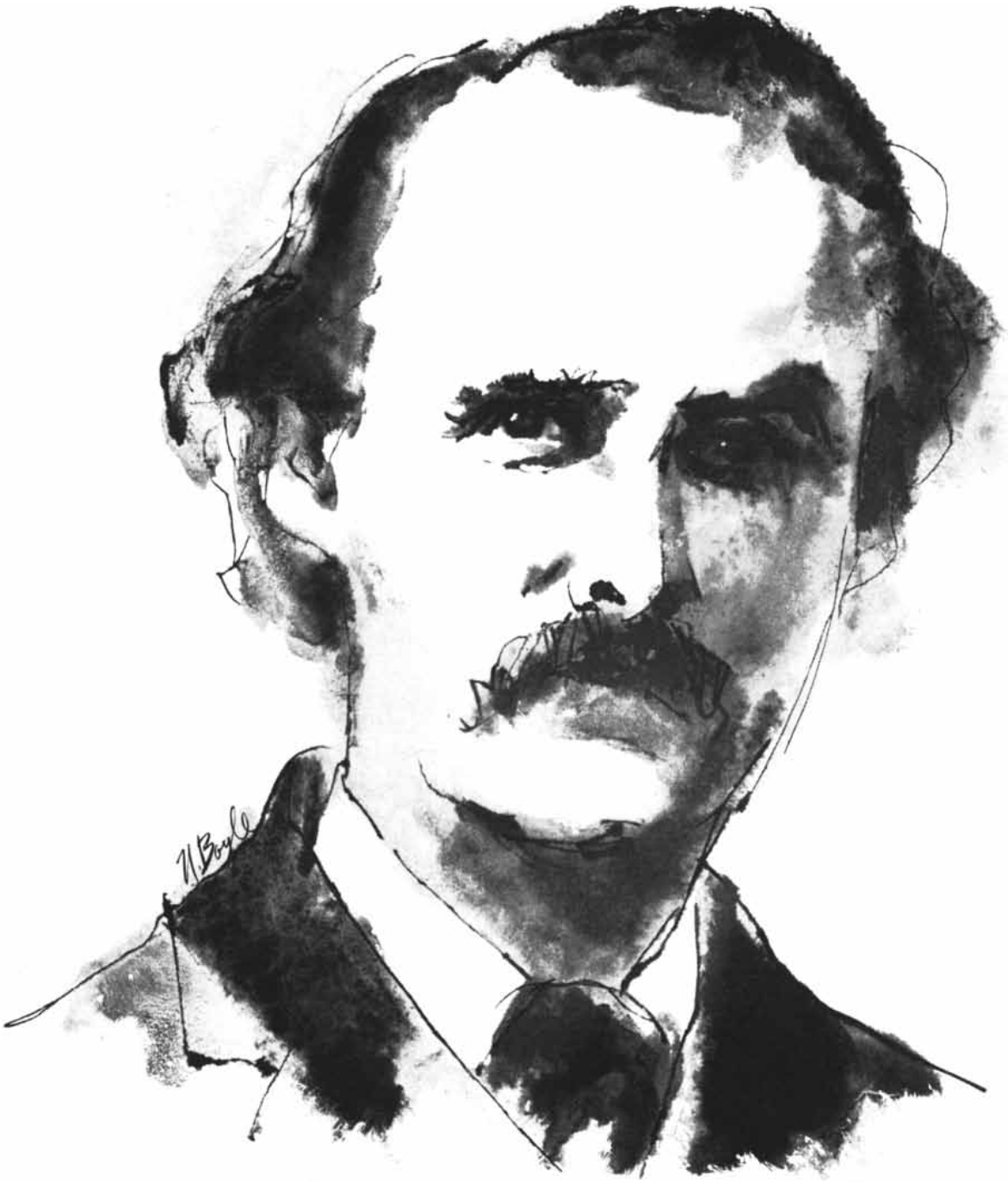

Alfred Marshall...on the tendencies of human action

"The laws of economics are to be compared with the laws of the tides, rather than with the simple and exact law of gravitation. For the actions of men are so various and uncertain, that the best statement of tendencies, which we can make in a science of human conduct, must needs be inexact and faulty. This might be urged as a reason against making any statements at all on the subject; but that would be almost to abandon life. Life is human conduct, and the thoughts and emotions that grow up around it. By the fundamental impulses of our nature we all—high and low, learned and unlearned—are in our several degrees constantly striving to understand the courses of human action, and to shape them for our purposes, whether selfish or unselfish, whether noble or ignoble. And since we *must* form to ourselves some notions of the tendencies of human action, our choice is between forming those notions carelessly and forming them carefully. The harder the task, the greater the need for steady patient inquiry; for turning to account the experience, that has been reaped by the more advanced physical sciences; and for framing as best we can well thought-out estimates, or provisional laws, of the tendencies of human action."

—*Principles of Economics*, 1892

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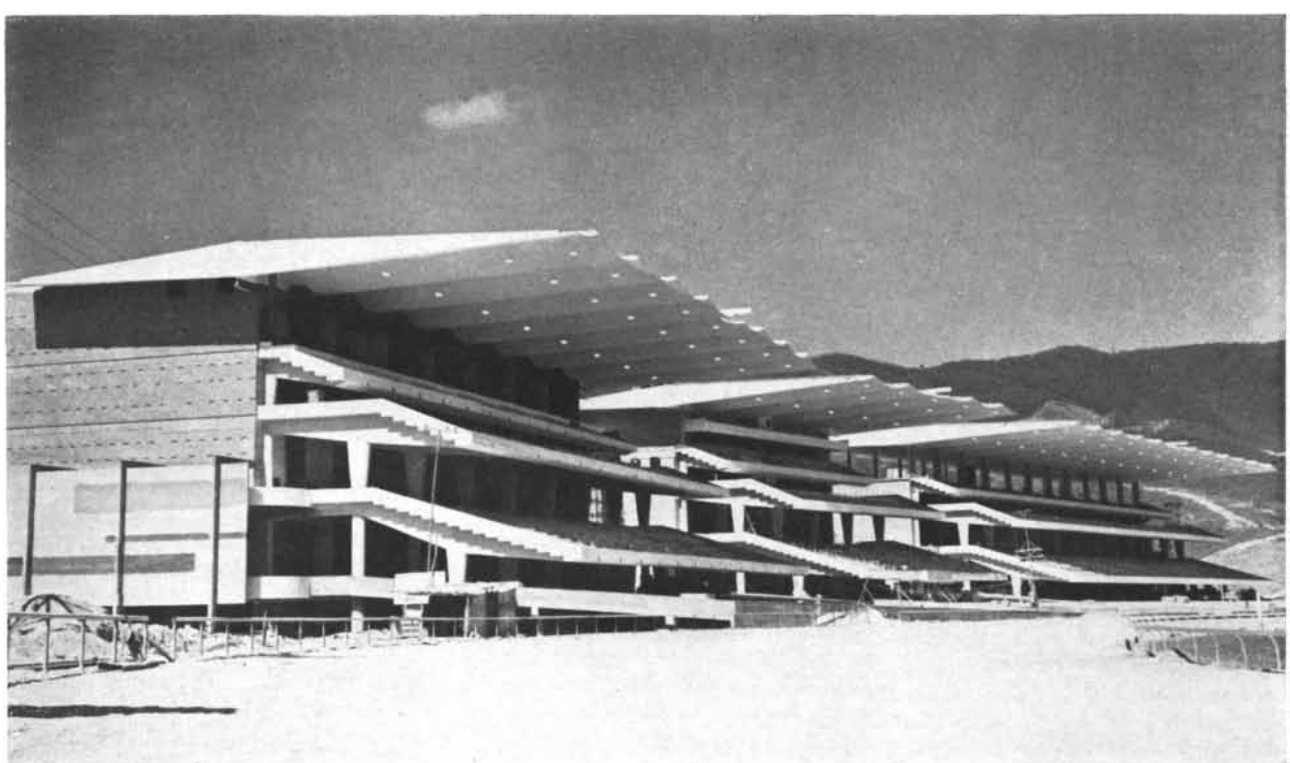
Established 1845 **SCIENTIFIC AMERICAN** July, 1958 Volume 199 Number 1

Prestressed Concrete

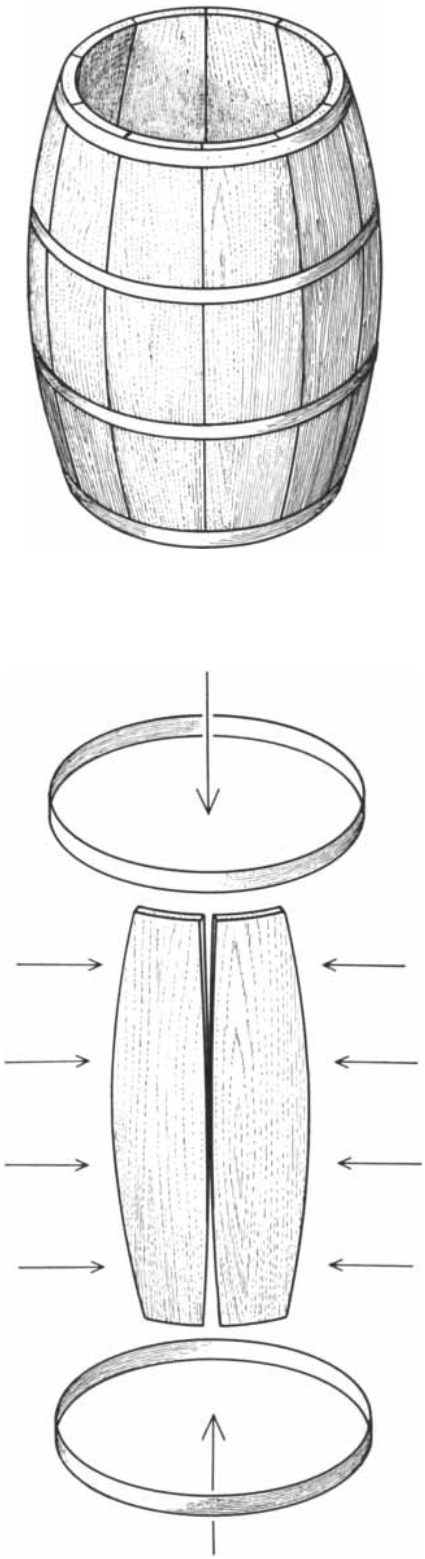
Concrete is made stronger by compression; steel, by tension. These opposing properties are combined to make a building material which is stronger than reinforced concrete and cheaper than steel alone

by T. Y. Lin

Pictured on the cover of this issue of SCIENTIFIC AMERICAN is a revolutionary building. Its bowl-shaped roof literally hangs from the building's circular frame—like a life net held by a circle of firemen. But the most remarkable feature of the structure is not its design. The roof is concrete! It represents a radical innovation in building material. The concrete is laced with cables of steel, and the two materials are wedded in a new way which makes concrete as supple as a diving board and gives the steel seven times its usual strength. The combination is called prestressed concrete. Developed within the last few years, it is already recognized as one of the great advances in construction of the 20th century. Prestressed concrete provides builders with a material of superb strength, flexibility and econ-



PRESTRESSED CONCRETE ROOF of the National Race Course at Caracas, Venezuela, projects 90 feet from its supporting pillars. The concrete of the roof is only three inches thick. When the Race Course opens in October, the grandstand will seat 35,000 people.



PRIMITIVE EXAMPLE of prestressing is the barrel. The wooden staves of the barrel are precompressed, and the metal bands around them are prestretched. The horizontal arrows indicate the direction in which the staves are compressed; the vertical arrows, that in which the bands are applied.

omy. Thousands of buildings and bridges have been built of it, and the manufacture of prestressed concrete in the U. S. is approaching a billion-dollar industry. It seems not too much to say that in construction we are passing from the age of steel to the age of prestressed concrete.

The idea is simplicity itself. Suppose we take a long block of concrete, put a bar of steel through it lengthways and tighten nuts at the ends of the bar so that the steel is stretched and its tension compresses the concrete. Concrete, which is strong in compression, also loses its tendency to crack when thus compressed; the steel, strong in tension, is tightened by the stretching. The stressed concrete span will now bear a considerable load. It is no longer brittle but actually resilient. Indeed, with prestressed concrete we can make a whippy fishpole or a bouncy diving board!

Prestressed concrete should not be confused with reinforced concrete, which simply has steel embedded in it for support. The novel feature of the new combination is the built-in stress, which stores energy in the concrete and the steel and thereby augments the strength of both.

The combination has several obvious advantages. It saves steel, because the steel sinews are merely cables or slim rods. The concrete protects the steel from corrosion and fire. And prestressed concrete can easily be molded into any desired form—a dome, a girder, an arch, a tank or whatever.

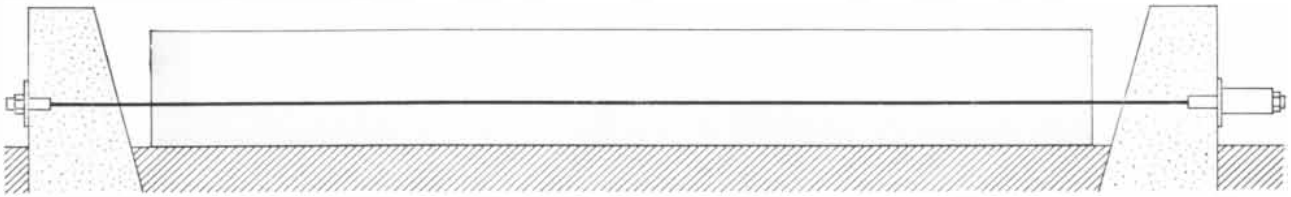
The prestressing idea is at least as ancient as the old-fashioned wooden barrel. The iron bands around the barrel are prestretched, and the wooden staves are precompressed. The barrel, when filled, say, with beer, does not leak; indeed, the pressure inside the barrel increases the tension on the hoops that hold the staves together [*see diagram at the left*]. The same principle has been employed in the U. S. since 1930 in huge circular tanks, holding millions of gallons of liquid, which are built of concrete with tightly wound bands of high-tensile steel.

As early as 1886 a San Francisco engineer named P. H. Jackson patented the idea of a prestressed concrete beam. He buried a steel bar (wrapped in grease and paper) in the concrete and tightened the bar with a nut to compress the concrete. Unfortunately his system did not work, because in time the concrete shrank to the point where his bar, made of ordinary steel, lost its tension and no longer compressed the concrete. About 1927 a French engineer, Eugène Freyssinet, made the idea practicable by using high-tensile steel, which could be stretched enough to keep most of its tension even after shrinkage of the concrete [*see diagrams on page 28*]. European builders took to prestressed concrete for many of their structures, especially after World War II, because it conserved scarce steel. In the U. S. the first use of prestressed concrete for a structure other than a tank came in 1950, when a bridge of this material was built in Philadelphia with the assistance of G. Magnel of Belgium, a pioneer in the field. Now there are thousands of prestressed concrete structures in this country, and more than 200 plants engaged in producing the new building material. The U.S.S.R. also has taken it up on a large scale. The U. S. and the U.S.S.R. are leading producers of prestressed concrete: it is estimated that last year each produced some 1.5 million cubic yards. The U.S.S.R. is known to be planning to raise its rate of production to nine million cubic yards by 1960.

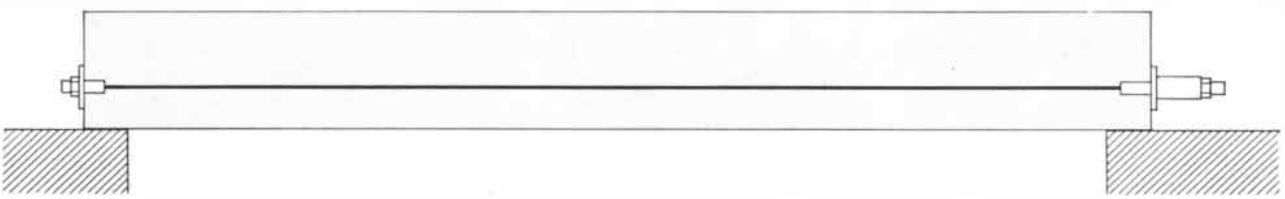
It is apparent that the prestressing idea can be applied not only to concrete but also to ceramics and other materials. For example, prestressed ceramic wings for airplanes have already been tested. The prestressing steel gives the wing sufficient strength, and the ceramic surface, because of its high resistance to air friction, looks like a promising answer to the heat barrier. Among other materials to which prestressing has been successfully applied are bricks, timbers and even ordinary steel, which can be made to bear heavier loads by prestressing it with embedded sinews of high-strength steel. But the ideal combination, from the standpoint of economy and flexibility, is high-strength steel and concrete.

The use of prestressed concrete on a large scale did not become feasible until high-strength steel was made available at reasonable prices. The steels now employed can withstand up to 250,000 pounds of tension per square inch of cross section. In prestressed concrete they are kept at a tension of about 140,000 pounds per square inch—seven times the tolerance of ordinary steel. The high-strength steel is about four times more expensive than the ordinary metal, but as the demand grows its cost will undoubtedly come down.

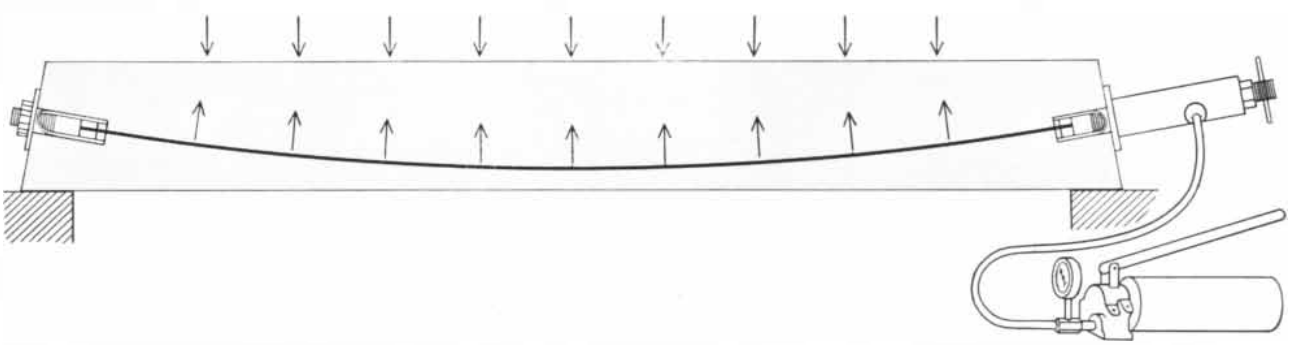
Now there are many possible ways of combining the steel and the concrete. The one most commonly employed adds to the compression of the concrete another most useful mechanical princi-



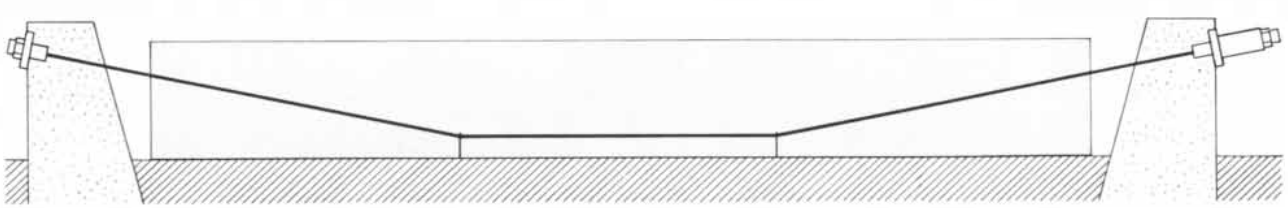
PRE-TENSIONING a prestressed concrete beam involves, in a simple case, (1) stretching a steel rod between two stout abutments. (2) pouring concrete around the rod and (3), after the concrete has set, releasing tension on rod so that it compresses the concrete.



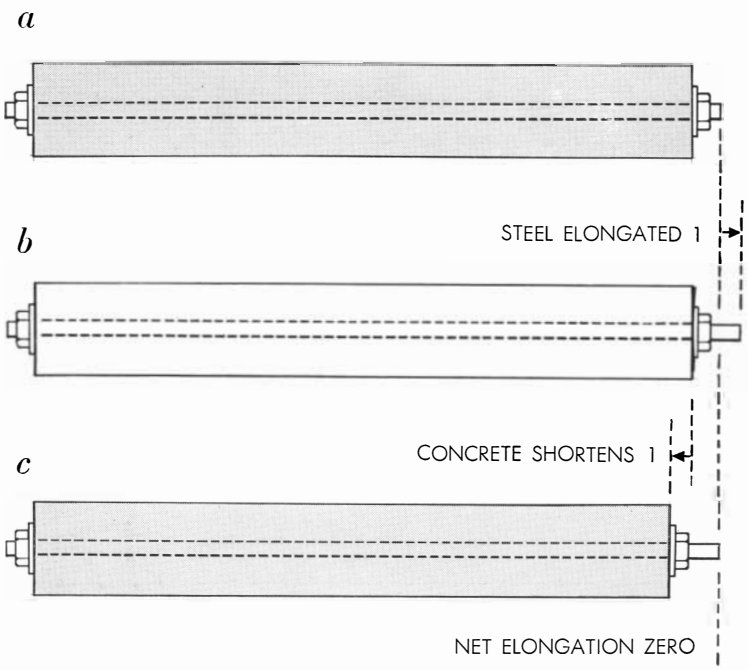
POST-TENSIONING a prestressed concrete beam involves, in a similarly simple case, (1) pouring the concrete around an unstretched steel rod which is encased in a tube and (2), when the concrete has set, stretching the rod by means of a screw jack (*right*).



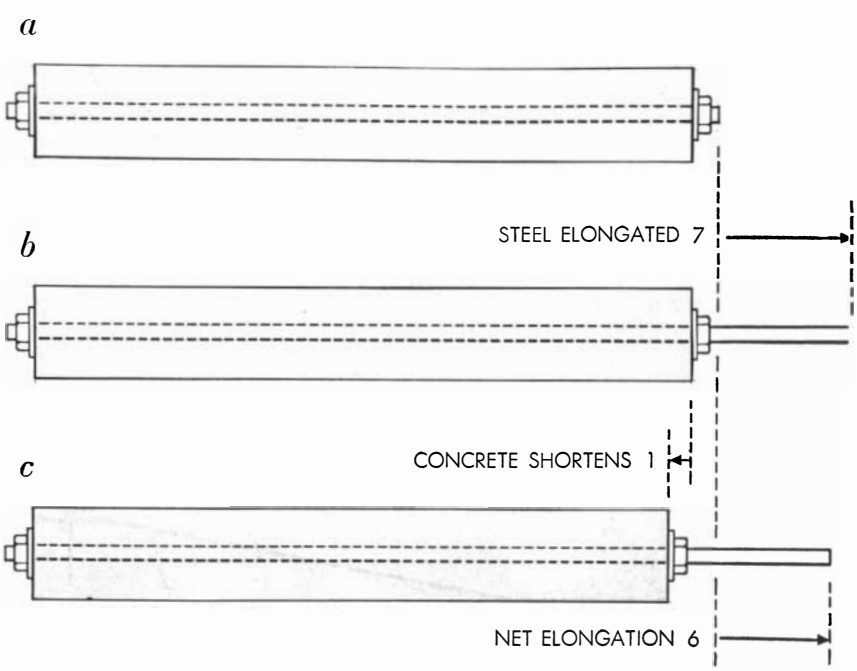
POST-TENSIONING IS USED to exert an upward force on a prestressed concrete beam by (1) loosely suspending a cable, (2) pouring concrete around it and (3) stretching the cable with a hydraulic jack. The upward force then equals the load on the beam.



PRE-TENSIONING IS USED to exert a similar upward force on a prestressed concrete beam by (1) stretching between abutments a cable which is anchored at two points, (2) pouring concrete around the stretched cable and (3) releasing the tension on the cable.



ORDINARY STEEL does not permit prestressing, for the reason depicted in these drawings. At top is a beam 100 feet long (the vertical scale is exaggerated with respect to the horizontal) ready for post-tensioning. In the middle drawing the ordinary steel rod has been stretched one inch, about as far as it will go. In the bottom drawing the concrete has shrunk one inch, allowing the steel rod to relax so that the concrete beam is no longer stressed.



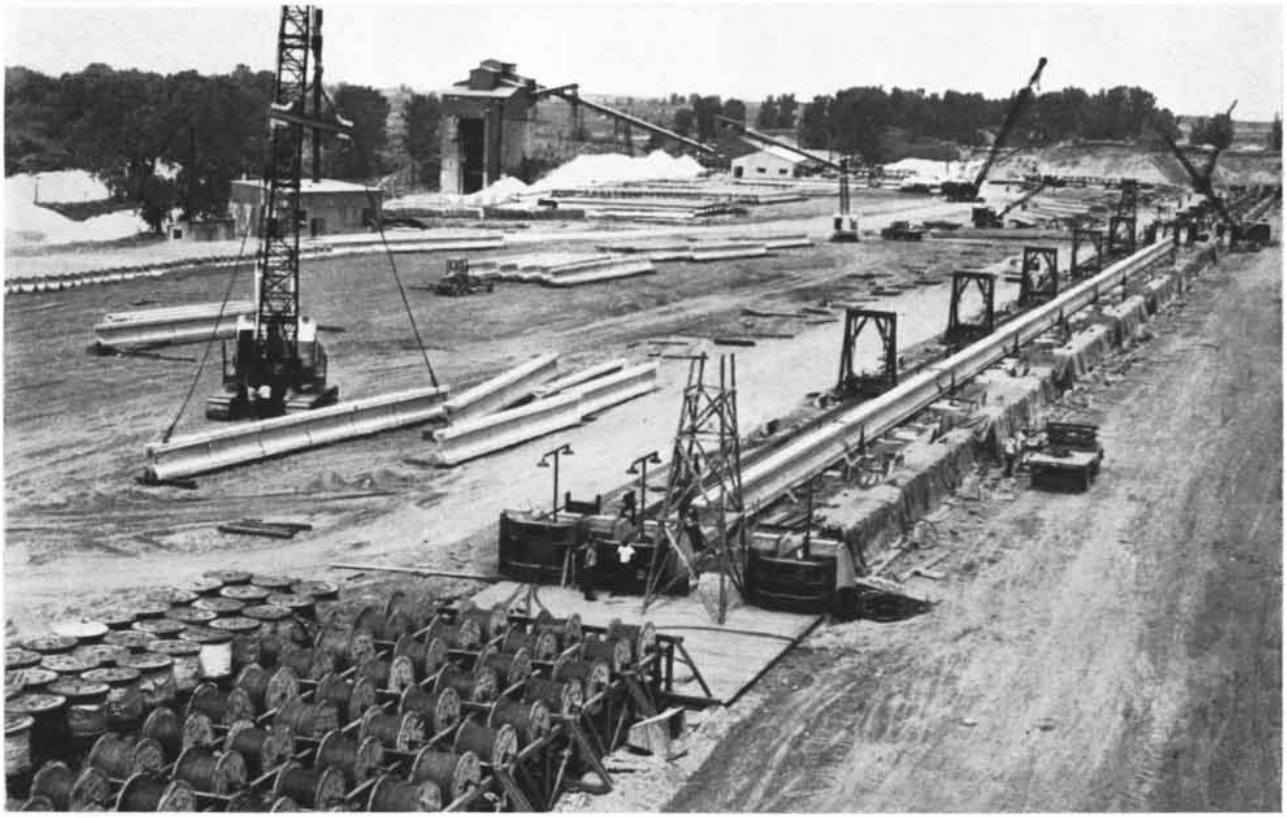
HIGH-STRENGTH STEEL makes prestressing possible. At top is a 100-foot beam ready for post-tensioning. In the middle the high-strength steel rod has been stretched seven inches. At bottom the concrete has shrunk one inch, leaving the rod still stretched six inches.

ple—namely, the principle of the suspension arch. Suppose we embed a curved steel cable in a concrete beam. The stretched cable exerts an upward force on the concrete, counteracting the force of gravity [*see lower diagrams on preceding page*]. If the upward force exactly balances the gravity force all along the beam, the beam in effect is carrying no load at all! In practice, of course, a construction beam (*e.g.*, in a bridge) has to carry variable and moving loads. But the beauty of such a prestressed concrete beam is that it needs to be made only strong enough to bear the imposed loads; its own weight is self-supported.

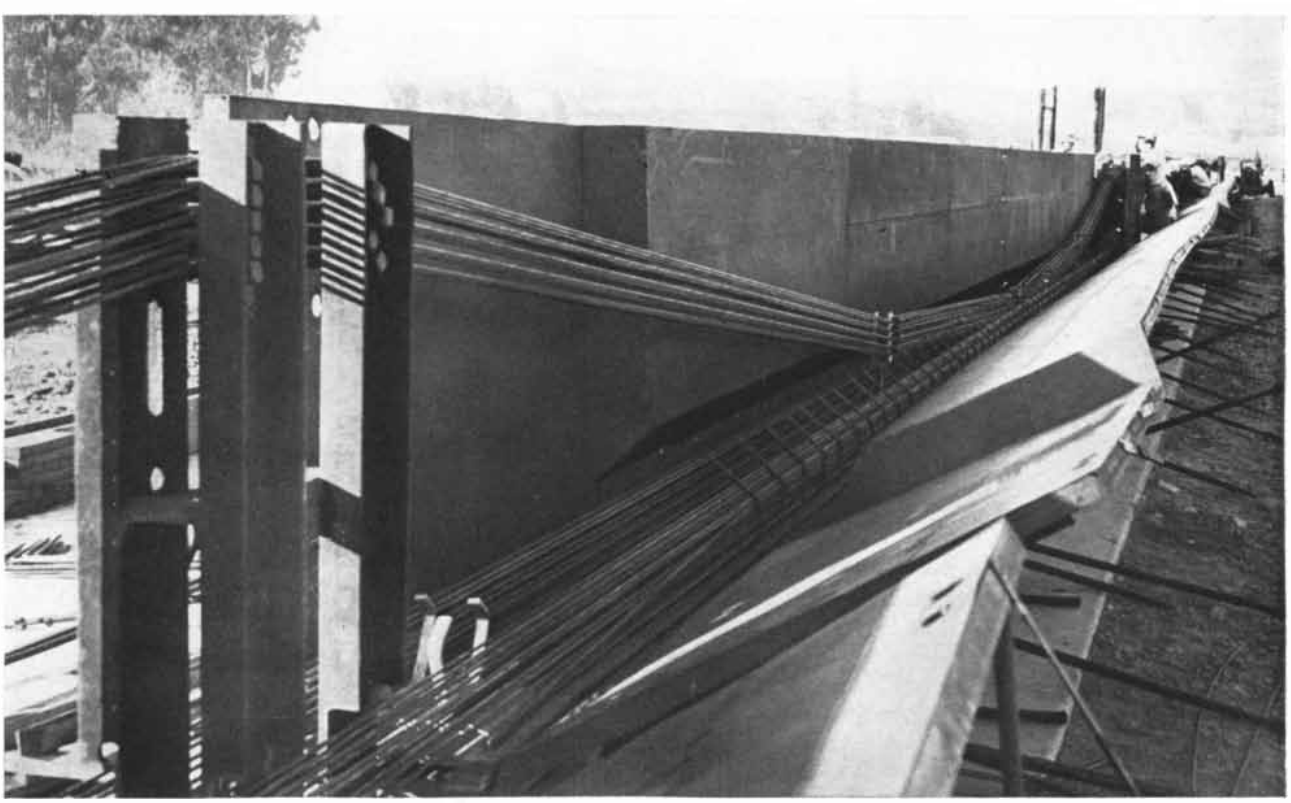
For the various forms and uses of prestressed concrete, three kinds of steel sinew are employed: steel wires about a quarter of an inch in diameter, twisted cables from a quarter of an inch to two inches in diameter and rods up to an inch and a quarter in diameter. The sinews are stretched and tightened in one of two ways, called pre-tensioning and post-tensioning. In the pre-tensioning process the wires or cables are stretched first and released from their end supports after the concrete has hardened around them; their snap-back compresses the concrete. In the post-tensioning procedure the steel wires are encased in tubes and remain relaxed until after the concrete hardens; then they are stretched by jacks and their ends are anchored against the concrete [*see illustrations on preceding page*]. The space around the wires in the tubes is then filled with cement by grouting. Various types of jacks and anchoring hardware have been developed for this process.

Some tough problems have had to be solved, by research and sometimes by costly trial and error. One is relaxation of the stress, either from loss of the steel's stretch under high tension or from shrinkage of the concrete. Another is corrosion: steel under high tension is unusually sensitive to corrosion. Fortunately the concrete coverage of the steel generally is sufficiently watertight to give excellent protection. Still other problems have to do with the capacity of prestressed concrete to withstand impacts and with measurement of its fire-resistive properties (excellent). With research and experience engineers are learning to avoid mistakes and to make the most of this new material. They are also looking into variations, such as using glass fibers as the sinews in place of steel.

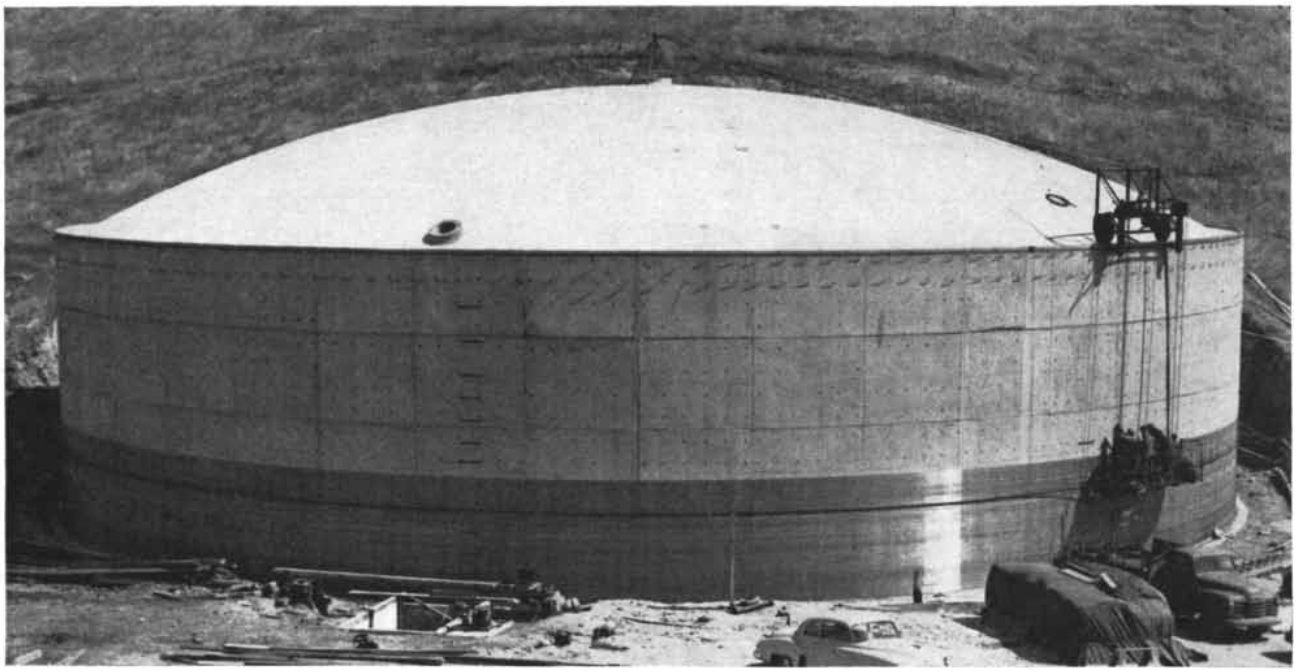
In engineering many factors besides the basic scientific principles are involved in applying any new technique or material. There are organizational, man-



PRE-TENSIONING PLANT of the Material Service Corporation in Chicago makes prestressed concrete beams for bridges. At lower left are reels of cable which feed three production lines 600 feet long. In the line at left the cables are stretched; in the line in the middle the beams have been cast and are ready to be removed in sections by cutting the cable; in the line at right the beams dry.



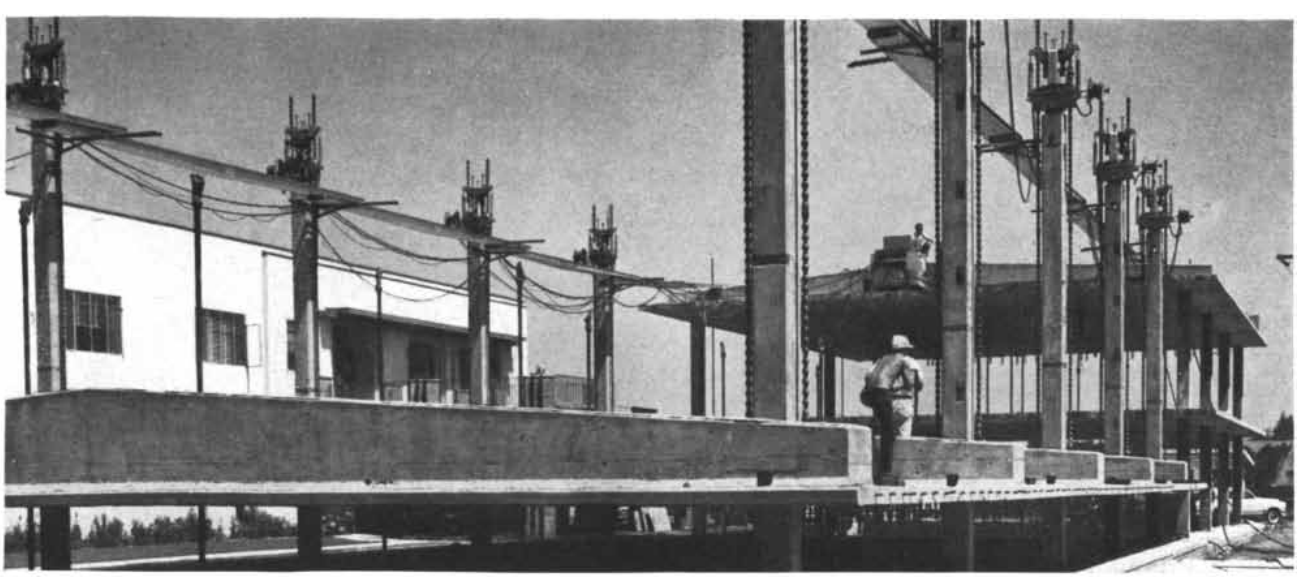
PRE-TENSIONED BEAM is made by Ben C. Gerwick, Inc., in San Francisco with a set of cables within it to exert an upward force on the finished beam. At right is half of the mold for the beam. This half is raised to a vertical position when the concrete is poured.



WATER TANK in Walnut Creek, Calif., is built by the system of the Preload Company, Inc. This system involves the principle of the old-fashioned barrel. The tank is built up of concrete slabs set on rubber pads. The whole tank is then tightly wrapped with wire.

agerial, marketing, legal and even personal equations to be solved. For example, prestressed concrete is most conveniently cast in a factory and offers many of the advantages of factory production. But this means that long and heavy pieces must be transported to the site of construction. In the U. S., with its extensive trunk highways and large truck trailers and cranes, the means of such transport are at hand. When the 24-mile bridge of prestressed concrete was built across Lake Pontchartrain in Louisiana, each span of the bridge, weighing 180 tons, was precast in a plant, carried to the site and set on the piers from barges. However, many prestressed concrete structures have been fabricated in the field. This calls for specially skilled labor at the site, but the new technique is nonetheless more economical and convenient than conventional methods of construction. Often the prestressed concrete slabs for a building are cast on the ground and raised to their positions as floors and roof by hydraulic jacks.

So far the use of prestressed concrete has been limited mainly to large structures such as bridges and buildings. The material yields great economies in the building of bridges: engineers estimate that $2 billion could be saved if prestressed concrete were used for one half of the bridges planned in the current U. S. highway building program. Most of the 289 bridges on the Illinois toll highway now under construction will be built of prestressed concrete, and the saving is said to be $4 million. The state of California has erected a number of college and hospital buildings of the



ROOF AND FLOOR SLAB of prestressed concrete is lifted into position by hydraulic jacks to make the building of the U. S. Geodetic Survey in Menlo Park, Calif. The pairs of rods beside the pillars of the building suspend the slab from the jacks above.

ROOF in Montevideo, Uruguay, was designed by the Preload Company. Small slabs of concrete are suspended from radial cables. The cables are stretched by placing bricks atop each slab. When interstices between slabs are filled with concrete, bricks are removed.

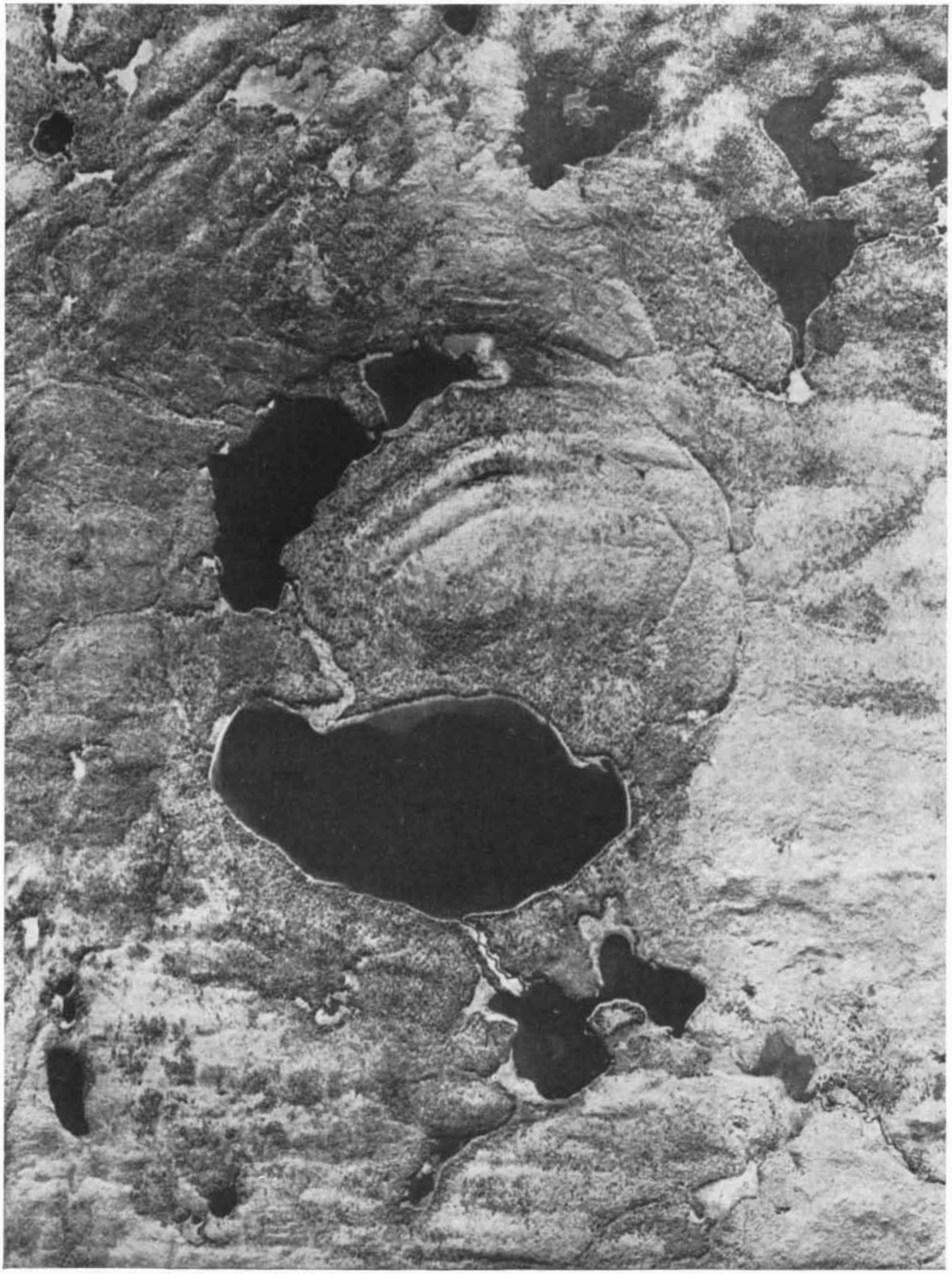
material; the slabs for these structures were cast at the site.

The flexible possibilities of prestressed concrete in buildings are beautifully illustrated by a couple of examples. At Caracas, Venezuela, the new National Race Course has a grandstand roof of prestressed concrete—only three inches thick—which projects 90 feet from its supporting pillars so that no posts obstruct the view [*see photograph on page 25*]. The edge of the roof is tipped upward about an inch by the pull of the steel wires; eventually it will flatten out, but it will never droop as conventional cantilevered roofs commonly do. The other example is a factory in Los Angeles whose roof, a three-inch slab of prestressed concrete covering 100,000 square feet, is filled with two inches of water to cool the building. The entire roof is watertight without waterproofing. It has carried water for a year now without any leakage.

Prestressed concrete is used around the world for foundations, dams, roads, airfield runways, railway ties (in Germany and the U.S.S.R.), even telephone poles (in Africa). The telephone poles are expected to last forever. The possible applications of the material seem almost limitless.

Last year a World Conference on Prestressed Concrete, held in San Francisco under the auspices of the University of California, was attended by more than 1,200 delegates from 30 nations. Sixty-four technical papers were presented and have been published as the Conference proceedings. They make plain that this new technology is certain to grow by leaps and bounds.

SPAN made of prestressed concrete sections is lifted into position to make the arch of a bridge on a highway which connects Caracas, Venezuela, with the seaport city of La Guaira. Built by the French firm of Campenon Bernard, the bridge has a span of 500 feet.



BRENT CRATER in central Ontario is a shallow depression about two miles across; its circular form, never observed at ground level, shows up clearly from the air. Geophysical investigations and borings reveal that it is a meteorite crater filled with sedimentary rocks 500 million years old. This photograph and those on pages 34 and 37 were made by the Royal Canadian Air Force.

FOSSIL METEORITE CRATERS

Canadian investigators have discovered meteorite craters at least 500 million years old. Clues from aerial photographs suggest that these fossil explosion pits are fairly common

by C. S. Beals

The surface of the earth near Brent, Ontario, is dented with a shallow, saucer-like depression about 200 feet deep and two miles across. For years fishermen, miners and lumbermen have tramped through the woods that cover it and around its two small lakes without noticing anything unusual about this bit of topography. Aerial photographs, however, show that the depression is almost perfectly circular [*see photograph on opposite page*]. Closer inspection of the ground, prompted by this observation, has revealed that in ages past a deep hole was gouged here in the primeval granite and gneiss of the Canadian Shield. Later submergence of the region filled the hole with younger sedimentary rocks. Beneath these sediments borings disclose a deep layer of shattered rock, apparently the debris of some gigantic explosion. In fact there is every reason to believe that this depression is the "fossil" crater of a huge meteorite which plowed into the earth and exploded some 500 million years ago.

The discovery and identification of the Brent crater demonstrate a virtue of aerial photography which has great value to geologists, archaeologists and other investigators. Pictures taken from sufficient altitude frequently resolve patterns that go unrecognized by observers on the ground. A search through some 400,000 aerial-mapping photographs of Canada has now turned up a dozen circular topographical features of possible meteoritic origin, one of them 20 miles in diameter. The few we have been able to investigate so far show evidence of the same cataclysmic origin. It seems, therefore, that meteorite craters are a great deal more common on the face of the earth than was heretofore supposed. These ancient scars indicate that the earth has been colliding with large chunks of iron and stone from outer space throughout a great part of its history. They also lay the foundation for a clear answer to the question, still debated in some quarters, of the origin of craters on the moon.

