SCIENTIFIC AMERICAN

LICHENS

FIFTY CENTS

October 1959

Lively as a walk on the moon

Now tired feet say *thank you* to shoe companies for an unusual kind of sole called "closed-cell sponge"—made from some of the types of rubber which Shell Chemical manufactures. It's so light you wonder if it's there, so buoyant you bounce when standing still, and so long-wearing you forget the word "repair."

Secret of this livelier sole is a way of processing synthetic rubber that makes it light and spongy, but keeps it waterproof and tougher than a bride's first piecrust.

Other types of Shell Chemical synthetic rubber are used for tires and toys, for tiles and seat cushions, or any other product that needs this tough, bouncy contribution to the American scene.

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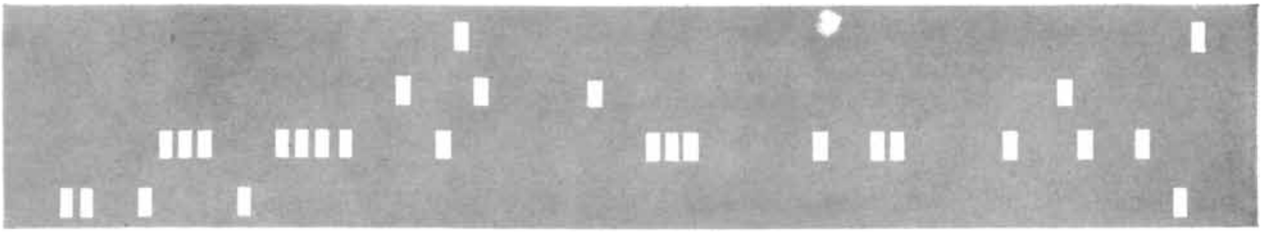
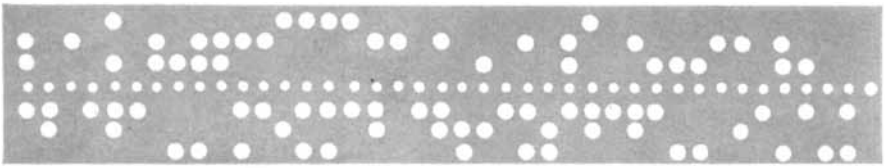


a new development of vital importance—*to users of punch cards and tape*



The Dobeckmun Company is now successfully laminating foil, Mylar* and paper in varying combinations to produce tape and card stocks of extremely high dimensional stability and strength. They have proven to be particularly valuable in complex control and programming systems that demand absolute fidelity of every component part.

If you have special tape or card stock requirements, we shall be delighted to work with your development people in producing a special material. We feel confident that somewhere within the framework of our skills and diversified products we can be of service to you. Write for brochure of complete details.

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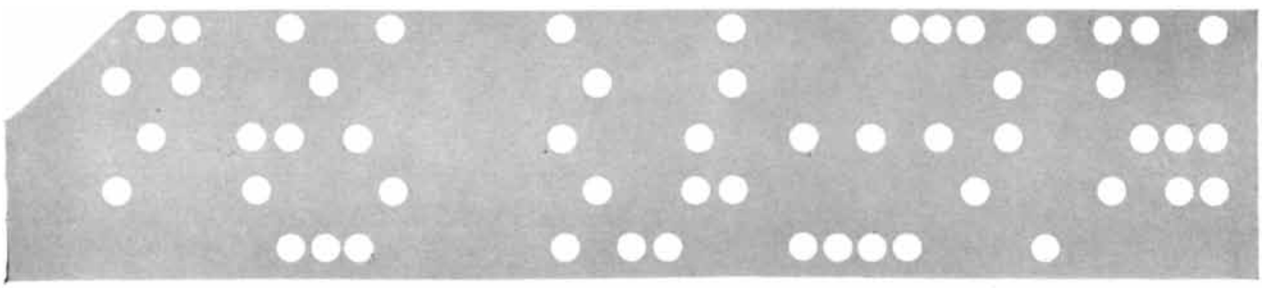
*MYLAR IS A REGISTERED DUPONT TRADEMARK



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THIS IS A HARD HAT. It's worn by men who get things done. It's the perfect symbol for the new spirit in New York State . . . a spirit that's working to create more and better job opportunities for everyone by encouraging business to grow.

Focal point of this new spirit is the capital city of Albany. The city is alive with "doers." Successful business and professional men who gave up positions of responsibility to help Governor Nelson Rockefeller make New York State an even better area for companies to locate and grow . . . an even more rewarding place to live and work.

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GET UP TO DATE ON NEW YORK STATE
where they're talking the businessman's language

Established 1845 **SCIENTIFIC AMERICAN** October, 1959 Volume 201 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover symbolizes the study of lichens, the humble growths that consist of two distinct plants: a fungus and an alga (*see page 144*). At the top of the painting is a specimen of the lichen *Cladonia cristatella*. On the left side of the painting the same lichen is enlarged and cut away. The green patch in the test tube is a culture of the alga of the lichen. In the dish at right is a culture of its fungus.

THE ILLUSTRATIONS

Cover painting
by John Langley Howard

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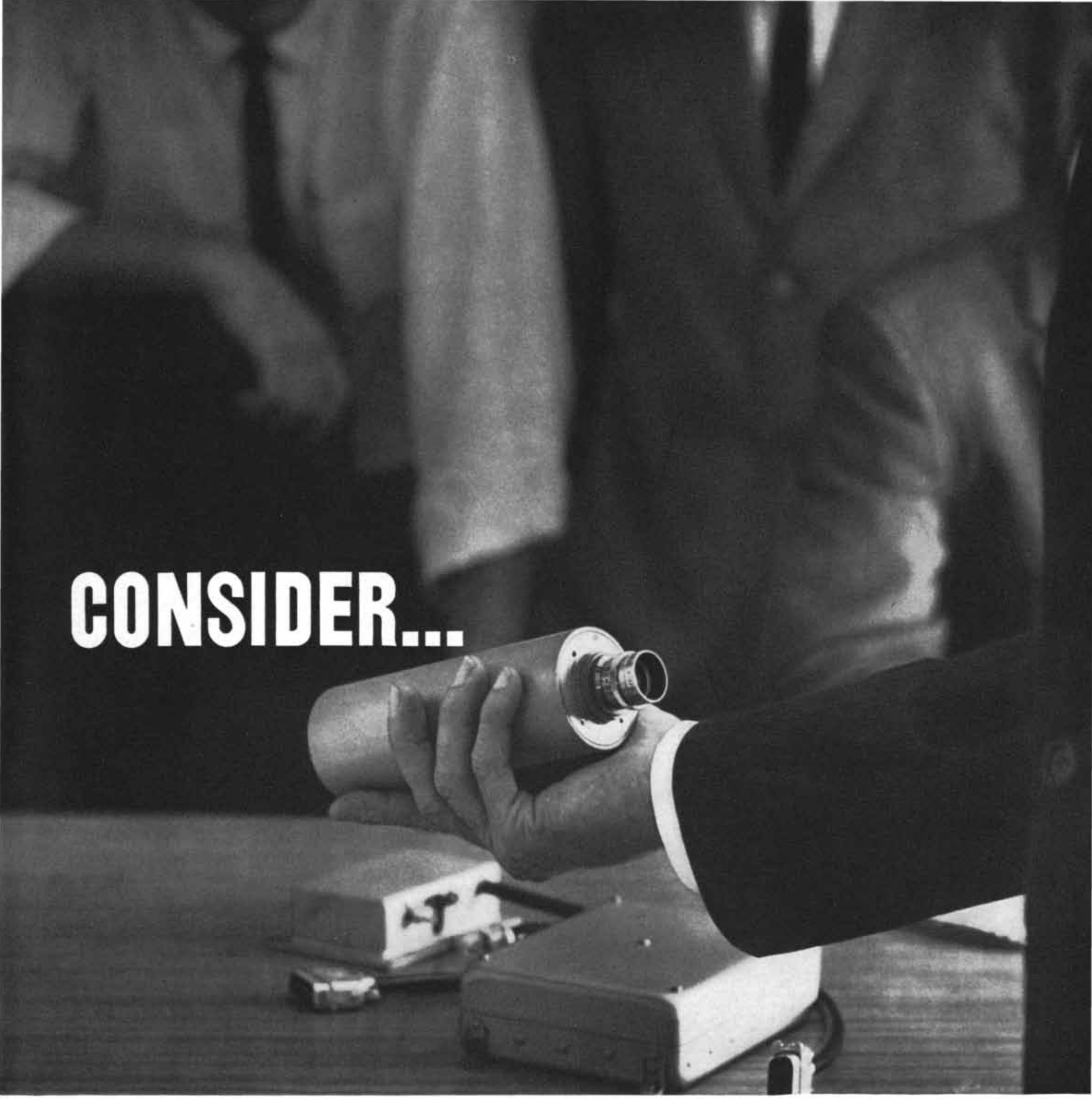
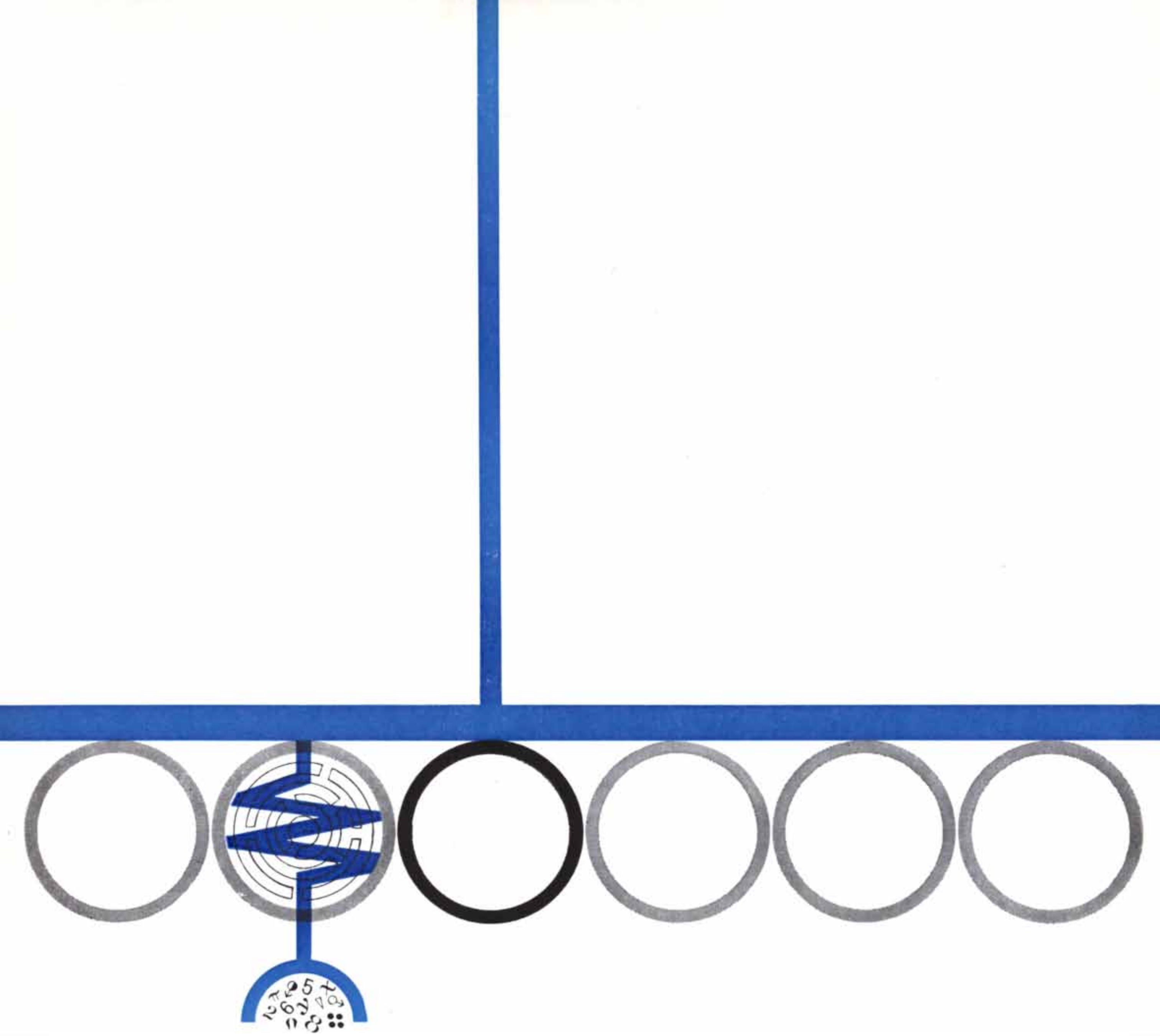

CONSIDER...



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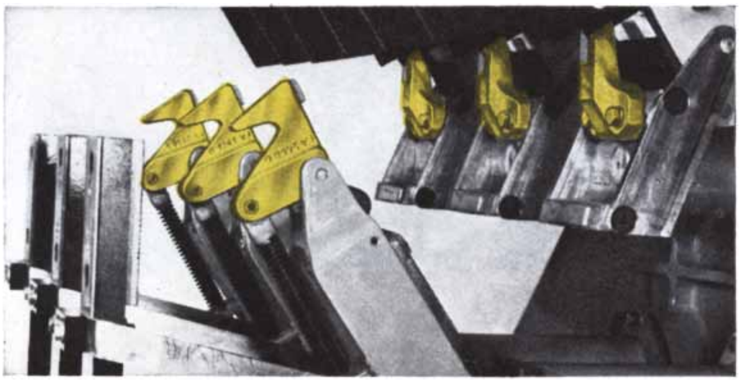
TWICE-WROUGHT METAL

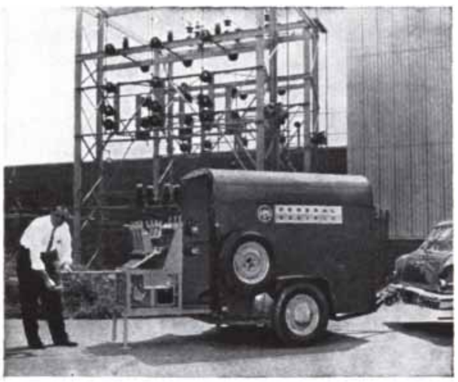
of die-pressed forgings helps Federal Pacific make new air circuit breakers more rugged—cuts machining costs in half

In its new Type DST magnetic air circuit breaker line, Federal Pacific Electric Company, Newark, N. J., builds in dependable operation and long life with parts of outstanding mechanical and adequate electrical properties.

Typical of this attention to detail are the arcing contacts (left). Similar parts previously used had been castings or built-up assemblies. Now the contact bodies are Anaconda Forging Brass-250 die-pressed forgings. The twice-wrought metal is denser, stronger, withstands mechanical shock better—reducing the fatigue factor and producing longer service life. The contacts also have higher conductivity. And best of all, their consistent dimensional accuracy and smooth finish cut machining costs in half.

RIGHT: Movable arcing contact assemblies at the left and the stationary arcing contact assemblies at the right in a 5-kv Federal Pacific Type DST air circuit breaker. They have a momentary current-carrying capacity of 60,000 amperes. Contact tips of tungsten alloy are silver-soldered to the forgings. These are two of several areas where Federal Pacific uses the superior physical properties of Anaconda die-pressed forgings to help provide dependable operation and long service life in its line of metal-clad switchgear.





Federal Pacific takes its circuit breakers out to industrial and electric utility customers. Here a representative sets up a demonstration of a 5-kv, 1,200-amp breaker in the field.

It is often easier than you think to achieve high quality and performance while simplifying fabrication and cutting over-all costs. American Brass technical specialists are constantly working with designers, production engineers and buyers, helping them meet their joint requirements—through the use of such Anaconda mill products as die-pressed forgings, extruded shapes, special-shape tubes. For this kind of practical help, see your American Brass representative or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Toronto 14, Ontario.

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LETTERS

Sirs:

Referring to James R. Newman's review of the biography of Ludwig Wittgenstein by Norman Malcolm in your August issue, I think that the following incident may be of interest.

In 1941 I met in Buenos Aires a Polish refugee physician, Dr. B. One day I saw him using a rather antiquated fountain pen. I had not seen a similar one for more than 20 years, and I asked him to show it to me. He did so, and told me that he got this fountain pen from a very unusual man by the name of Baron von Wittgenstein as a souvenir during World War I. He told me that Baron von Wittgenstein was interested in philosophy and that they met in a field hospital, where they were both male nurses. Dr. B. told me that they spent a great deal of free time together, often playing chess in the evenings and at nights while on duty, and became very close friends. One night Wittgenstein took out his fountain pen and handed it over to Dr. B. as a souvenir. Some time later Wittgenstein told Dr. B. that he had, among other properties, a castle in Norway, and that he was giving this castle to Dr. B. as a gift. Dr. B., not seeing any reason for such an expensive gift, told him so and declined to accept it. This made Wittgenstein very angry, and he broke the friendship. Dr. B. told me that he often wondered what had happened to Wittgenstein, and was very pleased and surprised when I informed him that he became one of the leading modern philosophers, and also suggested that he write to him at Cambridge, which Dr. B. did. Evidently Wittgenstein either still was offended, or did not remember Dr. B., because he never replied.

W. W. NOWINSKI

Medical Branch
University of Texas
Galveston, Tex.

Sirs:

The excellent article by Robert D. Allen ["The Moment of Fertilization"; SCIENTIFIC AMERICAN, July] concerns what occurs in the sea urchin and sea cucumber. So often what is true regarding a phenomenon in lower species of animals does not hold in man or certain mammals.

In observations during the past eight years on over 1,500 living human oöcytes, follicular and tubal ova (by means of phase-contrast microscopy) it has been learned that in the human more than one spermatozoon penetrates the zona pellucida, the perivitelline area, the oöplasmic membrane, and more than one passes on into the oöplasm; at no time is there any evidence of fertilization membrane formation as occurs in the sea urchin; the entire fertilizing spermatozoon penetrates into the oöplasm of the human ovum and it remains intact until its head is brought into closest proximity with the pronucleus of the mature ovum. In other words, in the human, at the time of fertilization there is multiple penetration of the ovum by whole spermatozoa; there is no fertilization membrane formation.

LANDRUM B. SHETTLES, M.D., Ph.D.

College of Physicians and Surgeons
Columbia University
New York, N. Y.

Sirs:

The basic processes which I described in my article "The Moment of Fertilization" are general for all eggs, be they human, sea-urchin or annelid. However, it is certainly true, as Dr. Shettles points out, that the *details* of these processes may differ among animal groups.

Sea urchins have become a standard material for the study of fertilization and many embryological problems because (1) they yield more eggs (and

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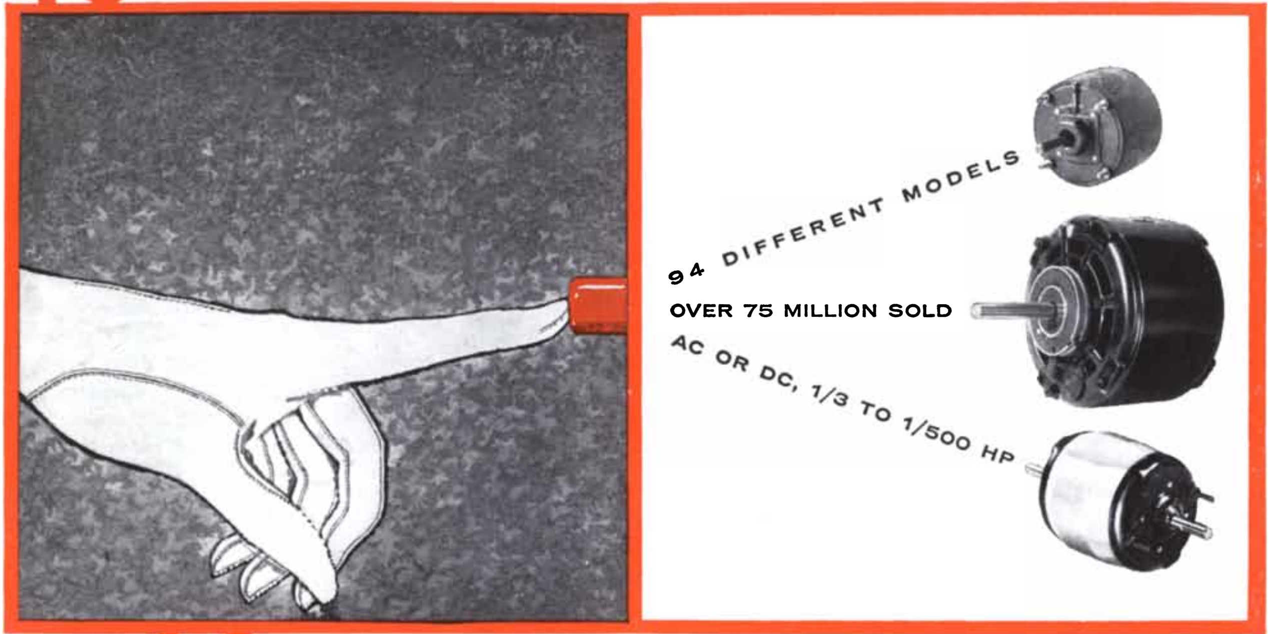

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more willingly) than humans and other mammals (2) the normal egg environment is far easier to duplicate in the laboratory than the equivalent of the uterine or tubular environment, and (3) the structure of a sea-urchin egg is comparatively simple and the eggs themselves are as a rule quite transparent. Considering these advantages, it is not surprising that research on fertilization in sea urchins has prospered far more than comparable work with mammals.

I might mention a couple of examples of fertilization processes which differ in detail but are apparently similar in general plan. First, cortical-granule breakdown such as I described for sea urchins occurs also in other echinoderms and in some chordates, annelids and mollusks. Other annelids and mollusks have cortical granules which remain intact. In contrast to both of these cases, tunicates apparently have no cortical granules, yet activation proceeds just as in the sea urchin, where the visible cortical changes appear to be so important a part of activation. This is usually taken to mean that the visible events in sea-urchin fertilization are a convenient indicator for submicroscopic changes which are common to all eggs.

The block against polyspermy is another case in point. Polyspermy can occur at the egg membrane, as is the case with sea urchins, or it can occur in the cytoplasm. Large, yolky eggs sometimes admit several sperm but then allow only one to form an aster and mate with the egg nucleus.

ROBERT D. ALLEN

Princeton University
Princeton, N. J.

ERRATA

On page 49 of the article "The Radio Galaxy" [SCIENTIFIC AMERICAN, August] it was stated that the mass of stars and gas in the nucleus of the galaxy, within a diameter of 100 to 200 light years, is five million solar masses. This latter figure should be 500 million solar masses.

On page 81 of the article "Ocean Waves" in the same issue it was said that a tsunami-warning network in the Pacific is operated by the U. S. Coast Guard. Actually the network is operated by the Coast and Geodetic Survey.

Air Force trailer-mounted MA-1A starter cart with improved AiResearch GTC 85-20 gas turbine unit.

AiResearch engineers inspecting improved AiResearch GTC 85-20 gas turbine unit after successful 5,000 start cycle test.

A world performance record for small gas turbine reliability has been established by this improved AiResearch GTC 85-20 unit . . . 5,000 start cycles. During each start cycle the turbine was brought to peak load twice, with a shut down time of only five minutes. This is equivalent to two main engine starts per cycle.

Throughout the entire test only routine maintenance was necessary plus replacement of one generator brush. AiResearch gas turbines now in production incorporate the improvements made in this newly tested unit.

Pneumatic power source for the Air Force's trailer-mounted MA-1A starter cart, the engine was torn down under supervision of Air Force personnel from Wright Air Development Center. It is now undergoing further tests upwards of 10,000 start cycles.

This intense product improvement in gas turbine reliability is matched only by AiResearch versatility. The world's largest manufacturer of lightweight turbomachinery, AiResearch has designed, developed and produced more than 8,500 gas turbines of all types vital to military and commercial ground support as well as auxiliary and prime power applications. Your inquiries are invited.

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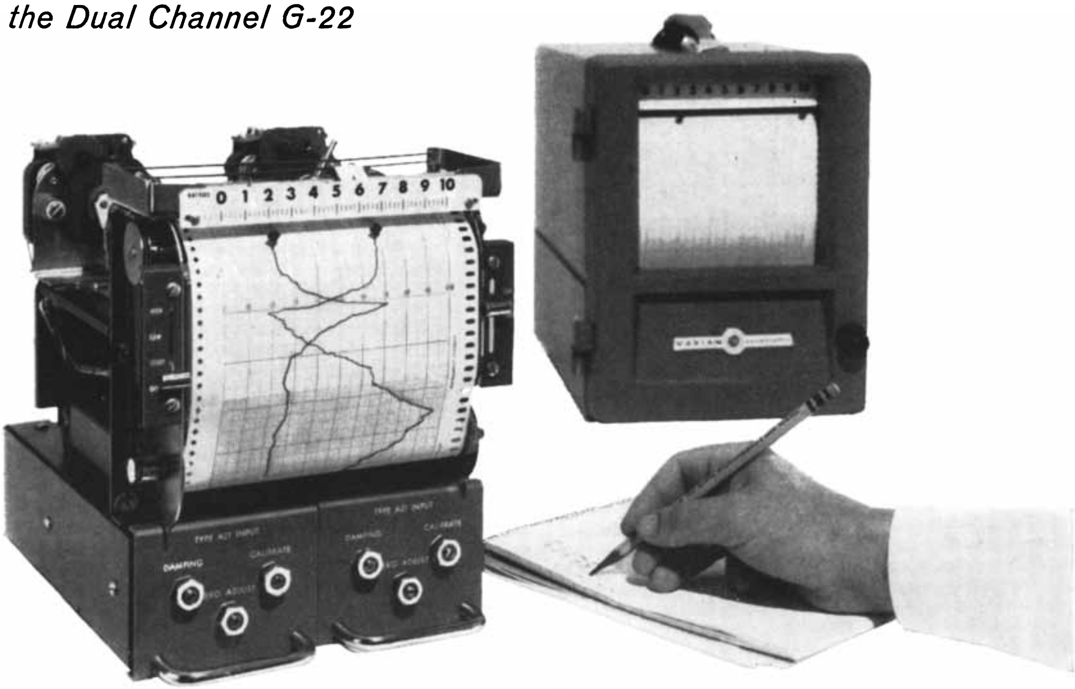

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FEATURES

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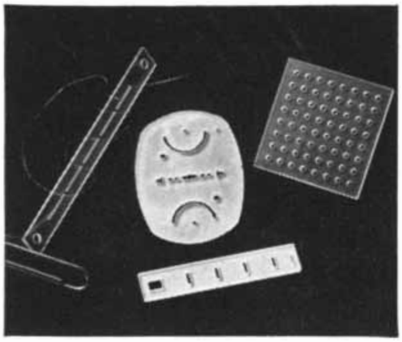

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- 7 blue
- 7 blue-green
- 6 green
- 18 sharp cut
- 5 yellow
- 8 infrared
- 4 miscellaneous

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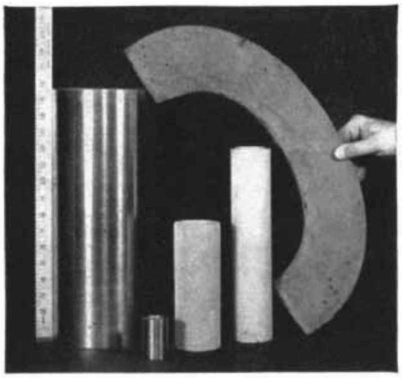

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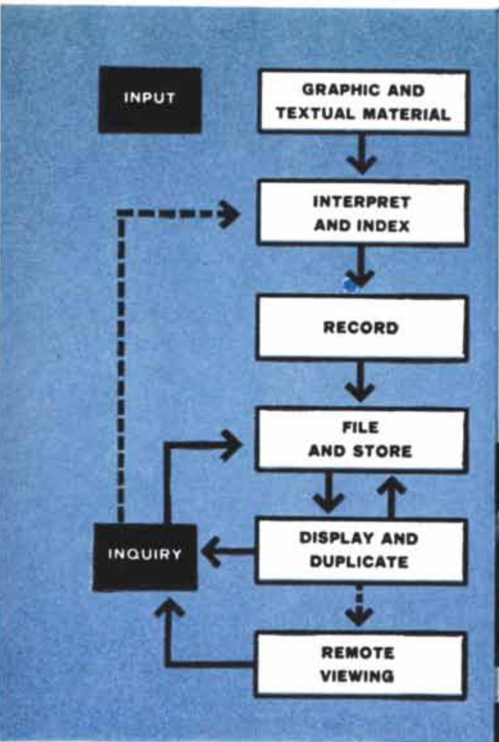

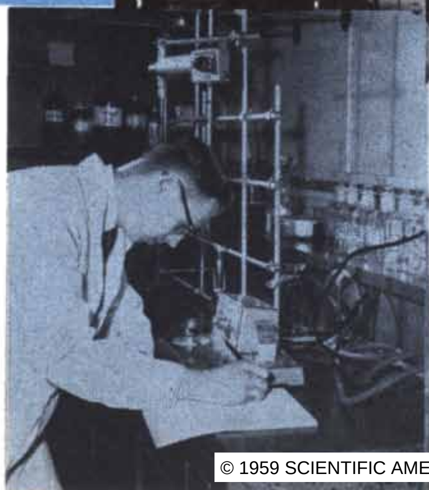

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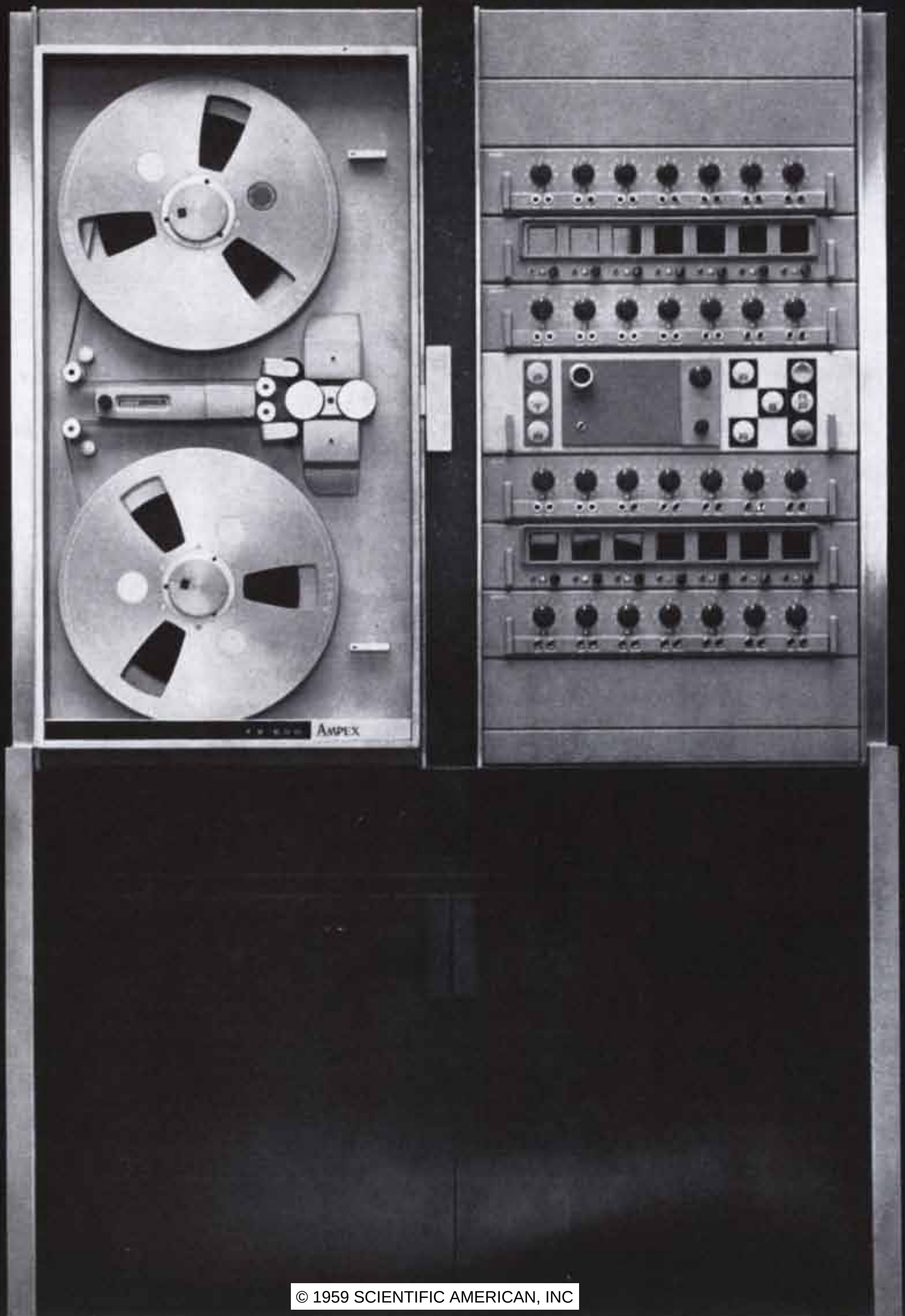
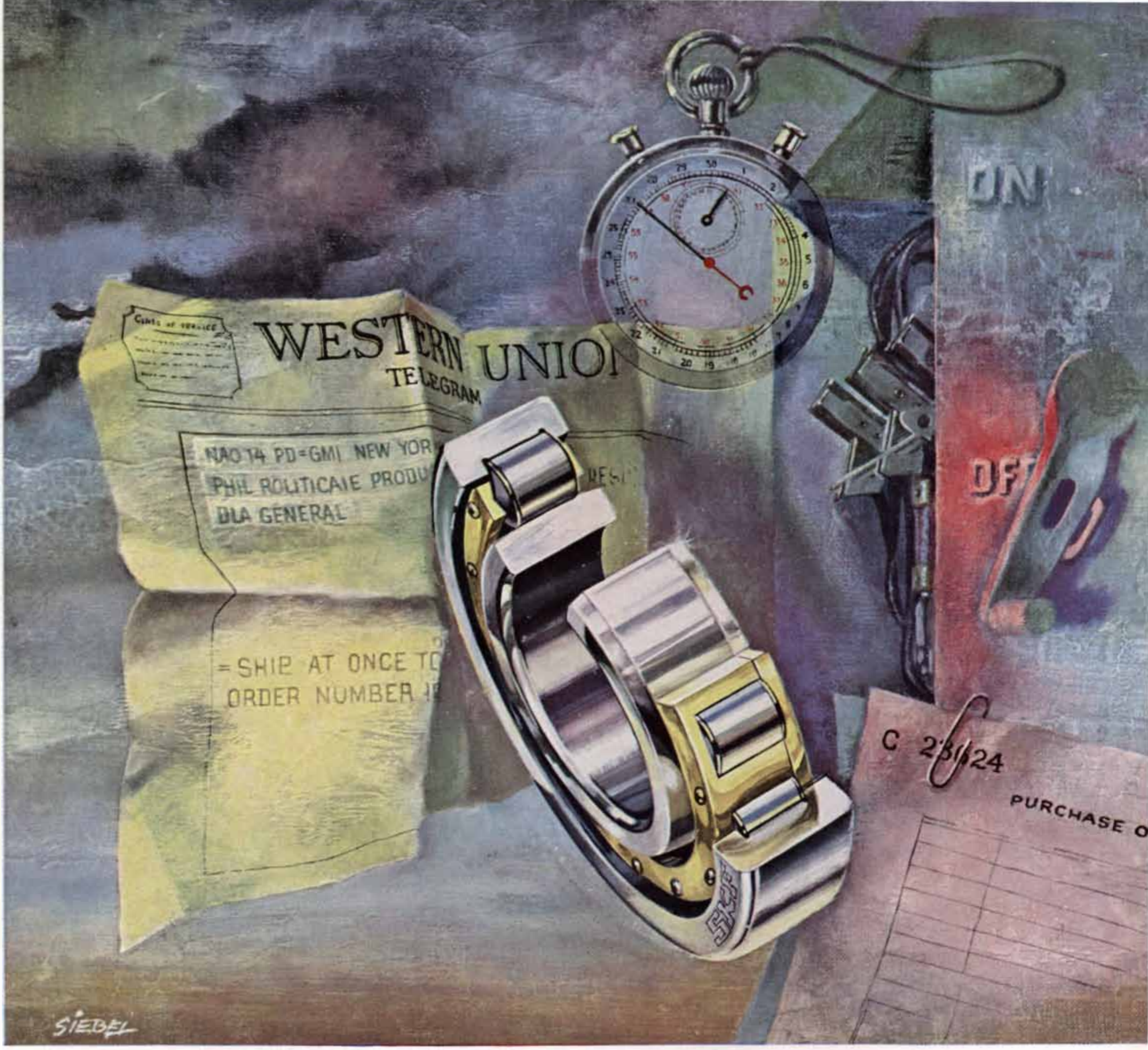

AMPEX



"A MARRIAGE OF ART AND INDUSTRY"

With these complimentary words an art instructor wrote to SKF recently to applaud the art used in a current SKF series of advertisements. The illustration above is one used in that series. This particular painting was reproduced in an SKF advertisement entitled "Parts Determine Downtime Costs." The accompanying copy pointed out how a single bearing failure might shut down a key machine, disrupt production—turn damage into disaster. It further suggested that an impartial, experienced SKF bearing analysis could easily circumvent this calamity. Are bearings a component of the products you build or buy?

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50 AND 100 YEARS AGO

OCTOBER, 1909: "The most sensational flight ever made in an aeroplane was that accomplished by Count de Lambert with his Wright biplane on October 18th, when he flew from Juvisy to Paris and back, covering a distance of about 30 miles in 49 minutes and 39 seconds. He flew over Paris at a great elevation, and cleared the Eiffel Tower nicely. He passed directly over the tower, which is 984 feet in height, turned his machine around and headed back for Juvisy. He landed safely and was greeted by Orville Wright, who had just arrived from Berlin after making a special flight for Emperor William—the first aeroplane flight the German Emperor had ever witnessed. While in Germany, Orville Wright also made a flight of record height, in which he reached an elevation of about 1,600 feet, as near as he could estimate."

"Dr. Frederick A. Cook has decided to submit to U. S. scientific and geographic organizations duplicates of the proofs which are at the University of Copenhagen. A simultaneous announcement is to be made in Denmark and this country as to whether he had furnished adequate proof that he had reached the North Pole. Henry Gannett, chairman of the United States Geographic Board, is chairman of the committee of the National Geographical Society which will pass on the records and proofs submitted by Commander Robert E. Peary to substantiate his claim that he reached the North Pole on April 6th, 1909."

"Halley's comet, for which astronomers have been watching so eagerly, has again been discovered. It was detected by Prof. Max Wolf on a photographic plate he had obtained by means of the 30-inch reflecting telescope at the Grand Ducal Observatory on the Koenigstuhl in Heidelberg, Germany, on Saturday night, September 11th. Its position was right ascension 6 hours, 18 minutes, 12 seconds; and declination 17 degrees, 11 minutes north. One day later the observation was confirmed by Heber D. Curtis, who succeeded in photographing the comet with the Crossley reflector at the Lick Observatory, Mount Hamilton, Calif. The location of the comet on the photographic plate agreed exactly with that indicated by Prof. Wolf."

"At last the Atlantic has been crossed by a steamship at a speed of over 26 knots, the *Mauretania* on her last trip to the westward having covered the course from land to land in four days, 10 hours and 51 minutes. Traveling at an average speed of 26.06 knots, she reduced her last record trip to the westward by 44 minutes."

OCTOBER, 1859: "The most astounding intelligence that we have received since our last issue is that of the explosion that occurred on board the *Great Eastern*, whereby eight engineers and firemen lost their lives by scalding and by inhaling the steam, and several others were severely injured. The disaster was caused by a defective water-heater, combined with great carelessness on the part of the engineer who had charge of the working of the engines at the time of the accident. The material damage consisted of one huge funnel or smoke-pipe, 40 feet high, being blown up vertically 30 feet and thrown on the deck, the collapse of the funnel under the deck, together with an explosion of the iron casing of the funnel. No damage was done to the hull, machinery or boilers; the engines never ceased working, but there was great consternation on board for some hours."

"At the eighth annual meeting of the American Pharmaceutical Association held in Boston last month, a committee appointed to examine articles of food and medicine for home consumption, to detect adulterations, presented a fearful list. We publish some of these, as reported by Dr. C. J. Carney, of Boston, Mass.: Beer—with nux vomica. Pickles and Bottled Fruits—with verdigris and sulphate of copper. Custard Powder—with chromate of lead. Tea and Snuff—with the same. Cayenne and Curry Powder—with red oxyd of lead. Flour and Bread—with hydrated sulphate of lime, plaster-of-Paris and alum. Vinegar—with sulphuric acid. Sugar—with sand and plaster-of-Paris. Some ground coffee was found to contain 60 pounds of common peas, 20 pounds of chicory, and 20 pounds of coffee in every 100 pounds, which was labeled 'Fine Old Java.' The proceedings of this convention should open the eyes of our people to the general base system of adulterating food, and should lead to the appointment of sanitary committees composed of scientific, honorable men in all our cities."

"Notwithstanding the dangers from which Mr. La Mountain escaped in his aerial voyage from St. Louis, in the early part of July, he exhibited the daring rashness of making another ascent, with Mr. J. Haddock, from Watertown, N.Y., on the 22nd of last month, and, as before, his life and that of his companion have been saved almost by a miracle. The ascent was splendid, and after rising to an altitude of three miles the balloon drifted eastward, and when seen, as night was closing around it, it was moving in the direction of the New York wilderness called 'John Brown's Track.' They were swept northward during the night, unknown to themselves, and came down three hundred miles distant in the northern wilderness of Canada. They were without food and proper clothing, having cast all overboard. They launched a scooped log on a deep creek and commenced through many perils, passing down through dangerous rapids, with shoes torn to pieces and garments in rags, and with only a couple of frogs for food, for four days. At last they came to a small lake, and beheld a column of smoke curling above the trees. On shore they found a camp of Indians and half-breeds in charge of Mr. Angus Cameron, a Scotsman who was exploring the region for timber. There they were told that it was 150 miles from human dwellings, with nothing north but a dense, uninhabited forest, stretching to the Arctic Circle. They would certainly have perished had Mr. Cameron not been there at that particular juncture."

"The expedition fitted out two years ago, under Capt. McClintock, at the expense of Lady Franklin, to search for her husband in the Arctic regions, has returned with full and correct tidings of the sad fate of Sir John Franklin and his companions. Captain McClintock found the record and remains of Franklin at Point Victory; and it seems that he died in June, 1847—about 11 years ago. The whole of his companions also perished, some at one place and some at another, in those inhospitable and desolate regions. We hope the last expedition to these dread solitudes of ice and snow has been made."

NEW EXPERIMENT IN TELEPHONY

It could speed up "dialing." Bell Laboratories people created it—and now it's being tested.

The telephone you see above embodies an important new concept. It "dials" by means of push buttons—promises more convenient telephoning. Bell System engineers are currently testing it for public reaction. Bell Telephone Laboratories developed it.

The Laboratories' invention of the transistor makes it possible. For the transistor permits a new kind of calling signal generator, mounted within the instrument.

To insure ease of operation, psychologists studied human reactions to various finger pressures and sizes and arrangements of buttons. All factors affecting speed and accuracy were thoroughly evaluated. Electrical and mechanical engineers brought together the human and physical factors, created a practical piece of apparatus. Industrial designers worked out the functional shape.

The new instrument sends a calling signal quite different from that of your present telephone. This poses a problem. Complex automatic switching must be changed to handle the new signals as well as the old ones. Switching engineers must devise ways to make this change in *thousands* of central offices—economically.

Most of the challenges have been met. Final judgment on this new concept depends on the outcome of field tests. Meanwhile, Bell Laboratories continues in its task of originating and developing devices to improve your Bell System telephone service.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

Clayton Weaver, *Superintendent (left), and* Forrest Holcomb, *Cracking Plant Operator, Leonard Refineries, discuss function of air supply in catalytic cracking and . . .*

How Cooper-Bessemer centrifugal compressor supplies big-volume air 'round-the-clock

As "Doc" Weaver, Superintendent of Leonard Refineries, Inc., Alma, Michigan explains . . . "Big centrifugals are the answer, of course, where modern processing calls for an extremely dependable air or gas supply at high volume and relatively low pressure. For example, our catalytic cracking requires this kind of air supply for burning coke off the catalyst. Our Cooper-Bessemer Type RS Centrifugal Compressor delivers 31,500 cfm at 30 psi discharge pressure. And, it produces this flow on a continuous, 24-hour basis. We are mighty pleased with its reliable performance."

Find out how Cooper-Bessemer Centrifugal Compressors can help solve *your* processing, air supply or compression problems for optimum economy. There is a type and size of unit for every need. Call our nearest office for complete details.

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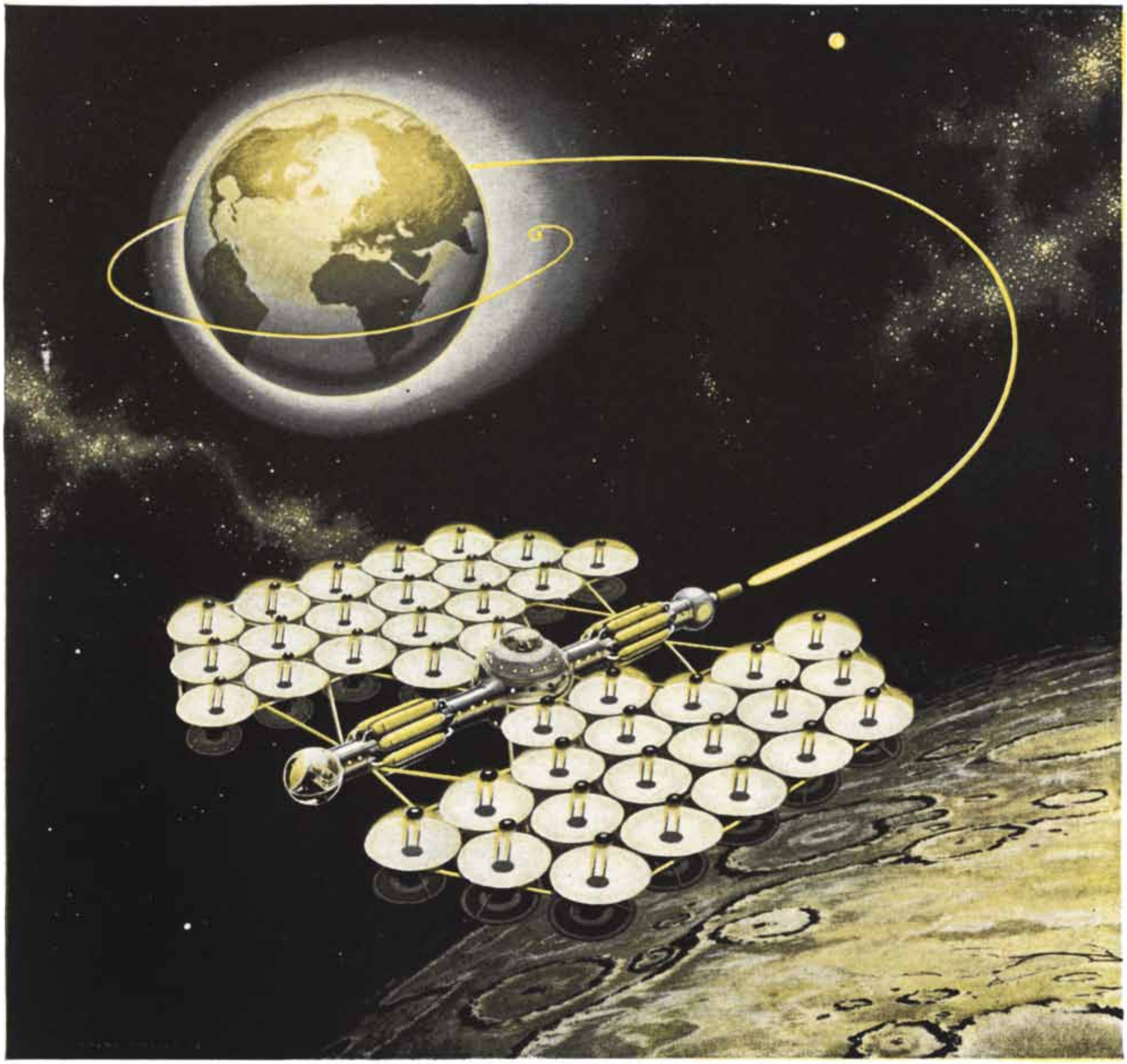

STEPS IN THE RACE TO OUTER SPACE

Cosmic Butterfly

Spreading its wings to absorb the eternal flow of solar energy is the Cosmic Butterfly, a space vehicle of a type first conceived by Dr. Ernst Stuhlinger of Redstone Arsenal.

Each of the fifty-foot parabolic mirrors in the wings concentrates the Sun's rays on a boiler at its focal point. Steam is developed, which drives a 200-kw turbo-generator in the base. Cooled by frigid outer space in heat diffusers, the steam reverts to water and is pumped back to the boiler to be used over and over again.

The current thus generated drives the main propulsion unit, an ion rocket in which powerful electric fields accelerate charged particles, shooting them from the rear of the rocket exactly as the electron gun in your TV set bombards the screen. Sunlight, then, is the power source, whereas cesium is the propellant.

While the recoil thrust is relatively small, the weightless vehicle is operating in a vacuum and the push is enough to enable the Butterfly to reach interplanetary speeds. Unlike conventional rockets, the Butterfly is under power the entire trip. Half way to its destination it turns around, and the ion thrust is used to slow the craft down to arrival speeds.

Since its thrust is entirely inadequate to cope with the gravity of major planets, the Cosmic Butterfly never lands. It is assembled in space and shuttles between artificial satellites.

The Cosmic Butterfly could carry ten passengers and 50 tons of cargo from an Earth satellite to a comparable one orbiting around Mars in about one year of continuous travel.

Inertial navigation systems will play an increasing role in the exploration of outer space. ARMA, now providing such systems for the Air Force ATLAS ICBM, will be in the vanguard of the race to outer space. ARMA . . . Garden City, N. Y. A Division of American Bosch Arma Corp.