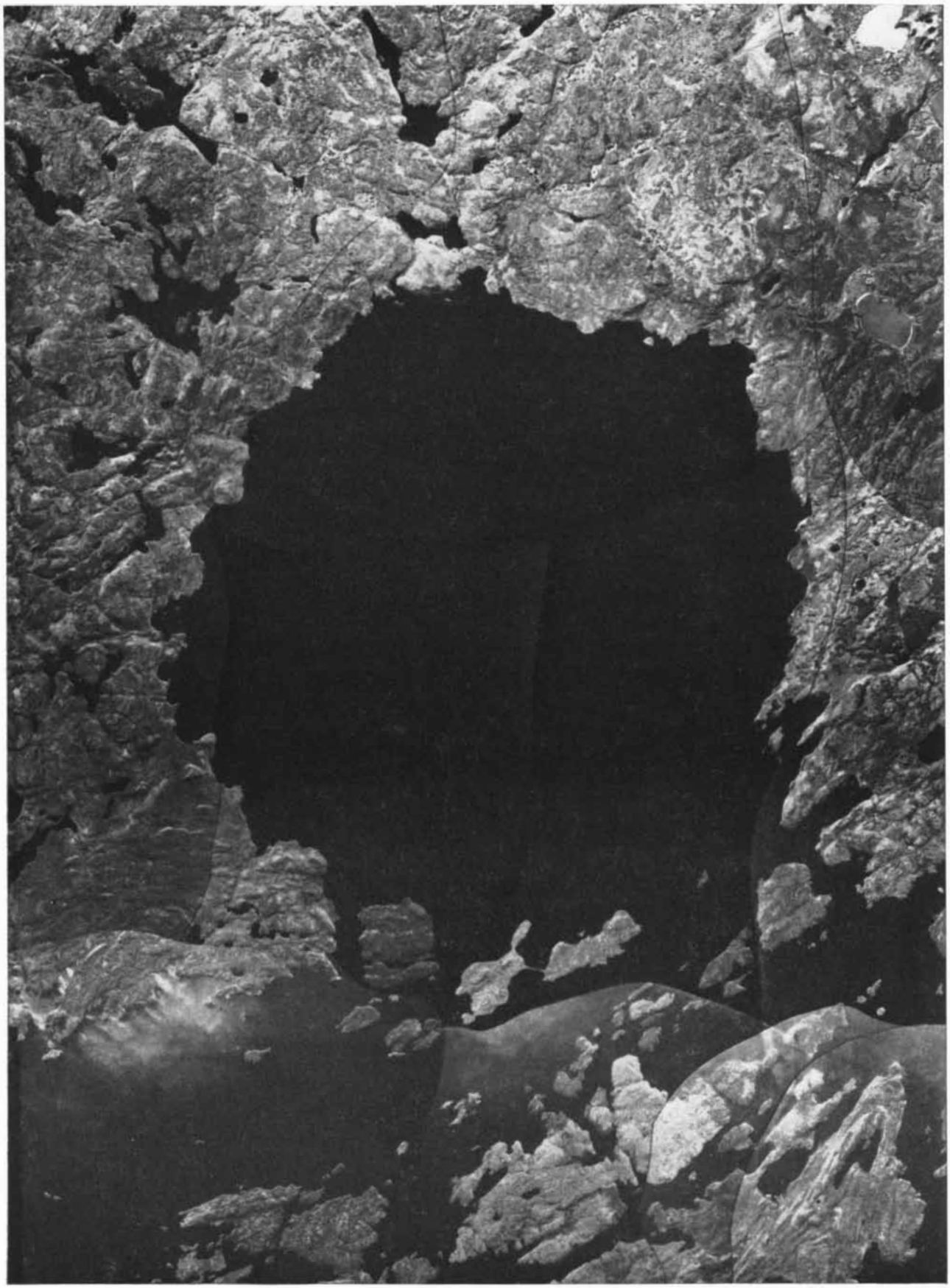
Only a century and a half ago so acute an observer as Thomas Jefferson expressed doubt that meteorites—"stones from the sky"—really existed. We know now, of course, that meteorites fall upon the earth almost continuously. Most meteors are tiny and vaporize as "shooting stars" in the thin outer reaches of the atmosphere. Some are big enough to survive the erosion of the atmosphere and plunge into the ground. But the really giant meteorites that explode upon impact and make large craters are so rare that until quite recently people did not suspect or else doubted their existence.

The first meteorite crater to be established as such is the great Barringer crater in the Arizona desert. From a distance it looks like a low, gray mesa, conspicuous against the reddish plain. Its gentle outer slopes are littered with sand, broken rock and angular blocks of limestone. Upon climbing to the top, visitors are astonished by what they see: a tremendous bowl, three quarters of a mile across and more than 600 feet deep, ringed by a steeply slanting wall sown with more fragments of rock. Even to a nongeologist the crater seems clearly to have been blasted out of the layers of limestone and sandstone whose contrasting strata encircle it. Closer examination shows that these strata have been tilted upward and outward by the force of the explosion [*see drawing on page 36*].

Conclusive evidence of the origin of this crater is the fragments of the meteorite itself. These lumps of nickel-iron and iron oxide, found in abundance in and around the crater, range in weight from a fraction of an ounce to more than half a ton. Years ago several thousand tons of them were smelted down for commercial purposes, and hundreds of fragments departed in the pockets of souvenir hunters. Substantial numbers, however, found their way into museums throughout the world. Their high nickel content and their peculiar crystalline structure prove that they came from outer space.

For years, despite this compelling evidence, many scientists argued that the crater was the work of a volcano or an underground gas explosion. D. M. Barringer, a mining engineer whose name the crater now bears, saw clearly from the first time he beheld it that only a giant meteorite could have blasted out this great hole in the rock and peppered the country for miles around with meteoritic fragments. Barringer deserves everlasting credit for sticking to his guns in the face of what was supposedly the best scientific opinion of his day. His stand has been amply confirmed by later investigation. Borings in the crater and beneath its rim have revealed a great deposit of crushed rock containing more meteoritic fragments.

The age of the Barringer crater has been estimated at 50,000 years. It has weathered little in the dry, stable climate of the region, and so has preserved the features that unmistakably establish its origin. Some 20 similar craters and clusters of craters of recent age have since been found scattered across the continents. The largest of them, the great Chubb crater in the northern wilderness of Quebec, is more than two miles in diameter and a quarter of a mile deep [see "The Canadian Meteor Crater," by V. B. Meen; SCIENTIFIC AMERICAN, May, 1951]. The smallest measures a few



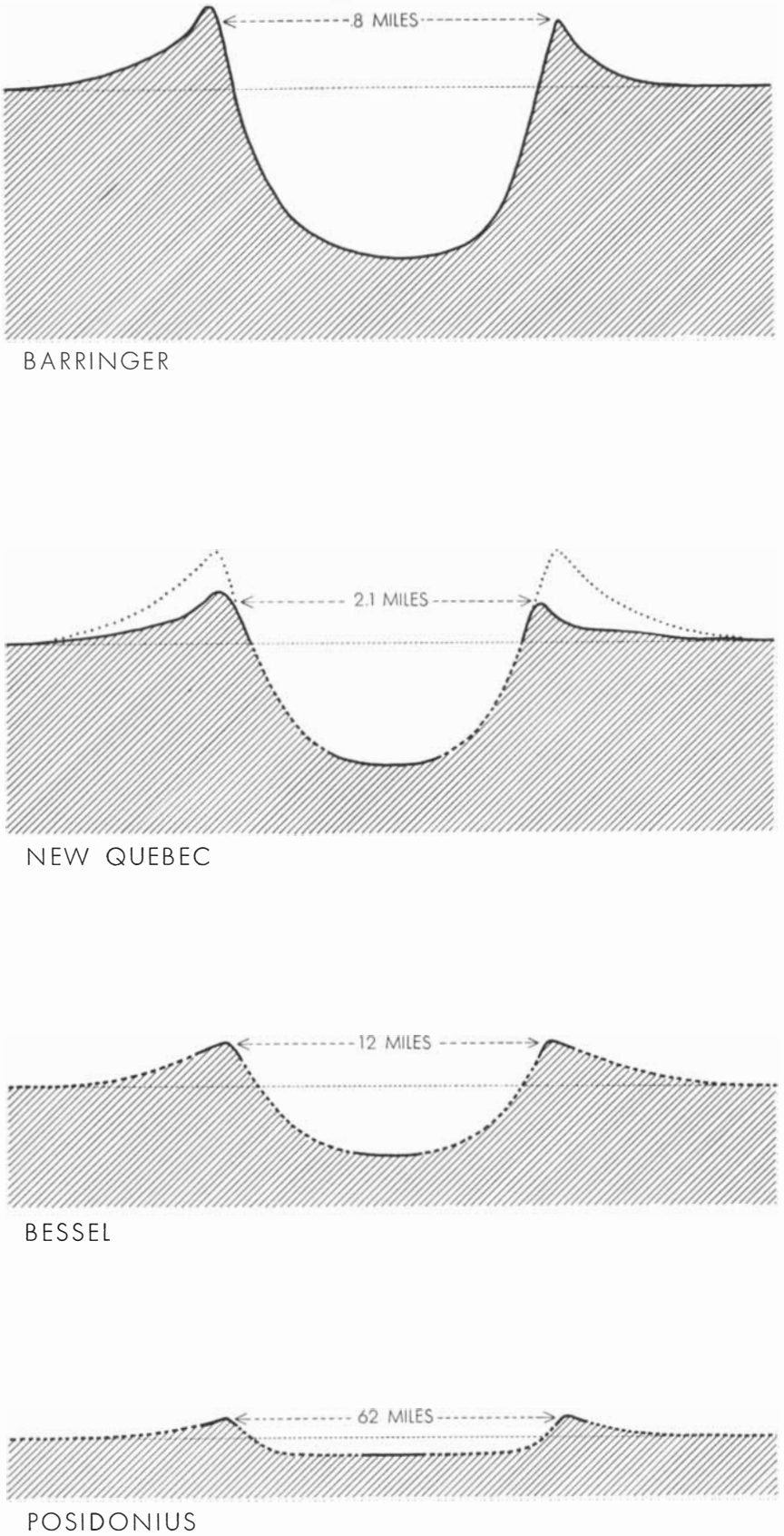
DEEP BAY CRATER, in northern Saskatchewan, is six miles across and 700 feet deep. Its original depth is estimated at 3,500 feet; the difference is probably accounted for by debris pushed in by glaciers. It is believed to be at least 60 million years old.

dozen yards across and a few yards deep. Invariably the outer slopes of the craters are gentle, the inner slopes steep (up to 35 degrees). Except where they have been filled with debris, their floors are lower than the surrounding plain. Where they occur in sedimentary rock the strata have been tilted upward and outward. In each crater great quantities of broken and pulverized rock littering the floor, slopes and surroundings testify to a great explosion, and other fragments usually furnish evidence that the missile was a meteorite.

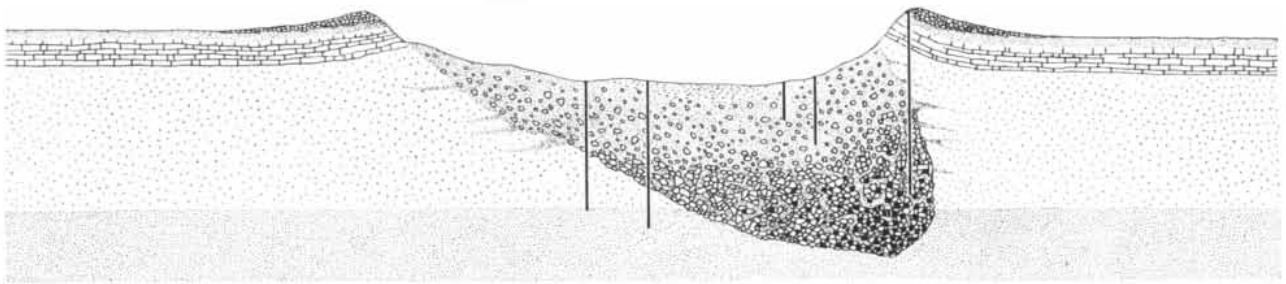
Depending on their age and location, these craters have been more or less modified during geologic history. The Wolf Creek crater, located in the almost inaccessible desert of northwest Australia, most closely approaches the Barringer model. It is somewhat smaller and has been filled in to some extent, but it is otherwise quite similar in character, having been blasted in sedimentary rock. Nickel-iron meteorite fragments place its origin beyond question. On the other hand, the Chubb crater was punched in granite subsequently eroded by glaciers. Most of the loose material that originally formed part of its rim has been scraped away, and this may explain why no meteoritic fragments have yet been found. The crater is filled to a depth of 800 feet by a lake which adds to its scenic splendor but hinders scientific investigation. Nonetheless, its similarity to the Barringer crater in major respects leaves very little doubt as to its origin. A more intensive search of the crater may well turn up some meteoritic material.

The meteorites that produced these large craters all fell in prehistoric times. Two clusters of meteorites have fallen in Siberia during the 20th century. Each dug out a widely scattered group of small craters. The earlier fall, in 1908, produced an air blast which felled forests, killed herds of reindeer and produced atmospheric effects at great distances from the fall. The second fall, in 1947, occurred only a few hundred miles from Vladivostok [see "The Great Meteor of 1947," by Otto Struve; SCIENTIFIC AMERICAN, June, 1950]. Soviet scientists have found many meteorites scattered around its numerous well-marked craters. It has not been demonstrated, however, that any of the meteorites exploded.

All the large meteorite craters are clearly the products of explosions. But the usual meteorite, weighing a few hundred pounds or less, buries itself in the



FAMILY RESEMBLANCE between earth craters (Barringer and New Quebec) and moon craters (Bessel and Posidonius) is shown by these cross sections from a study by Peter M. Millman of the Dominion Observatory. The vertical dimension is exaggerated but has the same relationship to the horizontal for each crater. The broken lines are conjectural.

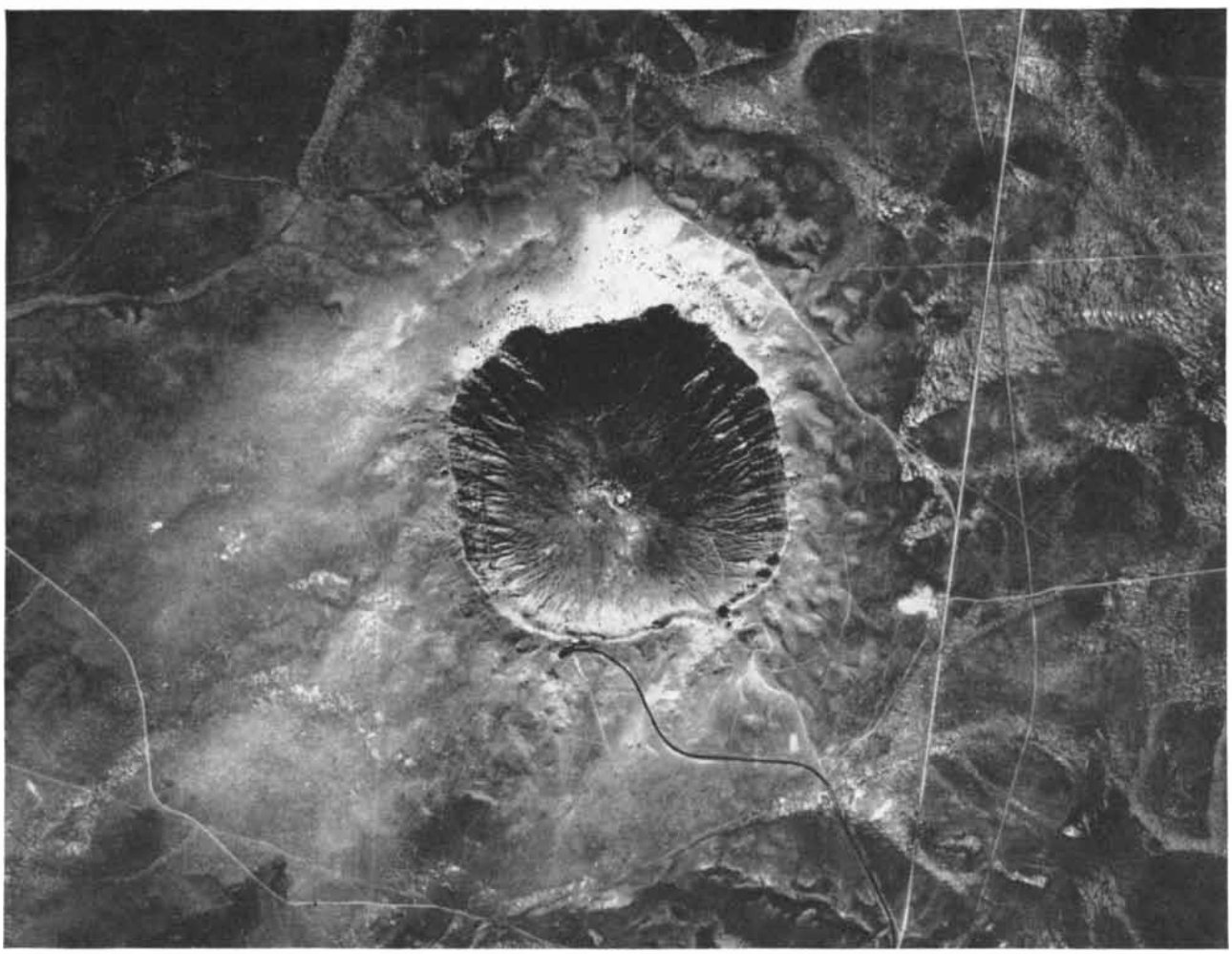


CROSS SECTION OF BARRINGER CRATER shows tilting of rock layers by a meteoritic explosion some 50,000 years ago. Borings beneath its floor and rim (*vertical lines*) have revealed a deep pocket of shattered rock containing meteorite fragments. Thousands of similar fragments, now mostly removed, have been found in and around the crater, some as much as five miles away.

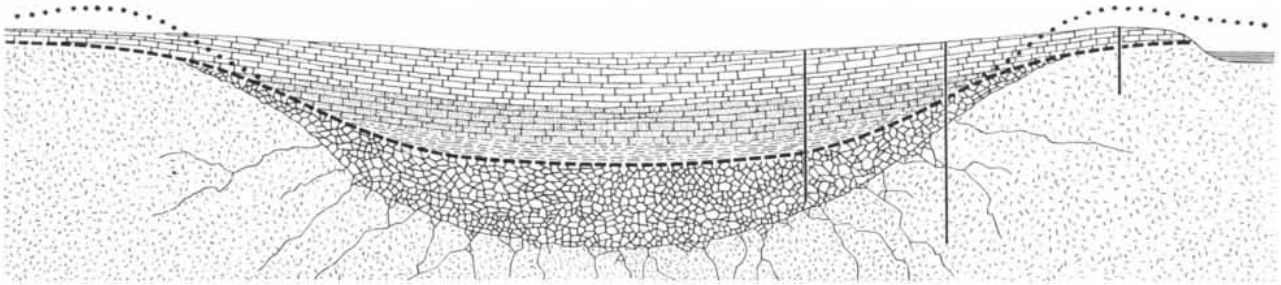
ground without exploding. Why did these giant meteorites explode?

A meteorite's energy is, of course, the product of its mass and the square of the speed with which it moves. Observation of the tiny meteors we see as shooting stars shows that they hit the earth's atmosphere at speeds ranging from 5 to 45 miles a second; large meteorites almost certainly arrive at similar speeds. The shooting star's energy, however, turns into heat and light; it literally burns up in friction with the atmosphere. Even a 100-pound meteorite will lose more than 85 per cent of its velocity in forcing its way through the atmosphere [*see graph at bottom of page 39*]. By the time it hits the ground, about 98 per cent of its energy will have been dissipated. On the other hand, a meteorite that weighs 50,000 tons develops much less air resistance in ratio to its mass and so loses less than 10 per cent of its velocity.

Evidently meteorites which are heavy enough can reach the earth at speeds of 10 to 20 miles a second. Calculations



BARRINGER CRATER, in the Arizona desert, is visible for miles around. This vertical view emphasizes its resemblance to lunar craters formed by meteorites. Cross section at the top of this page runs roughly from the bottom to the top of the photograph.



CROSS SECTION OF HOLLEFORD CRATER shows the layers of limestone and shale deposited in it about 500 million years ago. Dotted lines show probable profile of its rim, which was eroded away before the crater was filled. Beneath its original floor (*broken line*) lie rock fragments cemented together. No meteoritic fragments have been found; they would have rusted away.

show that an object moving at 20 miles a second possesses energy equivalent to 65 times its weight in nitroglycerine. In the instant of collision with the earth's surface this energy of motion is transformed to energy of heat and compression, and the meteorite becomes an immensely powerful explosive. Its detonation deals a tremendous blow to the rock at the point of impact, hollowing out the crater, tilting up the surrounding strata and reducing vast tonnages of rock to rubble and powder which are thrown out of the crater and strewn about the surrounding countryside. The meteorite itself is blown to fragments. This explains why no substantial meteoritic "ore body" has been found at the bottom of any of the large craters and why most of the fragments are found outside, not inside, the crater rim.

It is hard to say just how large a meteorite must be to blast out one of these big craters. Estimates of the mass of the Barringer meteorite range from 8,500 tons up to nearly eight million tons. One complication in attempting the estimate

HOLLEFORD CRATER, in Ontario farmland, is obscured by ancient erosion, later rock deposits and present cultivation. An aerial photograph such as this emphasizes the small differences in vegetation and topography which hint at the crater buried beneath them.

is the question whether the meteorite has met the earth head-on or has hit it from behind; *i.e.*, whether the meteorite is traveling in the opposite or the same direction as the earth. Obviously a meteorite colliding head-on with the earth, moving at 18 miles per second, will have a much greater impact than one which hits the retreating earth.

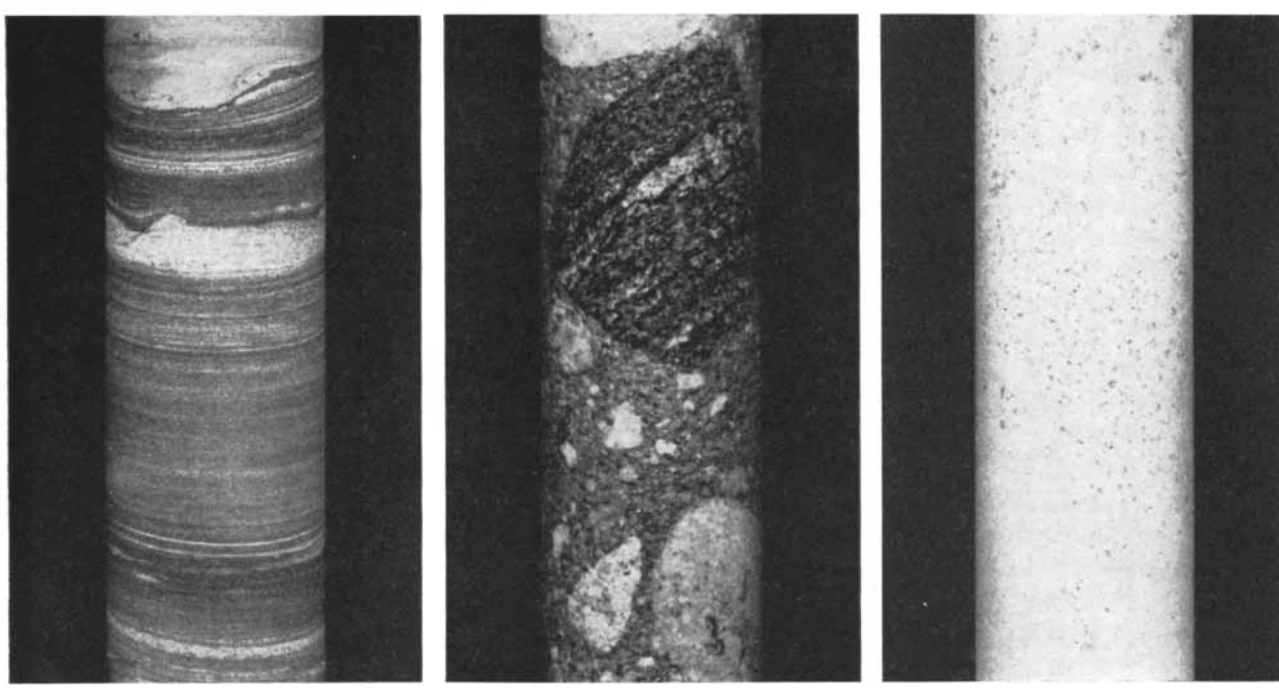
The most spectacular meteorite craters are not on the earth but on the moon. Some of them, hundreds of miles in diameter, are visible with a good pair of binoculars. When viewed through an astronomical telescope, these great pits are truly breathtaking. Almost all scientists now agree that meteorites caused the great majority of them. Most of the moon's craters show the same gentle outer slopes and steep inner walls as those on the earth. Measurements of the shadows cast by their walls show another family trait that relates them to the terrestrial craters: the larger the diameter of the crater, the flatter is its profile [*see drawings on page 35*]. Taking this cue, the astrophysicist Ralph B. Baldwin plotted the ratio of the depth to the diameter for several hundred explosion craters, ranging in size from those made by man to the biggest on the moon [see "The Craters of the Moon," by Ralph B. Baldwin; SCIENTIFIC AMERICAN, July, 1949]. His plot produced a smooth curve, with the moon's lunar craters at one end, bomb and other man-made craters at the other, and the terrestrial meteorite craters neatly bridging the gap in between [*see chart at top of opposite page*]. Explosions, plainly, must have caused them all. Only the explosion of meteorites, some the size of small moons, could have produced the moon's craters.

The tens of thousands of craters that pock the face of the moon show that at some time in the past our sister-member of the solar system underwent an intensive or prolonged bombardment by large meteorites. The earth must certainly have sustained some part of this bombardment. On the airless and waterless moon the craters have been preserved; on earth they have mostly been erased by erosion or buried.

The discovery of the Brent fossil crater showed that the processes of erasure and concealment do not always go on to completion, even after millions of years. In our survey of aerial photographs we have already located a dozen additional circular features in the topography of Canada. Since these photographs cover only one half of the Dominion, it is possible that many more such features await discovery.

Unfortunately most of the depressions detected from the air lie in remote, not easily accessible regions. The two investigated so far, however, have yielded the same clear evidence of meteoritic origin as Brent. One of these is a circular depression a mile and a half in diameter located in inhabited farm land near Holleford, Ontario. It was easy in this case to follow up the lead of the aerial photograph with a fully instrumented survey. Seismic soundings and measurements of gravity and magnetism at once indicated the existence of a deep basin filled with lighter deposits. Drillings confirmed the conclusions of these geophysical observations. Cores from three drill holes [*see photographs below*] showed that the crater is filled with sediments of the Paleozoic Period to a depth of 800 feet. Below these sediments are several hundred feet of fractured, granulated and powdered rock, weakly cemented together, and beneath these fragments lies the undisturbed Pre-Cambrian rock of the Canadian Shield. The diameter-depth ratio of the crater lands nicely on the Baldwin curve, though much of the rim seems to have eroded away even before the sediments were deposited within. Like the Brent crater, the one at Holleford is about 500 million years old. No meteorite fragments have been found at either site. Metallic fragments would long ago have rusted away, and pieces of rocky meteorite would be practically indistinguishable from terrestrial rocks.

The other crater, a spectacular scenic feature, has often been remarked by



DRILL CORES from the Holleford crater show (*left*) limestone from the sedimentary rock with which it is filled, (*center*) rock fragments, now cemented together, which formed its original floor and (*right*) the undisturbed bedrock out of which it was blasted.

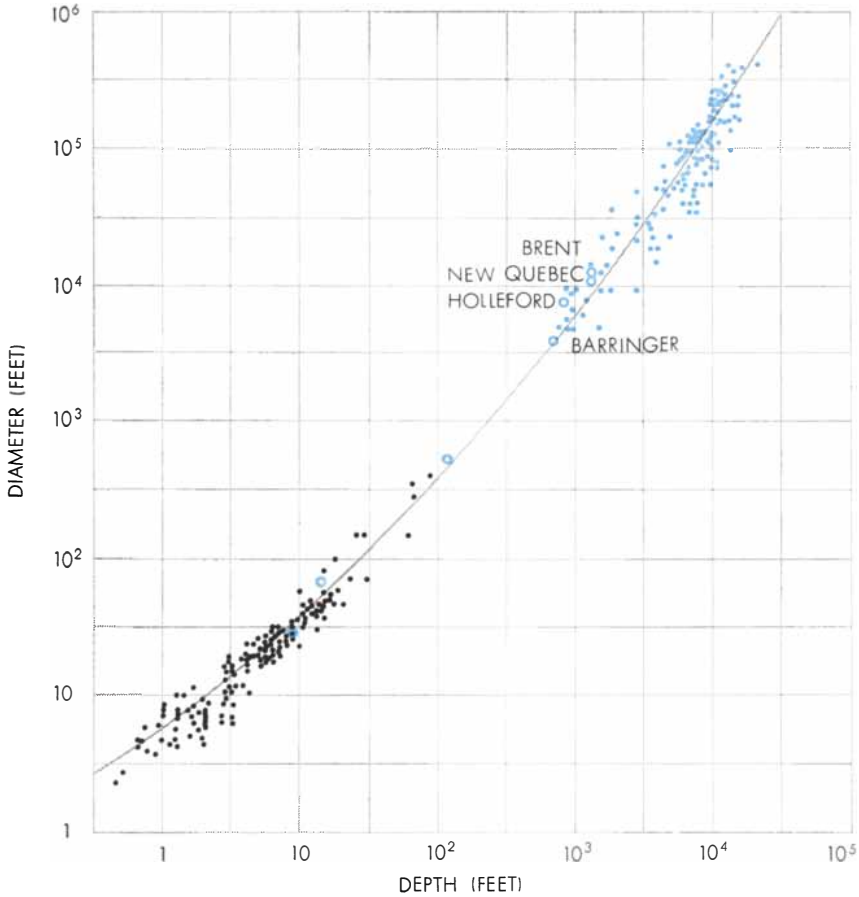
travelers in the wilderness of northern Saskatchewan and is the subject of legends among the local Indians. Called Deep Bay, it is an almost perfectly circular appendage of Reindeer Lake, six miles across and 700 feet deep. In 1956 M. J. S. Innes of the Dominion Observatory made his way to this remote region by seaplane and boat and developed impressive evidence that Deep Bay is indeed a meteoritic crater.

Glaciers have swept away the loose debris of the explosion, but the bedrock portion of the rim still rises several hundred feet above the lake shore, high enough to isolate the bay from the general drainage of the area. The rock structures in which it lies are not related to the crater but break off short at the rim, and the rim itself is fractured into huge, angular blocks. Measurements around the periphery show gravity increasing away from the bay in every direction, which indicates a deep hole partly filled with loosely packed rocks. According to Baldwin's diameter-depth formula, the crater would originally have been about 3,500 feet deep, but glaciers have probably pushed in a great deal of material.

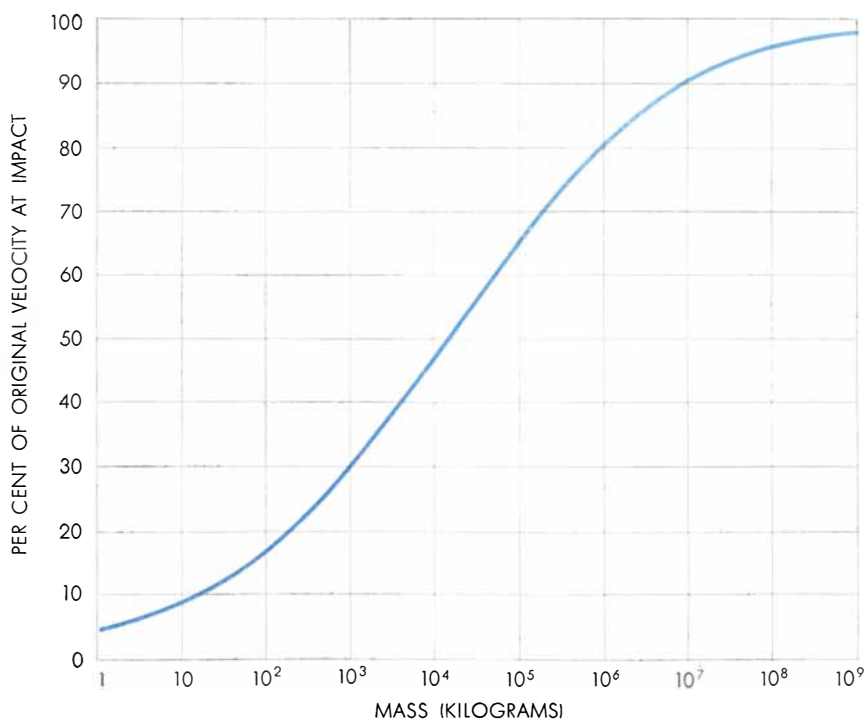
The age of this crater is difficult to fix with certainty. The extent of erosion suggests an age of millions rather than thousands of years. But it is probably much younger than the Brent and Holleford craters, because it is not so completely filled in. Fossils in bits of shale found around its edge indicate a minimum age of 60 million years.

These ancient craters prove that meteorites have been hitting the earth for a very long time, but the known craters are not yet numerous enough to indicate that our planet has been as severely bombarded as the moon. The main meteoritic bombardment may have taken place during a fairly brief period when the moon was particularly exposed—because of the orbital relations of the earth, the moon and the rest of the solar system. Or perhaps during the rain of meteorites the earth was still molten and the objects sank into it without a trace.

The best hope for an answer to this question lies in pushing the search for additional craters. The extension of aerial photographic surveys over much of the world is making available a wonderful store of new material on the earth's topography. With scientists in many countries working on these photographs, it will be surprising if we do not before long have news of other ancient craters.



EXPLOSIVE ORIGIN of different types of craters is shown when their depths are plotted against their diameters. Man-made explosion craters (*black dots*), terrestrial meteorite craters (*colored circles*) and lunar craters (*colored dots*) all lie along the same curve.



IMPACT VELOCITY of a meteorite depends on its mass. Small meteorites lose most of their velocity to air resistance; their loss in energy (which varies as the square of the velocity) is even greater. Only large meteorites retain enough velocity to explode on impact.

More about Bat "Radar"

A sequel to an earlier article which described the capacity of bats to locate objects by supersonic echoes. This natural sonar is now known to incorporate extraordinary refinements

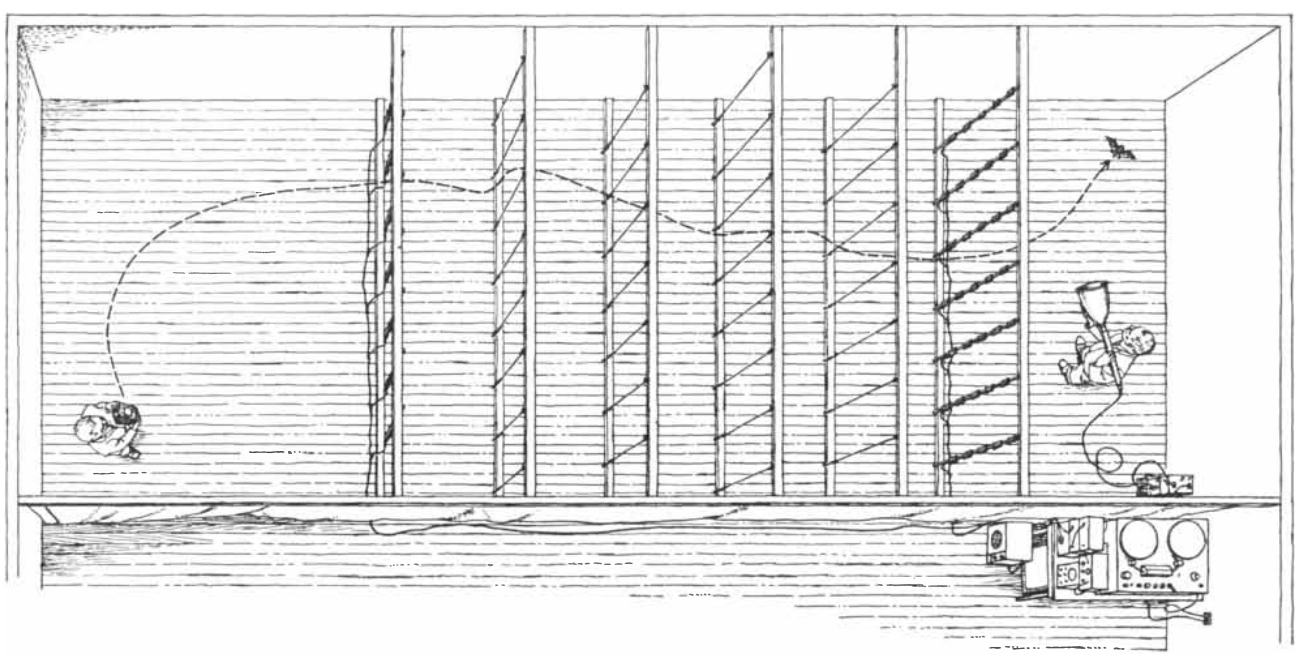
by Donald R. Griffin

In these days of technological triumphs it is well to remind ourselves from time to time that living mechanisms are often incomparably more efficient than their artificial imitations. There is no better illustration of this rule than the sonar system of bats. Ounce for ounce and watt for watt, it is billions of times more efficient and more sensitive than the radars and sonars contrived by man [*see table at bottom of page 42*].

Of course the bats have had some 50 million years of evolution to refine their sonar. Their physiological mechanisms for echolocation, based on all this accumulated experience, should therefore repay our thorough study and analysis.

To appreciate the precision of the bats' echolocation we must first consider the degree of their reliance upon it. Thanks to sonar, an insect-eating bat can get along perfectly well without eyesight. This was brilliantly demonstrated by an experiment performed in the late 18th century by the Italian naturalist Lazaro Spallanzani. He caught some bats in a bell tower, blinded them and released them outdoors. Four of these blind bats were recaptured after they had found their way back to the bell tower, and on examining their stomach contents Spallanzani found that they had been able to capture and gorge themselves with flying insects in the field. We know from experiments that bats easily find insects in the dark of night, even when the insects emit no sound that can be heard by human ears. A bat will catch hundreds of soft-bodied, silent-flying moths or gnats in a single hour. It will even detect and chase pebbles or cotton spitballs tossed into the air.

In our studies of bats engaged in insect-hunting in the field we use an apparatus which translates the bats' high-pitched, inaudible sonar signals into audible clicks. When the big brown bat (*Eptesicus fuscus*) cruises past at 40 or 50 feet above the ground, the clicks sound like the slow put-put of an old marine engine. As the bat swoops toward a moth, the sounds speed up to the tempo of an idling outboard motor, and



OBSTACLES in the form of thin vertical wires are avoided by a bat despite the presence of interfering noise. The noise comes from banks of loudspeakers to left and right of the four sets of wires. Man at right holds microphone which picks up bat's signals.

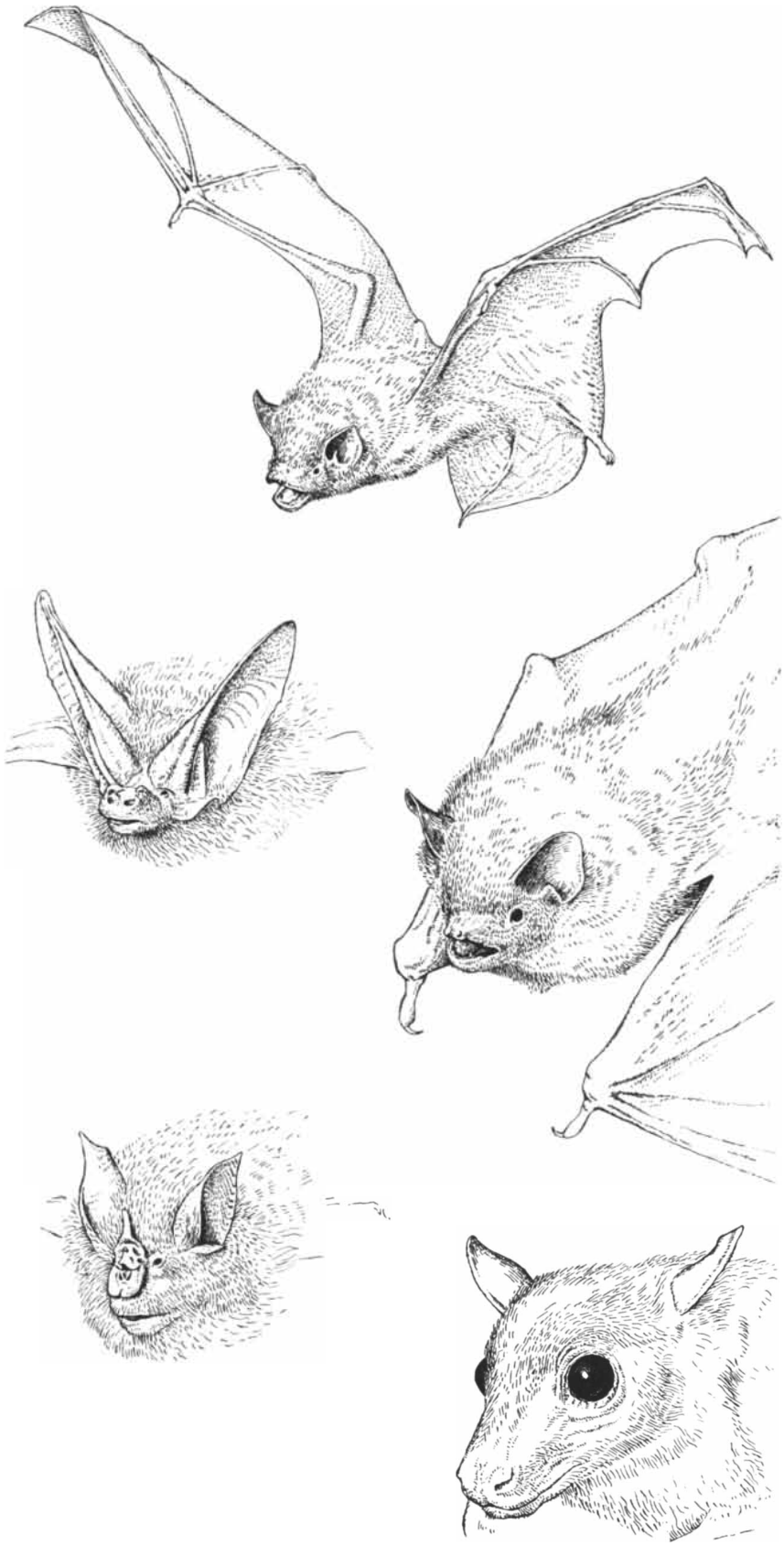
when the chase grows really hot they are like the buzz of a model-airplane gasoline engine. It seems almost certain that these adjustments of the pulses are made in order to enable the bat to home on its insect prey.

At the cruising tempo each pulse is about 10 to 15 thousandths of a second long; during the buzz the pulses are shortened to less than a thousandth of a second and are emitted at rates as high as 200 per second. These sound patterns can be visualized by means of a sound spectrogram [*see charts on page 43*]. Within each individual pulse of sound the frequency drops as much as a whole octave (from about 50,000 to 25,000 cycles per second). As the pitch changes, the wavelength rises from about six to 12 millimeters. This is just the size range of most insects upon which the bat feeds. The bat's sound pulse may sweep the whole octave, because its target varies in size as the insect turns its body and flutters its wings.

The largest bats, such as the flying foxes or Old World fruit bats [see "Bats," by William A. Wimsatt; SCIENTIFIC AMERICAN, November, 1957], have no sonar. As their prominent eyes suggest, they depend on vision; if forced to fly in the dark, they are as helpless as an ordinary bird. One genus of bat uses echolocation in dark caves but flies by vision and emits no sounds in the light. Its orientation sounds are sharp clicks audible to the human ear, like those of the cave-dwelling oil bird of South America [see "Bird Sonar," by Donald R. Griffin; SCIENTIFIC AMERICAN, March, 1954].

On the other hand, all of the small bats (suborder *Microchiroptera*) rely largely on echolocation, to the best of our present knowledge. Certain families of bats in tropical America use only a single wavelength or a mixture of harmonically related frequencies, instead of varying the frequency systematically in each pulse. Those that live on fruit, and the vampire bats that feed on the blood of animals, employ faint pulses of this type.

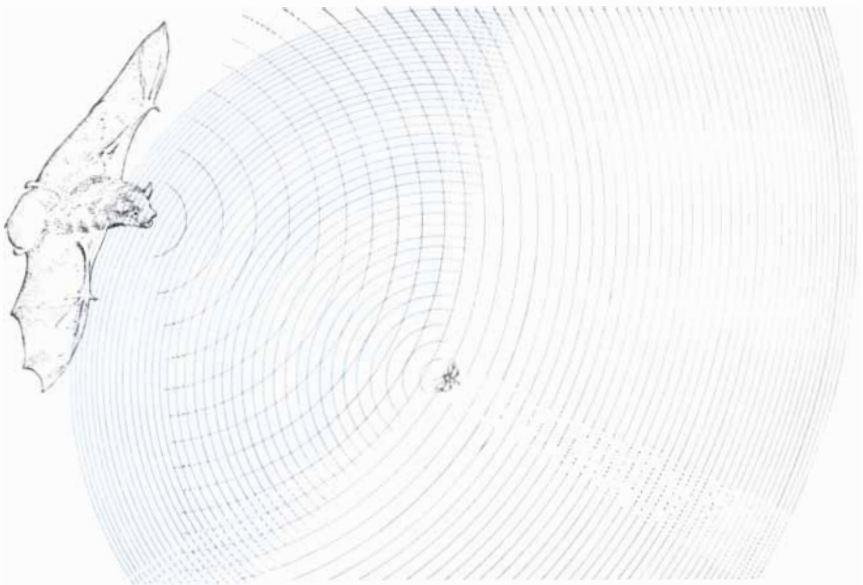
Another highly specialized group, the horseshoe bats of the Old World, have elaborate nose leaves which act as horns to focus their orientation sounds in a sharp beam; they sweep the beam back and forth to scan their surroundings. The most surprising of all the specialized bats are the species that feed on fish. These bats, like the brown bat and many other species, have a well-developed system of frequency-modulated ("FM") sonar, but since sound loses much of its energy in passing from air into water and *vice*



BATS shown in these drawings all use some type of echolocation system except for the fruit bat *Rousettus*, which appears at bottom right. The other species represented are the small brown bat *Myotis lucifugus* (*top*), the long-eared bat *Plecotus* (*left center*), the large brown bat *Eptesicus* (*right center*) and the horseshoe bat *Rhinolophus* (*bottom left*).

versa, the big puzzle is: How can the bats locate fish under water by means of this system?

Echolocation by bats is still such a new discovery that we have not yet grasped all its refinements. The common impression is that it is merely a crude collision warning device. But the bats' use of their system to hunt insects shows that it must be very sharp and precise, and we have verified this by experiments in the laboratory. Small bats are put through their maneuvers in a room full of standardized arrays of rods or fine wire. Flying in a room with quarter-inch rods spaced about twice their wingspan apart, the bats usually dodge the rods successfully, touching the rods only a small percentage of the time. As the diameter of the rods or wires is reduced, the percentage of success falls off. When the thickness of the wire is considerably less than one tenth the wavelength of the bat's sounds, the animal's sonar becomes ineffective. For example, the little brown bat (*Myotis lucifugus*), whose shortest sound wavelength is about three millimeters, can detect a wire less than two tenths of a millimeter in diameter, but its sonar system fails on wires less than one tenth of a millimeter in diameter.



INSECT IS LOCATED by means of reflected sound waves (*colored curves*). Variation in the spacing of the curves represents changing wavelength and frequency of the bat's cry.