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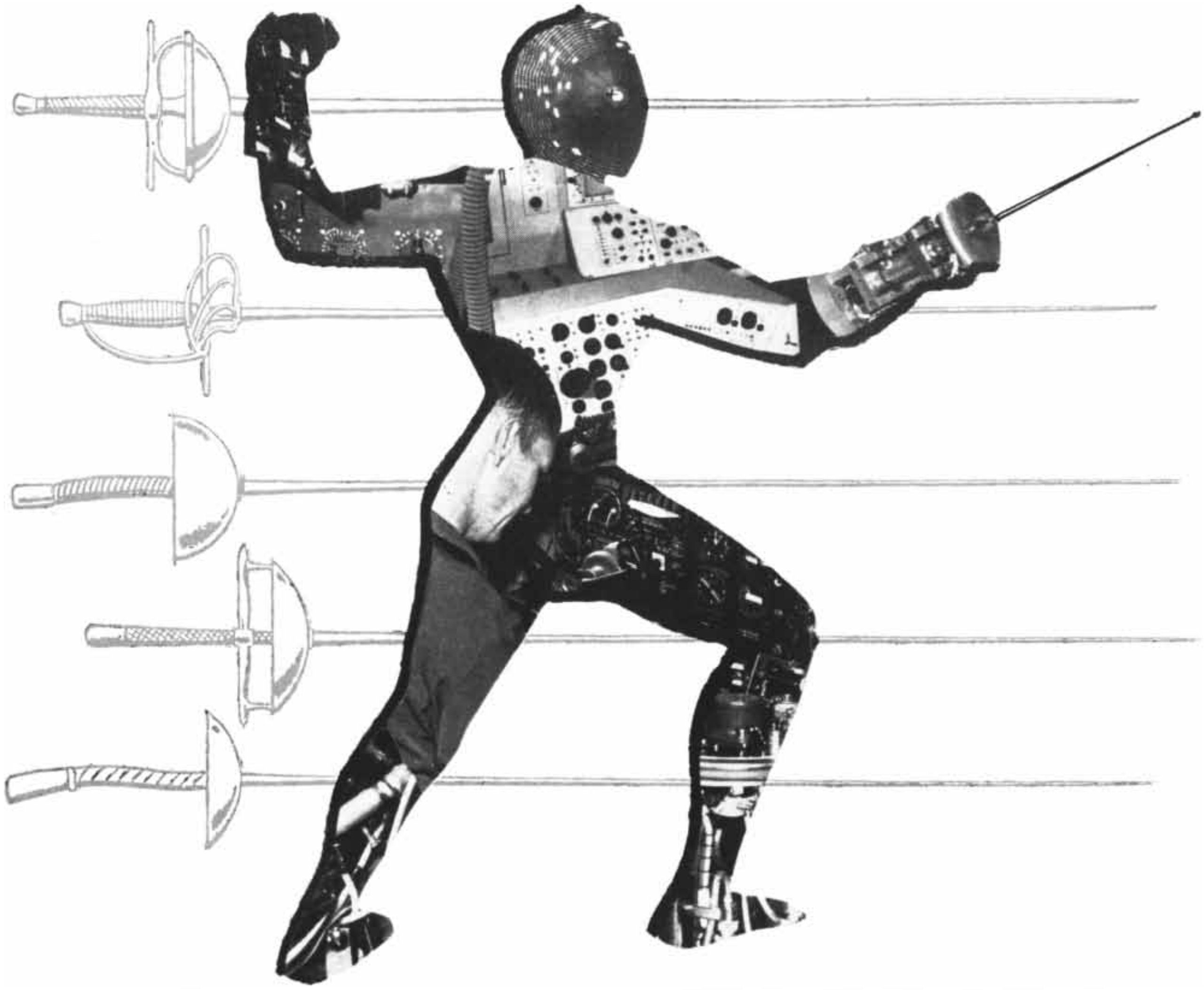

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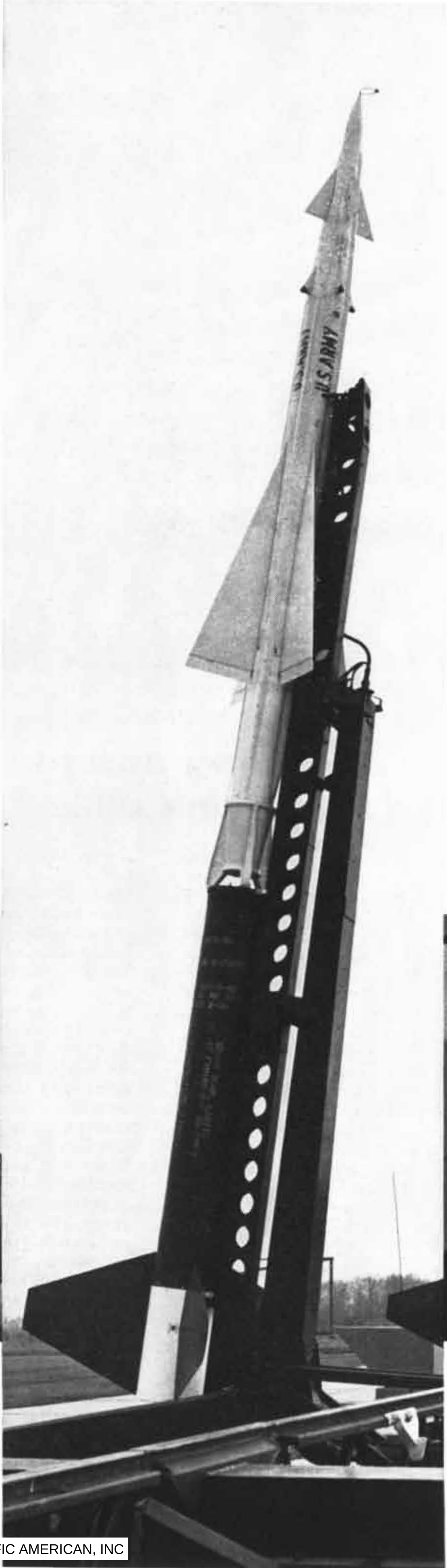
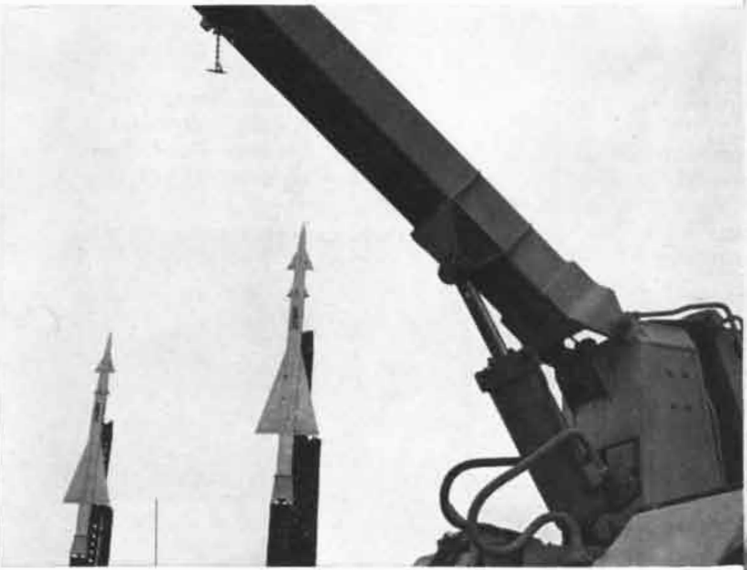
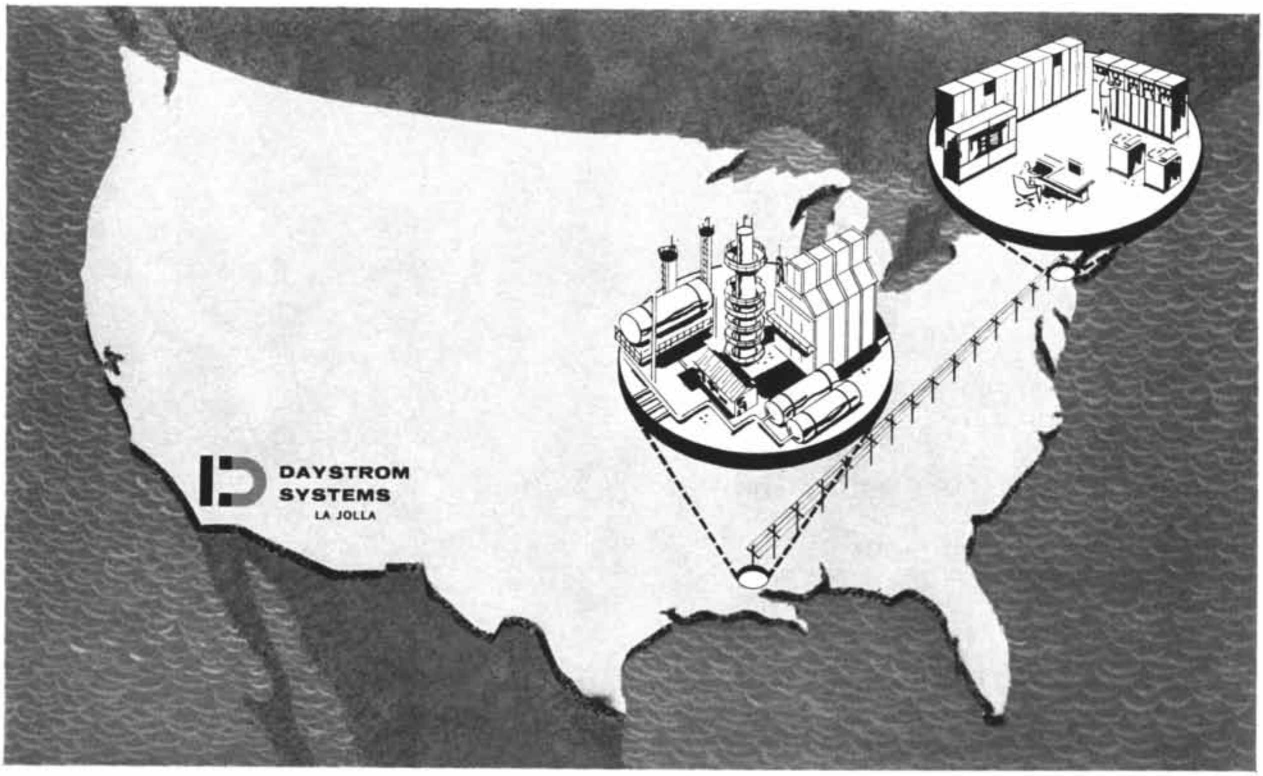




How light can you make a steel boom for any missile system without sacrificing strength? The proper selection of USS High-Strength Steels or Constructional Alloy Steels has cut the weight of similar equipment as much as ⅓—and *increased* the strength and service life.



Now...in addition to on-line computer systems

Operating and test data reduction via telephone link utilizing any computer facility

The new Daystrom TPR Scanning System represents a revolutionary approach with vast implications where there are requirements for immediate or continuous computer analysis of plant operating or test data. The availability of this new tool will influence industry's plans in a number of important areas, which include process studies, experimental test work in the military and nuclear areas, and testing for performance guarantees.

For the first time, the TPR (tape programmed raw) data scanner makes it possible and practical to link a test or operational plant facility directly to any computer in the country for instant computation of data. This is made possible by the utilization of standard telephone communication services, and permits stationing of all engineering and computer programming personnel at the project site, where all phases of the work may be handled.

The importance of this development is brought into sharp focus by the almost non-existence of computer facilities at actual plant or test sites. The utilization of telephone circuits completely circumvents this problem since it makes little difference whether the computer facility to be used is located in an adjoining building, company headquarters or at a rental facility. Distance represents no problem other than nominal telephone service charges.

Telephone communication of this type is a practical reality in the business machine field and is being used every day by leading companies for inventory control, accounting and other purposes. The Daystrom TPR Data Scanner is the first system that has been specifically designed to handle the problems involved in gathering large amounts of analog data peculiar to plant and test facility operation.

The TPR Data Scanner's feature of tape programming provides unlimited flexibility. This permits unrestricted application of the equipment to various types of facilities even though they may be completely different in nature.

Typical of the unequalled performance specifications are 0.1% accuracy at the 99% confidence level, together with extremely high signal to noise ratio at scanning rates up to 40 variables per second. 100% solid state circuitry and full parity checking are incorporated. Input channels may be as few as 100 or as many as 6000.

For further information, write or telephone Daystrom Systems, Dept. A-124, Miramar Road, La Jolla, Calif. GLencourt 4-0421.

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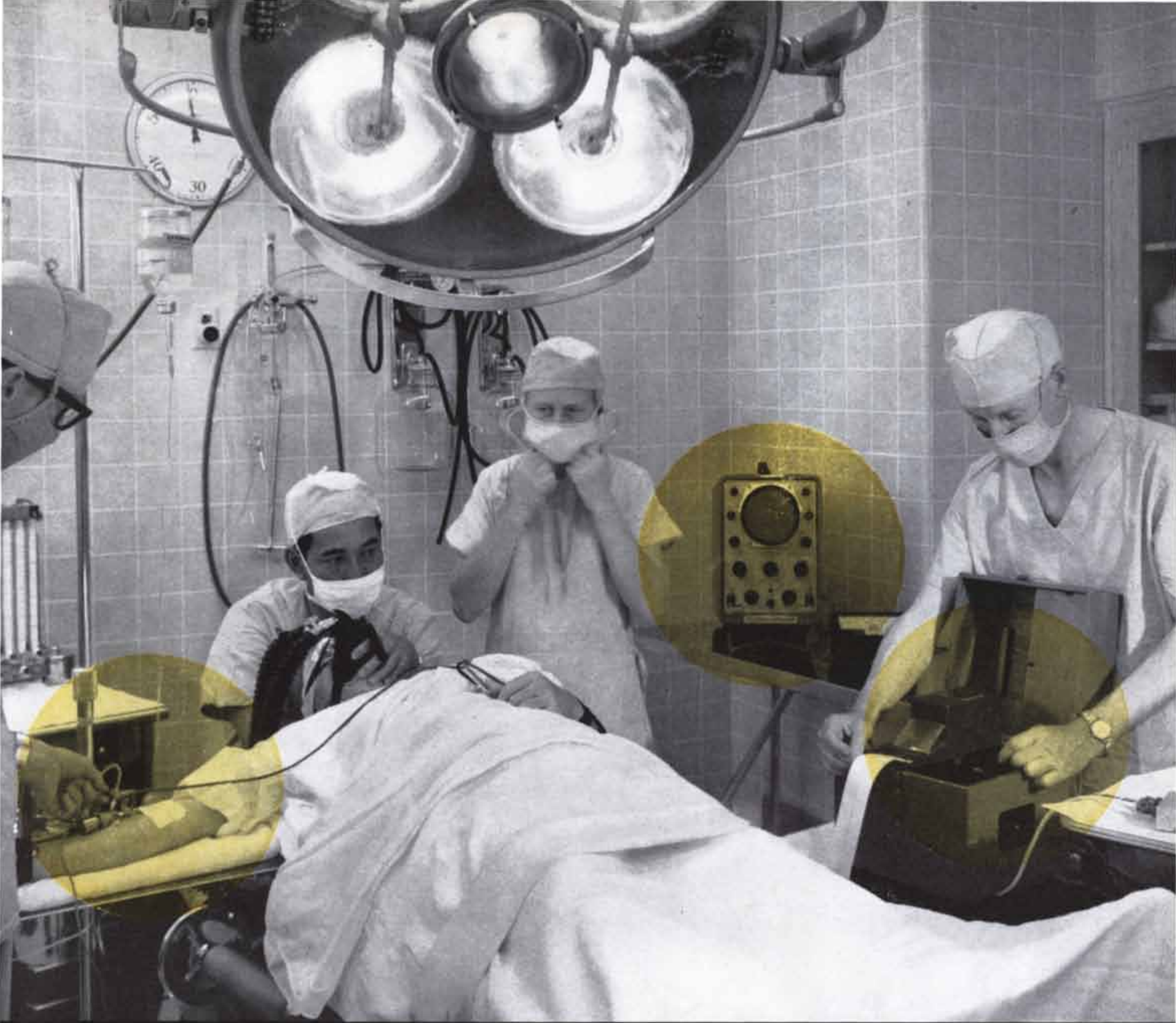

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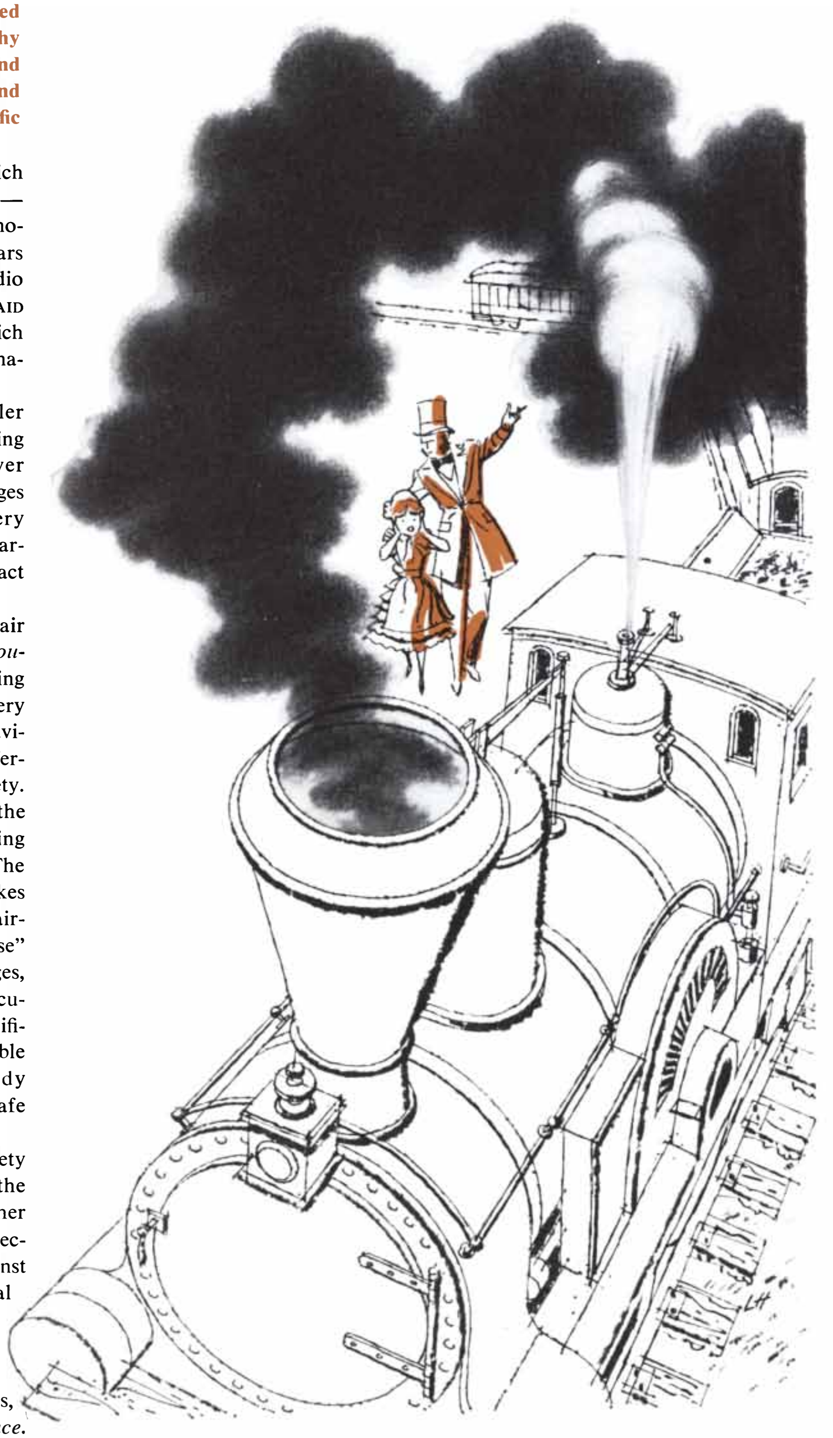
THE AUTHORS

JOHN P. MERRILL ("The Transplantation of the Kidney") is director of the cardiorenal section at the Peter Bent Brigham Hospital in Boston, and assistant professor of medicine at the Harvard Medical School. He was born in Hartford, Conn., in 1917, took his A.B. degree at Dartmouth in 1938, and his M.D. at Harvard in 1942. He was an Army Air Force physician from 1943 until he returned to Peter Bent Brigham in 1947. For five years he was an Established Investigator there for the American Heart Association. Merrill studied how heart action is affected by changes in the body fluid; this led him to kidney-transplant work. Merrill comments: "We found that these changes were most marked in people with kidney disease. We then found that we could modify these changes with the artificial kidney . . . but in patients with chronic disease, the artificial kidney gave only temporary relief." Merrill and his co-workers decided that kidney transplants might solve the problems of such patients. He spent a year in England and France studying the basic immunology of transplanting kidneys, and returned to Boston to apply what he had learned.

SYDNEY CHAPMAN ("The Earth in the Sun's Atmosphere") is a mathematician, astronomer and geophysicist. Born in Manchester, England, in 1888, he obtained degrees in engineering and mathematics from the University of Manchester and continued his studies in mathematics at the University of Cambridge. After some years as an astronomer at the Greenwich Observatory, he taught mathematics as a fellow and lecturer at Trinity College, Cambridge, and as professor at the universities of Manchester, London and Oxford. During World War II he served as deputy scientific adviser to the British Army. Since 1951 he has been advisory scientific director and visiting professor of geophysics at the University of Alaska, and since 1955 has been a member of the research staff of the High Altitude Observatory of the University of Colorado. He has been president of several British scientific societies, and of various international scientific organizations—most recently of the central committee for the International Geophysical Year.

LEONARD G. AUSTIN ("Fuel Cells") is an instructor in the fuel technology department of Pennsylvania State University. He is working on his Ph.D. and is also directing studies of fuel cells and coal grindability. Austin was born 30 years ago in London, and took his bachelor's degree in chemistry, physics and mathematics from the University of London in 1950. He qualified as a chartered fuel technologist in 1954, and has worked in the coal-gas industry in England and in the Fuel Technology Branch of the Central Electricity Generating Board of the United Kingdom. His main concern was the air pollution caused by power stations, and he "found the detective work involved in interpreting air pollution measurements so fascinating I hope to start research along these lines in the U. S." Before coming to this country in 1957, he lectured at Northampton College of Advanced Technology and at the Borough Polytechnic, both in London.

GEORGE WALD ("Life and Light"), professor of biology at Harvard University, is one of the world's leading authorities on the chemistry of vision. A native of New York City, he was graduated from New York University in 1927, had his graduate training with Selig Hecht at Columbia University, and then went to Germany on a National Research Council Fellowship. Working in Otto Warburg's laboratory in Berlin (1932-33) he discovered vitamin A in the retina, and in the same year established its role in visual processes in the laboratories of Paul Karrer in Zurich and Otto Meyerhof in Heidelberg. In 1934 Wald went to Harvard, where he has remained and has elucidated the complex chemical reactions through which vision is excited by light. "Years ago I used to worry about the degree to which I had specialized. Vision is limited enough, yet I was not really working on vision, for I hardly made contact with visual sensations, except as signals, nor with the nervous pathways, nor the structures of the eye, except the retina. Actually my studies involved only the rods and cones of the retina, and in them only the visual pigments. A sadly limited, peripheral business, fit for escapists. But it is as though this were a very narrow window through which at a distance one can see only a crack of light. As one comes closer the view grows wider and wider, until finally through this same narrow window one is looking at the universe. It is like the pupil of the eye, an opening only two to three millimeters across in daylight, but yielding a wide angle of view, and maneuverable enough to be turned in all directions. I think this is the way it al-



ways goes in science, because science is all one. It hardly matters where one enters, provided one can come closer, and then one does not see less and less, but more and more, because one is not dealing with an opaque object but with a window." Wald's work has brought him many honors, the latest being the Rumford Premium of the American Academy of Arts and Sciences (a gold medal, a silver medal and $5,000).

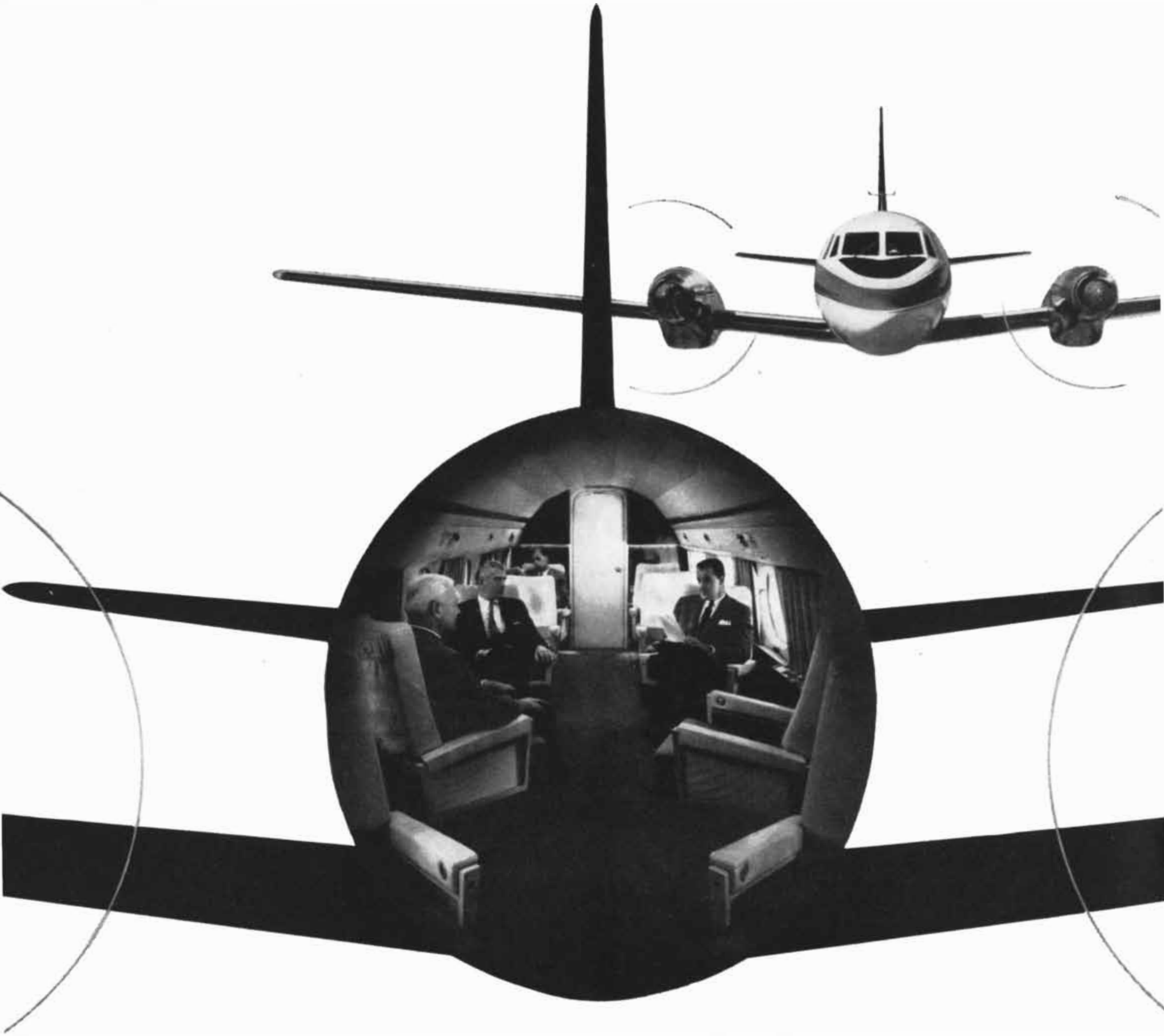
B. J. ALDER and THOMAS E. WAINWRIGHT ("Molecular Motions") are both theoretical physicists on the staff of the Lawrence Radiation Laboratory in Livermore, Calif. Alder was born in 1925 in Duisberg, Germany. He was a Swiss citizen, and received his high-school education in Switzerland. He came to the U. S. in 1941, and from 1944 to 1946 he was an electronic technician in the Navy. In 1947 he acquired a B.S. in chemistry from the University of California. He took his M. S. there in 1948 in chemical engineering, and shifted to the California Institute of Technology for his Ph.D. in 1951. He was an instructor in chemistry at the University of California from 1951 to 1954, held a one-year Guggenheim Fellowship at the universities of Cambridge and Leiden, and in 1955 took up his present work at the Lawrence Radiation Laboratory. Wainwright is 32 years old. He received his college education at the University of Utah and Montana State College, and took his Ph.D. in physics at the University of Notre Dame in 1953. He joined the Lawrence Laboratory in 1954.

JOHN A. KING ("The Social Behavior of Prairie Dogs"), a staff scientist at the Roscoe B. Jackson Memorial Laboratory in Bar Harbor, Me., is a city boy who has always been fond of mammals. He was born in Detroit in 1921, and spent most of his youth in the city. At the University of Michigan, where he took his B.A., M. S. and Ph.D. degrees, he at first collected mammals in traps for the University Museum. "The dead mammals we found in our traps each morning only told us what animals lived where, but the carcasses did not reveal how they lived. . . . This problem is still my chief interest." During World War II he piloted B-17 bombers. He served at an air base at Rapid City, S. D., and became acquainted with the mammals of that region. It was here that he developed his interest in colonial mammals, and this led to his prairie-dog studies. He camped with his wife among the prairie dogs and bison of Wind Cave National Park for two summers. King has been at the Jackson Laboratory since 1951, and is now studying the development of behavior in the deer mouse.

I. MACKENZIE LAMB ("Lichens") is director of the Farlow Reference Library and Herbarium and lecturer in botany at Harvard University. A native of London, he took his B.Sc. degree at the University of Edinburgh in 1933, and his doctorate there in 1943. He was assistant keeper in charge of the Lichen Herbarium at the British Museum in London from 1935 to 1946. Then he served as professor of cryptogamic botany at the University of Tucumán in Argentina until 1950. (Cryptogams include ferns, mosses, and other plants that do not produce flowers or seeds.) He moved to Canada to become curator of cryptogamic collections at the National Museum of Canada, Ottawa, where he remained until he went to Harvard in 1953. During World War II Lamb was on leave from the British Museum, and served as botanist as well as a dog-driver and surveyor's assistant in the Falkland Islands Dependencies Survey and in the Antarctic.

A. C. CROMBIE ("Descartes") lectures on the history and philosophy of science at the University of Oxford. He is the author of two books: *Augustine to Galileo* (reissued in a two-volume revised and expanded edition this year under the title *Medieval and Early Modern Science*), and *Robert Grosseteste and the Origins of Experimental Science: 1100-1700*. The author of numerous articles, he was also the original editor of the *British Journal for the Philosophy of Science*. He has served as visiting professor of philosophy at the University of Washington, and he is now Shreve Fellow at Princeton University. Crombie is working on a study of Descartes as a scientific thinker, especially his influence on the development of physiological and biological theory. His interest in Descartes is part of his concern with the logic and "natural history" of scientific discovery. His article on Hermann von Helmholtz appeared in SCIENTIFIC AMERICAN for March, 1958.

ASA BRIGGS, who reviews *The Two Cultures and the Scientific Revolution*, by C. P. Snow, and *Technology and the Academics*, by Sir Eric Ashby, in this issue, is professor of modern history at the University of Leeds in England. He has been a faculty member at the University of Oxford, and spent 1953-54 at the Institute for Advanced Study in Princeton.



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He put a new twist in an old trick

His problem was to take a 3"x 6"x 3-foot piece of wave guide tubing made of .08-inch thick aluminum and to twist one end 90° to the other *without buckling or stretching any part of it . . . so that a cross section taken anywhere along its length remained a perfect rectangle.*

The standard solution for a problem like this: Support the tube internally with a solder-like substance that's melted in, cooled, melted out after twisting. It won't work here because the mass of the substance is too great.

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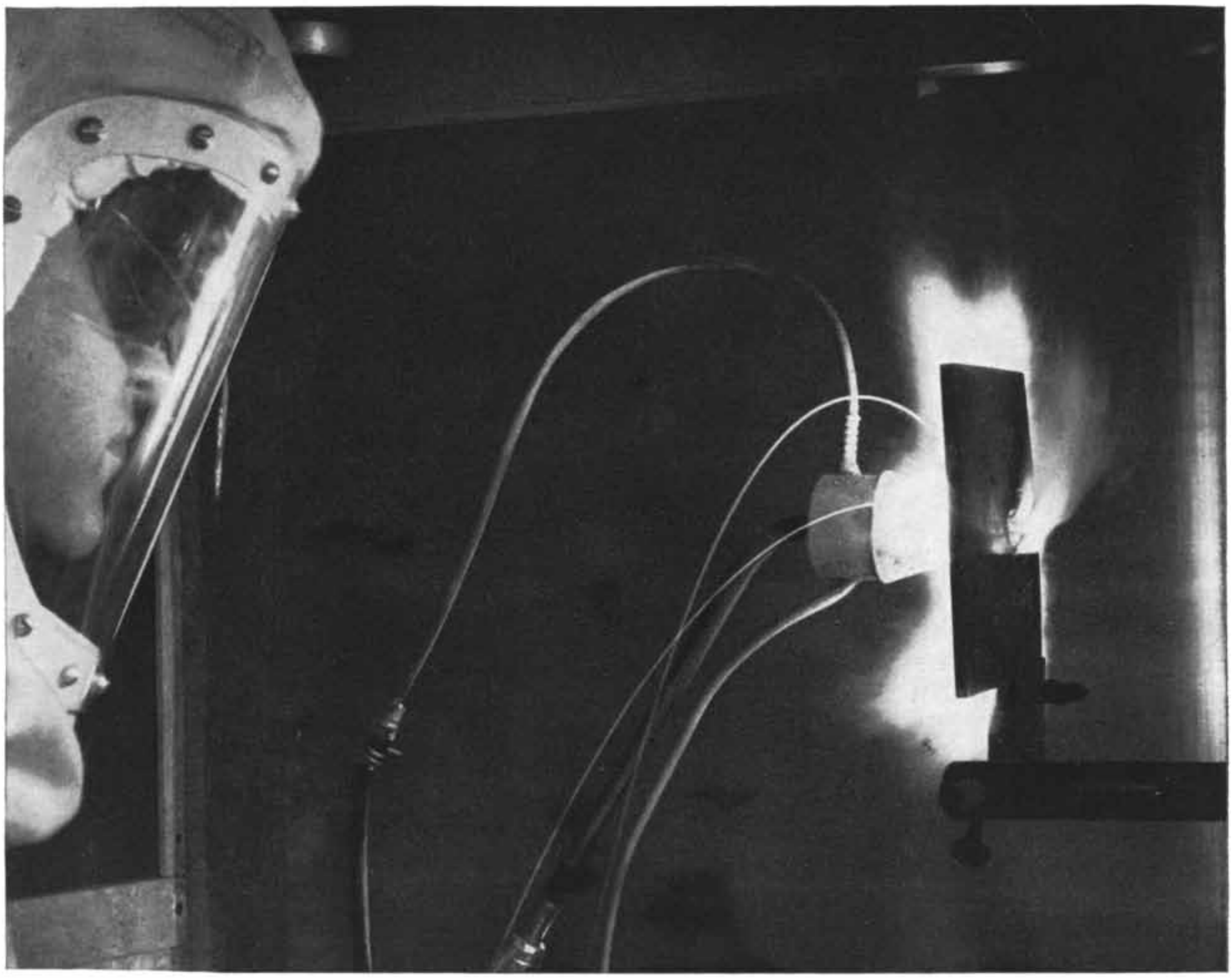

Measure dc currents
0.3 ma to 1 ampere
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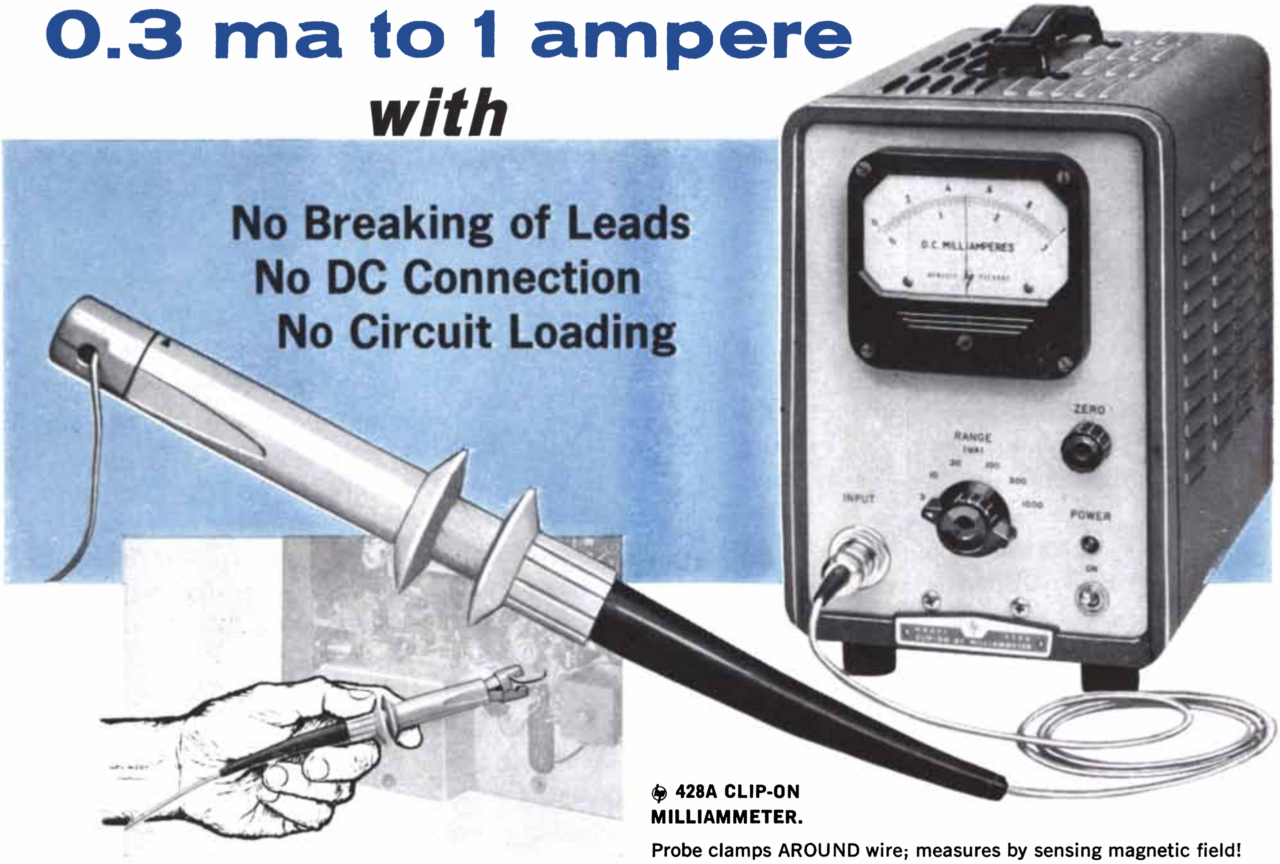

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With the ⓗⓟ 428A Milliammeter and its new probe, you literally "*clamp around*" and read! You get maximum accuracy because there is no effective circuit loading from the 428A's dc probe. The instrument easily measures dc currents in the presence of ac. And insulation is more than adequate to insure safe measurements at all normal voltage levels.

For extremely low current level measurement, sensitivity can be increased by looping the conductor through the "jaws" of the 428A probe two or more times.

Brief specifications are given here; for complete details and demonstration *on your bench*, call your ⓗⓟ representative or write direct.

Specifications

Current Range: Less than 0.3 ma to 1 amp, 6 ranges. Full scale readings from 3 ma to 1 amp: 3 ma, 10 ma, 30 ma, 100 ma, 300 ma, 1 amp.

Accuracy: ± 3% ± 0.1 ma.

Probe Inductance: Less than 0.5 μh maximum.

Probe Induced Voltage: Less than 15 mv peak.

Effects of ac in circuit: Ac with peak value less than full scale affects accuracy less than 2% at frequencies different from the carrier (40 KC) and its harmonics.

Power: 115/230 v ± 10%, 50-60 cps, 70 watts.

Size: Cabinet mount, 7½" wide, 11½" high, 14¼" deep. Weight 19 pounds. Rack mount, 19" wide, 7" high, 12½" deep. Weight 24 pounds.

Probe Tip Size: Approximately ⅝" x 7/16". Wire aperture diameter 3/16".

Price: (Cabinet) $475.00; (Rack) $480.00.

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a report by LINDSAY

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...NEWS IS HAPPENING AT NORTHROP

How the Outer Edge of the Earth's Atmosphere Can Be the Training Ground for Man's First Landing on the Moon

by Norman V. Petersen

Chief of the Astro Systems and Research Laboratories, Norair Division of Northrop Corporation

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For ten seconds the capsule would hover motionless above the earth's atmosphere — supported by the reverse thrust of the rocket blast. Then the pilot and capsule would re-enter the atmosphere in a low-speed free fall. After re-entry, the descent would be completed by parachute.

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The Transplantation of the Kidney

A kidney can be transplanted from one person to another, but the body is normally "immune" to the graft and rejects it. In certain special cases, however, the immune response of the body can be circumvented

by John P. Merrill

If the human body were a simpler sort of mechanism, it might be possible to save many lives by replacing defective organs and tissues with healthy "spare parts" taken from the bodies of donors, either living or recently dead. The blood bank, of course, already functions as an approximation of this idea. Some hospitals also store corneas and sections of blood vessel, both of which can be transplanted by surgery. It is usually impossible, however, to transplant a whole organ such as a kidney, or even to graft skin successfully from one person to another.

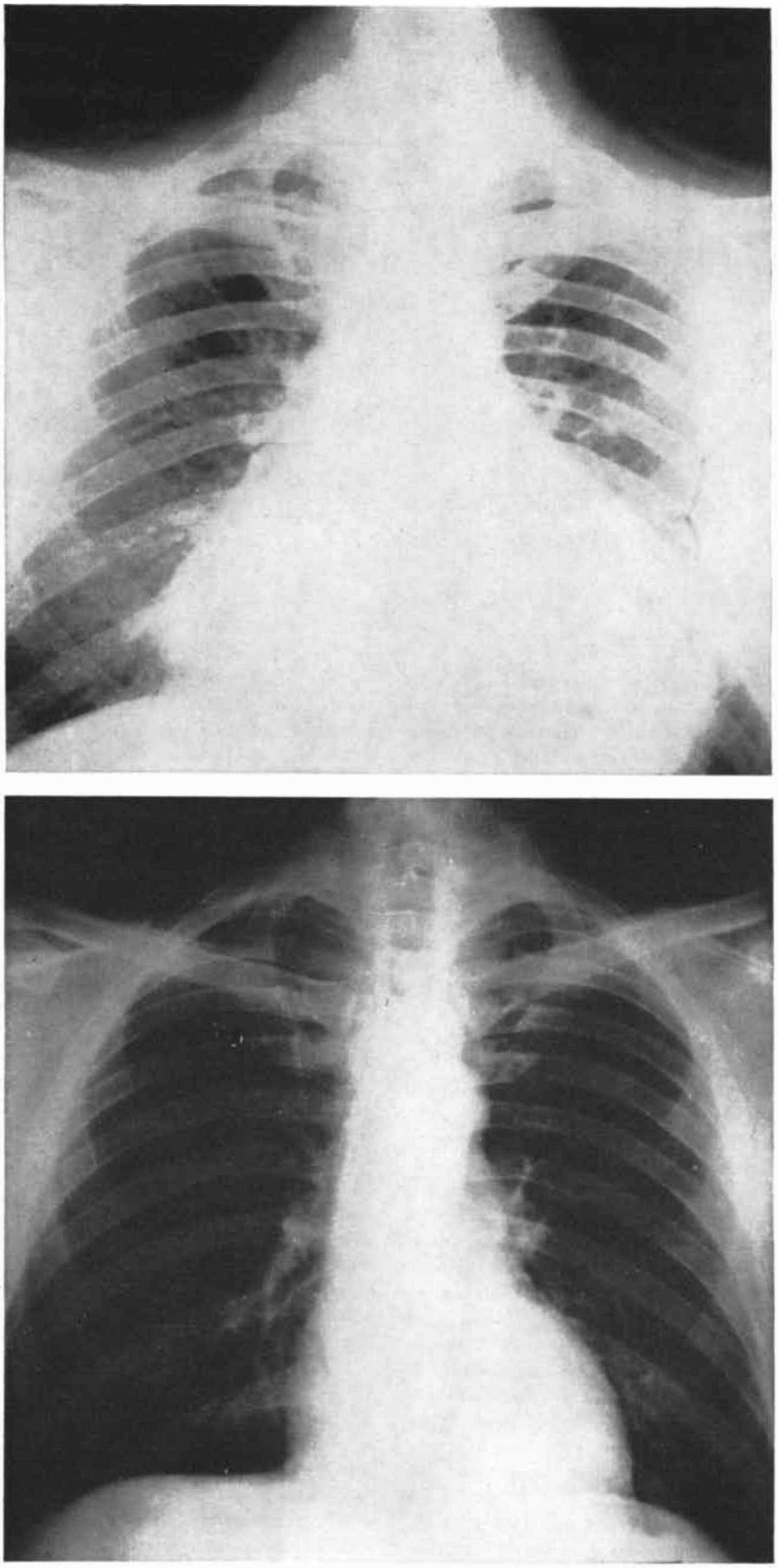
The nature of this impasse is suggested by the familiar fact that blood must be "typed" and matched with care if transfusion is to be helpful and not disastrous. The tissue of each individual has its own chemical identity. Upon exposure to foreign tissue it rallies the most powerful defensive mechanism it possesses, the immune response, to destroy and reject the foreign tissue. The apparent exceptions—blood, cornea and blood vessel—each in its way proves the rule. Properly matched blood does not evoke the response, nor does the biologically rather inert corneal tissue. Transplanted blood vessels serve merely as "bridges" to guide the regeneration of the body's own tissue. The successful achievement of true "homografts" thus remains for the present a frontier of experimental surgery and of research in biochemistry and immunology. At the Peter Bent Brigham Hospital and the Harvard Medical School a group of us has been working at this frontier with results so far that give promise only to the extent that they have added to general understanding of the underlying problems. We work with the kidney, an organ eminently suited for transplantation. Most individuals have two normal kidneys and can live perfectly well with one. The elective surgical removal of one kidney involves little risk, and the surgical connection of the blood vessels of the donated kidney to the vessels of the recipient is generally not prohibitively difficult. Many chronic kidney-diseases are progressive and cannot be arrested by any therapy. Kidney tissue destroyed by disease heals by scarring, and the fibrous scar-tissue in turn tends to destroy more functional units of the organ. Thus the only possible cure often seems to be a new kidney.

E. Ullmann of Vienna made the first attempts to transplant the kidney in experimental animals at the beginning of the century. He was able to remove a kidney from an animal and then restore it to the same animal (an autograft), but could not successfully transplant the organ from one animal to another of the same species (a homograft). In 1908 Alexis Carrel transplanted kidneys in both dogs and cats. He observed that the transplanted kidney was infiltrated with plasma cells, a species of white cell found in the bloodstream. All subsequent observers have noted infiltration by these cells and their next of kin: the lymphocytes. In 1923 C. S. Williamson of the Mayo Clinic attributed the infiltration of the grafted kidney to a "biological incompatibility" between donor and recipient.

In an extensive series of investigations beginning in the 1940's, W. J. Dempster, a British experimental surgeon, gave further substance to this concept of biological incompatibility. He knew that it had been demonstrated that a second transplant of skin from one animal to another of the same species was much more speedily rejected than the first. He extended these observations and found that if the animal had been made "immune" to a donor by a skin graft, it would react in the same way to a kidney transplanted from the same donor. By this time it was believed that an important role in the immune response is also played by the so-called antibodies: molecules that are produced by the blood-forming tissues and perhaps also by the white cells and that react with great specificity to foreign molecules. In his microscopic studies Dempster found indications that not only did the host react against the graft; in some cases the kidney graft itself was evincing an immune reaction against the host.

The first attempt to transplant a kidney in man is recorded in Russian medical literature of the 1930's; the effort was not successful. In this country unsuccessful attempts were reported in 1950. In France somewhat later healthy kidneys taken immediately from guillotined criminals failed to survive transplantation into patients chronically ill with uremia.

Our work at Peter Bent Brigham dates from the attempt by Charles A. Huf-

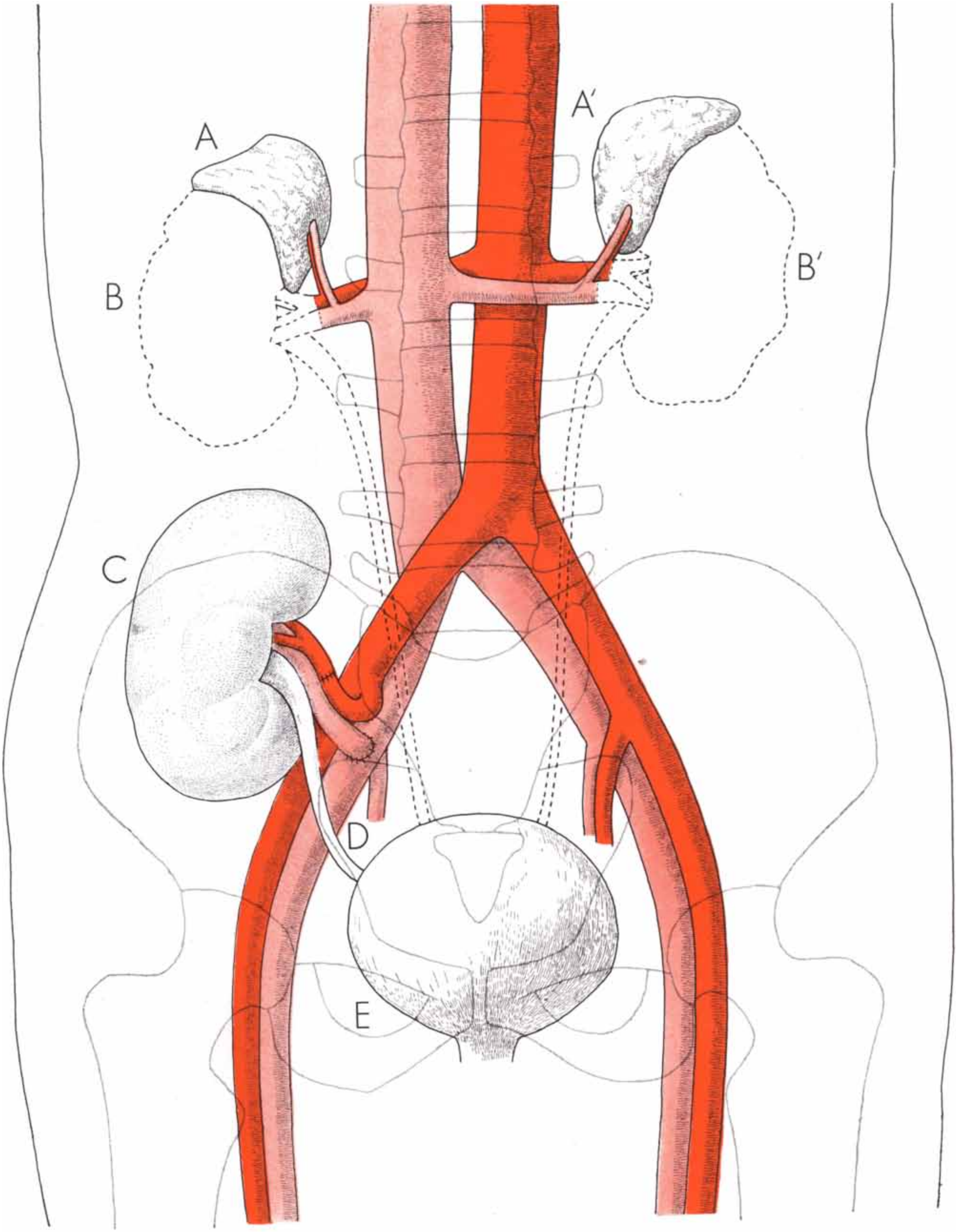


ENLARGED HEART AND FLUID IN CHEST, visible in top radiograph, are signs of severe high blood-pressure and heart failure resulting from kidney disease. The pressure of the fluid interferes with heart action. Bottom radiograph shows return to normal in same patient three weeks after he had received a graft of a kidney from his identical-twin brother.

nagel and Ernest K. Landsteiner to attach a kidney to the arm of a patient acutely ill with uremia. The kidney secreted a few drops of urine but never developed measurable function. The patient, however, recovered from her attack of acute kidney failure. In 1955 David M. Hume, Benjamin F. Miller, George W. Thorn and I reported our experience in nine similar procedures. All of the patients were terminally ill and required treatment with artificial kidneys. Indeed, without the artificial kidney we could not have undertaken this procedure in patients as sick as these. The transplanted kidneys came from patients who had died of chronic heart disease. In eight cases we grafted the kidney into a "pocket" fashioned in the skin on the middle of the upper thigh. We connected the blood vessels of the kidney to the vessels of the thigh. The ureter, the tube that drains urine from the kidney into the bladder, was led to an opening in the skin. Three considerations prompted the placing of the kidney in this bizarre position: the surgical procedure was somewhat less extensive than placing it in the abdomen; we could measure urine as it came directly from the kidney, thus avoiding the complicating factor of the output of the two defective kidneys; and we could more easily remove the kidney if the procedure failed or if the kidney became infected, leaving the patient certainly no worse than before. Four of the nine transplanted kidneys functioned; two did so well that the patients had some relief of symptoms. In one of the two patients, a South American physician with severe uremia and high blood-pressure, the kidney functioned for five and a half months before it failed; the patient was even able to leave the hospital for three months.

These results in human patients were far more encouraging than experiments with animals had led us to expect. In dogs grafted kidneys had functioned for only five to 12 days; then blood appeared in the urine and the kidneys suddenly failed. Moreover, microscopic examination revealed that the changes in the transplanted human kidneys were much less drastic than those in the dog. At first we thought that the species difference between dogs and men might account for the difference in behavior of the transplants.

In 1953, however, I was fortunate enough to be in Paris to observe a case in which a kidney had been transplanted. A healthy young man had fallen from a roof and severely injured a kid-



TRANSPLANTED KIDNEY (C) is placed in the abdominal cavity as shown in this diagram. Its blood vessels are attached to nearby vein and artery. Ureter (D) is implanted in bladder (E). The defective kidneys (B and B′), indicated by broken lines, are removed, while the adrenal glands (A and A′), normally located on top of the kidneys, are left in place in the patient.

ney, which was then removed by a surgeon in a hospital outside of Paris. Unfortunately the kidney turned out to be the only one the patient possessed. A week later surgeons in Paris transplanted a kidney into the young man from his mother. The immediate results were striking. The kidney began to form urine and functioned well for three weeks, greatly decreasing uremia and improving the patient's condition. But on the 21st day blood appeared in the urine and soon the kidney stopped functioning.

In the post-mortem examination we found that this kidney, transplanted from a healthy donor into a previously healthy recipient, had behaved very much like the grafted dog kidneys. The microscopic picture was almost identical. We now realized that the difference between grafted dog and human kidneys that we had observed had stemmed not from any species difference but from the fact that we had transplanted kidneys from chronically ill individuals into other chronically ill individuals. Our sick subjects apparently did not react as violently against sick kidneys as healthy subjects (or dogs) do against healthy kidneys. Skin grafts to chronically ill uremic patients confirmed this deduction; the grafts survived seven to 10 times as long as those on normal healthy recipients. Apparently the general depression of body function in these patients also depresses the immune response to the homograft.

At this juncture we listed our accomplishments: We had acquired a good deal of technical experience in transplanting kidneys and in the care of critically ill uremic patients, and we had learned that the immune response was not so violent in chronically ill people.

In 1954 we were confronted with a unique opportunity to apply this experience. David Miller, an alert physician in a nearby U. S. Public Health Service hospital, was caring for a young veteran who was dying of severe kidney failure and high blood-pressure. A daily visitor to his bedside was his apparently identical twin. Miller knew of our work on kidney transplantation. He also knew that biological incompatibility was the reason transplantation of tissues generally failed. He reasoned that if the two young men were identical twins, their tissues might not be biologically incompatible. As is well known, identical twins develop from a single fertilized egg; they not only resemble each other in appearance but also have a high degree of biological identity. What is more, skin transplants between identical twins have succeeded. With these considerations in mind Miller referred the patient and his brother to the Peter Bent Brigham Hospital.

To be sure that these twins were identical we transplanted skin from each to the other. Knowing that such a transplant might "take" for a prolonged period (though not permanently) in the sick twin, we were especially concerned to observe the result in the healthy twin. Both grafts took normally. Although this was the critical test, we thoroughly investigated other significant similarities that might confirm identical inheritance. A geneticist carefully compared the boys' facial features, iris color and pattern, hair color and form, shape of the ears and even taste similarities. A hematologist found their blood groups identical in all the major categories and in 20 separate subcategories. Extensive examinations convinced us that the healthy twin was free from all kidney and other diseases. Thus we had adequate medical and genetic bases for proceeding with the transplantation.

On the other hand, we had no precedent for the removal of a perfectly normal kidney from a healthy individual, and this consideration weighed heavily in our deliberations. Meanwhile the sick twin grew sicker. His uremia became so bad that it required treatment with an artificial kidney; his blood pressure continued to rise, with dangerous effects upon his heart and blood vessels. Finally, two days before Christmas, 1954, a normal kidney was removed from the donor twin by J. Hartwell Harrison and transplanted by Joseph E. Murray into the sick recipient.

Murray placed this kidney not in the thigh but in the hollow of the pelvis, inside the abdominal cavity, where its surroundings resembled its normal habitat [*see illustration on page* 59]. He connected the kidney's artery to a branch of the large iliac artery and its vein to a vein in the pelvic cavity through which blood flows from one leg. The operation cut off the blood supply of the healthy kidney for almost an hour. In spite of this delay, when the clamp was released from the artery to which the grafted kidney was attached the kidney became a healthy pink, and within minutes urine began to drip slowly from the end of the ureter. Murray thereupon implanted the ureter directly into the bladder so that the urine would drain normally. In this case we wanted no possibility of technical failure to compromise our very real chance to avoid the immunologic barrier.

By the time the patient had left the operating room, urine was definitely flowing, and over the succeeding days and weeks the kidney gradually improved its function. The patient's uremia cleared up; his appetite and mental processes improved. Then—and this was beyond our expectation—we observed a drop in blood pressure. Six weeks after the transplantation we performed two operations, the first to remove one of the patient's diseased kidneys and the second to remove the other kidney. Following the second operation the blood pressure at last fell to normal, where it has remained ever since. All signs of heart

KIDNEY GRAFT INTO THIGH is shown in radiograph and diagram. The femur, the

strain and hemorrhage from smaller blood vessels soon disappeared.

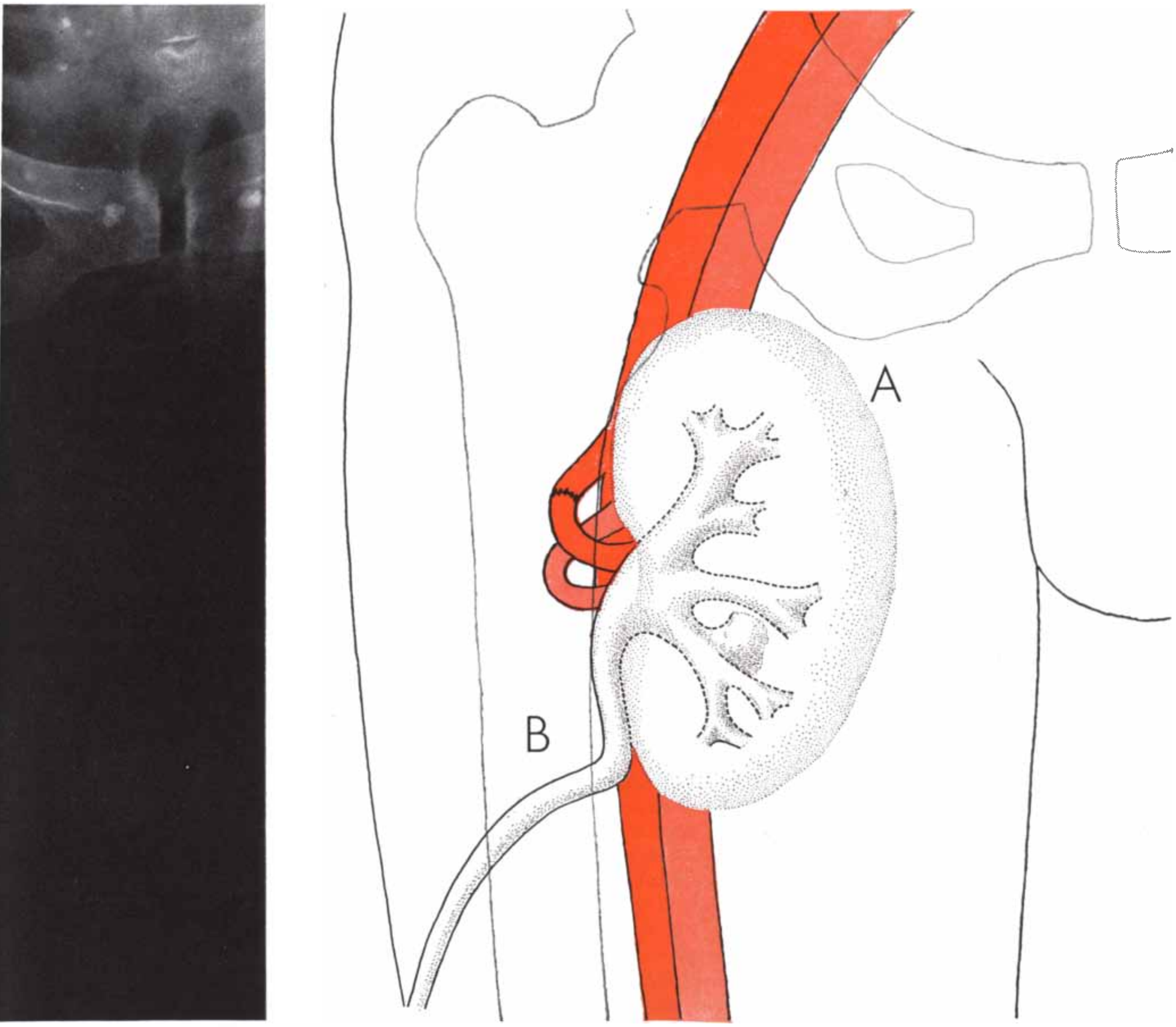
This was a dividend we had not fully anticipated. The role of the damaged kidney in causing high blood-pressure had been investigated in experimental animals for many years. This case provided the first opportunity to study in a human subject the kidney's role in high blood-pressure by first adding a normal kidney in the presence of two diseased ones and then removing the diseased kidneys in separate operations. We have now been able to make the same observations in six successful kidney transplants between identical twins; in each case the sick twin was a victim of severe hypertension.

Since 1954 we have transplanted a total of 13 kidneys between identical twins. Each of the 13 recipients had been terminally ill with uremia; 10 are alive and healthy today.

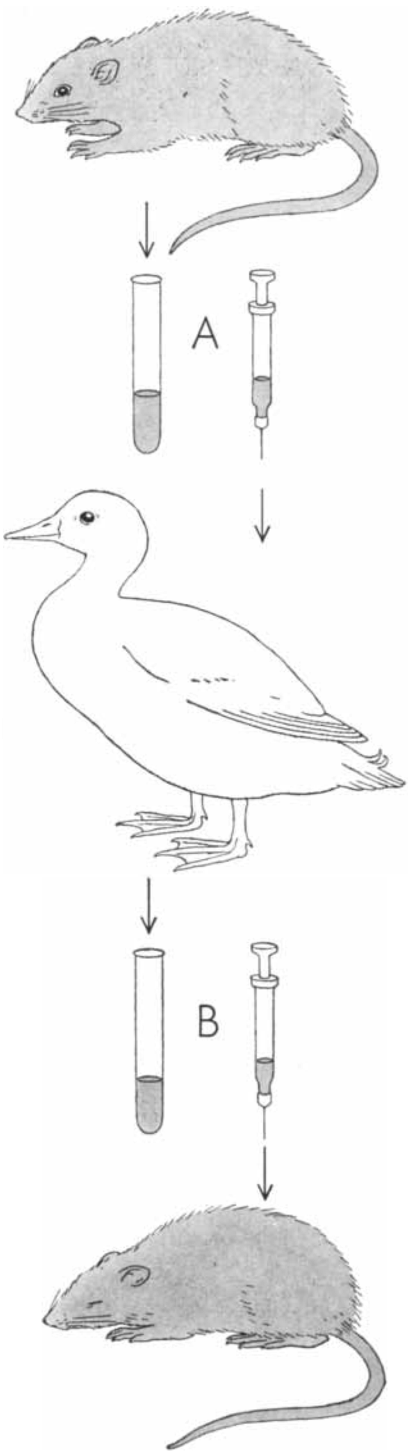
The kidney is of course one of the most complex organs in the body. It not only disposes of wastes but also delicately regulates the content and balance in the blood of salts and other substances. Our 10 successful transplants show that it can continue to do so in a totally different location in a different individual. Furthermore, the kidney functions even though its nerve connections are severed. This was indicated some time ago in animal-kidney autografts, and has been proved by our successful human transplants.

The moral problem of taking a healthy kidney from a healthy donor is acute, we feel, when the twins are minors. In such cases we have asked court permission to perform the graft. Permission has been granted on the ground that the healthy child would suffer more from the psychical loss of his twin than from the physiological loss of a kidney that can be spared.

The graft failed in one of our 13 cases because a congenital abnormality of the blood vessels in the donated kidney pre-



ureter and the kidney's pelvis and calyxes are visible in the radiograph. Diagram shows the ureter (B) and the renal cortex (A) as well as the blood-vessel connections of grafted kidney. Eight early grafts were done in this way in case grafted kidney had to be removed.



BRIGHT'S DISEASE IN RAT is produced by injecting extract of rat kidney (A) into a duck, which produces antibodies against this foreign tissue. Duck antibodies (B) injected into the rat now mask rat's kidneys; rat's antibody system attacks its own kidneys because they seem to be "foreign tissue."

vented them from fitting the vessels of the recipient. The other two deaths, following initially successful transplantation, gave us a critically important insight into the working of the immune response.

We found that these two patients had died because their transplanted kidney developed the nephritis (Bright's disease) from which they had suffered before the operation. Why was this finding important? For many years workers have been able to produce in animals a disease that appears to be the equivalent of human nephritis. To do this they make a serum from ground-up rat kidney and inject it into a rabbit. The immune response in the rabbit produces antibodies against this foreign material. When serum from the rabbit's blood is injected into the rat, the antibodies attack the rat's kidneys, causing the disorder that so resembles nephritis. A condition even closer to human nephritis is produced by injecting the ground-up rat kidney into a duck. When the duck serum is injected into the rat, the duck antibodies somehow mask the rat's kidneys so that the rat's tissues no longer "recognize" them. The rat then produces antibodies that act against its own kidneys.

Such investigations had strongly suggested that in human nephritis the body has formed antibodies against the kidneys. Proof of this hypothesis, however, had been lacking. Now we had transplanted normal kidneys into patients with nephritis, and had seen these kidneys contract the disease. Apparently in man, as well as in the rat, either antibodies circulating in the blood plasma or sensitized lymphocyte white cells had attacked the grafted kidney. Since skin grafts had taken in both of our cases, we knew that the attack upon the transplanted kidneys was no ordinary immune reaction to a graft.

The identical-twin grafts have demonstrated that where an immunological barrier does not exist kidneys can be successfully transplanted to cure otherwise incurable kidney and vascular disease. This limited success in surgery furnishes an additional motive for investigation of the immunological barrier, which is a problem of great fascination in itself. From long experience with skin grafts, investigators have a clear picture of the normal course of the immune response. A piece of skin from one person transplanted to the forearm of another will assume a firm, healthy appearance for several days as blood vessels grow into it. Four to five days after transplantation, however, the small vessels begin to be plugged, the skin becomes discolored in a patchy fashion and the skin cells become necrotic and die, to be overgrown by the epithelial cells of the host's skin. After this the host will react much faster in rejecting a new skin transplant from the same donor. This acceleration in the reaction suggests that the recipient's tissues have in some way learned to "recognize" as foreign the tissue from the donor.

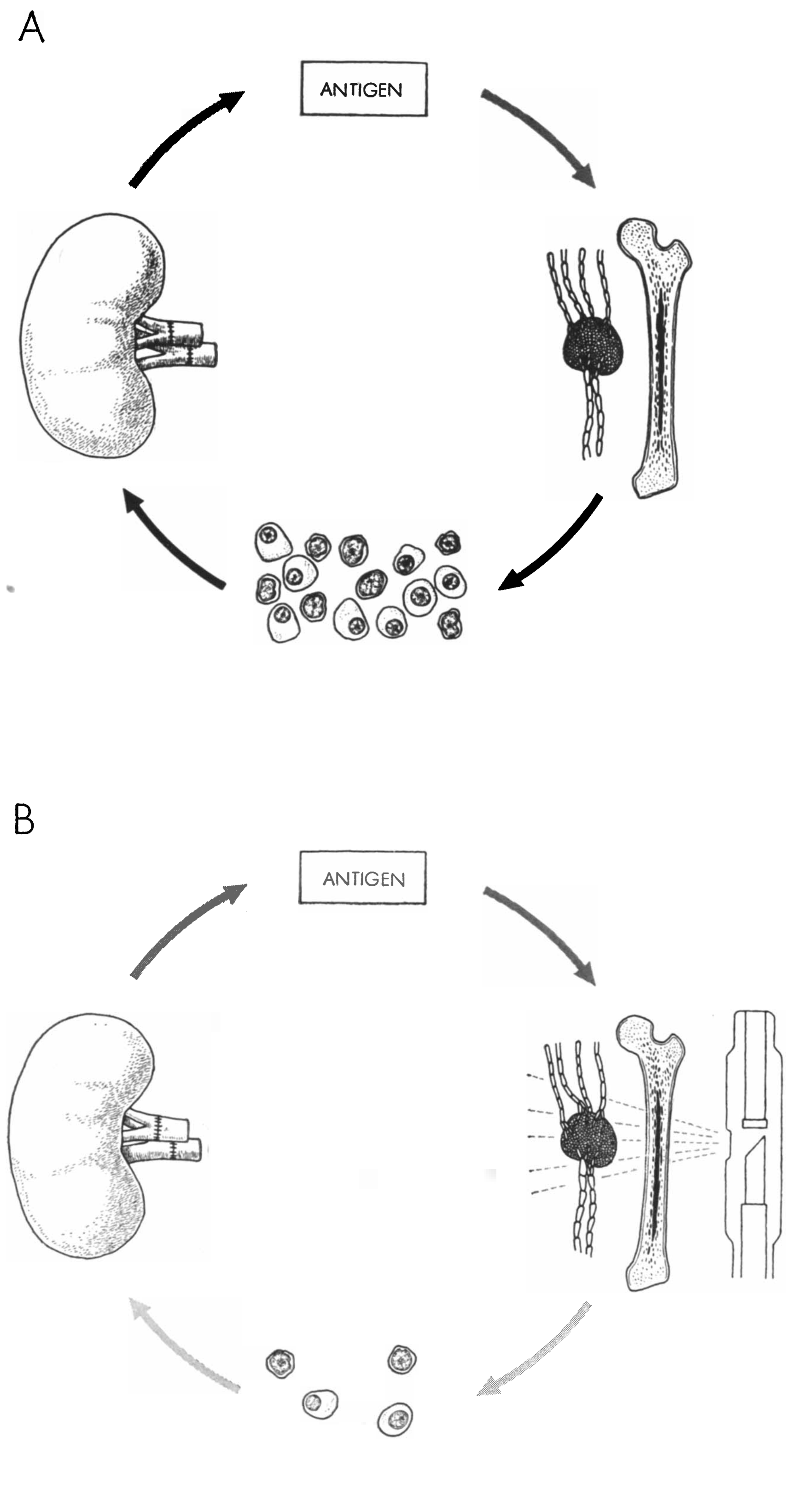
The recognition system involves the reticuloendothelial tissues of the body, which are found in the bone marrow, in the lymphatic system and spleen and in the liver. These are the blood-forming tissues and also the generators of the immune response, as the source both of white cells and of antibodies. In some way contact with antigens produced by a graft of foreign tissue "teaches" the reticuloendothelial system to recognize the foreign material. After the "lesson" by a first graft from a particular individual, the system is sensitized and the rejection of any subsequent graft of any kind of tissue from that individual is speeded up.

One tortuous detour around the immune response is suggested by the fact that the response is not fully developed in many animals until after birth. Thus day-old chicks may tolerate skin grafts from other chicks. In rats this neutral period when skin grafts may be accepted can extend to as late as 10 days after birth. The maturing reticuloendothelial system of the young animal is still learning to recognize the tissues of the animal; a hypothetical "self-marker" in these tissues presumably tells the reticuloendothelial system not to develop antibodies to them. R. E. Billingham and P. B. Medawar of University College London have injected the spleen cells of brown mice into embryonic white mice and found that as adults these white mice tolerated skin grafts from brown mice [see "Skin Transplants," by P. B. Medawar; SCIENTIFIC AMERICAN, April, 1957]. The immature recognition system of the embryonic mice apparently accepted the foreign cells as having the "self-marker."

In solving the problem of tissue transplantation in man, however, we do not expect to make popular the injection of cells from a prospective donor into the human fetus. There is another approach that is receiving consideration. This is the destruction or incapacitation of the crucial centers of the reticuloendothelial system by means of total body irradiation, followed by the transplantation of bone marrow. The idea is to obliterate the patient's own recognition system and replace it with one compatible with the tissue to be grafted. The feasibility of this admittedly heroic procedure has been supported by limited success in terminal cases of leukemia, in which the massive irradiation is, of course, directed to the destruction of malignant cells. In experimental animals destruction of the bone marrow by radiation has made it possible to graft marrow and other tissues not only from other animals but from animals of a different species!

We have attempted to use this procedure in two terminal cases of kidney disease to condition the patient for transplantation of a kidney. In both cases the bone-marrow transplant eventually failed. Indeed, there is no evidence from the world's medical literature that transplanted bone marrow has ever functioned in man for more than a few weeks.

Recently we have attempted another experiment that combines experience both with irradiation and with the reduced intensity of the immune response in chronically ill patients that we had noted in our first series of kidney grafts. This experiment also applies the knowledge, gained from more recent work with experimental animals, that a large dose of antigen introduced into the bloodstream may produce tolerance to foreign tissue where a small dose excites the immune response. We transplanted a kidney from a healthy man to his critically uremic brother. Though the men were probably not identical twins, we hoped that their relationship might make for some immunologic compatibility. The recipient was chronically and dangerously ill, and he was given a total dose of X-rays large enough to depress his reticuloendothelial tissues severely. Immediately after the last irradiation, the kidney was transplanted. A transplanted kidney of course introduces a large dose of antigen directly into the bloodstream. As the patient's reticuloendothelial system recovers from the radiation, it may be forced to become familiarized with the antigens of the transplanted kidney and accept them as carrying a "self-marker," after the precedents in research with animals. It is as yet too early to evaluate the results of this transplant, but initially it appears to be successful. Obviously the combination of circumstances favoring its success is unusual. The general principles, however, are universal, and give us some idea of the way in which not only kidneys but other living tissues may eventually be routinely transplanted.



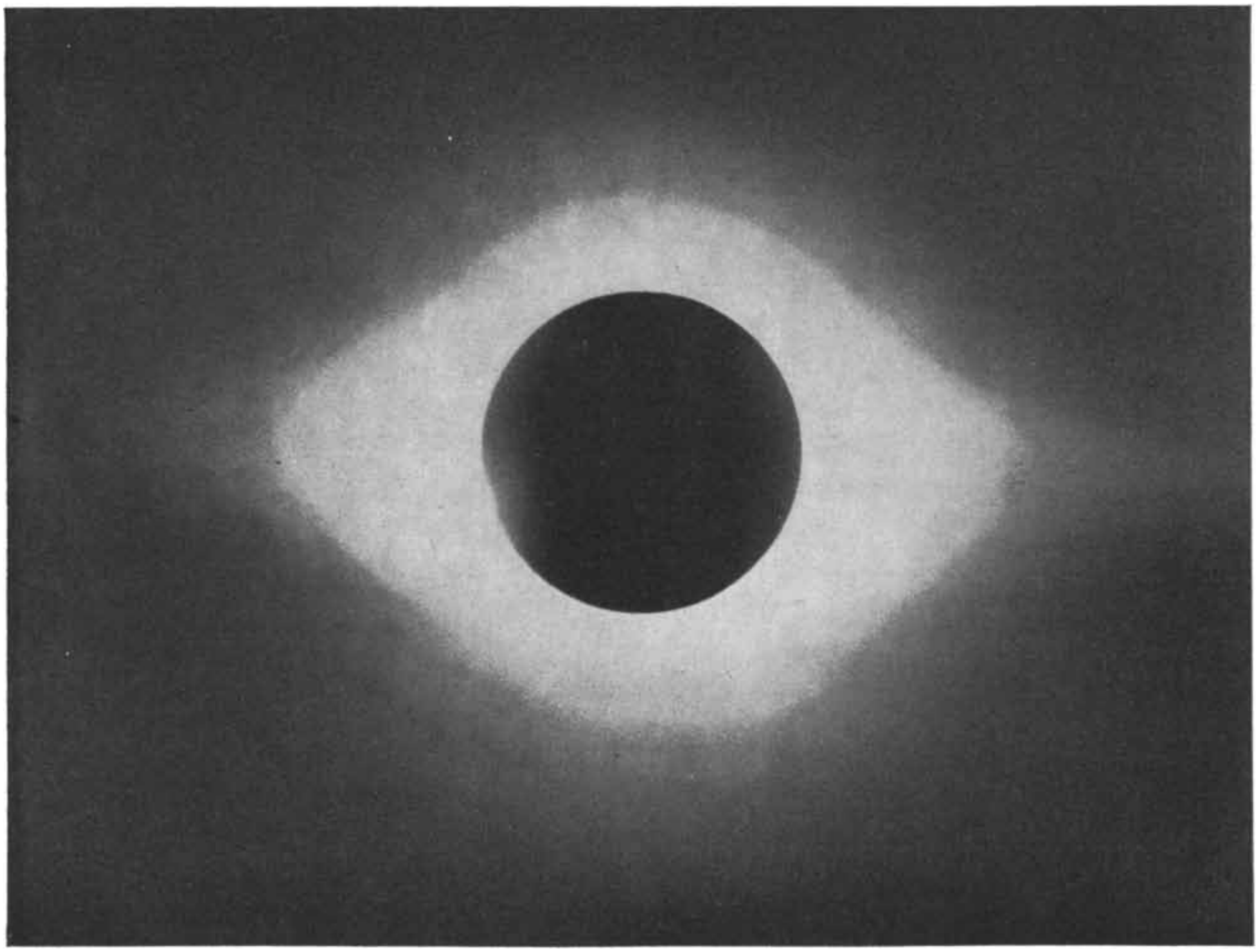
IMMUNE RESPONSE TO GRAFTED TISSUE is diagrammed. The transplanted kidney in diagram A produces large quantities of an antigen that arouses and "teaches" the antibody and white-cell system to recognize this foreign tissue. Then antibodies and scavenger cells attack grafted tissue. Diagram B indicates that X-rays suppress antibody system of bone marrow and lymph nodes (*right*), reducing the immune response to the transplanted kidney.

The Earth in the Sun's Atmosphere

The atmosphere of the sun may extend beyond the orbit of the earth before its density falls to that of the gas in interstellar space. Where, then, does the earth's atmosphere end and the sun's begin?

by Sydney Chapman

How big is the earth? If the question refers to the solid ground beneath our feet, the answer is of course that the earth has a radius of some 4,000 miles. This the Greek geometer and astronomer Eratosthenes discovered more than 2,000 years ago. But how big is the earth if we include its atmosphere? A century ago the answer would have been that the atmosphere adds very little to the size of the earth; it is only recently that we have come to realize that the radius of the atmosphere is much greater than that of the solid earth. The belts of charged particles that surround the earth, which were discovered only last year, extend outward at least seven earth radii. There is even reason to believe that the atmosphere may envelop the moon, though the atmospheric gas would obviously be ex-



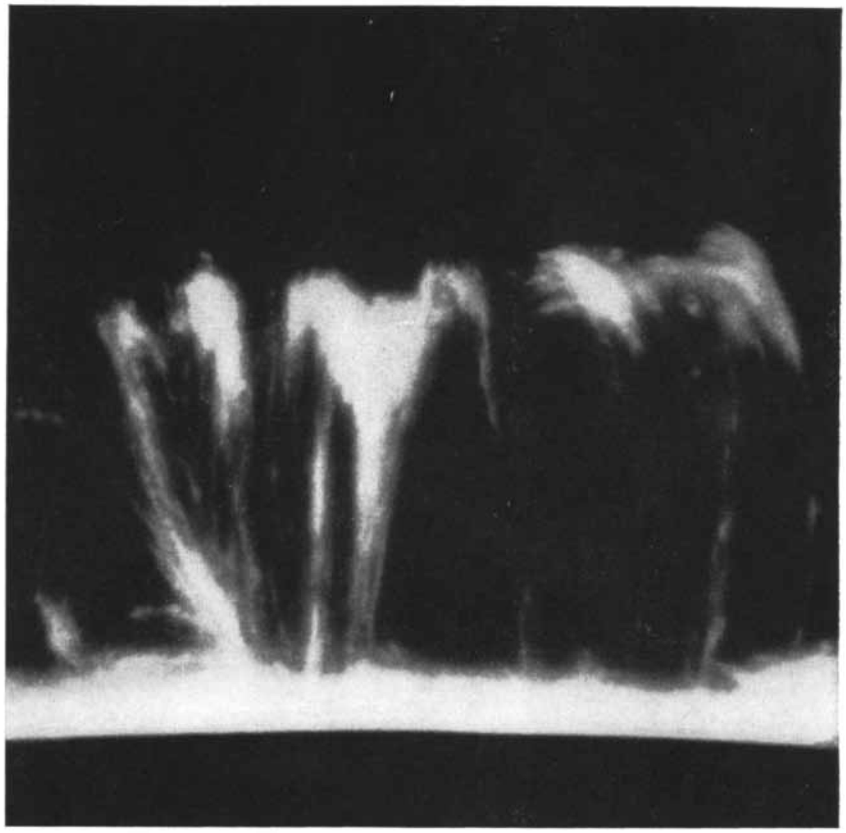
UNUSUALLY QUIET SOLAR CORONA was photographed during eclipse of June 30, 1954. Rounded appearance of the moon is due to overexposure at its edges. The photograph was made by M. Waldmeier of the Federal Astronomical Observatory of Switzerland.

tremely thin at this distance. Where, indeed, can the earth's atmosphere be considered to end?

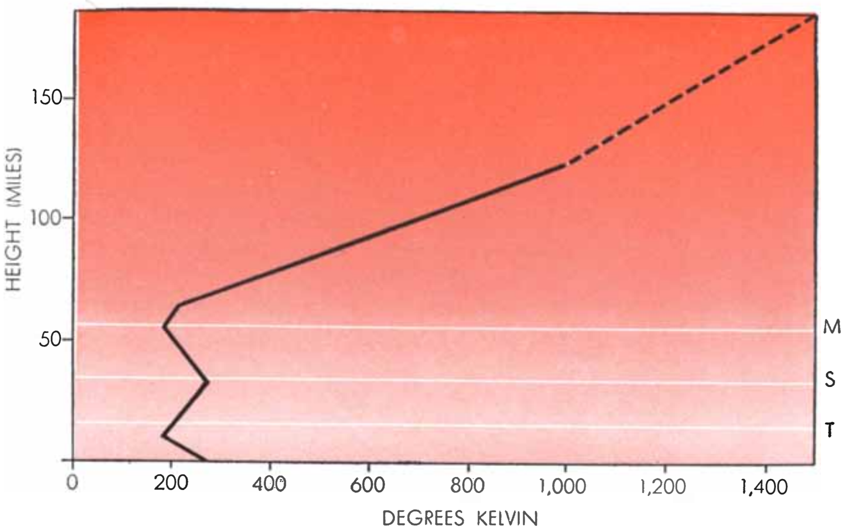
Here the answer involves a related question: How big is the sun? Anyone can see that the sun appears to have a sharp edge and thus a definite size. Astronomy books say that the radius of the sun is 435,000 miles. But the sun is wholly gaseous, even to its center; it can be considered all atmosphere. What appears to be its surface is a layer called the photosphere, where its density decreases steeply outward. The sun's atmosphere can be said to end only at a distance where its density has fallen to that of the gas in interstellar space. In the vicinity of the earth the solar atmosphere may have a density of about 9,000 protons (hydrogen nuclei) and 9,000 electrons per cubic inch. This is an extremely thin gas, but it is nonetheless many times denser than the gas in interstellar space.

The temperature of the sun's atmosphere at the distance of the earth may be as high as 100,000 degrees Kelvin (degrees centigrade above absolute zero). This temperature is maintained by the even higher temperature of the gas in the solar corona, the very hot layer above the photosphere. Because the gas closer to the sun is hotter, a particle moving away from the sun is likely to have greater energy (*i.e.*, speed) than a particle moving toward the sun. When such an outgoing particle collides with an incoming one, it transmits part of its energy to the incoming particle; the incoming particle may even be turned away from the sun. In this fashion heat is handed step by step across interplanetary space to the earth's atmosphere; it is the process we call conduction.

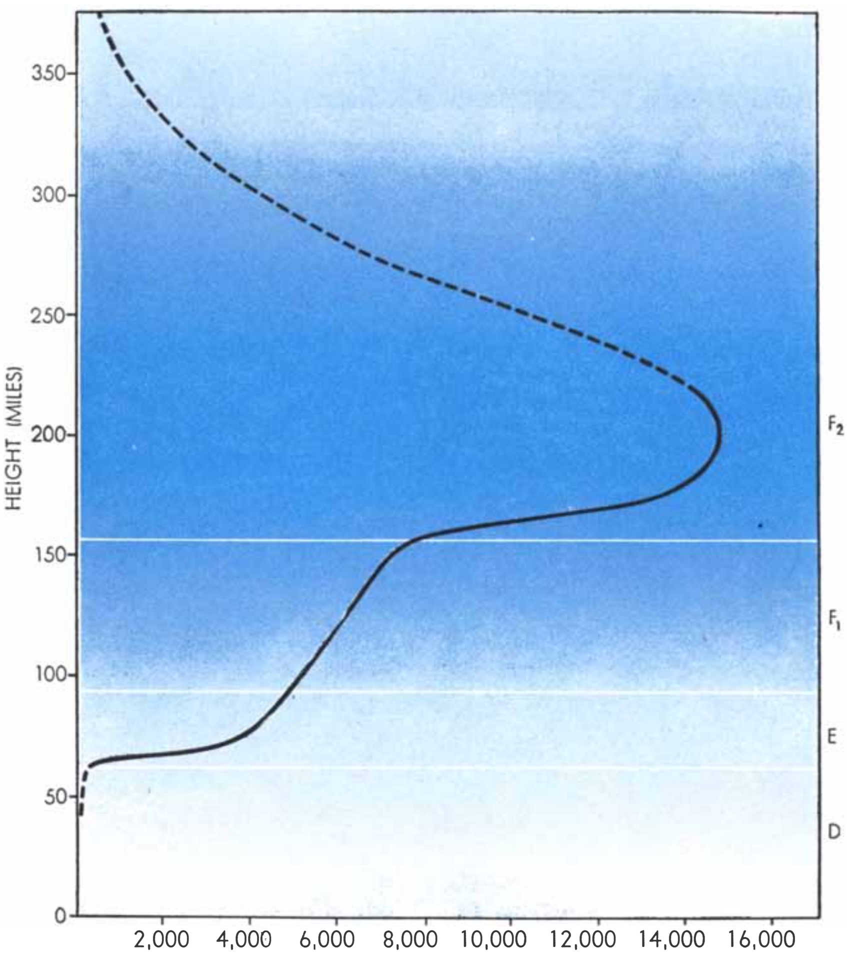
Of course conduction is not the only way in which heat is transmitted from the sun to the earth. Most of the heat is conveyed by electromagnetic radiation, visible and invisible. In a third process storms in the sun's lower atmosphere propel energetic particles directly from the photosphere into the atmosphere of the earth; this is a particularly violent form of what we call convection. Thus the sun and the earth "touch" each other through their atmospheres. The heat transmitted by conduction and convection, however, amounts to less than a millionth of that conveyed by radiation. It is sunlight that provides the overwhelming part of the energy that warms the earth, drives its winds and maintains its life. Still, the effects of conduction and convection are not negligible. The particles accelerated by solar storms, to



VIOLENT PROMINENCES soar through the lower corona above "active centers" on the sun in these photographs made at the Sacramento Peak Observatory in Sunspot, N. Mex. Here the disk of the sun is eclipsed not by the moon but artificially by the coronagraph.



TEMPERATURE of the earth's atmosphere (given in degrees Kelvin, or degrees centigrade above absolute zero) is plotted against altitude. Colored tone reflects the temperature indicated by the curve. Divisions of the tone are the tropopause (T, between troposphere and stratosphere), stratopause (S, between stratosphere and mesosphere) and mesopause (M, at top of mesosphere). Temperature above 125 miles is uncertain (*broken line*).



DENSITY OF ELECTRONS in the earth's atmosphere is similarly plotted. The colored tone reflects the densities indicated by the curve. The divisions of the tone show the boundaries between the four layers of the electron-rich region, or ionosphere: D, E, F_1 and F_2.

choose but one example, can profoundly disturb radio communication.

The scientific study of the earth's atmosphere began in the 17th century with the invention of the barometer and the thermometer. The great French mathematician Blaise Pascal showed that when a barometer is taken up a mountain, its reading decreases. Thus he demonstrated that the instrument measures the weight of overlying air. It was also found that air temperature decreases about 2.1 degrees C. with every 1,000 feet of altitude.

More than a century ago it became known that there is a limit to possible coldness—an absolute zero 273 degrees below the zero on ordinary centigrade thermometers. If the temperature of the air continued to decrease with altitude at the rate indicated by thermometers on mountains and in balloons, it would reach absolute zero at about 20 miles above sea level. That would be the limit of the atmosphere. Such a thin shell of air surrounding the massive globe would make an insignificant change in our conception of the size of the earth. However, about 60 years ago thermometers carried aloft by kites (and later by balloons) showed that the temperature of the air stops decreasing when it reaches about −50 degrees C., at an altitude of roughly six miles. Today we call the region of decreasing temperature the troposphere, and the region immediately above it the stratosphere. If the temperature remained constant above the troposphere, we should have to settle upon a minimum significant density of air in order to set a limit to the atmosphere. But the temperature does not remain the same; at an altitude of some 30 miles (the top of the stratosphere) it rises to about zero degrees C. Above the stratosphere is the mesosphere, which extends to about 50 miles; here the temperature drops again. But above the mesosphere the temperature rises steadily with altitude, at least so far as it has been measured by rockets.

Between about 50 and 300 miles is the region of the atmosphere called the ionosphere. Here X-rays and ultraviolet radiation from the sun are absorbed by the atoms and molecules of the air, many of which are shaken apart in the process. Some of their dissociated fragments are electrically charged, or ionized, whence the ionosphere gets its name. The region ascends in several layers, denoted D, E, F_1 and F_2 [*see illustration at left*]. In the F_2 layer of the ionosphere the density of electrons reaches 15 million per cubic inch, indicating the presence of a corresponding number of oppositely charged positive ions.

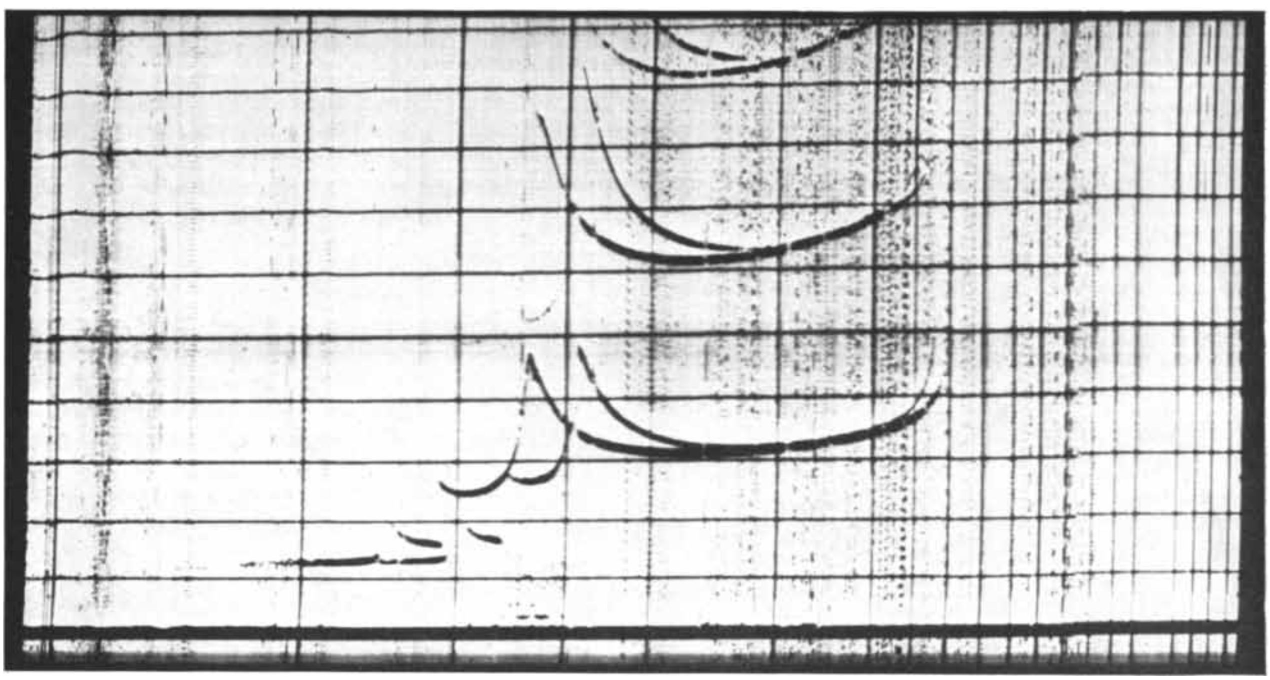
During the International Geophysical Year artificial satellites and "lunar probes" carried instruments into still higher regions of the atmosphere. The instruments revealed that the earth is encircled by energetic particles in two belts, now named for James A. Van Allen, the leader of the group of physicists who made the discovery. The Van Allen belts appear to lie between the northern and southern latitudes where auroras commonly occur, and to be absent above the poles. They consist of fast-moving electrons and protons (and perhaps heavier ions) which spiral along the lines of force in the earth's magnetic field and travel back and forth between northern and southern latitudes. These particles must certainly be considered part of the earth's atmosphere; they extend the radius of the earth at least sevenfold, corresponding to a 350-fold increase in volume.

Recently I have tentatively suggested that the earth's atmosphere may extend well toward the moon, perhaps even enveloping it. It is at such distances that the earth's atmosphere may meet that of the sun. The next few years should provide the measurements and other evidence that will disprove, confirm or modify this suggestion. At present some of my colleagues consider it a possibility; others think it unlikely.

The solar atmosphere may be regarded as that part of the sun which is outside the photosphere. We cannot see this atmosphere through our own, unless the brilliant photosphere is somehow obscured. By happy chance the moon's size, distance and orbit are such that it can just eclipse or appear to cover up the photosphere from time to time. Then the sun's atmosphere is briefly visible. Its appearance is truly astonishing. Instead of being "round" like the photosphere, or the atmosphere of our planet, it has a highly irregular outline, with "rays" or "plumes" of curious shape and varying extent. The part below the level of the great irregularities is called the chromosphere. The upper, irregular part is the solar corona. Using the coronagraph, devised some years ago by the French astronomer Bernard Lyot, we can observe the inner part of the solar corona without an eclipse.

The study of the corona has revealed that at 25,000 miles above the sun's surface it is exceedingly hot: approximately one or two million degrees Kelvin as compared with 6,000 degrees K. at the photosphere. This implies an average upward change or gradient of from 40 to 80 degrees per mile. We do not yet know why the corona is so hot, but we think it has to do with the agitation that we generally observe at the photospheric level and above. The appearance of the corona varies with the 11-year sunspot cycle. Its shape changes frequently and seems to be related to violent storms on the sun. These throw hot gas upward; sometimes it falls back and sometimes it shoots away from the sun in isolated clouds or continuing streams. This solar gas, like the sun as a whole, consists mainly of atoms of hydrogen, nearly all of them ionized or broken up into protons and electrons.

On page 64 is a photograph of the corona made during the eclipse of June 30, 1954. The corona extends outward for more than two solar radii, in directions that lie in the plane of the sun's equator (at right angles to the axis about which the sun rotates). During this eclipse D. E. Blackwell of the University of Cambridge and his colleagues also photographed the corona by refined methods from an aircraft at 30,000 feet. Here the general brightness of the sky is so reduced that the coronal light and its



REFLECTION OF RADIO WAVES from the ionosphere is shown in this "ionogram" made by the National Bureau of Standards' Central Radio Propagation Laboratory in Boulder, Colo. The horizontal lines in the ionogram indicate height; the vertical lines the frequency (increasing from left to right) of the radio signals. The band just above the bottom is caused by the outgoing signals. The curved pair of traces around the third horizontal line from the bottom are echoes from the F_1 layer (*lower trace*) and the F_2 (*upper trace*). Below and to the left of these traces are shorter traces representing echoes from the E layer. The pair of traces above middle of ionogram are caused by "two-hop" echoes from the F_1 and F_2 layers; the pair of traces at top, by "three-hop" echoes.

polarization could be measured out to 20 solar radii. The coronal light is mainly sunlight scattered by electrons and dust. Sheets of polarizing material were placed in front of four of the eight lenses of the camera to help distinguish between the contributions of the electrons and the dust. The dust may come from the debris of comets captured by the massive planet Jupiter; it is probably falling toward the sun. The electrons are a normal part of the solar atmosphere. Protons are interspersed with them in equal number, but cannot be detected by photographing the coronal light. The electron density ranges from about 150 million per cubic inch close to the sun to some 50,000 at 20 solar radii. These may seem to be big numbers, but they imply that the gas is very rare by ordinary standards. In fact, if the gas could be bottled, it would be a better vacuum than any we can create on earth. In the air near the ground there are about 400 billion billion molecules per cubic inch.

During the 1954 eclipse the sun was exceptionally calm; its outer atmosphere was as nearly stable as it ever is. In this condition the solar atmosphere may rotate with the rest of the sun for a considerable distance above the photosphere; its period of rotation would be the same as that of the photosphere—25 days. Farther away from the photosphere the steady atmosphere may rotate more slowly, perhaps at the speed with which the planets move along their orbits. When the atmosphere is in this condition, energy will flow out of the sun by radiation and by conduction, and the flow by convection is at a minimum.

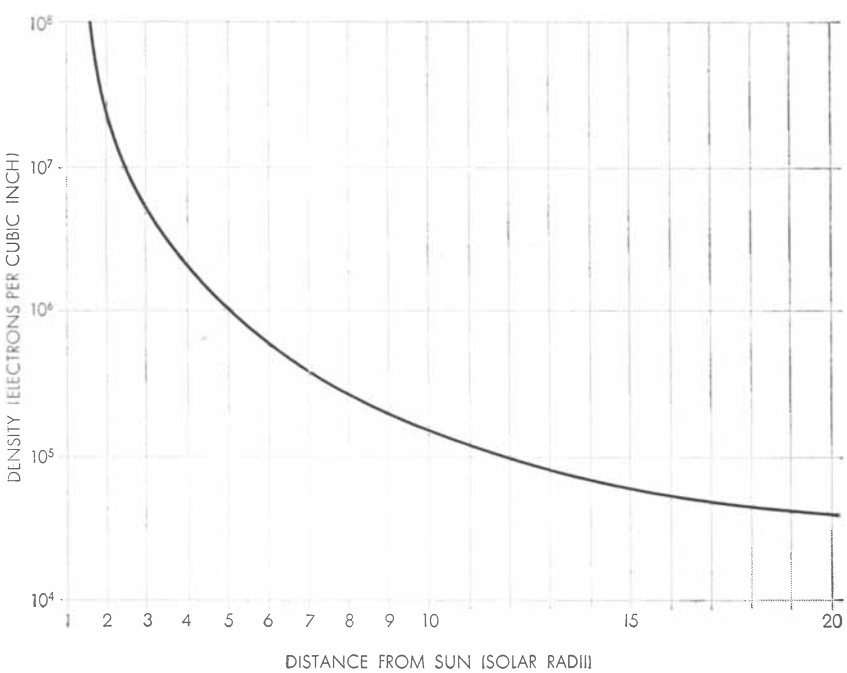
The corona emits some energy by radiation, but at an altitude of about 50,000 miles above the photosphere the amount of energy carried away by radiation is small in comparison with that removed by conduction. If we assume that the conduction is steady, a simple calculation suggests how the temperature of the sun's atmosphere diminishes with distance from the photosphere. The way in which the conductivity of the gas varies with the temperature of the coronal gas is clearly indicated by the kinetic theory of gases; it turns out that the temperature of a steadily rotating, conductive solar atmosphere must decrease very slowly with distance. If such an atmosphere has a temperature of a million degrees K. near the photosphere, its temperature will still be of the order of 200,000 degrees at the distance of the earth.

However, a study of the outward decrease of the number of electrons per cubic inch up to 20 solar radii indicates a more rapid fall of temperature. This is taken to be due to turbulence, even in this quietest corona. But the study also indicates that the fall of temperature begins from a level of two million degrees instead of one million. Nonetheless the estimated temperature at 20 solar radii is about 300,000 degrees, less than the calculated conductive value. Extrapolation of the temperature to the distance of the earth is uncertain, but there the temperature may still be on the order of 100,000 or 50,000 degrees, and therefore the gas will be very hot.

If we know how the temperature of a static atmosphere varies with height, and if we also know the nature of the atmospheric gas, we can calculate the density of the gas. At the distance of the earth, but along the sun's axis of rotation (*i.e.,* at right angles to the plane of the earth's orbit), the density of the sun's atmosphere is very low: perhaps about 3,000 electrons and 3,000 protons per cubic inch. This is about a 16th the density at a distance of 20 solar radii from the photosphere. For the present we cannot calculate the density of the solar gas in the plane of the earth's orbit, and hence in the vicinity of the earth, because of uncertainties in the speed with which the gas rotates. At 20 solar radii the rotation only slightly affects the density distribution.

Some indication of the density of the solar atmosphere in the vicinity of the earth is provided by the zodiacal light. This light is almost as bright as the Milky Way on clear, dark nights in latitudes of 40 degrees or less. In the tropics it appears to be an ill-defined, nearly vertical pillar of light; in higher latitudes it is tilted with the plane of the ecliptic, in which the planets move around the sun. The concentration of the zodiacal light toward the plane of the ecliptic suggests that the dust and electrons which scatter sunlight and thus give rise to the phenomenon are rotating around the sun. To measure how much of this light is scattered by dust and how much by electrons we must measure its intensity and polarization, and this is quite difficult. Recent studies of the zodiacal light indicate, however, that the region near the earth contains about 9,000 electrons and 9,000 protons per cubic inch. The figure is not yet certain and may well be too high.