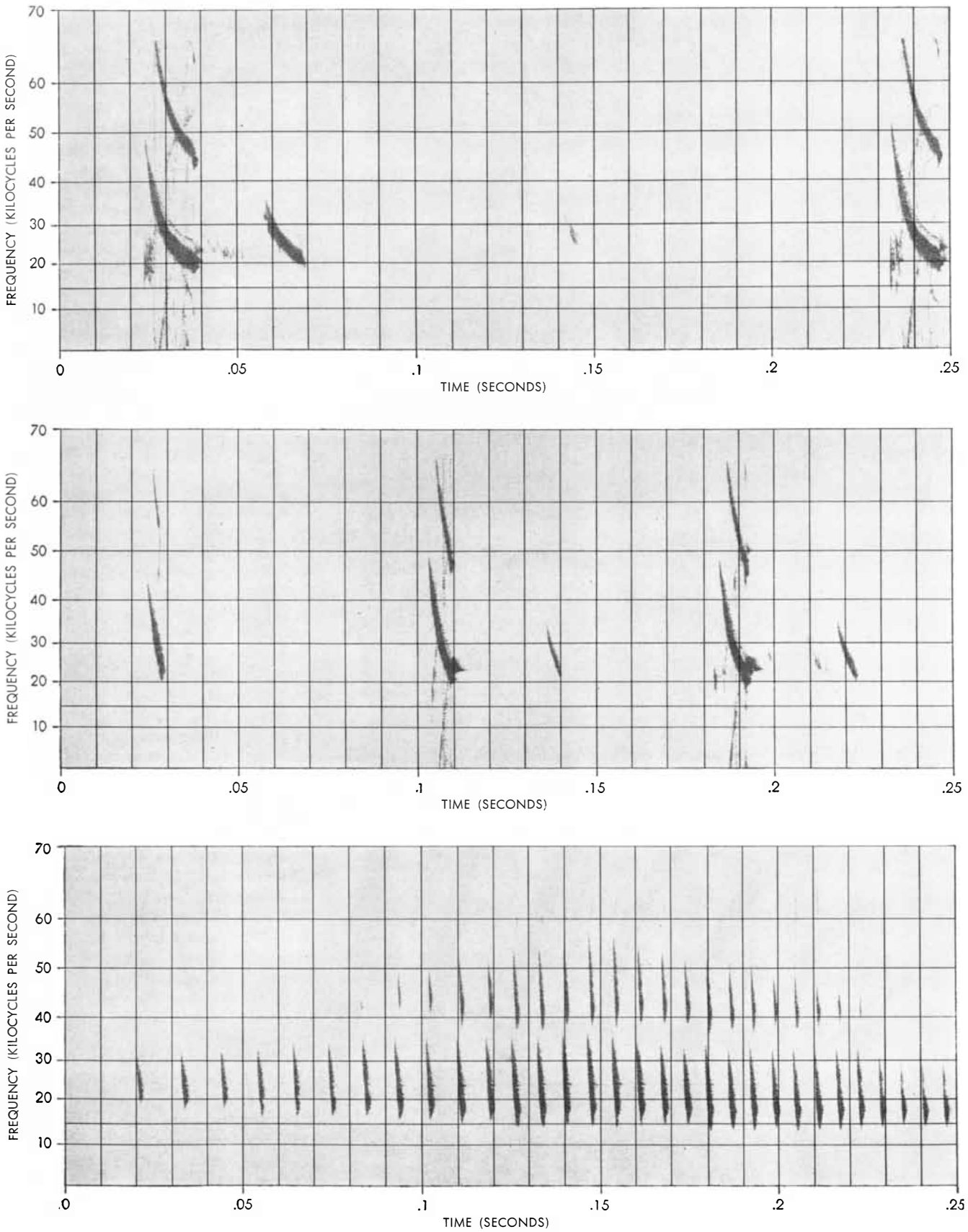
When obstacles (including insect prey) loom up in the bat's path, it speeds up its emission of sound pulses to help in location. We have made use of this fact to measure the little brown bat's range of detection. Motion pictures, accompanied by a sound track, showed that the bat detects a three-millimeter wire at a distance of about seven feet, on the average, and its range for the finest wires it can avoid at all is about three feet. Considering the size of the bat and of the target, these are truly remarkable distances.

Do the echoes tell the bat anything about the detected object? Some years ago Sven Dijkgraaf at the University of Utrecht in the Netherlands trained some bats to distinguish between two targets which had the form of a circle and a cross respectively. The animals learned to select and land on the target where they had been trained to expect food. Bats can tell whether bars in their path are horizontal or vertical, and they will attempt to get through a much tighter spacing of horizontal bars than of vertical bars. In gliding through a closely spaced horizontal array the bat must decide just how to time its wingbeats so that its wings are level, rather than at the top or bottom of the stroke, at the moment of passage. All in all, we can say that bats obtain a fairly detailed acoustic "picture" of their surroundings by means of echolocation.

	BAT	RADARS		SONAR
	EPTESICUS	SCR-268	AN/APS-10	QCS/T
RANGE OF DETECTION (METERS)	2	150,000	80,000	2,500
WEIGHT OF SYSTEM (KILOGRAMS)	.012	12,000	90	450
PEAK POWER OUTPUT (WATTS)	.00001	75,000	10,000	600
DIAMETER OF TARGET (METERS)	.01	5	3	5
ECHOLOCATION EFFICIENCY INDEX	2×10^{9}	6×10^{-5}	3×10^{-2}	2×10^{-3}
RELATIVE FIGURE OF MERIT	1	3×10^{-14}	1.5×10^{-11}	10^{-12}

COMPARISON of the efficiency of the bat's echolocation system with that of man-made devices shows that nature knows tricks which engineers have not yet learned. "Echolocation efficiency index" is range divided by the product of weight times power times target diameter. "Relative figure of merit" compares the echolocation efficiency indexes with the bat as 1.

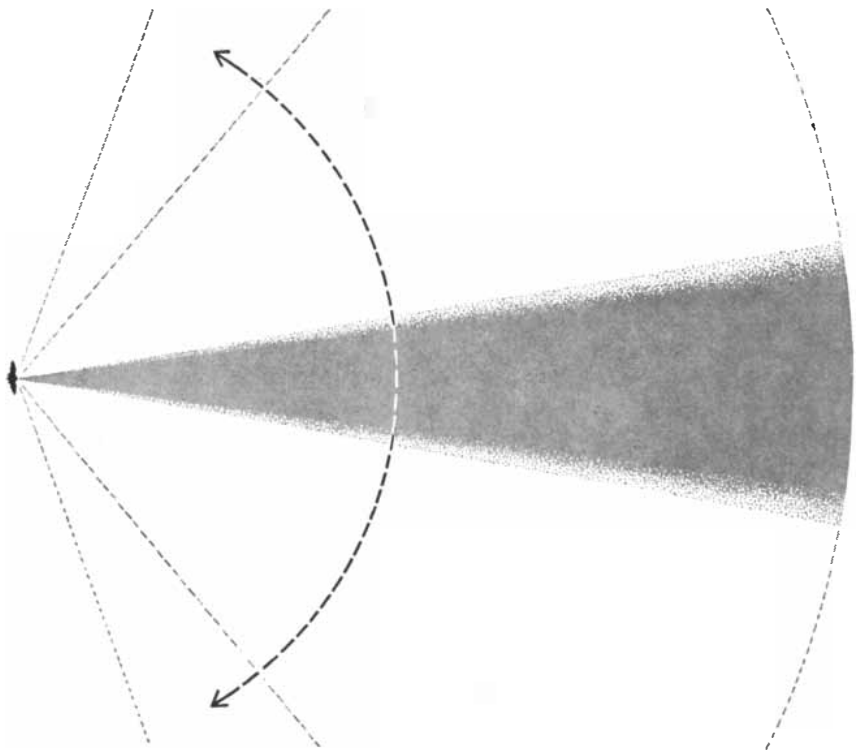
Probably the most impressive aspect of the bats' echolocation performance is their ability to detect their targets in spite of loud "noise" or jamming. They have a truly remarkable "discriminator," as a radio engineer would say. Bats are highly gregarious animals, and hundreds fly in and out of the same cave within range of one another's sounds. Yet in spite of all the confusion of signals in the same frequency band, each bat is



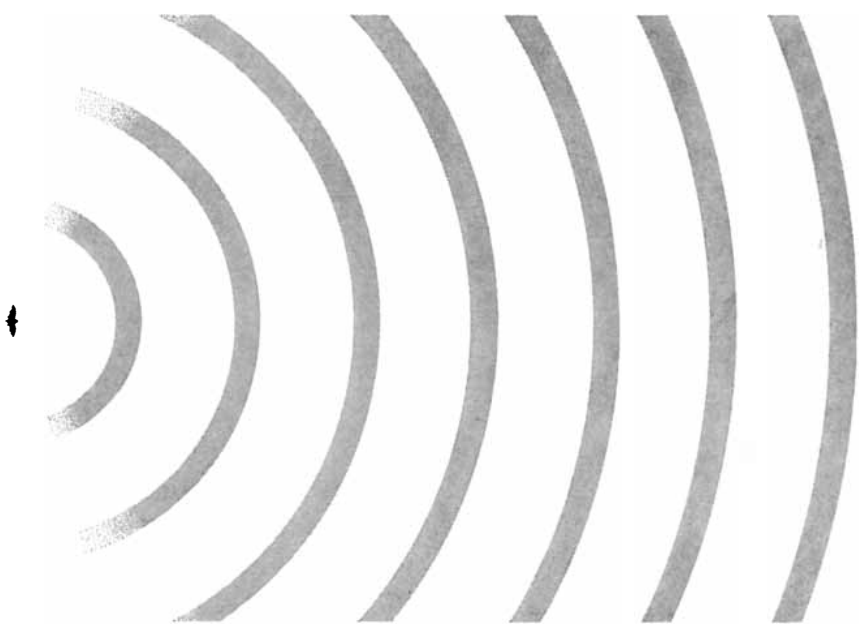
ORIENTATION SOUNDS of the large brown bat were recorded as slanting traces in these spectrograms while the animal was cruising (*top*), beginning pursuit of an insect (*middle*) and closing in on its prey (*bottom*). The traces appearing at .06 seconds in the top spectrogram and at .14 and .22 seconds in the middle spectrogram are echoes, which probably come from nearby buildings.

able to guide itself by the echoes of its own signals. Bats learned long ago how to distinguish the critically important echoes from other distracting sounds having similar properties.

We have recently tested the bats' discriminatory powers by means of special loudspeakers which can generate intense sound pulses. We found that a continuous broad-band noise which all but drowned out the bats' cries did not disorient them. They could still evade an insect net with which one tried to catch them; they were able to dodge wires about one millimeter in diameter; they landed wherever they chose.



NARROW BEAM which sweeps back and forth is emitted by horseshoe bat in hunting insects. Beam is about 20 degrees wide, has a constant frequency and a pulse length of 50 feet.



WIDE BEAM of short, frequency-modulated pulses is emitted by most bats while hunting. Each pulse (*gray curves*) is about 1.5 feet long. Beam is fixed with respect to bat's head.

In some experiments A. D. Grinnell and I did succeed in jamming certain FM bats, but it was not easy, and the effect was only slight. We worked on a species of lump-nosed bat (*Plecotus rafinesquii*) which emits comparatively weak signals. With two banks of loudspeakers we filled the flight room with a noise field of about the same intensity as the bats' echolocation signals. The more skillful individual bats were still able to thread their way through an array of one-millimeter wires spaced 18 inches apart. Only when we reduced the wires to well below half a millimeter in diameter (less than one tenth the wavelength of the bats' sounds) did the bats fail to detect the wires.

To appreciate the bats' feats of auditory discrimination, we must remember that the echoes are very much fainter than the sounds they emit—in fact, fainter by a factor of 2,000. And they must pick out these echoes in a field which is as loud as their emitted sounds. The situation is dramatically illustrated when we play back the recordings at a reduced speed which brings the sounds into the range of human hearing. The bat's outgoing pulses can just barely be heard amid the random noise; the echoes are quite inaudible. Yet the bat is distinguishing and using these signals, some 2,000 times fainter than the background noise!

Much of the modern study of communication systems centers on this problem of discriminating information-carrying signals from competing noise. Engineers must find ways to "reach down into the noise" to detect and identify faint signals not discernible by ordinary methods. Perhaps we can learn something from the bats, which have solved the problem with surprising success. They have achieved their signal-to-noise discrimination with an auditory system that weighs only a fraction of a gram, while we rely on computing machines which seem grossly cumbersome by comparison.

When I watch bats darting about in pursuit of insects, dodging wires in the midst of the nastiest noise that I can generate, and indeed employing their gift of echolocation in a vast variety of ways, I cannot escape the conviction that new and enlightening surprises still wait upon the appropriate experiments. It would be wise to learn as much as we possibly can from the long and successful experience of these little animals with problems so closely analogous to those that rightly command the urgent attention of physicists and engineers.

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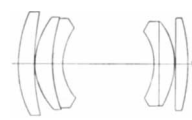
By reading our circulars a person can no more acquire proficiency in counterfeiting than he can in autoradiography of tissue sections, spectrography, astrophysical research, or investigations with nuclear track emulsions. Nevertheless, as long as intentions are legal, it doesn't hurt early in the game to obtain from us the essential facts about the specialized photographic materials we manufacture for these purposes.

New sheets entitled "Kodak Sensitized Materials for Autoradiography," "Kodak Spectrum Analysis Plates and Films and Kodak 'Spectroscopic' Plates and Films," and "Kodak Nuclear Track Materials" are obtainable without charge from Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. He who asks for all three impresses us with the scope of his ambitions but strains our credulity a mite.

Four sharp eyes

After all these years—the recent ones with high-speed digital computers helping—it surprises outsiders that lens designers should still expect to find new combinations of curvatures, refractive indices, thicknesses, and spacings that will substantially improve photographic lens performance. But they do, to the pain of the authors of yesteryear's superlatives. A sort of continuous auction goes on, at which optical manufacturers keep bidding up the number of lines per millimeter resolved on film in accordance with Method 7 of MIL-STD-150.

In 6-inch to 12-inch focal lengths for 70mm aerial film at relative apertures around *f*/2.8 to *f*/3.5, we revel for the moment in beating the previous high by nearly twice. We have had a run of good luck in recent months. We did it with our 6-inch *f*/2.8 *Kodak Aero Ektar Lens,*



Formula M-360. Here are the minimum resolution figures we get at full aperture for a sample lens of this formula photographing high-contrast, 3-line, clear-on-black resolution targets on Kodak Super-XX Aerial Recon Film with white light through a Kodak Wratten No. 12 Filter:

semi-field	0°	2.5°	5°	7.5°	10°	12.5°	15°
lines/mm	56	56	63	62	49	38	33

These figures are very close to what used to be quoted for the capabilities of the film itself. Only nowadays our film people smile at the conceptual *naiveté* of a resolving power figure for film. Only the resolving power of the film-lens combination retains some significance. This significance, too, tends to attenuate after an hour at the blackboard with an earnest man.

There are three other Kodak Aero Ektar Lenses in this class. They are all manufactured on contract, not stocked for off-the-shelf sale. They are not cheap. They are comparatively heavy. Distortion, though moderate, exceeds cartographic limits. Above all else, the driving force behind these lenses is to reduce the need for large size in aerial cameras. Only organizations whose interest is commercial or professional need inquire. They should address themselves to Eastman Kodak Company, Military and Special Products Sales, Rochester 4, N. Y.

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

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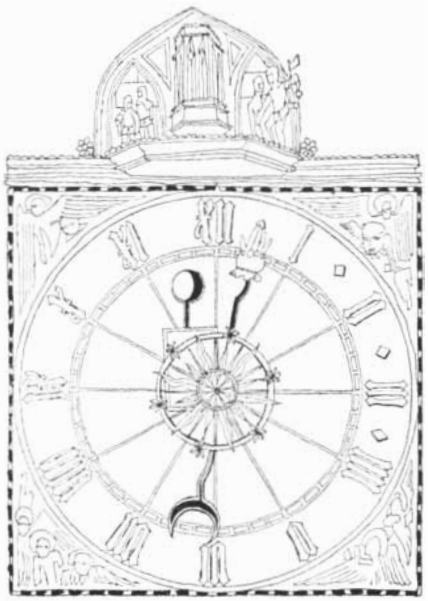

The Cost of Secrecy

Many scientists have suspected that secrecy restrictions have held back U. S. scientific progress. A congressional subcommittee has now made this view official. In a report summarizing hearings over the past two years, the House Special Subcommittee on Government Information concluded that "the Federal Government has mired the American scientist in a swamp of secrecy" and that the classification of scientific information played a part in "the nation's loss of the first lap in the race into space."

Soon after the report was released, the Department of Defense announced that it was preparing to declassify almost all documents dated before 1946. Representative John E. Moss of California, chairman of the Subcommittee, described this step as "encouraging but exceedingly timid." A Department of Defense spokesman, conceding that it was "just a step," described the declassification problem as a "cancer" which has been growing for years and will take time to remove.

The Subcommittee's report, declaring that "the only real national security lies in scientific progress," recommended three important changes in security measures:

1. A system of uniform security clearance applying to all government agencies and defense contractors. This would end the present system under which a scientist with top-secret clearance from the Army must get a second clearance to do work for the Navy, a third for the Air Force and a fourth for the Atomic Energy Commission.

2. Abolition of the "need-to-know" rule, which bars even a cleared scientist from secret information unless he can show its relevance to the work he is doing.

3. An end to attempts to classify "basic laws of nature" as secret.

Witnesses before the Subcommittee repeatedly counterposed "security by achievement" to "security by secrecy." The classic concepts of military security, they said, are not applicable today. "Science," said one witness, "results not from a conversation between two human beings but from a conversation between a human being and nature. And . . . you can't shut nature up."

Scientific witnesses agreed that security policies have slowed down scientific progress and wasted money by forcing duplication of experiments, by holding up projects while key scientists are repetitively cleared and by inhibiting communication among scientists. Donald J. Hughes of the Brookhaven National Laboratory told the Committee that, in areas of nuclear physics which have been "open" in the U. S. and secret in the U.S.S.R., U. S. research is much further ahead than in areas which have been secret in both countries.

Several witnesses also said that the security clearance procedure and the restrictions on discussion in many important scientific fields have discouraged many scientists from tackling problems in these fields. Nobel laureate Harold C. Urey told the Committee that since 1946 he has deliberately sought out subjects which would not take him into classified fields. "Determining the temperatures in the ancient oceans," he said, "is not likely to become a classified subject." Otto Struve of the University of California told the Committee: "If I had a bright idea in the field of nuclear fusion, I would go to sleep and forget about it."

Scientists and Department of Defense witnesses agreed that a central problem was the persistent tendency to overclassify documents. Witnesses ascribed this partly to "the neurosis of the times" and partly to the fact that "there is no penalty for stamping something secret which shouldn't be kept secret." The report notes that more than a million persons now have the authority to classify in-

formation. Once a document is classified, it is almost impossible to get it declassified. Directives intended to facilitate declassification have been "ignored in substance and spirit," the Committee found.

Scientific witnesses urged that all documents be declassified automatically after a certain period unless specifically reclassified.

Trevor Gardner, former Assistant Secretary of the Air Force for Research and Development, described the case of an internationally known scientist whose clearance was withdrawn. "Unfortunately," said Gardner, "this man has such inventive ability that he keeps on coming up with 'secret' and 'top secret' ideas, even though his clearance is removed." The Air Force solved the problem by giving the man an unclassified contract: "As soon as he gets some interesting results, we classify the results and he no longer has access to them. . . . We can't seem to classify his head."

So far no legislation covering the Committee's recommendations has been drafted. According to Representative Moss, the problem should be handled by the Executive Branch.

Teaching Money

The National Science Foundation has made an initial grant of $100,000 to the School Mathematics Study Group, set up at Yale University to consider ways of improving mathematics teaching in high schools. The mathematics group, patterned after the Physical Science Study Committee at the Massachusetts Institute of Technology, will probably recommend changes in the curriculum and prepare textbooks, teachers' manuals, monographs and teaching aids such as motion pictures. At its first meeting this summer some 40 mathematicians and high-school teachers will consider syllabuses for high-school algebra and geometry courses. E. G. Begle of Yale is director of the group. An advisory committee is to be named by the presidents of the American Mathematical Society, the Mathematical Association of America and the National Council of Teachers of Mathematics.

Another teaching grant, totaling $2.5 million, was awarded last month by the Donner Foundation of Philadelphia to establish chairs in physical science at

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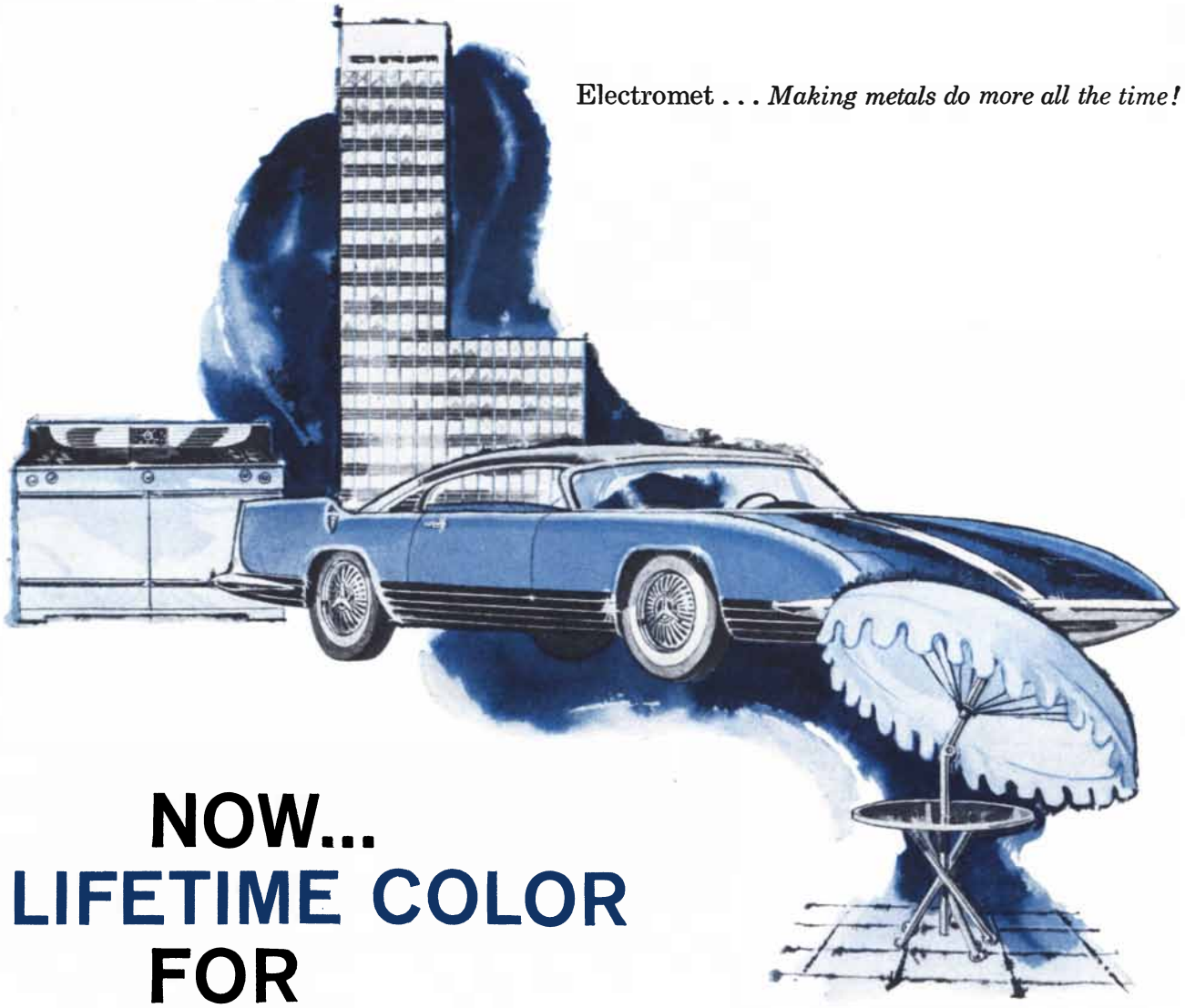

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five Eastern universities. With an endowment of $500,000, each professorship will pay about $20,000 a year. The recipients are Harvard University, Princeton University, Yale University, the University of Pennsylvania and the Massachusetts Institute of Technology.

Data from the Sputniks

The U.S.S.R. has begun to relax its reticence on details of its satellites and their findings. Last month *Pravda* published an extensive report on the information gathered by the first two sputniks and a fairly detailed description of the third.

As U. S. observers had already reported, the first two satellites showed that at 140 miles, the low point of their orbits, the air is five to 10 times denser than had been thought. Soviet scientists found that the density is greater in high latitudes than near the Equator, and that it varies during the day, being lowest at night and reaching a maximum at midday. The temperature at 140 miles also was higher than expected.

Ionization in the outer parts of the ionosphere was measured by the bending of the sputniks' radio signals. The ionization increases by 10 to 15 times between 60 and 180 miles; beyond this maximum, in the region from 180 to 310 miles, it falls off by half.

Cosmic-ray counters registered a 40-per-cent increase from 140 to 430 miles. The intensities at various latitudes confirmed an earlier suspicion that the earth's magnetic equator at high altitudes is tilted with respect to the equator at the surface. On one occasion the satellites' counters showed a sudden rise of 50 per cent in cosmic radiation, although ground stations reflected no change.

Laika, the first space dog, withstood its journey in Sputnik II well as long as its food held out. During the take-off acceleration its heart rate was three times faster than normal, but an electrocardiogram showed "no morbid symptoms." Pressed against the floor of its chamber by the great acceleration, the animal breathed shallowly and rapidly. Once the satellite was in orbit, the dog's pulse and respiration gradually returned to normal. Laika was apparently not overly disturbed by its weightless condition; its motions were "moderate and rather smooth." Probably because of weightlessness, the animal's heart took three times longer to regain its normal rhythm than in acceleration experiments in the laboratory.

Nothing was learned about the effects of cosmic radiation on the dog. To obtain this information it would have been necessary to examine the animal after its flight.

The third sputnik, launched on May 15, is described as a "big, complex flying laboratory outfitted with the most up-to-date and perfect equipment." A conical object 11 feet 9 inches high and 5 feet 8 inches in diameter at the base, it weighs 2,925 pounds over all, including 2,134 pounds of instruments and batteries. Its initial orbit had a perigee of 150 miles and an apogee of 1,168 miles.

Among the phenomena being measured by this flying laboratory are atmospheric pressure, the earth's magnetic field, the electric charge on the satellite and in the surrounding air, the intensity of corpuscular radiation from the sun, the temperature inside the vehicle and at its surface. Impacts of micrometeorites are being counted. A mass spectrometer is weighing the particles in the ionosphere, thus determining its chemical composition. An experiment of "special significance" is an attempt to find gamma rays in the cosmic radiation.

All the instruments are controlled by a master timing-device which turns them on and off at appropriate intervals. The information they collect is stored in memory circuits and read out when the vehicle passes over ground stations. The temperature inside the satellite is regulated automatically by means of movable shutters which change the reflectivity of the surface. Power is provided by chemical and solar batteries.

Commenting on the size and weight of Sputnik III, one Soviet Academician said it could easily have housed "a human being with a food pantry and additional equipment." Until the problem of safe return is solved, however, the experiment would be "premature." Another scientist pointed out that the propulsion system which put the 2,900-pound satellite into orbit could send a small object to the moon. "But then," he added, "the scientific importance of such an experiment would be relatively small, due to the impossibility of putting aboard any serious equipment for scientific investigation."

Nobelium

The new synthetic element 102, nobelium, is now a member in good standing of the periodic table, but there is some doubt as to who put it there. Last year an international group working in Sweden claimed to have made the isotope nobelium 253 by bombarding curium 244 with nuclei of carbon 13. Now Albert Ghiorso and his co-workers

at the University of California's Radiation Laboratory announce that they were unable to duplicate the Swedish experiment but they have manufactured nobelium 254 by bombarding curium 246 with carbon 13.

Because of nobelium's short half-life—three seconds—the California group could not identify the element directly. But they detected its longer-lived decay product, fermium 250, by its radioactivity and by chemical separation.

Chemical Jig

A new and simple method for making giant straight-chain molecules has been developed by John F. Brown and Dwain M. White of the General Electric Company. The G.E. chemists hold the individual molecular links, or monomers, end to end in a kind of chemical jig and join them together by irradiating them with electrons. The jig is a crystal of a material such as urea, which is perforated with long, narrow tunnels. Monomers of the right size can fit lengthwise in the tunnels but cannot turn around. Once the monomers have been linked, the urea crystal is dissolved. The success of the method depends on matching the size of the tunnel to the diameter of the monomers.

Using urea and thiourea crystals as jigs, Brown has prepared straight-chain polymers of butadiene, vinyl chloride, vinylidine chloride, cyclohexadiene and acrylonitrile. His polybutadiene is said to be a hard, tough, crystalline solid, whereas in its usual branched form this polymer is rubbery.

Association for Research

Several universities and other institutions have formed the Associated Midwest Universities to promote research at Argonne National Laboratory. The chief impetus to the new organization was provided by the Atomic Energy Commission's recent authorization of a 12.5-billion-electron-volt accelerator to be built at Argonne. This will be the first big machine in the Midwest, and its facilities will be made available to physicists through the association.

Associated Midwest Universities is not related to the Midwestern Universities Research Association (MURA), although many of its members also belong to the latter group. MURA is concerned with design of advanced accelerators.

Present members of the new association are: the Battelle Memorial Institute, Carnegie Institute of Technology, Case Institute of Technology, Illinois

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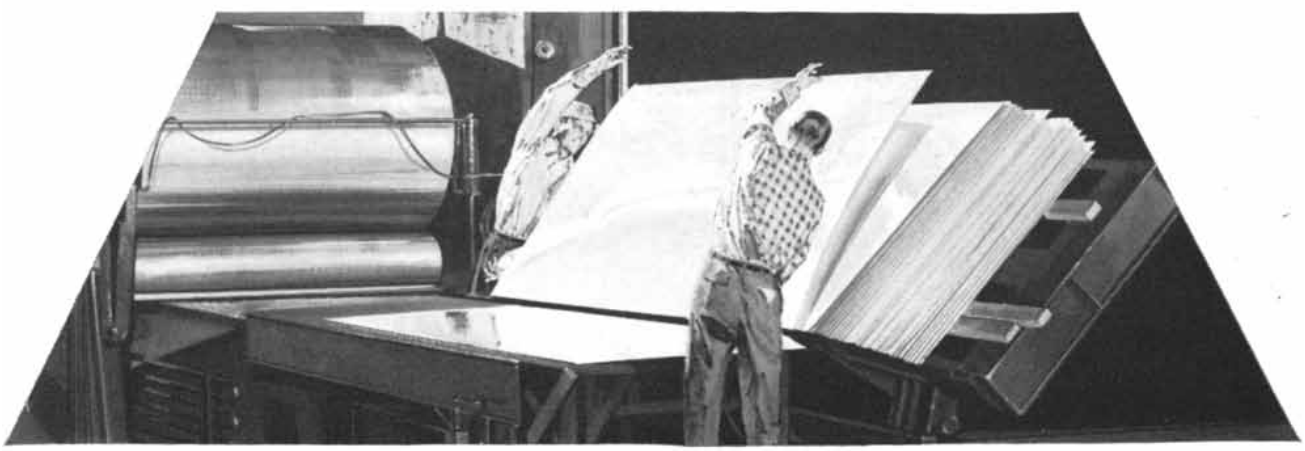

Udimet 500, a superior alloy proven by extensive high temperature applications, is now available in sheet in production quantities for early delivery. It is produced in widths to 48″ by 144″ in length and in thickness down to .010″. The alloy combines very high stress rupture life with excellent ductility and fatigue resistance in the 1200°F to 1800°F ranges.

Many other vacuum induction melted alloys are also now marketed in sheet form by the Utica Metals Division.

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Separating Helium

As an unexpected result of studying the diffusion of gases through various materials, K. B. McAfee of the Bell Telephone Laboratories has come up with a radically new method of separating helium from natural gas—a method which may recover millions of cubic feet of helium now lost every day.

McAfee was testing materials used as insulation for submarine telephone-cables, and he discovered that Pyrex glass was practically impermeable to all gases except helium. The helium molecule, consisting of only a single atom, is the smallest of all gas molecules—some 25 per cent smaller than the hydrogen molecule, which has two atoms. It diffuses through Pyrex glass about a thousand times more readily than hydrogen. McAfee conceived the idea of putting natural gas under pressure in a chamber packed with thin-walled glass tubing; the helium would pass through the walls into the tubing and thus be separated from other gases such as hydrogen and methane. The idea worked; the helium collected in the tubing is practically pure at the first pass.

McAfee's discovery promises more efficient and more economical recovery of helium. The present method of obtaining helium from natural gas in the U. S. is low-temperature distillation, and the entire supply of helium comes from four such plants operated by the Bureau of Mines. But the distillation process is feasible only for gas containing at least 1 per cent helium; the helium in less rich natural gas is being lost at the rate of 10 million cubic feet per day. Studies at Bell indicate that the new process could salvage this helium.

Simple Virus

Biophysicists at the California Institute of Technology have isolated an ideal organism for research in heredity—a bac-

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terial virus with but a single molecule of genetic material, and a small molecule at that.

To researchers in genetics any bacterial virus is like a nugget of 24-carat gold. Once it sheds its protein coat and enters a bacterium to reproduce, it consists of nothing but pure genes; *i.e.*, molecules of deoxyribonucleic acid (DNA). But deciphering the genetic message is an awesome task. Presumably the code is contained in the order of the segments that make up the strands of the DNA molecule. The well-known virus T2 contains about 10 DNA molecules with a total of some 400,000 segments. A mutation might involve a change in just one of the segments.

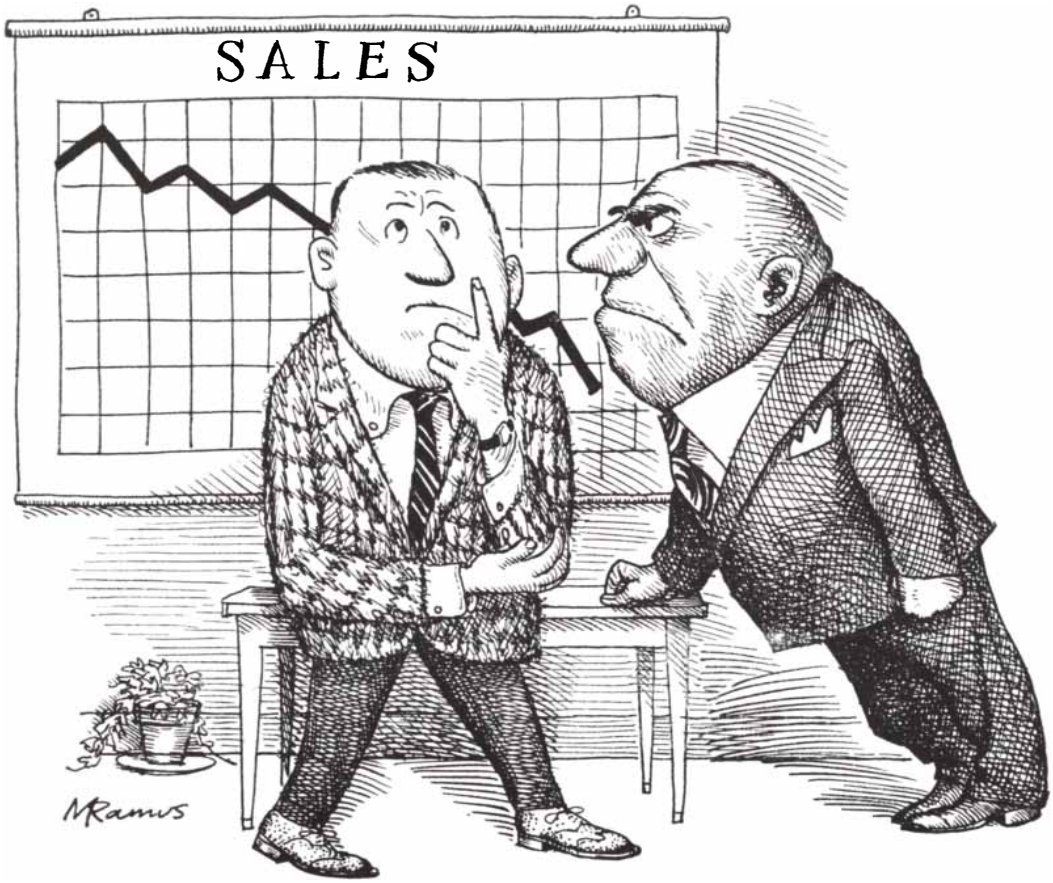
The new virus contains just one molecule of DNA with about 5,500 segments. The Cal Tech group, led by Robert L. Sinsheimer, developed methods of purifying, weighing and measuring the virus and separating its DNA. The group has also isolated mutant strains. Writing in the Cal Tech magazine *Engineering and Science*, Sinsheimer says his laboratory has begun "to examine the structure and functions of these particles in the most intensive way."

Profile of Creativity

According to a psychologist at the University of Chicago, creativity in science depends less on intelligence than on drive and certain personality traits. Morris I. Stein made a five-year psychological study of 67 industrial chemists. He found no significant difference in intelligence between the creative and noncreative members of this sample. But he did find a personality pattern which was characteristic of the creative group.

The creative individual, according to Stein's analysis, tends to set his sights on more distant goals and to have a better mastery of complex ideas and personal relationships. He sees himself as different from other people, acts less conventionally, is more tolerant of unconventional behavior in others. The creative scientist analyzes a problem slowly and carefully, then proceeds rapidly with the solution. The less creative man is apt to flounder in a disorganized attempt to get a quick answer. The creative scientist works longer hours and spends more of his leisure time on activities related to his profession. He places a higher value on creative effort and feels keenly any restriction upon its exercise in his job.

Using the data he has gathered, Stein is now designing a test to predict the potential creativity of job applicants.



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Ivy league shrugged. "Okay, no dancing girls . . . *wait!* I've got a new wave length. Have you read about Pfizer *Lysine?* Terrific! It's something called an amino acid. Gives cereal products the high protein quality of meat or eggs. That kind of health bonus could really get *Ruffage* off the launching pad!"

The manager squints. "Boy, I think you may have it. Get Pfizer on the phone."

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Biological Oxidation

How does the living cell "burn" carbohydrates and fats? It does so by means of an intricate web of chemical reactions which have been localized in the minute intracellular particles called mitochondria

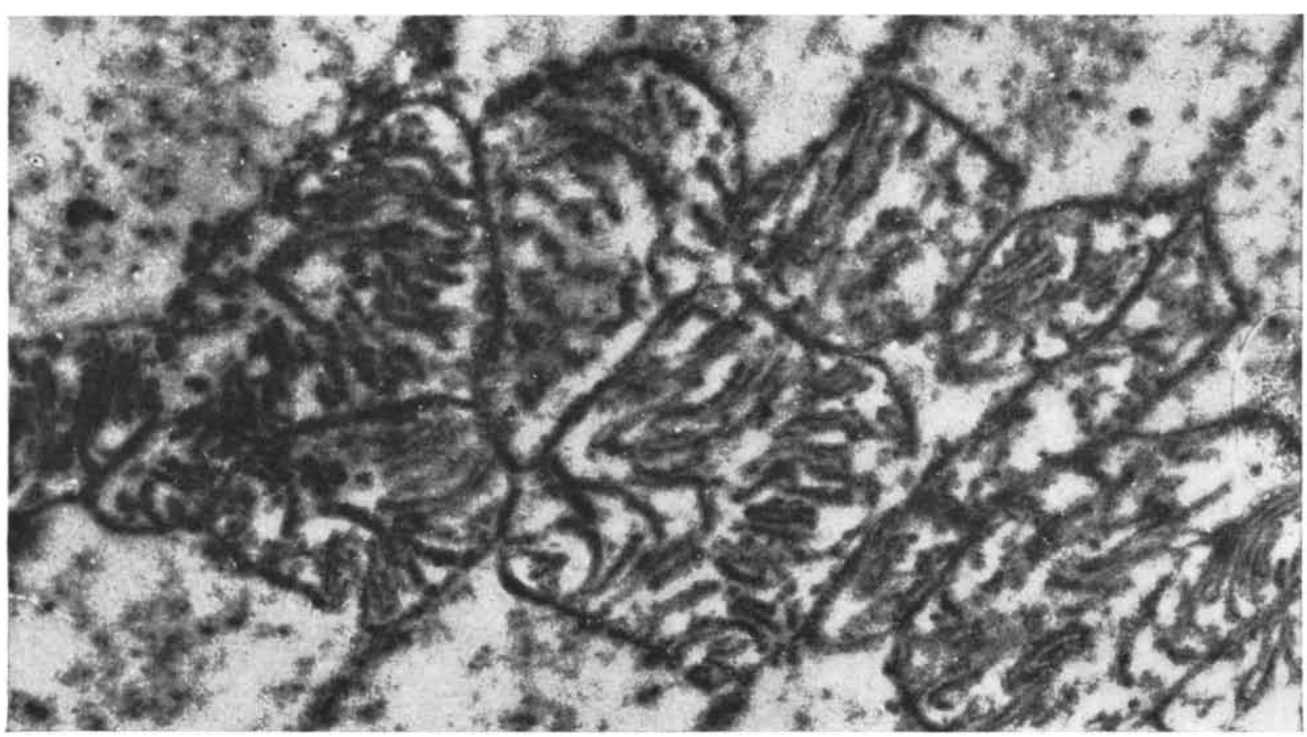
by David E. Green

Every schoolboy is taught that the body obtains energy by burning food with oxygen. Possibly he visualizes a mysterious furnace of some sort in his interior, because the textbooks are disappointingly vague on just how the system works. The nature of the engine that converts food into chemical energy has been a complete enigma.

For almost 180 years a long succession of illustrious chemists have worked on the problem and found it tantalizingly elusive. But some of the elements of the puzzle are at last beginning to fall into place, and we can now begin to form a picture of the energy-generating machinery of the cell.

The story began in 1777, when Antoine Laurent Lavoisier discovered that respiring animals take up oxygen from the air and convert it into carbon dioxide. His experiments led him to conclude that animals produce their body heat by the combustion of foodstuffs with oxygen. How this could happen at the low body temperature was hard to understand, and various fanciful theories were propounded. But throughout the 19th century chemists could find no reasonable explanation as to why molecular oxygen, ordinarily inert chemically, should become so active in the body.

At the turn of the 20th century Otto Warburg of Germany put the problem on the rails again. Studying the oxidation of amino acids by air in the presence of specially prepared animal charcoals, he decided that iron in the charcoal acted as a catalyst to activate oxygen. Warburg found a wealth of evidence that his iron-containing catalyst was responsible for many biological oxidations. Eventually



SECTION OF BEEF HEART-MUSCLE shows clusters of mitochondria along the muscle fibrils. Each mitochondrion has a double wall and contains a series of tubelike "cristae" stacked like logs on a pile. The structures are magnified about 47,000 diameters. D. L. Filmer and Paul Kaesberg of the University of Wisconsin made this electron micrograph and those on the opposite page.

he identified the catalyst as a respiratory enzyme which he called *Atmungsferment*; he described the enzyme as a protein combined with a molecule called heme or iron porphyrin—the same red molecule present in the hemoglobin of blood. According to Warburg, the iron atom was the key to all oxidations occurring in the body.

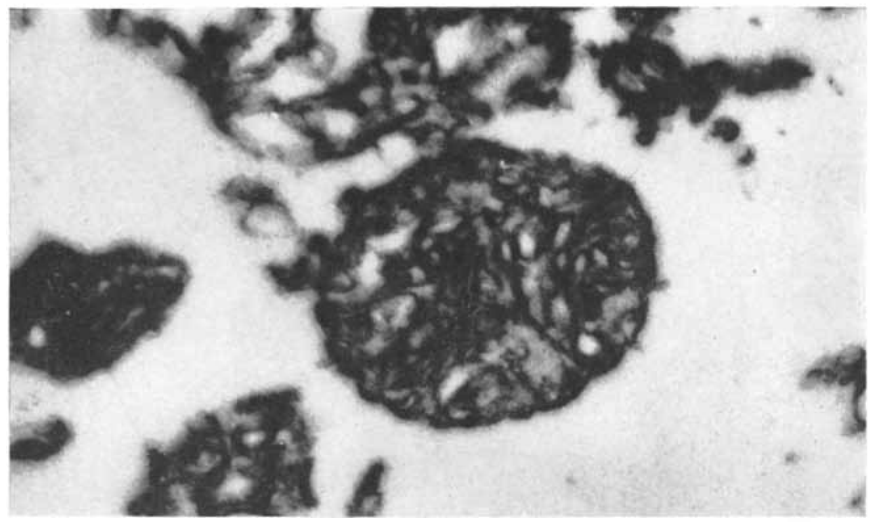
Warburg's discovery put biochemists on the right track by directing attention to the catalysts of the cell. But he overreached himself by fixing on iron as the only catalytic principle and by ascribing almost mysterious catalytic powers to his *Atmungsferment*, which he pictured as converting substances to carbon dioxide and water in one fell stroke, as it were. The Warburg scheme was soon challenged by Heinrich Wieland in Germany and Torsten Thunberg in Sweden, who developed a very different picture. They found that biological substances could be oxidized by agents other than molecular oxygen, and that the primary reaction was removal of hydrogen from the substrate—a reaction called dehydrogenation or hydrogen transfer. Wieland used synthetic catalysts to demonstrate this dehydrogenation. Thunberg found that natural enzymes, called dehydrogenases, also could do so.

Wieland concluded that the dehydrogenation reaction played the main role in the combustion of foodstuffs; the function of oxygen, he thought, was merely to oxidize the hydrogen acceptor (the enzyme) so as to remove the hydrogen (in the form of water) and release the catalyst again. For almost two decades a battle royal raged between the Warburg and Wieland schools. Warburg refused to recognize the existence of dehydrogenases; Wieland saw no need for Warburg's *Atmungsferment* enzyme.

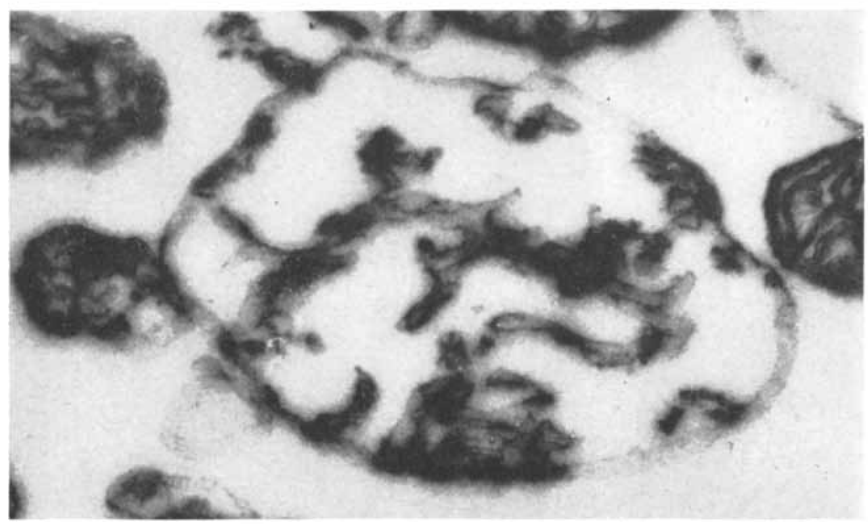
Then in the late 1920s the genius of David Keilin of the University of Cambridge resolved the deadlock between the two giants of German biochemistry. He showed that both were partly right: dehydrogenation with the aid of a catalyst was indeed the primary event in the oxidation of substrates in the body, but to complete the process the activation of oxygen by a catalyst (Warburg's *Atmungsferment*) was also necessary.