Whatever it turns out to be, it is likely to be greater than the 10 to 200 particles per cubic inch encountered in interstellar space. When the sun's atmosphere becomes that thin, it merges with the interstellar gas. Calculations based upon measurements of the zodiacal light or upon the molecular theory of gases suggest that the sun's atmosphere extends at

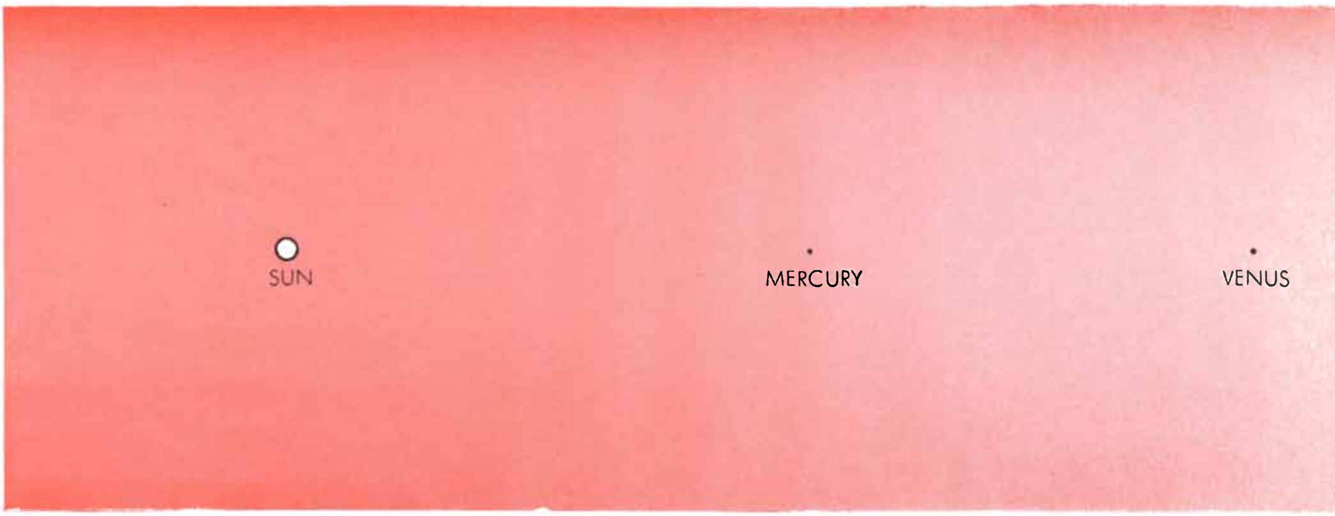


DENSITY OF ELECTRONS in corona was measured during eclipse of June 30, 1954, by D. E. Blackwell of the University of Cambridge and his colleagues. The density falls from about 150 million electrons per cubic inch near sun to about 50,000 at 20 solar radii.

ZODIACAL LIGHT is the broad glow in this photograph made last year by Blackwell and M. F. Ingham. The camera was mounted at an altitude of 17,100 feet in the Bolivian Andes. Stars caused the narrow streaks as the earth turned during the 10-minute exposure.

least beyond the orbit of the earth, and that there it is likely to be quite hot. Thus when the sun is quiet, the earth moves along through a rare extension of the solar atmosphere consisting of very hot ionized hydrogen: protons and electrons in rapid motion.

The earth's own atmosphere ends at the height at which its density has fallen to the density of the surrounding solar atmosphere. There must be a continuous transition between the two atmospheres. The density of the earth's atmosphere of course increases from top to bottom, and its temperature decreases from the 100,000 degrees K. of the surrounding solar gas to about 200 degrees in the D layer of the ionosphere. This large temperature drop involves a gradient that causes heat to flow by conduction from the solar gas down to the ionosphere. One might think that the solar gas and the outermost regions of the earth's atmosphere are far too attenuated to be able to conduct much heat. In reality the ability of a gas to transmit heat is almost independent of its density. It is true that the heat capacity of a gas is less at lower densities, but this only means that the heat flowing into the earth's atmosphere from the surrounding solar gas must be drawn from a great volume of this gas. However, it is not easy to calculate exactly how much heat will flow into the earth's atmosphere from the solar gas. One major difficulty is caused by the earth's magnetic field, which extends out into space and controls the movements of the hydrogen ions that comprise the outermost atmosphere. Most of the ions probably come from the sun's atmosphere. Caught in the earth's magnetic field, they can move freely along the lines of force and con-



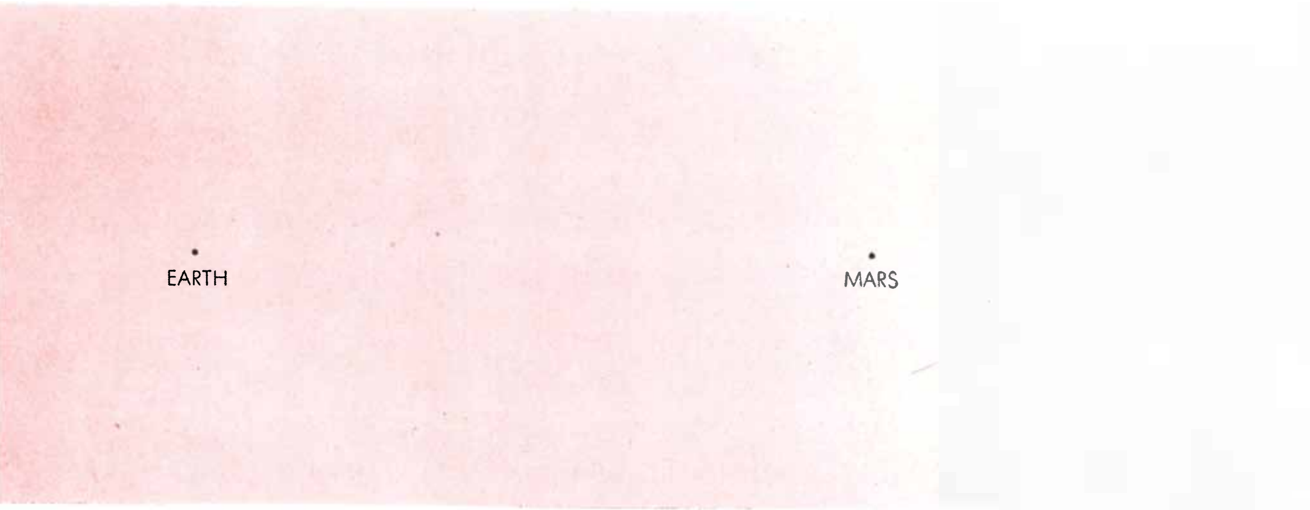
DECREASE IN TEMPERATURE of the sun's extended atmosphere with distance from the sun is represented by the colored tone in this schematic cross section of the inner solar system. At the photosphere of the sun (its visible surface) the temperature is

INCREASE IN TEMPERATURE of the earth's atmosphere with distance from the earth is represented by the colored tone in this cross section. The temperature at the surface of the earth is about 300 degrees K. This temperature may increase until it reaches

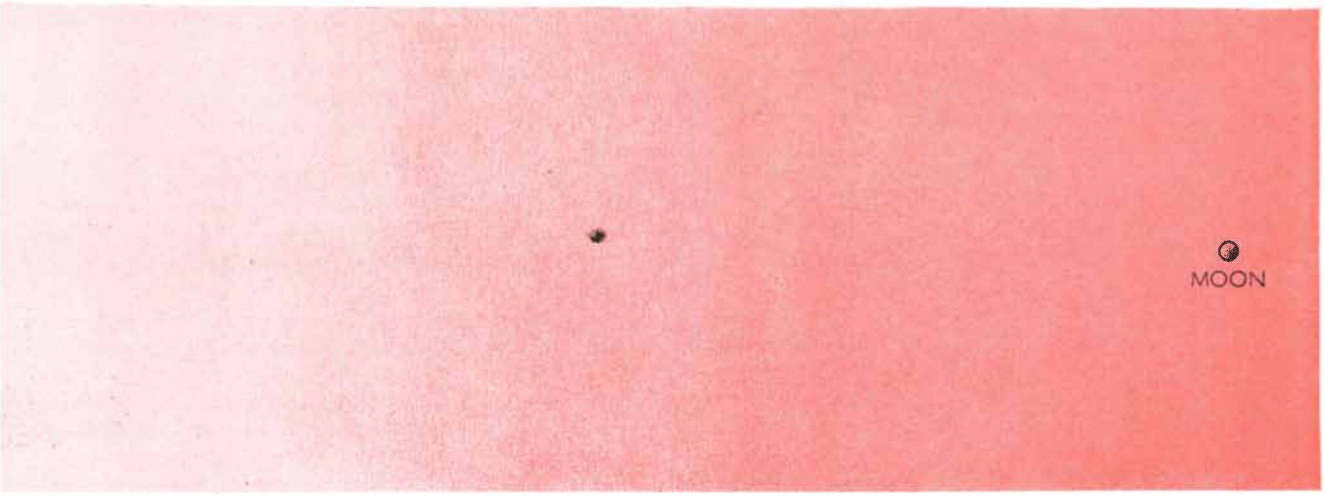
duct heat north and south. But they cannot move so freely and conduct heat up or down in low latitudes—across the lines. Thus the heat from the solar gas flows more easily into the earth's atmosphere over polar regions than into the atmosphere over lower latitudes.

No one has yet seriously attempted to solve the difficult problem of how much heat actually flows in from the solar gas, or to calculate the shape and distribution of the resulting temperature contours around the earth. Perhaps the heat conducted through the ionized hydrogen sets up a general circulation in the thicker underlying layer of un-ionized hydrogen. This could make the temperature at the bottom of this layer more uniform around the earth, so that the amount of heat flowing down into the F layers of the ionosphere would be much the same over the poles and over the equator. At present we have no idea whether this is so.

We do know, however, that heat flows downward through the atmosphere that lies below the peak ion density of the F_2 layer, because the temperature there is increasing with altitude. Some of this downward flow is likely to come from the hot solar gas surrounding the earth; some must come from the energy of sunlight absorbed around the F_2 peak and above; some must come from the Van Allen belts. Which of these various sources supplies the most heat? At present we do not know the temperature gradients below and above the F_2 peak exactly enough to answer this question. Rockets and artificial satellites may soon provide the information. The total heat flow just below the F_2 peak is certainly very small: perhaps one microwatt per square inch. Heat conducted from the solar gas is only part of this flow, perhaps only a small part. The much greater energy from the sunlight that falls on the sunward hemisphere of the earth traverses the whole atmosphere and reaches the ground, though clouds can reflect some of it back into space. The atmosphere absorbs only a small fraction of the radiant energy, but this fraction affects the temperature and composition of air at all levels. The highly attenuated gas of the earth's outer atmosphere absorbs extremely small amounts of radiant energy, which add very little to the heat flowing downward from the solar gas. The heat conducted from the solar gas is absorbed before it penetrates into the lower atmosphere; thus it determines the distribution and extent of the outermost



6,000 degrees Kelvin. In the corona above the photosphere, however, it may be two million degrees K. At the distance of the earth it may still be 100,000 degrees. Beyond the earth it drops more rapidly because the ions of the solar atmosphere recombine.



that of the enveloping atmosphere of the sun. This may occur only at a distance greater than that of the moon. Around the earth are the two Van Allen radiation belts, the temperature of which is not appreciably higher than that of the surrounding outer atmosphere.

layers of the atmosphere, but has virtually no effect at lower levels.

In the F layers of the ionosphere the temperature rises several degrees C. with each mile of altitude. Only a fraction of this increase is the result of heat flow from the solar gas. Above a height of one earth radius from the ground the gradient may fall to one degree per mile or less, and it slowly decreases at higher altitudes. Hence to reach the temperature of the solar gas, if this is 100,000 degrees, we may have to go out 300,000 miles, which is more than the distance to the moon. The temperature gradient and the distance to the nearest solar gas may not be the same in all directions outward from the earth. If it is less in the plane of the earth's equator, the moon may still be outside the earth's atmosphere and may be moving through the solar gas. But if these ideas are correct, we must conclude that the Van Allen radiation belts, high as they are by ordinary reckoning, are relatively low-level features of the earth's atmosphere.

Of course the picture of the hot solar gas steadily conducting a weak stream of energy into the earth's atmosphere is dramatically changed by the frequent storms on the sun, which shoot out great clouds of gas at speeds of 1,000 miles per second. The outrushing gas greatly disturbs the rotation and temperature of the far-reaching solar atmosphere, and probably carries some of the atmosphere along with it. During the storms the sun sends out extra energy by convection of moving gas. The speed of the hot gas coming directly from the sun enables it to penetrate quite a distance into the earth's atmosphere; when it impinges on the earth in this way, it produces a magnetic and ionospheric storm. Some of the gas particles are magnetically deflected toward the polar regions and penetrate the atmosphere to a height of 60 miles or so; they ionize and heat the gas, making it luminous. This we see as an aurora. Some of the gas may be trapped in the Van Allen belts, at least in the outer belt.

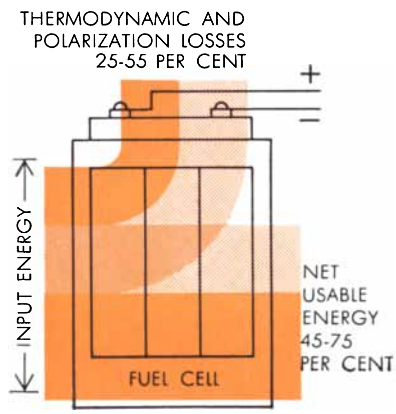
Our consideration of the extent, nature and interrelationships of the solar and terrestrial atmospheres has not really answered the question: How big is the earth? But perhaps it has served to illuminate the much more important problem of the interaction of the two atmospheres, as well as to demonstrate that there is still a great deal to be learned about them.

FUEL CELLS

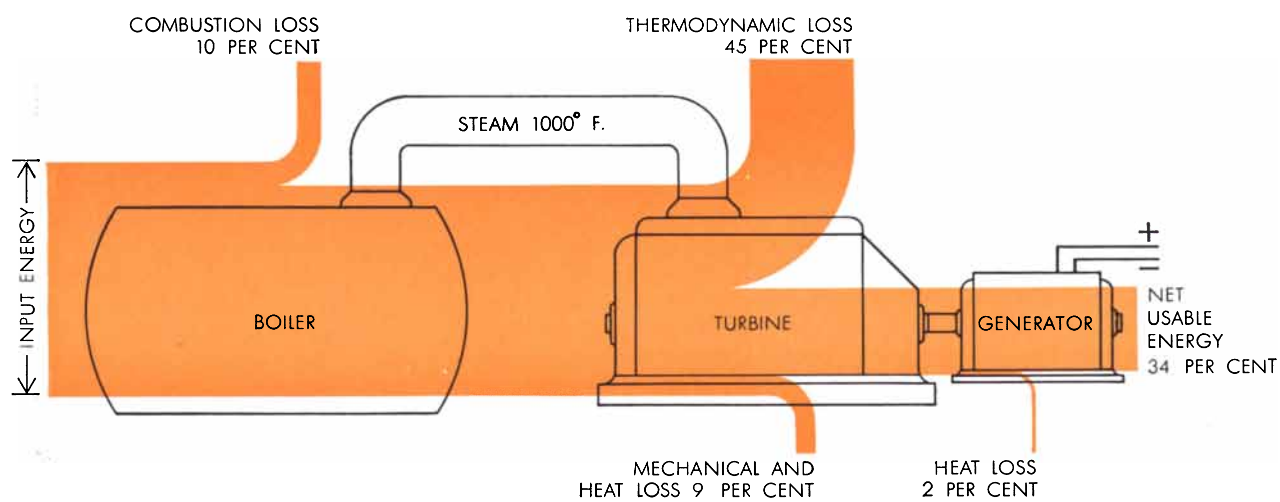
Devices that convert chemical energy directly into electricity, thus circumventing the inefficiency of the heat engines used to drive electric generators, are now under intensive development

by Leonard G. Austin

Civilization gets most of the energy it consumes from the energy of the chemical bonds in coal, petroleum and natural gas. But in the process of putting that chemical energy to work, it throws most of it away. The energy is first converted, by combustion of the fuel, into heat. The heat is then converted, by several kinds of heat engine, into mechanical energy, which may in turn be converted into electricity. These transformations yield less than half of the original energy as useful work. But the fault does not lie in the energy-converting machines. Though the most modern central power-stations manufacture electricity at an efficiency of only 35 to 40 per cent, the performance of boilers, turbines and generators has been improved over the years until it now approaches the maximum which can be expected from the heat-steam-electricity cycle. Internal-combustion engines have reached a corresponding peak of efficiency at 25 to 30 per cent, and high-temperature gas turbines are approaching their limit at 40 per cent. The ceiling on efficiency is partly imposed by the second law of thermodynamics, which dictates the downhill flow of energy throughout the cosmos. At the operating temperatures of heat engines—temperatures set by the strength of materials and the economics of heat transfer—this law decrees that more than half of the original chemical energy must be lost in irrevocably wasted heat. Further energy is lost to the friction that is encountered in any machine.



With conventional energy-converting technology approaching a dead end, power engineers are seeking ways to bypass the heat cycle and to convert the chemical energy of fuels directly into electricity. The notion is not a new one. In 1839 the English investigator Sir William Grove constructed a chemical battery in which the familiar water-forming reaction of hydrogen and oxygen generated an electric current. Fifty years later, also in England, the chemists Ludwig Mond and Carl Langer developed another version of this device which they called a fuel cell. But the dynamo was



EFFICIENCY OF FUEL CELL is potentially greater than that of conventional generating equipment. Fuel cell (*top left*) converts 45 to 75 per cent of its input energy (*color*) into electricity compared to 34 per cent for typical steam turbogenerators (*bottom*).

then coming into its own, and although research continued spasmodically the difficulties encountered deterred any extensive effort to develop fuel cells. Since 1944, however, the fuel cell has come under active development again, and at least one is now in practical use.

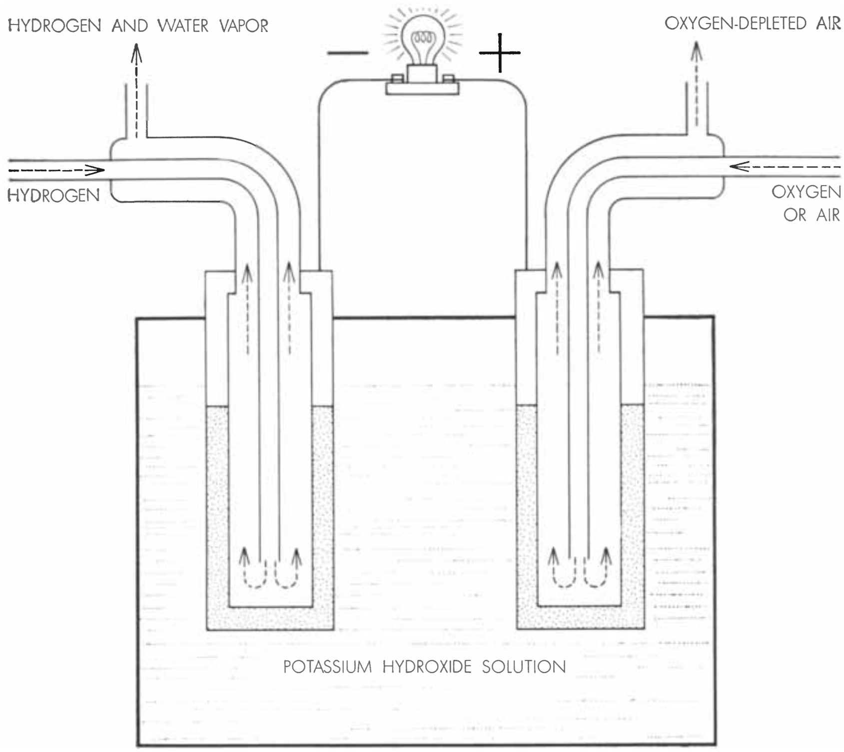
The first voltaic pile and its modern descendant, the dry battery, are fuel cells in a sense: they convert chemical energy directly into electricity. But they use expensive "fuels" such as zinc, lead or mercury that are refined by the expenditure of considerable energy from fossil fuels or hydroelectric power. A true fuel cell uses the basic fuel directly, or almost directly. In theory the fuel cell may approach 100 per cent efficiency in converting the chemical energy of the fuel into electricity; actual efficiencies of 75 per cent—more than twice that of the average steam power-station—are quite feasible.

Fuel cells hold other attractions for contemporary engineering. An artificial satellite, for example, requires a small, light battery that can deliver a high electrical output. The fuel cell can meet these specifications from energy compactly stored in a liquid or gaseous fuel and in oxygen, as opposed to the cumbersome plates of an ordinary battery.

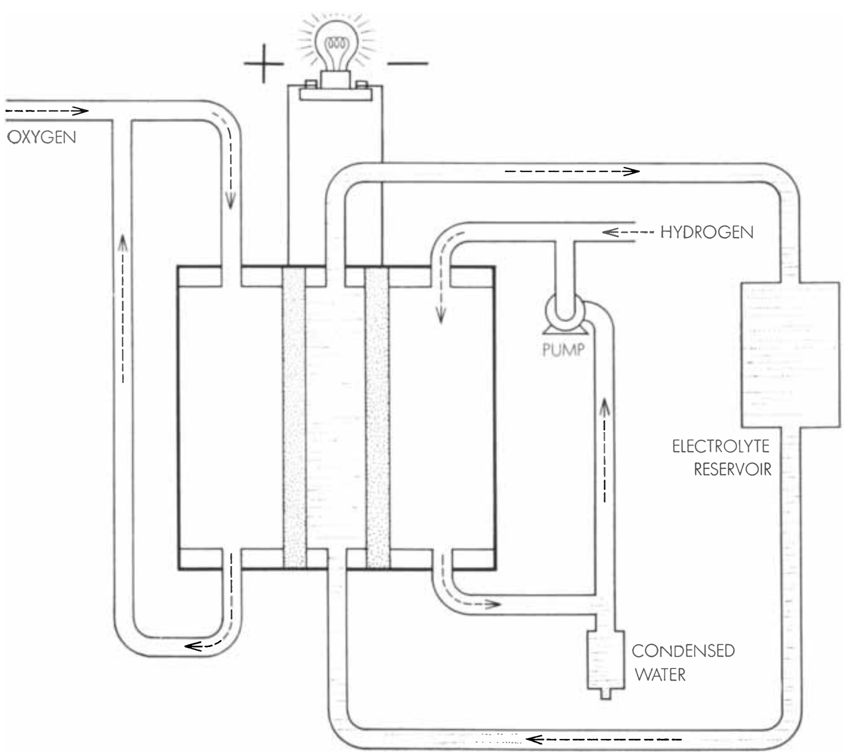
In public transportation the electric motor possesses a number of advantages over the gasoline or Diesel engine, including higher speed, more rapid acceleration, quietness and absence of noxious exhaust gases. However, the high capital cost of the electrical distribution system has caused a decline in electric transport during the past two decades. A few battery-powered delivery trucks still operate in some cities, but they suffer competitively from the low power-to-weight ratio of their lead batteries and from the long periods required for recharging. A fuel cell that could operate efficiently on gasoline or oil and could be "recharged" by the filling of its tank might reverse the present trend toward gasoline and Diesel locomotives, trucks and buses. Ultimately fuel cells might make the quiet, non-air-polluting electric automobile a reality.

The realization of these attractive possibilities will require a great deal of development work. To understand some of the difficulties to be surmounted, let us consider the fuel cell in which hydrogen and oxygen combine to produce an electric current and water.

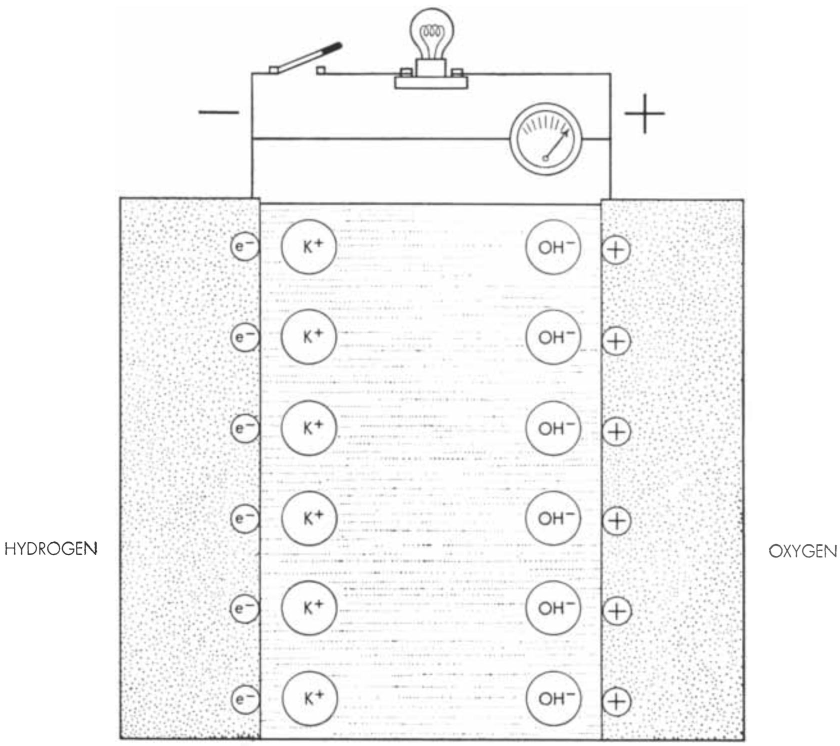
As everyone knows, hydrogen and oxygen burn to produce water. They do so because separately they possess more



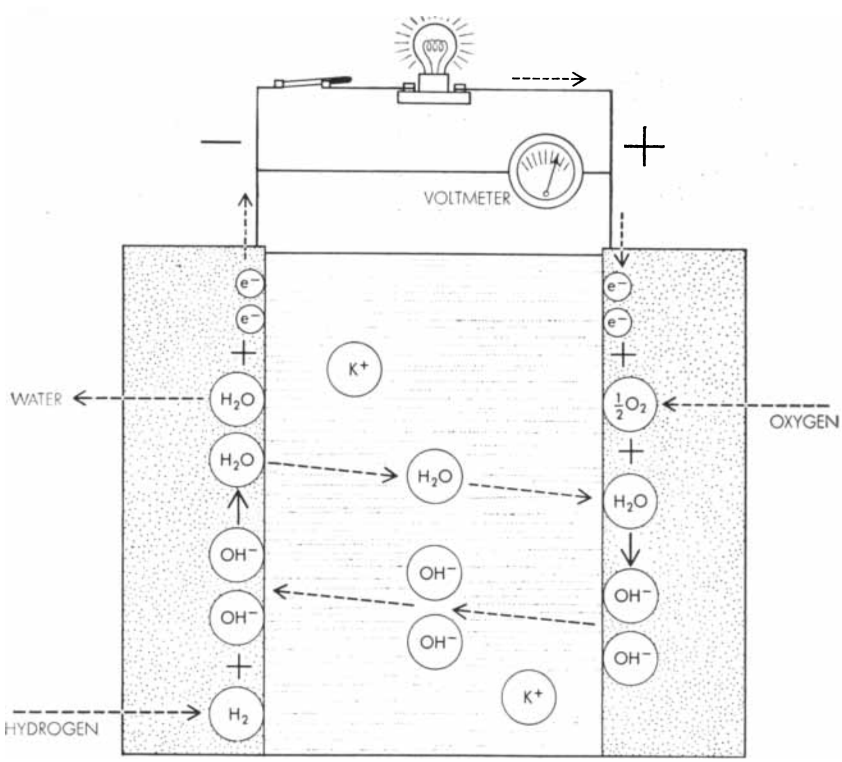
HYDROGEN-OXYGEN FUEL CELL, shown schematically, consists of two porous carbon electrodes (*dotted areas*) separated by an electrolyte such as potassium hydroxide. Hydrogen enters one side of the cell; oxygen, the other. Atoms of both gases diffuse into the electrodes, reacting to form water and to liberate electrons which flow through the circuit.



ANOTHER HYDROGEN-OXYGEN CELL was developed recently by Francis T. Bacon of the University of Cambridge. His cell consists basically of an electrolyte solution held between two thin electrodes of porous nickel. Gases under pressure diffuse through the electrodes and react with the electrolyte, which is held in tiny pores in the opposite surface.



WHEN FUEL-CELL CIRCUIT IS OPEN, the hydrogen electrode accumulates a surface layer of negative charges that attracts positively charged potassium ions in the electrolyte solution. Similarly, the oxygen electrode attracts negative ions to balance its positive charge. These layers prevent further reaction between the gases and the electrolyte.



WHEN CIRCUIT IS CLOSED, the gases and electrolyte react to produce a flow of electrons. A catalyst embedded in the electrode dissociates hydrogen gas molecules into individual atoms, which combine with hydroxyl ions in the electrolyte to form water. The process yields electrons to the electrode. The electrons flow through the circuit to the positive electrode, where they combine with oxygen and water to form hydroxyl ions. The ions complete the circuit by migrating through the electrolyte to the negative electrode.

energy than water and therefore "prefer" to exist in combination. However, at ordinary temperatures and pressures, additional "activation" energy is needed to raise the molecules to the energy state at which the reaction will ignite; this energy barrier ordinarily prevents the reaction from proceeding at room temperature. Activation energy may be illustrated by the following analogy. In a large number of people there may be one man capable of clearing a seven-foot high-jump bar, several capable of clearing six feet, thousands who can jump five feet, hundreds of thousands who can jump four feet, and so on. Molecules are like that with respect to their individual energy content: only a small fraction of them have high energies at room temperature. If the energy barrier for a reaction is comparable to an eight-foot hurdle, no reaction occurs. Raising the temperature has the effect of increasing the "jumping ability" of the molecules until some can clear the activation-energy barrier. At about 500 degrees centigrade a hydrogen-oxygen mixture will combine explosively, and the chemical energy is converted to heat.

In a hydrogen-oxygen fuel cell essentially the same chemical reaction is made to take place, but the reaction is stepwise at a lower energy of activation for each step. This can be considered as analogous to requiring the molecule to jump several barriers only four feet high, instead of one barrier eight feet high. The reaction thus proceeds quite quickly at room temperature. The cell is also designed so that one of the essential steps in the reaction is the transfer of electrons, from the negative terminal of the cell to the positive terminal, by an electrical connection. The flow of electrons, which is of course an electric current, can be used to drive an electric motor, light a lamp or operate a radio. Instead of the chemical energy of the reaction being immediately converted to heat, a large part of it is carried by the electrons, which can give up the energy as useful electrical work.

The cell consists of two porous electrodes separated by an electrolyte, which in this case is a concentrated solution of sodium hydroxide or potassium hydroxide. On the negative side of the cell, hydrogen gas diffuses through the electrode; hydrogen molecules (H_2), assisted by a catalyst embedded in the electrode surface, are adsorbed on the surface in the form of hydrogen atoms (H). The atoms react with hydroxyl ions (OH^-) in the electrolyte to form water, in the process giving up electrons to the electrode; the water goes into the electrolyte. This reaction is also aided by the catalyst.

The flow of these electrons around the external circuit to the positive electrode constitutes the electric output of the cell and supports the oxygen half of the reaction. On the positive side of the cell oxygen (O_2) diffuses through the electrode and is adsorbed on the electrode surface. In a somewhat indirect reaction the adsorbed oxygen, plus the inflowing electrons, plus water in the electrolyte, form hydroxyl ions. Here again a catalyst helps the reaction to proceed. The hydroxyl ions complete the circle by migrating through the electrolyte to the hydrogen electrode [*see bottom illustration on opposite page*].

If the external circuit is open, the hydrogen electrode accumulates a surface layer of negative charges that attracts a layer of positively charged sodium or potassium ions in the electrolyte; an equivalent process at the oxygen electrode similarly balances its accumulated positive charge. These electrical "double layers" prevent further reaction between the gases and the electrolyte. The presence of the electrical layers provides the potential that forces the electrons through the external circuit when connection is made.

When the circuit is closed and the resistance across the external circuit between the electrodes is high, the reaction proceeds at a moderate rate, and a high percentage of the reaction energy is released as electricity, with only a little lost as heat. Part of the energy is expended at all times, however, in driving the chemical reactions over the barrier of the activation energies of the reactions inside the cell, and this energy appears as heat within the cell. The function of the catalysts in the electrodes is to lower the energy barriers, thus decreasing the amount of useful energy that is converted to heat. As resistance in the external circuit goes down, the current flow increases and a rising proportion of the energy is consumed in overcoming the energy barriers within the cell. With the increase in the reaction rate, heat losses go up rapidly. At zero resistance (short circuit) the reaction proceeds so rapidly that it becomes equivalent to combustion, producing only heat. Thus the reaction energy of the fuel cell resembles the energy of water behind a dam. By allowing the water to escape slowly through the blades of a turbine, we compel it to do useful work. If we open the floodgates, the water gushes out without performing any work.

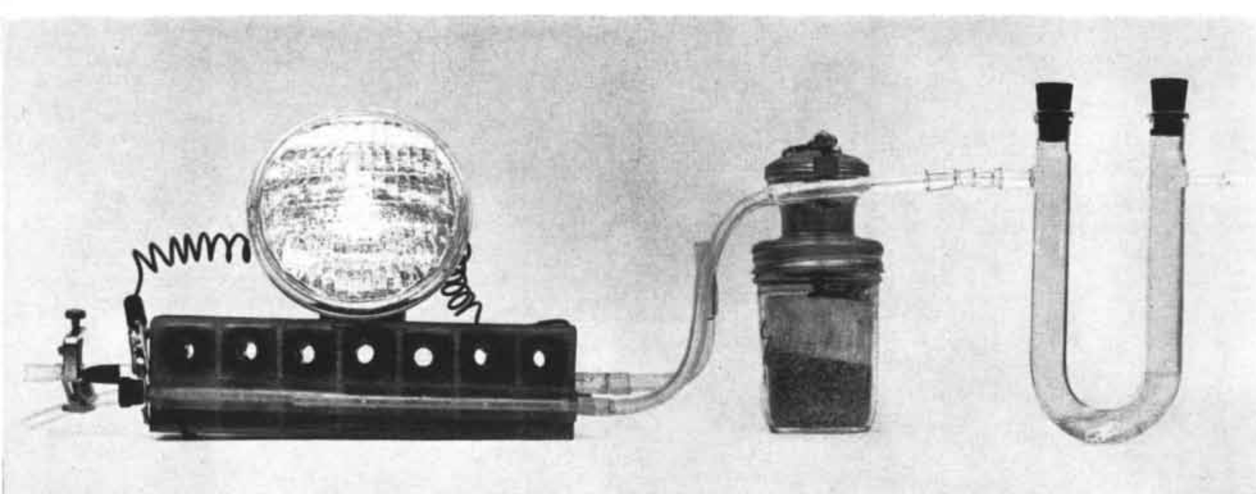
In addition to the expenditure of energy needed to drive the reaction over activation-energy barriers, the fuel cell must consume some energy to force gas molecules through the electrodes to the reaction area, to transport hydroxyl ions from one electrode to the other and to overcome the electrical resistance of the electrodes themselves. These losses reduce the cell voltage below the theoretical ideal. A common working standard of voltage efficiency for fuel cells, however, is 75 per cent.

In practice, at the present stage of the art, other considerations loom larger than simple efficiency. For instance, a standard criterion is the power output per cubic foot of cell when the cell is converting 75 per cent of the thermodynamically available energy into electricity. Another important factor is the length of time a cell can operate before its performance falls off due to the deterioration of the electrode or the electrolyte.

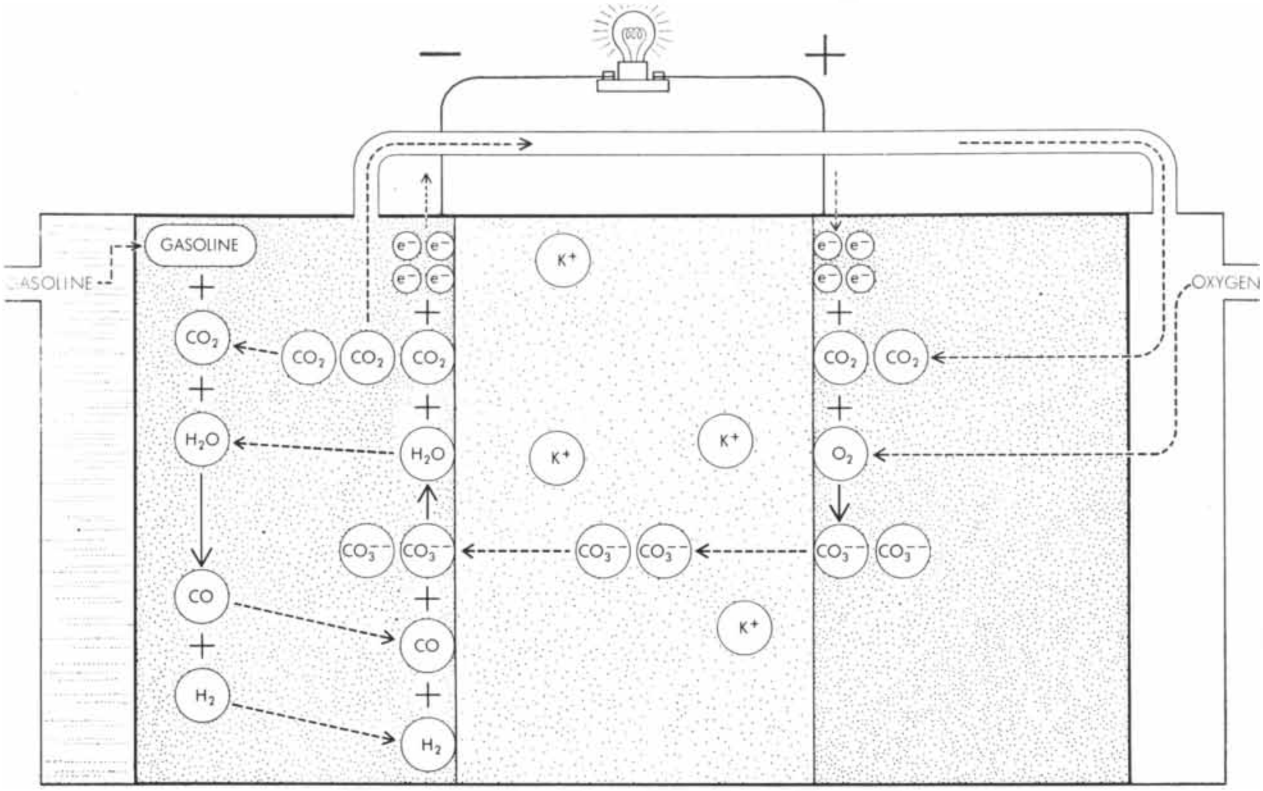
In a typical hydrogen-oxygen cell the electrodes consist of porous carbon impregnated with catalysts: fine particles of platinum or palladium in the hydrogen electrode and cobalt oxide, platinum or silver in the oxygen electrode. To prevent flooding of the pores by the electrolyte, which would cut down the active surface, the electrodes are waterproofed with a layer of paraffin wax about one molecule thick. This thin film allows ions and individual water molecules to pass through to the internal surfaces of the electrode, but prevents the water from flooding the pores. To bring the electrodes closer together and thus speed ion transport, the electrodes are typically arranged as concentric tubes or adjacent plates. Cells of this type developed by Karl Kordesch of the National Carbon Company have won the distinction of being the first practical fuel cells; the U. S. Army uses them to power its "silent sentry" portable radar sets. Some have been in operation for more than a year with no appreciable decline in performance.

Low-temperature hydrogen-oxygen cells are limited in their applications, although they may find widespread special uses. Hydrogen is a costly fuel and the power-to-volume ratio of the cell (about one kilowatt-hour per cubic foot) makes it too bulky for use in vehicles.

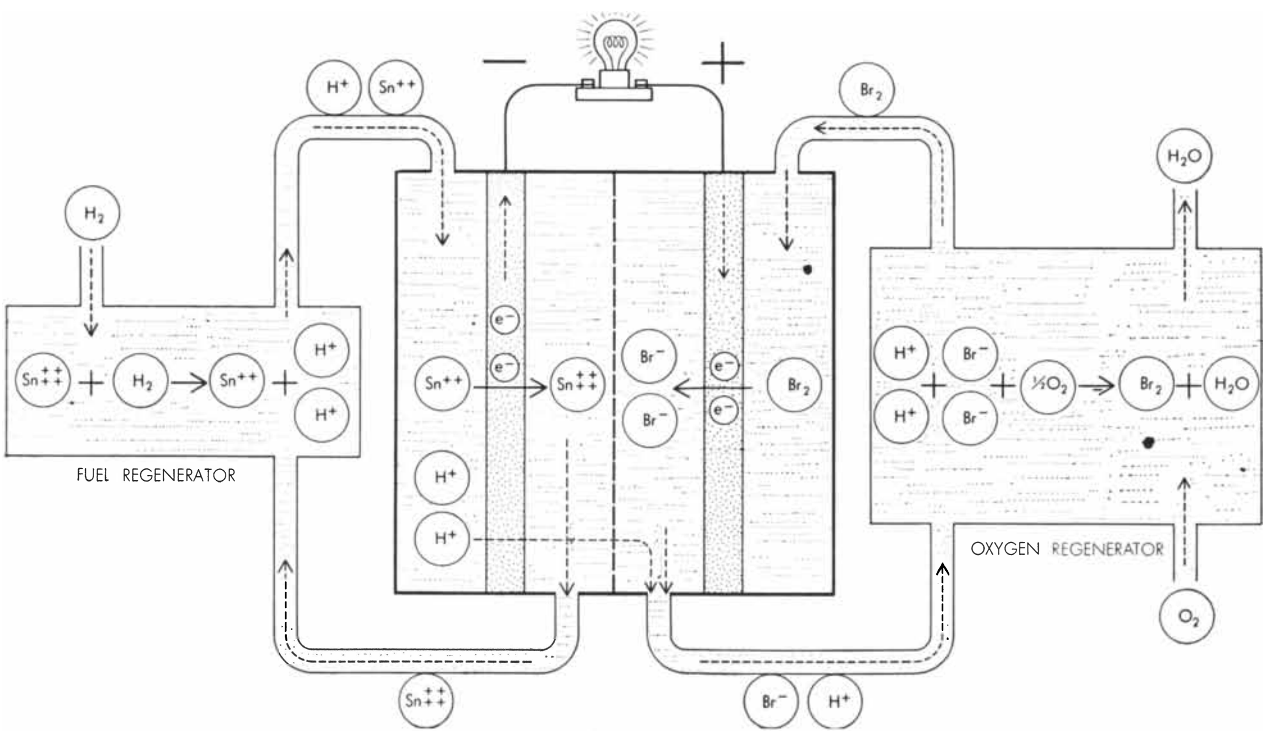
An obvious way to improve the performance of hydrogen-oxygen cells is to



LABORATORY MODEL of a simple fuel cell reacts hydrogen with the oxygen in air. Hydrogen is generated in jar at right by dropping water onto calcium hydride. The gas then flows through carbon tubes in a block of Lucite, where it reacts with an electrolyte. The electrolyte in turn reacts with the oxygen that diffuses into other carbon tubes. The power output of the cell is three watts.



HIGH-TEMPERATURE FUEL CELL operates above 500 degrees centigrade and uses fuels such as gasoline or natural gas. The cell contains two electrodes tightly pressed against a "solid" electrolyte, which is usually a molten salt such as potassium carbonate. The fuel in the cell is usually broken down (by reaction with steam and carbon dioxide) to produce hydrogen and carbon monoxide. These gases then diffuse into the negative electrode, where they react with carbonate ions in the electrolyte, forming carbon dioxide and water and giving up electrons. The electrons flow through the circuit to the positive electrode, where they combine with oxygen and carbon dioxide to form carbonate ions. The carbonate ions complete the cell's electrical circuit by flowing back to the negative electrode.



REDOX CELL is so named because in it the fuel and oxygen react with oxidizing and reducing agents in two so-called regenerators. The hydrogen reduces (adds electrons to) tin ions, which then give up electrons to the electrode. The electrons flow to the positive electrode. On the positive side of the cell, oxygen oxidizes (takes electrons from) bromide ions, converting them to bromine. In turn, the electrons flowing into the positive electrode reduce the bromine to bromide ions, which are then returned for regeneration.

operate them at higher pressures (which speed up gas transport through the electrodes) and higher temperatures (which speed up the electrochemical reactions). By appropriate design and insulation the waste heat liberated in the cell can be used to maintain the cell at the proper operating temperature.

The best-known cell of this type has been developed by Francis T. Bacon of the University of Cambridge. It operates at temperatures up to 250 degrees C. with gas pressures up to 800 pounds per square inch. The electrodes are of porous nickel about 1/16-inch thick and are usually in the form of disks or plates. A thin surface layer on the electrode, penetrated by very fine pores, constitutes the reaction area. The electrolyte, a concentrated solution of potassium hydroxide, can enter these pores, but pressure differences within the electrode prevent it from flooding the larger pores in the body of the electrode, through which gas percolates to the reaction area. The Bacon cell produces six times as much power per cubic foot as the low-temperature cell. With this relatively high output, the cell should have bright prospects as a standby source of auxiliary power in airplanes. It can deliver as much as 150 watts per pound, as against 10 watts for the lead-acid storage batteries currently in use.

To produce economical power on a large scale, fuel cells must "burn" cheap fuels such as natural gas, vaporized gasoline or the mixture of gases obtained from the gasification of coal. The extraction of energy from such fuels calls for operating temperatures above 500 degrees C. Since aqueous electrolytes would boil away at these temperatures, the electrolyte consists of some molten salt, usually a carbonate of sodium or potassium mixed with lithium carbonate to lower the melting point. In the most efficient of these cells, the electrolyte is held in a matrix of porous refractory material. The electrodes, made of a variety of metals or metallic oxides, are tightly pressed against the "solid" electrolyte.

In these cells the fuel does not necessarily combine directly with oxygen as hydrogen does in the hydrogen-oxygen cell. Usually the fuel is "cracked" to hydrogen and carbon monoxide by reaction with steam and carbon dioxide, which the fuel cell produces as by-products. This cracking may be conducted outside the cell, or inside the cell on the electrode surface. In the current-generating reaction the hydrogen and carbon monoxide diffuse into the cell at the negative electrode, where they react with carbonate ions in the electrolyte, forming carbon dioxide and water and giving up electrons to the electrode. At the positive electrode, oxygen or air takes up the electrons flowing in from the external circuit and reacts with the carbon dioxide to produce the carbonate ions. The migration of carbonate ions through the electrolyte from the positive to the negative electrode completes the circuit [*see top illustration on opposite page*].

High-temperature fuel cells, intensively investigated only since World War II, still perform poorly. The best of them produce no more than half a kilowatt per cubic foot—half the yield of the low-temperature hydrogen-oxygen cell and a twelfth the yield of the Bacon cell. However, the progress already made in hydrogen-oxygen cells suggests that further research can improve the performance of high-temperature cells by a factor of 10 or more.

In the "redox" cell—named for reduction and oxidation—the fuel and oxygen do not react directly with each other. Rather, the fuel and oxygen are made to react with other substances in "regenerators" outside the cell to produce chemical intermediates, which in turn generate current in the cell. The over-all reaction is the same as that of combustion, however, because the intermediates are regenerated. A typical cell of this type, developed in England under the leadership of Sir Eric Rideal, utilizes tin salts and bromine as intermediates. The fuel reduces (*i.e.*, adds electrons to) tin ions, which then give up the added electrons to the negative electrode and return to react with more fuel. The oxygen similarly oxidizes (*i.e.*, takes electrons from) bromide ions, converting them to bromine, which then takes up electrons from the positive electrode and returns as bromide ions for regeneration [*see bottom illustration on opposite page*]. A similar cell, using titanium salts instead of tin, is under development by the General Electric Company.

In principle redox cells should be able to achieve high efficiencies. The intermediates can be chosen so that the electrode reactions are rapid and yield high currents with little energy loss. With suitable catalysts and operating conditions it may be possible to carry out the regeneration reactions at satisfactory efficiencies. However, the problems involved in the regenerators have not yet been solved. Moreover, the two electrolyte systems must be separated from each other by an impermeable membrane to keep the bromine from mixing and reacting with the tin or titanium ions. All known membranes of this sort have a rather high electrical resistance. It has not yet been demonstrated that the redox cell represents any improvement over simpler types.

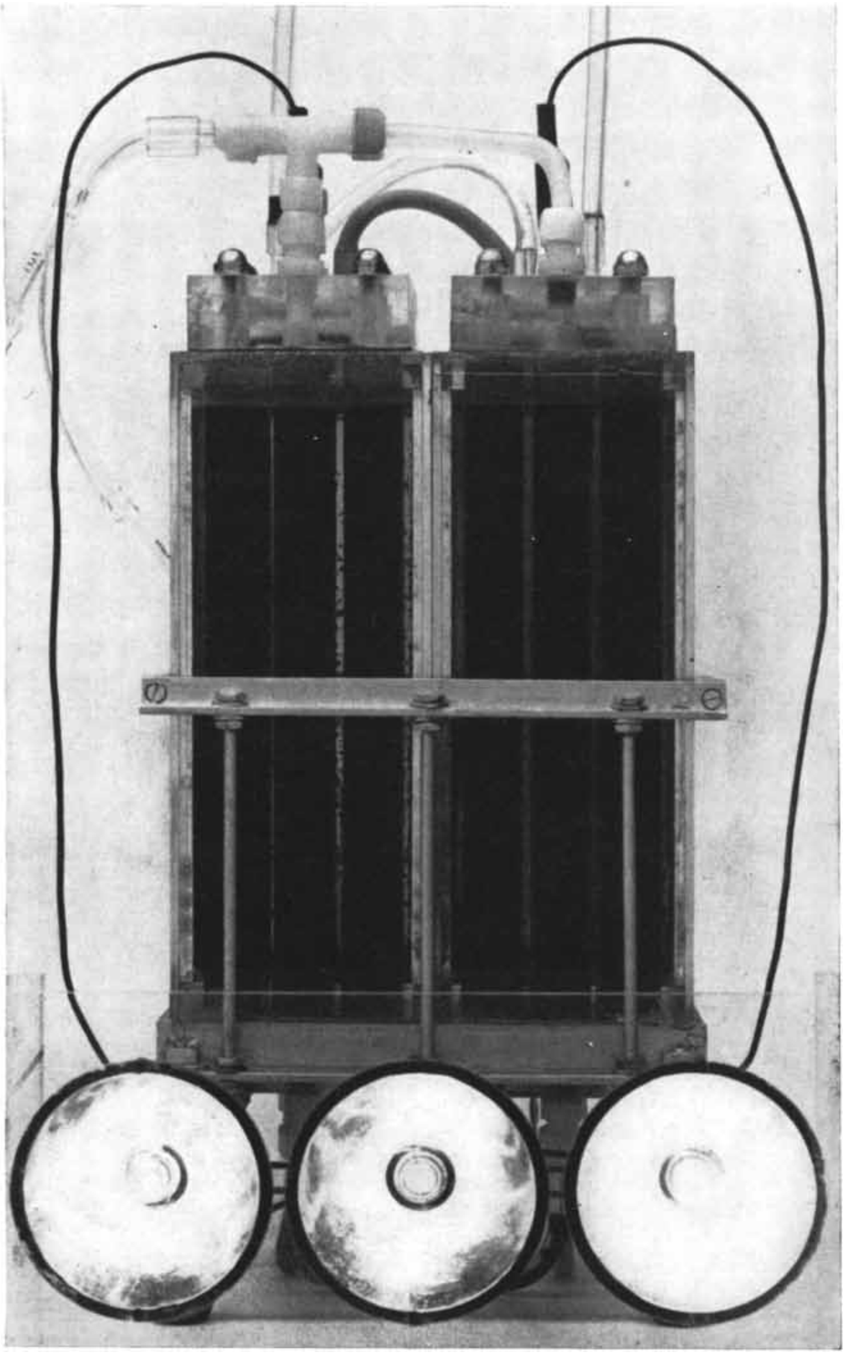
Engineers are working on a number of other reaction cycles and combinations of cycles. Each of them presents knotty technical difficulties. But the fundamental processes of electrochemistry are fairly well understood, probably because electrochemical experiments require no expensive apparatus and thus fit well into university budgets. The future development of the fuel cell is thus a question of applied rather than basic research.