The Cytochromes

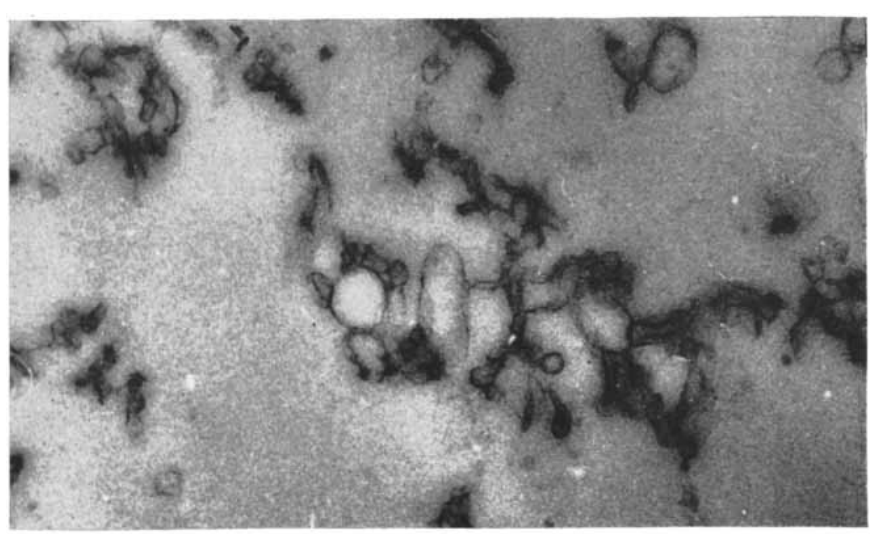
Keilin, a parasitologist by training, was studying the wing muscles of bees and moths under the microscope. To detect chemical changes in the muscles he put the prism of a hand spectroscope in the place of the eyepiece of the micro-



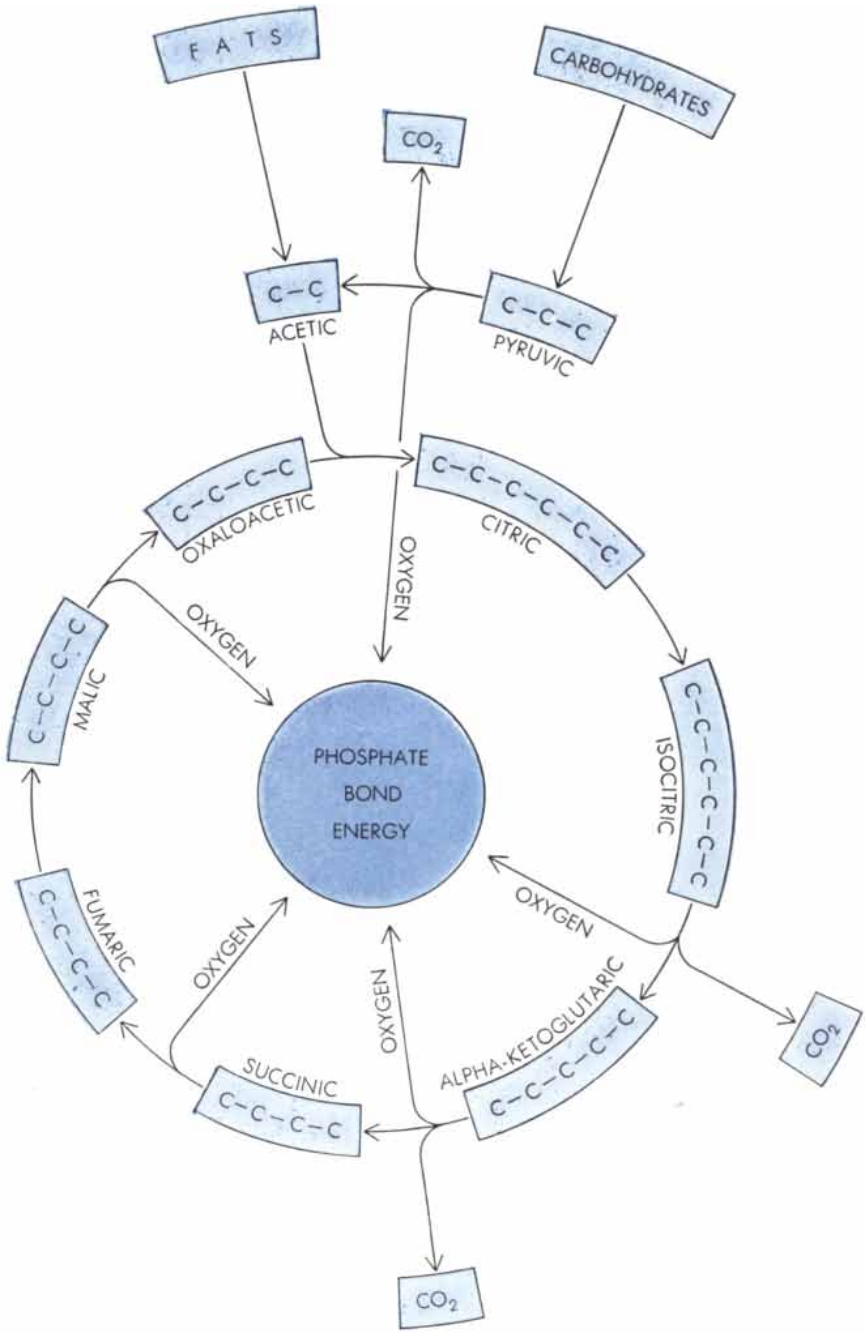
ISOLATED MITOCHONDRIA enlarged 55,000 diameters show some damage sustained during separation. The outer envelope has become less distinct and the cristae are disturbed.



MITOCHONDRIA DAMAGED by freezing and thawing have few intact cristae remaining. It is difficult to distinguish the outer envelope from the membranes of the cristae.



MITOCHONDRIAL FRAGMENTS were obtained by breaking up damaged mitochondria with sonic vibrations. Particles with a double membrane are parts of broken cristae.



CITRIC ACID CYCLE yields energy-rich phosphate bonds of adenosine triphosphate (ATP) using fats or carbohydrates as fuel. A series of acids are converted from one to another by means of enzymes and oxygen. The number of carbon atoms (C) in each acid is indicated. Each turn of the cycle is powered by the addition of acetic acid to oxaloacetic acid.

scope. He then discovered that when the muscles contracted, four sharp bands appeared in the absorption spectrum of the tissue. These bands disappeared when the muscles returned to the resting condition.

Keilin soon realized that oxygen was implicated in this change. In the resting muscle the oxygen tension is relatively high; in the contracting muscle it is comparatively low. Examining many different kinds of living cells and tissues, Keilin found that as a general rule the spectral bands appeared only when the oxygen tension was low. Why did these bands show up only in the absence of oxygen? Clearly they must reflect the reduced (*i.e.*, oxygen-deprived) form of some substance or substances in the cells. Keilin eventually identified the material responsible for the bands as a group of substances he christened the cytochromes: cytochromes *a*, *b* and *c*.

He proceeded to extract the cytochromes from muscle cells. The extract itself showed no spectral bands, but when a substrate such as succinic acid was added to it, the bands appeared at once. Evidently the succinic acid acted as a reducing agent, providing electrons for the reduction of the cytochromes. Now Thunberg had shown that the oxidation of succinic acid required a dehydrogenase. Keilin's simple experiment therefore vindicated the Thunberg-Wieland position that the primary reaction in biological oxidation was a dehydrogenation of the substrate. The reaction here took place in the absence of oxygen from the solution.

But there is also a second reaction. As soon as oxygen is bubbled through the extract, the bands disappear, which means that the reduced cytochromes have now been re-oxidized. How does the supposedly inert molecular oxygen bring this about? Keilin's experiments convinced him that a catalyst was necessary, and he was quick to perceive that the properties of Warburg's *Atmungsferment* fitted the requirements of this catalyst. He renamed Warburg's enzyme cytochrome oxidase. Now the rival theories fitted together into one whole. The Thunberg-Wieland reaction reduced the cytochromes; the Warburg reaction oxidized them again. Both reactions were necessary for biological oxidation. And the cytochromes were the connecting link. They turned out to be a combination of a protein with heme, or iron porphyrin—the functional group that Warburg had identified in his enzyme.

The Electron-Transfer System

Keilin drew from all this a new concept of the cellular apparatus responsible for oxidations. He called it the respiratory chain, or the terminal electron-transfer system. The essential feature of the system that converts foodstuffs ultimately to carbon dioxide and water, he said, is the transfer of electrons from the substrates to oxygen. The cytochromes act basically as carriers which shuttle the electrons along. There is a stepwise transfer of electrons through a series of catalysts: Keilin identified them as the dehydrogenases (at the reducing end), the cytochromes and cytochrome oxidase (at the oxidizing end).

Keilin's concept of the electron-transfer system is the foundation stone of all present thinking about biological oxidation. It is interesting that a microscope, a hand spectroscope and a few test tubes were all the equipment he needed to resolve the long, futile polemics on the

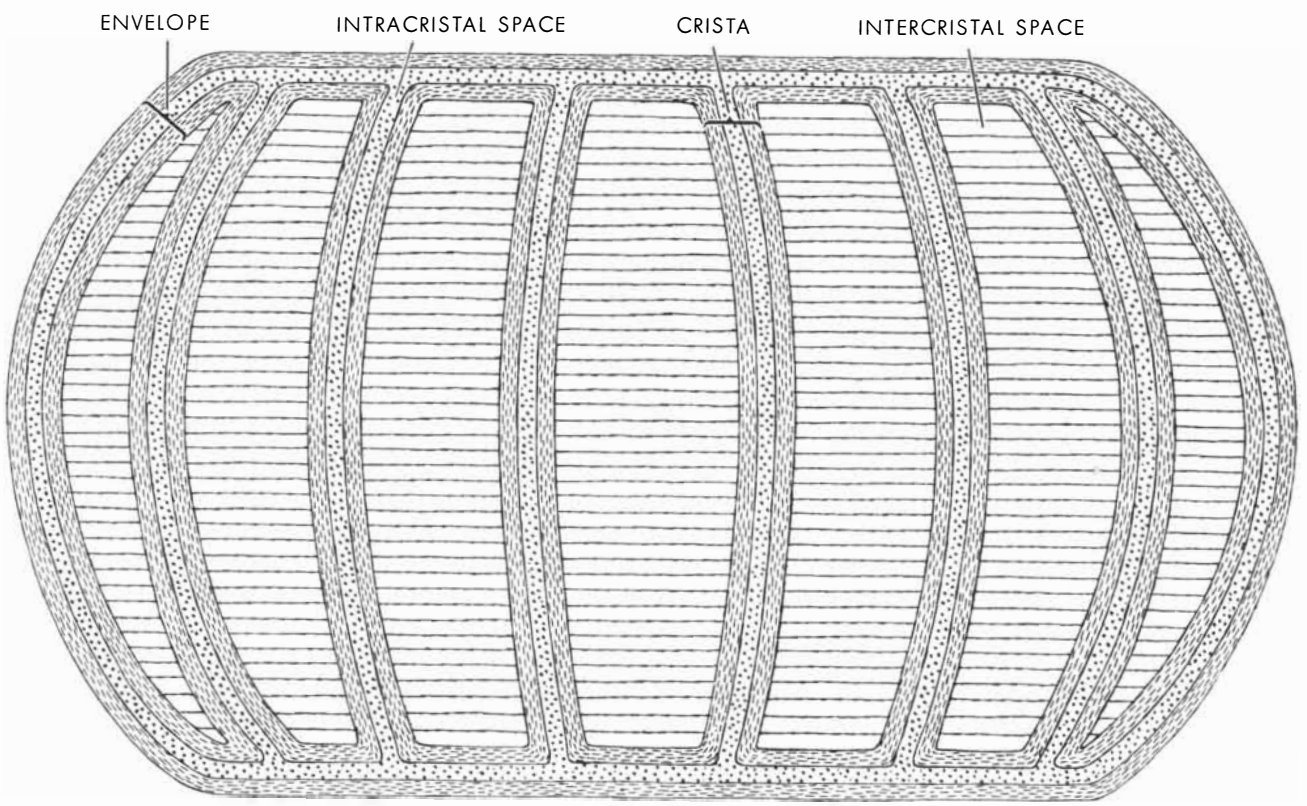
subject and arrive at his enormously fruitful idea. When he had finished, chemists were in a position to seek answers to clear, specific questions. The problem now was to learn exactly what substances were oxidized in the oxidation chain and how the process liberated energy for the work of the body. As often happens in science, the missing items of information were eventually supplied by investigators who had utterly different interests.

The Citric Acid Cycle

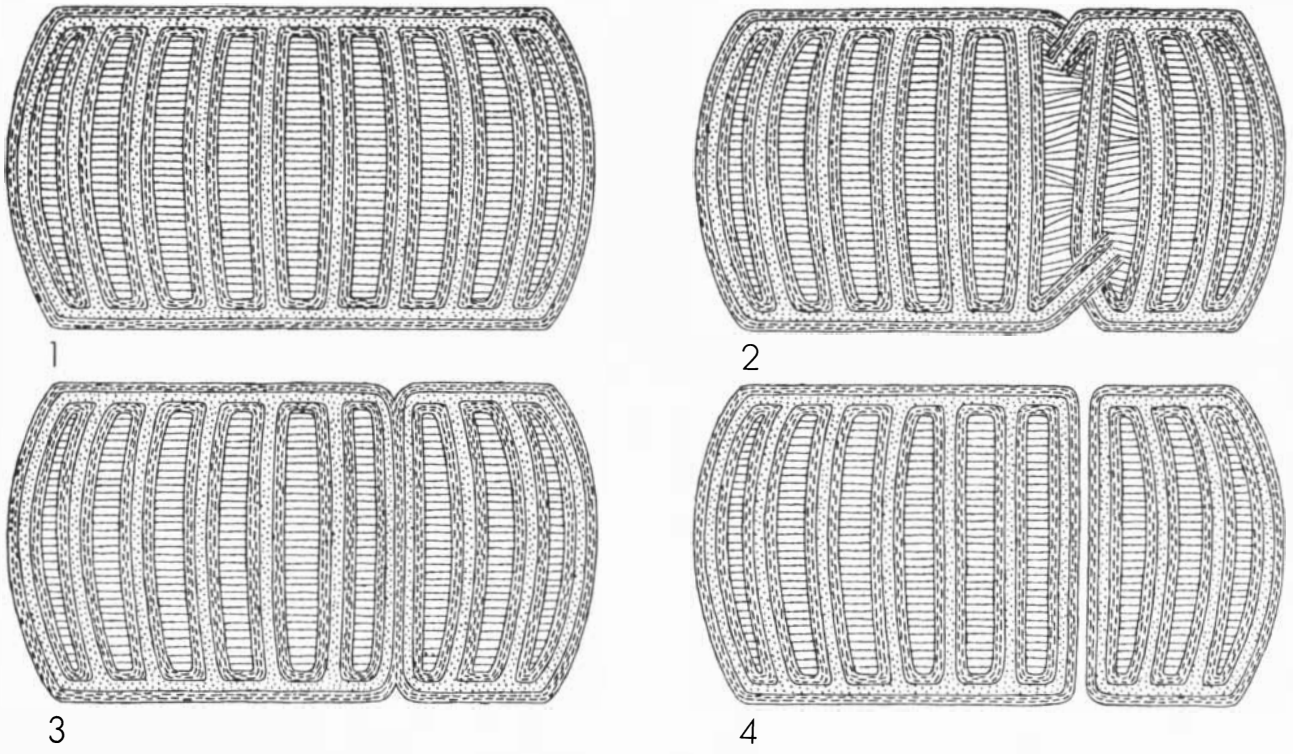
Two discoveries supplied the crucial facts. One was Hans Krebs's finding of the citric acid cycle—a chain of reactions which oxidizes carbohydrates such as sugar to carbon dioxide and water. This cycle is the soul of simplicity [*see diagram on opposite page*]. Sugar in the form of pyruvic acid is first oxidized to a compound (call it No. 1) which in turn combines with oxaloacetic acid to form No. 3. Now four separate oxidations take place in order, and at the end No. 3 is broken down to carbon dioxide and water, leaving oxaloacetic acid behind. That is to say, the complete cycle in effect burns a molecule of pyruvic acid to carbon dioxide and water and at the same time regenerates the combining partner, oxaloacetic acid. Then the process repeats itself: oxaloacetic acid leads another molecule of pyruvic acid to the molecular slaughter. Each time around pyruvic acid is annihilated and oxaloacetic acid is regenerated. It soon became clear that not only sugar but also fats were consumed by way of the citric acid cycle. In short, the citric acid cycle was recognized as the principal energy-yielding process of all cells and organisms which depend upon oxygen.

Meanwhile two workers (in separate laboratories) turned up the other pertinent discovery. V. A. Belitzer in the U.S.S.R. and Herman Kalckar in Denmark learned that the oxidation of various substances (all later found to participate in the citric acid cycle) was coupled with conversion of the compound adenosine diphosphate to adenosine triphosphate (ATP). This phenomenon, called oxidative phosphorylation, goes to the very heart of the problem of energy production, for ATP is the battery that delivers energy for many processes of the body, including the manufacture of key materials, the contraction of muscle, and so on. That the formation of ATP was coupled to electron transport (bonding inorganic phosphate to adenosine diphosphate) was hardly noticed at the time the discovery was reported, but it was destined to rank in importance with the earlier discovery of the citric acid cycle.

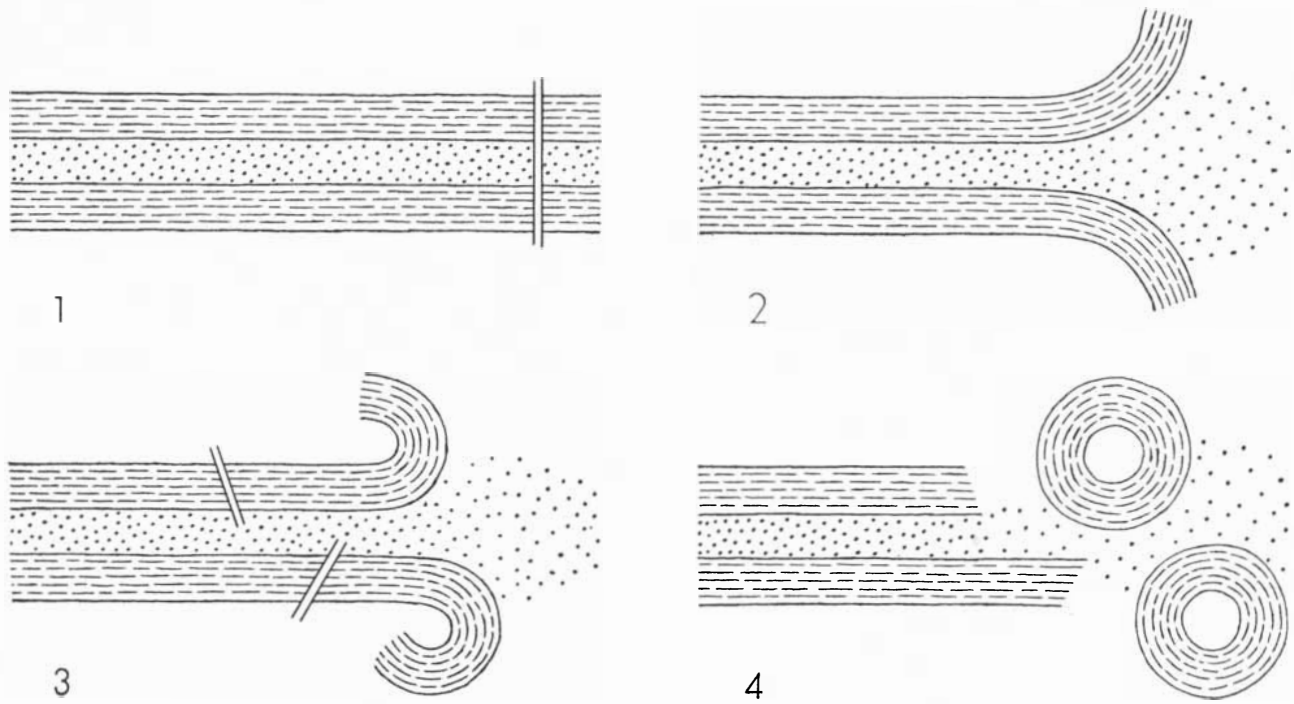
Now came a development which brought together all these separate findings. In 1945 I set out to try to isolate an enzyme which acted to dehydrogenate pyruvic acid. The enzyme had resisted isolation, and all my efforts to extract it from the kidneys of rabbits failed. It was inseparably attached to certain particles in the cell which carried out a whole complex of functions—the citric acid cycle, the oxidation of fatty acids, the transport of electrons, and oxidative phosphorylation. After many grueling months of utterly unsuccessful attempts to separate the dehydrogenase, it dawned upon me that all these functions, including the dehydrogenation, must be wedded together in one giant organized unit—a mosaic of many enzymes [see "Enzymes in Teams," by David E. Green; SCIENTIFIC AMERICAN, September, 1949]. The most remarkable feature of the system was that all of the enzymes and coenzymes necessary for the various functions were packaged in the particle in just the right proportions, and, as far as one could tell, there was no excess



STRUCTURE OF A MITOCHONDRION is shown diagramatically. The outer envelope and the cristae have double walls forming a continuous system. The walls contain the enzymes needed for electron transport, and these enzymes probably occur in a repeating structure within the walls. The enzymes which are involved in the citric acid cycle are apparently in the intracristal space.



DAMAGE TO MITOCHONDRIA which does not alter the function of the particles could be explained by a twisting off of sections of a mitochondrion in such a way that each portion contained intact cristae. Each piece would then be like a miniature mitochondrion.



ELECTRON-TRANSPORT PARTICLES may result when cristae are broken up (1). If intracristal material is lost (2) and the membranes fragment (3), particles form (4) which are capable of transporting electrons but not of conducting oxidative phosphorylation.

baggage. The case for the existence of an organized complex of enzymes—a new kind of unit—seemed overwhelming.

The idea was distasteful, however, to many biochemists; they had just achieved their first intoxicating successes in isolating individual enzymes. They took sharp issue with the experimental evidence for the mosaic concept. But the idea soon received the strongest kind of support, and from an entirely unexpected quarter. Two independent groups—Van Rensselaer Potter and Walter C. Schneider at the University of Wisconsin and Albert L. Lehninger and Eugene P. Kennedy at the University of Chicago—separated out certain known bodies of the cell and found that they could carry out the very reactions which we had assigned to our complex of enzymes. These particles were the mitochondria, the tiny cell bodies now known to house the cell's energy generators [see "Powerhouse of the Cell," by Philip Siekevitz; SCIENTIFIC AMERICAN, July, 1957].

The Mitochondrion

We can regard the mitochondrion as a machine whose function is to generate ATP by the oxidation of pyruvic acid. The fuel for the machine is derived from carbohydrates and fats; the furnace is the citric acid cycle; the main product is ATP, and the by-products are carbon dioxide and water. The same basic mechanism exists in the cells of all organisms that require oxygen—animals, plants and microbes.

So the problem of understanding how the body converts foodstuffs to energy by oxidation resolves itself into the problem of learning the structure and functioning of the mitochondrion. How are the hundred or more enzymes arranged within the mitochondrion? How are they bonded together into one coherent organization? How do the enzymes concerned with the several functions mesh together? How is the transfer of electrons coupled to the formation of ATP? These and other questions are the object of intensive investigations in many laboratories in all parts of the world. A few exciting discoveries have been made.

From photographs of thin sections of mitochondria made with the electron microscope we can draw a rough diagram of the structure of a mitochondrion. It consists of an envelope enclosing a group of structures which are called "cristae" [*see diagram on page 59*]. The material in the envelope and in the cristae is probably identical; at present no distinction can be made between these two parts of the mitochondrion.

Now the mitochondrion can be broken up, by certain techniques, into smaller pieces with the same structure which in effect are miniature mitochondria [*see diagrams at top of opposite page*]. These particles are capable of carrying out all the functions of the parent body. If mitochondria are subjected to strong sonic vibrations, they are pulverized into still smaller pieces. These particles are essentially double-walled fragments of the cristae. They have lost the capacity for citric-acid-cycle oxidations, but retain the functions of electron transport and oxidative phosphorylation.

With more brutal fragmentation procedures we can break down the mitochondrion to even simpler particles consisting only of an envelope enclosing a space. Apparently, fragmented sections of the original envelope curl up to form closed bubbles [*see diagrams at bottom of opposite page*]. This particle can carry out neither the citric acid cycle nor oxidative phosphorylation. But it retains the function of transporting electrons: we call it the electron-transport particle.

The evidence thus suggests that the mitrochondrion is a giant polymer made up of a certain repeating unit which forms its internal and external membranes. This unit contains the apparatus for transferring electrons and for oxidative phosphorylation. And in the space within the membranes of both the outer envelope and the internal cristae are the enzymes that carry out the oxidations of the citric acid cycle. In the intact mitochondrion these enzymes lie close to the enzymes of the electron-transfer chain located in the many membrane layers forming the structure of the system.

We can break down the electron-transport particle (the repeating unit) into smaller and smaller fragments, and eventually we should be able to learn its composition and the arrangement of its components, just as chemists have worked out the structure of some proteins. Many of the molecules making up the electron-transfer chain have already been identified. They are all proteins, and each contains some highly characteristic functional group. Thus two contain a form of the vitamin riboflavin; these catalyze the oxidation of succinic acid and dihydropyridine nucleotide. Four contain iron porphyrin as the functional group: these of course are the cytochromes. At least two proteins laden with fat—lipoproteins—have been fished out of the fragments.

There is every reason to believe that all the enzymes and other components of the electron-transfer chain are arranged in a particular order and pattern,

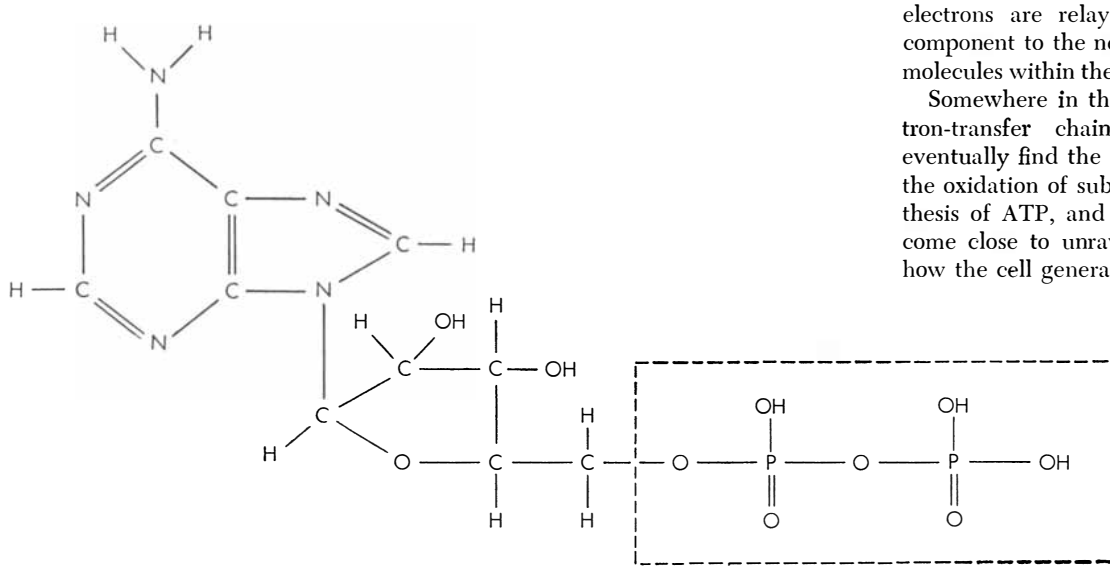
and that they are combined in certain precise proportions—like a giant molecule. The pattern and composition are yet to be determined. But something has been learned about the cement that bonds the components together. The substances that are effective in taking the particle apart (dissecting the molecule) are all chemicals which react with fatty materials: they are alcohols, bile acids, fatty detergents. Thus it appears that the cement is a combination of fat with protein—that is, lipoprotein. Lipoproteins have an unusual property which may explain why nature has selected them to act in this binding capacity. They can bind or react equally well with molecules soluble in water and those soluble in fat.

The chemical investigation of fatty substances contained in the electron-transfer particle has opened a Pandora's box of exotic compounds. They include all the so-called essential fatty acids of the cell, vitamins E and K and coenzyme Q, a new quinone hitherto unrecognized; there are strong suspicions that most of the known and possibly some unknown fat-soluble vitamins will be found to be involved one way or another in the electron-transfer chain.

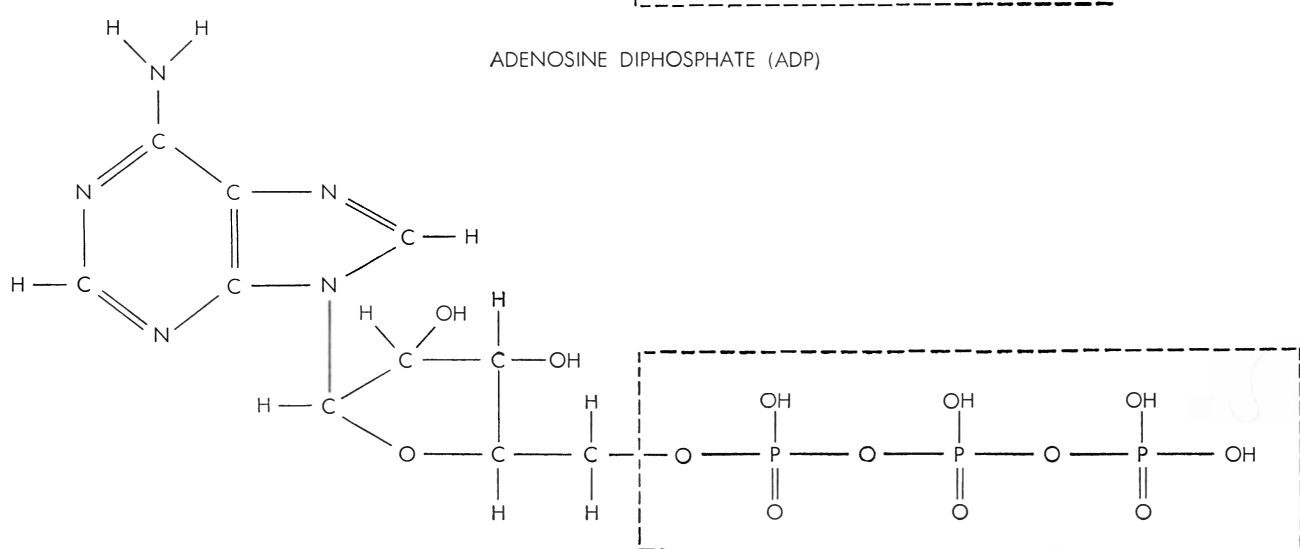
The Transfer of Electrons

As to how the electrons are transported, there is still no really satisfactory answer. Britton Chance of the University of Pennsylvania has suggested that they may be passed along via collisions between adjacent molecules in the electron-transfer chain, but it is difficult to see how the molecules can move about in a rigid structure in which they are all bonded to one another. Perhaps the electrons are relayed from one fixed component to the next by small, mobile molecules within the lipoprotein cement.

Somewhere in the maze of the electron-transfer chain biochemists will eventually find the connection between the oxidation of substrates and the synthesis of ATP, and with that they will come close to unraveling the secret of how the cell generates energy.



ADENOSINE DIPHOSPHATE (ADP)



ADENOSINE TRIPHOSPHATE (ATP)

(PYRUVIC ACID)

$$CH_3COCOOH + 5O + 15\ ADP + 15H_3PO_4 \longrightarrow 3CO_2 + 17H_2O + 15\ ATP$$

ADENOSINE TRIPHOSPHATE (ATP) contains three phosphate groups (*broken lines*), while adenosine diphosphate (ADP) has two of the energy-rich groups. Conversion of ADP to ATP (*equation at bottom*) requires pyruvic acid, oxygen and phosphoric acid.

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*MARLEX is a trademark for Phillips family of olefin polymers.

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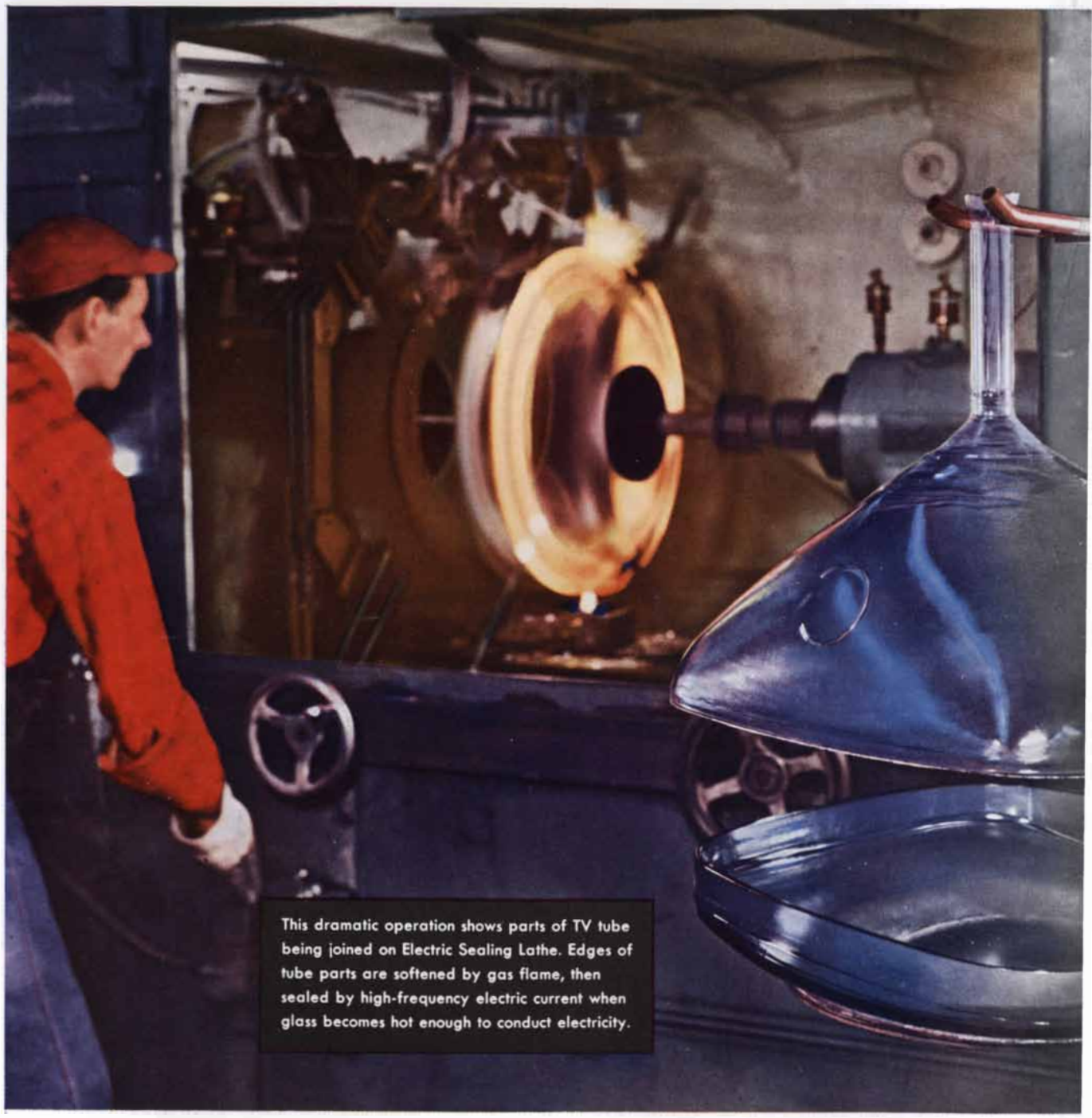
Correct Lubrication in Action...

How Mobil Saved



This dramatic operation shows parts of TV tube being joined on Electric Sealing Lathe. Edges of tube parts are softened by gas flame, then sealed by high-frequency electric current when glass becomes hot enough to conduct electricity.

Mobil

Complete Engineering Program
Proved Petroleum Products

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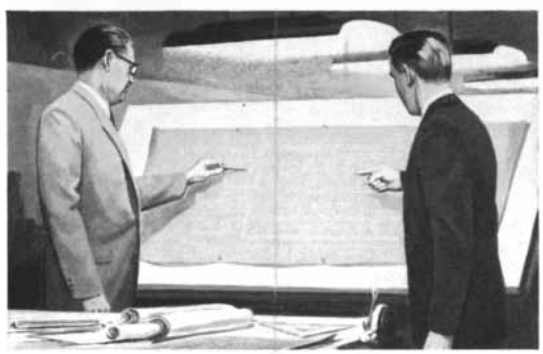
Corning Glass $14,880

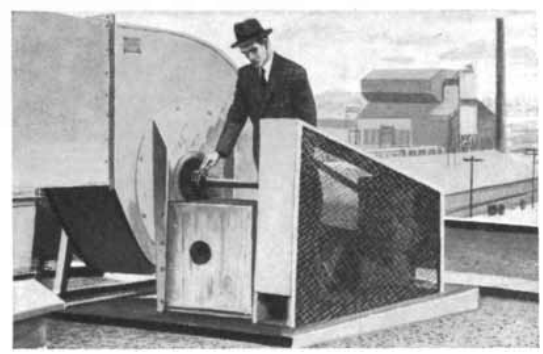
Since making the bulb for Edison's lamp, Corning Glass Works has continually pioneered in the development of new types of glass. At the same time Corning has developed intricate machines and manufacturing methods that enable it to produce the most precise glass items at production line pace.

Mobil has worked with this company for many years. It has met the challenge of demanding and often unique lubrication requirements with products and service so effective that they have resulted in constant and significant savings. Corning's records show that, in 1957 alone, savings made through Mobil Correct Lubrication amount to over $14,000.

Some of these savings are briefly documented below. All of them are the result of Mobil working hand-in-hand with Corning personnel . . . training them in maintenance methods . . . studying production problems, making lubrication studies . . . using Mobil research and laboratory facilities to cut costs, keep pace with Corning's needs. Why not find out how Mobil *Correct Lubrication* can reduce maintenance costs, increase profits in *your* plant?

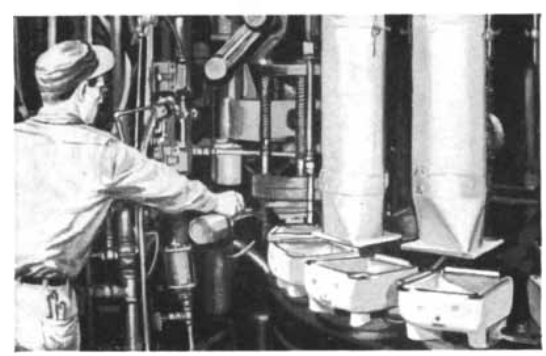


Lubrication study increases maintenance efficiency—Mobil engineers working with maintenance supervisors made complete study of machine lubrication requirements and application . . . even blueprinted oiler routes down to last detail . . . saved maximum time and money for Corning.



Outdoor bearing replacement eliminated—Air circulating system power units located on plant roof are subjected to abnormal corrosion and temperature extremes. Mobil maintenance recommendation cut servicing time by 300 hours . . . eliminated bearing replacements . . . saved $920 a year.

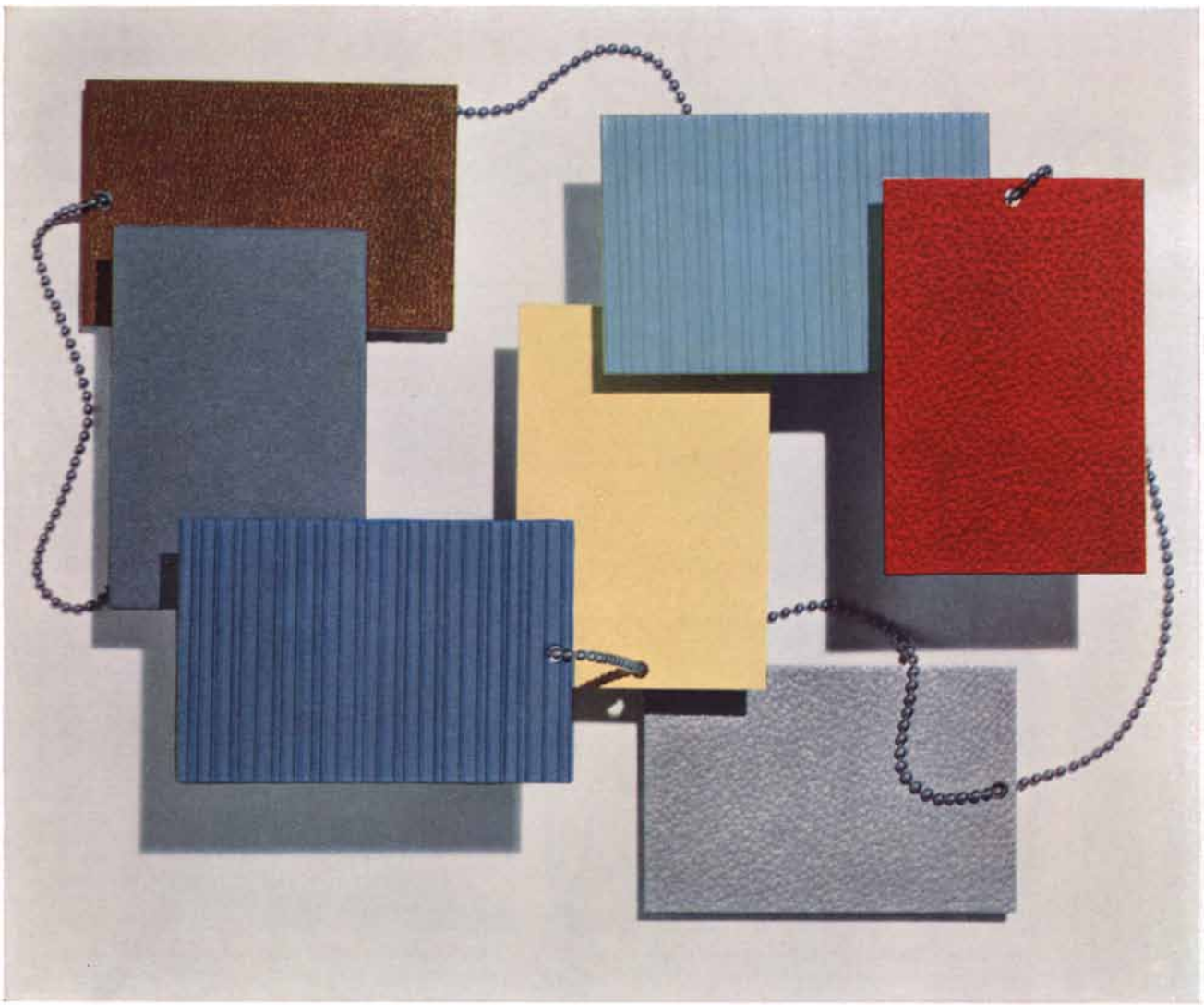
$2,785 saved on lift-truck maintenance—Prior to Mobil recommendation, Corning's gasoline-powered lift-trucks were overhauled every 4 months. Use of *Mobiloil Special* lengthened overhaul period to 12 months, cut oil consumption in half, reduced maintenance time by 144 hours a year.



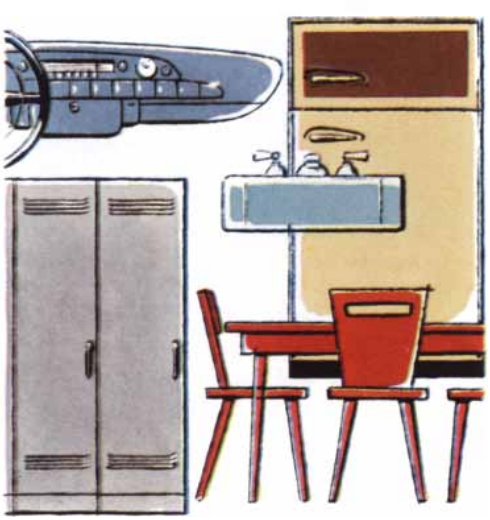
Shear spray lubricant saves $11,175—In automatic glass-forming machines, steel shears that cut molten glass were pitting, rusting, leaving excessive "shear" marks on molded material. Mobil introduced product, about 1/10 cost of previous lubricant, to cut reject rate, reduce maintenance and parts replacement.

Correct Lubrication

Another reason You're Miles Ahead with Mobil!



New USS steels with color and texture will brighten the look of tomorrow



It is steel, but to the eye and to the touch it does not look nor feel like steel. Its surface can be textured in many new designs, or made to look like other materials if desired. And it is as pleasant to touch as it is to look at.

It is steel with a colorful and extremely durable skin of vinyl plastic. The skin, applied at the steel mill as a liquid, is cured on the surface as an integral part of the steel sheet. It is impervious to moisture and has excellent scuff and abrasion resistance. Because the skin is so tough, the sheet can be fabricated in essentially the same manner as any other steel sheet.

Development work on these new USS steels, and methods of producing them economically, are being perfected at U. S. Steel's Research Center. They are just another example of the new ideas you can expect from U. S. Steel's extensive research and development programs—ideas that will be helping *you* in the future, both at work and during your leisure hours. United States Steel Corporation, 525 William Penn Place, Pittsburgh 30, Pa.

USS TRADEMARK **United States Steel**

PREDATORY FUNGI

Plants which trap insects are familiar in the folklore of biology. Less well-known, but more important in the balance of nature, are certain molds which ensnare and consume small animals in the soil

by Joseph J. Maio

Unless man succeeds in duplicating the process of photosynthesis, it appears that animals will always have to feed upon plants. But the plant world exacts its retribution. A number of plants have turned the tables on the animal kingdom, reversing the roles of predator and prey. These are the plant carnivores—plants that trap and consume living animals. Most famous are the pitcher plant, with its reservoir of digestive fluid in which to drown hapless insects; the sundew, with its flypaper-like leaves; and Venus's-flytrap, with its snapping jaws. But there are other carnivorous plants of larger significance in the balance of nature. We ought to know them better because they are to be found in great profusion and variety in any pinch of forest soil or garden compost. They are microscopic in size, but just as deadly to their animal prey as the sundew or Venus's-flytrap.

These tiny predators are members of the large group of fungi we call molds. They grow in richly branching networks of filaments visible to the naked eye as hairy or velvety mats. Molds do not engage in photosynthesis. Like most bacteria, they lack chlorophyll and so must

NEMATODE WORM IS TRAPPED by the adhesive fungus *Trichothecium cystosporium* in this photomicrograph by the British biologist C. L. Duddington. The entangling network of the fungus is at right; the body of the worm extends to the left. The oval object below the body of the worm is one of the spores by which the fungus reproduces. At lower right are the remains of another worm.

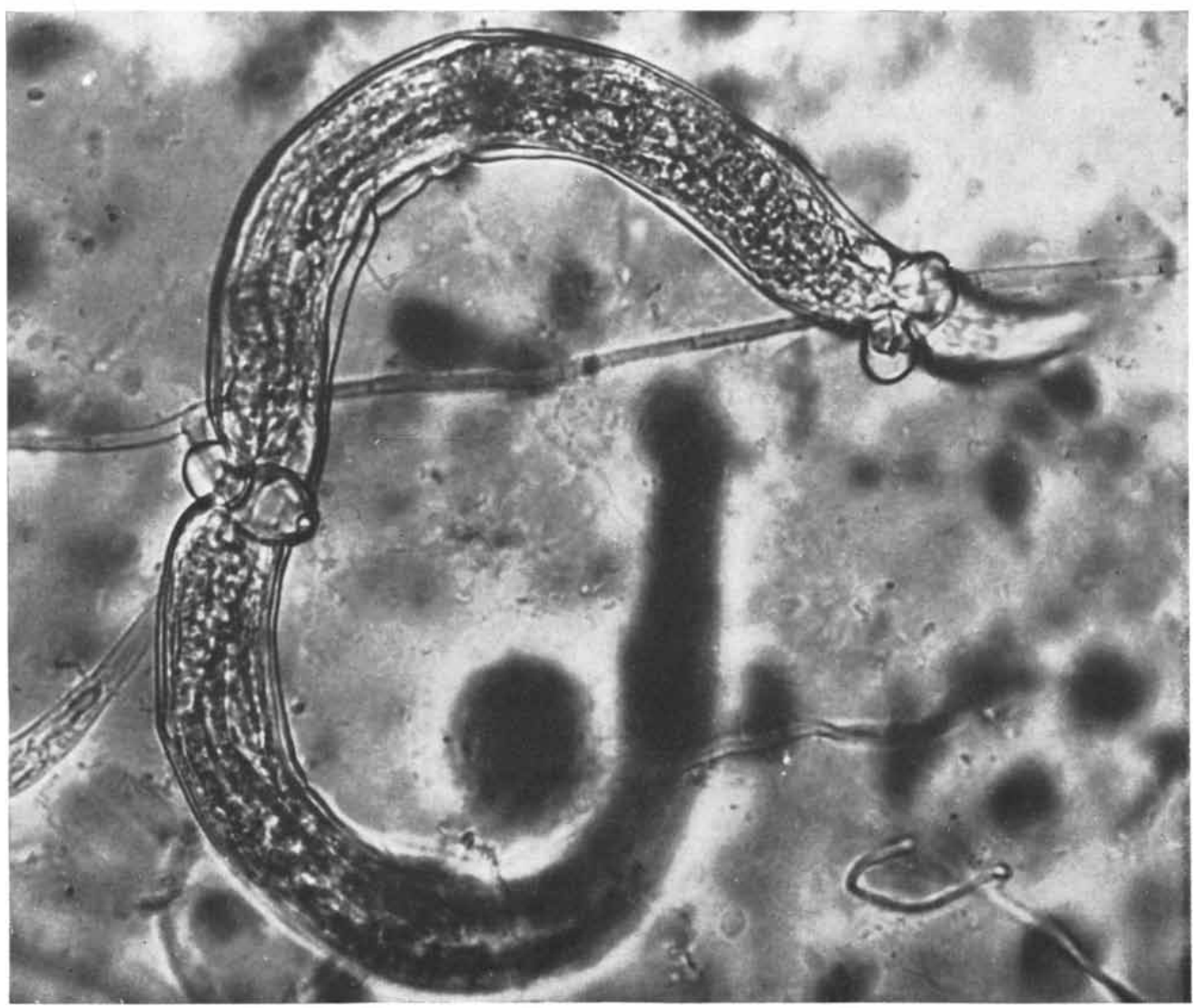
derive their food from other plants and from animals. Molds have long been familiar as scavengers of dead organisms, promoters of the process of decay. It was not until 1888 that a German mycologist, named Friedrich Wilhelm Zopf, beheld molds in the act of trapping and killing live animals—in this case the larvae of a tiny worm, the wheat-cockle nematode.

The nematodes (eelworms, hookworms and their like) are not the only prey of these animal-eating plants. Their victims run the gamut from the comparatively formidable nematodes down to small crustaceans, rotifers and the lowly amoeba. Charles Drechsler of the U. S. Department of Agriculture, a student of the subject for some 25 years, has identified a large number of carnivorous molds and matched them to their prey. Many are adapted to killing only one species of animal, and some are equipped with traps and snares which are marvels of genetic resourcefulness. How they evolved their predatory habits and organs remains an evolutionary mystery. These molds belong to quite different species and have in common only their behavior and some similarities of trapping technique. They present a challenging subject for investigation which may throw light on some fundamental questions in biology and may lead also to new methods for control of a number of crop-killing nematodes.

The simplest of the molds have no special organs with which to ensnare their victims. Their filaments, however, secrete a sticky substance which holds fast any small creature that has the misfortune to come in contact with it. The mold then injects daughter filaments into the body cavity of the victim and digests its contents. Most of the animals caught in this way are rhizopods—sluggish amoebae encased in minute hard shells. Sometimes, however, the big, vigorous soil nematodes are trapped by this elementary means.

More specialized is an unusual water mold, of the genus *Sommerstorffia*, which catches rotifers, its actively swimming prey, with little sticky pegs that branch from its filaments. When a rotifer, browsing among the algae on which this mold grows, takes one of these pegs in its ciliated mouth, it finds itself impaled like a fish on a hook.

Some molds do their trapping in the spore stage. The parent mold produces staggering numbers of sticky spores. When a spore is swallowed by or sticks



TWO CONSTRICTING RINGS of the fungus *Dactylaria gracilis* grasp another nematode in this photomicrograph by Duddington. The nematode was first caught by the head (*upper right*), and then flicked its body into another ring (*left center*). The rings deeply constrict the body of the worm. The horizontal line above the middle of the picture is a filament to which the rings are attached.

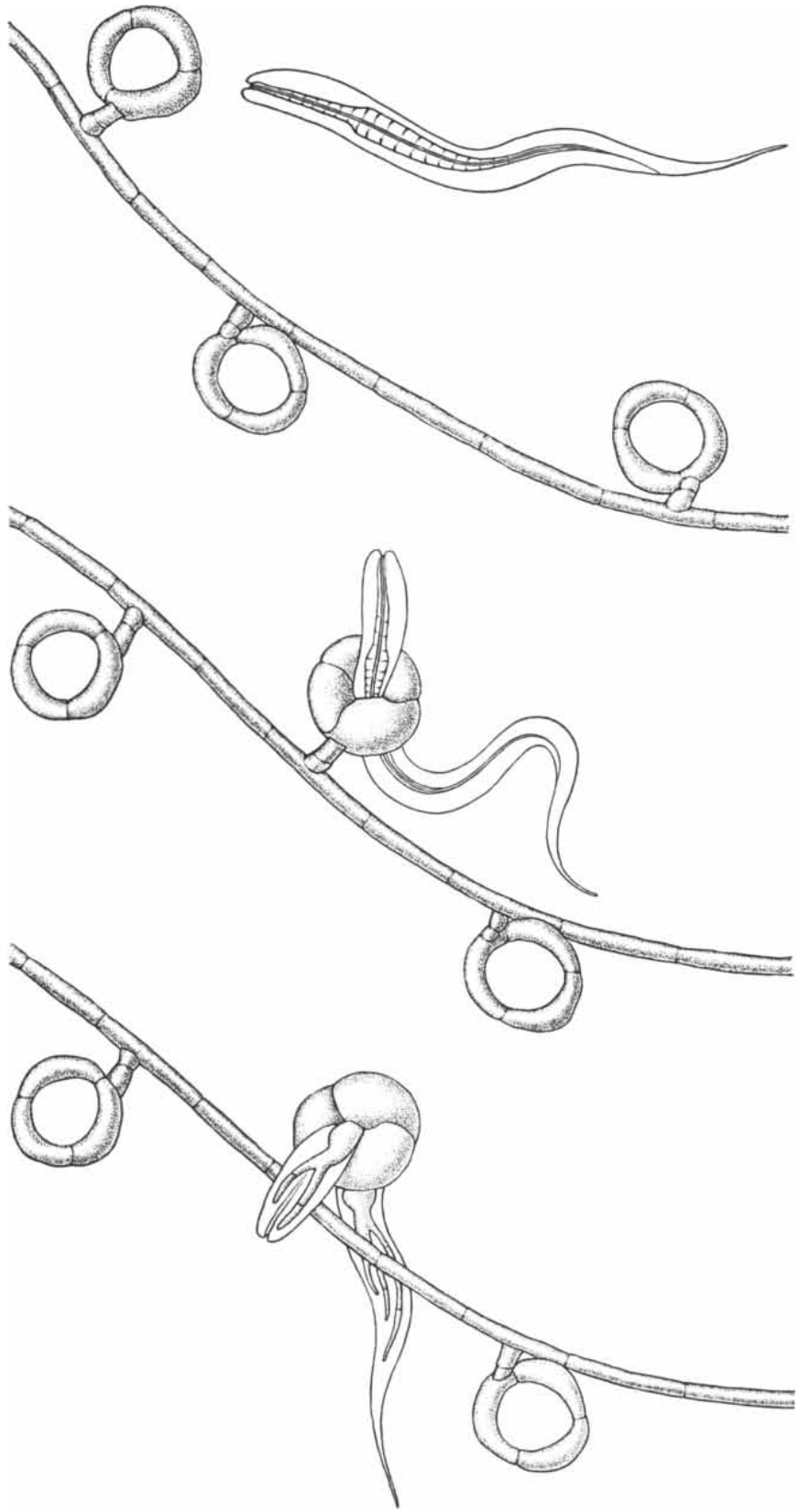
to a passing amoeba or nematode, it germinates in the body of its luckless host and sends forth from the shriveled corpse new filaments and new spores to intercept other victims.

The most remarkable of all killer molds are found among the so-called *Fungi Imperfecti*, or completely asexual fungi. The advanced specialization of these molds is particularly interesting because they are not killers by obligation but can live quite well on decaying organic matter when nematodes, their animal victims, are not available. If nematodes are present, these molds immediately develop highly specialized structures which re-adapt them to a carnivorous way of life. They will do so even if they are merely wetted with water in which nematodes have lived.

One of these molds is *Arthrobotrys oligospora*, the nematode-catching fungus that was first studied by Zopf. When nematodes are available, it develops networks of loops, fused together to form an elaborate nematode trap. An extremely sticky fluid secreted by the mold seems to play an important role in capturing the nematode, which need not even enter the network in order to be held fast. The fluid is so sticky that one-point contact with the network frequently is enough to doom the nematode. In its frenzied struggles to escape, the worm only becomes further entangled in the loops, and finally, after a few hours of exertion, weakens and dies. The destruction these molds can cause in a laboratory culture of nematodes is appalling, particularly from the point of view of the nematode!

Two French biologists, Jean Comandon and Pierre de Fonbrune, have made motion pictures which show that the fungus's secretion of this adhesive substance is accompanied by intense activity in its cells. Material in the cytoplasm of the cell streams toward the point of contact with the worm. The mold may be bringing up reserves of adhesive and digestive enzymes to subdue the nematode; it may also secrete a narcotic or an intoxicant to speed the process.

Even more artfully contrived are the "rabbit snares" employed by some molds. First fully described by Charles Drechsler, these are rings of filament which are attached by short branches to the main filaments, hundreds of them growing on one mold plant. The rings are always formed by three cells and have an inside diameter just about equal to the thickness of a nematode. When a nematode, in its blind wanderings



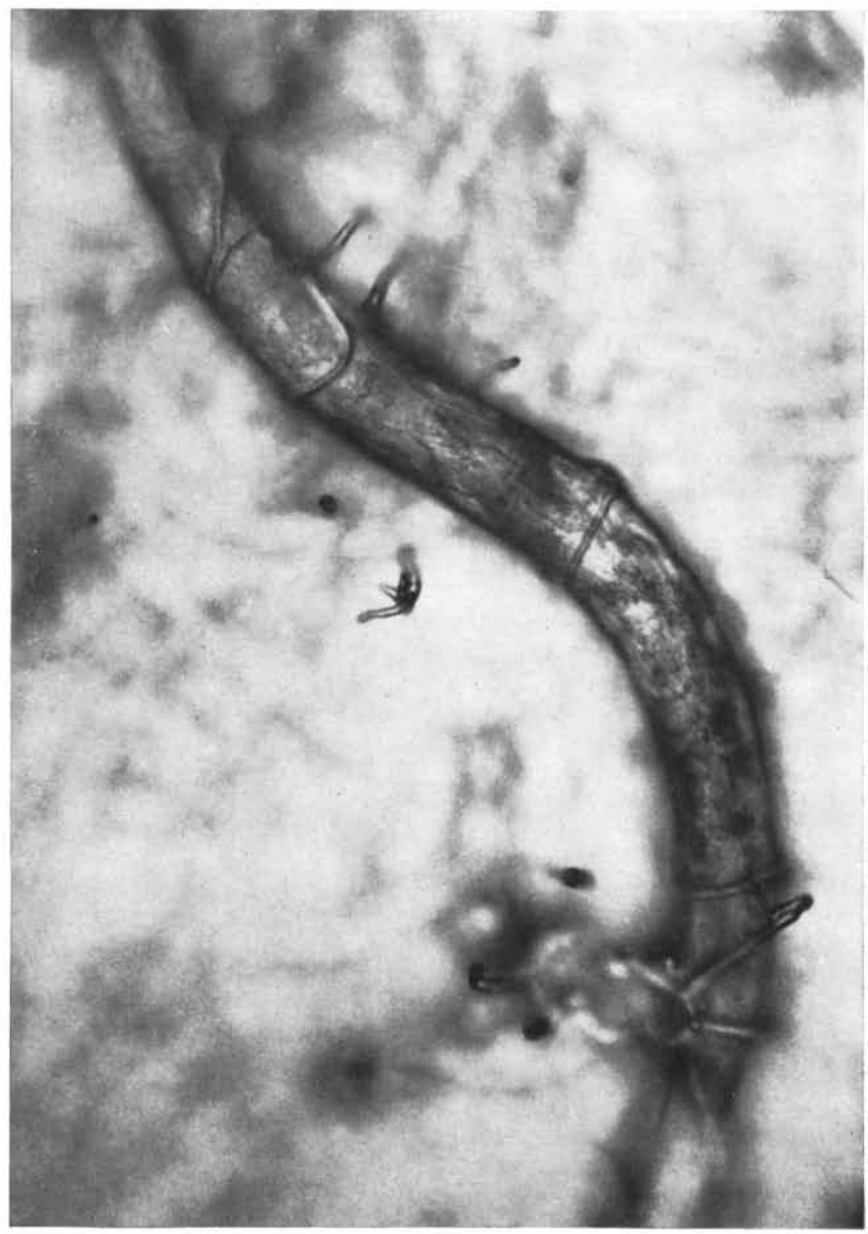
CAPTURE AND CONSUMPTION of a nematode worm by a fungus of the constricting-ring type is depicted in this series of three drawings. At the top the worm approaches a ring attached to a filament of the fungus. In middle the three cells of one ring have expanded to trap the worm. At bottom filaments have branched out of the fungus to digest the worm.

through the soil, has the ill luck to stick its head into one of these rings, the three cells suddenly inflate like a pneumatic tire, gripping it in a stranglehold from which there is no escape.

The rings respond almost instantaneously to the presence of a nematode; in less than one tenth of a second the three cells expand to two or three times their former volume, obliterating the opening of the ring. It is difficult to understand how the delicate filaments can hold the powerfully thrashing worm in so unyielding a grip. Occasionally a muscular worm does escape by breaking the ring off its stalk. But this victory only postpones the inevitable. The ring hangs on like a deadly collar and ultimately generates filaments which invade the worm, kill it and consume it.

We are not yet sure what cellular mechanisms activate these deadly nooses. We know that in the case of the constricting ring of one mold the activating stimulus is the sliding touch of the nematode as it enters the ring. A nematode that touches the outer surface of the ring will not trigger the mechanism. But if the worm passes inside the ring, its doom is certain. This mold, then, exhibits a sharply localized "paratonic" or touch response like that of the Venus's-flytrap.

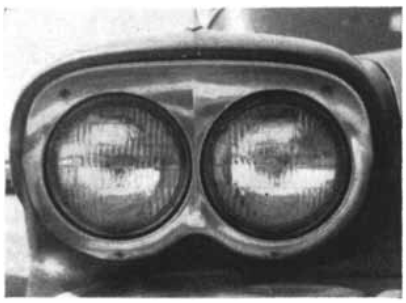
Perhaps the inflation of the cells is caused by a change in osmotic pressure, resulting in an intake of water either from the environment or from neighbor-



NEMATODE IS INVADED by filaments of a fungus which has trapped it. This photomicrograph was made by David E. Pramer of the New Jersey Agricultural Experiment Station.

THIS IS GLASS

a bulletin of practical new ideas from Corning



On the beam

It looks as if the four-eyed automobile is here to stay. The reason?

The old style 7-inch lamp had two filaments and was a *compromise* design since *neither* high nor low beam operated at peak efficiency.

New style lamps are smaller ($5\frac{3}{4}$″) and are mounted two-to-the-fender. The outer light is a passing (low) beam, aimed just below and to the right of dead ahead. It also has an auxiliary high beam which is used with the high beam of the inner lamp. Net result: *More light* where you can use it . . . on the road and free of glare.

Though the lenses used in these lamps don't look complex, each is precision-made from heat-resistant glass. Pressed into the surface of every lens are some 100 prisms, each *held to* ±.1° in production.

There's also a glass parabolic reflector for each lens—the combination being a neat example of *mass* production of *precision* glass products. Also involved: Hermetic sealing of glass and metal parts.

Corning currently produces components for some 250 different sealed beam assemblies, with sizes ranging from 2 to 8 inches in diameter.

You may not need headlights, but if you have a problem involving light control, Corning may have the answer. And don't overlook the savings you can realize from mass production of precision parts. We'd like a chance to solve some of your problems.

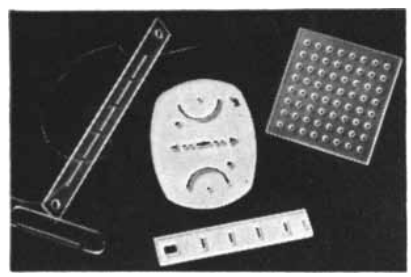
Wee

This 25 ml conical micro flask measures 75mm. in height. It has two necks, both ground to what is called a "standard taper," very accurate and smooth.

Such petite and precise PYREX brand glassware is fashioned from Corning's glass No. 7740. This glass is eminently practical in labs (and in many tough industrial applications) because it stands up to most acids and alkalies, doesn't cloud, even with distilled water. And it's bothered not a bit by high temperatures or thermal changes.

This microware flask is one of the more than 9,000 items (standard and custom) we make for labs. Much of it is highly intricate stuff that is hand-made by skilled lampworkers. The whole line is neatly detailed in a new, 358 page catalog, LG-1. If you're in a lab and haven't received your copy, send for one.

Also ask for Bulletin B-83, "Properties of Selected Commercial Glasses." All about 7740 and many other glasses; very good to have on file.



360,000 holes per square inch!

No problem at all, putting that many holes in that space, when we use FOTOFORM®, a glass that's "machined" by chemistry.

We start with a photosensitive glass (one of a number of very *special* types from Corning). Using a photographic negative of the pattern you want and an ultraviolet source, we make a contact print on the glass. Then heat to convert exposed areas into etchable glass. Next, treat with acid to dissolve out the etchable image, leaving the pattern you want. Further processing converts to the form of FOTOFORM best suited to your final application.

What's FOTOFORM good for? Making *ultra*-precise mechanical and electrical parts.

Such as? Fine mesh (600 line) screens, brush holders for digital converters, various kinds of substrates, printed circuits, attenuator plates, dielectric spacers . . . and lots more.

Experience so far indicates that FOTOFORM makes feasible patterns and parts that would be *impossible* or *impractical* by other methods.

Added incentive: There's *no* need for costly dies and jigs and you *eliminate* grinding, cutting, and drilling.

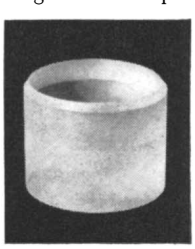
FOTOFORM is non-porous, dimensionally stable, free from internal flaws and voids, able to operate continuously at 500°C, and has zero moisture absorption.

Easily applied to small runs or mass production and well-suited to automation, it looks like a real contribution to many fields, especially electronics.

For more facts and figures ask for "New Developments in Corning FOTOFORM Glass." Check the coupon.

Attention photon counters

Now available from Corning is a new, high-lead-content glass for use in Cerenkov counters. A crystal clear glass with a specific gravity of 4.63, it permits better energy resolution than any glass currently used with this type of spectrometer.



Designated code 9766, it has an index of refraction of 1.724 and a transmittance of 82.8% at 400 Ä for 10 radiation lengths. Send for detailed fact sheets or other data you desire. ***Corning can do almost anything with glass.***

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ing cells. Or perhaps it results from changes in the colloidal structure of the cell protoplasm. There is a recent report from England that the constricting rings of one species react to acetylcholine—the substance associated with the transmission of impulses across synapses in the animal nervous system!

Some species of molds prey upon root eelworms that infest cereal crops, potatoes and pineapples. This has inspired experiments to use these fungi to control the pests. In one early experiment, conducted in Hawaii by M. B. Linford of the University of Illinois and his associates, a mulch of chopped pineapple tops was added to soil known to harbor the pineapple root-knot eelworm. This mulch produced an increase in the numbers of harmless, free-wandering nematodes which thrive in rich soil. The presence of these decay nematodes stimulated molds in the soil to develop nematode traps, which caught the eelworms as well as the harmless species. A recent experiment in England gives similar promise that the molds may be effective against the cereal root eelworm. Plants protected by stimulated molds showed slight damage compared to the eelworm-ravaged control plants.

Investigators in France have reported an experiment which suggests that molds may be used to control nematode parasites of animals as well as those of plants. Two sheep pens were heavily infested with larvae of a hookworm, closely related to the hookworms of man, which causes severe pulmonary and intestinal damage to sheep. One of the pens was sprinkled with the spores of three molds that employ snares or sticky nets to trap nematodes. Healthy lambs were placed in both pens. After 35 days of exposure the lambs in the pen inoculated with the molds were found free of infection, while those in the control pen showed signs of infestation with the worm.

The carnivorous molds offer many possibilities for future investigation. One subject that needs to be explored is their role in the complex biology of the soil. We would also like to know more about the physiological mechanism that underlies the extraordinary behavior of the nematode "snares." The results of experiments on mold control of nematodes are already encouraging. They suggest that one day these peculiar little plants may perform an even more important role in agriculture than they played in nature, silently and unobtrusively, throughout the millennia before their discovery.

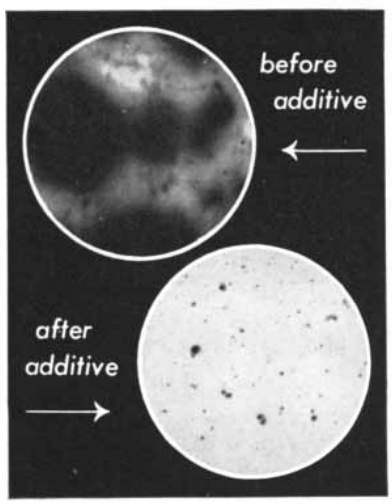
MASTERING THE MOLECULE...WITH ELECTRON MICROSCOPY

Electron Microscope helps New York Central save $2½ millions a year on fuel

Using an RCA Electron Microscope, scientists at the New York Central's new Technical Research Center in Cleveland studied the physical make-up of a refinery by-product that could never before be used in diesels. They have announced that, by means of an additive, certain non-combustible particles could be made to burn—so the fuel would deliver full power. This new type of fuel provides more horsepower per gallon than ordinary diesel oil. Not only that . . . it's a penny per gallon cheaper. With such savings the Central's fuel bill can be reduced by about $2,500,000 a year!

Other research areas opened up by the Electron Microscope include the study of metals and their structures; metal decomposition by friction; greases to withstand severe operating conditions and reduce wear; coatings and chemicals.

Electron microscopy is of major importance in every field of research and development in which such physical characteristics of matter as particle size, shape, distribution and structure must be considered. With its high resolving power and the ability to produce direct image magnifications up to 200,000X the RCA Electron Microscope is opening new avenues of achievement throughout science and industry. A convenient grouping of controls and the automating of many operations contribute to the extremely high efficiency of RCA Electron Microscopes. Installation supervision and contract service are available through the RCA Service Company.



Electron micrographs of refinery by-product

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Write for full particulars about the RCA Electron Microscope.
RCA, Dept. H-111, Building 15-1, Camden, N.J.
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RADIO CORPORATION of AMERICA

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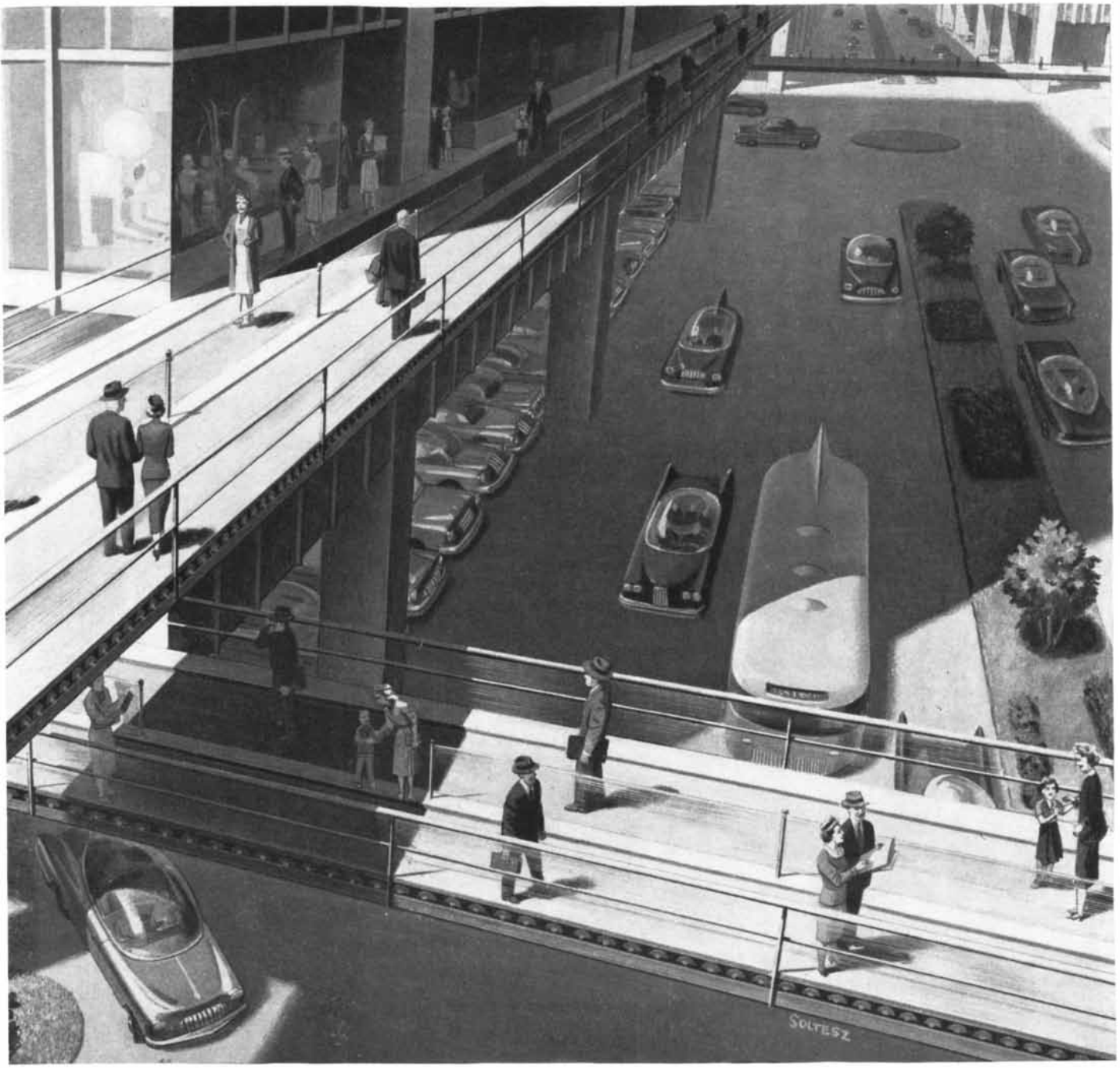
TOMORROW'S MOBILE ELEVATED SIDEWALKS

. . . reinforced with Du Pont industrial fibers

The problem of moving tons of ore for tens of miles has been solved by the use of tremendously strong conveyor belts made of rubber reinforced with Du Pont high tenacity rayon. Well within the capabilities of such belts are elevated transportation systems for pedestrian traffic.

As demands on materials grow, engineers turn increasingly to strong, durable fibers for reinforcing their products. Du Pont fibers can be used to strengthen rigid materials such as plastics and flexible materials such as rubbers and other elastomers. They are often indispensable in attaining needed shock resistance, tensile strength, flex strength. These fibers can improve the electrical insulating properties of the embedding material as well as its resistance to heat and chemicals.

For example, reinforced air bellows for new automobile suspension systems are made possible by the strength and flex resistance of Du Pont nylon fibers. For guided missiles, critical electrical parts such as terminal boards and switches may be molded of a high-pressure laminating material reinforced with *Orlon** acrylic fiber. Aircraft bearings are based on a "self-lubricating" woven liner made with *Teflon** TFE-fluorocarbon fibers. Reinforcing blankets of *Dacron** polyester fiber are employed in molding heat-sterilizable surgical trays and bowls that resist abrasion, stains and acids. Fibers are available in the form of woven cloth, non-woven mat and



loose fibers . . . or pre-mixed in special molding compounds. Their properties can be engineered to the end use.

Chances are that Du Pont fibers can make an important contribution to one of your products. Du Pont's experience, testing and research activities offer you an authoritative source of assistance. Let us help you with your next materials problem.

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BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY*

WRITE FOR YOUR COPY

The 80 pages of "Du Pont Fibers in Industry" are edited especially for the engineer and designer. The properties of Du Pont nylon, "Dacron", "Orlon", "Teflon" and *Super Cordura** high tenacity rayon are described in detail. Technical and performance data are presented for most present-day industrial fiber applications. Write: E. I. du Pont de Nemours & Co. (Inc.), Textile Fibers Dept., 5518-C Nemours Bldg., Wilmington 98, Delaware.

DU PONT FIBERS FOR INDUSTRY

STONE AGE CAMP SITE was excavated beside the Kalambo River above Kalambo Falls. Actually the excavators dug down through several camp sites, the earliest of which has been laid bare in the foreground. At lower left is the partly burned trunk of a tree.

THREE SUCCESSIVE CAMP SITES were revealed by this excavation near Kalambo Falls. In the foreground is an Early Stone Age site strewn with tools. Two feet above it, as indicated by the vertical stick, is another site. A Middle Stone Age site is a foot higher.

EARLY MAN IN AFRICA

In recent years the Dark Continent has yielded the bones of man-apes and the oldest known human tools. A general account of these finds, with special reference to the author's excavations at Kalambo Falls

by J. Desmond Clark

Was Africa the birthplace of the human species? Archaeologists looked almost everywhere else before they turned to the "dark continent." Now that they have begun an active search for evidences of the origin of man in Africa, their efforts, particularly since World War II, have been richly rewarded. To the copious finds of bones of the Australopithecines, the South African "ape-men" who may have been contemporaries or possibly even ancestors of the earliest men, the diggers in Africa have recently added many other important discoveries. They have turned up the earliest ape found anywhere in the world. They have discovered what look like the oldest stone tools made by man or a manlike creature. And they have unearthed some remarkable sequences of deposits which show the development of man's early tools from crude pebble-choppers to the polished hand-axes of the Middle Stone Age.

Before I describe our own recent finds at the Kalambo Falls in Northern Rhodesia, let me review briefly what Africa has yielded so far about early man and his possible ancestors. The best place to start is with the Australopithecines, whose chief investigators have been Raymond A. Dart, the late Robert Broom and his successor J. T. Robinson [see "The Ape-Men," by Robert Broom; SCIENTIFIC AMERICAN, November, 1949]. The ape-men were about four and a half feet tall, walked upright and, according to the anatomist Sir Wilfred Le Gros Clark, should be classed among the relatives of man, on the basis of their teeth. How close were they to man? Debates on this question have hinged mainly on conflicting evidence as to whether or not the ape-men used tools.

The Australopithecines lived about half a million years ago, and pebble tools of about the same age have been found along African rivers. (Pebble tools were stones with one face chipped so that they could be used for chopping or scraping.) Unfortunately it has been difficult to link the ape-men to the tools. The ape-men's bones have been found only in caves, whereas the tools generally have turned up in open river valleys, where bones are not preserved. Along with the remains of the ape-men in the cave rock there are often broken bones of other animals. These facts led Dart and Broom to conclude that the Australopithecines lived in caves and killed animals for food with some sort of natural club (*e.g.*, a broken tree branch). The anthropologist Kenneth P. Oakley argued, on the other hand, that the ape-men may have lived in the open and themselves been dragged into the caves by large animals (*e.g.*, saber-toothed cats) that preyed on them.

Two years ago Robinson and C. K. Brain discovered some pebble tools in caves containing bones of ape-men at Sterkfontein. Their finding may reopen the whole question. Should further excavations show that the Australopithecines lived in the caves and made tools and fire, they may be reconsidered as possible ancestors of man. The general weight of the evidence, however, is against this idea. The ape-men are too recent in time and too specialized in some anatomical respects to be man's ancestor. They probably were a separate branch stemming from the same ancestor from which man evolved.

In an old lake bed next to Lake Victoria the archaeologist L. S. B. Leakey found what seems to be the earliest definitely human fossil in Africa. It is a piece of jawbone with clear signs of a chin—usually considered an identifying mark of true man. The fossil apparently is considerably more than half a million years old. So we may guess that in the period between half a million and a million years ago two manlike creatures roamed central and southern Africa: *Homo*, a true man with a comparatively large brain, who was the toolmaker, and *Australopithecus*, the man-ape with a small brain (500 to 600 cubic centimeters), who may have looked much like the common anthropoid ancestor from which *Homo* also came.

If we have practically no fossils of the earliest men, we are hardly better off when we come to the next stage of man's development—the men who advanced from pebble tools to the hand-ax. This culture (named Chelles-Acheul) apparently originated in Africa and spread from there to Europe and Asia. Of the men who made the hand-axes we have found only a few broken skull fragments, among them some pieces of jaw at various sites in Africa and the Swanscombe brain case in England. We cannot tell from the fragments whether these men were *Homo sapiens* or closer to the Java and Peking forms of man. Sapient or not, they have left us an abundance of tools testifying to their culture, and it is to the tools that we must turn to learn what sort of men they were.

The best picture of this history in all the world was excavated by Leakey in the now famous Olduvai Gorge in northern Tanganyika [see "Olduvai Gorge," by L. S. B. Leakey; SCIENTIFIC AMERICAN, January, 1954]. Here, in a deep series of stratified lake beds, Leakey traced the development of the hand-ax culture through 11 stages from the pebble-tool era to finely finished axes and cleavers of the Middle Stone Age. No-

SITES mentioned in the text of this article are located on this map of Africa. Hopefield (*bottom*) is where part of the skull of Saldanha Man, named for Saldanha Bay, was found.

where else has anyone found so clear a consecutive record of man's early history. It covers more than a quarter of a million years of cultural evolution. Two of Leakey's strata are sufficiently undisturbed to portray actual moments in the experience of man at this site. One shows that early hunters drove a giant sheep, a giant ox and other now extinct animals into a swamp and then feasted upon them at their leisure. The other, at a much later time, depicts a feast upon a hippopotamus. The area is littered with stone flakes and the hand-axes and cleavers that the hunters made on the spot to deal with the hippo's carcass.

Intensive searches have been going on in many parts of Africa to find other camping and living sites of Stone Age men. In 1953 my own group, working for the Rhodes-Livingstone Museum and the Northern Rhodesia National Monuments Commission, discovered some richly laden old lake beds at the Kalambo Falls, and we have since spent two more seasons excavating their remarkable contents. The site is especially interesting for a number of reasons. It is not far from the cave where the famous skull of Rhodesian man, one of the early men of Africa, was found many years ago. It has yielded up, like Olduvai Gorge, a long succession of human encampments. And it has preserved many evidences besides stone tools to inform us about the people who lived here and about the climate and environment of their time.

The Kalambo waterfall is one of the highest in the world [*see photograph on page 82*]. The water of the Kalambo River plunges here over a sheer cliff 726 feet high into a dark and eerie gorge, through which it flows on into Lake Tanganyika. Above the falls the river meanders sluggishly through a three-mile-wide valley which was once a small lake. Successive filling and drying up of the lake laid down as much as 70 feet or more of soil deposits, which form a series of old lake beds going back more than 150,000 years. Erosion has cut through and laid bare many of these strata.

The shore of this lake, we discovered, was a favorite camping place of Stone Age men. Digging down through the successive layers we found one floor after another where hunters had made their camps and left their stone tools. The record covers the span from the end of the Early Stone Age through the Middle Stone Age. Every floor had a profusion of tools—cleavers, hand-axes, crude picks which must have been used for working

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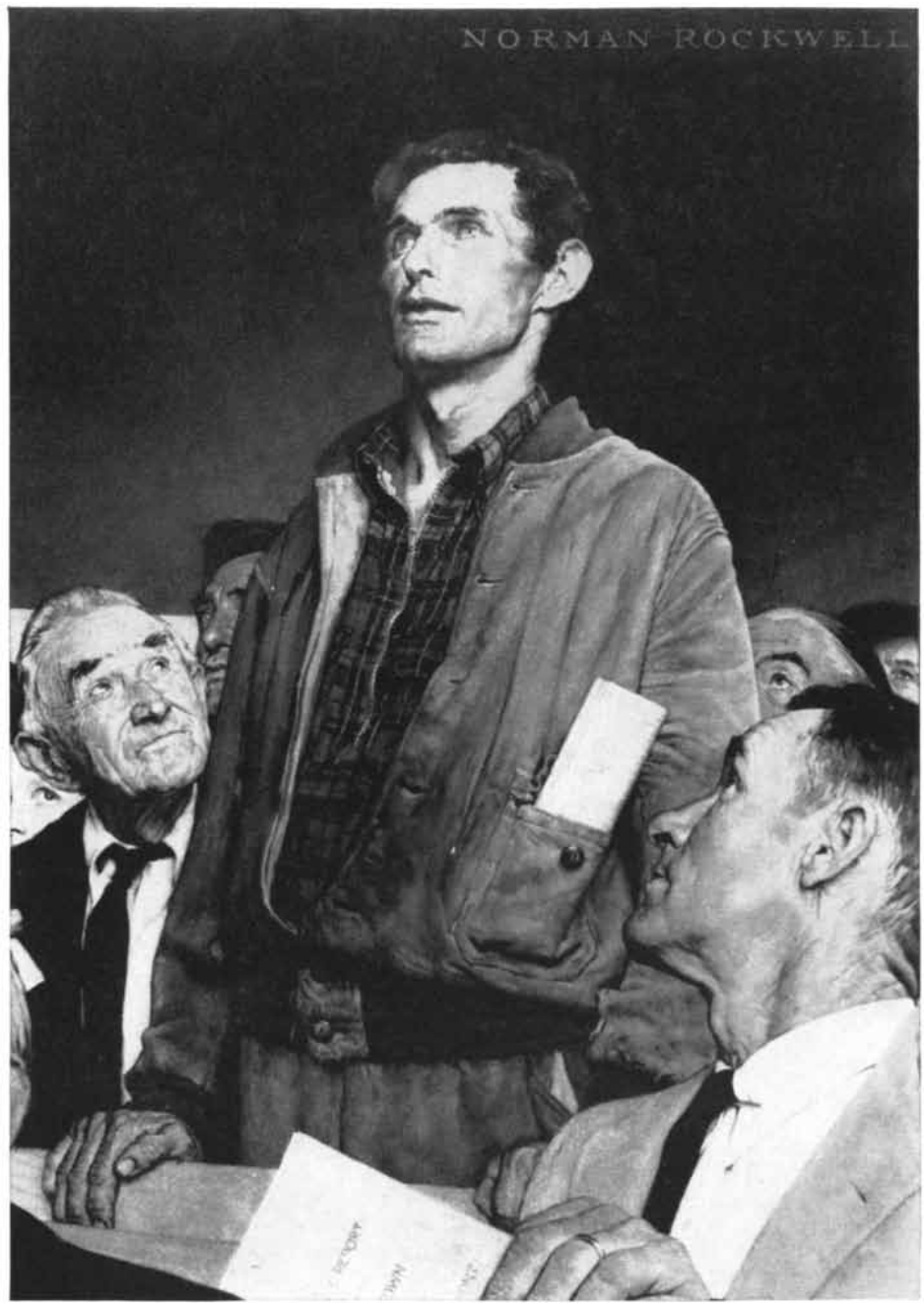

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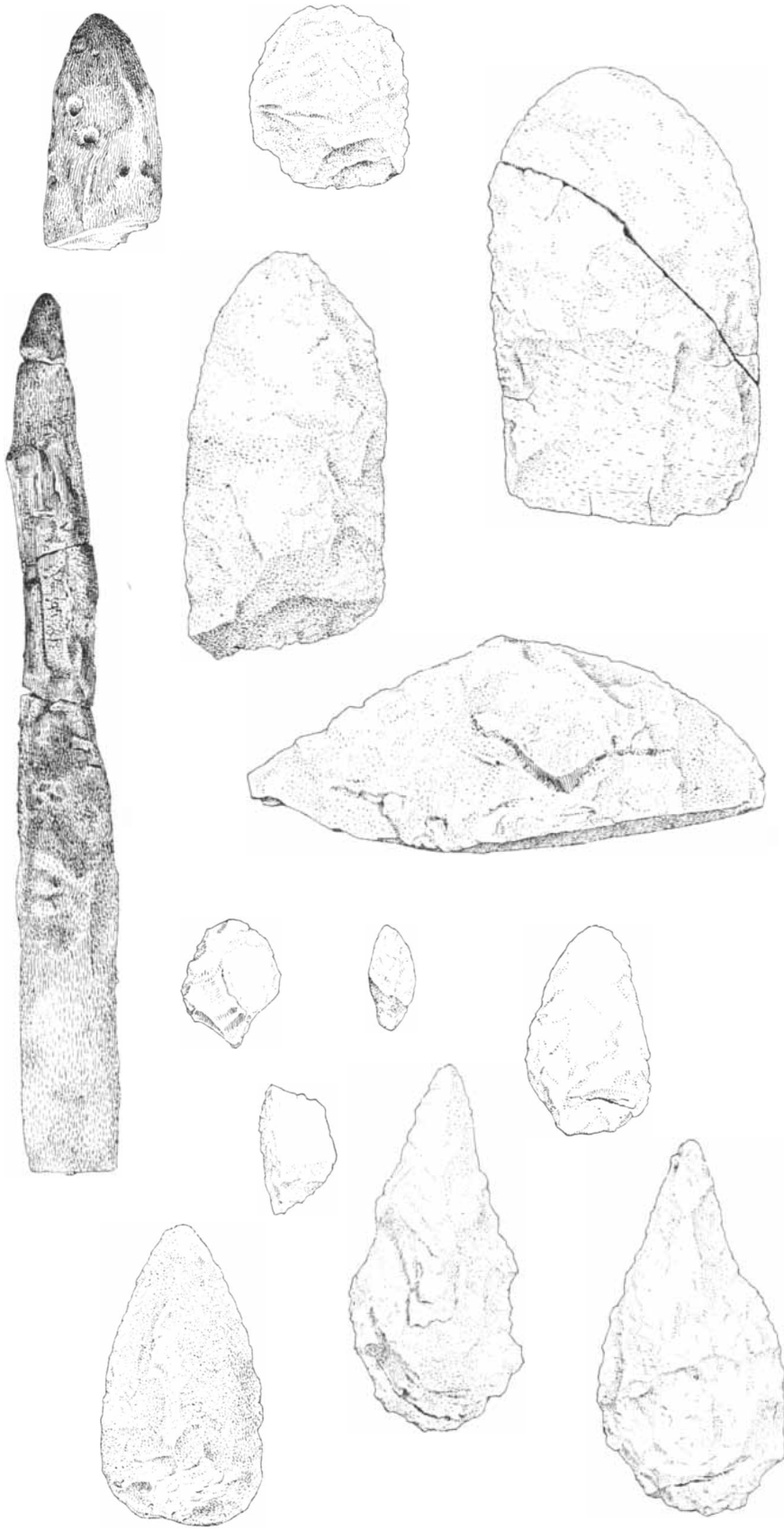

EARLY STONE AGE TOOLS were found near Kalambo. At top left and middle left are pointed pieces of partly burned wood which are thought to have been used as tools. Above the three stone tools at bottom are four smaller "flake" tools struck from larger pieces of stone. The remaining stone tools in this illustration are various kinds of hand-axes.

wood, delicate flake tools for cutting and scraping, and even the stone anvils on which the makers chipped and fashioned their tools. They used stone that lent itself to fine workmanship—chert, quartzite and a fine-grained sandstone. Most of the tools were still in mint condition when we unearthed them; indeed, in a demonstration at a Pan-African Congress of Prehistory in 1955 Leakey skinned an antelope with one of the prehistoric cleavers we found at the Kalambo site.

Meat formed a considerable part of the diet of these early men. Their camp sites are littered with bones of elephants, rhinoceroses, giraffes, antelopes, giant pigs and baboons. The hand-axes and cleavers probably were developed as implements to cut up and skin animals. What is unusual in Africa is the finding of many small flake tools along with the larger implements; in most of the European sites of the hand-ax culture these more delicate tools are missing, probably because they were separated by river flows. The small stone chisels and scrapers indicate that hand-ax man made tools, weapons and other objects of wood and bone.

As a matter of fact, at Kalambo Falls we have been lucky enough to find a number of preserved wooden implements. Most of them seem to be digging sticks, perhaps for digging up roots and bulbs; one fragment looks like a spear point, another, the end of a throwing stick; there are also pieces of bark which may have been dishes or trays. Charred logs at the same site testify that hand-ax man used fire.

In deep deposits below the normal river level we found the waterlogged remains of ancient tree trunks, branches, leaves, stems, seed pods and fruit seeds. The deposits were also rich in fossilized pollen, which gives us valuable new evidence about the climate in prehistoric times. It appears that when hand-ax man lived in this area of tropical Africa the climate was cooler and wetter than it is today. And some of the highlands near Lake Tanganyika may have provided hand-ax man with retreats where he could survive through dry periods of the Pleistocene.

Not until fairly late in the Pleistocene—some 50,000 years ago—do we get our first good look at hand-ax man in Africa. Several skulls of this period or somewhat later have been found in various parts of the continent. They show that man in Africa had developed into two main types: one resembling the

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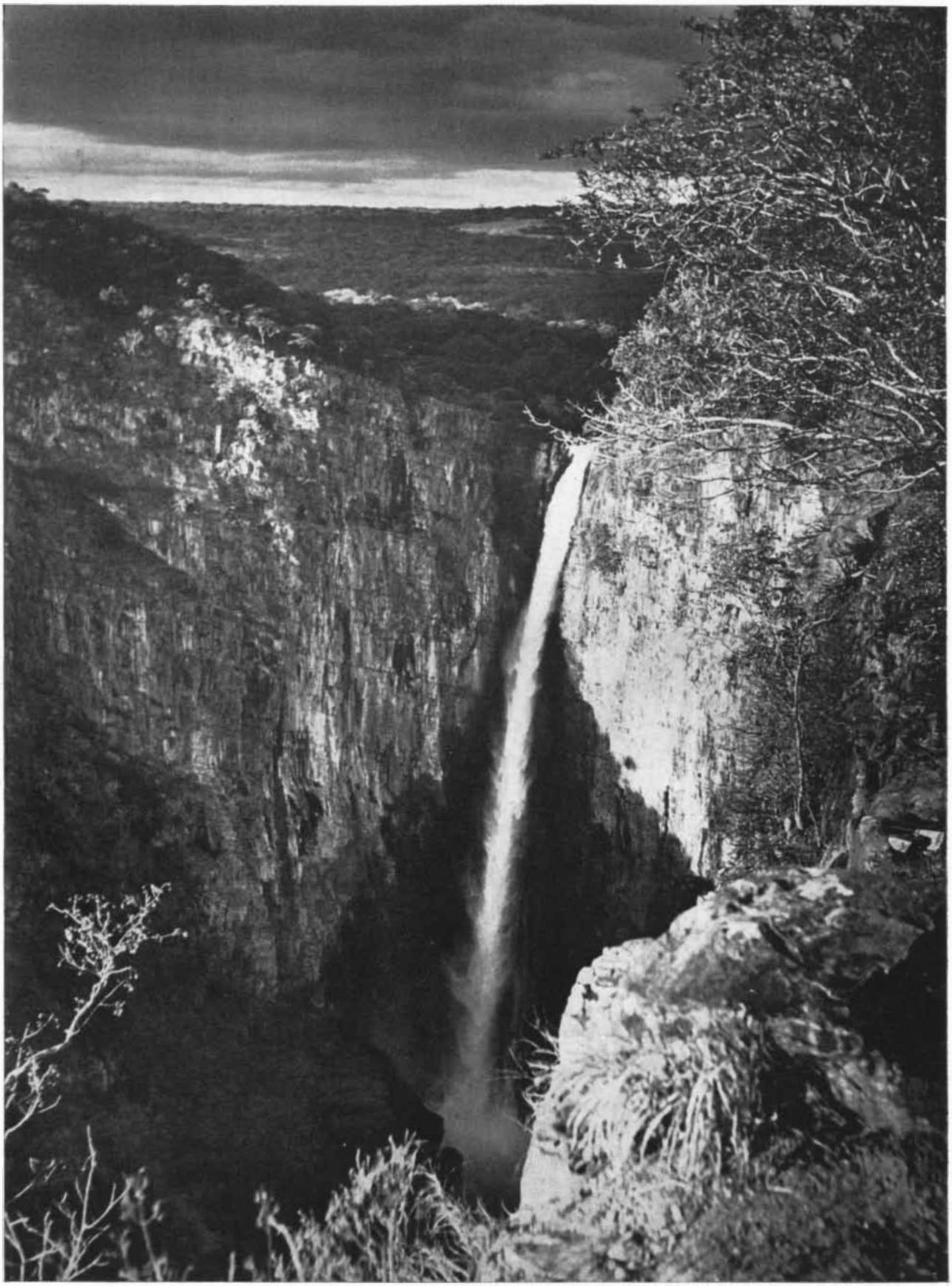

KALAMBO FALLS, 726 feet from top to bottom, is one of the highest in Africa. Above the falls in prehistoric times was a lake beside which generations of Stone Age men camped. The lake ran out when the Kalambo River cut through hills which dammed it.

modern aborigines of Australia, the other the Bushmen of South Africa.