Low-temperature and moderate-temperature hydrogen-oxygen cells should come into use during the next few years as low-weight, easily "charged" batteries. The development of strong, lightweight containers, perhaps made of plastic-impregnated glass fibers, would reduce the poundage if not the cubic footage needed to store the reaction gases. Where cost is not too important, the hydrogen could be stored as solid lithium hydride and the oxygen as solid calcium superoxide. Moderate-temperature cells may well be used to power submarines. Such vessels, like nuclear submarines, could cruise for extended periods without surfacing and would be far quieter in operation than nuclear vessels.

Hydrogen-oxygen cells may also furnish a means of capturing the power of the sun. Investigators at the Stanford Research Institute have developed a catalytic process for decomposing water into hydrogen and oxygen by sunlight. Used in conjunction with fuel cells, which would recombine the hydrogen and oxygen into water, a solar photolysis plant covering two square kilometers of desert could provide as much energy as a 100,000-kilowatt power-station in continuous operation. The over-all efficiency of such a plant, estimated at 25 per cent, would be two and a half times that of present solar batteries or solar boilers.

In auxiliary installations at nuclear power-stations, hydrogen-oxygen cells may help to bring down the cost of nuclear power. The high capital cost of nuclear-power plants requires that they be operated at near-peak capacity if they are to yield cheap electricity. Power generated during daily or seasonal periods of low demand might be used to electrolyze water into hydrogen and oxygen, which would then be made to yield the stored energy via fuel cells during peak-demand periods. The large volume of gas generated might be stored in "sausage skins" of plastic film buried underground to eliminate wind damage.

If the performance of high-temperature fuel cells can be substantially improved, large-scale electric power might be generated near sources of cheap natural gas. The power produced would of course be in the form of direct rather than alternating current, and though high-voltage direct current is somewhat easier to transmit than alternating current, fuel cells apparently cannot produce high voltages. Large numbers of cells must be connected in series, and above 700 volts there is electrical leakage through the insulation separating the terminals. Large-scale power from fuel cells should therefore find its first application in electrochemical processes such as the production of aluminum, which utilize large quantities of direct current at low voltage. Electrochemical industries may then congregate near natural-gas sources as they now cluster around hydroelectric installations.



EXPERIMENTAL FUEL CELL operates at room temperature and atmospheric pressure. It produces 20 watts of electrical power, enough to light three bicycle lamps. The two Lucite boxes composing the cell contain an electrolyte solution and nine porous carbon electrodes, four for hydrogen and five for oxygen. This cell, and the one on page 75, were photographed in the laboratories of the National Carbon Company in Parma, Ohio.

The hydrogen-oxygen cell may make an unorthodox contribution of its own to the chemical industries. With slight modifications a low-temperature cell can employ instead of hydrogen a liquid fuel such as methyl (wood) alcohol, which it oxidizes to formic acid. The power output is very low, but the formic acid is almost free of impurities. Ethyl alcohol can similarly be oxidized to acetic acid, an important raw material in the manufacture of plastics and lacquers. Such processes, amounting to a sort of electrolysis in reverse, may prove useful in the manufacture of other industrial chemicals. Since the energy released would be extracted as electricity rather than heat, unwanted side reactions could be held to a minimum. It would be ironic if fuel cells should find their principal application in the production of chemicals rather than of power.

Attempts to construct cells that would operate directly on coke or coal, the cheapest of fuels, have been disappointing. Far more promising is the mixture of hydrogen, carbon monoxide and hydrocarbons that can be made from coal. With suitable equipment to remove tar and grit, it could be piped directly from the gasification plant and used hot. However, a really low-cost process for generating gas from coal has yet to be devised.

A high-output fuel cell operating on liquid fuel would find immediate application in trucks and locomotives. The technology of electric traction is well developed and is waiting for a compact power-unit utilizing a cheap fuel that can be easily stored and pumped. Designers will have to figure out a simple way to warm up the cell to operating temperature; the high-temperature cell is not a self-starter.

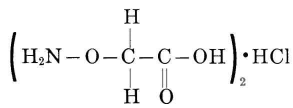
The possibilities of fuel cells are great, but not all these possibilities are going to be realized. Although much small-scale development work remains to be done, some cells have reached the stage where further progress will require large amounts of money and faith. No doubt some of this money will be wasted, and some of the faith will be misplaced. Fuel cell development is not a field for the faint-hearted.

Kodak reports on:

a biochemical reagent and metabolic inhibitor that transforms *Salmonella*... how modern scientific research is organized... a new method of metal working

A deft way with ketones

(Aminooxy)acetic Acid Hemihydrochloride, known in the biochemical literature as carboxymethoxylamine hemihydrochloride and with less chance for confusion as



is now going to become even better known as Eastman 5336.

Now that the great virtue of easy availability has been bestowed on this compound, it commands interest on several grounds:*

1) The still mysterious transformation of bacilli and colonies of bacilli into the so-called L form—a bacteriological phenomenon being closely watched—has been shown to be induced in *Salmonella typhosa* by this acid in a narrow concentration range (*J. Bact.*, *59*,775).

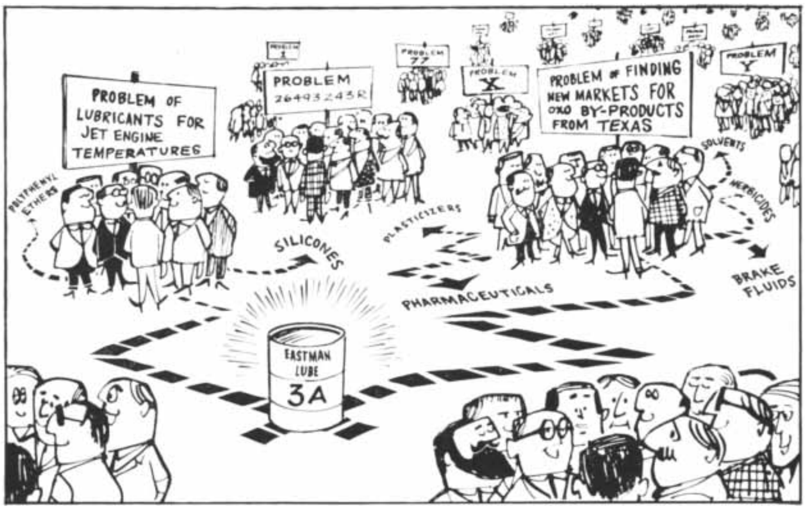
2) Its ability to combine in living organisms with α-ketones, principally pyruvate, makes it a metabolic inhibitor useful as a bacteriostatic agent in preparations of high protein content, such as blood-typing serums and bacterial vaccines (*J. Bact.*, *55*,1).

3) It is useful as a reagent for the isolation of very small amounts of ketones from unsaponifiables such as cholesterol and its metabolic products (*J. Biol. Chem.*, *114*,539).

4) It is useful for isolation of α-estradiol from human pregnancy urine (*J. Biol. Chem.*, *134*,591).

Abstracts of the latter two analytical procedures with Eastman 5336, or List No. 41 of some 3700 other Eastman Organic Chemicals, will be furnished upon application to Eastman Organic Chemicals Department, Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company). The compound itself may be ordered at $3.55 for 5 grams.

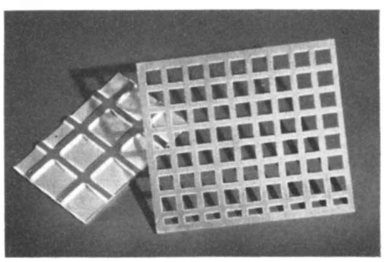
*'Tis a speculation whether progress in these matters was advanced or retarded by Hans Thacher Clarke's leaving us 32 years ago to build Columbia University's great Department of Biological Chemistry. (Aminooxy)acetic acid was first synthesized in Germany in 1893. It is astounding what a large proportion of all organic chemicals later found interesting for one reason or another were first synthesized in Germany in 1893. Apparently this one, like so many others, just lay there in the literature until Professor Clarke suggested it for reaction with carbonyl compounds. Shortly after the suggestion proved fruitful, he and a collaborator came out with an improved synthesis of the compound. At this point, had he still been heading up the production of Eastman Organic Chemicals, he would doubtless have added it to our list, making it conveniently available to all way back in 1936 and thus advancing progress. But if he hadn't quit to be a college professor, he'd be tied up in a lot of dull business routine. This would have retarded progress because he wouldn't have been sitting around with graduate students and research scholars tossing out brilliant suggestions that are still gaining momentum a quarter century later. Anyway, the synthesis we use for Eastman 5336 now is not identical with Dr. Clarke's. A Texan who tried his synthesis reported she wound up with merely ammonium chloride unless she was very careful.



The hot oil project

That, roughly, is how these things develop. The principal constituents of *Eastman Lube 3A* are straight-chain fatty acid esters of trimethylpentanediol, a compound obtained by a certain setting of the valves at our "oxo process" plant in Longview, Texas. No other of the 16 currently accepted 350°F lubricants does so well in the crucial lead corrosion test as *Eastman Lube 3A*, which doesn't even require a special additive to keep it from attacking lead after six months. On the other crucial tests demanded by MIL-L-7808C, *Eastman Lube 3A* makes out OK. Those who need further facts to be impressed can write Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company), where friendships formed at a comparatively cool 350°F are expected to warm with the hot pursuit of lubricity to higher temperatures but never in themselves to prove lubricous.

Photo-milling



New methods of metalworking do not come along often enough to be ignored. Here are two examples of what we call "photo-milling." The one on the right could, of course, have been done on a punch press if die cost had been justifiable. No die was used, nor were the openings cut individually. The one on the left looks like a milling machine job, for sure. It isn't.

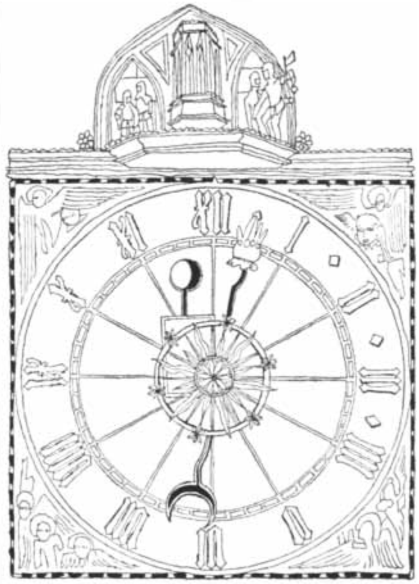
This sort of thing is now best done photographically with a new light-sensitive preparation called *Kodak Metal-Etch Resist*. You spray it on, or dip, and dry. Then you expose to bright light under a film on which you have photographed the pattern. After a simple development, a flush that washes away the resist where the pattern kept the light off, and a bit of baking to remove the developer solvent, the metal is ready for whatever chemical or electrolytic etching works best. The resist protects from etching action vigorous enough to remove a quarter-inch of aluminum and considerable depths of stainless steel, tool steel, magnesium, titanium, and possibly some metals we know nothing about. To get the benefit of our thinking on the subject, write Eastman Kodak Company, Graphic Reproduction Division, Rochester 4, N. Y.

Price quoted is subject to change without notice.

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

Kodak
TRADEMARK

SCIENCE AND



Test Suspension

As the Geneva Conference on banning nuclear weapons tests recessed last month to await the outcome of President Eisenhower's talks with other heads of state, the conferring governments agreed to continue their existing moratorium on testing. The meetings were adjourned for six weeks from August 26 to October 12. On the day of adjournment the U. S. announced that the term of its voluntary suspension, which was to have expired on October 31, would be extended to December 31 "to allow a reasonable period of time for the negotiations to proceed following their resumption." Great Britain said that it would hold off so long as the Geneva talks showed some prospect of success. The U.S.S.R. declared that it would not resume testing unless the Western powers did. Attributing the stalemate at Geneva "exclusively" to "the positions of the Western powers," the U.S.S.R. went on to "reaffirm that it is willing immediately to sign an agreement with the U. S. and the United Kingdom on the cessation of the testing of all types of nuclear weapons for good."

The next nuclear detonation may be set off not by the existing nuclear powers but by France. That government has reiterated its intention to develop its own atomic weapons and to conduct an early test explosion in the Sahara.

Federal Radiation Council

A Federal Radiation Council has been created to advise the President on radiation safety and to recommend radiation-safety policies to be followed by Federal agencies. The Council consists of the chairman of the Atomic Energy Commission and the secretaries of Defense, Commerce, and Health, Education and Welfare. Arthur S. Flemming, Secretary of Health, Education and Welfare, was named first chairman of the Council, and George B. Kistiakowsky, special assistant to the President for science and technology, will serve as adviser.

Under the directive setting up the Council, the Public Health Service will have the chief responsibility for collecting information on fallout, medical X-ray and other radiation hazards. The National Committee on Radiation Protection and Measurement, however, is expected to continue its present work of devising methods for measuring radiation and drawing up standards for X-ray machines and other radiation equipment.

The establishment of the Council is a step in a program designed to make the regulation of radiation primarily a part of the general environmental sanitation activities of state and local health departments. Under the Atomic Energy Act of 1946, the AEC has been responsible for controlling hazards from bomb tests, reactor operations and the processing and handling of radioactive materials. The arrangement is generally considered to have been the best possible in 1946, but has recently led to difficulties. In addition to putting the AEC in the position of being both judge and policeman of its own activities, no provision was made for the setting of maximum permissible tolerances for fallout radioactivity in food and drinking-water; nor is such an important source of radiation as X-ray machines covered. Moreover, the activities the AEC is charged with regulating are becoming increasingly more numerous and difficult for a single agency to monitor.

Two remedies were proposed. One was to give the Public Health Service the entire responsibility for radiation safety. The other—the course being followed—was to transfer the bulk of such activities to the states, with the Public Health Service acting as an information-gathering agency and a Federal council recommending standards and establishing policy for Federal agencies working with radiation. Legislation now before Congress will allow the states to take over many of the AEC's regulatory functions. In anticipation of its passage, the President's executive order also directs the AEC to help the states—several of which have already drawn up comprehensive radiation codes—prepare for their new task.

Nuclear Navy

The exploits of the nuclear submarines *Nautilus* and *Skate* have obscured the fact that the application of nuclear energy in ship propulsion is advancing at an almost exponential rate. This past summer the ninth and tenth nuclear vessels to join the U. S. Navy (the guided-missile cruiser *Long Beach* and the missile-firing submarine *Halibut*) slid down the ways with scarcely a ripple of public notice. All the vessels but the *Long Beach* are submarines, the latest of which are equipped with S5W reactors, the first nuclear reactor in mass production. The fact that these reactors are technologically three generations removed from the one first installed in the *Nautilus* only five years ago is a measure of the rapidity of progress in naval reactors.

The nuclear-ship program is still being pushed vigorously. Nuclear naval expert John E. Kenton, writing in *Nucleonics*, states that by the end of the year the U. S. will have 16 nuclear ships, and that by the end of 1960 it will have launched 10 more, including the destroyer *Bainbridge* and the aircraft carrier *Enterprise*. The *Enterprise* will be truly a mastodon of the seas: her 86,000-ton displacement will make her the world's largest warship and quite possibly the largest ship ever built. Eight reactors will drive her through the water at a speed of 33 to 35 knots and will operate for five years without refueling.

Oceanographic Congress

The difference between continental and oceanic areas of the world is more than skin deep. The Mohorovicic discontinuity—the boundary between the earth's crust and mantle—is known to be nearer the earth's surface beneath the sea than beneath the continents; thus the earth's crust is but four to six kilometers thick in many parts of the oceanic areas, as against 25 to 35 kilometers below the continents.

Land-sea differences extend down into the mantle. Study of shear waves generated by earthquakes has revealed a minimum-velocity zone in the mantle at a depth of 50 kilometers beneath the sea. Beneath the land, the minimum occurs at a depth of 100 kilometers. The difference in depth of the minimum-velocity zone argues a difference in density between portions of the mantle underlying the oceans and those underlying land masses. The difference extends down to at least 400 kilometers below the surface of the earth.

The earthquake-wave study, the work of several investigators, was reported by W. Maurice Ewing of Columbia University's Lamont Geological Observatory at the first International Oceanographic Congress, held at the United Nations under the joint sponsorship of UNESCO and the American Association for the Advancement of Science. For the congress, 800 delegates and six oceanographic vessels came to New York. The ships included the 5,960-ton *Mikhail Lomonosov*, one of the U.S.S.R.'s large research-vessels, and the French vessel *Calypso*.

The congress heard several reports indicating a growing conviction among physical oceanographers that the continents are drifting apart. Among them were reports by Ewing and Bruce C. Heezen, also of the Lamont Observatory, concerning mid-ocean ridges. Such ridges form a connected system 40,000 miles in length and extend into all oceans except the North Pacific. Detailed soundings of several of the ridges—which generally parallel adjacent coasts in striking fashion—have revealed the presence of pronounced rifts at the ridge crests, as though the earth were cracking apart at the crests. Other studies, moreover, indicate that the ridge crests are areas of great geological activity. Almost all Atlantic Ocean earthquakes (the most carefully studied) have their epicenters in the rifts. Though still few in number, ocean-bottom heat-flow studies uniformly show the ridges to be areas of abnormally high flow of heat from the interior of the earth. Ewing described the ridges as areas of strong convection currents in the interior of the earth—convection currents that could have played a part in breaking up the single continental massif proposed 35 years ago by the German meteorologist Alfred Wegener, and that could still be driving the continents apart.

Curiously the one oceanic area without a mid-ocean ridge, the North Pacific, was reported by Henry W. Menard of the Scripps Institution of Oceanography to be the locale of an extensive system of ocean-bottom fracture lines. Recent surveys by Soviet and Scripps Institution vessels have shown the North Pacific to contain numerous "major" linear fractures, each with many branching "minor" linear fractures. A chart of the fractures in part of the North Pacific floor would look like a herringbone weave.

In another paper Gustaf O. S. Arrhenius of the Scripps Institution offered a new way to investigate the question of whether the earth's poles have wandered or have always had their present position. Tropical trade winds bring up nutrient-rich waters from the depths of the ocean. The nutrients stimulate the production of organic matter, resulting in a relatively heavy rain of sediment on the ocean floor near the Equator. Unusually thick deposits of sediment, Arrhenius pointed out, could provide a clue to the location of the Equator, and therefore the poles, in ages past. Unfortunately it will take a project like the Mohole—the proposed shaft to the Mohorovicic discontinuity—to penetrate ocean sediments deeply enough to find such sedimentary maxima. Present-day ocean-bottom corers cannot penetrate the sediments far enough to provide useful information on the period before the beginning of the recent ice ages.

External Fetus

Much that is now obscure about the development of the young of mammals (including man) would be clear if there were a way to observe the fetus directly without disturbing it *in utero.* This still seems beyond reach. But three ingenious investigators at the Caroline Institute in Stockholm have found a means of making the animal fetus accessible for at least several hours of study.

The procedure is to deliver the fetus, but not the placenta, by Caesarean section; the placenta is left in place, and the fetus is left connected to the placenta by the umbilical cord.

Thirty years ago Arthur St. George J. McC. Huggett, a British physiologist, employed a similar technique to measure oxygen and carbon dioxide exchange between mother and fetus in goats. However, in order to assure conditions as nearly physiological as possible, Huggett immersed the fetus in an artificial equivalent of the amniotic sac—a tub of warm, saline solution. The Caroline investigators found this unnecessary. Fetuses can be kept in good condition for as long as two days with the aid of a warming light and simple precautions to prevent the umbilical cord from drying out.

The three investigators were Carl Gustaf Bernhard and Göran M. Kilmodin of the Caroline Institute faculty and Irwin H. Kaiser of the University of Minnesota. They utilized the procedure to obtain electroencephalograms of fetal sheep—the first detailed fetal encephalograms ever recorded.

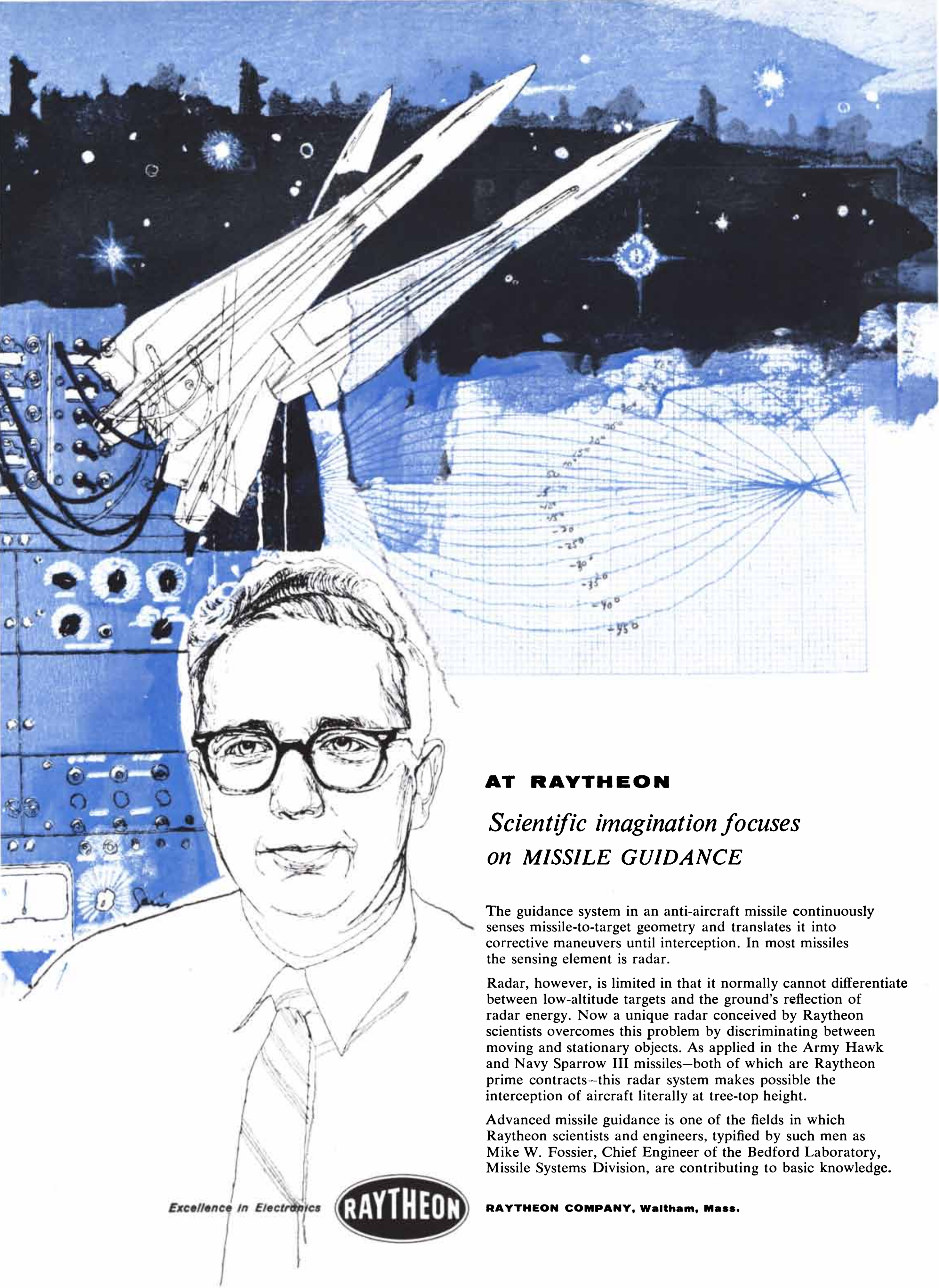
Electrical activity of the lamb brain was found to begin just short of halfway through gestation—about the 70th day of the normal gestation period of 150 days. A distinctive "fast activity" predominated until the 100th day, when electrical waves of adult type began to appear. Coordinated responses from the brain as a whole did not show up until near term.

The fetal externalization technique can be applied to rabbits, dogs and other mammalian species as well as to sheep and goats. Kaiser, now chairman of the department of obstetrics and gynecology at the University of Minnesota Medical School, emphasized that the technique is more important than the first results obtained with it. It can be used to investigate systematically the effects of oxygen deprivation, maternal anesthesia, immunological responsiveness and a host of other problems in fetal physiology.

Universal Explosive

What makes the universe expand? If, as the evolutionary theory of cosmology holds, it began its history with a big bang, then the outrushing of galaxies results from the primordial explosion. But if the universe has always existed in a steady state, its density maintained by the continuous creation of new matter, some other force must account for its expansion. Now the British cosmologists R. A. Lyttleton and Hermann Bondi suggest that the force may be the familiar one of electrostatic repulsion.

According to the steady-state theory, new matter is created in the form of hydrogen atoms. It has always been supposed that the hydrogen atom is electrically neutral, the positive charge of its nucleus being exactly offset by the negative charge of its single electron. Lyttleton and Bondi point out that this is just an assumption. If the charges of proton and electron are not quite equal, the atoms as a whole will be charged and will repel each other. A difference of two parts in a billion billion would account for the observed expansion rate, according to Lyttleton's calculations. He told a recent meeting at the California Institute


AT RAYTHEON
Scientific imagination focuses on MISSILE GUIDANCE
The guidance system in an anti-aircraft missile continuously senses missile-to-target geometry and translates it into corrective maneuvers until interception. In most missiles the sensing element is radar.
Radar, however, is limited in that it normally cannot differentiate between low-altitude targets and the ground's reflection of radar energy. Now a unique radar conceived by Raytheon scientists overcomes this problem by discriminating between moving and stationary objects. As applied in the Army Hawk and Navy Sparrow III missiles—both of which are Raytheon prime contracts—this radar system makes possible the interception of aircraft literally at tree-top height.
Advanced missile guidance is one of the fields in which Raytheon scientists and engineers, typified by such men as Mike W. Fossier, Chief Engineer of the Bedford Laboratory, Missile Systems Division, are contributing to basic knowledge.
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of Technology that it might soon be possible to detect such a difference and predicted that the proton would turn out to have the larger charge.

Evolution of the Clock

An 11th-century Chinese manuscript describing the construction of an astronomical clock appears to have filled in one of the missing links of horological history. Until recently, explains J. Needham of the University of Cambridge in *Proceedings of the Royal Society*, the mechanical clock was generally thought to be an invention of 14th-century European craftsmen. In the past few years, however, it has gradually become clear that the medieval clock was not so much of an innovation as had been supposed. Descriptions and corroded fragments of complicated astronomical "pre-clocks" such as water clocks, planetary models and mechanical star-maps have survived from Greek and Arabic times [see "An Ancient Greek Computer," by Derek J. de Solla Price; SCIENTIFIC AMERICAN, June]. The discovery of these devices raised more questions than it answered. Not only did they operate quite differently from European clocks; they were also designed for computing the motion of heavenly bodies rather than for timekeeping.

Many of the questions were answered recently with the translation of "New Design for an Astronomical Clock," written in 1092 by Su Sung, a scientific scholar of the Sung dynasty. The clock described in the manuscript was actually constructed in 1088 and housed in a pagoda-like tower 30 to 40 feet high. Like its ancient Greek and Arabic predecessors, Su Sung's clock was designed primarily for computation: its mechanism turned a globe and a celestial sphere that indicated the movements of heavenly bodies. But the clock mechanism also turned five disks on which were inscribed representations of stylized human figures that indicated the time.

Su Sung's tower resembled European clocks not only in that it kept time, but also in that it had an escapement: a device for dividing the clock's input power into impulses of equal duration. Such devices had been called the "soul" of the European mechanical clock and were regarded as exclusively European inventions.

The difference between the two types of clock lies in their power supply: where the European clocks used power from a falling weight or an expanding spring, Su Sung's obtained its power from a

trickle of water steadily flowing into small cups on a water wheel. A "stopping-tongue" connected to several alternating balancing levers ingeniously provided the necessary escapement.

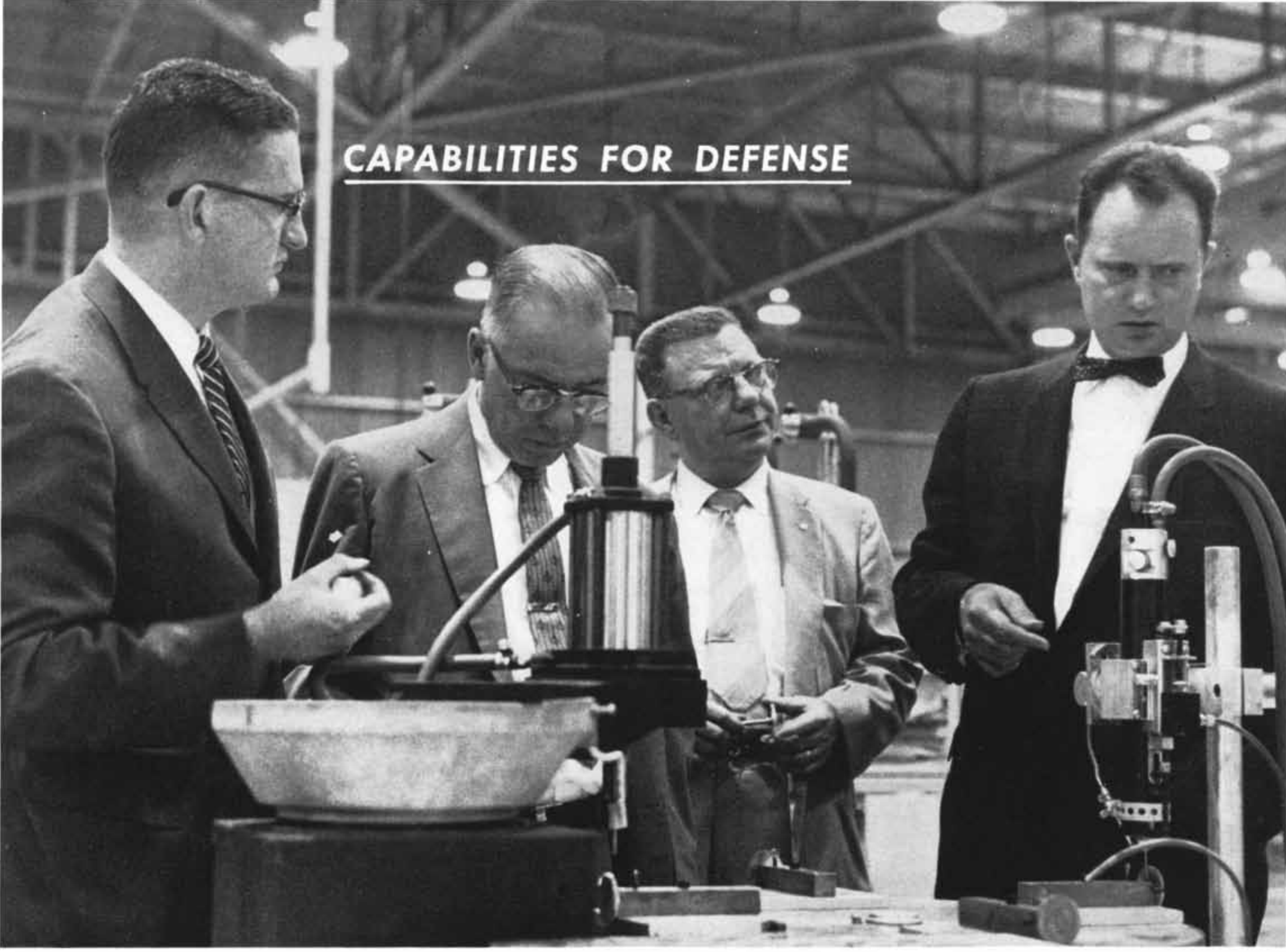
Needham points out the significance of the fact that the clockwork operated not by any mechanical oscillation but rather by gravity acting periodically on a water wheel. Thus, he says, Su Sung's clock combined the technology of ancient water clocks with that of the medieval mechanical clock in one continuous line of evolution.

Palsied Poet

If an ancient marble head in the University Museum of the University of Pennsylvania represents the Greek poet Menander (343-291 B.C.), then Menander probably had cerebral palsy. "The Head," as it is called, is one of about 40 known ancient copies of an undiscovered original bust. It shows a man who suffered brain damage quite early in life, according to Temple Fay, Philadelphia neurologist. He has published a medical analysis of the sculpture in *Expedition*, quarterly journal of the University Museum.

According to Fay, the right side of the frontal bone is smaller than the left; the right orbit is smaller and the right eyeball is recessed; the right cheekbone is less prominent than the left; the right ear is lower than the left; the crease from the corner of the mouth to the nose is drawn outward on the right, and the right halves of both lips are smaller than the left; the right half of the face is smaller than the left; the right side of the neck and tissues of the shoulder are drawn up as they would be in a person suffering mild paralysis, and the sternomastoid muscle is clear-cut on the left but "lost" in what appears to be a contraction of the neck and shoulder tissues on the right. Fay doubts that the differences are due to poor sculpture, and comments: "The analysis of the entire disproportion of the features would strongly suggest . . . that not only was the artist excellent in detail portrayal, but also exact in the reproduction of an adult type of developmental deficiency arising from an early parietal type of hemiplegia."

There is only slight direct evidence that the sculpture does represent Menander, and there is rather unreliable evidence that he walked with a languid gait and had a squint. Most people cannot detect a squint in "The Head." Some authorities think it may be a portrait of the Latin poet Virgil (70-19 B.C.).



PLANNED COST REDUCTION: Each Westinghouse defense division has closely controlled programs to reduce costs. Manufacturing, engineering and accounting representatives establish goals in advance and see that they are achieved. Here, for example, members of the *Electronics Division* group inspect an automatic assembly device designed to help the division reduce production costs $630,000 in 1959.

Here's how Westinghouse manufacturing capabilities produce better defense systems faster, at lower cost

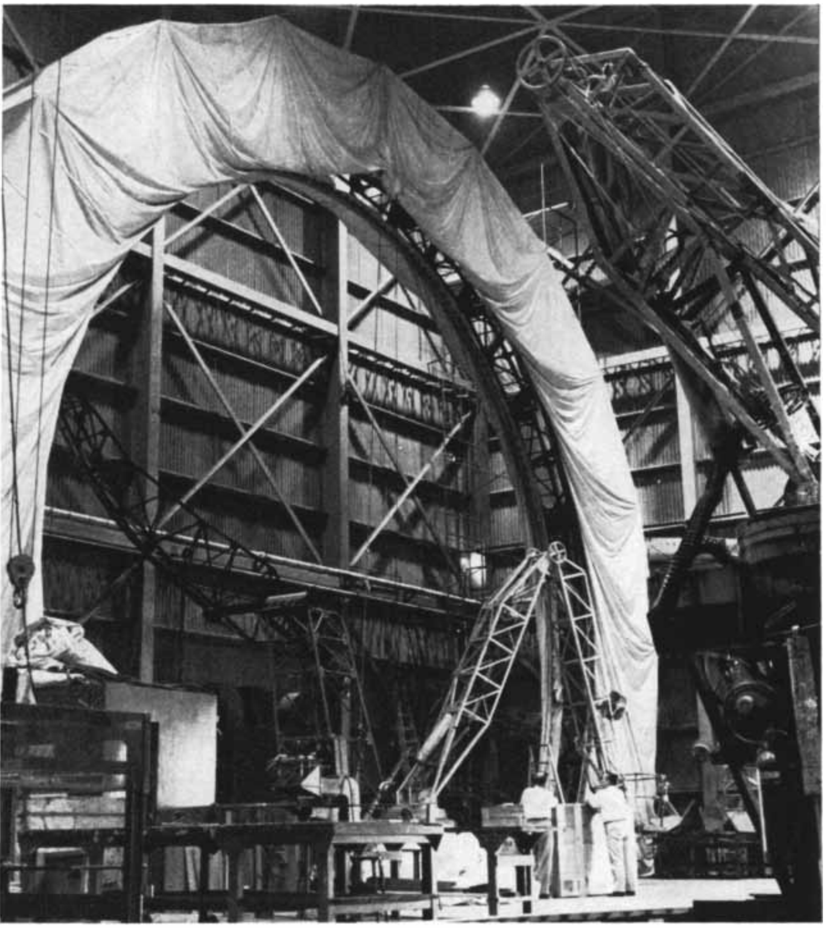
MODERN INSTRUCTION METHODS introduced by Westinghouse result in considerable savings in time and money. Video Instruction Technique (VIT), shown in use at *Air Arm Division,* eliminates costly, time-consuming training. Using this method, untrained personnel progress from one assembly to another without prior instruction.

GROUPED FOR EFFICIENCY: Baltimore divisions of Westinghouse are located near each other for quick interchange of information, personnel and equipment, to meet schedules and balance work loads. The *Air Arm* and *Electronics* divisions, shown below, are adjacent to Baltimore's Friendship International Airport.

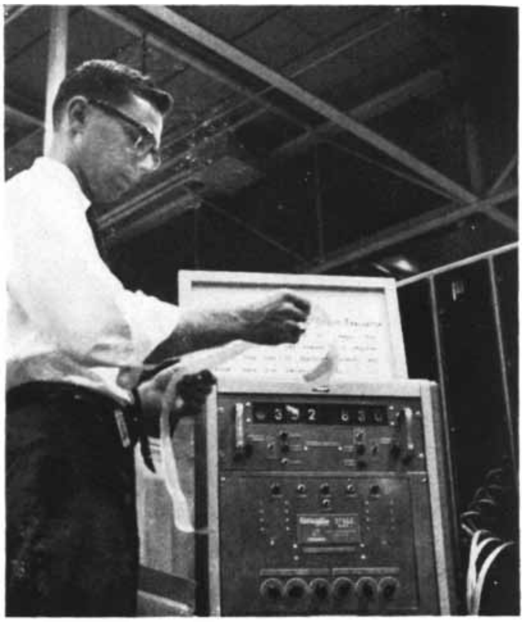
CONTINUED

Here's how Westinghouse manufacturing capabilities produce better defense systems faster, at lower cost

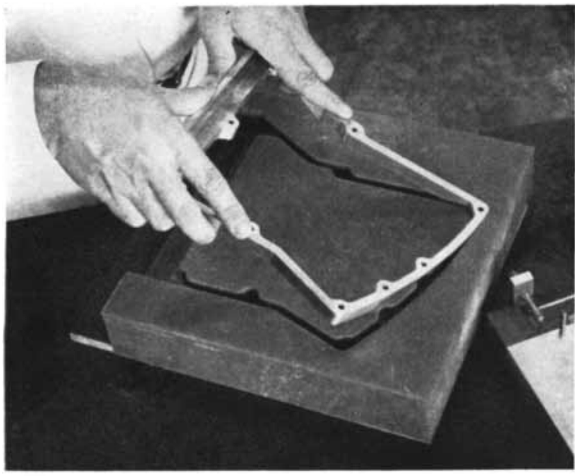
CONTINUED



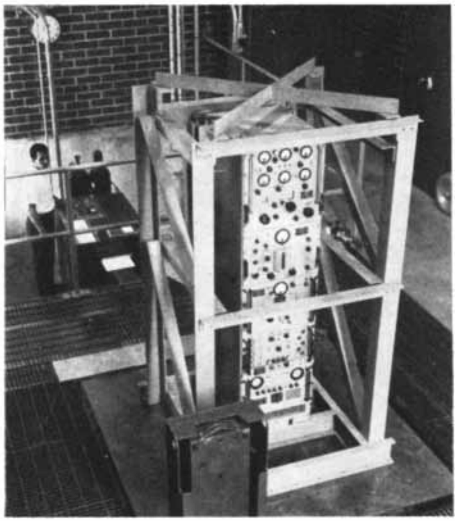
SPECIAL FACILITIES: Efficient production of military systems often requires specially designed facilities. Above, *Electronics Division* antenna "hangar", built for assembly and testing of the "PARABALLOON" air-inflated antenna.



AUTOMATIC TESTING: Tape-controlled automatic equipment lowers test and inspection costs at Westinghouse defense plants. These controls are used in production as well as in environmental testing. Above, the Westinghouse-developed Self Programming Automatic Circuit Evaluator (SPACE) at the *Electronics Division* performs circuit tests 70 times faster than can be done manually.

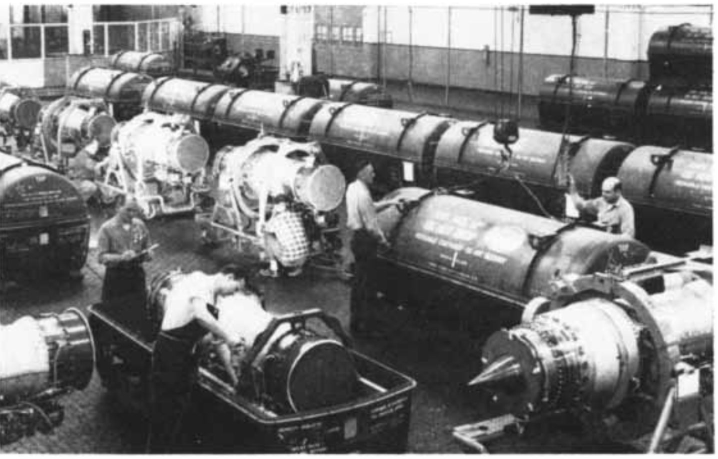


LOW COST TOOLING: Westinghouse reduces manufacturing costs through extensive use of plastic tooling techniques. This flexible mold was fashioned at the *Air Arm Division* from one original machined part. It can be used to produce hundreds of duplicate plastic parts to exact dimensions in a fraction of the time required under previous methods. Cost reductions average five to one.

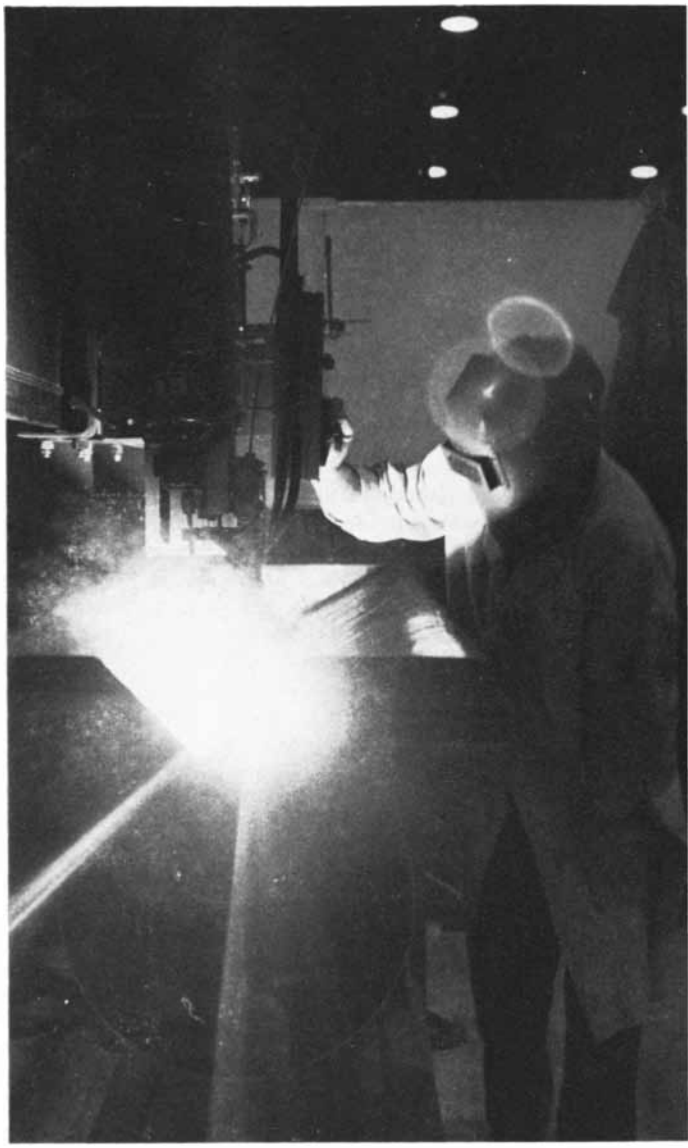


ENVIRONMENTAL TESTING: Military equipment must function reliably under extreme operating conditions. To insure such performance, each Westinghouse defense division makes available the most modern environmental test equipment. Here , a Navy shipboard transmitter undergoes vibration test at *Electronics Division.*

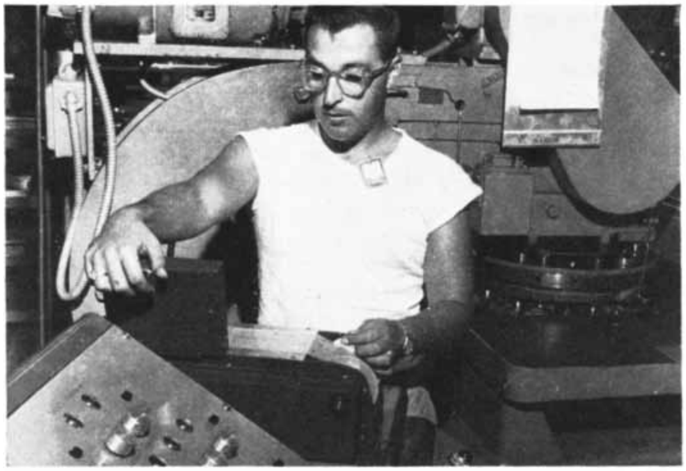
ADVANCED DEVELOPMENTS: The world's first brushless generators, shown at right, are typical of Westinghouse advances. Built by the *Aircraft Equipment Department,* these revolutionary brushless generators have performed for thousands of dependable hours. They are used in advanced electrical systems provided by Westinghouse for today's military and commercial jet planes.



MASS PRODUCTION CAPABILITY: Aircraft engines come off the line at the 85-acre plant of the *Aviation Gas Turbine Division*. Facilities like these offer exceptional capacity for mass producing military items to rigid specifications.

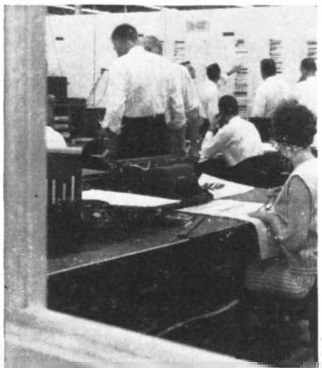


AUTOMATIC EQUIPMENT: Use of automatic equipment like the welding machine above at the *Ordnance Department* gives time savings of 6 to 1 over manual methods. Automatic machinery also assures uniform high quality and low costs.



ADVANCED TECHNIQUES reduce costs and manufacturing time while maintaining high quality standards. Above, a Westinghouse-modified punch press at the *Air Arm Division* operates automatically by tape or dial control. It reduces lead time, cuts costs 60 to 70 percent over use of templates.

PROGRAM VISIBILITY: Efficient scheduling and shop loading are programmed at a glance by manufacturing planners keeping up-to-the-minute charts on individual equipments, manpower, machine loadings, material and assembly flow. Chart room below is at *Air Arm Division*.



REDUCED PRE-PRODUCTION COSTS: This new Westinghouse data communications system cuts up to 50 percent from time lapse between design and data availability for weapons production. Called MMI (Mechanized Manufacturing Information), the system is used by *Air Arm Division*

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LIFE AND LIGHT

Life depends on a narrow band in the electromagnetic spectrum. This is a consequence of the way in which molecules react to radiation, and must hold true not only on earth but elsewhere in the universe

by George Wald

All life on this planet runs on sunlight, that is, on photosynthesis performed by plants. In this process light supplies the energy to make the organic molecules of which all living things are principally composed. Those plants and animals which are incapable of photosynthesis live as parasites on photosynthetic plants. But light—that form of radiant energy which is visible to the human eye—comprises only a narrow band in the spectrum of the radiant energy that pervades the universe. From gamma rays, which may be only one ten-billionth of a centimeter long, the wavelengths of electromagnetic radiation stretch through the enormous range of 10^{16}—10,000 million million times—up to radio waves, which may be miles in length. The portion of this spectrum that is visible to man is mainly contained between the wavelengths 380 to 760 millimicrons (a millimicron is ten millionths of a centimeter). By using very intense artificial sources one can stretch the limits of human vision somewhat more widely: from about 310 to 1,050 millimicrons. The remarkable fact is that, lying altogether within this slightly wider range of wavelengths, and mainly enclosed between 380 and 760 millimicrons, we also find the vision of all other animals, the bending of plants toward light, the oriented movements of animals toward or away from light and, most important, all types of photosynthesis. This is the domain of photobiology.

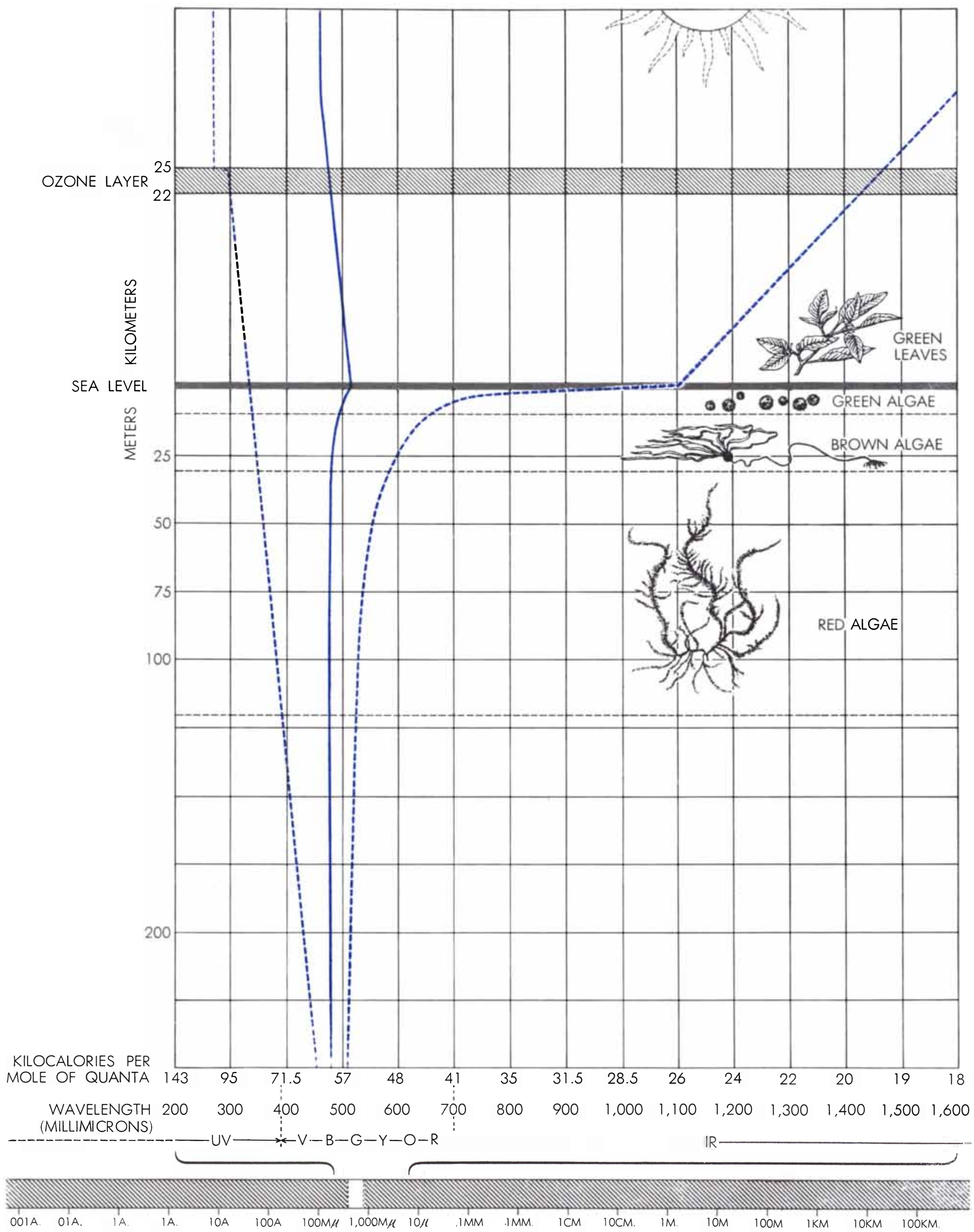
Why these wavelengths rather than others? I believe that this choice is dictated by intrinsic factors which involve the general role of energy in chemical reactions, the special role that light energy plays in photochemical reactions, and the nature of the molecules that mediate the utilization of light by living organisms. It is not merely a tautology to say that photobiology requires the particular range of wavelengths we call light. This statement must be as applicable everywhere in the universe as here. Now that many of us are convinced that life exists in many places in the universe (it is hard to see how to avoid this conclusion), we have good reason to believe that everywhere we should find photobiology restricted to about the same range of wavelengths. What sets this range ultimately is not its availability, but its suitability to perform the tasks demanded of it. There cannot be a planet on which photosynthesis or vision occurs in the far infrared or far ultraviolet, because these radiations are not appropriate to perform these functions. It is not the range of available radiation that sets the photobiological domain, but rather the availability of the proper range of wavelengths that decides whether living organisms can develop and light can act upon them in useful ways.

We characterize light by its wave motion, identifying the regions of the spectrum by wavelength or frequency [*see illustration at top of pages 94 and 95*]. But in its interactions with matter—its absorption or emission by atoms and molecules—light also acts as though it were composed of small packets of energy called quanta or photons. These are in fact a class of ultimate particles, like protons and electrons, though they have no electric charge and very little mass. Each photon has the energy content: $E = hc/\lambda$, in which h is Planck's universal constant of action (1.58×10^{-34} calorie seconds), c is the velocity of light (3×10^{10} centimeters per second in empty space) and λ is the wavelength. Thus, while the intensity of light is the rate of delivery of photons, the work that a single photon can do (its energy content) is inversely proportional to its wavelength. With the change in the energy of photons, from one end of the electromagnetic spectrum to the other, their effects upon matter vary widely. For this reason photons of different wavelengths require different instruments to detect them, and the spectrum is divided arbitrarily on this basis into regions called by different names.

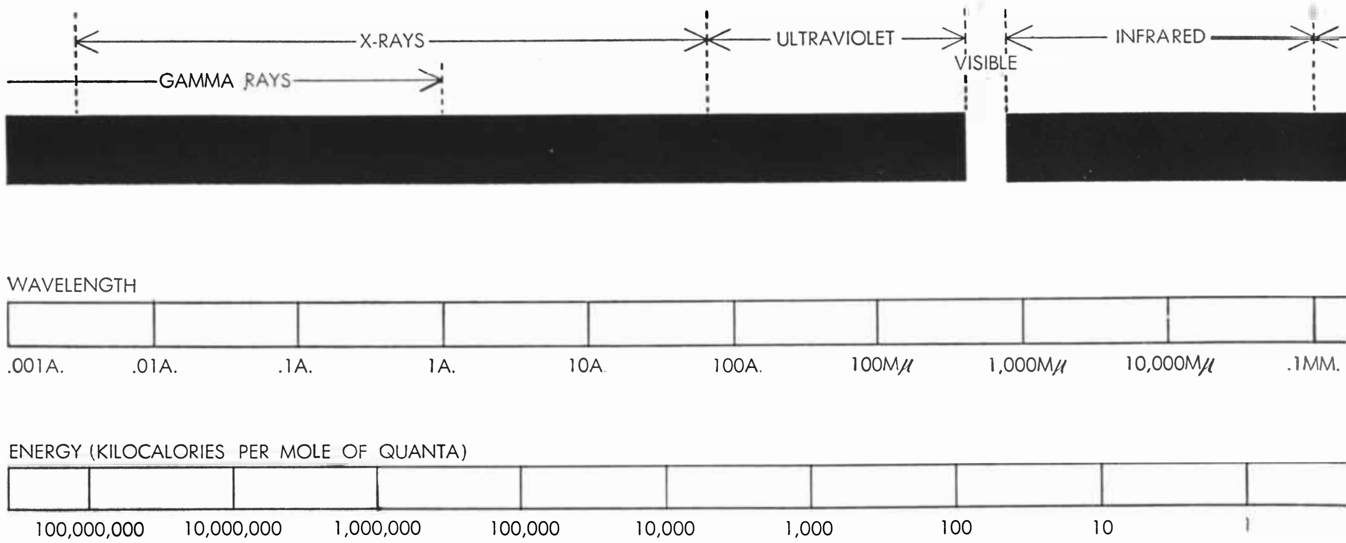
In the realm of chemistry the most useful unit for measuring the work that light can do is the "einstein," the energy content of one mole of quanta (7.02×10^{23} quanta). One molecule is excited to enter into a chemical reaction by absorbing one quantum of light; so one mole of molecules can be activated by absorbing one mole of quanta. The energy content of one einstein is equal to 2.854×10^7 gram calories, divided by the wavelength of the photon expressed in millimicrons. With this formula one can easily interconvert wavelength and energy content, and so assess the chemical effectiveness of electromagnetic radiations.

Energy enters chemical reactions in two separate ways: as energy of activation, exciting molecules to react; and as heat of reaction, the change in energy of the system resulting from the reaction. In a reacting system, at any moment, only the small fraction of "hot" molecules react that possess energies equal to or greater than a threshold value called the energy of activation. In ordinary chemical reactions this energy is acquired in collisions with other molecules. In a photochemical reaction the energy of activation is supplied by light. Whether light also does work on the reaction is an entirely separate issue. Sometimes, as in photosynthesis, it does so; at other times, as probably in vision, it seems to do little or no work.

Almost all ordinary ("dark") chemical



SPECTRUM OF SUNLIGHT at the earth's surface is narrowed by atmospheric absorption to the range of wavelengths (from 320 to 1,100 millimicrons) that are effective in photobiological processes. The sunlight reaching the domain of life in the sea is further narrowed by absorption in the sea water. The solid colored line locates the wavelengths of maximum intensity; the broken colored lines, the wavelength-boundaries within which 90 per cent of the solar energy is concentrated at each level in the atmosphere and ocean. The letters above the spectrum of wavelengths at bottom represent ultraviolet (UV), violet (V), blue (B), green (G), yellow (Y), orange (O), red (R) and infrared (IR). Other usages in the chart are explained in the illustration at top of next two pages.



ELECTROMAGNETIC SPECTRUM is divided by man into qualitatively different regions (*top bar*), although the only difference between one kind of radiation and another is difference in wavelength (*middle bar*). From gamma rays, measured here in angstrom units, or hundred millionths of centimeter (A.), through light waves, measured here in millimicrons, or ten millionths of a centi-

reactions involve energies of activation between 15 and 65 kilogram calories (kilocalories) per mole. This is equivalent energetically to radiation of wavelengths between 1,900 and 440 millimicrons. The energies required to break single covalent bonds—a process that, through forming free radicals, can be a potent means of chemical activation—almost all fall between 40 and 90 kilocalories per mole, corresponding to radiation of wavelengths 710 to 320 millimicrons. Finally, there is the excitation of valence electrons to higher orbital levels that activates the reactions classified under the heading of photochemistry; this ordinarily involves energies of about 20 to 100 kilocalories per mole, corresponding to the absorption of light of wavelengths 1,430 to 280 millimicrons. Thus, however one approaches the activation of molecules for chemical reactions, one enters into a range of wavelengths that coincides approximately with the photobiological domain.

Actually photobiology is confined within slightly narrower limits than photochemistry. Radiations below 300 millimicrons (95 kilocalories per mole) are incompatible with the orderly existence of such large, highly organized molecules as proteins and nucleic acids. Both types of molecule consist of long chains of units bound to one another by primary valences. Both types of molecule, however, are held in the delicate and specific configurations upon which their functions in the cell depend by the relatively weak forces of hydrogen-bonding and van der Waals attraction.

These forces, though individually weak, are cumulative. They hold a molecule together in a specific arrangement, like zippers. Radiation of wavelengths shorter than 300 millimicrons unzips them, opening up long sections of attachment, and permitting the orderly arrangement to become random and chaotic. Hence such radiations denature proteins and depolymerize nucleic acids, with disastrous consequences for the cell. For this reason about 300 millimicrons represents the lower limit of radiations capable of promoting photoreactions, yet compatible with life.

From this point of view we live upon a fortunate planet, because the radiation that is useful in promoting orderly chemical reactions comprises the great bulk of that of our sun. The commonly stated limit of human vision—400 to 700 millimicrons—already includes 41 per cent of the sun's radiant energy before it reaches our atmosphere, and 46 per cent of that arriving at the earth's surface. The entire photobiological range—300 to 1,100 millimicrons—includes about 75 per cent of the sun's radiant energy, and about 83 per cent of that reaching the earth.

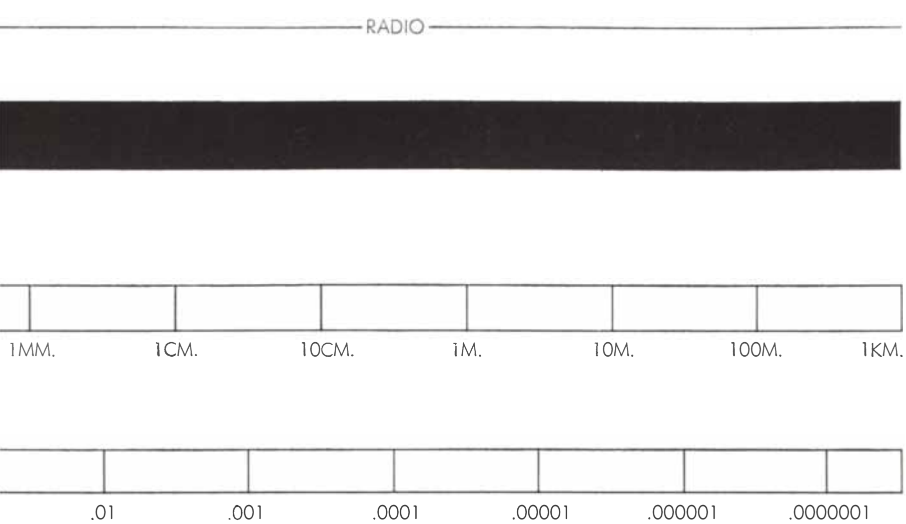
From about 320 to 1,100 millimicrons—virtually the photobiological range—the sun's radiation reaches us with little modification. The atmosphere directly above us causes an attenuation, mainly by scattering rather than absorption of light, which is negligible at 700 millimicrons and increases exponentially toward shorter wavelengths, so that at 400 millimicrons the radiation is reduced by about half. In the upper atmosphere, however, a layer of ozone, at a height of 22 to 25 kilometers, begins to absorb the sun's radiation strongly at 320 millimicrons, and at 290 millimicrons forms a virtually opaque screen. It is only the presence of this layer of ozone, removing short-wave antibiotic radiation, that makes terrestrial life possible.

At long wavelengths the absorption bands of water vapor cut strongly into the region of solar radiation from 720 to 2,300 millimicrons. Beyond 2,300 millimicrons the infrared radiation is absorbed almost completely by the water vapor, carbon dioxide and ozone of the atmosphere. The sun's radiation, therefore, which starts toward the earth in a band reaching from about 225 to 3,200 millimicrons, with its maximum at about 475 millimicrons, is narrowed by passing through the atmosphere to a range of about 310 to 2,300 millimicrons at the earth's surface.

The differential absorption of light by water confines more sharply the range of illumination that reaches living organisms in the oceans and in fresh water. The infrared is removed almost immediately in the surface layers. Cutting into the visible spectrum, water attenuates very rapidly in succession the red, orange, yellow and green. The short-wavelength limit is also gradually drawn in, so that the entire transmitted radiation is narrowed to a band centered at about 475 millimicrons, in the blue.

Photosynthesis

Each year the energy of sunlight, via the process of photosynthesis, fixes nearly 200 billion tons of carbon, taken up in

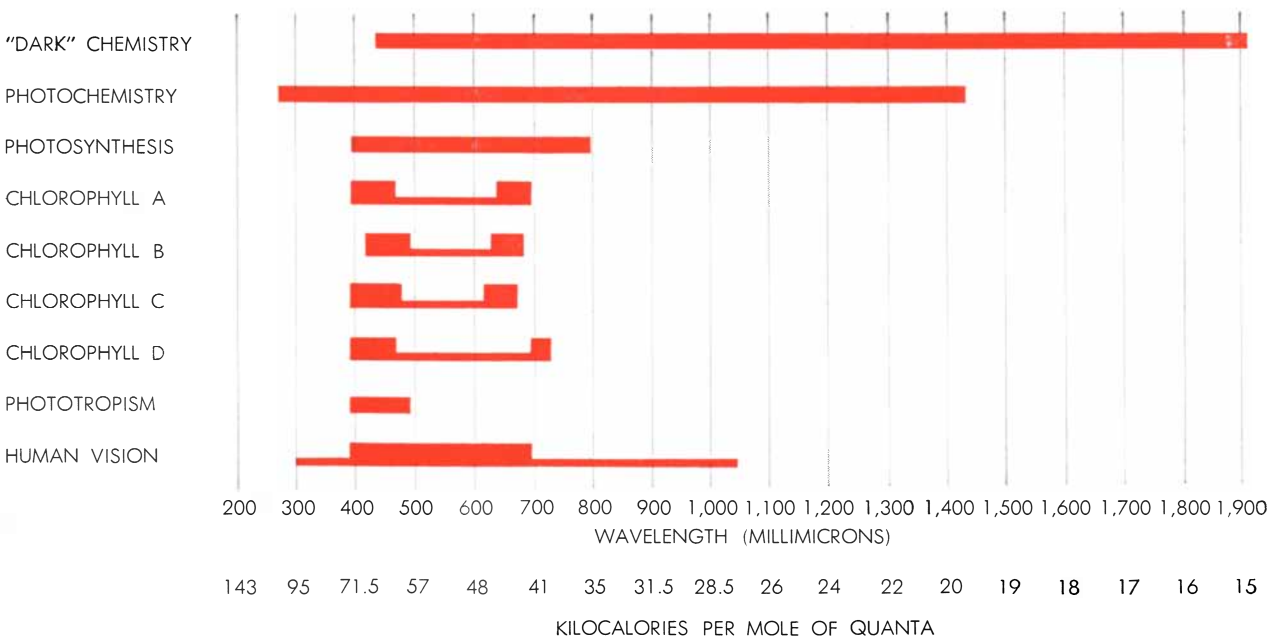


meter (Mμ), the waves range upward in length to the longest radio waves. The difference in wavelength is associated with a decisive difference in the energy conveyed by radiation at each wavelength. This energy content (*bottom bar*) is inversely proportional to wavelength.

the form of carbon dioxide, in more complex and useful organic molecules: about 20 billion tons on land and almost 10 times this quantity in the upper layers of the ocean. All the carbon dioxide in our atmosphere and all that is dissolved in the waters of the earth passes into this process, and is completely renewed by respiration and the decay of organic matter once every 300 years. All the oxygen in our atmosphere, having been bound by various oxidation processes, is renewed by photosynthesis once in about 2,000 years.

In the original accumulation of this capital of carbon dioxide and oxygen, early in the history of the earth, it is thought that the process of photosynthesis itself profoundly modified the character of the earth's atmosphere and furnished the essential conditions for the efflorescence and evolution of life. Some of the oldest rock formations have lately been discovered to contain recognizable vestiges of living organisms, including what appear to have been photosynthetic forms. So for example iron gunflint cherts found in southern Ontario contain microscopic fossils, among which appear to be colonial forms of blue-green algae. These deposits are estimated to be at least 1.5 billion years old, so that if this identification can be accepted, photosynthesis has existed at least that long on this planet.

It now seems possible that the original development of the use of light by organisms, through the agency of chlorophyll pigments, may have involved not primarily the synthesis of new organic matter, but rather the provision of stores of chemical energy for the cell. A few years ago the process called photosynthetic phosphorylation was discovered, and has since been intensively explored, mainly by Daniel I. Arnon of the University of California. By a still-unknown mechanism light forms the terminal high-energy phosphate bonds of adenosine triphosphate (ATP), which acts as a principal energy-carrier in the chemistry of the cell. One of the most interesting features of this process is that it is anaerobic; it neither requires nor produces oxygen. At a time when our atmosphere still lacked oxygen, this process could have become an efficient source of ATP. Among the many things ATP does in cells one of the most important is to supply the energy for or-



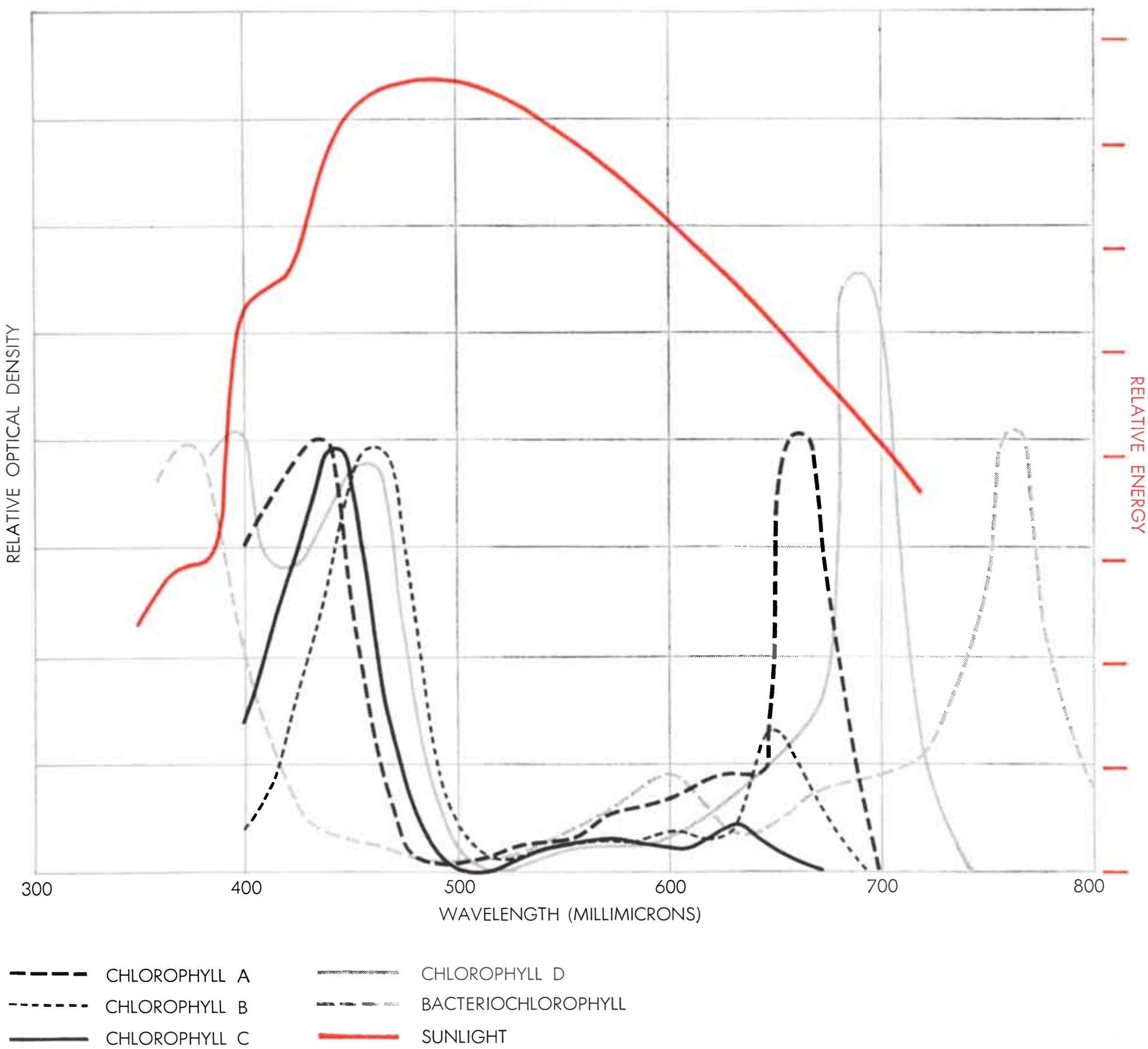
ENERGY CONTENT OF LIGHT is matched to the energy requirements of chemistry and photobiological processes and to the absorption spectra of photoreactive substances. The thicker segments of the bars opposite the chlorophylls indicate the regions of maximum absorption of light in each case, and the thicker segment in the bar opposite human vision indicates the normal boundaries.

ganic syntheses. This direct trading of the energy of sunlight for usable chemical energy in the form of ATP would therefore already have had as by-product the synthesis of organic structures. Mechanisms for performing such synthesis directly may have been a later development, leading to photosynthesis proper.

The essence of the photosynthetic process is the use of the energy of light to split water. The hydrogen from the water is used to reduce carbon dioxide or other organic molecules; and, in photosynthesis as performed by algae and higher plants, the oxygen is released into the atmosphere.

We owe our general view of photosynthesis in great part to the work of C. B. van Niel of the Hopkins Marine Station of Stanford University. Van Niel had examined the over-all reactions of photosynthesis in a variety of bacteria. Some of these organisms—green sulfur bacteria—require hydrogen sulfide to perform photosynthesis; van Niel discovered that in this case the net effect of photosynthesis is to split hydrogen sulfide, rendering the hydrogen available to reduce carbon dioxide to sugar, and liberating sulfur rather than oxygen. Still other bacteria—certain nonsulfur purple bacteria, for example—require organic substances in photosynthesis. Here van Niel found that the effect of photosynthesis is to split hydrogen from these organic molecules to reduce carbon dioxide, liberating in this case neither oxygen nor sulfur but more highly oxidized states of the organic molecules themselves. Finally there are forms of purple bacteria that use molecular hydrogen directly in photosynthesis to reduce carbon dioxide, and liberate no by-product.

The efficiency of photosynthesis in algae and higher green plants is extraordinarily high—just how high is a matter of continuing controversy. The work of reducing one mole of carbon dioxide to the level of carbohydrate is in the neighborhood of 120 kilocalories. This energy requirement, though the exact figure is approximate, cannot be evaded through any choice of mechanism. Thanks to the



ABSORPTION SPECTRA of various types of chlorophyll show the regions of the spectrum in which these substances absorb sunlight most effectively, measured on scale of relative optical density at left. Paradoxically the chlorophylls absorb best at the ends of the spectrum of sunlight, where energy, shown on scale at right, falls off steeply from the maximum around middle of the spectrum.

selective absorption of the green chlorophyll pigment, light is made available for this process in quanta whose energy content is 41 or 42 kilocalories per mole, corresponding to quanta of red light of wavelength about 680 millimicrons. It is apparent, therefore, that several such quanta are required to reduce one molecule of carbon dioxide. If the energy of light were used with perfect efficiency, three quanta might perhaps suffice.

About 35 years ago the great German biochemist Otto Warburg performed experiments which appeared to show that in fact about four quanta of light of any wavelength in the visible spectrum are enough to reduce a molecule of carbon dioxide to carbohydrate. This might have meant an efficiency of about 75 per cent. Later a variety of workers in this country and elsewhere insisted that when such experiments are performed more critically, from eight to 12 quanta are required per molecule of carbon dioxide reduced. This discrepancy led to one of the bitterest controversies in modern science.

Many of us have grown tired of this controversy, which long ago bogged down in technical details and fruitless recriminations. I think it significant, however, that a number of recent, non-Warburgian, investigations have reported quantum demands of about six, and in at least one case the reported demand was as low as five. These numbers represent very high efficiencies (50 to 60 per cent), though not quite as high as Warburg prefers to set them.

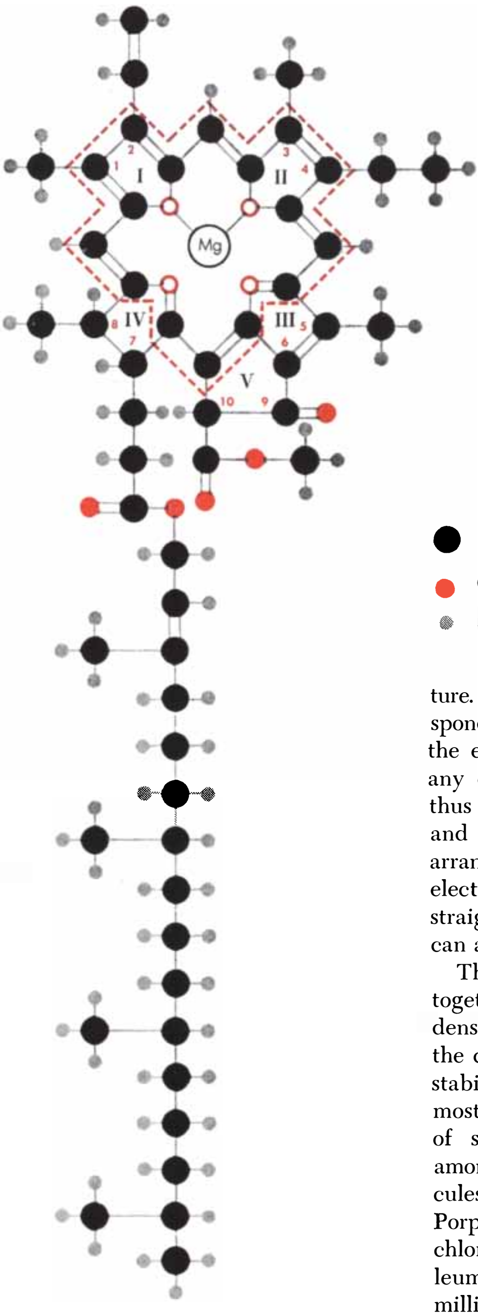
Investigators have now turned from the question of efficiency to a more fruitful study of the specific uses to which quanta are put in photosynthesis. This is yielding estimates of quantum demand related to specific mechanisms rather than to controversial details of experimentation.

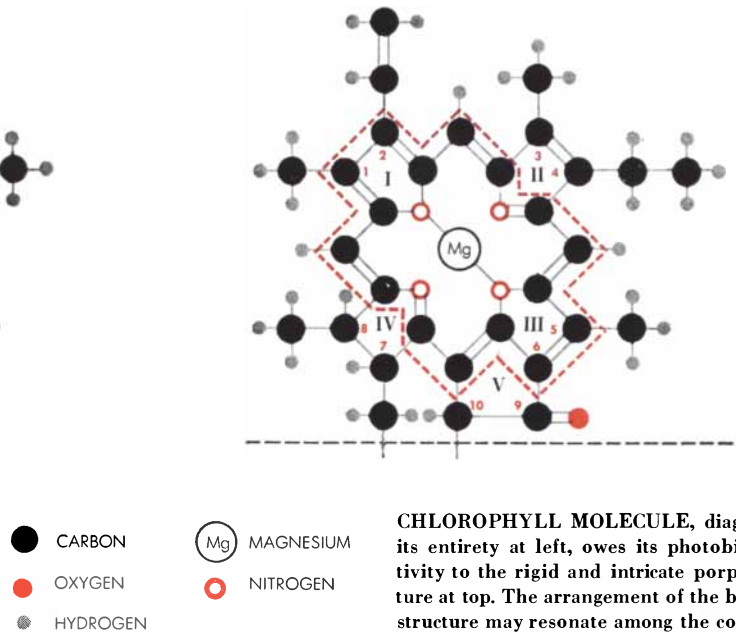
To reduce one molecule of carbon dioxide requires four hydrogen atoms and apparently three high-energy phosphate bonds of ATP. If we allow one quantum for each hydrogen atom (a point not universally conceded), that yields directly a quantum demand of four. If the ATP can be supplied in other ways, for example by respiration, four may be enough. If, however, light is needed also to supply ATP, by photosynthetic phosphorylation, then more quanta are needed; how many is not yet clear. Yet if one quantum were to generate one phosphate bond, the theoretical quantum-demand of photosynthesis, with all the energy supplied by light, would be four plus three, or seven. That would represent a high order of efficiency in the conversion of the energy of light to the energy of chemical bonds.

It is curious to put this almost obsessive concentration on the efficiency of photosynthesis together with what I think to be one of the most remarkable facts in all biology. Chlorophylls, the pigments universally used in photosynthesis, have absorption properties that seem just the opposite of what is wanted in a photosynthetic pigment. The energy of sunlight as it reaches the surface of the earth forms a broad maximum in the blue-green to green region of the spectrum, falling off at both shorter and longer wavelengths. Yet it is precisely in the blue-green and green, where the energy of sunlight is maximal, that the chlorophylls absorb light most poorly; this, indeed, is the reason for their green color. Where the absorption by chlorophyll is maximal—in widely separated bands in the violet and red—the energy of sunlight has fallen off considerably [*see illustration on opposite page*].

After perhaps two billion years of selection, involving a process whose efficiency is more important than that of any other process on earth, this seems an extraordinarily poor performance. It is a curious fact to put together with Warburg's comment (at one point in the quantum-demand controversy) that in a perfect nature, photosynthesis also is perfect. I think that the question it raises may be put more usefully as follows: What properties do the chlorophylls have that are so profoundly advantageous for photosynthesis as to override their disadvantageous absorption spectra?

We have the bare beginnings of an answer; it is emerging from a deeper understanding of the mechanism of photosynthesis, in particular as it is expressed in the structure and function of chlorophyll itself. Chlorophyll *a*, the type of chlorophyll principally involved in the photosynthesis of algae and higher plants, owes its color, that is, its capacity for absorbing light, to the possession of a long, regular alternation of single and double bonds, the type of arrangement called a conjugated system [*see illustration on next two pages*]. All pigments, natural and synthetic, possess such conjugated systems of alternate single and double bonds. The property of such systems that lends them color is the possession of particularly mobile electrons, called pi electrons, which are associated not with single atoms or bonds but with the conjugated system as a whole. It requires relatively little energy to raise a





CHLOROPHYLL MOLECULE, diagrammed in its entirety at left, owes its photobiological activity to the rigid and intricate porphyrin structure at top. The arrangement of the bonds in this structure may resonate among the configurations

pi electron to a higher level. This small energy-requirement corresponds with the absorption of radiation of relatively long wavelengths, that is, radiation in the visible spectrum; and also with a high probability, and hence a strong intensity, of absorption.

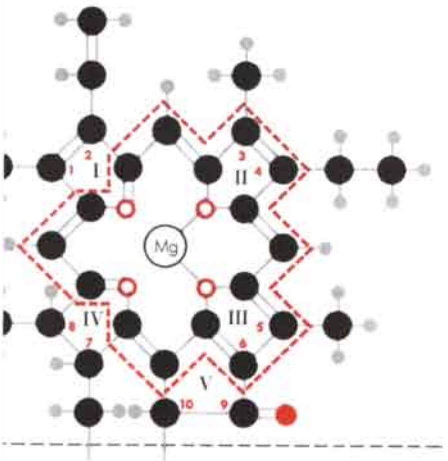
In chlorophyll this conjugated system is turned around upon itself to form a ring of rings, a so-called porphyrin nucleus, and this I think is of extraordinary significance. On the one hand, as the illustration on these two pages shows, it makes possible a large number of rearrangements of the pattern of conjugated single and double bonds in the ring structure. Each such arrangement corresponds to a different way of arranging the external electrons, without moving any of the atoms. The molecule may thus be conceived to resonate among and be a hybrid of all these possible arrangements. In such a structure the pi electrons can not only oscillate, as in a straight-chain conjugated system; they can also circulate.

The many possibilities of resonance, together with the high degree of condensation of the molecule in rings, give the chlorophylls a peculiar rigidity and stability which I think are among the most important features of this type of structure. Indeed, porphyrins are among the most inert and stable molecules in the whole of organic chemistry. Porphyrins, apparently derived from chlorophyll, have been found in petroleum, oil shales and soft coals some 400 million years old.

This directs our attention to special features of chlorophyll, which are directly related to its functions in photosynthesis. One such property is not to utilize the energy it absorbs immediately in reaction, but to trap it for a time, and pass it on intact to other, neighboring chlorophyll molecules. It has been shown that chlorophyll forms a long-lived metastable state, which, upon absorption of a quantum of light, retains a large part of the energy for a half-life of the order of five ten-thousandths of a second, perhaps 1,000 times longer than might otherwise be the case. In the structure of the chloroplasts, the functional assemblages of chlorophyll molecules in the cell, the chlorophyll molecules are in position to transfer energy from one to another, by a radiationless transfer akin to the way electrical energy is transferred in an induction motor. This capacity for transferring the energy about, so that it virtually belongs to a region of the chloroplast rather than to the specific molecule of chlorophyll that first absorbed it, makes possible the high efficiency of photosynthesis. While photosynthesis is proceeding rapidly, many chlorophyll molecules, having just reacted, are still in position to absorb light, but not to utilize it. In this way large amounts of absorbed energy that would otherwise be degraded into heat are retained and passed about intact until used photosynthetically.

One sign of the capacity to retain the energy absorbed as light and pass it on relatively intact is the strong fluorescence exhibited by chlorophyll. This green or blue-green pigment fluoresces red light; and however short the wavelengths that are absorbed—that is, however large the quanta—the same red light is fluoresced, corresponding to quanta of energy content about 40 kilocalories per mole. This is the quantity of energy that is passed from molecule to molecule in the chloroplast and eventually made available for photosynthesis.

The generally inert structure of chlorophyll must somewhere contain a chemically reactive site. Such a site seems to exist in the five-membered carbon ring, usually designated ring V in the structural diagrams. James Franck of the University of Chicago some years ago called attention to the possibility that it is here that the reactivity of chlorophyll



diagrammed in the middle and at the right. These and other possible configurations of the bonds help to make it possible for the chlorophyll molecule to trap and store energy which is conveyed to it by light quanta.

is localized. Recent experiments by Wolf Vishniac and I. A. Rose of Yale University, employing the radioactive isotope of hydrogen (tritium), have shown that chlorophyll, both in the cell and in solution, can take up hydrogen in the light though not in the dark, and can transfer it to the coenzyme triphosphopyridine nucleotide, which appears to be principally responsible for transferring hydrogen in photosynthesis. There is some evidence to support Franck's suggestion that the portion of chlorophyll involved in these processes is the five-membered ring.

Chlorophyll thus possesses a triple combination of capacities: a high receptivity to light, an inertness of structure permitting it to store the energy and relay it to other molecules, and a reactive site equipping it to transfer hydrogen in the critical reaction that ultimately binds hydrogen to carbon in the reduction of carbon dioxide. I would suppose that these properties singled out the chlorophylls for use by organisms in photosynthesis in spite of their disadvantageous absorption spectrum.

Photosynthetic organisms cope with the deficiencies of chlorophyll in a variety of ways. In 1883 the German physiologist T. W. Engelmann pointed out that in the various types of algae other pigments must also function in photosynthesis. Among these are the carotenoid pigments in the green and brown algae, and the phycobilins, phycocyanin and phycoerythrin (related to the animal bile-pigments) in the red and blue-green algae. Engelmann showed that each type of alga photosynthesizes best in light of the complementary color: green algae in red light, brown algae in green light, red algae in blue light. He pointed out that this is probably the basis of the layering of these types of algae at various depths in the ocean.

All these pigments act, however, by transferring the energy they absorb to one another and eventually to chlorophyll *a;* whatever pigments have absorbed the light, the same red fluorescence of chlorophyll *a* results, with its maximum at about 670 to 690 millimicrons. The end result is therefore always the same: a quantum with an energy content of about 40 kilocalories per mole is made available to chlorophyll *a* for photosynthesis. The accessory pigments, including other varieties of chlorophyll, perform the important function of filling in the hole in the absorption spectrum of chlorophyll.

Still another device helps to compensate for the failure of chlorophyll to absorb green and blue-green light efficiently: On land and in the sea the concentration of chlorophyll and the depth of the absorbing layer are maximized by plant life. As a result chlorophyll absorbs considerable energy even in the wavelengths at which its absorption is weakest. Leaves absorb green light poorly, yet they do absorb a fraction of it. One need only look up from under a tree to see that the cover of superimposed leaves permits virtually no light to get through, green or otherwise. The lower leaves on a tree, though plentifully supplied with chloroplasts, may receive too little light to contribute significantly to photosynthesis. By being so profligate with the chlorophylls, plants compensate in large part for the intrinsic absorption deficiencies of this pigment.

Phototropism

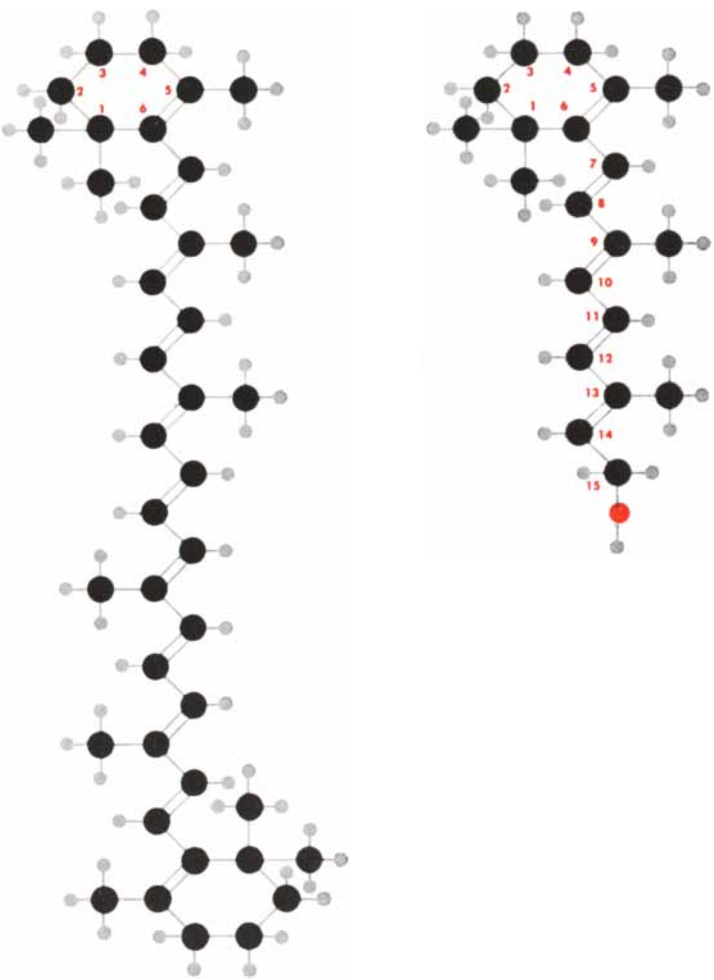
The phototropism of plants—their tendency to bend toward the light—is excited by a different region of the spectrum from that involved in photosynthesis. The red wavelengths, which are most effective in photosynthesis, are wholly ineffective in phototropism, which depends upon the violet, blue and green regions of the spectrum. This relationship was first demonstrated early in the 19th century by a worker who reported that when he placed a flask of port wine between a growing plant and the light from a window, the plant grew about as well as before, but no longer bent toward the light. Recently, more precise measurements with monochromatic lights have shown that the phototropism of both molds and higher plants is stimulated only by light of wavelengths shorter than approximately 550 millimicrons, lying almost completely within the blue-green, blue and violet regions of the spectrum.

Phototropism must therefore depend on yellow pigments, because only such pigments absorb exclusively the short wavelengths of the visible spectrum. All types of plant that exhibit phototropism appear to contain such yellow pigments, in the carotenoids. In certain instances the carotenoids are localized specifically in the region of the plant that is phototropically sensitive. The most careful measurements of the effectiveness of various wavelengths of light in stimulating phototropism in molds and higher plants have yielded action spectra which resemble closely the absorption spectra of the carotenoids that are present.

A number of lower invertebrates—for example, hydroids, marine organisms that are attached to the bottom by stalks—bend toward the light by differential growth, just as do plants. The range of wavelengths which stimulate this response is also about the same as that in plants. It appears that here also carotenoids, which are usually present in considerable amount, may be the excitatory agents. Phototactic responses, involving motion of the whole animal toward or away from the light, also abound throughout all groups of invertebrates. Unfortunately no one has yet correlated accurately the action spectra for such responses with the absorption spectra of the pigments that are present, so that no rigorous identification of the excitatory pigments can be made at present. This is a field awaiting investigation.

Vision

Only three of the 11 major phyla of animals have developed well-formed, image-resolving eyes: the arthropods (insects, crabs, spiders), mollusks (octopus, squid) and vertebrates. These



CAROTENE MOLECULE (*left*) **is probable light-receptor in phototropism and is synthesized by plants. In structure it is a double vitamin A molecule** (*right*)**. Vitamin A, in turn, is precursor of retinene molecule** (*see illustration on page 102*)**, which mediates vision.**

three types of eye are entirely independent developments. There is no connection among them, anatomical, embryological or evolutionary. This is an important realization, for it means that three times, in complete independence of one another, animals on this planet have developed image-forming eyes.

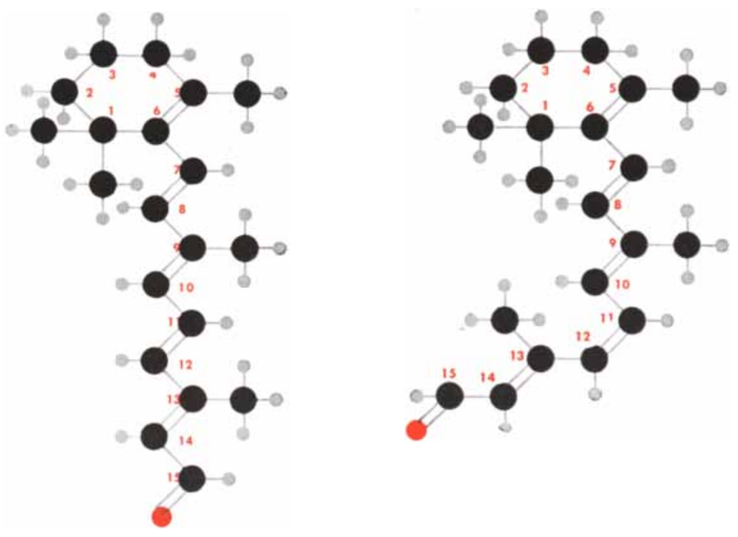
It is all the more remarkable for this reason that in all three types of eye the chemistry of the visual process is very nearly the same. In all cases the pigments which absorb the light that stimulates vision are made of vitamin A, in the form of its aldehyde, retinene, joined with specific retinal proteins called opsins. Vitamin A ($C_{20}H_{29}OH$) has the structure of half a beta-carotene ($C_{40}H_{56}$), with a hydrogen and a hydroxyl radical (OH) added at the broken double bond.

Thus animal vision not only employs substances of the same nature as the carotenoids involved in phototropism of plants; there is also a genetic connection. Animals cannot make vitamin A *de novo*, but derive it from the plant carotenoids consumed in their diet. All photoreception, from phototropism in lower and higher plants to human vision, thus appears to depend for its light-sensitive pigments upon the carotenoids.

The role of light in vision is fundamentally different from its role in photosynthesis. The point of photosynthesis is to use light to perform chemical work, and the more efficiently this conversion is accomplished, the better the process serves its purpose. The point of vision is excitation; there is no evidence that the light also does work. The nervous structures upon which the light acts, so far as we know, are ready to discharge, having been charged through energy supplied by internal chemical reactions. Light is required only to trigger their responses.

Because this distinction is not always understood, attempts are frequently made to force parallels between vision and photosynthesis. In fact, these processes differ so greatly in their essential natures that no deep parallelism can be expected. The problem of quantum demand, for example, raises entirely different issues in vision as compared with photosynthesis. In photosynthesis one is interested in the minimum number of quanta needed to perform a given chemical task. In vision the problem hinges not on energetic efficiency but on differential sensitivity. The light intensities within which animals must see range from starlight to noonday sunlight; the latter is about a billion times brighter than the former. It is this enormous range of intensities that presents organisms with their fundamental visual problem: how to see at the lowest intensities without having vision obliterated by glare at the highest.

In the wholly dark-adapted state a vertebrate rod, the receptor principally involved in night vision, can respond to the absorption of a single quantum of visible light. To be sure, in the human eye, in which this relationship has been studied most completely, this minimal response of a single rod does not produce a visual sensation. In the dark-adapted state, seeing requires that at least five such events occur almost simultaneously within a small area of retina. This arrangement is probably designed to place the visual response above the "noise level" of the retina. From careful electrophysiological measurements it seems that a retina, even in total darkness, transmits a constant barrage of randomly scattered spontaneous responses to the brain. If the response of a single rod entered consciousness, we should be seeing random points of light flickering over the retina at all times.



RETINENE MOLECULE is the active agent in the pigments of vision. Upon absorbing energy of light the geometry of the molecule changes from the so-called *trans* arrangement at left to the *cis* arrangement at right. This change in structure triggers process of vision.

The eye's extraordinary sensitivity to light is lost as the brightness of the illumination is increased. The threshold of human vision, which begins at the level of a few quanta in the dark-adapted state, rises as the brightness of the light increases until in bright daylight one million times more light may be needed just to stimulate the eye. But the very low quantum-efficiency in the light-adapted condition nonetheless represents a high visual efficiency.

The statement that the limits of human vision are 380 and 760 millimicrons is actually quite arbitrary. These limits are the wavelengths at which the visual sensitivity has fallen to about a thousandth of its maximum value. Specific investigations have pursued human vision to about 312 millimicrons in the near ultraviolet, and to about 1,050 in the near infrared.

In order to see at 1,050 millimicrons, however, 10,000 million times more light energy is required if cones are being stimulated, and over a million million times more energy if rods are being stimulated. This result came out of measurements made in our laboratory at Harvard University during World War II in association with Donald R. Griffin and Ruth Hubbard. As we exposed our eyes to flashes of light in the neighborhood of 1,000 millimicrons, we could not only see the flash but feel a momentary flush of heat on the cornea of the eye. At about 1,150 millimicrons, just a little farther into the infrared than our experiments had taken us, the radiation should have become a better stimulus as heat than as light.

The ultraviolet boundary of human vision, as that of many other vertebrates, raises a special problem. Ordinarily our vision is excluded from the ultraviolet, not primarily because the retina or its visual pigments are insensitive to that portion of the spectrum, but because ultraviolet light is absorbed by the lens of the eye. The human lens is yellow in color and grows more deeply yellow with age. One curious consequence of this arrangement is that persons who have had their lenses removed in the operation for cataract have excellent ultraviolet vision.

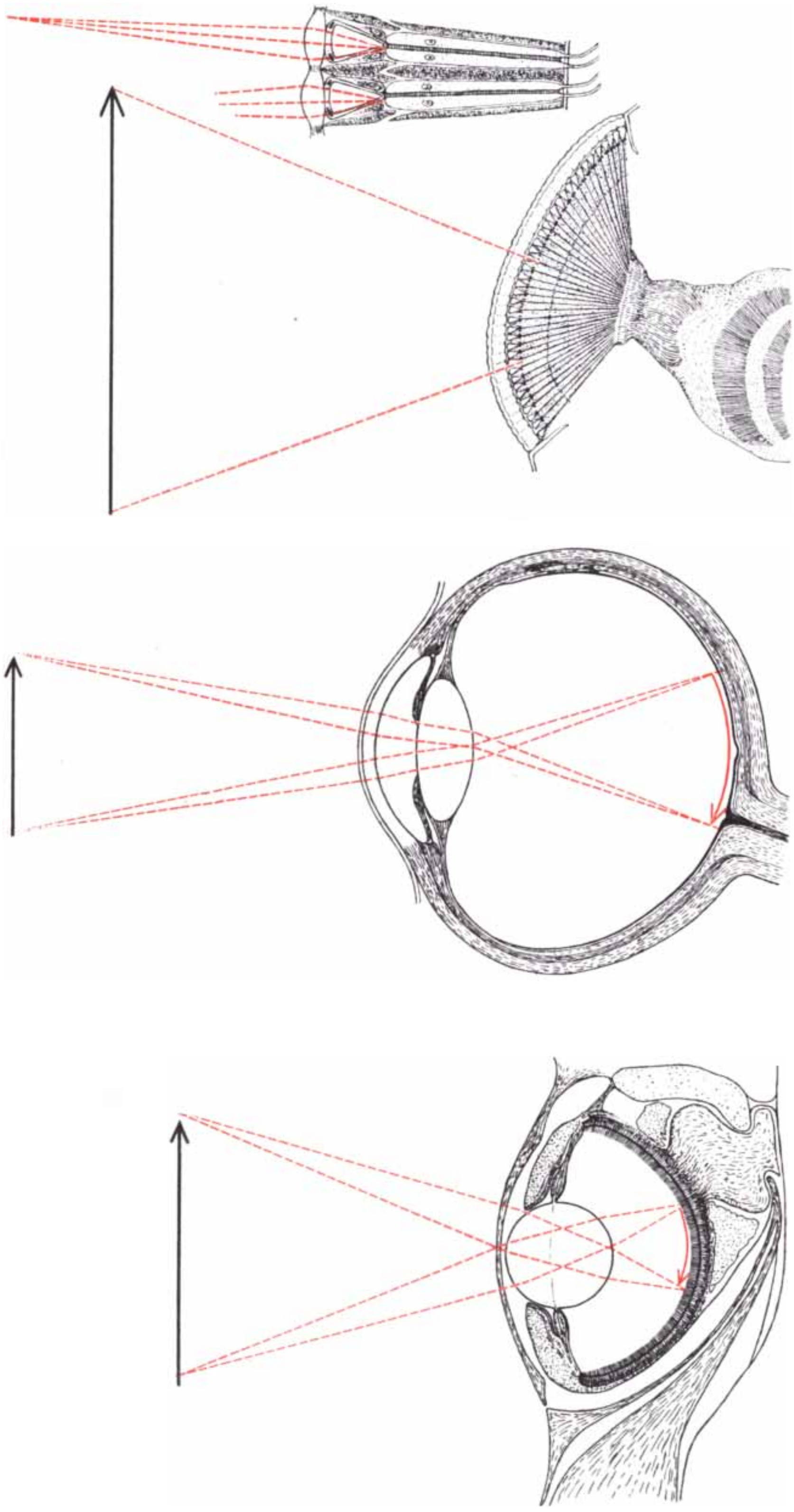
One may wonder how it comes about that man and many other vertebrates have been excluded from ultraviolet vision by the yellowness of their lenses. Actually this effect is probably of real advantage. All lens systems made of one material refract shorter wavelengths more strongly than longer wavelengths, and so bring blue light to a shorter focus than red. This phenomenon is known as chromatic aberration, or color error, and even the cheapest cameras are corrected for it. In default of color correction the lens seems to do the next best thing; it eliminates the short wavelengths of the spectrum for which the color error is greatest.