The fossils appear to be forerunners of the modern types they resemble. (The present short, small-brained Bushmen of southern Africa may be a hybrid development from the early Australoid and Bushmanoid.) Of the Australoid type we have several specimens, notably a nearly complete skull and some limb bones found in 1921 at Broken Hill in Northern Rhodesia (he is known as Rhodesian man) and part of a skull found recently near Saldanha Bay in the Cape Province. These fossils bear considerable resemblance to Neanderthal man: they have pronounced brow ridges surmounting a massive face. But Rhodesian man's limb bones show that he walked upright with his head erect, instead of in the Neanderthaloid crouch.

Both the Australoid and the Bushmanoid men had fairly large brains and a Middle Stone Age culture. They made simple stone tools of varying degrees of finish, depending on the demands of their environment and way of life, and there is evidence that they used wooden spears and digging sticks. But from this time forward the men of Africa began to lag behind Europe and Asia in cultural and mental development. By the end of the Pleistocene, some 10,000 years ago, the stream of human progress had shifted to the Near East and western Europe, and lower Africa had already become a backwater. Indeed, in many parts of Africa men were still living in a Stone Age culture up to only a few hundred years ago.

The reasons for this cultural and mental stagnation are not entirely clear. But we can surmise that climate and the environment had a lot to do with it. In western Europe the hardships and precarious living of the last ice age must have forced man to become inventive and resourceful in order to survive. In much of Africa, on the other hand, rainfall was plentiful, food abundant and existence comparatively easy. The old ways of finding a living were good enough.

I have merely indicated briefly the sense of excitement and the ferment of activity with which investigators are now digging into man's past in Africa. We ourselves are looking forward eagerly to taking up again next year our excavations at Kalambo Falls, where much work remains to be done. We think there is good reason to hope that mankind will find in Africa the answers to its long search for its own origins and ancestry.

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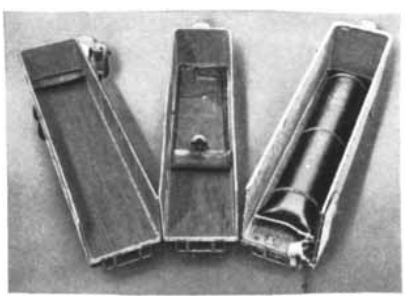

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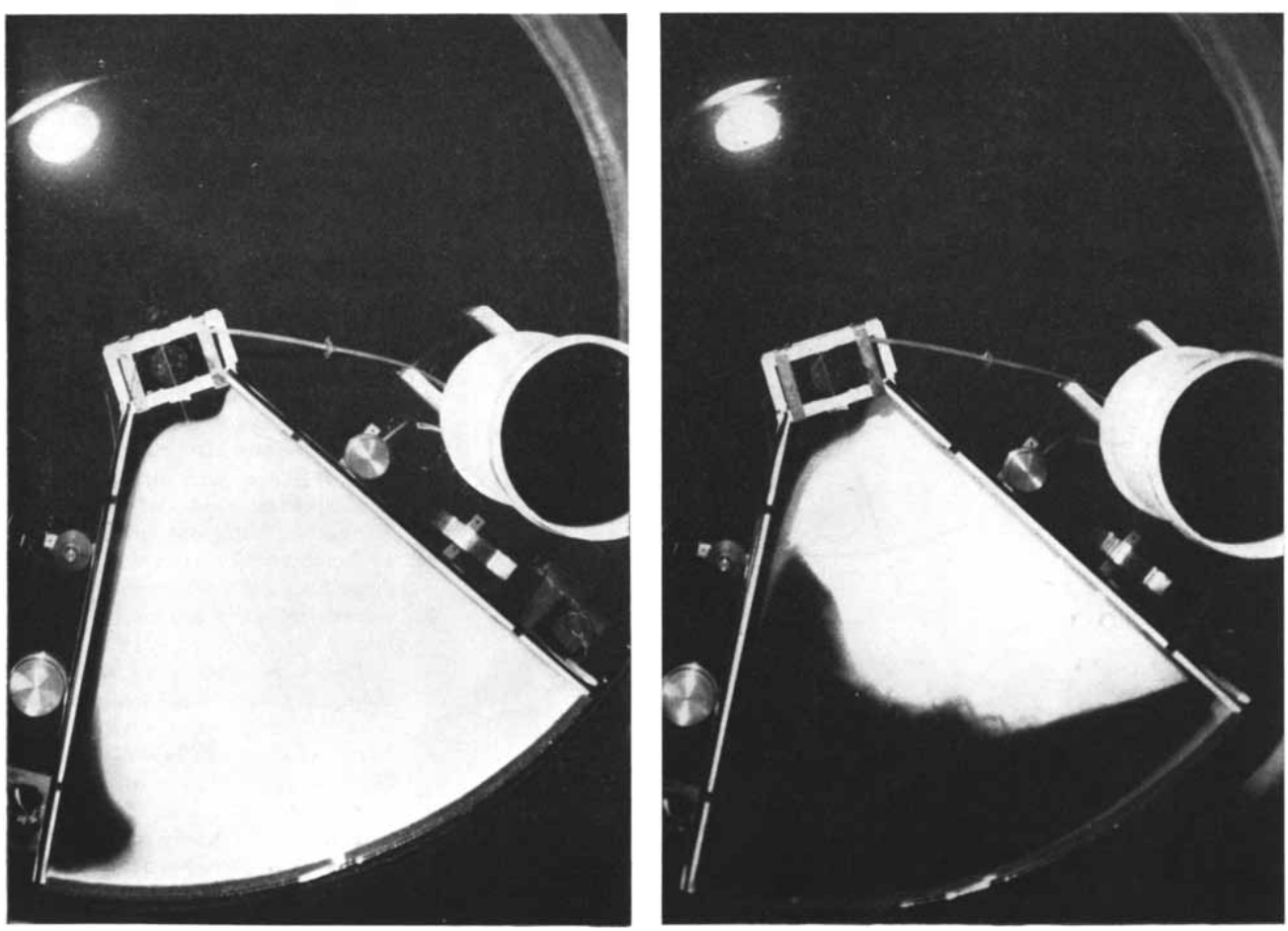
The Circulation of the Abyss

Unseen and still largely uncharted currents in the ocean depths are a major force in determining world climate. A new theory indicates that these currents have a surprising pattern of flow

by Henry Stommel

There is a good deal of talk these days about controlling the world's climate. Optimistic promoters of the earth sciences hold out visions of turning tropic deserts or arctic wastes into temperate and fertile plains. Of course we could not hope to do this by brute force. To deflect major wind systems or ocean currents, or to heat the outdoors, would call for engineering works on a scale that man cannot even dream of. But, some people suggest, perhaps if we knew enough about the mechanics of the atmosphere and the ocean circulations we might be able to find some critical time and place where a relatively small man-made disturbance could set off a snowballing reaction which would produce a major alteration in weather patterns. Actually this prospect is quite remote. It does add some spice, however, to a study such as oceanography.

The general circulation of the world's oceans is a matter of great interest, not only from various practical points of view—climate, fishing, dumping of ra-



CIRCULATION PATTERNS in the deep ocean are simulated in a rotating, wedge-shaped basin. Ink poured in at the point of the wedge (the "pole") flows down along "western" edge (*left*), turns and flows over the rest of the bottom (*right*) toward the "pole".

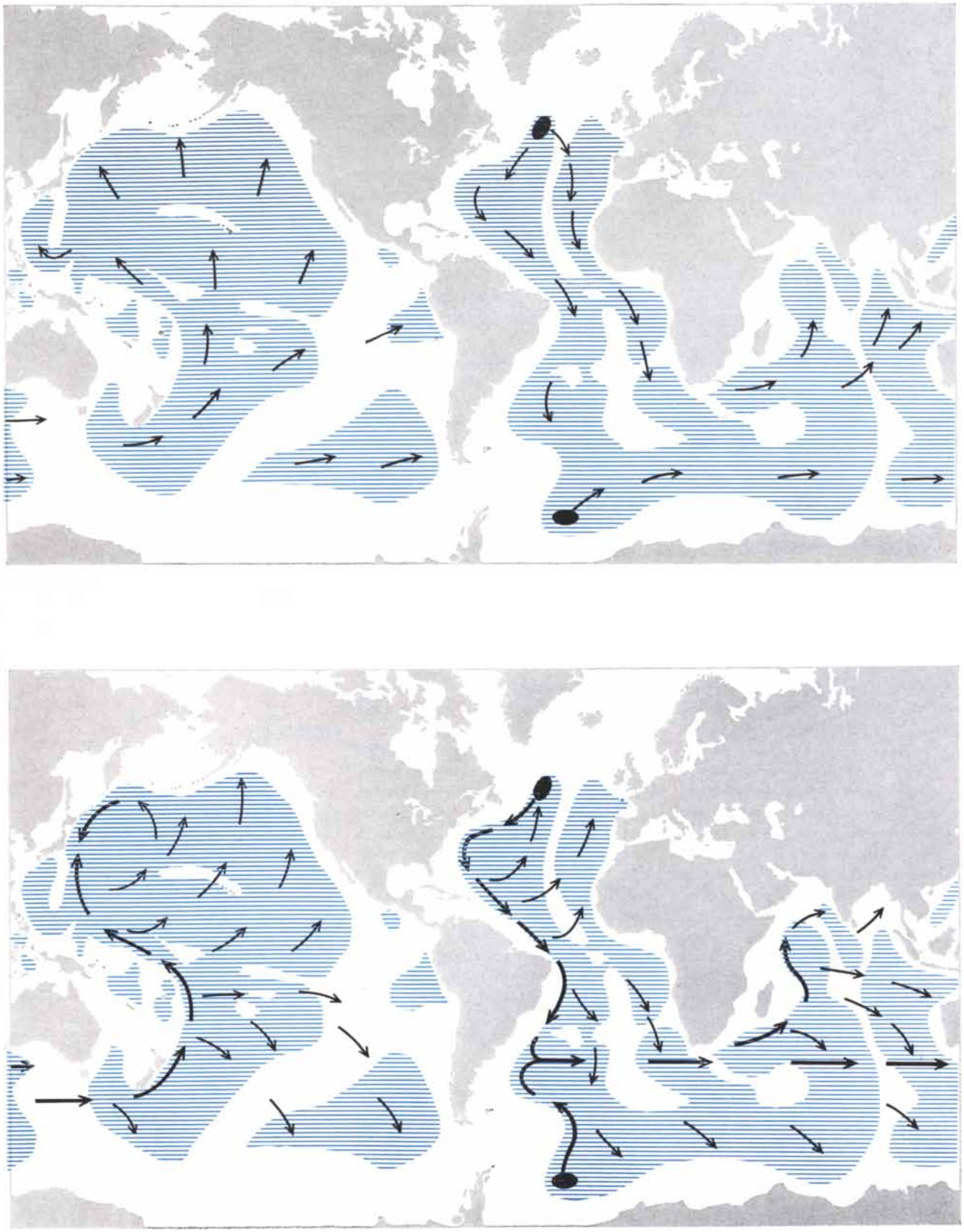
OXYGEN CONCENTRATION at a depth of 4,000 meters (about 13,000 feet) is indicated by colored areas on map. The numbers given in the key are milliliters of oxygen per liter of water. White areas are regions where the ocean bottom is less than 4,000 meters deep. This projection places the North Pole at top and the South Pole near the center of the map.

dioactive wastes and so forth—but primarily from the standpoint of understanding the dynamics and history of the planet on which we live. We know that the great surface currents (*e.g.*, the Gulf Stream) are important to us. Even more significant is the circulation of the oceanic water as a whole. And to get any sort of picture of this circulation we must find out about the movements of water in the ocean deeps. This is difficult to do: we have had no reliable means of getting direct, accurate measurements of the currents or the massive general flow at great depths. Our inferences have to be based mainly on indirect indications such as the comparative densities, salinities and pressures of the water at various places and various depths.

One item of evidence is the amount of dissolved oxygen in the waters of the abyss. Ocean water receives oxygen only at or near the surface—by direct contact with the atmosphere and by the action of photosynthesis in floating plants. After the water sinks to deeper levels it gradually loses some of its dissolved oxygen: the gas is consumed in chemical reactions with dead microorganisms. Therefore the amount of dissolved oxygen in a sample of deep water is a rough index to the "age" of the water since it sank from the surface.

Now when we measure the oxygen content of the deep water in various parts of the oceans, a distinctive pattern emerges [*see map at the left*]. The "youngest" deep waters (richest in oxygen) are found in the western North Atlantic and around the Antarctic Continent. The concentration in the other oceans diminishes with increasing distance from these sources: the water poorest in oxygen is that at the bottom of the vast and little explored basin off Peru. It thus appears that there are only two important regions where substantial amounts of water sink from the surface to the abyss: in the North Atlantic and around Antarctica. This water evidently spreads gradually into the Indian Ocean and finally northward into the Pacific.

The oxygen studies tell us, then, that there is a general sluggish circulation of water along the ocean bottoms from the North Atlantic and the Antarctic to the other oceans. We have another indication of this global flow. The deep water in all the oceans is very cold—only a few degrees above freezing. This is true even in the tropics; only the top 1,500 feet of water is warm. The warm surface water does not mix deeply with the colder water beneath it; this must mean that the



TWO THEORIES of the deep circulation are represented on these maps. On the older view (*top*) water flows in broad currents toward the Equator from its sources (*black ovals*) in the North Atlantic and the Antarctic, and then spreads through the Indian Ocean up into the Pacific. According to the author's theory (*bottom*) the flow away from the sources is confined to intense currents on the western edge of the oceans. These in turn feed a broad flow that carries water toward the poles in each of the ocean basins.

warm layer is held up by a continual upwelling of cold water from below. This slow rise of water (about an inch per day at mid-depths) represents a movement of water amounting to several thousand times the total daily discharge of the Mississippi River. Obviously all that water continually coming up from the depths must be replaced by an inflow into those depths—*i.e.*, it betokens a massive deep circulation.

The simplest circulation pattern that would fit the facts we have reviewed is a broad, sluggish, spreading current coming straight down the Atlantic and joining the current from the Antarctic to flow through the Indian Ocean and then up into the Pacific [*see upper map on the preceding page*]. Until recently most oceanographers accepted this general picture. But I believe that the rotation of the earth and considerations of fluid dynamics make another picture more likely. The general reasoning behind this new theory is as follows.

In the open ocean the flow of the bottom water must be different from that in a river. It should be more like the flow of air in the atmosphere. As every reader of weather maps knows, air does not travel directly from high-pressure to low-pressure areas. It circulates around the highs and lows, because of the so-called Coriolis force arising from the earth's rotation. That is, the air travels along the lines of equal pressure, or isobars. Now my own construction of the pattern of isobars in the deep ocean, based on dynamical considerations and on the requirements for the supply of upwelling water, shows a flow from the Equator toward the poles. The flow originating near the poles, it then appears, may be carried by strong currents along the western sides of the ocean basins, just as there are strong currents along these routes at the ocean surface [see "The Circulation of the Oceans," by Walter H. Munk; SCIENTIFIC AMERICAN, September, 1955]. We postulate a strong, deep current running down the western North Atlantic and up the western South Atlantic. When they come together, the currents merge and turn eastward, flowing up the eastern coasts of Africa and Asia [*see lower map on the preceding page*].

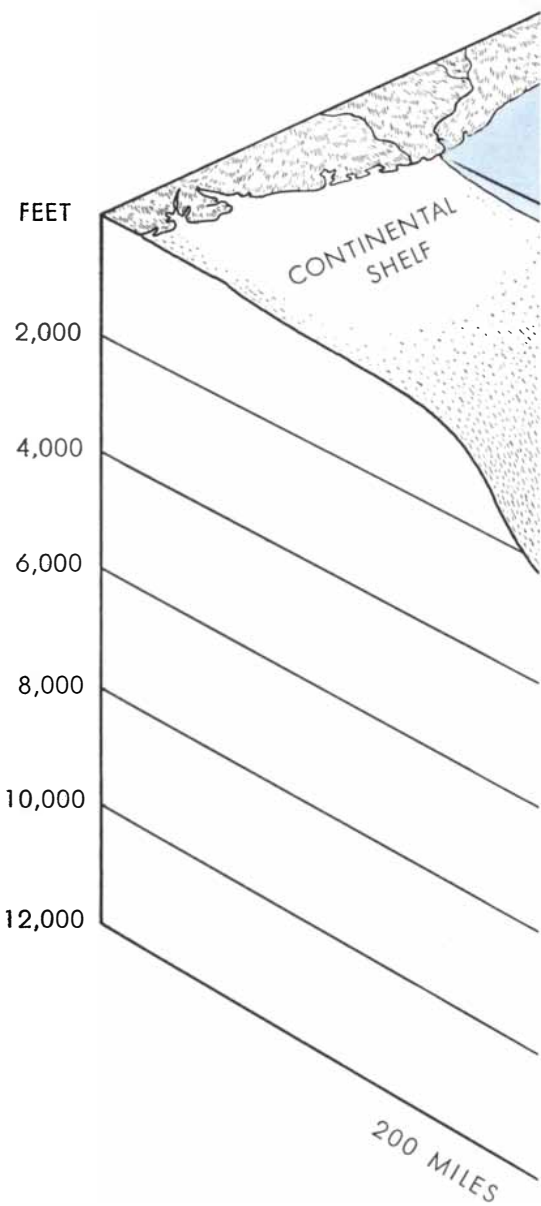
Two independent observations have partly confirmed this theoretical scheme. Last year a joint British-American oceanographic expedition found a strong deep current in the western Atlantic. It flows beneath the Gulf Stream but in the opposite direction, from north to south, just as the theory predicts. Detection of the current was made possible by a new device for investigating the motion of deep water, invented by the British oceanographer John C. Swallow. It is a float which is cleverly designed to seek a predetermined level under the surface and then to remain there, drifting with the current. The float has a small ultrasonic transmitter sending signals which locate its position. The expedition made the soundings off Charleston, S.C. They found that floats lowered to levels below 6,500 feet drifted southward at velocities between two and eight miles per day.

The other confirmation of the new circulation scheme was supplied by the German oceanographer Georg Wüst. Analyzing the pressure distributions in the South Atlantic, he was able to show that the flow of deep waters in that ocean is confined to relatively narrow streams along the continental slopes off Brazil and Argentina.

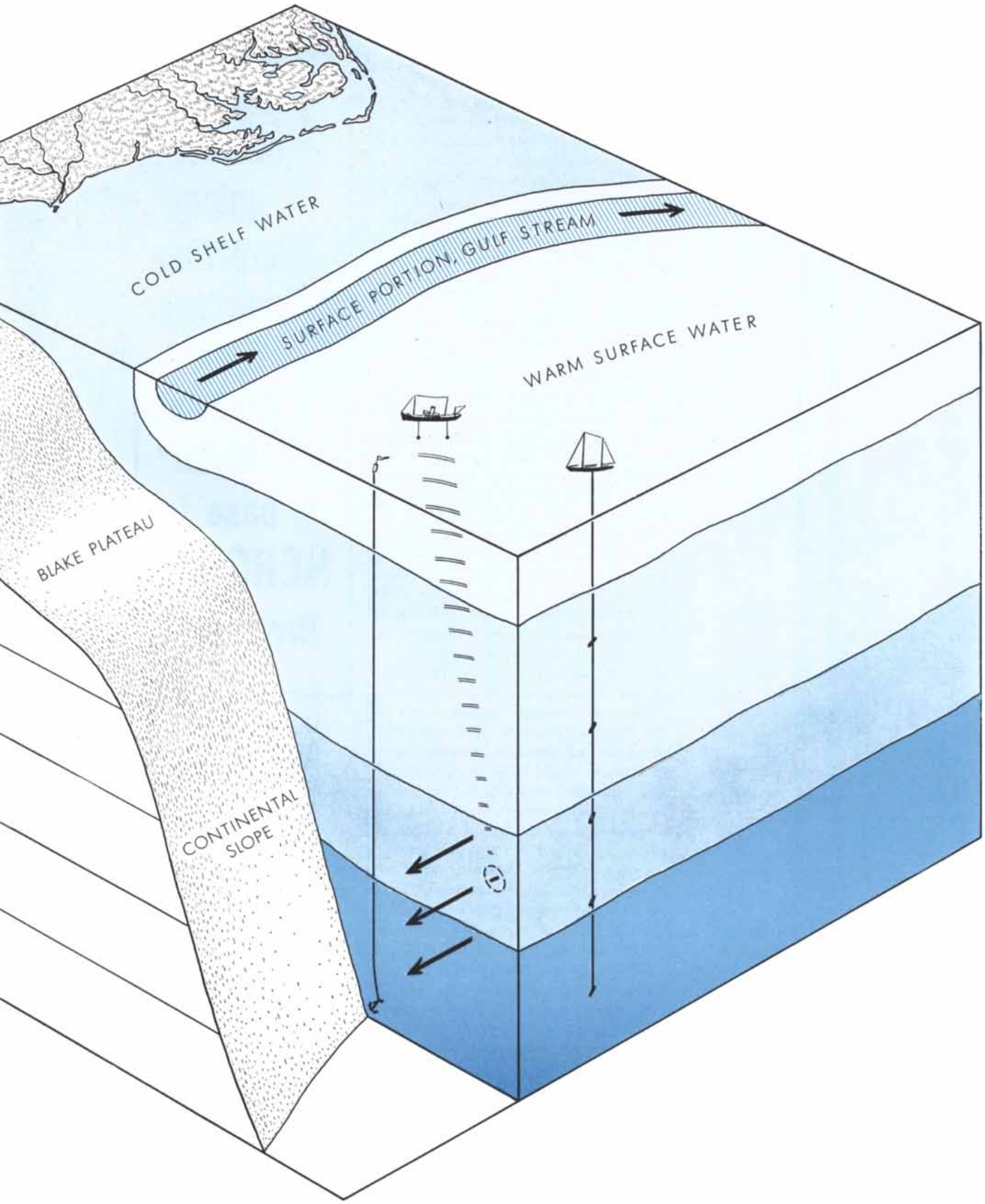
Thus we now can score two modest victories for the theory. I think it sporting to risk a few further predictions. We should find (1) a countercurrent underneath the Agulhas Current off the East Coast of Africa, (2) a narrow northward current in the western South Pacific, let us say along the slopes of the Tonga-Kermadec Trench, and (3) only a weak flow underneath the Japan current.

The theory has also been buttressed by some laboratory experiments at the Woods Hole Oceanographic Institution. Liquid in a flat-bottomed, rotating basin has the same type of circulation patterns as water on the spherical, rotating earth. Alan Faller at Woods Hole set up a wedge-shaped section in the basin to simulate a single ocean. The point of the wedge corresponds to a pole of the earth, the sides to the coastlines of the ocean and the outer perimeter to the Equator. When this sector was set into rotation and some dyed water was poured into the liquid at the "pole," the dye moved through the "ocean" just as the theory predicts. First it flowed in a narrow current along the "western" edge; at the "Equator" it turned and flowed slowly over the basin toward the center [*see photographs on page 85*].

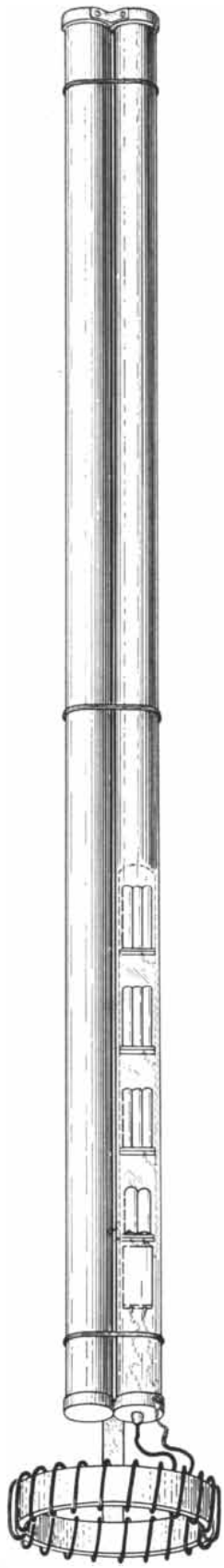
With ingenuity you can reproduce this experiment yourself in a small tin dish on a phonograph turntable. The dish should be covered with a sheet of glass to prevent air currents from disturbing the water surface. Most turntables revolve in a direction opposite to that of the earth, so the boundary cur-



DEEP CURRENT flowing southward under the Gulf Stream off Charleston, S.C., was discovered last year by a joint British-



American oceanographic expedition. This cutaway view shows the British vessel *Discovery II* (*left*) receiving ultrasonic signals from a submerged float (*black bar*) which is drifting with the deep current. The American ship *Atlantis* (*right*) is recording other data such as temperature, salinity and density. The float is the first device with which undersea circulations can be measured directly.



UNDERWATER FLOAT is slightly less compressible than sea water; thus it sinks until its density equals that of surrounding liquid. Oscillator in the tube at right sets up ultrasonic vibrations in the ring at bottom.

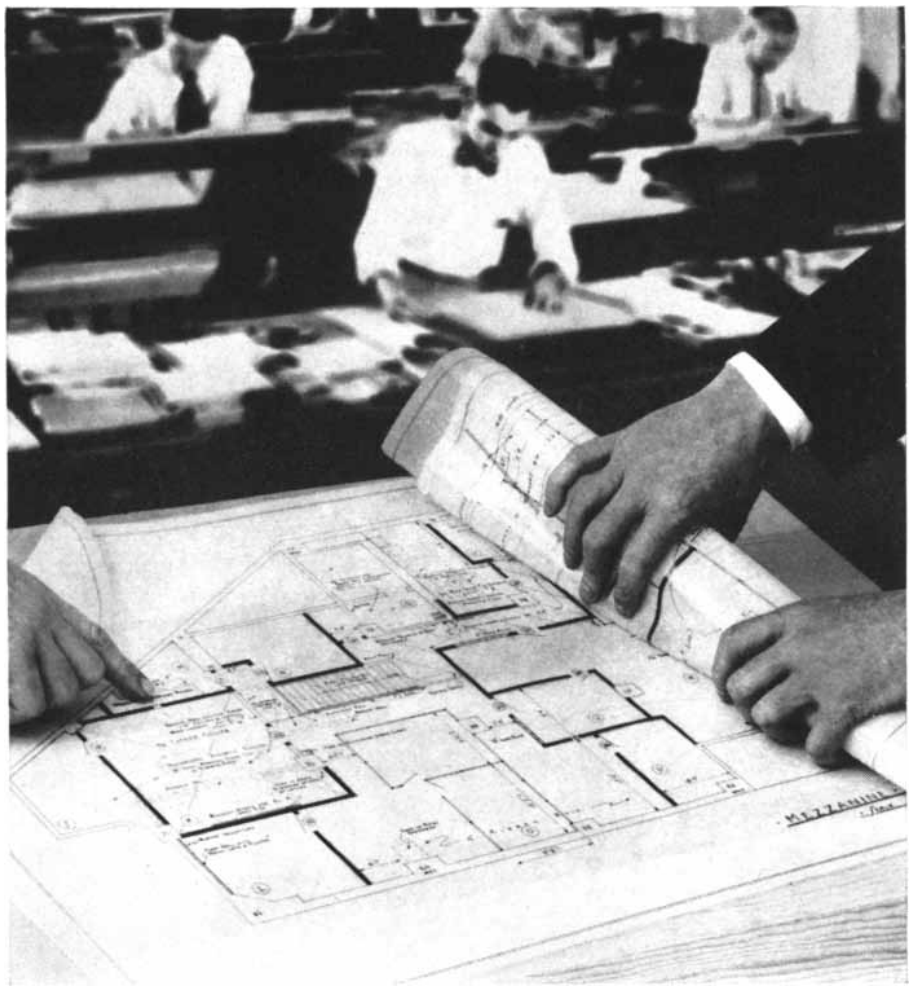
rent will probably show up on the "eastern" wall instead of the "western."

Now let us go back to the question of controlling climate. In view of what we have learned about the circulation pattern, is there any hope of finding critical areas in the ocean where modest engineering works might somehow change the world's climate?

The most attractive fantasy is a dam across the Straits of Gibraltar. Such a dam would need only about 10 times the fill used to build the Fort Peck Dam in Montana. A Gibraltar dam has occasionally been considered by engineers interested in bringing hydroelectric power to Spain and North Africa. How might it affect climate?

There is a deep current from the Mediterranean into the Atlantic which carries very salty water and helps make the Atlantic the saltiest ocean in the world. If this flow were dammed, the salinity of the Atlantic might drop, so that in 30 years or so it might be no more salty than the Pacific. This in turn would reduce the density of the water; the water near the Arctic might then cease to sink to the bottom. If so, only the waters of the Antarctic would sink to supply the deep ocean currents. In several hundred years the abyssal circulation of the oceans would be vastly altered. What is more, if the North Atlantic water stopped sinking, much of the warm surface water that now flows along the Gulf Stream as far as the Arctic off Norway would be diverted eastward and southward and thus be held in a nearly closed system in the Atlantic. As a result of the reduction of heat transport to the Arctic, the ice packs covering the sea would grow. According to a new theory suggested by the oceanographer Maurice Ewing, this would lead to a decline of the glaciers on land and to a general warming of the earth.

Common sense rebels against such an argument. It is hard to imagine so fantastic an effect from so small an intervention by man. And indeed the argument is loaded with unproved assumptions and tenuous speculations. We could construct an equally plausible argument that the same stratagem might cool rather than warm the earth. I cite this entertaining fantasy only to show that we need a great deal more information before we can begin to talk knowledgeably about altering the climate. All such speculations merely illustrate how little actual knowledge we have and how valuable it would be to develop a better quantitative understanding of the ocean circulation.



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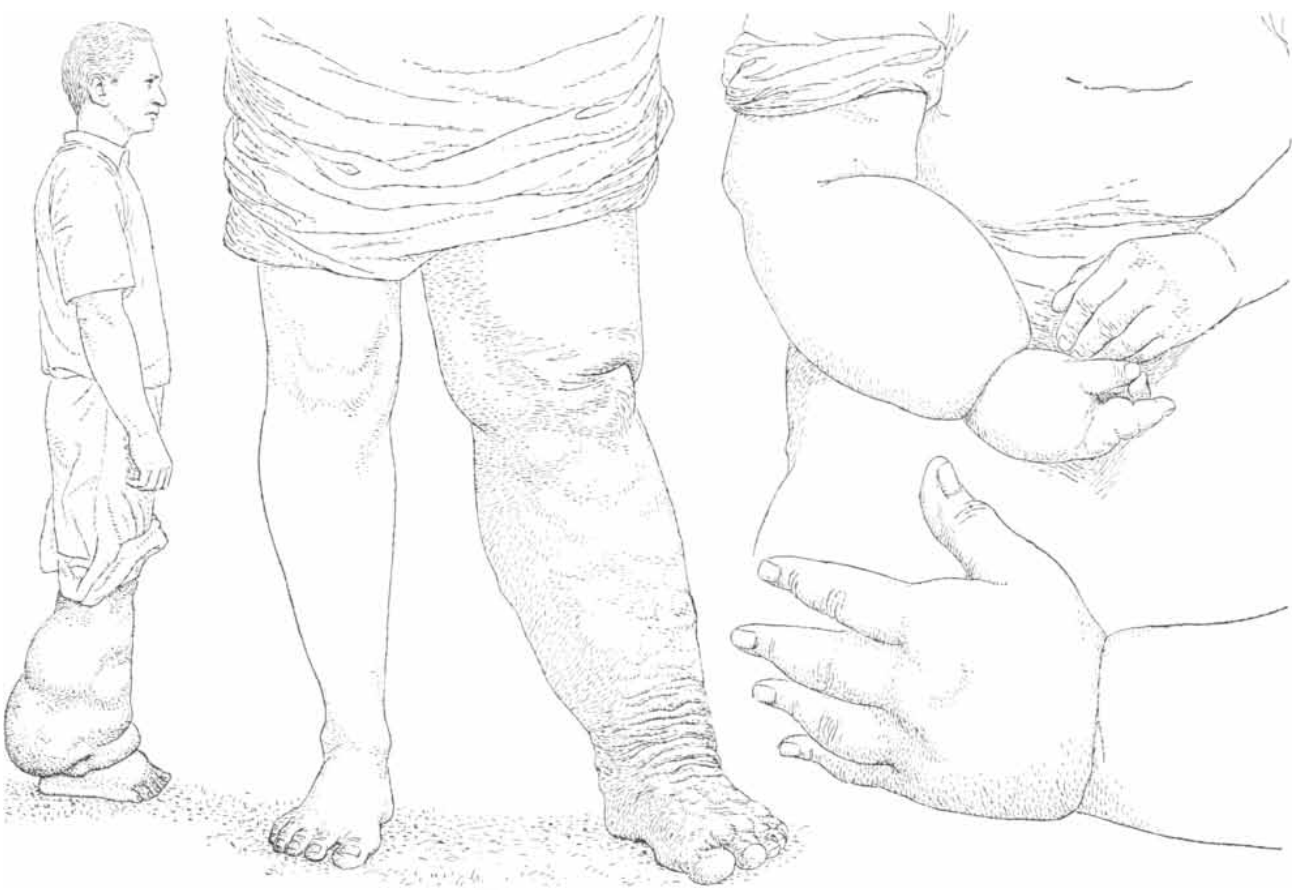
FILARIASIS

This disease gives rise to the grotesque deformities known as elephantiasis. It is caused by threadlike worms whose activities vary in a remarkable manner with night and day

by F. Hawking

When European explorers discovered the South Sea islands, they were charmed by the beauties of the blue lagoons and the fronded palm trees, but they were also horrified by the strange deformities that afflicted some of the inhabitants of these pleasant lands. Legs and arms so swollen that they looked like the limbs of elephants, monstrously enlarged genitals—here was an appalling human disease that the medical men of Europe had not encountered before. They soon found, however, that "elephantiasis" occurred throughout the hot, damp tropics, in China, India, Africa, the West Indies. A century of investigation of this spectacular disorder by workers in many parts of the world has cleared away much of the mystery, and recent researches now give us reason to hope that the disease can be eradicated.

The development of elephantiasis usually starts in childhood, between the ages of 10 and 15. The victim begins to have acute attacks of inflammation in one or more limbs, with severe pain and high fever. After a few days the attack subsides, but the limb remains a little swollen, and gradually over a period of five to 10 years, with successive attacks,



ELEPHANTINE DEFORMITIES which occur in tropical areas result from infection with the parasitic worm *Wuchereria bancrofti*. The worms lodge in tiny vessels which drain the body-fluid lymph from the limbs. As the vessels become blocked, the limb enlarges.

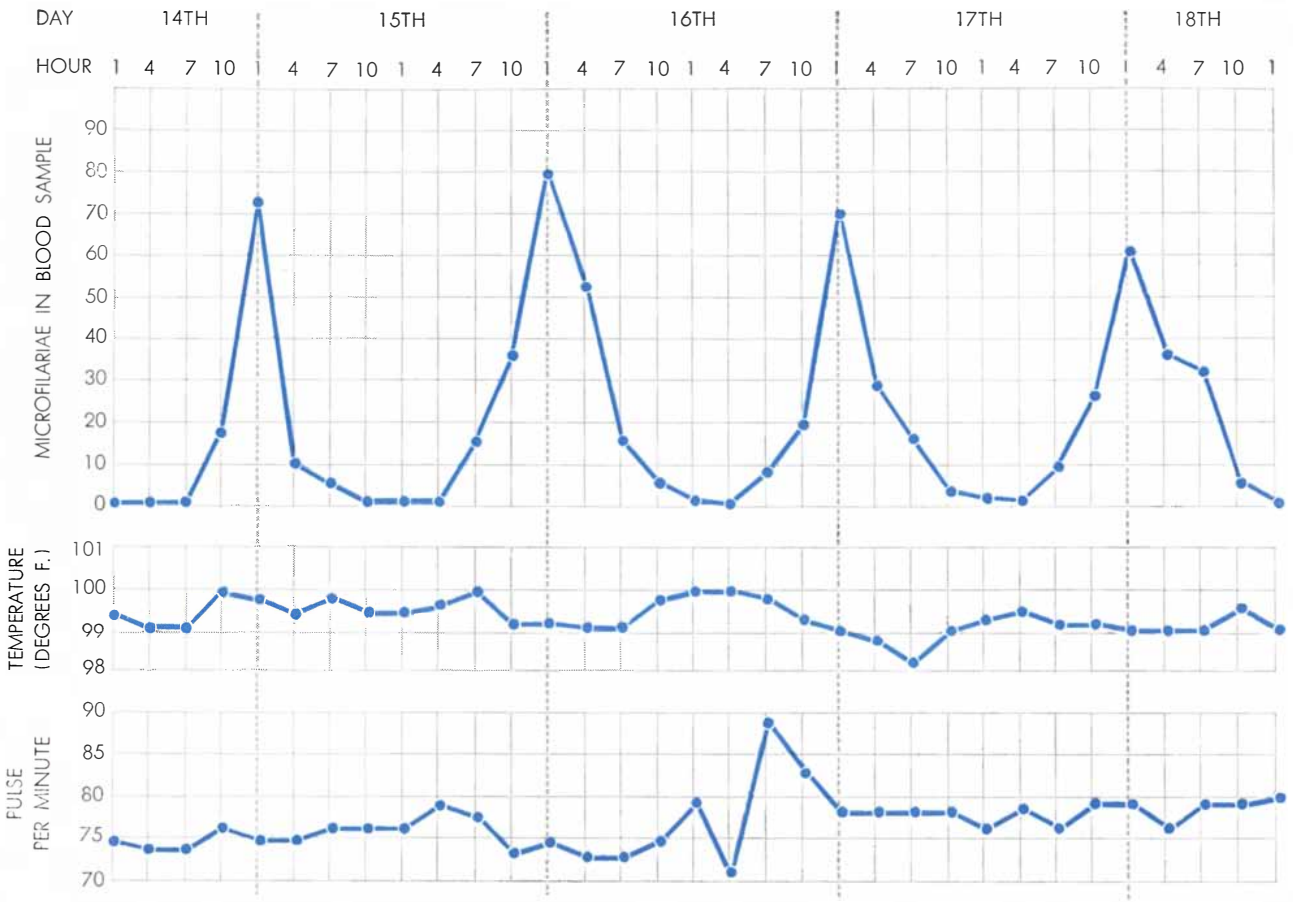
the limb grows larger and larger. The soft connective tissue just under the skin becomes enormously swollen with water and with fibers of scar tissue.

Physicians came to realize that this swelling and overgrowth were produced by blockage of the small vessels which drain the lymph, the watery, nearly colorless fluid of the body. Eventually investigators examining the fluid discovered the cause of the blockage: a threadlike worm now known as *Filaria bancrofti* or *Wuchereria bancrofti* ("filaria" comes from the Latin word for thread). In its adult stage the worm lives in lymphatic vessels of the body, especially those of the groin, the spermatic cord and the lower part of the abdomen. Usually it causes no harm; like many other parasites, this species tends to live harmoniously with its host. In heavily infected areas of the world probably nearly all of the adult population have been infected with the filarial worm at some time or other, but only 1 to 15 per cent of those infected develop elephantiasis. In these cases the worms multiply sufficiently to produce inflammation, and the resulting scar tissue then blocks the tiny lymphatic vessels. The swelling develops when all the vessels draining a leg, an arm or the scrotum have become blocked in this way.

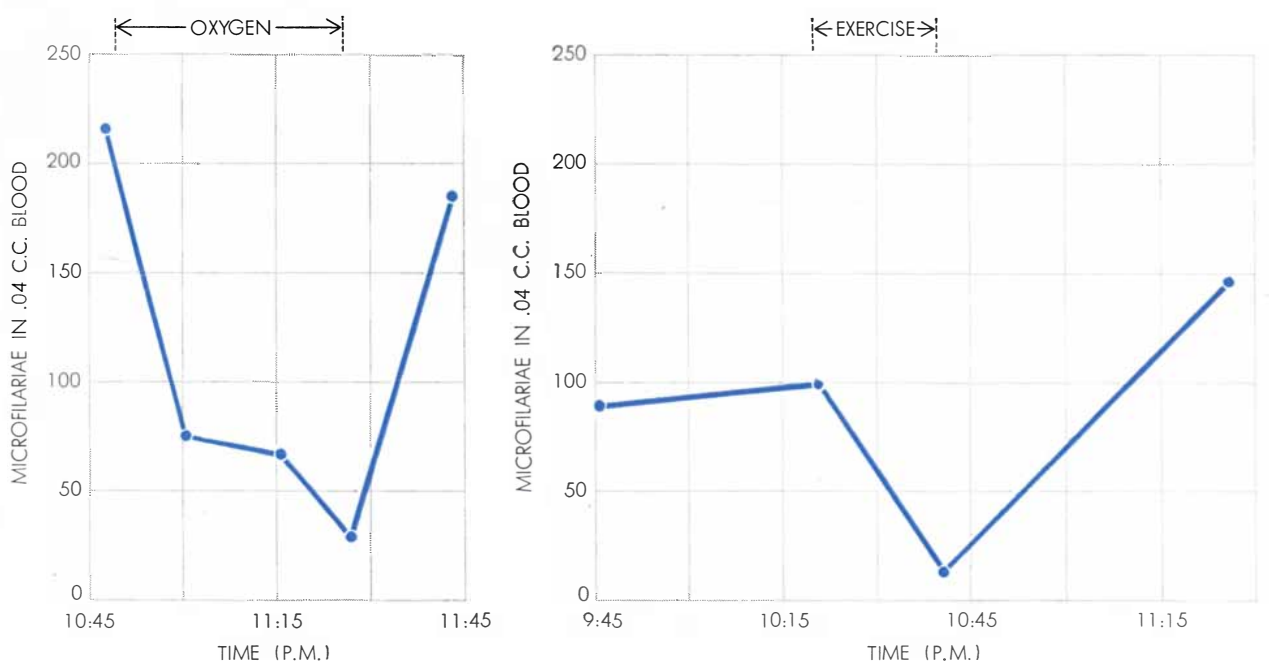
The female worm, about three and a half inches long, has two long uterine tubes which occupy most of her body cavity and continually generate eggs; thus she is a reproductive machine capable of turning out enormous numbers of young. The much smaller male (thinner and less than half as long) similarly consists in large part of a sperm-producing tube; when it mates with the female, by twisting its tail around her body and inserting two small spikes in her vulval opening, it injects great numbers of sperm, which remain stored in her uterus and fertilize the unending stream of eggs. Hence the only thing that stands in the way of unlimited reproduction of these worms is the fact that the male and the female do not always meet. Fortunately it is a difficult feat for a male worm (possessing little sense of perception or power of locomotion) to find a female worm in the dark and immense spaces of the human body. As a consequence the worms are not likely to produce new generations unless their population density in the body is high, and therein, as we shall see, lies the basis of our hopes for controlling the disease.

The tiny young larvae, called microfilariae, pour out of the mother and

FILARIAL LARVA is threadlike in human blood (*top*) but becomes sausage-shaped (*bottom*) after a few days in a mosquito. The upper photomicrograph, which enlarges the worm some 1,250 diameters, shows the dark-stained nuclei of its digestive tract. The lower picture, made by the phase-contrast technique, enlarges the larva about 700 diameters.



DAILY CYCLE of microfilariae was discovered by Patrick Manson. This chart reproduces a portion of the original record for one of his patients. It shows the regular appearance and disappearance of the worms in the blood. Temperature and pulse were less rhythmic.



DISAPPEARANCE of microfilariae from the blood can be induced at night by having a patient breathe pure oxygen (*left*) or by having him exercise strenuously (*right*). Microfilariae returned to the blood as soon as oxygen breathing or exercise was stopped.

are transported via the lymphatic vessels to the bloodstream, where they circulate throughout the body. Certain curious and significant facts about these organisms were discovered in the 1880s by a young medical missionary in China named Patrick Manson, whose work is one of the classic stories of tropical medicine.

Working at Amoy in South China, Manson encountered many cases of men suffering from huge swellings or tumors of the scrotum, some of whom he was able to relieve by surgery. During a visit home in London he read all he could about elephantiasis and the filarial worms that had been discovered in the urine and blood of its victims. When he returned to China, he plunged into an eager investigation of the infection, so far as his busy medical practice would permit. One of the questions that fascinated him was the fate of all those larval worms that poured into the blood. Why did the young worms pass their time in the bloodstream, whereas the adult filariae preferred to live in the lymphatic vessels? Manson eventually decided that the larvae must pass to some blood-sucking insect and develop to maturity there. The commonest blood-sucking insects in Amoy were mosquitoes, so he experimented with them. He found that after a microfilaria was swallowed by a mosquito, it developed in about 10 days into a much enlarged worm, which was ready to attack the next man bitten by the mosquito. This was the first time it had been clearly shown that an insect was a necessary intermediary in transmitting a disease from one man to another. (Years later Manson guessed, by analogy with filariasis, that malaria also must be transmitted by mosquitoes, and this hypothesis was proved correct by Ronald Ross, who received the Nobel prize for his work on malarial parasites. But that is another story.)

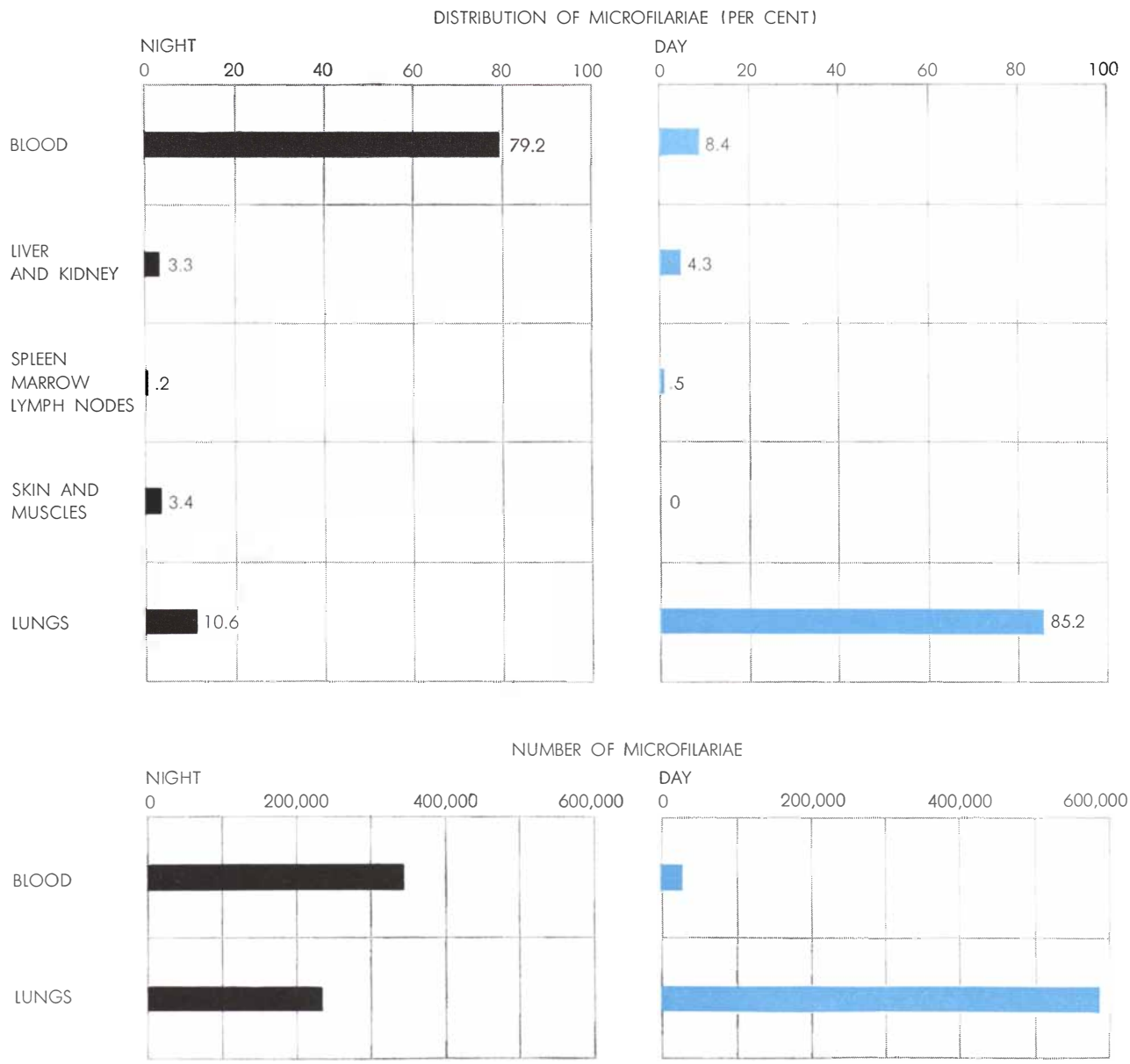
Manson instituted a search for filarial worms in the blood of his patients. He had two Chinese assistants take blood samples for examination, one during the day, the other in the evening after sunset. Oddly the evening assistant made many more finds of microfilariae than the daytime assistant. Inspired by this observation, Manson arranged for blood counts of two filaria-infected patients at four-hour intervals for 10 days and nights, and he discovered that the microfilariae regularly disappeared from their blood about nine o'clock in the morning and reappeared about sunset. The worms increased in numbers until midnight and then declined again to total disappear-

ance by morning. This "microfilarial periodicity" was maintained with the greatest regularity day after day. When Manson's discovery was reported at a meeting of a well-known scientific club in London, it was received with bushels of chaff; one wit inquired whether the worms "carried watches."