One group of animals, however, makes important use of the ultraviolet in vision. These are the insects. The insect eye is composed of a large number of independent units, the ommatidia, each of which records a point in the object, so that the image as a whole is composed as a mosaic of such points. Projection by a lens plays no part in this system, and chromatic aberration is of no account.

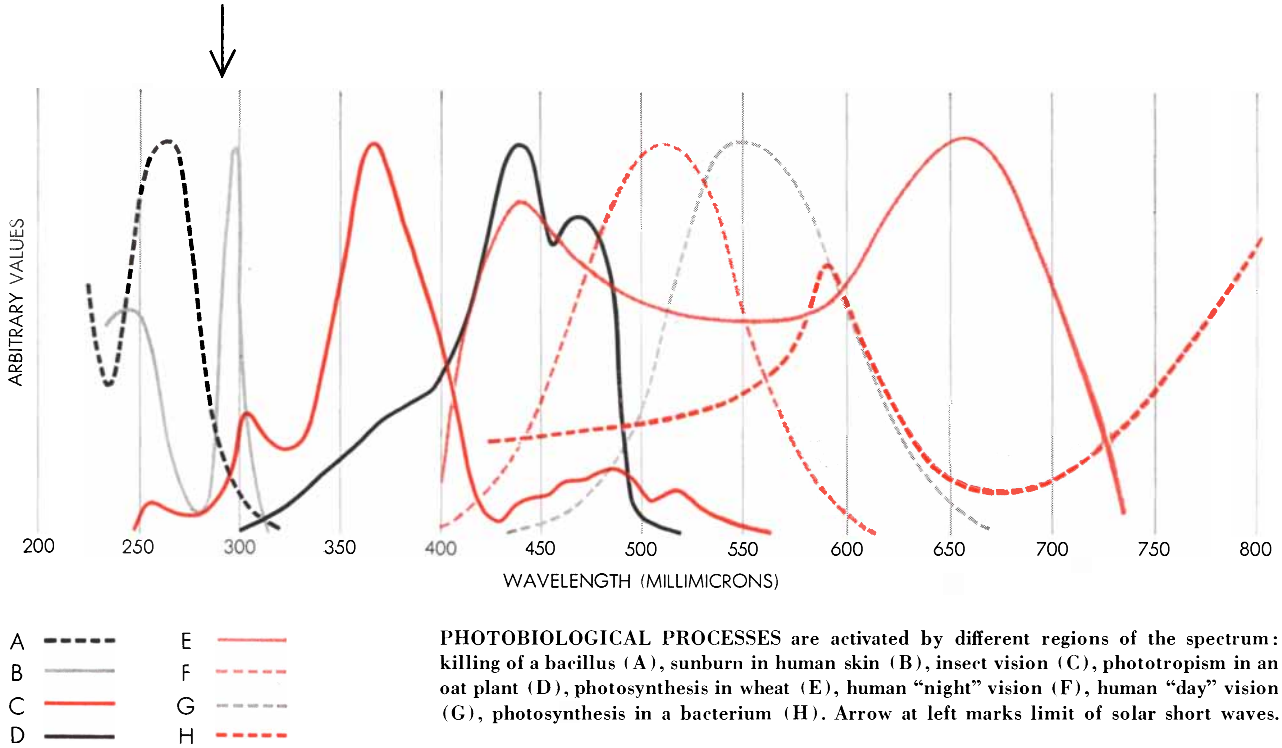
How does it happen that whenever vision has developed on our planet, it has come to the same group of molecules, the A vitamins, to make its light-sensitive pigments? I think that one can include plant phototropism in the same question, and ask how it comes about that all photoreception, animal and plant, employs carotenoids to mediate excitation by light. We have already asked a similar question concerning the chlorophylls and photosynthesis; and what chlorophylls are to photosynthesis, carotenoids are to photoreception.

Both the carotenoids and chlorophylls owe their color to the possession of conjugated systems. In the chlorophylls these are condensed in rings; in the carotenoids they are mainly in straight chains. The chlorophylls fluoresce strongly; the carotenoids, weakly or not at all. Much of the effectiveness of the chlorophylls in photosynthesis is associated with a high capacity for energy transfer; there is as yet no evidence that such energy transfer has a place in vision.

I think that the key to the special position of the carotenoids in photoreception lies in their capacity to change their shapes profoundly on exposure to light. They do this by the process known as *cis-trans* isomerization. Whenever two carbon atoms in a molecule are joined by a single bond, they can rotate more or



EYES of three kinds have evolved quite independently in three phyla: insects (*top*), vertebrates (*center*) and mollusks (*bottom*). In all three types of eye, however, the chemistry of vision is mediated by retinene derived from the carotenoids synthesized by plants.



PHOTOBIOLOGICAL PROCESSES are activated by different regions of the spectrum: killing of a bacillus (A), sunburn in human skin (B), insect vision (C), phototropism in an oat plant (D), photosynthesis in wheat (E), human "night" vision (F), human "day" vision (G), photosynthesis in a bacterium (H). Arrow at left marks limit of solar short waves.

less freely about this bond, and take all positions with respect to each other. When, however, two carbon atoms are joined by a double bond, this fixes their position with respect to each other. If now another carbon atom is joined to each of this pair, both the new atoms may attach on the same side of the double bond (the *cis* position) or on opposite sides, diagonally (the *trans* position). These are two different structures, each of them stable until activated to undergo transformation—isomerization—into the other.

Carotenoids, possessing as they do long straight chains of conjugated double bonds, can exist in a great variety of such *cis-trans* or geometrical isomers. No other natural pigments approach them in this regard. Porphyrins and other natural pigments may have as many or more double bonds, but are held in a rigid geometry by being bound in rings.

Cis-trans isomerization involves changes in shape. The all-*trans* molecule is relatively straight, whereas a *cis* linkage at any point in the chain represents a bend. In the composition of living organisms, which depends in large part on the capacity of molecules to fit one another, shape is all-important.

We have learned recently that all the visual pigments known, in both vertebrate and invertebrate eyes, are made with a specifically bent and twisted isomer of retinene. Only this isomer will do because it alone fits the point of attachment on the protein opsin. The intimate union thus made possible between the normally yellow retinene and opsin greatly enhances the color of the retinene, yielding the deep-orange to violet colors of the visual pigments. The only action of light upon a visual pigment is to isomerize—to straighten out—retinene to the all-*trans* configuration. Now it no longer fits opsin, and hence comes away. The deep color of the visual pigment is replaced by the light yellow color of free retinene. This is what is meant by the bleaching of visual pigments by light.

In this succession of processes, however, it is some process associated with the *cis-trans* isomerization that excites vision. The subsequent cleavage of retinene from opsin is much too slow to be responsible for the sensory response. Indeed, in many animals the visual pigments appear hardly to bleach at all. This seems to be the case in all the invertebrate eyes yet examined, in which the entire transformation in light and darkness appears to be restricted to the isomerization of retinene. It seems possible that similar *cis-trans* isomerizations of carotenoid pigments underlie phototropic excitation in plants. Experiments are now in progress in our laboratory to explore this possibility.

Bioluminescence

In addition to responding to light in their various ways, many bacteria, invertebrates and fishes also produce light. All bioluminescent reactions require molecular oxygen; combustions of one kind or another supply the energy that is emitted as light. In photosynthesis light performs organic reductions, releasing oxygen in the process. In bioluminescence the oxidation of organic molecules with molecular oxygen emits light. I used to think that bioluminescence is like vision in reverse; but in fact it is more nearly like photosynthesis in reverse.

What function bioluminescence fulfills in the lives of some of the animals that display it is not yet clear. The flashing of fireflies may act as a signal for integrating their activities, and perhaps as a sexual excitant. What role may be fulfilled by the extraordinary display of red, green and yellow illumination in a railroad worm is altogether conjectural. There is one major situation, however, in which bioluminescence must play an exceedingly important role. This is in the sea, at depths lower than those reached by surface light, and at night at all depths. It would be difficult otherwise to understand how fishes taken from great depths, far below those to which light from the surface can penetrate, frequently have very large eyes. For vision at night or at great depths, it is not necessary that the organisms and objects that are visible themselves be bioluminescent. Bioluminescent bacteria abound in the ocean, and many submerged objects are coated sufficiently with luminous bac-

teria to be visible to the sensitive eye.

It has lately been discovered that the rod vision of deep-sea fishes is adapted to the wavelengths of surface light that penetrate most deeply into the water: the blue light centered around 475 millimicrons. Furthermore, sensitive new devices for measuring underwater illumination have begun to reveal the remarkable fact that deep-sea bioluminescence may also be most intense at about 475 millimicrons. The same selection of visual pigments that best equips deep-sea fishes to see by light penetrating from the surface seems best adapted to the bioluminescent radiation.

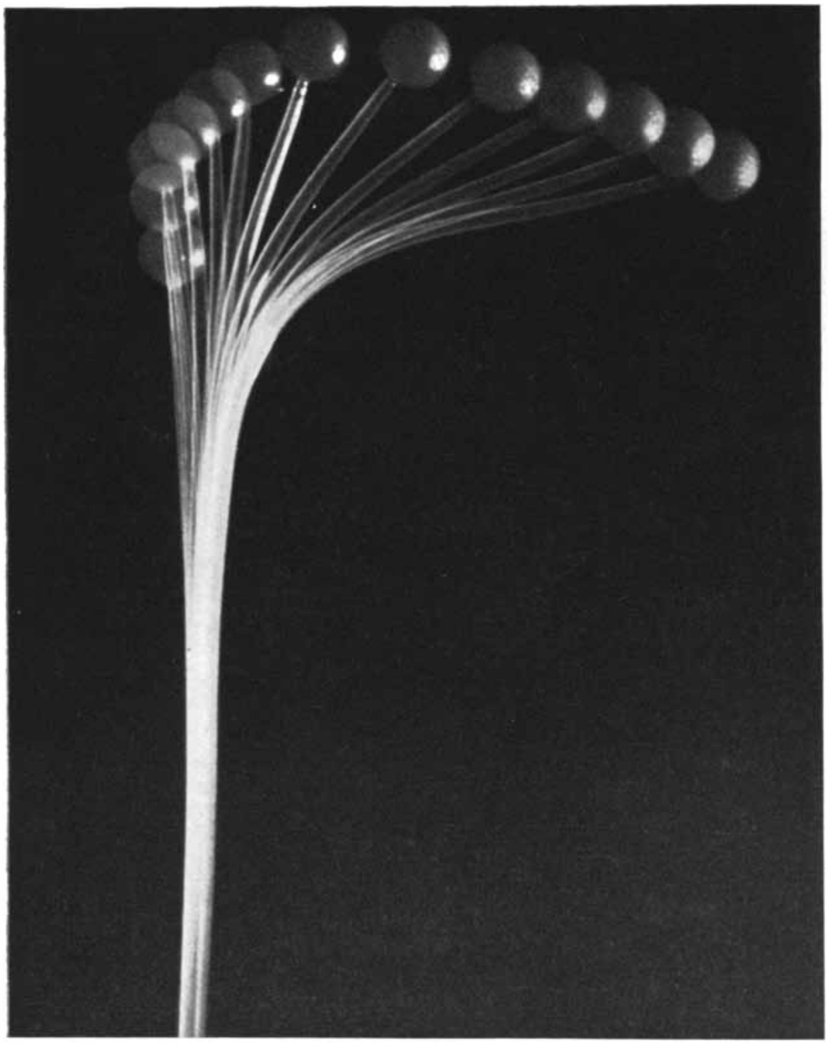
Just as light quanta must be of a certain size to activate or provide the energy for useful chemical reactions, so chemical reactions emit light in the same range of wavelengths. It is for this reason, and no accident, that the range of bioluminescent radiations coincides well with the range of vision and other photobiological processes.

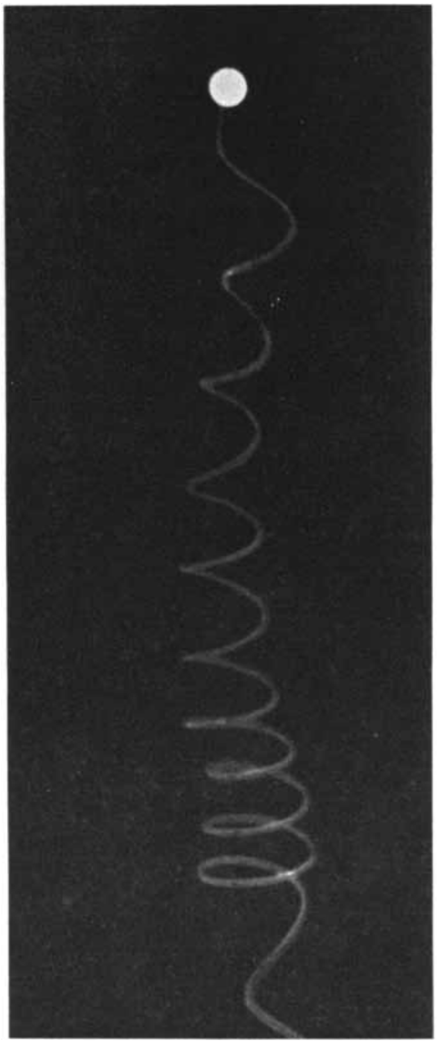
Light and Evolution

The relationship between light and life is in one important sense reciprocal. Over the ages in which sunlight has activated the processes of life, living organisms have modified the terrestrial environment to select those wavelengths of sunlight that are most compatible with those processes. Before life arose, much more of the radiation of the sun reached the surface of the earth than now. We believe this to have been because the atmosphere at that time contained very little oxygen (hence negligible amounts of ozone) and probably very little carbon dioxide. Very much more of the sun's infrared and hard ultraviolet radiation must have reached the surface of the earth then than now.

Some of the short-wave radiation, operating in lower reaches of the atmosphere and also probably in the surface layers of the seas, must have been important in activating the synthesis and interactions of organic molecules which formed the prelude to the eventual emergence of the first living organisms. These organisms, coming into an anaerobic world, surrounded by the organic matter that had accumulated over the previous ages, must have lived by fermentation, and in this process must have produced as a by-product very large quantities of carbon dioxide. Part of this remained dissolved in the oceans; part entered the atmosphere.

Eventually the availability of large amounts of carbon dioxide, much larger than are in the atmosphere today, made





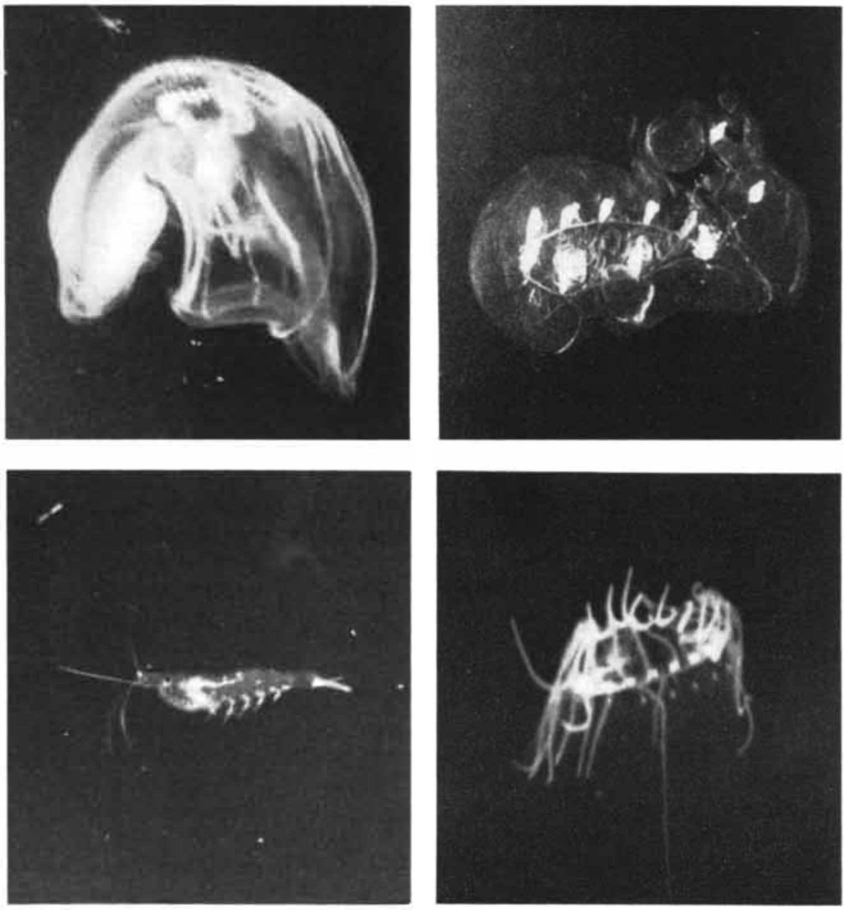
PHOTOTROPISM in the fruiting body of the mold *Phycomyces* is demonstrated in these photographs from the laboratory of Max Delbrück at the California Institute of Technology. The multiple photograph at left, with exposures made at intervals of five minutes, shows the fruiting body growing toward the light source. In the photograph at right, the stalk of the fruiting body has been made to grow in an ascending spiral by placing it on a turntable which revolved once every two hours in the presence of a fixed light-source.

possible the development of the process of photosynthesis. This began to remove carbon dioxide from the atmosphere, fixing it in organic form. Simultaneously, through the most prevalent and familiar form of photosynthesis, it began to produce oxygen, and in this way oxygen first became established in our atmosphere. As oxygen accumulated, the layer of ozone that formed high in the atmosphere—itself a photochemical process—prevented the short-wavelength radiation from the sun from reaching the surface of the earth. This relief from antibiotic radiation permitted living organisms to emerge from the water onto the land.

The presence of oxygen also led to the development of the process of cellular respiration, which involves gas exchanges just the reverse of those of photosynthesis. Eventually respiration and photosynthesis came into approximate balance, as they must have been for some ages past.

One may wonder how much of this history could have occurred in darkness, by which I mean not merely the absence of external radiation but a much more specific thing: the absence of radiation in the range between 300 and 1,100 millimicrons. A planet without this range of radiation would virtually lack photochemistry. It would have a relatively inert surface, upon which organic molecules could accumulate only exceedingly slowly. Granted even enough time for such accumulation, and granted that eventually primitive living organisms might form, what then? They could live for a time on the accumulated organic matter. But without the possibility of photosynthesis how could they ever become independent of this geological heritage and fend for themselves? Inevitably they must eventually consume the organic molecules about them, and with that life must come to an end.

It may form an interesting intellectual exercise to imagine ways in which life might arise, and having arisen might maintain itself, on a dark planet; but I doubt very much that this has ever happened, or that it can happen.



BIOLUMINESCENT CREATURES of the ocean were made to take these photographs of themselves by means of a camera designed by Harold E. Edgerton of Massachusetts Institute of Technology and L. R. Breslau of the Woods Hole Oceanographic Institution. The feeble luminescence of the animals was harnessed to trigger a high-speed electronic flash.


COMBINING ADVANCED TECHNOLOGIES

DETECTION, TRACKING, ACQUISITION AND FIRE CONTROL

The General Precision companies are applying a broad knowledge of radar, including airborne Doppler techniques, to development of new systems for target detection and acquisition, missile velocity measurement and fire control.

Servo components, microwave components and stable platforms for these systems are designed and manufactured within the group.

This work has led to research in related areas such as high resolution radar and advanced infrared techniques.

An optical tracking device developed and manufactured within the group is being used in a series of space explorations to photograph planets for the first time from outside the earth's atmosphere. This balloon-borne Star Tracker device locks a larger telescope onto its target and enables it to hold the planet's image within one second of arc. A study program on a stellar comparator is also underway.

A large part of the fire control equipment for advanced U.S. Navy surface and subsurface antisubmarine warfare programs is being developed and produced within the group.

SIMULATION, TEST AND GROUND SUPPORT

Training equipment for virtually every type of fighter and bomber in the armed forces is produced in the group.

Progress in human engineering techniques is resulting also in development of simulators designed around sophisticated man-machine concepts—simulators for missile training and for duplication of space flight conditions and submarine operations.

In the field of go-no-go missile test equipment, systems-oriented equipment has been developed which has built-in "reasoning" processes and is capable of reacting to given stimuli.

For example, these systems automatically and continuously test products, systems and components, retaining each test result and rejecting or approving according to pre-programmed standards. Research is being done on "intelligent" machines which one day could devise and build other machines and perform other complex functions, using learning and adaptive processes similar to those of man.

Group technologies have been combined to produce complete ground support checkout equipment including analog, analog-digital hybrid systems, fully digital checkout and programming techniques and automatic electronic components inspection. Another capability is an electronic system called TRACER* for accurate control and unique identification of mobile units and personnel.

General Precision television equipment is in use for remote observation of jet and rocket engines, missile and weapon firings and nuclear reactor operations, for underwater surveillance and visual systems in jet aircraft simulators.

*TRADEMARK

MANUFACTURING SKILLS IN DYNAMICS

Manufacturing military products today depends not only on precision mechanics but also upon scientific application of skills in dynamics—the use of dynamic forces to measure the extreme tolerances required for component and system work.

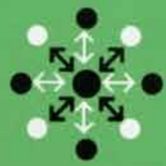
Specially designed equipment is used for this purpose in the General Precision companies. One example: a FRINGE-COUNT* Micrometer, which provides measurements to a millionth of an inch using the wavelength of light as its standard.

Manufacturing with electrons and protons as basic cutting tools, or in controlled quantities as building blocks, is already well advanced in the group. Thin film technology—the deposition of thin films of various materials measured in angstroms—is being developed for unique new components.

Modern facilities for manufacturing and testing within the group include complete environmental laboratories for simulation of all conditions a system or component is likely to encounter, ultra-clean assembly facilities for guidance components, and an unsurpassed temperature-controlled metrology laboratory.

*TRADEMARK

MANAGEMENT AND CORPORATE STRENGTH



The ability of the General Precision group to manage programs on the technical, production and financial levels is demonstrated by a number of important assignments.

One is the prime contract for the key portion of the FAA airways modernization program—the Data Processing Central. This is the most comprehensive systems engineering job ever undertaken for air traffic control, and involves several associate contractor companies outside the group.

Considerable experience has been acquired also through the systems management of a number of ASW warfare and other military programs.

The managements of the four companies and of General Precision determine which company or team is best qualified to carry out specific programs. Financing for all programs also is provided through the parent corporation.

In addition, the group can call on the resources of other General Precision companies—including capabilities in electrical and electronic, photographic and process control fields.

Although these affiliated companies serve mostly non-military markets, their skills are contributing to the solution of defense problems. Recent examples: development of a heat exchanger for a nuclear aircraft engine, and production of the first U. S. military searchlight incorporating a 2,000 candles/mm^2 light source.

The General Precision companies operate nationwide facilities occupying over 2,500,000 square feet of floor space and employ over 16,000 people—4,500 of whom are scientists, engineers and technicians.

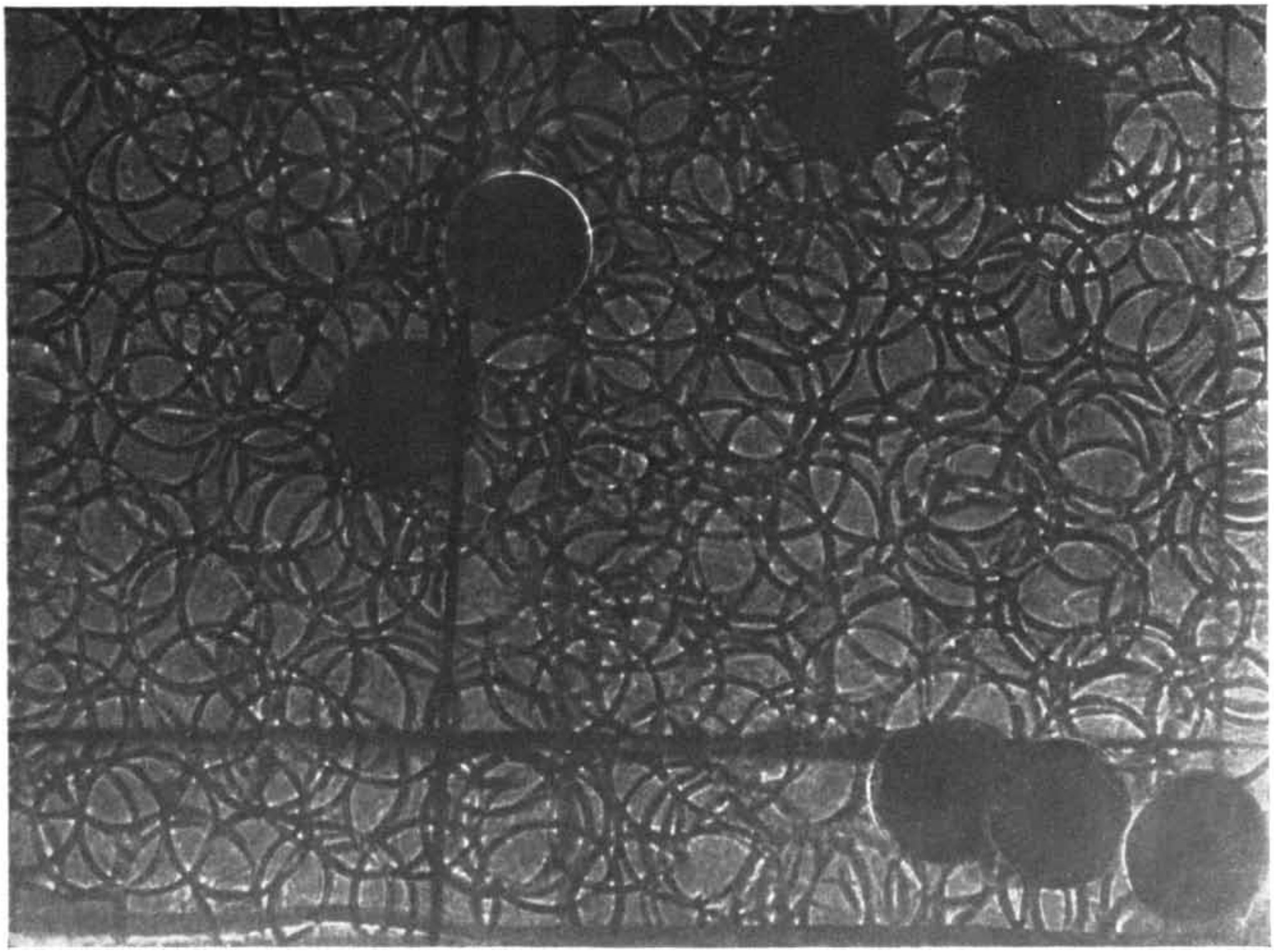
Molecular Motions

One of the aims of molecular physics is to account for the bulk properties of matter in terms of the behavior of its particles. High-speed computers are helping physicists realize this goal

by B. J. Alder and Thomas E. Wainwright

During the 19th century, as evidence in favor of the atomic theory mounted, an ancient hope of science began to bear fruit. As long ago as the first century B.C. Lucretius had proposed not only that matter is composed of tiny particles called atoms, but also that the behavior of these particles is the key to understanding the properties of bulk matter. For centuries this idea remained simply an interesting hypothesis. Then Isaac Newton set forth laws of motion from which the behavior of atoms might be calculated. At the same time a number of investigators were making quantitative observations on the gross properties of matter. The stage was set for an attempt to realize Lucretius' dream.

The earliest tries were mostly unsuccessful. But in 1739 Daniel Bernoulli succeeded in proving that the product of the pressure and the volume of a gas is proportional to the average kinetic



PHYSICAL MODEL of a molecular system consists of gelatin balls suspended in a tank of liquid. The tank is shaken to generate typical patterns of separations between balls. In the experiment depicted here separations were measured for the seven black balls.

energy of its atoms, provided that the atoms do not interact. His result is in fact valid for gases at very low density, where interactions between atoms or molecules are rare. It was not until the 19th century, however, that the program got under way on a grand scale, with the work of such men as Rudolf Clausius, James Clerk Maxwell and Ludwig Boltzmann. The task they faced was immense. Their predecessors had dealt with such problems as computing the orderly motions of a few planets under the gravitational attraction of the sun. These men were concerned with millions of particles, colliding with one another and darting about in all directions. To follow the trajectory of any individual atom in a piece of matter it would be necessary to know the position at all times of every other particle close enough to exert a force on it. The total force on the atom could then be computed from instant to instant, and, assuming that Newton's laws applied, its motion could be calculated.

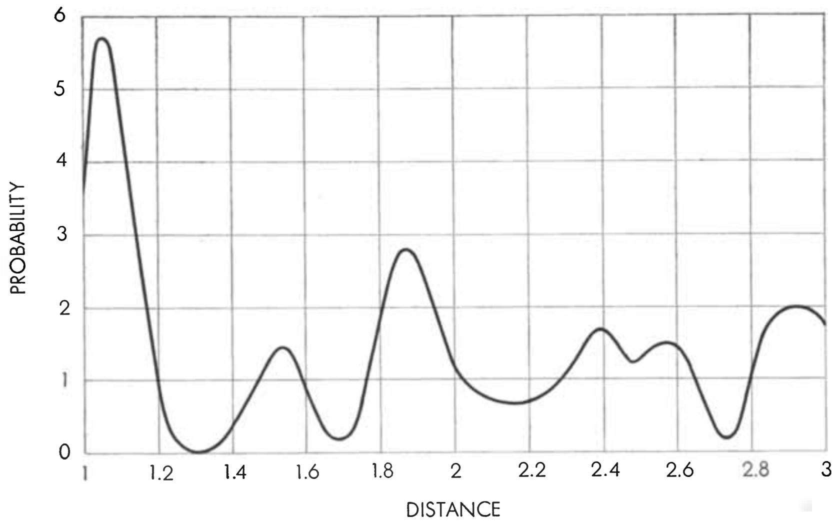
In practice such a detailed calculation was hopelessly complicated for a dozen particles, let alone millions. Fortunately it was not necessary. The bulk properties of matter depend upon the average behavior of many atoms, and not upon the detailed motion of each. Therefore statistical methods could be used and a new branch of physics known as statistical mechanics grew up. The statistical approach fulfilled many of its founders' hopes. In some problems, however, even this type of mechanics bogged down in cumbersome mathematics.

Today we are in a position to overcome some of the practical difficulties. Using high-speed computers we can perform calculations that were hitherto impossible. With the help of these machines we are moving a little closer to the ideal of understanding the properties of matter in terms of the mechanical behavior of its constituent particles.

In many applications of statistical mechanics it is possible to proceed with no knowledge of the velocities of individual atoms. We ask only how the atoms are distributed on the average in space. From this distribution alone many of the properties of the material can be calculated.

To appreciate what is meant by the spatial distributions, imagine that we have a microscope powerful enough to see the individual atoms or molecules in a sample of matter, and a camera fast enough to stop them in their rapid flight. A stereoscopic picture made with this arrangement shows how the particles are distributed at a given instant. We examine the particles in the snapshot in turn, measuring the distances between each one and all the others. The information is summarized on a graph, with distance of separation plotted along the horizontal axis, and the number of pairs at each distance along the vertical [*see illustration below*].

Suppose we make a number of snap-



DISTANCE-OF-SEPARATION PLOT for a crystalline solid is characterized by peaks and valleys. Peaks represent preferred distances of separation between the molecules of the crystal. Horizontal axis measures distance in molecular diameters. Vertical axis measures the relative probability that pairs of particles will lie at each distance. From this curve it is possible to calculate the actual numbers of pairs that are separated by each distance.

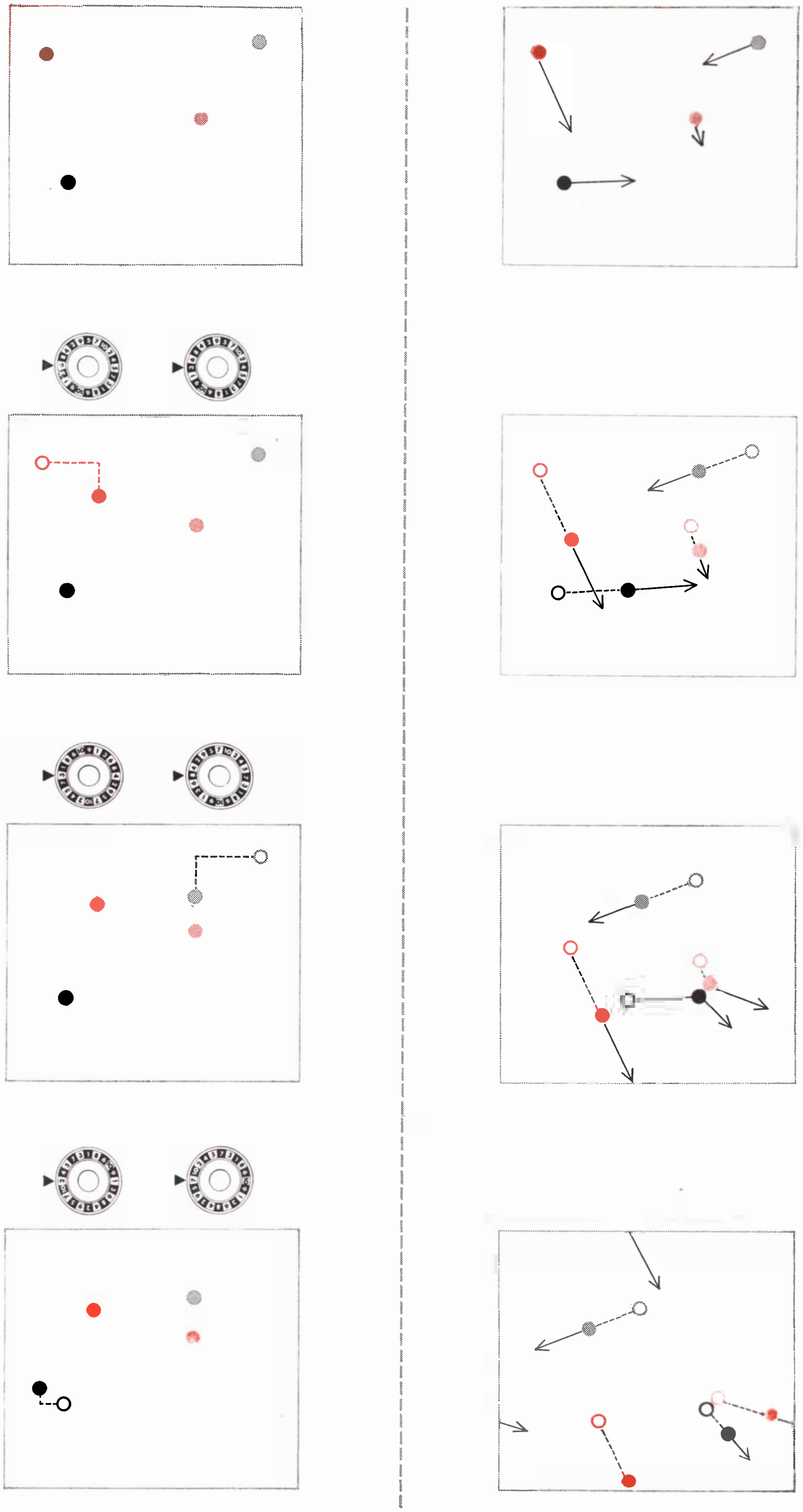
shots in rapid succession, say 1,000 in a second. We plot the distances of separation in each picture and then obtain the average of all the curves. This graph represents the average distribution of pair separations for that second. If the system is in equilibrium, then the average distribution remains constant for all time.

Between each pair of molecules in a piece of matter there is a force that depends on the distance between them. Assuming that we know how the force varies with distance, we can, for example, use our average plot to compute the forces exerted on a typical molecule by its neighbors. This gives us the pressure of the system.

How do we actually find the distances of separation in a system of invisible particles darting about erratically at tremendous speeds? In some cases we can obtain the information experimentally. A beam of X-rays sent through a solid or a liquid is diffracted in a way that depends on the spacing between the particles of the substance. From the size and intensity of spots in the diffraction pattern we can deduce the distances of separation and the number of pairs at each separation. For a crystalline solid the pair-separation graph shows a number of distinct peaks and valleys, as in the illustration on the opposite page. The peaks indicate that the molecules tend to lie preferentially at certain specific distances from one another. This is what we should expect if the molecules are arranged in an orderly grid or lattice. As the temperature of the solid is lowered, the peaks in the plot become sharper, showing that the molecules vibrate less widely about their central positions in the lattice. With increasing temperature, on the other hand, the peaks grow broader. If the material is heated above its melting temperature, the peaks are still present at distances as small as a few molecular diameters. They disappear at large distances because the lattice structure has disintegrated, and there is no longer an ordering force between molecules at longer ranges.

From the point of view of statistical mechanics we should like to be able to find the distribution of distance between molecules theoretically and to explain how physical conditions such as temperature and density influence the distribution. This would enable us, for example, to predict the pressure or energy of a substance from its temperature and density.

One way of approaching the problem



COMPUTER TECHNIQUES for calculating molecular distributions in three dimensions are illustrated schematically in these two-dimensional drawings. Monte Carlo method (*left*) moves particles according to a random-number table (represented by roulette wheels). Molecular-dynamical method (*right*) computes the actual trajectories. Open dots represent old positions of particles; solid dots, new positions. The particles are considered as being able to pass through the walls of the imaginary container and to re-enter on the opposite side.

is to construct a mental model of a system of particles, usually assuming a simplified law of force between them, and to devise some means of "shaking" the system; that is, moving the particles about at random. From time to time we stop shaking and make a "snapshot," recording the distances of separation of all the pairs of particles. Then the snapshots are averaged.

It should be understood that the random moves of the particles in the model are not the same as the motions that carry molecules from one place to another in real matter. The moves are simply a device for generating possible spatial arrangements. Because the moves are artificial, the order in which the resulting configurations occur is also unrealistic. In a system in equilibrium, however, the order of snapshots does not matter. The average plot is the same regardless of the sequence in which the individual curves are considered.

A relatively easy model to deal with is one in which the particles are taken to be hard spheres, like marbles. There is no attractive force between them, and they repel each other only when they collide. Simple though it is, this model duplicates some of the properties of real systems surprisingly well, as we shall see later on.

To construct a hard-sphere system we choose imaginary marbles of a suitable size and place them in an imaginary box (usually a cubical one for the sake of convenience). There is not only no force of attraction between marbles, but also no force of gravity; each sphere stays just where it is put. The size of the box depends on the density assigned to our hypothetical material. If we have chosen a low enough density, the process is straightforward. The marbles can be put in at random, with little chance that any will overlap. Such an overlap is of course disallowed. Whenever it occurs, we must remove the last marble put in and try placing it elsewhere. The same thing is true after shaking: snapshots in which marbles overlap are ruled out. At sufficiently low densities, corresponding to the gaseous state in real materials, the frequency of overlaps is negligible. It is not too difficult to generate mathematically as many distance-of-separation patterns as we wish.

As the density is increased, however, that is, as the average distance between marbles gets smaller, it becomes harder to put in the marbles at random without running into interference. With each succeeding particle we must try

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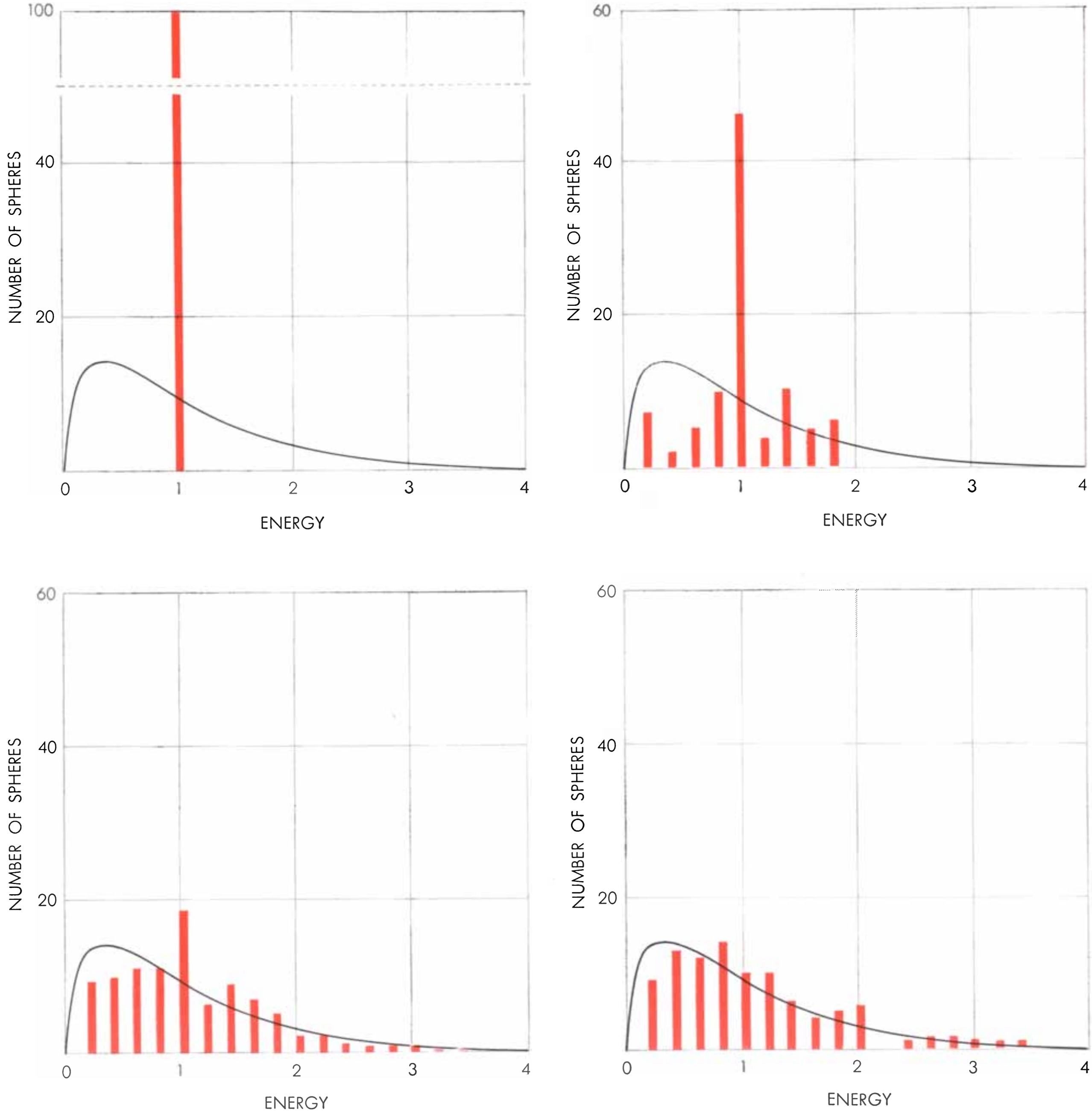
more and more random positions before finding an empty spot. Eventually no more marbles can go in. The box is not completely full, but it is inefficiently packed. By rearranging the marbles already in it, we can make room for more. At this density matter begins to act like a liquid. In a liquid the spheres can rearrange themselves only if numbers of them move cooperatively. This situation makes the mathematics of shaking more cumbersome.

At still higher density, corresponding to that of a crystalline solid, the problem becomes simpler again. If the marbles are packed in an ordered array, and are touching one another, the box is completely full and shaking has no effect. The marbles cannot move at all. Now when the density is decreased slightly (by making the box bigger or the marbles smaller), the particles can rattle around their positions in the lattice, but cannot escape. This approximates the situation in a real crystal. If the marbles are shrunk still further, they will eventually be able to escape from the cages formed by their neighbors and trade places. The lattice disappears and the solid melts. But each particle can escape from its lattice position only if its neighbors move cooperatively in such a way as to leave it a wide enough path. Again the mathematics becomes harder to carry out.

One way around the computational



EQUILIBRIUM DISTRIBUTION of kinetic energies is rapidly attained by a system of 100 hard spheres, each having an energy of one unit (*top left*). Equilibrium pattern is represented by curve; numbers of particles at various energies, by bars. Drawings at top right, bottom left and bottom right show distribution after 50, 100 and 200 collisions, or an average of one, two and four per particle.

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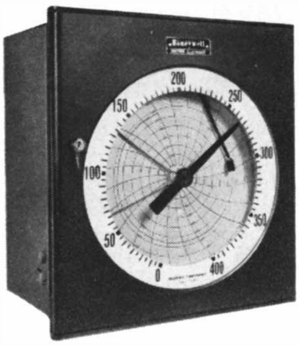

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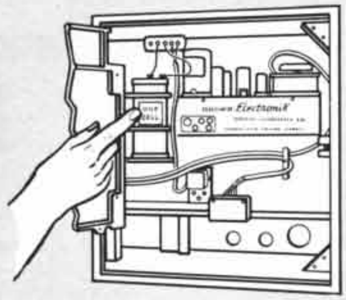

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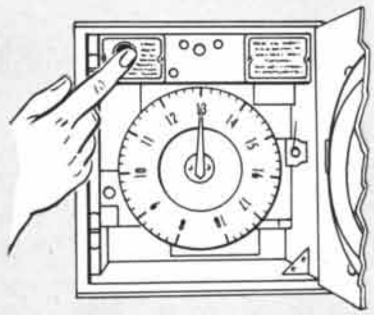

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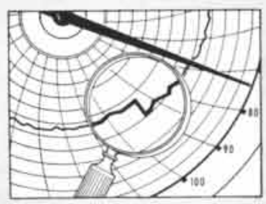

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problem is to make a physical model and actually shake it. Some years ago Joel Hildebrand and his colleagues at the University of California performed just such an experiment. They suspended gelatin balls in a tank of liquid whose density was equal to that of the gelatin, so that the gravitational force was canceled by buoyancy. Placing the tank on a vibrating tray, they made a series of photographs from which the average distances of separation between the balls could be plotted. Their curve resembled plots made from X-ray studies of liquids.

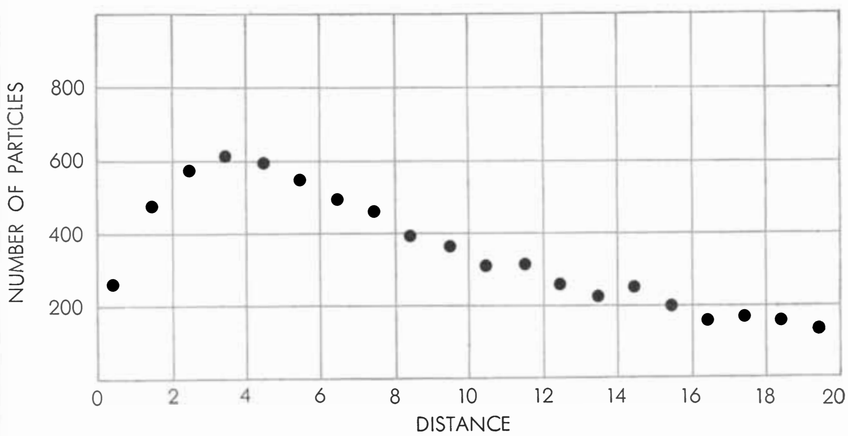
No physical model, however, is altogether satisfactory. The chief problem is the difficulty of assuring that the shaking is really random.

With the help of a fast computer the experiment can be "performed" much more neatly by purely mathematical means on an ideal system. This has been done by a group at the Los Alamos Scientific Laboratory. Each particle is represented by a set of three numbers, specifying the three-dimensional coordinates of its center (x, y and z). Having located all the particles by feeding the appropriate sets of numbers into the machine, we make our first "photograph," recording the distances of separation between all pairs. Now we proceed to "shake" the particles one by one, using the so-called Monte Carlo method. We choose a particle at random and displace it, that is, change its x, y and z coordinates. The amount of each change is decided by picking one of a series of random numbers generated by the machine. If the move is a legal one—that is, if the displaced particle does not overlap any of the others—we make a second snapshot, again recording all distances of separation. Then we displace a second particle, and so on.

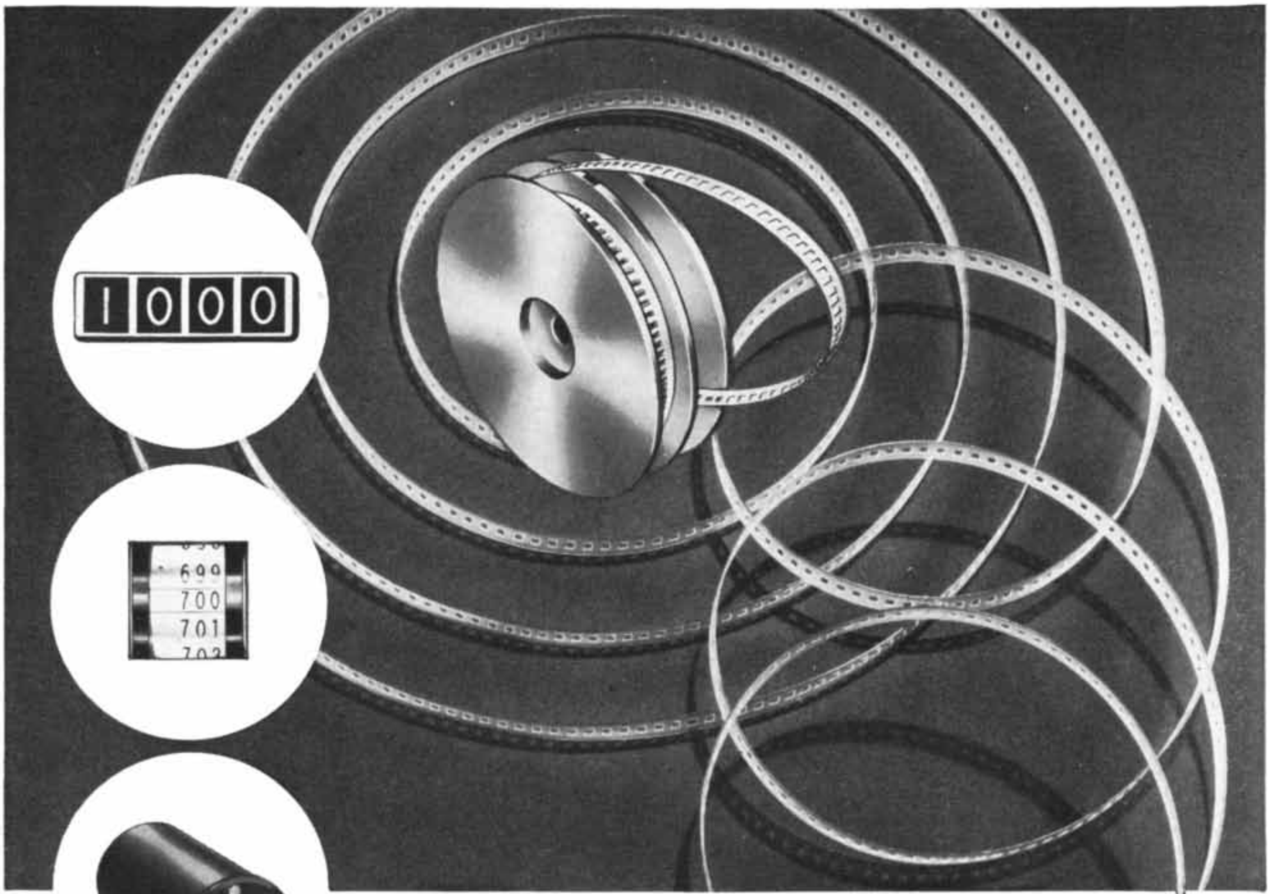
Whenever a move turns out to be illegal, we return the displaced particle to its former position and use the corresponding distribution of distances a second time in the averaging. This procedure gives effect to the comparative probability of each distribution. The more often a random change in a distribution leads to an impossible configuration, the more probable is that distribution.