The day-night cycle of the microfilariae in the blood, confirmed by many other observers, has remained one of the intriguing puzzles of tropical medicine. Manson saw at once an understandable evolutionary explanation: the mosquito that transmits the filarial parasite in China bites at night, and the emergence of the worms in the blood at this time is therefore an adaptation to the mosquito's habits. But why did the microfilariae disappear from the blood by day, and what mechanism regulated their alternate appearances and disappearances?

Manson suggested that during the day the worms retired to the heart, the lungs and the neighboring great arteries—like small birds hiding in a bush in daytime. He based this idea on an observation that microfilariae were found to be most numerous in these organs in a filarial patient who had committed suicide at 8:30 a.m., *i.e.*, the time of day when the worms had all but disappeared from the bloodstream. Clayton Lane, another investigator, proposed a different theory: that the microfilariae were daily destroyed by large phagocytic cells of the body and were daily replaced in the infected patient by the adult female worms, which hatched a new batch each evening. Both Manson's theory and Lane's were tested by transfusion experiments, but the results were inconclusive.

My colleagues and I at the National Institute for Medical Research in London took up the question some years ago and decided to experiment on certain African monkeys which show a mi-



DISTRIBUTION OF MICROFILARIAE was traced in monkeys by examining tissues of a monkey killed during the day (*upper left*) and one killed at night (*upper right*). Almost all the larval worms were in the blood at night and in the lungs in daytime. Actual numbers of microfilariae in blood and lungs were compared by sampling tissues of a living monkey at different times (*lower chart*). The worms disappearing from the blood by day seemed to equal the increase of worms appearing simultaneously in the lungs.

crofilarial periodicity like that in human beings. With monkeys we were able to perform controlled studies, taking counts and examining the various organs at selected times of day and night, either by removing the organs by surgery or by post-mortem examination.

These counts soon gave us a clear answer. Most of the organs (liver, kidney, spleen, skin, muscles) never contained many microfilariae, either by day or by night. But the lungs always had a considerable accumulation of them, the number declining somewhat at night. In short, we found that the capillary blood vessels of the lungs are the haven where the young filarial worms collect, and at night they are released from there into the general bloodstream.

Why do the microfilariae retire to the lungs during the day? We must postulate that the lung capillaries are the most favorable place for the young worms to live, perhaps because of the abundance of oxygen. According to this conception, periodicity is a compromise which enables the microfilaria to make the best of both worlds. It spends the daytime in the lungs enjoying the favorable conditions there; it comes out at night into the bloodstream hoping to meet the mosquito; in the morning, if it has been disappointed, it goes back to the lung to rest and recuperate until the next night. Although many microfilariae accumulate in the capillaries of the lung, they seem to cause little or no damage to the lung tissues.

What holds the worms in the lungs? Do the lung capillaries have some sort of diurnal property that causes them to lock in the worms by day and let them out at night? This seems unlikely. There is a filarial parasite in West Africa that is transmitted by a fly which bites by day; the larval worms in this case circulate in the blood in the daytime (an evident adaptation to the biting habits of the fly). So we have to conclude that it is not the lung capillaries but the microfilariae themselves that decide when they will leave the capillaries. Possibly the worm does this by changing its shape, possibly by some other mechanism; we do not yet know.

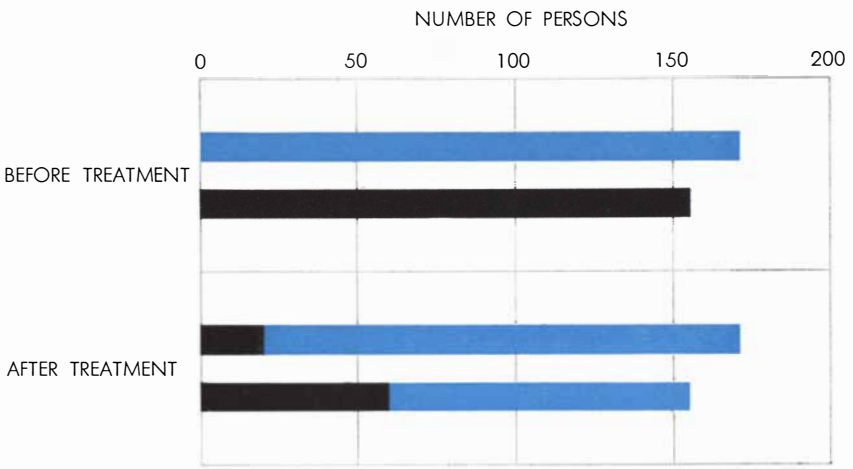
Finally, how do the microfilariae know whether they should come out by day or by night? Presumably they respond to some stimulus supplied by the diurnal rhythms of the host. Many properties of the body (*e.g.*, body temperature, alkalinity, the tension of carbon dioxide in the lungs, etc.) show cyclic fluctuations during the 24 hours. My colleague J. A. McFadzean and I have tested the effects of various physiological devices. We

found that vigorous exercise at night will drive most of the microfilariae out of the circulating blood back into the lungs. Breathing pure oxygen has the same effect. Contrariwise, if a monkey is deprived of oxygen, its infecting microfilariae rush out of the lungs into the bloodstream in daytime.

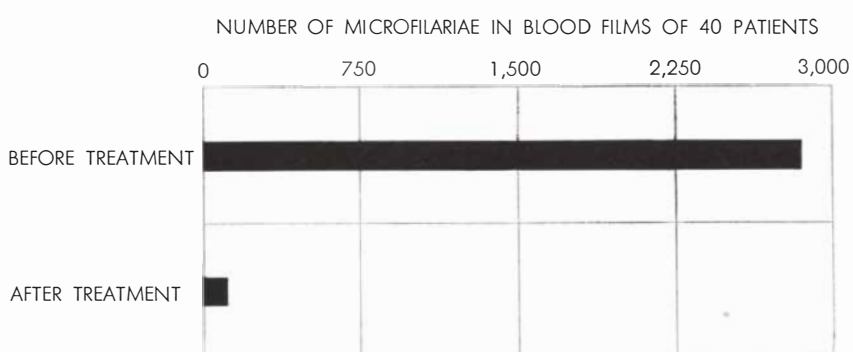
Unfortunately the different species of filariae we studied differed in their reactions to these various procedures. This difference of behavior was unexpected, and it raises the question whether the stimuli responsible for periodicity are the same for all species. The fact that almost all the species of microfilariae seem to be remarkably sensitive to changes of oxygen pressure (although they do not all react to it in the same way) is intriguing. One feels that somehow or other this sensitivity to oxygen must have something to do with the causation of periodicity. Yet the normal variation in oxygen pressure (and the other stimuli) during the usual 24-hour cycle of the body is so small that it cannot be the sole cause of the periodicity.

Turning now to the practical side of dealing with filariasis as a disease, we can be optimistic. Control of mosquitoes with insecticides will help (although DDT has not been altogether successful in eradicating the mosquitoes that carry filariae). Since 1947 a more direct attack on filariasis has been possible, as a result of the discovery of the drug Hetrazan by workers at the Lederle Laboratories in the U. S. This drug, taken by mouth, eliminates most of the microfilariae from the blood within an hour, and further treatment kills or sterilizes the adult worms.

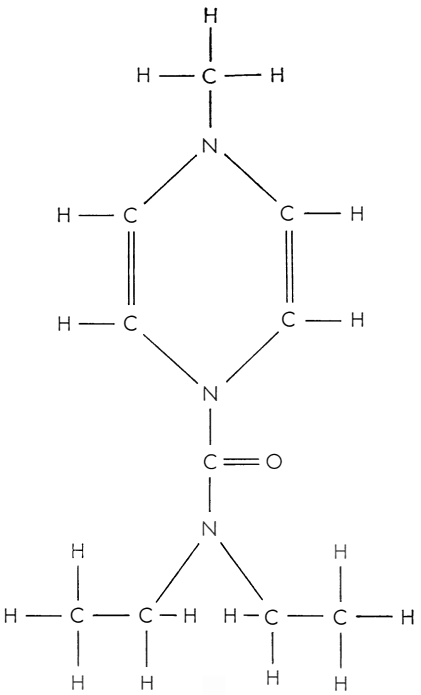
Killing the worms, however, does not necessarily cure the disease, for the blockage of lymphatic vessels with scar tissue, which is responsible for elephantiasis, persists after the worms have gone. The best hope is to eradicate the disease by giving the drug to all the in-



HETRAZAN TRIAL was carried out at Kennaba, a village in West Africa. Before treatment 155 persons had microfilariae in their blood (*black bar*), and 171 were free of infection (*colored bar*). After infected persons had been treated for 10 months, only 60 (*black section of lower bar*) still had filariasis, but 20 new cases had appeared (*black of upper bar*).



DROP IN FILARIAL DENSITY followed Hetrazan treatment. Before treatment blood samples from 40 persons contained a total of 2,845 microfilariae. After treatment similar samples showed only 113, a 96-per-cent reduction. Since a rather high density is needed for the adults to mate, the filariae might die out eventually if the low level were maintained.



MOLECULAR STRUCTURE of Hetrazan consists of atoms of nitrogen (N), carbon (C), and hydrogen (H). Another name for the compound is diethylcarbamazine.

fected people in a vulnerable area. The worms do not have to be wiped out completely; if they are only reduced to a low numerical level, the possibility of reproduction in the body becomes so small that they will eventually die out, as I mentioned earlier.

This use of the drug has now been tested in various parts of the world; we made such a test in West Africa in 1951 and there have been other tests on a large scale in Tahiti and in India. Briefly, the tests have shown that if all the people in a district take a daily dose of the drug for five days, or six to 12 doses spread over weeks or months, most of the filariae can be destroyed. If the treatment is repeated for several years on the people who still contain worms, the disease can be reduced to negligible proportions or eradicated altogether. Unfortunately it is not always easy to persuade people to take medicine in order that their neighbors will not catch a disease. Paradoxically, it is easier to control filariasis in heavily infested areas, where the people fear to contract elephantiasis and so are eager to cooperate, than it is in lightly infested areas, where the dangers of filariasis are less conspicuous. But as populations in the tropics become more health-conscious, it should be possible to get rid of filariasis in most of the areas where it now produces so much deformity and suffering.

MATHEMATICAL GAMES

Some diverting tricks which involve the concept of numerical congruence

by Martin Gardner

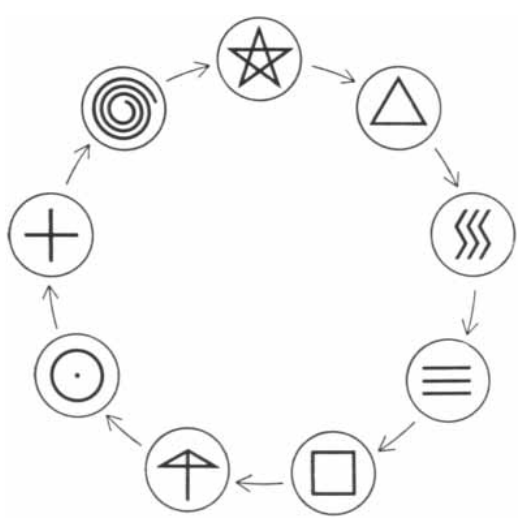
Jot down your telephone number. Scramble the order of the digits in any way you please to form a new number, then subtract the smaller number from the larger. Add all the digits in the answer. Now place your finger on the star in the circle of mysterious symbols at the bottom of this page and count them clockwise around the circle, calling the star 1, the triangle 2 and so on until you reach the number that was the final step in the procedure given above. Your count is sure to end on the spiral.

The operation of this little trick is not hard to understand, and it provides a painless introduction to the concept of numerical congruence formulated by the great German mathematician Carl Friedrich Gauss. If two numbers have the same remainder when divided by a given number called k, they are said to be congruent modulo k. The number k is called the modulus. Thus 16 and 23 both have a remainder of 2 when divided by 7 and are therefore congruent modulo 7.

Because 9 is the largest digit in the decimal number system, the sum of the digits of any number will always be congruent modulo 9 to the original number. The digits in this second number can then be added to obtain a third number congruent to the other two, and if we continue this process until only one digit remains, it will be the remainder itself. For example, 4,157 has a remainder of 8 when divided by 9. Its digits total 17, which also has a remainder of 8 modulo 9. And the digits of 17 add up to 8. This last digit is called the digital root of the original number. It is the same as the number's remainder modulo 9, with the exception of numbers with a remainder of 0, in which case the digital root is 9 instead of 0.

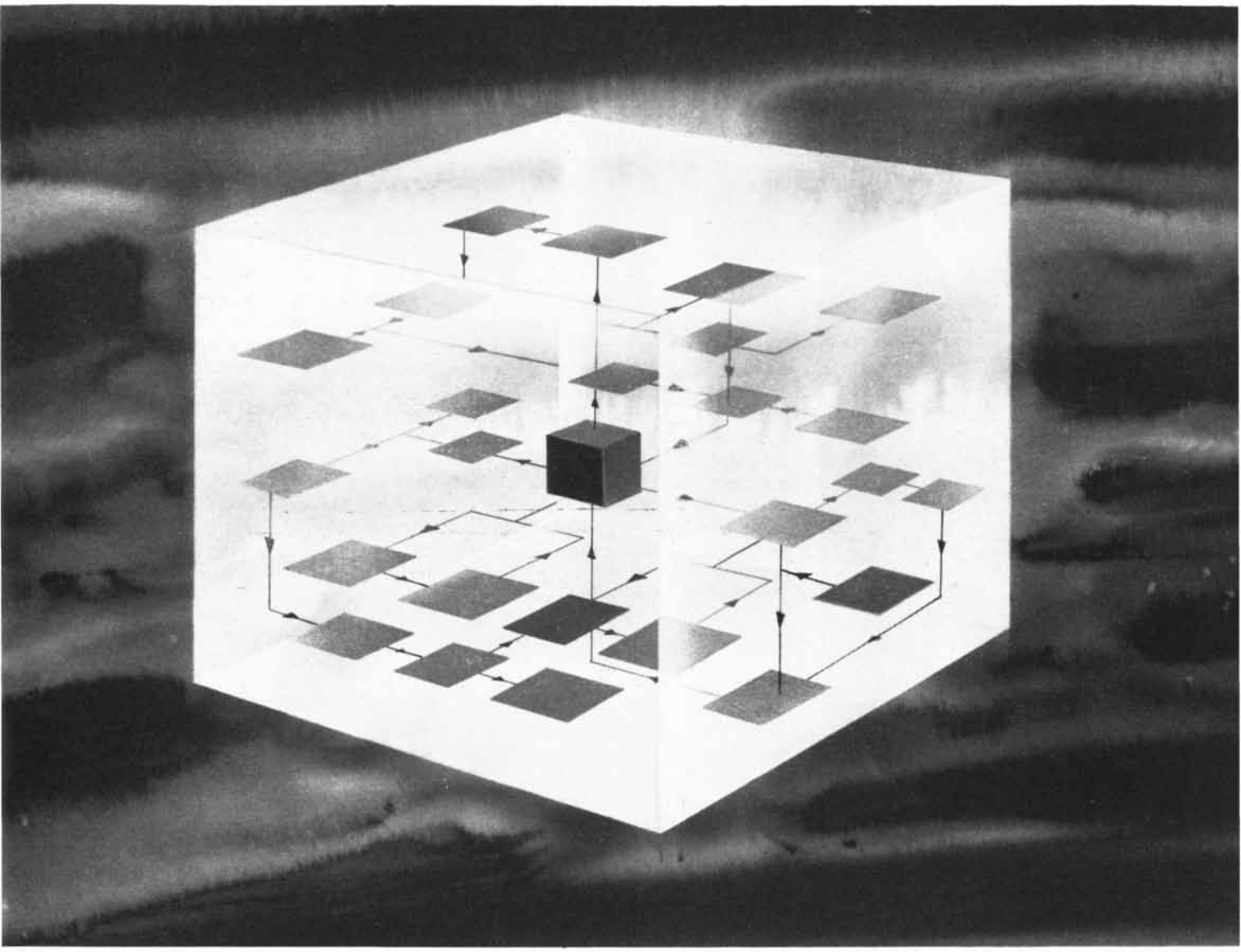
Obtaining the digital root is simply the ancient process of "casting out 9's" used by accountants for checking results before computing devices made the technique obsolete. If whole numbers are added, subtracted, multiplied or evenly divided, the answer will be congruent modulo 9 to the number obtained by adding, subtracting, multiplying or dividing the digital roots of the same numbers. Thus to check quickly a sum involving large numbers you obtain the digital roots of the numbers, add them, reduce the answer to a root, then see if it corresponds to the digital root of the answer you wish to test. If the roots fail to match, you know there is an error somewhere. If they do match, the probability is 8/9 that your computation is correct.

Let us see how all this applies to the telephone-number trick. Scrambling the digits of the number naturally will not change its digital root. When one number is subtracted from a larger one with the same digital root (that is, the same remainder when divided by 9), it is easy to see that the answer must have a digital



Symbols for a trick with a telephone number

REPORT FROM IBM YORKTOWN RESEARCH CENTER, NEW YORK



Simulation of the business firm

Recent preliminary studies at the IBM Yorktown Research Center indicate that techniques of digital computer simulation may be applied to problems of business firms operating under certain economic and statistical conditions. There are several phases to this investigation.

One phase involves the simulation of a firm's internal structure, including production planning, production, error-sensing and error-correction, through a system of decision centers interconnected by a communication network. *Another phase* of these studies involves a simulation of the activities of several firms in a competitive environment where the movement toward long-run equilibrium (or away from it) takes place via entry or exit of firms due to shift in market demand. At present, several situations of this type have been studied.

These projects begin to reveal the kind of assistance that may be expected from the use of simulation methods to study business. Work of this kind may lead to a means of more closely relating the economics of business firms to recent developments in production theory, inventory control, data processing and related fields—that is, to the development of a new branch of economic theory.

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root of 9 (that is, it must be evenly divisible by 9). Adding the digits in this answer will not change the digital root, so we are certain to end the procedure with a number that is a multiple of 9. Since there are nine symbols in the mystic circle, the count is sure to end on the ninth symbol from the first.

A knowledge of digital roots often furnishes amazing shortcuts in solving problems that seem unusually difficult. For example, suppose you are asked to find the smallest number composed of 1's and 0's which is evenly divisible by 225. The digits in 225 have a digital root of 9, so you know at once that the required number must also have a digital root of 9. The smallest number composed of 1's that will have a digital root of 9 is obviously 111,111,111. Adding zeros at significant spots will enlarge the number but will not alter the root. Our problem is to increase 111,111,111 by the smallest amount that will make it divisible by 225. Since 225 is a multiple of 25, the number we seek must also be a multiple of 25. All multiples of 25 must end in 00, 25, 50 or 75. The last three pairs cannot be used, so we attach 00 to 111,111,111 to obtain the answer—11,111,111,100.

Mathematical games also frequently lend themselves to digital-root analysis, as for example this game played with a single die. An arbitrary number, usually larger than 20 to make the game interesting, is agreed upon. The first player rolls the die, scoring the number that is uppermost. The second player now gives the die a quarter turn in any direction, adding the number he brings to the top to the previous score. Players alternate in making quarter-turns, keeping a running total, until one of them wins by reaching the agreed-upon number or forcing his opponent to go above it. The game is difficult to analyze because the four side numbers available at each turn vary with the position of the die. What strategy should one adopt to play the best possible game?

The key numbers in the strategy are those which have digital roots that are the same as the digital root of the goal. If you can score a number in this series, or permanently prevent your opponent from doing so, you have a certain win. For example, the game is often played with the goal of 31, which has a digital root of 4. The only way the first player can force a win is by rolling a 4. Thereafter he either plays to get back in the series 4-13-22-31, or plays so that his opponent cannot enter it. Preventing an opponent from entering the series is somewhat tricky, so I shall content myself with saying only that one must either play to five below a key number, leaving the 5 on the top or the bottom of the die; or to four or three below, or one above, leaving the 4 on the top or the bottom.

There is always one roll, and sometimes two or three, which will guarantee a win for the first player, except when the digital root of the goal happens to be 9. In such cases the second player can always force a win. When the goal is chosen at random, the odds of winning greatly favor the second player. If the first player chooses the goal, what should be the digital root of the number he picks in order to have the best chance of winning? This question will be answered next month by a chart showing the winning rolls for each root.

A large number of self-working card tricks depend on the properties of digital roots. In my opinion the best is a trick currently sold in magic shops as a four-page typescript titled "Remembering the Future." It was invented by Stewart James of Courtright, Ontario, a magician who has probably devised more high-quality mathematical card tricks than anyone who ever lived. The trick is explained here with James's permission.

From a thoroughly shuffled deck you remove nine cards with values from ace to 9, arranging them in sequence with the ace on top. Show the audience what you have done, then explain that you will cut this packet so that no one will know what cards are at what positions. Hold the packet face down in your hands and appear to cut it randomly but actually cut it so that three cards are transferred from bottom to top. From the top down the cards will now be in the order: 7-8-9-1-2-3-4-5-6.

Slowly remove one card at a time from the top of this packet, transferring these cards to the top of the deck. As you take each card, ask a spectator if he wishes to select that card. He must, of course, select one of the nine. When he says "Yes," leave the chosen card on top of the remaining cards in the packet and put the packet aside.

The deck is now cut at any spot by a spectator to form two piles. Count the cards in one pile, then reduce this number to its digital root by adding the digits until a single digit remains. Do the same with the other pile. The two roots are now added, and if necessary the total is reduced to its digital root. The chosen card, on top of the packet placed aside, is now turned over. It has correctly predicted the outcome of the previous steps!

Why does it work? After the nine cards are properly arranged and cut, the 7 will be on top. The deck will consist of

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Dr. Charles F. Meyer
Assessment Division Supervisor
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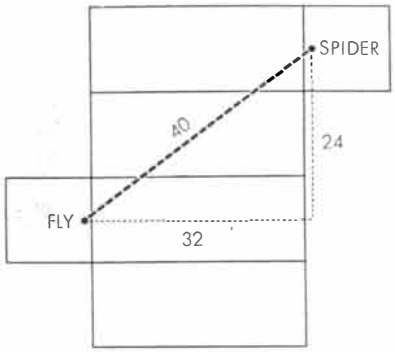


The problem of the spider and the fly

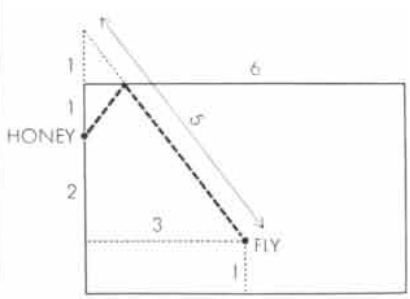
43 cards, a number with a digital root of 7. If the spectator does not choose the 7, it is added to the deck, making a total of 44 cards. The packet now has an 8 on top, and 8 is the digital root of 44. In other words, the card selected by the spectator must necessarily correspond to the digital root of the number of cards in the deck. Cutting the deck in two parts and combining the roots of each portion as described will, of course, result in the same digit as the digital root of the entire deck.

The answers to last month's problems follow.

The shortest walking path of the spider to the fly is exactly 40 feet, as indicated on the unfolded room shown in the drawing at the top of this page. The reader may be surprised that this geodesic carries the spider across five of the room's six sides.

The fly reaches the honey along the five-inch path drawn on the unrolled cylinder depicted at the bottom of this page. This is the path that would be taken by an imaginary beam of light moving across the rectangle from fly to honey and reflected by the rectangle's upper boundary. Clearly it is the same length as the hypotenuse of a right triangle with sides of three and four, as indicated.

The two fractions whose cubes add up to six are 17/21 and 37/21.



The problem of the fly and the honey

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THE AMATEUR SCIENTIST

How a Kansas amateur group counts meteors by reflection of radio waves

Conducted by C. L. Stong

In recent years many backyard observatories have acquired a new aspect. The circle of cane-bottomed chairs which formerly welcomed the visitor has all but vanished in favor of the relay rack, high-gain amplifier and data recorder. Even the place where the visitor once put his eye has been usurped by a small black box. The telescope continues to sweep the sky from its central spot beneath the dome, but the whir and click of automatic devices now accompany the stars on their silent march.

Today it is not unusual to find amateur astronomers operating a dozen or more electronic instruments which were all but unknown before World War II. The trend was launched when electric motors developing a fraction of a horsepower began to displace mechanical clocks for driving small telescopes in right ascension. Then came vacuum tubes, tied together by feedback circuits, to regulate the motors. Amateurs next discovered that the photoelectric cell makes a good substitute for the eye, particularly on fatiguing jobs such as keeping a star centered on crosshairs. The introduction of electronics into amateur astronomy suggested a logical new development: amateur radio astronomy.

Many amateurs have expressed interest in building a radio telescope, but few have actually built one. The chief barrier appears to be the lack of a simple design. If any amateur has built such an apparatus with the facilities of the average basement workshop, this department would like to hear about it. Meantime we have learned of a group in Manhattan, Kan., which has completed a related project: a device to count meteors electronically. The apparatus is described by W. S. Houston, editor of *The Great Plains Observer*, official bulletin of amateur astronomers in the Midwest.

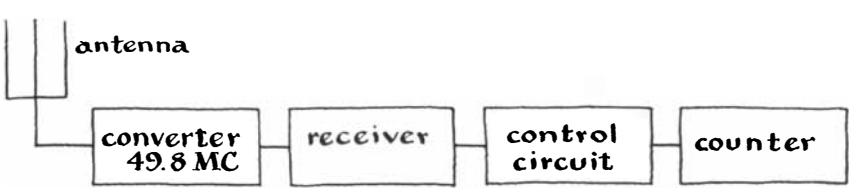
"When a meteor flames through the upper atmosphere at a height of 50 to 100 miles," writes Houston, "it leaves an ionized trail in the air which may vary in diameter from a few feet to a mile or more, depending on the size of the meteor. The mechanism responsible for the trail is not fully understood. Some trails last several minutes. Others vanish after a second or less. In any case, such trails act as excellent reflectors for radio waves, especially those in the range of 30 to 90 megacycles. Short-wave transmitting stations too distant for normal reception come in loud and clear when their signals are reflected by meteor trails. The duration of the propagation depends on how long the displaced electrons bounce around before recombining with atoms of gas.

"There is nothing new about this, of course. Radio 'hams,' at least the handful who go in for experiments aimed at extending the bounds of knowledge, have long been accustomed to hearing weak signals from long distances suddenly build up to window-rattling proportions and to developing psychological resistance to the brief yowls which occasionally punctuate otherwise clean transmissions. As long ago as 1940 the hams correctly ascribed these weird effects to meteors. Cliff Simpson (W0YUQ), a pioneer in the ultrahigh-frequency portion of the radio spectrum at Manhattan, Kan., had been seriously playing with meteor propagation for several years when the great Giacobinid meteor shower came along on October 9, 1946. The fall created something of a sensation in ham circles. Radiotelephone signals came through from stations hundreds of miles away on frequencies normally limited to line-of-sight transmission. The reflected paths were so solid that many lengthy conversations took place.

"As is often the case, particularly in radio, the scientific world trailed the amateurs. Meteor propagation failed to attract serious interest until the National Bureau of Standards a few years later installed a 20-kilowatt station at Cedar Rapids, Iowa, for the study of forward-scatter propagation between the Midwest and Washington, D.C. Numerous brief intervals of high transmission were immediately observed; thus the Bureau independently discovered what the hams had known for years.

"Last fall the local section of the American Meteor Society at Manhattan decided to take advantage of the phenomenon for making a systematic count of meteors. Thanks to the invaluable cooperation of two local hams, Simpson and Ben Mullinix, we have installed an automatic system not only for making a continuous, round-the-clock count of meteors, but also for monitoring auroral effects.

"On a clear night, anywhere on earth, you may expect to see about six meteors per hour. As many as one per second may appear on some nights. Because the observer's field of view is limited, meteors counted at any one location represent only a minute fraction of the total fall. Rough calculations indicate that some four million meteors bright enough to be seen cross the sky every 24 hours. By including those brighter than the 10th magnitude the estimate rises to four billion. Counting a reliable sample of that many invisible objects within the range of a single observer was impossi-



Block diagram of electronic meteor-counting system

ble before the development of very sensitive photographic plates, and it was not easy thereafter. Background light from the sky limits the time during which sensitive plates can be exposed before they become fogged and thus also limits the number of meteors which can be detected with a single plate. The radio counter avoids these limitations, although it introduces a few of its own.

"The transmitter we use is the Bureau of Standards station at Cedar Rapids. The frequency is 49.8 megacycles. The station is beamed toward Washington, D.C., by a rhombic antenna, a diamond-shaped array of wire supported by telephone poles which creates a highly directional pattern of radio waves. However, enough energy leaks from the sides of the structure to send a strong signal in our direction. Actually, because of the earth's curvature, the signal crosses Kansas at a height of about 15 miles, so that we cannot receive it directly. But meteor trails reflect part of the signal to our station.

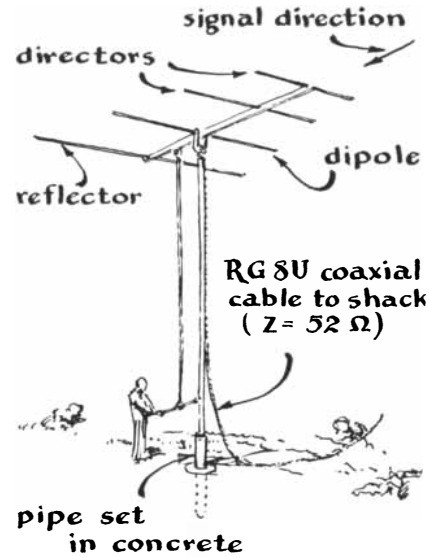
"We pick up reflected signals by a directional antenna of the Yagi type, about the size and same design as a conventional television antenna. The antenna is made of aluminum tubing, one tube being cut in the middle for the receiving dipole, a slightly longer one backing the dipole as the reflector, and two progressively shorter ones mounted in front as directors. The geometry of the assembly is adjusted to the frequency of the transmitter for maximum response. The Yagi is mounted on a steel support for rotation in both azimuth and elevation. The support consists of a pair of telescoping steel pipes, one of which is sunk in concrete. The array is turned by hand. The antenna stands about 10 feet above the ground. Normally we point it toward the horizon, but it can be elevated to any angle desired. A 50-ohm coaxial cable carries the signal into the observatory.

"The incoming signal is fed to a short-wave converter tuned to 49.8 megacycles and locked on frequency by a quartz-crystal oscillator. We normally detect a signal on this frequency only when the signal is reflected by a meteor trail. Trying to tune a receiver by occasional signal bursts proved too much for our patience, so we decided that crystal control is a must. Parts for the converter cost $12.50. The receiver is an Army surplus job modified considerably by Simpson. It is also crystal-controlled, and it is fed by the converter at seven megacycles. The receiver features a so-called 'squelch' circuit which in principle resembles the conventional automatic volume-control. Instead of maintaining the output at a uniform level, the squelch circuit cuts the sound completely in the absence of a signal and turns the set on fully when signals appear which are higher than the average background noise. A control is provided for adjusting the squelch to any desired signal level. Hence the output of the receiver is dead until a signal appears. Finally the receiver is equipped with a variable oscillator, the output of which can be mixed with the signal. The pitch of the resulting beat note can thus be adjusted as desired.

"Audio output from the receiver is fed to a control circuit which in turn actuates a sensitive relay. The control circuit is built around a 6SQ7 tube, as shown in the accompanying illustration [*next page*]. The arrangement functions both as a detector for converting the audio signal to direct current and as an amplifier for energizing the relay. A delay element is built into the control circuit which discriminates against groups of signal pulses which persist for less than three seconds. Such groups register a single count. The delay arrangement consists of a one-megohm resistor bridged by a two-microfarad capacitor connected between the Stancor choke and ground. If control of the response time is desired, the fixed resistor may be replaced by a rheostat. The relay is of the type used for controlling model airplanes by radio. They are sold by most hobby shops. The transformer [T_1 *in the illustration*] is a conventional output-transformer hooked up backward.

"The counter is a standard telephone job of the rachet type that is available on the surplus market. It is energized through the relay of the control circuit and reads to 9999. A loudspeaker is bridged across the output of the receiver so that the observer can monitor meteors by ear.

"The system is not free of error. Lightning strokes, even at appreciable distances, are counted along with meteors. The difference can be spotted by ear. Meteors cause a beat note; lightning makes a short, crackling hiss. The level of the squelch setting has an important effect on the count, and it tends to drift. As an aid in maintaining the optimum adjustment we inserted a milliammeter in the circuit. The operation of light switches, plugging or unplugging appliances into the power line, and so on are also counted. When the sporadic E layer of the ionosphere appears, the relay pulls down, putting us out of business. In short, any noise greater than the threshold at which the squelch circuit is set to operate will register as a count or, if it lasts long enough, mask a count.

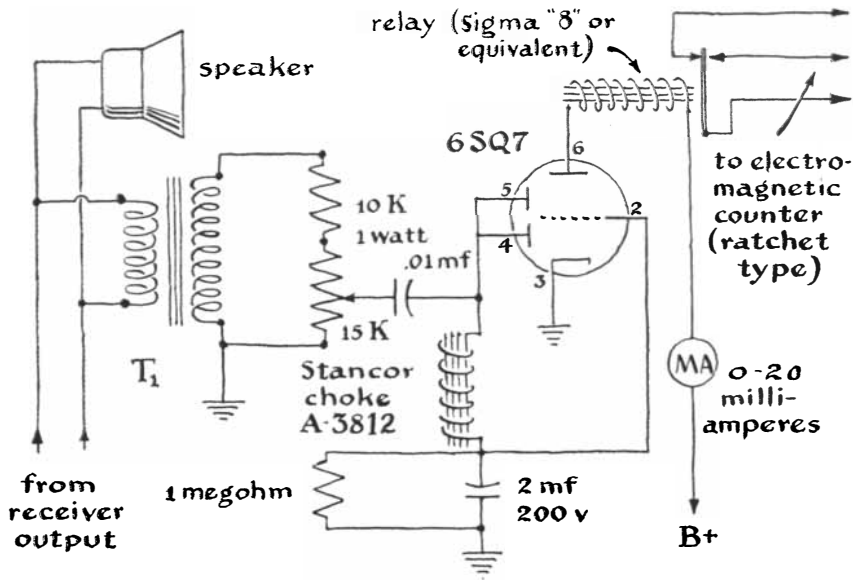


Yagi antenna of the system

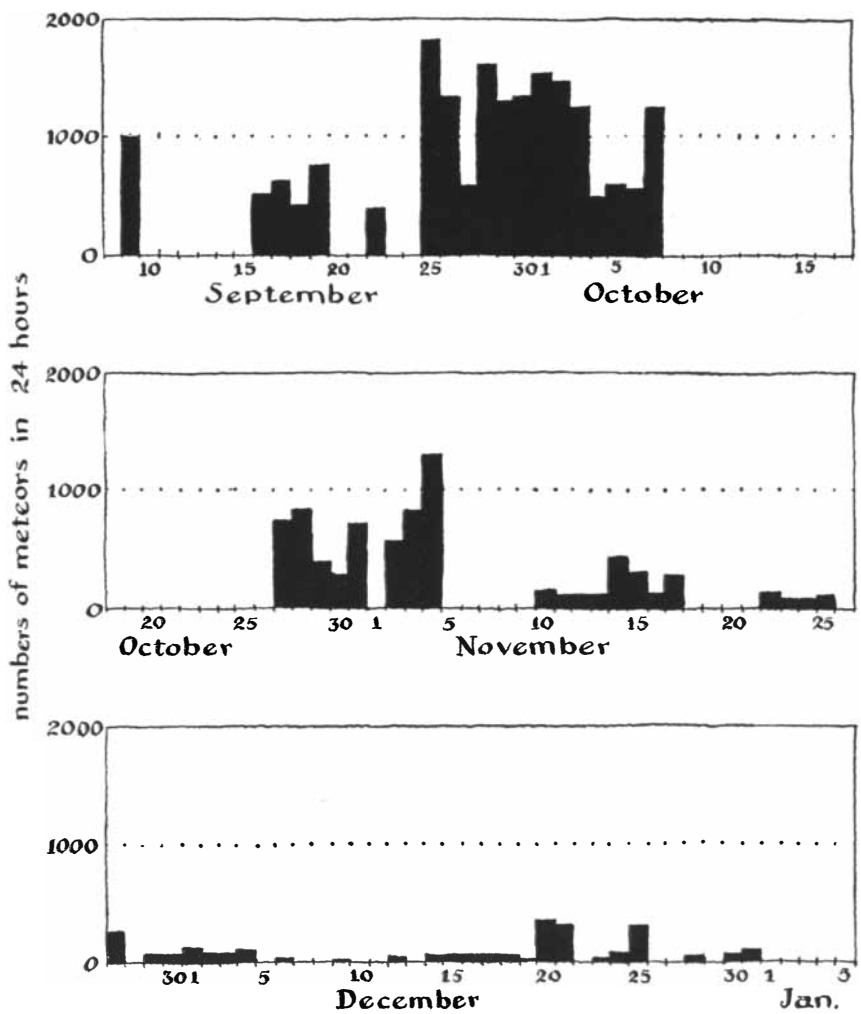
"A number of alternative methods are available for reducing the error, if one is willing to dig into his wallet. For example, Simpson has suggested a system based on two receivers. The outputs of the two units would be connected so that the signal voltages would be 180 degrees out of phase and would buck one another. One receiver would be locked to the frequency of the transmitter by a quartz-crystal oscillator. The other would be tuned to a slightly different frequency. Both receivers would pick up equal amounts of noise. The resulting noise signals would oppose each other in the control circuit and disappear. In contrast, the desired signal would appear at the output of only one receiver (the one tuned to the transmitted frequency)—and hence would pass through the control circuit unopposed. A pair of BC 454 surplus receivers should work nicely in such an application. Only one would require modification for crystal control; the other would function solely as a noise detector.

"We found that many meteors, particularly those of long duration, produced a warbling note. At first each fluctuation was counted as an individual trail. This was cured by the delay circuit, which holds the relay closed during momentary lulls and prevents overcounting. Too much delay can be introduced. We compromised on a delay of three seconds. If two or more meteors fall within this interval, our equipment counts them as one.

"When the system first went into op-



Schematic diagram of the control circuit of the meteor-counting apparatus



Record of meteors counted electronically by the Kansas group

eration we asked: 'Are we really counting meteors?' We got the answer by watching near the horizon in the direction of Cedar Rapids. Within a minute or so a faint streak of light appeared in the sky. The counter clicked and the speaker emitted a loud beep. The system worked! In general we observed that any meteor which can be seen makes an abnormally loud beep. We estimate that the system is capable of counting meteors down to the ninth magnitude. We have not explored the angular range over which we can get radio-visual coincidences, but one night we observed a coincidence at an altitude of 45 degrees. Incidentally, visual meteors more than 30 degrees off the axis of the Yagi are not counted. None are heard if the antenna is turned at right angles to the direction of the transmitting station.

"The system operates over an area considerably greater than an observer can cover visually. Visual observations are limited to a cone some 30 degrees in diameter. The beam of our system covers about 40 degrees. When the radio cone is projected to the area containing the trails, it is obvious that far more sky is under surveillance than a visual observer beneath the area could command. The counting rate of the system is accordingly higher, even for meteors of the first magnitude, than would be reported by a visual observer. If the squelch circuit is turned off, the normal count rises to as much as 200 per hour, and can be heard by listening for trails under the noise. With the squelch fully on, only brighter meteors are counted or heard; they run from 25 to 500 per day.

"The system can also be used for detecting auroras. When the northern lights are active, even if not visible from Manhattan, we can turn the Yagi north and count meteors. Signals directed to the north by the transmitter apparently bounce off meteor trails and the aurora reflects the signals back to us. We accordingly monitor auroras by pointing the Yagi to the north and keeping it there as long as the counter operates.

"The apparatus has now been in intermittent operation for about 10 months, with gaps in the records representing thunderstorms and time out for adjustments, modifications and repairs. During the early passes of Sputnik I and Sputnik II we shut the system down so that we could borrow the Yagi for satellite tracking. The station is now fully equipped for satellite work, thus removing this handicap to the meteor program.

"Some of the raw data gathered during the last four months of 1957 are shown in the accompanying chart [*at*

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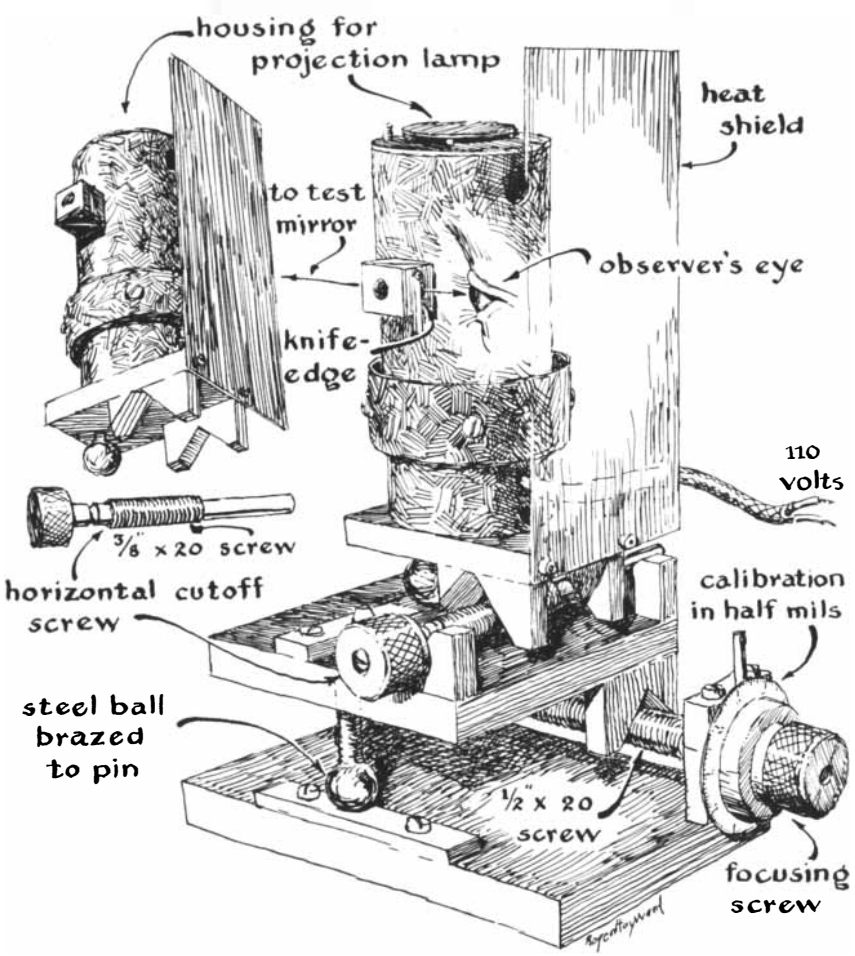
bottom of page 110]. It is too early to estimate how good these records may be. We are still looking for sources of error and attempting to learn the best methods of operation. Our goal is a full year's run. Amateurs who would like to hear meteors on ordinary receivers should tune to the 20-megacycle channel of WWV or to a comparable channel of some other high-powered transmitter which has either faded out or almost out. Bursts of strong signal will mark the fall of meteors. Some patience may be needed, particularly if one is uncertain of the precise point at which to tune the receiver. Those who detect the Cedar Rapids beam all the time of course cannot use it for meteor counting."

In making a reflecting telescope the amateur first grinds one disk of thick glass on top of another with successively finer grades of abrasive between. The grinding action is such that the upper disk of the pair develops a slightly concave spherical surface. This surface is polished on a lap of filtered pitch charged with rouge and then, by continued polishing, deepened toward the center just enough to transform the sphere into the desired paraboloid.

In most small telescopes the difference between the sphere and paraboloid amounts to only a few millionths of an inch. For measuring such fine dimensions the amateur uses a remarkably primitive instrument first suggested by the French physicist Léon Foucault. Basically the device consists of an artificial star and the edge of a knife. Foucault's star was merely a pinhole illuminated by a candle. Rays from a pinhole situated adjacent to the center of curvature of a spherical mirror come to focus at a point directly opposite the pinhole on the other side of the mirror's optical axis. When the eye is placed behind the focus, the spherical figure appears flat. If a knife-edge is passed through the focus, the disk darkens uniformly. But any departures from the true sphere deflect the rays so that the departures appear as hills or valleys magnified about 100,000 times.

Most amateurs prefer to work with more sophisticated versions of Fou-



An amateur's apparatus for the Foucault knife-edge test

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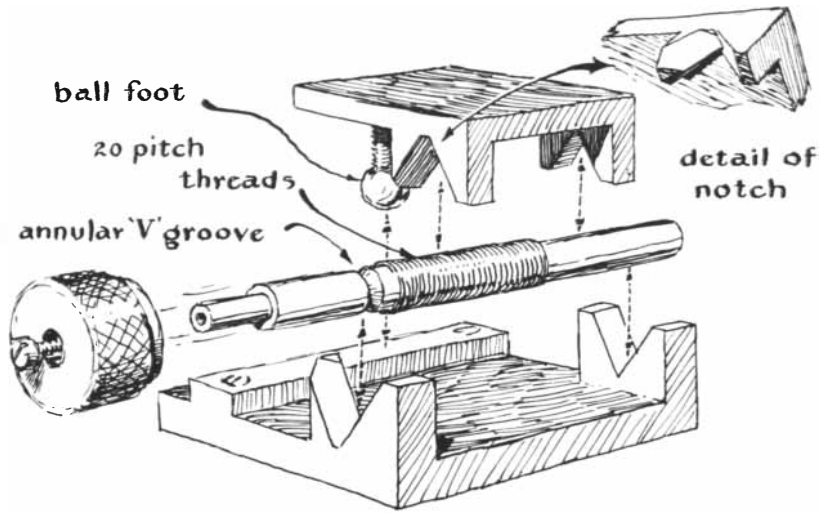


Foucault-apparatus carriage based on the principle of kinematical design

cault's apparatus, although the truly patient fellow can get along with the classic setup. C. N. Fallier of Hicksville, N.Y., submits a version of the instrument.

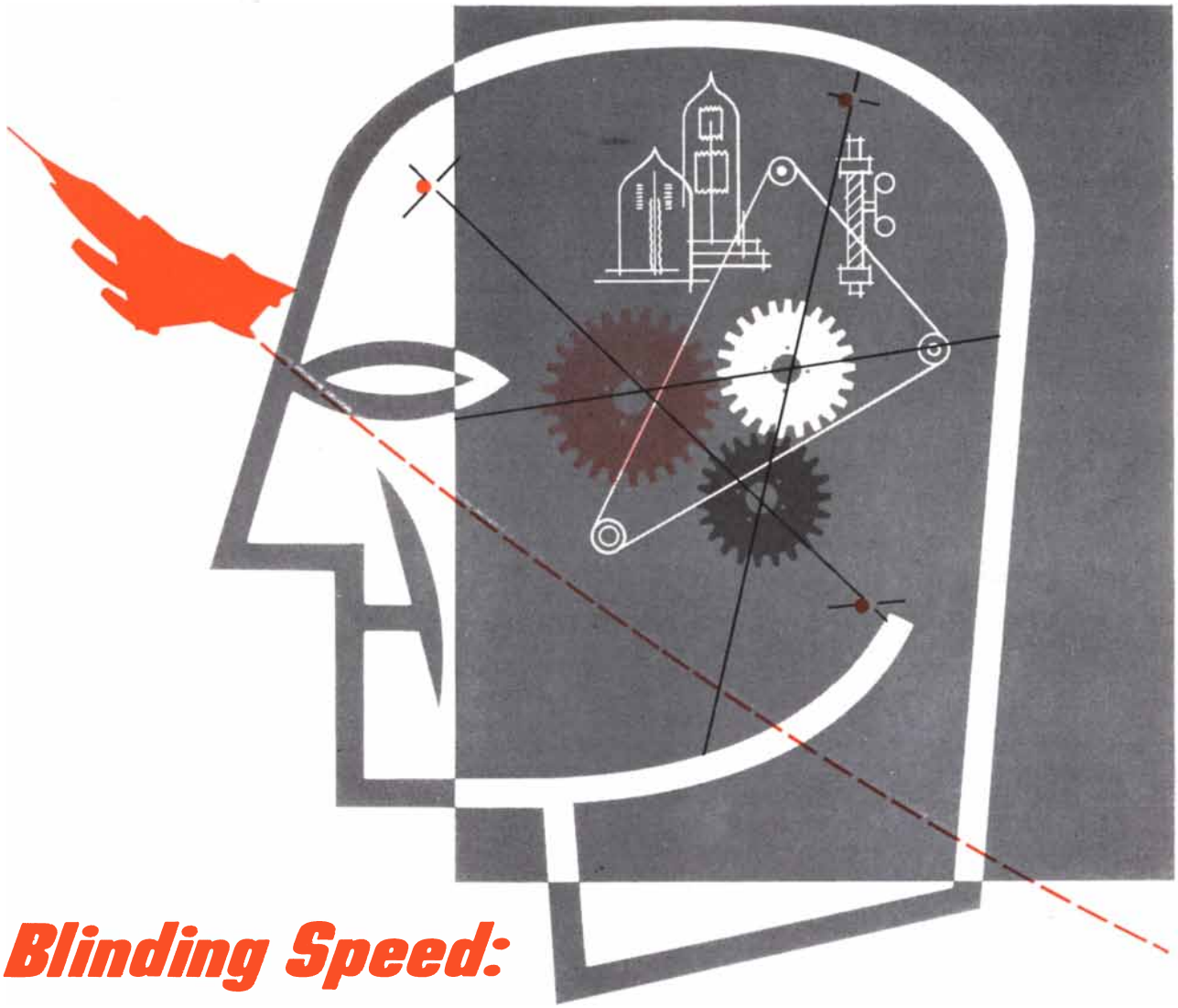
"Like numerous other amateurs," he writes, "I have read reams of literature on grinding, polishing and figuring mirrors for reflecting telescopes. While most of these papers have been manifestly clear as to the mirror itself, the Foucault knife-edge tester is invariably dismissed as a rudimentary device—usually described as a tin can with a lighted pinhole and a movable knife-edge fitted to a hand-drawn scale.

"After many attempts (with as many failures) to make accurate measurements with such home-built testers, I decided to make the job easier for myself. My design uses a light bulb, pinhole and knife-edge, and so does not depart in essentials from Foucault's arrangement. But I have combined them in a stable mechanical assembly which is convenient to use, easy to make, and which yields highly reproducible measurements. The design provides for both longitudinal and transverse movement of the knife-edge under the control of feed screws [*see illustration on page 112.*]

"The device resembles the compound rest of a lathe but is based on the principle of kinematical design described by John Strong in his *Procedures in Experimental Physics*. This principle states that a body must have at least six minus n points in contact with a second body if it is to have only n degrees of freedom. The screw for advancing the carriage in the direction of the mirror has been accordingly provided with five points of contact with respect to its reference body, the base. This is accomplished by beveling one arm of one of the two V-notches in which the screw rides. The bevel engages the annular V-groove of the screw shaft and accounts for two contacts. The unbeveled arm of the same V-notch makes the third contact with the screw. The flat arms of the remaining V-notch provide the remaining two for a total of five contacts. Thus the screw has one degree of freedom, that of rotation. In contrast, the carriage which rides on the screw is provided with six points of contact with respect to its reference body (the screw and the base): five with the screw and one by the ball in contact with the base proper. Thus the position of the carriage is uniquely determined by each setting of the screw. The design of the transverse carriage conforms to the same principle.

"The only machine work involved in making the unit is the removal of threads from each end of the prethreaded screw stock (for contact with the V-notch bearings), and the cutting of the annular V-groove in the shaft. All other work can be accomplished with a hacksaw, file and drill. The dials and knurled knobs are from surplus gear.

"The light source is a conventional incandescent bulb of the type used in sound heads of 16-millimeter movie projectors. The beam is deflected at a 90-degree angle by a microscope cover-glass. This is not the best possible arrangement because the two surfaces of the glass reflect a double image of the pinhole. I plan to overcome this by replacing the cover-glass with a beam-splitter of the prism type. A piece of ground glass is mounted between the lamp and pinhole to prevent a magnified image of the lamp filament from appearing at the focus."



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BOOKS

About the life and work of Sir Arthur Eddington

by James R. Newman

ARTHUR STANLEY EDDINGTON, by A. Vibert Douglas. Thomas Nelson and Sons Ltd. ($6.25).

Sir Arthur Eddington was a leader of the 20th-century revolution in science, and one of its victims. He was a leader as an astronomer, and as an apostle and interpreter of the theory of relativity. He was a victim as a philosopher. No contemporary man of science, I venture to say, has penetrated more deeply into the scheme of the physical world. Yet he came upon the scene both too late and too early. When in 1915 Einstein completed the general theory of relativity, Eddington was 33. He was among the first to grasp its significance fully; his contributions to its development and understanding earn him a place with such pioneers as Willem de Sitter, Hermann Minkowski and Hermann Weyl. But, as the British astronomer Herbert Dingle has observed, Eddington's view of the nature of the scientific problem was in 1916 "so firmly established in his mind that it was impossible, even for him, then to shake it off; and that view was incompatible with the implications of relativity." Eddington used a metaphor to describe the conservatism of his fellow physicists in general; he said they tried to fit the organism of relativity into the Procrustean bed of their Victorian philosophies. The fact is that he made the same attempt. Inevitably he failed. Few persons today delve in his philosophy; even fewer take much thought to his complex and obscure fundamental theory. But the feeling persists that in this last work lie truths which he alone had glimpsed—a vision which he perceived but could not utter.

Eddington died in 1944. Three years later a lectureship was instituted at the University of Cambridge as a memorial to him. In the lectures philosophers, scientists, historians, theologians have paid tribute to the character and thought of this admirable man. Recently Noel B. Slater, a British mathematician, published an analysis of the development of Eddington's posthumous volume, *Fundamental Theory*, based on a study of several manuscript versions of the work. Now we have a biography by A. Vibert Douglas, a former pupil and research associate of Eddington, who is professor of astronomy at Queen's University in Ontario. Dr. Douglas's task was not easy, because written material relating to her subject's life was scant. Eddington kept a journal which described his student and his Greenwich Observatory days, his travels and holiday activities, but beginning with his middle years it contained nothing except a record of his "cycling mileages," and the sales and receipts of his books. The only other source was a series of letters to his mother, who died in 1924. Dr. Douglas had to scratch for anecdotes, opinions of contemporaries, and other bits and pieces. She has turned out a respectable chronicle, neither personally revealing nor profound, but a straightforward account from which one may form one's own picture of this solitary, inward bachelor.

Eddington was born in Kendal, an ancient town of the English Lake District, in December, 1882. His parents were Quakers, and throughout his life he remained deeply committed to this peaceful faith. His father, a man of excellent education, was headmaster of a local Friends' school. He died in an epidemic of typhoid at the age of 34, leaving his wife poor and with two small children: Arthur, aged two, and a daughter, Winifred, aged six. Despite her very limited means Mrs. Eddington managed to send her son to private schools. Arthur was reportedly precocious. He had a prodigious memory and a passionate interest in large numbers. He learned the 24 × 24 multiplication table before he could read, counted the letters in the Book of Genesis (as part of a larger program he had set himself to count the letters in the entire Bible), and when he was four promenaded in the evening so that he could count the stars. At 10 he began his career as an astronomer by borrowing a three-inch telescope and surveying the sky. He had good teachers who appreciated him and stimulated his scientific bent; he repaid their devotion by scholastic achievements. With the help of various scholarships won in competitive examinations, he gained an education at Owen's College, Manchester, and at Trinity College, Cambridge. At Owen's he is remembered as "a small boy who went to college in a cap" in the days when bowlers were *de rigueur*; however, it was soon recognized "that what was under the cap was at least as extraordinary as the cap itself." Never, said the principal, had he met a boy so modest, so gentlemanly, so able.

His record at Trinity was no less brilliant. With that historic college, where Isaac Barrow, Newton, Macaulay, Tennyson, James Clerk Maxwell, Lord Rayleigh, Joseph Larmor and J. J. Thomson had made their "intellectual home," he began in 1902 a connection which, except for an interlude of a year and a half following graduation, was to last 42 years. He threw himself into work for the competitive examinations called the mathematical tripos, and soon impressed his contemporaries with his immense capacity for concentration. E. T. Whittaker and Alfred North Whitehead were among his teachers. After two years he took the tripos and came out on top. It was the first time a second-year man had won the distinction of Senior Wrangler. Exceptionally quiet and reserved, he formed few friendships, but he did not hold himself entirely aloof from his fellow students. With one close companion, C. J. A. Trimble, he took long, strenuous walks and climbs and spent many holidays. Cycling was his favorite sport. The careful record he kept from 1898 to 1944 of special rides shows many cycling trips of 100 miles or more a day; even in the last year of life he often pedaled solo 50 to 75 miles in a few hours. In addition

to these athletic statistics, his diary describes his journeys abroad and his readings. His tastes were broad, ranging from Homer to Kipling and Kenneth Grahame. A knowledge of French, German and Italian enabled him to read Molière, Goethe and Dante in the original.

In 1906 he accepted a post as chief assistant at the Royal Observatory in Greenwich. For seven years he enjoyed the many duties of a practical astronomer: observational work, checking star catalogues, compiling data for statistical analysis, computing instrumental constants. He redetermined the longitude of a geodetic station on the island of Malta; went to Brazil on an eclipse expedition; wrote papers on a wide range of astronomical problems, several having to do with the motions of stars. Soon after coming to Greenwich he was elected a Fellow of Trinity College, and in 1913 he was appointed to the Plumian chair of astronomy at Cambridge. The following year he was elected a Fellow of the Royal Society. His career was "well launched and thirty years of achievement lay before him."

Eddington's first book, *Stellar Movements and the Structure of the Universe*, was published in 1914. It gained him instant recognition as both a creative astronomer and a lucid and engaging writer. Addressed to the general scientific reader as well as to astronomers, the book opened to view a fresh, truly magnificent aspect of the physical universe. Herbert Dingle has said that when he first acquired his copy he learned to see the sky "with new eyes." In each subsequent book Eddington led "an increasing number of people to see with new eyes the ever-expanding universe of stars and atoms and radiation, and the strangely beautiful mathematical relationship between them."

Among Eddington's astronomical papers of this period, several deal with radiation pressure, a subject to which he made a momentous contribution. The central problem was how a star maintains its internal equilibrium. Gravity and gas pressure were thought to be the major factors. Early in the century the German astronomer Karl Schwarzschild, following up some pioneer work by R. A. Sampson, proposed a theory of radiative equilibrium for a star's atmosphere. Eddington extended this with an ingenious model of the interior of a star. According to his model the pressure exerted on the stellar gas "by the outsurging heat and especially by the shorter wavelengths of the radiant energy would almost balance the entire downward pull of gravity in a giant star." Gas pressure was relegated to a minor role. To explain the longevity of stars he suggested that they drew "on some unknown supply of energy"—perhaps "a slow process of annihilation of matter." This unknown source was elucidated 20 years later by Hans Bethe's cycle of nuclear changes; but even as vaguely envisaged by Eddington the idea fell, as Dr. Douglas says, "like yeast" into the minds of contemporary scientists. A less yeasty effect was felt by one investigator: James Jeans, already noted for his researches in mathematical physics. His field of interest included astronomy, and on various occasions he had challenged Eddington's views. The notion of a constant generation of energy within a star made Jeans distinctly feverish. To the delight of their audiences the two men now verbally whacked each other at various scientific meetings. Jeans suggested that Eddington's bizarre conclusions were due to his weakness in arithmetic; Eddington replied in effect that Jeans didn't know how to read. A gentlemanly tone prevailed, but the radiations were unmistakably intense. It is almost unnecessary to add that neither man persuaded the other to budge.

Eddington worked for some time on the problem of pulsating stars—the Cepheid variables. This provoked another word war with Jeans, as did Eddington's famous paper on the relation between the masses and luminosities of the stars. The latter study is one of the best examples of Eddington's power and imagination as an astronomical thinker.

A giant star of low density could be supposed to be extremely bright because its "ether-waves," from X-rays to light, are forced out by a steep temperature gradient. Yet there was a huge discrepancy, which prevailing theories could not explain, between the star's expected and observed brightness: the latter fell short of the former by a factor of many millions. Eddington showed that the radiation waves are "hindered and turned back by their adventures with the atoms and electrons," and thus the leakage to the surface of the star is considerably reduced. On the assumption that a star behaves as though it were a "perfect" gas (*i.e.*, a gas composed of perfectly elastic molecules which neither attract each other nor spin), he was able to demonstrate an astonishing correlation, for all ordinary stars, between mass and luminosity. The more massive the star, the more energy it pours out. He ransacked his mind for an explanation of this surprising result. The dwarf stars raised a sticky point because they were thought to be too dense to obey the law of perfect gases; yet the mass-luminosi-

ty ratios of dwarfs also fell on the theoretical curve and confirmed his formula. Then it occurred to him that within a star "disrupted atoms may pack together to a far higher density than ordinary matter," without any breakdown of perfect-gas conditions. The sun, he asserted, in spite of being denser than water, really is a perfect gas. Even more incredible were the properties of the "white dwarfs," such as the companion of Sirius. He calculated that this F-type star had a surface area and diameter about the same as that of the earth, yet a mass about four fifths that of the sun. Its density therefore was fantastic—more than 50,000 grams per cubic centimeter. The conclusion was absurd, but it was inescapable. Indeed, it foretold an Einstein shift of spectral lines actually confirmed by observations at Mount Wilson shortly thereafter. In *The Internal Constitution of the Stars,* published in 1926, were summarized the preceding 15 years of Eddington's brilliant astronomical investigations.

I turn back to consider briefly Eddington's interest in relativity.

In 1911 Einstein announced his principle of equivalence, and four years later he completed the general theory of relativity. Because of the war there was no direct communication between German and British scientists, but in 1916 Eddington received from the Dutch physicist Willem de Sitter copies of his own papers and of Einstein's latest paper. As a Quaker, and only for that reason, Eddington had been exempted from military service (the British were spectacularly stupid during that war about deferring scientists, which is why the physicist H. G. J. Moseley and other exceptional men were killed) and thus had had time to apply himself to the new ideas. He quickly recognized their supreme importance and mastered the very difficult absolute calculus and tensor mathematics needed to follow the argument. The Physical Society of London asked him to analyze Einstein's system, and in 1918 he published a masterly *Report on the Relativity Theory of Gravitation.* No subject was better suited to Eddington's bent of thought, to his scientific skills and philosophical leanings. It stirred the mystic and visionary in him, as well as the cosmologist and mathematician. In the *Report,* as J. G. Crowther has written, Eddington not only restated Einstein's work, but "joyfully took wings in flights of physical and mathematical thought and fancy of his own."

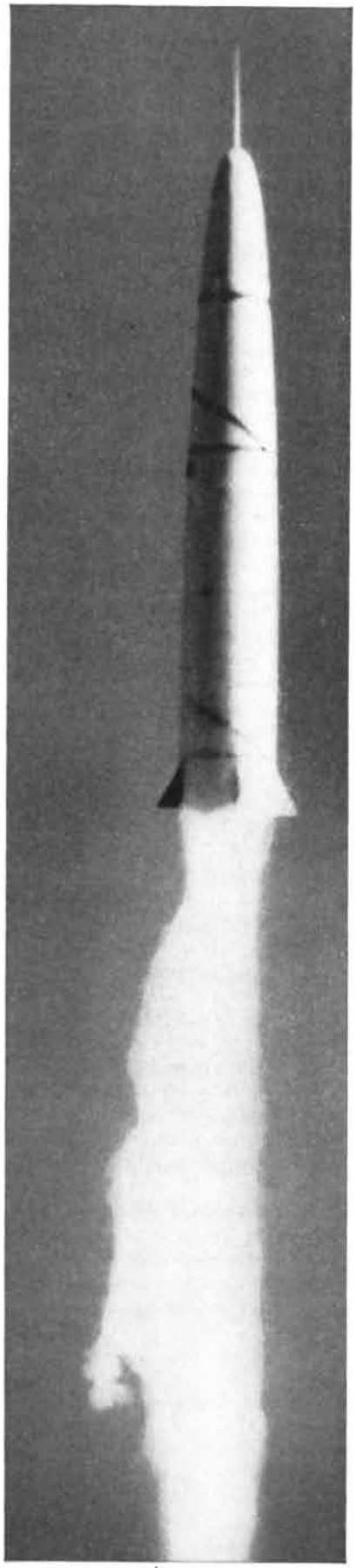
A crucial test of the general theory involved the determination of the deflection of light by a gravitational field. The total solar eclipse of May 29, 1919, offered an excellent opportunity for confirmation. As the leading exponent of relativity theory, Eddington was selected to head the eclipse expedition to the small island of Principe off the west coast of Africa. (Another expedition went to Sobral in Brazil.) He sailed in March and, after landing a month later, conducted intense preparations to set up the necessary equipment. On the day of the eclipse, Eddington noted in his diary, "a tremendous rainstorm came on." About noon the rain stopped and photographs were made through breaks in the clouds. The program had to be carried out "in faith." He himself did not see the eclipse, "being too busy changing plates." For six nights he and his companion E. T. Cottingham developed the photographs, the days being spent in measurement. At last came a moment which Eddington later said was the greatest in his life: "The one plate I measured gave a result agreeing with Einstein."

Eddington wrote a letter to Einstein giving the results of the measurements. At the same time he expressed concern over confirmation of another criterion, the displacement of solar absorption lines toward the red. Einstein replied, congratulating him. "I am amazed," Einstein wrote, with a curious but perhaps unintentional note of condescension, "at the interest which my English colleagues have taken in the theory in spite of its difficulty." He admitted that if the displacement effect did not exist in nature, "then the whole theory would have to be abandoned." (A few years later the effect was found.)

Whitehead, in his book *Science and the Modern World,* described the occasion when the expedition results were announced to the Royal Society. "The whole atmosphere of tense interest was exactly that of the Greek drama: we were the chorus commenting on the decree of destiny as disclosed in the development of a supreme incident. There was dramatic quality in the very staging: the traditional ceremonial, and in the background the picture of Newton to remind us that the greatest of scientific generalisations was now, after more than two centuries, to receive its first modification. Nor was the personal interest wanting: a great adventure in thought had at length come safe to shore."

Though he spoke of relativity as a sideline to his primary interest in astronomy, Eddington never turned his attention away from Einstein's work. In 1920 he published his famous *Space, Time and Gravitation,* which explained the underlying ideas and results of relativity theory with a minimum of mathematical symbols. It was not always easy reading, but it was a book of supreme fascination even for those who could follow only fragments of the exposition. He philosophized as well as explained. His metaphysics were far from clear, and he had a disconcerting way of mixing impeccable logic with misty speculation. But his words cast a spell, and his persuasive powers, while one was under the spell, were irresistible. Knowledge of the physical world, he asserted, is knowledge "of structural form, and not knowledge of content." That content, whatever it might be, is not within the reach of the methods of physics. Relativity makes evident what some philosophers have long suspected: the mind singles out for recognition certain qualities of the world, but these exist "only in the same sense as an unlimited number of walks exist on an open moor." The existence is "latent unless someone gives a significance to the walk by following it." In short, it is we who determine sense-data by our interpretations, who impose structure, who regain from nature, which is infinitely varied, that which our minds have put into nature. "We have found," he wrote in an oft-quoted paragraph, "a strange footprint on the shores of the unknown. We have devised profound theories, one after another, to account for its origin. At last, we have succeeded in reconstructing the creature that made the footprint. And lo! it is our own."

To the *Philosophical Transactions* of the Royal Society, the *Philosophical Magazine* and other journals Eddington sent important papers on different aspects of relativity. He completed a generalization of Weyl's theory of the electromagnetic and gravitational fields. In 1923 he published his now-classical *The Mathematical Theory of Relativity.* It must not be supposed that he merely explained and elaborated the original theory. He gradually diverged from the papers of Einstein, de Sitter and Weyl. He introduced "a modification into Weyl's affine geometry and formulated a geometry of world-structure, by means of parallel displacement, which broke new mathematical ground and made a notable contribution to geometry quite apart from its specific application to relativity theory and the physical world." The value of this work is beyond dispute, but as to other aspects of his researches in relativity there is less agreement. In 1953 Einstein sent to Dr. Douglas his opinion of Eddington's labors. After praising his theory of stars, Einstein observed: "His creative achieve-



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ment in the field of relativity and the theory of matter did not carry conviction for me. But this may be *my* fault. The German physicist and philosopher Lichtenberg once said: If a head and a book collide with a hollow sound—this is not necessarily caused by the book. "

"I believe there are 15,747,724,136,275,002,577,605,653,961,181,555,468,044,717,914,527,116,709,366,231,425,076,185,631,031,296 protons in the universe and the same number of electrons." Thus Eddington opened one of the Tarner Lectures in 1938. He was of course being mischievous, but he was in dead earnest about the accuracy of his arithmetic. This rather large number (136×2^{256}) was the culmination of years of effort to formulate a comprehensive theory of the universe. What was the main idea? No one is entirely sure, but at least we can follow a lucid interpretation by the late Sir Edmund Whittaker, the distinguished mathematician to whom Eddington entrusted the preparation for press of his posthumous *Fundamental Theory*.

The heart of the book is a new principle derived from a supposed relationship between certain important numbers such as "the radius curvature of the earth, the recession-velocity constant of the external galaxies, the number of particles in the universe, and the physical constants such as the ratio of the mass of the proton to that of the electron, the ratio of the gravitational to the electrical force between a proton and an electron, the fine-structure constant and the velocity of light." Whittaker guides us out of this fearsome tangle. One may distinguish between two kinds of assertions in physics. First, there are quantitative assertions, *e.g.*, "The value of the reciprocal of the fine-structure constant is 137"; or, "The masses of the electron, the mu meson, the pi meson, the tau meson and the proton are approximately in the ratios 1, 200, 300, 1,000 and 1,836." Second, there are qualitative assertions, *e.g.*, "The velocity of light is independent of the motion of its source"; or, "It is impossible to detect a uniform translatory motion, which is possessed by a system as a whole, by means of observations of phenomena taking place wholly within the system." Eddington's principle depends on the distinction between these two types of assertions. "All the quantitative propositions of physics," says the principle, "that is, the exact values of the pure numbers that are constants of science, may be deduced by logical reasoning from qualitative assertions, without making any use of quantitative data derived from observation." Eddington gave a more dramatic statement of the principle: "An intelligence unacquainted with our universe but acquainted with the system of thought by which the human mind interprets to itself the content of its sensory experience, should be able to attain all the knowledge of physics that we have attained by experiment. He would not deduce the particular events and objects of our experience but he would deduce the generalizations we have based on them. For example, he would infer the existence and properties of radium but not the dimensions of the earth."

A concrete instance of the principle is Archimedes' discovery that *pi* can be calculated by theoretical methods, without having to make measurements of circles of different sizes. Whittaker gives another illustration of pure "Eddingtonianism": Leibniz's advocacy of the subordination of the science of quantity, dealing with numerical relations, to the science of quality, which treats of order and similarity.

Many objections have been raised against the principle, and against the structure Eddington erected upon it. One of the most serious, and, in a sense, most obvious, criticisms is that the qualitative conceptions from which the universe is to be deduced are as likely to be imperfect, and therefore as certain to be superseded, as the quantitative values of physics. When Archimedes determined *pi* he believed, as did scholars for centuries thereafter, that it is an eternal number giving the ratio of the circumference to the diameter of every circle in actual space. But as Whittaker points out, this assumes that Euclidean geometry is "the true geometry of the universe," whereas in fact there is now reason to believe that the geometry of the universe is non-Euclidean. *Pi* is *pi*, to be sure, forever; but it is not a permanent key to every lock in the physical world. There is a graveyard filled with qualitative assertions of science which once served their purpose as the basis of successful predictions, but were finally superseded.

Another objection to Eddington's principle is that the so-called constants of nature—for example, the fine-structure constant 137—derived in accordance with his ideas are "absolutely constant," whereas in several cosmological theories "they are represented as increasing or decreasing, depending in one way or another on the age of the universe at the time when they are measured."

The system Eddington outlined in his book *Relativity Theory of Protons and Electrons*, elaborated in his many papers on the equations of the physicist P. A. M. Dirac, on relativity and on quantum theory, and brought to its most finished—though still unfinished—form in *Fundamental Theory*, carried no general conviction. He had not, as he said, the "smallest doubt" of its validity and would allow no compromise. "People will understand me all right," he wrote Dingle, "when they realize they have got to do so—and when it becomes the fashion 'to explain Eddington.' " This fashion he did not live to see. Most physicists and astronomers found it hard to follow his argument, and when they could they were skeptical. Some were "openly scornful, calling [his theory] number magic and mere juggling." Philosophers were repelled by his speculations as a hodgepodge of half-baked epistemology and misleading metaphors. Yet a discerning few felt, as Whittaker did, that Eddington was a man of genius, and that the value of his basic theory "lies less in its conclusions than in its power of dissolving prejudices and suggesting new and fruitful ideas."

Much of the criticism of Eddington's writings is undoubtedly well directed. His penchant for paradoxes, his gift for seductive images, his untenable philosophical interpretation of physical events made him a prime target for clear thinkers, in particular Susan Stebbing, who cut both him and Jeans to ribbons in her lethal little book *Philosophy and the Physicists*. But, apart from recognizing his scientific achievements and his incomparable insights, it would be unreasonable to deny and ungrateful to forget that in his popular writings—*The Nature of the Physical World* is perhaps the best example—he was a major benefactor of society. He stimulated the teaching and learning of physical science; he enlarged understanding of its scope and methods; he excited a taste for adventure in scientific thought. For countless persons of my generation Eddington's books were an incomparable delight in intellectual clarification.

He was a man of absolute integrity, a thoroughly good man. He had that simple straightforwardness, Bertrand Russell observed, which is characteristic of some of the greatest men of science. His work is graced by a poet's sympathy, illuminated by a poet's sense of truth and unity. He deserved to see further than other men, and time, I suspect, will prove he did.

Short Reviews

JOHN LOCKE, by Maurice Cranston. The Macmillan Company ($8). John Locke is a towering figure in the history

ABOUT MEN AND WEAPONS

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of thought. He did not merely introduce a system; he changed the ways in which men think. His famous *Essay on the Human Understanding* laid the foundations of empiricism in the theory of knowledge. It foreshadowed the modern school of analytical philosophy; it cleared away a good deal of metaphysical rubbish (though it produced some of its own); it promulgated a doctrine of primary and secondary qualities, which, even after Bishop Berkeley exploded it, continued to exercise a profound influence on the development of science and to provide a fertile source of scientific discovery. Locke was also a great political philosopher. In his *Letters for Toleration* and *Two Treatises of Government* he set forth his enlightened ideas on liberty and the necessity of tolerating opposite opinions, and he declared his passionate belief that the consent of the people is the sole basis of a government's authority (and that rebellion is justified if those holding authority exceed it and break the social contract). These views had an enormous effect upon the future of political theory and practice in America as well as Europe. Interesting thinkers, however, are not always interesting in their person, and it has long been the accepted view that Locke was not an interesting human being. We have now in this massively detailed biography a better opportunity than ever before to judge the matter for ourselves. The author has had access to a very large collection—several thousands of documents—of Locke's personal papers which he left to his young cousin. These, which were never fully consulted, were acquired by the Bodleian Library at Oxford in 1948. On the basis of the personal papers and other fresh materials, Maurice Cranston has drawn an admirable portrait—scrupulous, sympathetic, urbane. Locke was many things in character and in action. The circumstances and events of his life were anything but pedestrian. He was an Oxford tutor, a diplomat, a politician and an economist. He was a physician who practiced rarely, collaborated with Thomas Sydenham, occasionally doctored the great, and usually prescribed sensible remedies which did not kill his patients. Once he made a diagnosis of trigeminal neuralgia, which was not only correct and saved the Countess of Northumberland from having a barber-dentist pull out all her teeth but was the first of its kind in medical history. Locke followed the science of his day, associated with *virtuosi,* and was on intimate terms with such men as Isaac Newton and Robert Boyle. As executor, with Newton, of Boyle's estate, he largely rewrote and published Boyle's *History of the Air,* which had been left in a fragmentary state. Though he is remembered as the founder of the Age of Reason, he was, as Cranston remarks, "both romantic in appearance and romantic in his ways. He seems to have taken a positively Gothic pleasure in mystery for the sake of mystery." Besides his major works he wrote on theology and on education. His notions in the latter field were decidedly "progressive," with touches of eccentricity—for instance, that children were not to be allowed to eat fruit because "it is a thing totally unwholesome," and that they should be required, to inure them against colds, to wear shoes "so thin that they might leak and let in water." He spent some years on the Continent, first as a traveler in France, later as an exile in Holland. His close relationship with Anthony Ashley Cooper, the powerful First Earl of Shaftesbury, at whose home he lived, serving first as a medical but soon as a political adviser, plunged him into the world of affairs, a hectic and dangerous world preceding the Revolution of 1688. This led to his being suspected of complicity in the Protestant Plot of 1682 and of other subversive tendencies, so that he was forced to flee England and to spend six years abroad, mostly in Amsterdam and Rotterdam. Shortly after William and Mary came to the throne he returned to find himself famous and to be rewarded with the highly lucrative position of Commissioner for Trade. But almost to the end of his life he was involved in public controversy. Despite this active and varied career, despite his achievements and his qualities, there are ample grounds for his reputation as a dull and disagreeable man, and even worse. He was cautious, timid and virginal. He was mean in money matters and drew a part of his comfortable income from the slave trade. His commercialism tinctured his philosophy as well as his writings. He had a passion for secrecy which led him not only to write to his lady friends—it is doubtful they were ever more than friends—in invisible ink but to publish his political writings anonymously. Locke's concern with the education of children was a concern with gentlemen's children. Poor children, he recommended, were to be "soundly whipped," to be put in working schools where they were to be given their "bellyful of bread daily," and in cold weather "a little warm water gruel: for the same fire that warms the room may be made use of to boil a pot of it." For "begging drones" he advised the press gang, mutilation (amputation of the ears) and transportation.

Cranston does not conceal the cruel and ugly sides of his subject. However, he does not explain the contradictions and paradoxes, so that Locke remains, in some ways at least, the enigma he always was. But he was a great man, and this exemplary narrative makes us know him as well perhaps as we ever shall.

FANTASIA MATHEMATICA, edited by Clifton Fadiman. Simon and Schuster ($4.95). An urbane editor who loves mathematics but pretends to little knowledge of it has gathered a number of short stories, some verse and a few literary knickknacks, all relating to his favorite subject. Plato is here, also James Branch Cabell, Karel Čapek and H. G. Wells; there are several topological fables, one of the best being about the subway train that hit a node on the track network and slithered into another dimension. Arthur Quiller-Couch, Lewis Carroll, Edgar Allan Poe, A. S. Eddington, Andrew Marvel, Thomas Dekker, A. E. Housman and Samuel Butler are among those in the poetry repertory. It must be confessed that mathematics succeeds only seldom in kindling the imagination of literary men. A rainbow enchants more of us than does the real number system, although it may be argued that the second is not less beautiful than the first. There is need to widen and educate our tastes, and, even if this book makes no such claims, it provides moments of entertainment.

THE EYE GODDESS, by O. G. S. Crawford. The Macmillan Company ($10). In this book the late O. G. S. Crawford, for 31 years the editor of the British archaeological magazine *Antiquity*, advances an intriguing theory. During excavations in 1937, in the remains of a temple at Brak in Syria, M. E. L. Mallowan found evidence of the cult of an Eye Goddess. The distinctive symbol of this agricultural fertility cult is the eye, often a weird, staring eye, carved or painted on seals, plaques, rocks, rings, walls, steles, vases, pots, statues and tombstones. Crawford knew of Mallowan's find; he also knew of places remote from Syria where eye- or face-idols had been uncovered. A theory of racial and cultural expansion evolved in his mind, and he set himself the task of proving it. His book assembles the evidence for the westward and northward spread of the Eye Goddess. In Troy and Greece, in Italy, Sicily and Spain, in North Africa and the Canary Islands, in Brittany, Britain, Ireland and northwest Europe, artifacts of every kind exhibit what appears to be the characteristic

representation of the eye or face which had its origins in the ancient East. The author does not insist on the validity of his theory. His "thread of continuity" holds the facts together, as he admits, "sometimes rather loosely." But he supports his speculation with many beautiful photographs (his own and those of others) and with reports of his extensive observations, and leaves it to prehistorians to reject or improve upon. An engrossing book.

CHINESE ART, by William Willetts. Penguin Books, Inc. ($3). This splendidly illustrated work, which comes in two volumes, is a 4,000-year history of Chinese art—jade carvings, bronzes, lacquer and silk art-objects, sculpture, pottery, painting, calligraphy, architecture. The attempt is made to relate these creative forms to the social, political and technological conditions out of which they arose. This is a book which only specialists can judge in detail but which the ordinary reader will find an education in itself.

Notes

THEORETICAL ASTROPHYSICS, edited by V. A. Ambartsumyan. Pergamon Press, Inc. ($22.50). For the English translation (by J. B. Sykes), the editor and three other leading Soviet astrophysicists, E. R. Mustel, A. B. Severnyi and V. V. Sobolev, have revised this comprehensive text, first published in Russian in 1952, which treats the main branches of the subject on the graduate level, and is designed for students and scientific workers.

VALUES IN A UNIVERSE OF CHANCE, by Charles S. Peirce; edited by Philip P. Wiener. Stanford University Press ($3.95). Selected writings of America's most original philosopher. There are included several famous essays on pragmatism and scientific thought, and other material, some of it heretofore unpublished, expressing Peirce's views on the humanistic and cultural aspects of science and philosophy.

THERMODYNAMICS, by Enrico Fermi. Dover Publications, Inc. ($1.75). An unaltered paperback reprint of the 1937 edition of Fermi's elementary treatise on pure thermodynamics.

A DICTIONARY OF STATISTICAL TERMS, by Maurice G. Kendall and William R. Buckland. Hafner Publishing Company ($4.50). A nonelementary dictionary, with French, German and Italian glossaries of statistical terms, prepared for the International Statistical Institute.

SOURCEBOOK ON ATOMIC ENERGY, by Samuel Glasstone. D. Van Nostrand Company, Inc. ($4.40). The second edition of this standard reference book contains fresh material on fundamental particles, the production of new elements, advances in the use of isotopes, improvements in experimental techniques and equipment, and a new chapter on nuclear reactors.

ANIMALS IN MOTION, by Eadweard Muybridge. Dover Publications, Inc. ($10). A companion to the same publisher's edition of *The Human Figure in Motion,* this volume presents 183 plates, also taken from Muybridge's famous *Animal Locomotion,* containing several thousand 19th-century action photographs, taken at speeds up to a 2,000th of a second, of horses, dogs, cats, lions, kangaroos, deer, elephants, eagles, baboons and other animals engaged in various motions.

THE CHEMICAL INDUSTRY DURING THE NINETEENTH CENTURY, by L. F. Haber. Oxford University Press ($7.20). A study of the economic aspects of the origins and growth of applied chemistry in Europe and North America in the 19th century. Particular attention is devoted to the British soda industry, the dyestuff concerns of Central Europe and chemical firms in the U. S.

PHILOSOPHY OF MATHEMATICS AND NATURAL SCIENCE, by Hermann Weyl. Princeton University Press ($1.95). A paperback reprint of a brilliant book on the structure of mathematics and the philosophy of science.

THE SOCIAL LIFE OF ANIMALS, by W. C. Allee. Beacon Press ($1.45). A paperback reissue of the late Warder Clyde Allee's memorable book on automatic cooperation as one of the fundamental biological processes.

THE EXPANDING UNIVERSE, by Sir Arthur Eddington. University of Michigan Press ($1.45). THE NATURE OF THE PHYSICAL WORLD, by Sir Arthur Eddington. University of Michigan Press ($1.95). In the attractive Ann Arbor paperback series, reprints of two of Eddington's brilliant courses of lectures, the first dealing with the structure of the universe, the second with the revolution in physics brought about by relativity and the quantum theory.

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JULY, 1958

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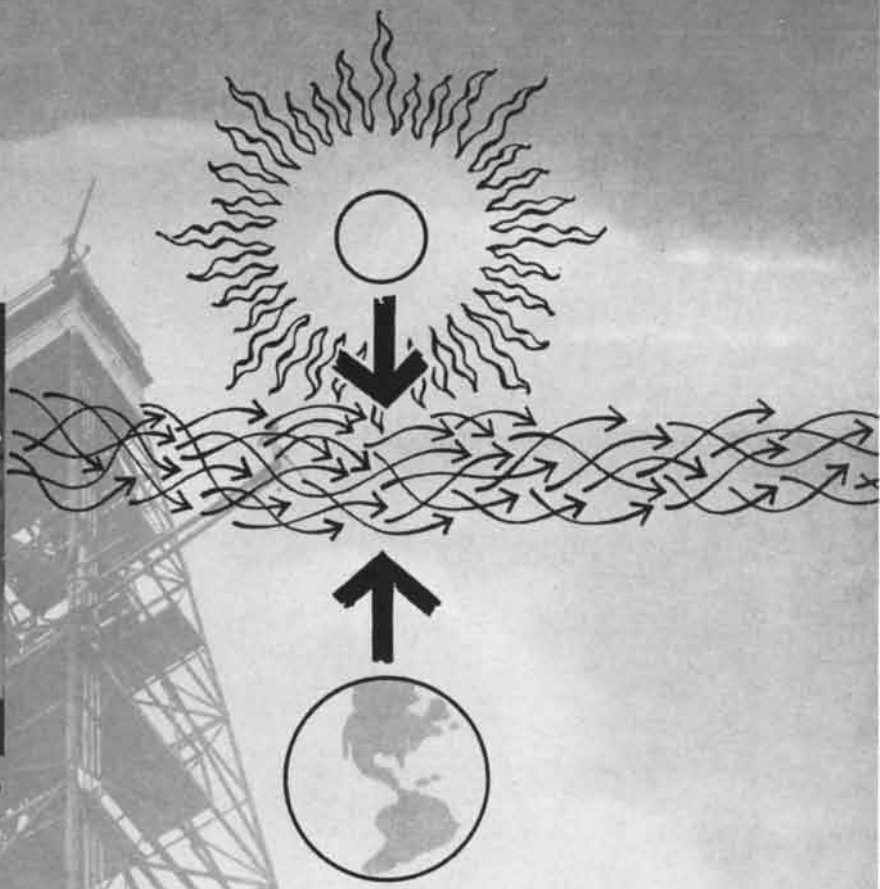

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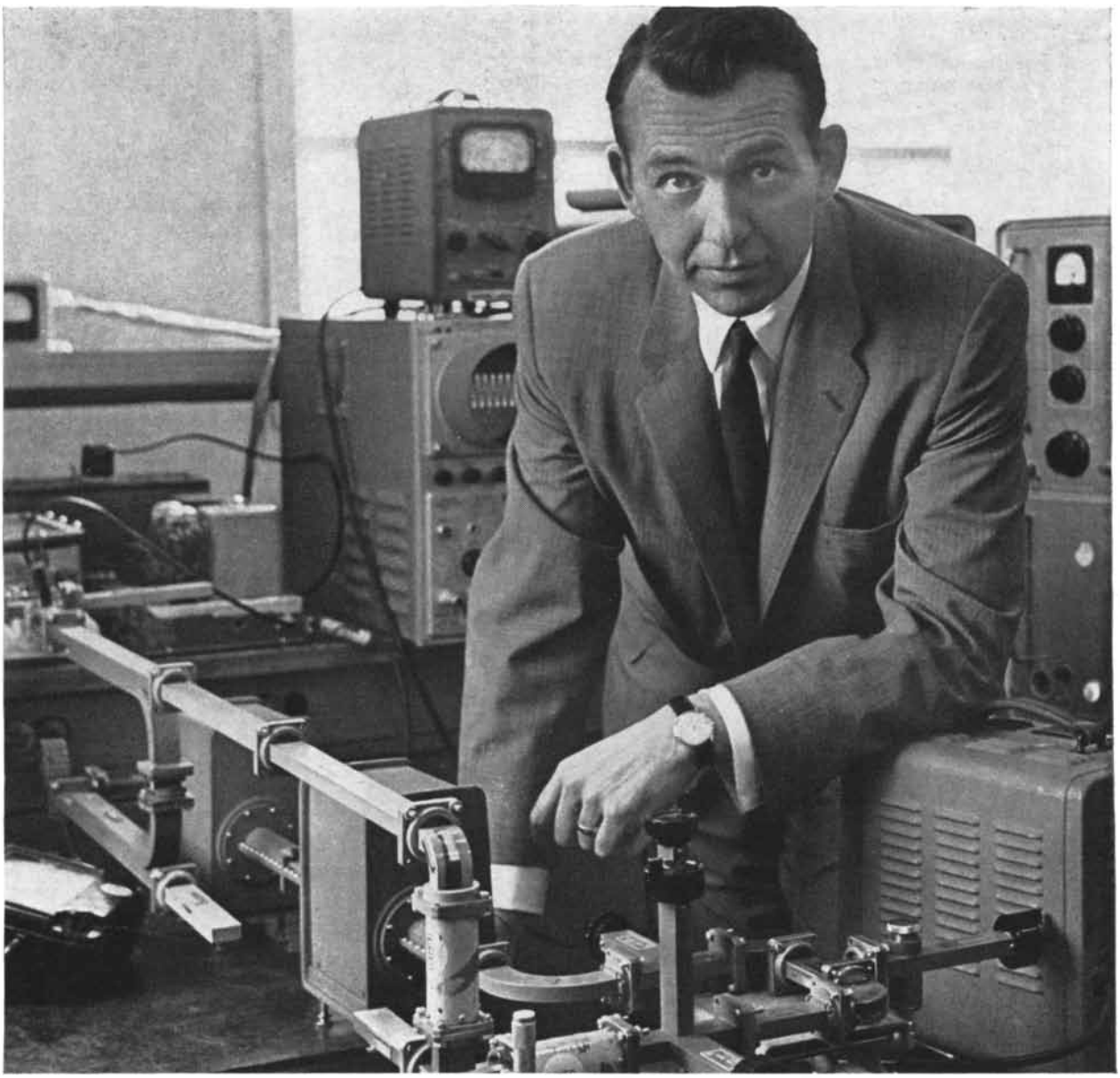

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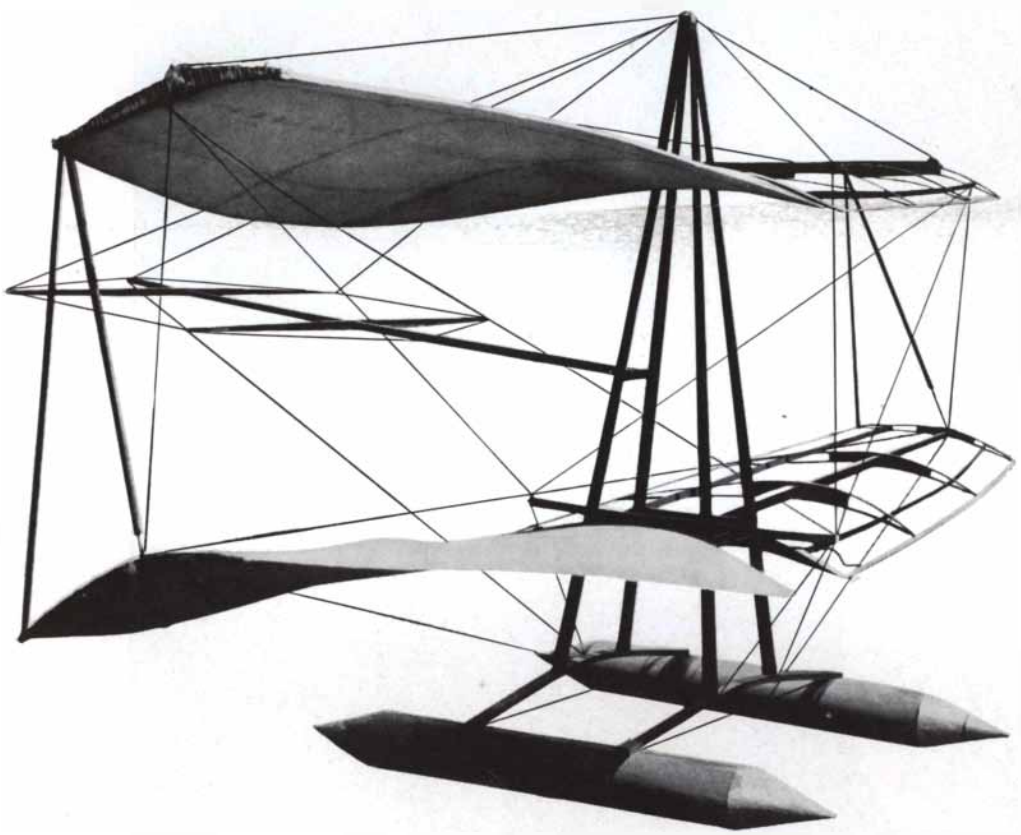

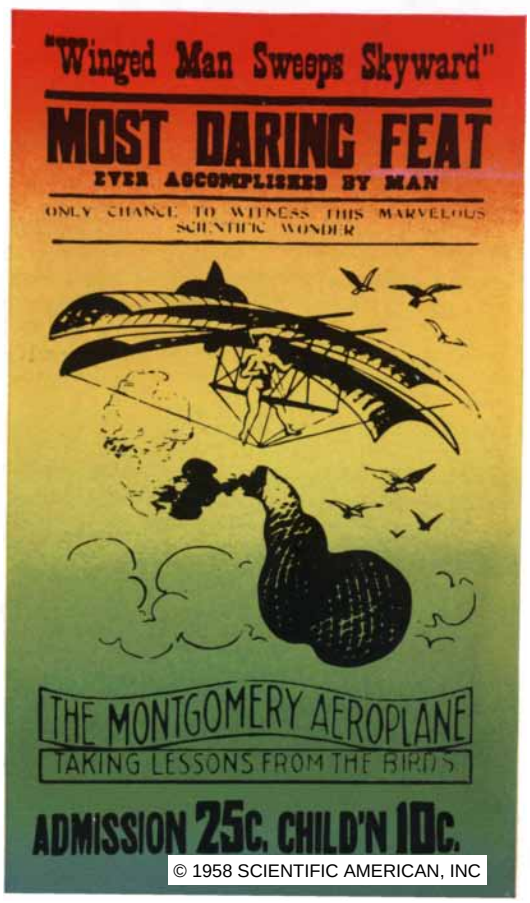

"Gallaudet is Making an Ass of Himself"

Lilienthal used the shifting weight of his body to maintain equilibrium and the American pioneer, Montgomery, had warped the wings of his gliders by pressing a guy wire with his foot. In 1897, two years before the Wrights, Edson Gallaudet, an instructor in Physics at Yale and head coach of the crew, constructed a model kite, now in the Smithsonian, which embodied the principle of the warping wing. Although Gallaudet was later to set up the first aircraft manufacturing concern in the country, the earliest ancestor of Convair, his tinkering with "flying gimcracks" was regarded as a "reflection on Yale." Accused of "making an ass of himself and a laughing stock of the faculty," Gallaudet resigned. His model was stored in a barn in Connecticut, unpatented.

From Chapter 4 of "Dynamic America," a history of 420 pages and 1500 illustrations to be published soon by Doubleday & Company and General Dynamics Corporation, 445 Park Avenue, New York 22, N. Y.

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