Monte Carlo calculations would of course be impossible to carry out by hand. Machines are quick and tireless, but they too have limitations. The largest existing computers can handle no more than about 500 particles in a reasonable calculating time. Machines soon to be available will have capacities for some 10,000. Even the latter figure is infinitesimal compared with the number of molecules in any weighable sample of matter. Yet it is remarkable how closely a system of just a few dozen particles can approximate the properties of real matter. One stratagem that helps make this possible is the proper choice of "boundary conditions."

In any sizable piece of matter the overwhelming majority of molecules are inside, surrounded by other molecules and interacting with them. Only a tiny fraction is at the surface or boundary at any time. However, in our hypothetical system of a few dozen or a few hundred particles a substantial proportion will always be near the walls of their imaginary container. A random displacement is thus likely to bring them into contact with the boundary rather than with another particle. To avoid this atypical situation the computer is programmed to allow the particle to pass freely through



DIFFUSION OF PARTICLES in a specific time is plotted from molecular-dynamical calculation. Horizontal coordinate measures square of distance (in arbitrary units); vertical coordinate, numbers of particles that have moved various distances from starting point.



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the walls of the box. Whenever a particle moves out through one wall, it is immediately brought back in through the opposite wall. In effect we have put the opposite boundaries together, just as a string of beads is brought together by tying its ends. Now every particle is surrounded by neighbors and interacts with them instead of with the wall.

High-speed computers and the Monte Carlo method have enabled us to overcome many of the mathematical difficulties of statistical mechanics. Liquids and melting solids have been studied with the hard-sphere model and the pressure determined from the average distribution of pair separations.

Furthermore, it has been possible to consider more realistic intermolecular forces. For instance, two particles may be assumed to attract each other when they are closer than a certain distance, but repel each other when they actually collide. The shaking process now becomes more complicated. In the hard-sphere case one move is as good as another so long as it does not bring two particles into the same space. But when particles interact at a distance, some moves become more probable than others. Thus two particles within the range of attraction are more likely to approach each other than to separate. In carrying out the Monte Carlo calculations we assign probabilities reflecting the force that tends to encourage or inhibit each displacement: a given type of move might be allowed only every third time it came up.

With these refinements it is possible to take into account more of the properties of a real physical system, such as temperature. When attractive forces are considered, the likelihood of a particular change in the distribution of molecules depends on the temperature. Hence by varying the assigned probabilities we can play the Monte Carlo game at various temperatures. The distribution-of-distance plots can then be used to calculate the pressure of the system at different densities and temperatures, and the results compared with measurements on actual samples.

In this way the pressure of argon has been successfully calculated over a range of temperatures and densities that is wide enough to include the solid, liquid and gas phases. Moreover, the computations can easily be extended into regions of very high temperature and pressure, which are difficult to attain in the laboratory.

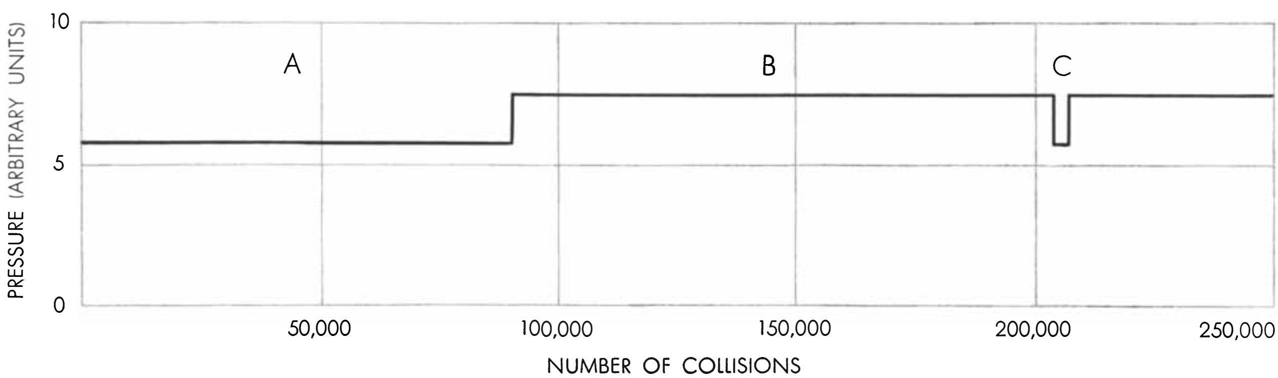
As has already been pointed out, the statistical mathematics of the Monte Carlo method produces accurate distributions of intermolecular distances. But it does not reproduce molecular motions. Hence it is restricted in its application to equilibrium properties such as pressure and energy. At the Lawrence Radiation Laboratory of the University of California we have undertaken a program to remove this deficiency. With the help of automatic computers we have been able to calculate the actual trajectories of a rather large number of individual particles. By means of such calculations it is possible to make theoretical determinations of properties that depend specifically upon details of molecular dynamics.

It turns out that a computer can follow the detailed motions of about as many particles as it can handle in the Monte Carlo method. We begin the calculation by assigning to each particle not only a position but also a velocity (*i.e.*, a speed and a direction of motion). Thereafter no element of chance is involved. The subsequent spatial patterns are predetermined. The machine calculates the path of every particle until two of them come close enough to exert a force on each other. Using Newton's laws of motion, the computer determines the effect of the forces on the two particles, and calculates their new velocities after the collision. Then it continues to compute all the trajectories until a second pair interacts, and so on. The same boundary conditions can be used as in the Monte Carlo method.

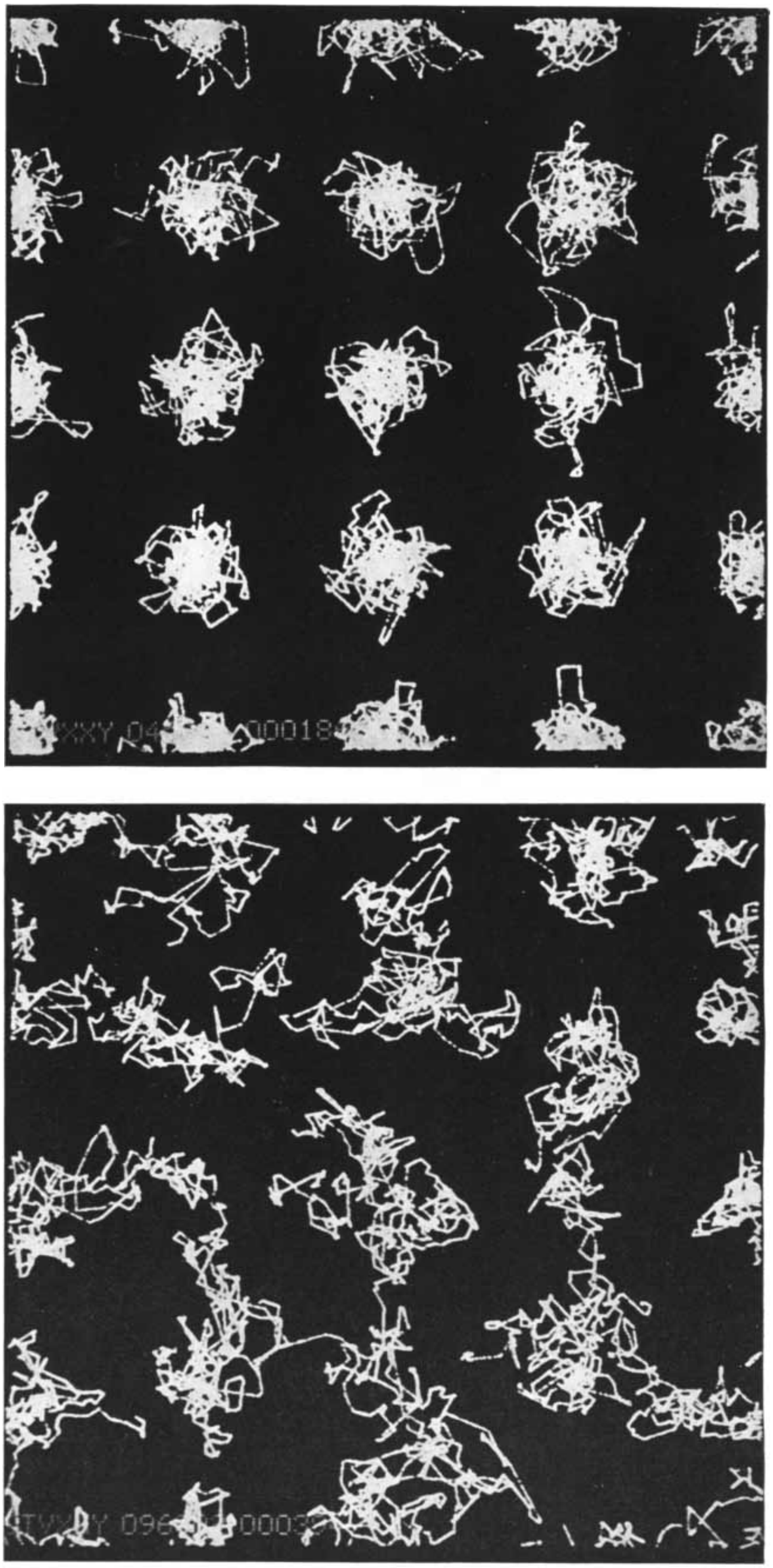
Of course we must make some assumption about the force between particles. The assumptions we make are not entirely realistic, but are designed to split a complex problem into simpler parts. Thus the mathematical complications arising out of realistic intermolecular forces can be isolated from those that are due simply to the large number of particles.

The two types of force that have been studied so far are the hard-sphere case and the so-called square-well interaction. In the latter there is no force between the particles until they approach to a certain distance. At this distance they abruptly attract each other. At shorter distances the attraction disappears, but if the particles then come close enough to touch each other they act like hard spheres and bounce apart. Since these particles move with constant velocity everywhere except when separated from one another by either the "attracting distance" or the "repelling distance," their motions are comparatively easy to compute. More realistic forces that vary smoothly with the distance of separation might be considered, but at the expense of more lengthy calculations.

The dynamical method is not restricted in its application to systems at equilibrium. It can, for example, be used to find how quickly the system reaches



PRESSURE-JUMPS in a hard-sphere system signal changes in phase between the fluid and solid state. Region A represents the low-pressure, solid phase, which lasted for about 100,000 collisions. Then the pressure increased abruptly to that of a fluid (*region* B), continuing in this state for another 100,000 collisions. In region C it dropped briefly back to the solid value for another 3,000 collisions.



PATHS OF PARTICLES in molecular-dynamical calculation appear as bright lines on the face of a cathode-ray tube hooked to the computer. Each cluster in upper photograph represents two hard spheres, one behind the other. In solid state (*top*) particles can move only around well-defined positions; in fluid (*bottom*) they travel from one position to another.

equilibrium. In one case a system of hard spheres was started out in the highly atypical condition in which all the particles had the same kinetic energy. The statistically expected distribution of energies was attained after very few collisions [*see illustration on page 118*].

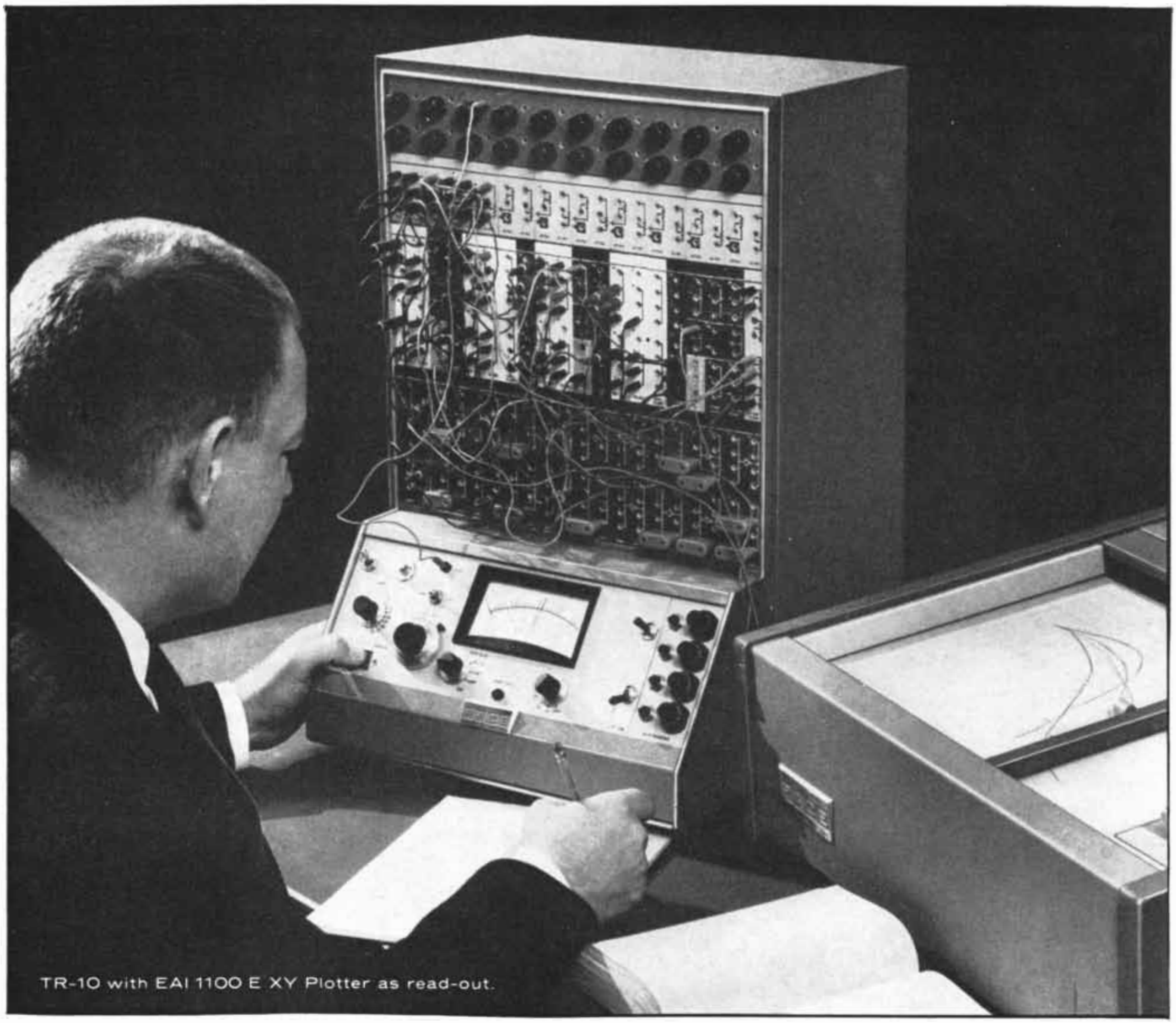
Once the system reaches equilibrium, distance-of-separation snapshots can be taken just as in the Monte Carlo method. These snapshots yield the same information as those achieved by statistical techniques. For example, they might be used to calculate the pressure. The dynamical method furnishes an additional way of arriving at the answer. If the system is considered to have reflecting walls, the pressure can also be calculated by considering the impacts of the molecules on the walls. Pressures in hard-sphere systems have been determined by both the Monte Carlo and the dynamical methods with very close agreement.

Because the configurations calculated by the dynamical method are in the correct temporal order, they enable us to study the time-dependent behavior of the system. This is important even after equilibrium has been attained. One example of time-dependent behavior is diffusion. At equilibrium the average total force on a molecule is zero, because the forces exerted on it by its neighbors are as likely to come from one side as another. Nevertheless any specific particle is likely to experience a succession of forces that leave it, after an interval of time, with a net displacement from its original position. In other words, it will diffuse. By noting the positions of the particles in successive snapshots, we can establish their rate of diffusion.

Albert Einstein's theory of diffusion predicts that the average of the squares of the net displacements of the particles is proportional to the time during which diffusion takes place. Molecular-dynamical studies have shown that the theory is true for hard-sphere fluids and have also determined the constant of proportionality for a wide range of fluid densities.

So far the most extensive study carried out by the dynamical method has been the calculation of the pressure of a hard-sphere system over a large range of densities. The main purpose was to shed some light on a long-debated question: Can a hard-sphere material have a sharp freezing point? Does the change from the disorganized configuration of the molecules in a liquid to the ordered lattice of a crystal occur gradually or suddenly, if the molecules are assumed to have no attractive forces?

If hard spheres are in an orderly ar-



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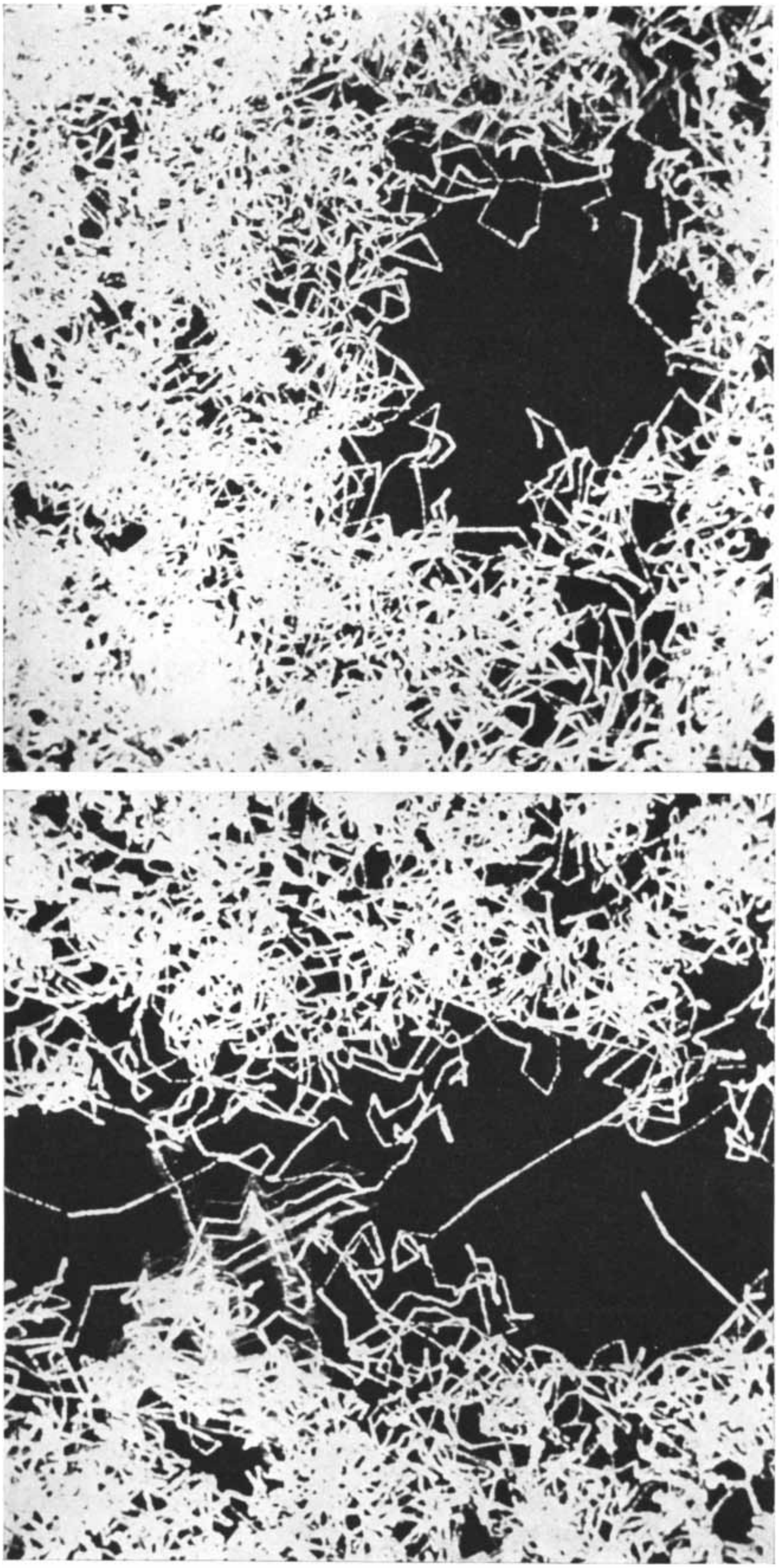


LIQUID-GAS SEPARATION is illustrated by molecular-dynamical calculations on particles with square-well interaction. Dark area in upper photograph represents a gaseous bubble, surrounded by particles whose motions characterize a liquid. Lower photograph shows the system at a later time, when some particles have vaporized and passed through the bubble.

rangement at a particular density, the system will have a lower pressure than if they are arranged at random, as in a liquid. Systems with as few as eight and as many as 256 hard-sphere particles have been studied. All exhibit sharp jumps in pressure when the density is held fixed somewhere between that of a crystal and that of a liquid [*see illustration on page 122*]. These pressure-jumps are associated with abrupt changes in the system from the orderly, crystalline phase to the random, fluid phase and vice versa. The size of the jump depends on the number of particles; the smaller the number, the larger the jump.

In all cases the system changed as a whole from one phase to the other: it was either entirely crystalline or entirely fluid. If a larger number of particles was used, we might expect to see a two-phase equilibrium, that is, part of the system crystalline and part of the system fluid. This would correspond to the physical situation in which ice and water, for example, can exist side by side in equilibrium at the freezing point.

In order to demonstrate the phase changes more vividly, a display system similar to a television picture-tube was hooked up to the computer. Each particle in the system was then represented by a dot on the face of the tube. By focusing a camera on the screen and leaving its shutter open, it was possible to record the trajectories of the moving dots on film. The photographs on page 124 show the imaginary material in both the crystalline and the fluid phases.

If we want to study the liquid-gas phase transition, we must consider molecules with attractive forces. Such a study has been made with 32-particle systems with square-well interactions [*see photographs at left*].

We have mentioned only some of the molecular-dynamical calculations that have been carried out thus far. They represent an ideal example of the application of automatic computers to scientific research. A knowledge of the physical laws is assumed. The straightforward but tedious mathematical calculations are carried out by machines that are specifically designed for that purpose.

Perhaps it is not too much to expect that the information obtained by means of computing machines may play a role analogous to that of laboratory experiments in the development of theory. When we have built up a sufficiently large body of numerical computations, we may be able to discern generalizations that are not apparent to us now.

The Social Behavior of Prairie Dogs

In building towns the prairie dog protects itself against predators and encourages the plants on which it feeds. Its social behavior is passed from generation to generation by both heredity and learning

by John A. King

The Great Plains of the North American West seemed endless and uninviting to many pioneers, who brought memories of the forests and hills of their homes in the East. Rainfall was sparse, the streams were shallow and there was little timber for building. The Indians, the deer and the great herds of bison—all perpetually on the move—seemed to share the pioneer's restlessness as he pressed across this open wilderness toward a homestead. The only settlers here were the town-dwelling prairie dogs; they sat upon their thresholds and barked at the intruding wagon trains.

When pioneers at last settled in the Great Plains, they opened war upon the prairie dogs and sought to eliminate them from the now-cultivated land. Long campaigns of poisoning were so successful that three decades ago some naturalists predicted the prairie dogs' imminent extinction. The prediction has not been fulfilled, but the busy rodents have all but disappeared from the Great Plains that once belonged to them; they flourish chiefly in the refuges afforded by the national parks.

It was in one of these refuges, Wind Cave National Park in the Black Hills of South Dakota, that I undertook to study prairie dogs during three summers and a winter. Not far from the park's main road is Shirttail Canyon, the lower terraces and floor of which are occupied by a large prairie-dog town of 75 acres and nearly 1,000 inhabitants. On one of the terraces, separated from the town by steep slopes, I built two burlap-screened platforms on six-foot towers. Thus concealed, I was able to observe the little animals without upsetting their normal way of life.

As befits a town-dweller, the prairie dog has developed well-defined patterns of social behavior that set it apart from other prairie rodents, such as the dispersed and secretive deer mice and ground squirrels. Moreover, the prairie dog's social behavior is central to its survival in the Great Plains environment.

By building towns that occupy acres and even square miles, prairie dogs modify their environment and make it more suitable to their needs. Within the towns their social organization protects them from predators, and their own regulation of population density minimizes the risk of famine. This highly effective mode of behavior is transmitted to each prairie-dog generation by the preceding one. From my vantage point in Shirttail Canyon, this "education" of the young was a most engaging sight.

The prairie dog is a plump, tawny rodent, weighing about two pounds and measuring 14 to 17 inches from nose to tail-tip. It belongs to the squirrel family and is related to the marmots. Of the five species of the prairie-dog genus *Cynomys*, it is the black-tailed species *ludovicianus* that builds its towns in the Great Plains. Its front feet are equipped with long digging claws, its ears are small and its eyes—which are especially adapted to the detection of aerial predators—are so high on its head that they are about the first things to appear as the animal emerges from its burrow.

On the Great Plains this species lives between the temperature extremes of the hot summers of Texas and the intense winters of North Dakota. Precipitation seems to be an important factor in its distribution. It occupies a belt that gets some 20 inches a year, which supports a dominant vegetation of prairie grasses. The relationship between the prairie dogs and the vegetation upon which they feed is an intricate one, and much remains to be learned about it. Apparently their feeding habits eliminate the taller vegetation growing in a prairie-dog town. This yields a twofold advantage: it deprives predators of dense cover and at the same time encourages fast-growing weeds with abundant fruits and seeds. The latter probably furnish a more varied and nutritious diet than the original vegetation. Some weeds such as the thistle seem to provide the prairie dogs, which rarely drink any free water, with moisture. Those non-food plants that still grow are clipped and left to wither in the sun.

A feature of the prairie-dog town that is perhaps even more striking than the altered pattern of vegetation is the mounds of soil that surround the 20 to 50 burrow entrances that dot each acre. These are a foot or two high and five or six feet across, and are often built after a rain, when the soil is soft and pliable. The prairie dogs dig and push the soil to the burrow and then tamp it into place with their noses. The mounds serve a dual purpose. During rains, water often rises several inches on the flat soil, and the mounds prevent swamping of the labyrinth of burrows. The mounds also serve as lookout stations; the prairie dogs sit atop them and from that vantage watch for predators and invading prairie dogs of other clans.

The many animals that hunt the prairie dog make watchfulness and readily accessible refuges vitally important. Eagles and hawks swoop upon prairie dogs from above, and bobcats and coyotes stalk them from any vegetative cover not cleared from the towns. In addition to being abundant the burrow-refuges must be deep enough to permit escape from fast-digging badgers, and they must have at least one additional exit in case the prairie dogs are followed through their burrows by the black-footed ferret.

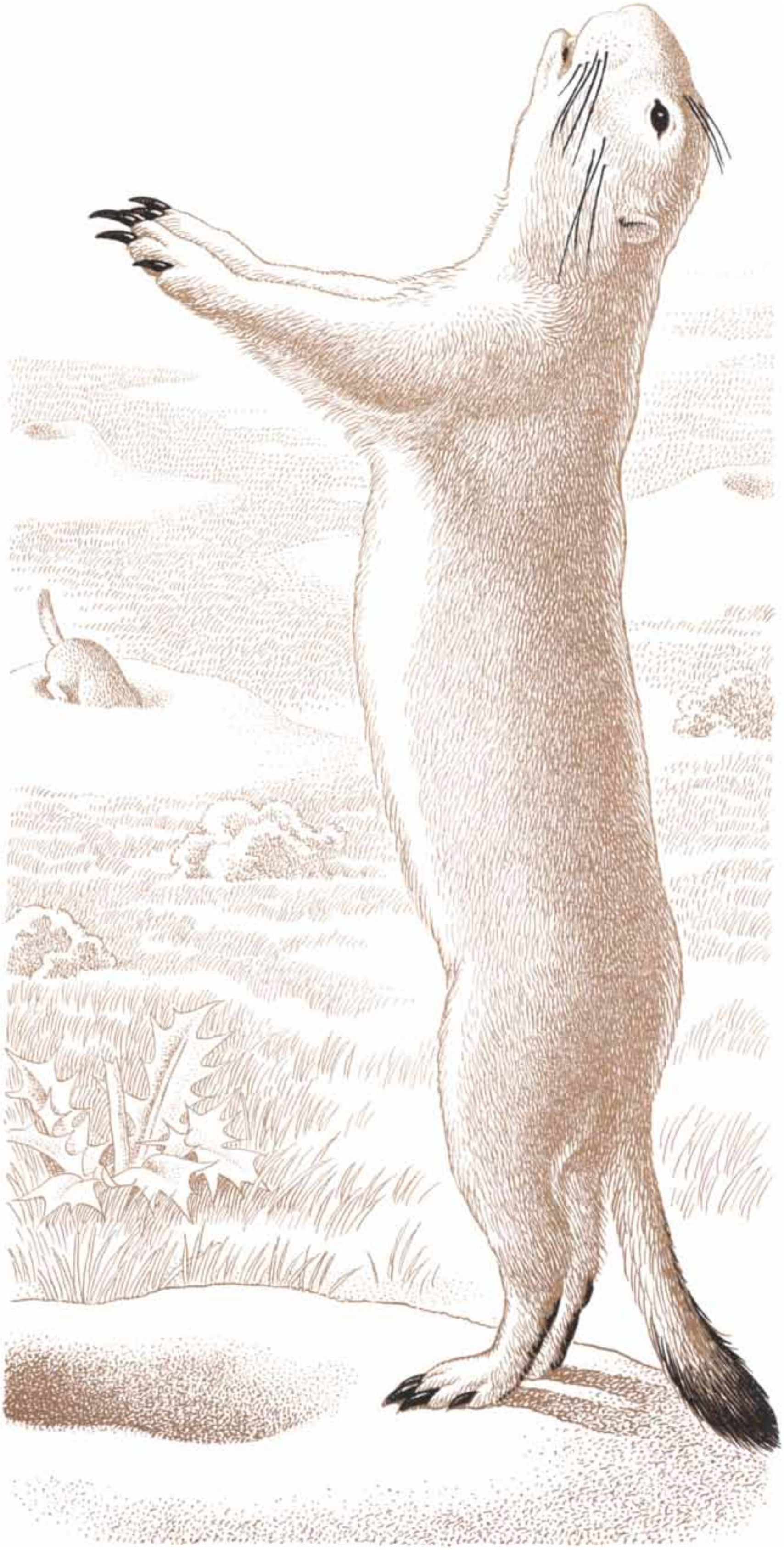
Not all trespassers prey on the prairie dogs. At times deer mice and cottontail rabbits use less-frequented burrows for temporary refuge. Ground squirrels may, when hard-pressed, go into a prairie-dog burrow. The prairie dogs react to these small mammals with indifference or mild curiosity. On one occasion, as I watched, a prairie-dog pup crept up to a rabbit, sniffed it and then attempted to chase it, but soon gave up as the rabbit bounded easily away.

Frequently I saw antelope spend most of a day in the prairie-dog town, feeding and lying in the shade of scattered pine trees. When the antelope first approached the town, the prairie dogs would bark at them and scurry to their burrows. But once the visitors proved harmless, the prairie dogs would peer at them from their burrows and even come out and feed within a few feet of them.

Occasionally a herd of some 200 bison passed through the town, sometimes staying for a week and sometimes only for an hour. A herd of that size spending the afternoon on a 75-acre town soon makes a shambles of it. A bison would approach a well-formed crater, paw it, dig at it with its horns and then, seeing that it made a nice tub for a dust bath, lie down to wallow, destroying both crater and burrow.

The prairie dogs reacted to the bison much as they did to the less robustious antelope. While the bison were active—wallowing or sparring with one another—the prairie dogs would remain in their burrows. But when the bison turned to grazing or quietly ruminating, the prairie dogs came out and fearlessly fed nearby. After the bison had left, the prairie dogs diligently repaired the damage. But some craters seemed to be favorite wallowing sites, and in the face of constant destruction the prairie dogs relinquished these to the bison and left them unrepaired.

Some prairie-dog towns are divided by topographic features into wards, but the most significant divisions within towns or wards are invisible and are imposed by the prairie dogs themselves. These are the territories of the prairie-dog clans, which we call coteries. The coterie is the basic unit of the town's social organization. Its identity is established and maintained by frequent friendly contacts among its members and hostile contacts with members of other coteries. Each coterie member is known to the others; all share the burrows and



TERRITORIAL CALL is sounded by prairie dogs of all ages and both sexes to signify territorial proprietorship, departure of a predator or just general well-being. Animal throws itself into upright posture to deliver the call, which is almost always echoed by others. When it indicates "all clear," the town may resound as other prairie dogs repeat call.

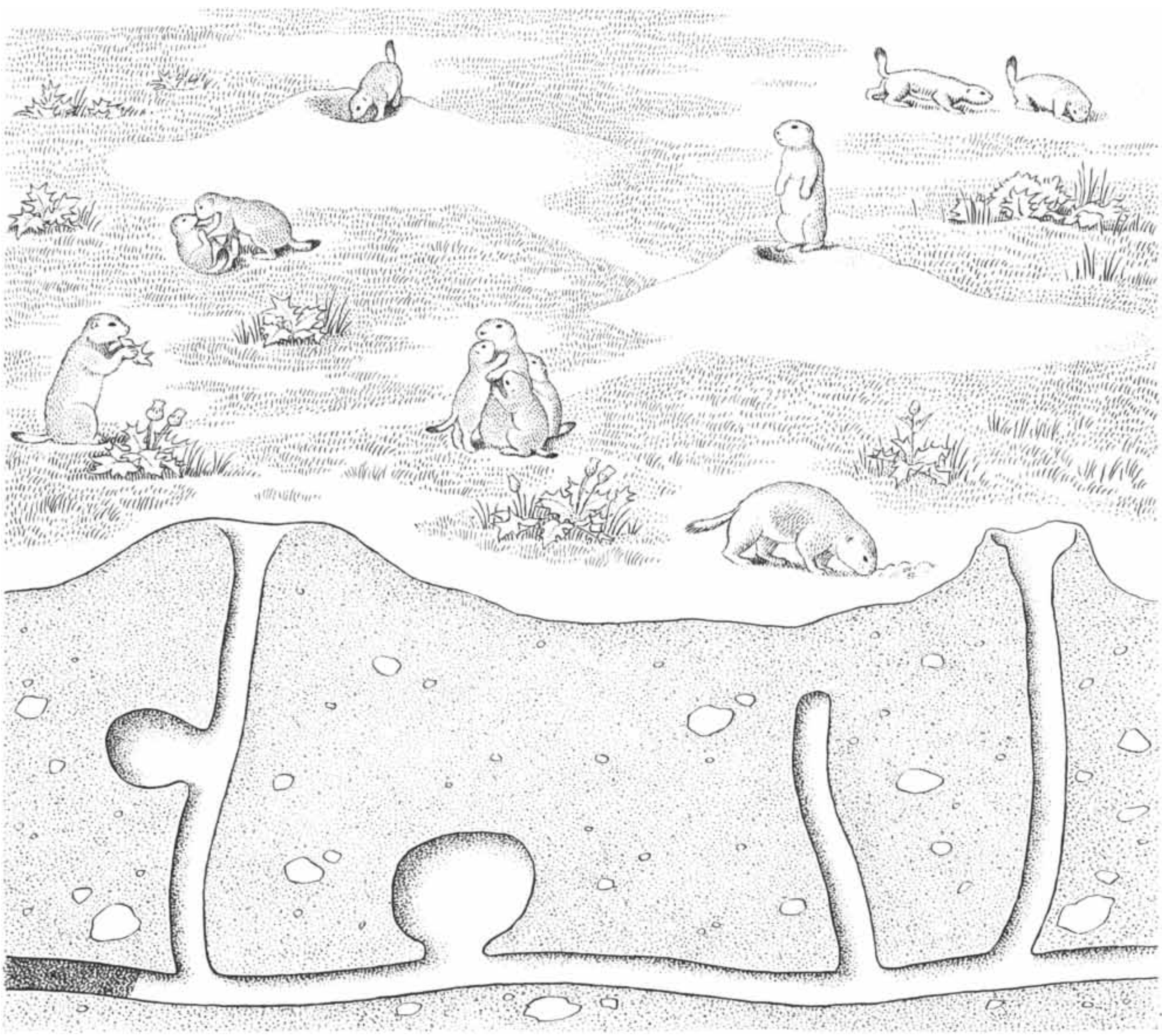
resources of their territory. Members of a coterie frequently groom each other, play and "kiss." They rarely dominate or antagonize one another. A coterie territory usually covers about seven tenths of an acre, though its extent may vary, particularly at the edge of a town, where the animals may move into adjacent uninhabited regions.

The coteries vary in composition. The elusive "average" consists of an adult male and three adult females together with about six offspring. Some coteries consist of two males and five females. One coterie I observed had 31 young, another failed to produce any young one year, and still another consisted of only two old males and a barren female.

While both the membership and size of the coterie change from season to season, its territory is substantially permanent. Even a complete change of individuals, as the old die or emigrate and the young replace them, does not alter the boundaries between territories. Males that invade a territory from another section of the town quickly learn from the members of the coterie where the territorial boundaries lie. And the prairie-dog pups soon learn the extent of their home territory. Probably the main feature of a territory's stability is the network of burrows that are so essential to the prairie dog's survival. Each burrow entrance is jealously guarded, since the loss of one entrance to an invader may open the entire system to trespass. Consequently the inhabitants carry their defense to the boundaries of their territory. Thus delimited and maintained, the territory endures as a heritage handed down through the generations.

Most of a prairie dog's travels are confined to its coterie territory, and these typically add up to more than a mile a day. Any part of the territory that is not visited on one day may become a center of activity the next. One adult male that I watched for an entire day traveled almost three miles within his three-quarter-acre domain. Early in the morning he drove an invader from the territory, and for the rest of the day he remained alert against further invasions—circling the periphery of the territory and examining other animals apparently to make sure that they were bona fide coterie members.

Many prairie-dog activities are directed toward making social contacts, and these seem to serve at least two functions. First, they provide a con-



LABYRINTH OF BURROWS honeycombs a prairie-dog town. The mounds surrounding the burrow entrances keep surface water out of the system. The mounds also serve as lookout vantage-points. Many burrows have at least two exits. Bulbous excavations are nesting chambers. The shaded area at bottom left is a temporary plug of dung. The passages are about three feet below the surface.

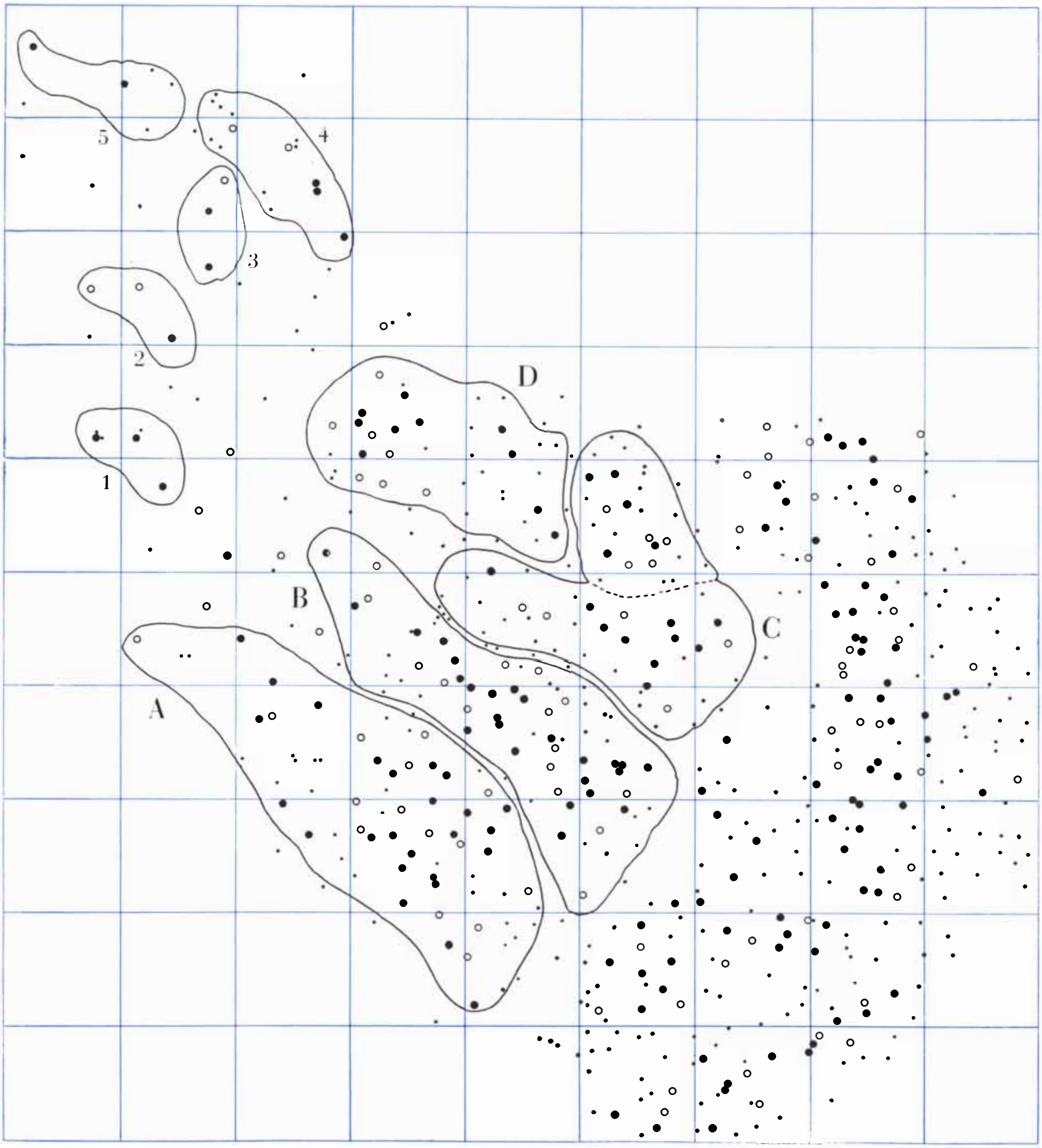
stant check against trespassers, and second, they help maintain relations among the members of a coterie and thus preserve the group. Two individuals feeding some distance apart may, upon seeing each other, run forward to meet; or one, seeing another on a crater, will run and sit beside him. Whatever the occasion, when two individuals meet they turn their heads toward each other, open their mouths, bare their teeth and "kiss." When familiars pass in a flight to a burrow, the kiss is hastily given. At other times it is more leisurely and prolonged. Two animals will meet and kiss; then one will roll over on its back, still maintaining oral contact. Often the kiss ends with both animals rapturously stretched out side by side; they then rise and move off to feed with their bodies pressed together.

The kiss seems primarily a means of distinguishing friend from foe. If two animals sight each other near the territorial boundary, or in any other circumstances in which they are uncertain of each other's identity, they lie down on their bellies and, flicking their tails, slowly creep toward each other until contact is made and the identification kiss exchanged. The open mouth which characterizes the kiss probably serves as a threat rather than an expression of affection. Each, seeing the other's mouth open and ready to bite, is probably made aware that the other is defending the integrity of the same territory and is hence a coterie member. Faced with the bared teeth and open mouth, an interloper runs off, while a resident stays and osculates.

The identification kiss is frequently a preliminary to a more elaborate ritual called grooming. After kissing, one prairie dog will begin to nibble and paw the other. The passive animal may roll over on its back better to expose itself to the stimulating ministrations of its partner; it crawls under the other's muzzle and encourages it to continue or to start again if it has stopped. All members of a coterie groom one another; males groom females and vice versa, adults groom the young and the young groom the adults and one another. The pups are particularly responsive to grooming by the adults and will chase and crawl under them in efforts to attract attention.

Perhaps the most significant sensory cue for uniting the coterie, and even the whole town, is the prairie-dog vocalizations. Prairie dogs were named for their bark, which is their only resemblance to dogs and which differs appreciably from a dog's bark. Prairie-dog barks may convey a particular meaning or several different ones. Generally the prairie-dog bark consists of a short nasal yip which varies in intensity and frequency with the stimulus. Some have a quite specific sound, others have many variations and, probably, many interpretations. The approach of danger provokes a warning call. Upon hearing it the other prairie dogs of the town interrupt their activities and sit up to see the cause of the alarm. If the bark is high-pitched and rapid, they stop whatever they are doing and dash immediately to their burrows.

The most distinctive vocalization is the two-syllable territorial call, which is delivered in a loud, clear series of two or three. The prairie dog throws its body upward, rising on its hind legs with its nose pointed straight up and its forefeet thrust out, and cries out with such force that it sometimes leaps from the ground. The pups also throw their whole bodies into the call, sometimes tumbling over backward in the effort. The territorial call is almost the antithesis of the bark. The bark communicates alarm, while most territorial calls are given in home territory where the animal feels secure. When delivered by a foraging prairie dog, the call may merely proclaim ownership of a territory. But it serves also to challenge an invader or to announce victory after a dispute. Among these gregarious creatures the territorial call sel-



PRAIRIE DOGS DIVIDE THEIR TOWNS into coterie territories (A, B, C *and* D), the borders of which they zealously guard. Numbered areas at upper left are new territories established by emigrating adults. Territory C is in process of being split. Solid circles indicate large, active burrows; open circles are smaller burrows; dots are holes without craters. Each square is 50 feet wide dom goes unanswered. When an animal utters it after the departure of a predator, the others join in, and what was simply an all-clear signal becomes a cacophony of togetherness.

With the exception of the vocalizations, which can be heard by the whole town, cooperative behavior does not extend to prairie dogs of other coteries; indeed, relations between coteries are quite hostile. Most conflicts between coteries arise over boundaries. When a coterie member, foraging at the limits of its own territory, passes into an adjoining territory, a resident of the area rushes up to drive it away. The invader may be only a few feet outside its own territory and, failing to recognize that it is trespassing, may refuse to yield. The ensuing struggle is a stereotyped ritual that consists more of threat than fight. The animals rush toward each other, stop short and freeze face to face. Then, in a kind of reverse kissing encounter, one of the disputants turns, raises and spreads its tail, exposing its anal glands, and waits for the other to approach. The latter cautiously draws near and sniffs. Then they exchange roles; they alternate in this way until the stalemate is broken by an attempt of one to bite the rump of the other. The "bitten" contestant (prairie dogs are rarely scarred) backs away a few feet and then returns to the fray. The dispute is often accompanied by much rushing back and forth and repetition of the smelling encounters. Finally some arbitrary boundary is established and the antagonists return to their foraging. Such disputes rarely result in boundary changes of more than a few feet and rarely in injury to the contenders.

In contrast to such innocuous and accidental trespasses, one coterie member may undertake a purposeful invasion of another territory. These invasions may simply be exploratory, as when an invader enters an unguarded territory and takes the opportunity to examine the strange burrows and terrain. If the residents do not discourage these explorations, the invader may grow arrogant and even sound his territorial call at the burrow entrances. At such times, however, the mere appearance of a resident is usually enough to send the explorer scurrying home. But some invasions are made by more aggressive males who are willing to fight for the territory. Their tactics are to remain just inside the invaded borders, sniffing at burrows and acquainting themselves with the various coterie members. This may go on for days or weeks. If the residents

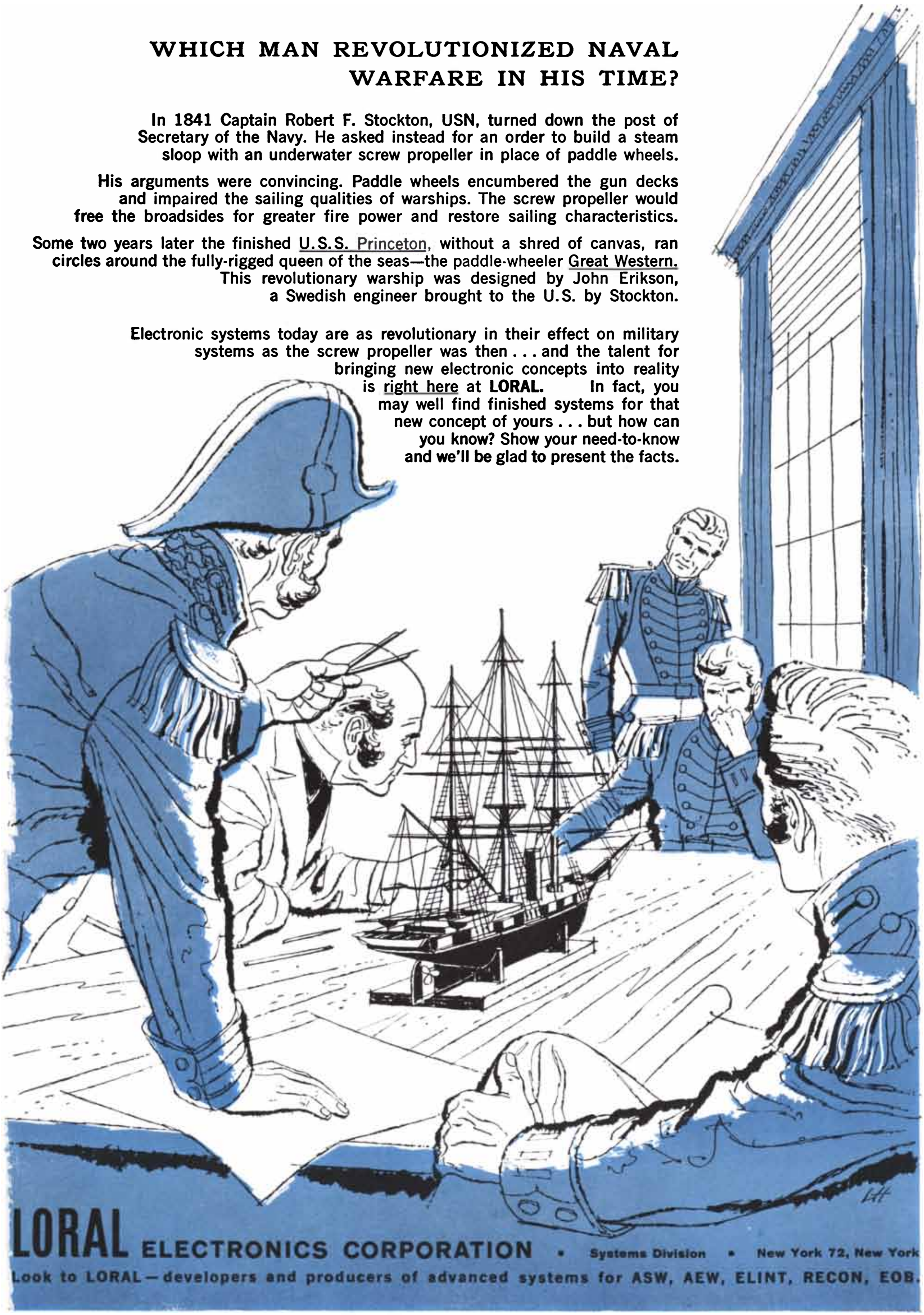
GROOMING ENCOUNTERS punctuate the prairie-dog day. All coterie members, young and old, male and female, groom each other. The practice probably serves to maintain friendly relations and provide precondition for social organization. Animals in top drawing rise after recognition kiss and begin grooming; then one lies down better to expose itself to the other. Later animals often go off to graze with their bodies pressed together.

threaten, the invaders run. But they do not run directly out of the territory; rather, they circle it while being chased and leave only when hard pressed, to return later. Each such encounter stops just short of combat and seems designed merely to test the residents' resistance. But ultimately the showdown comes and the invader fights the resident male. The victor takes, or reaffirms, possession of the territory and the vanquished is permanently driven away.

These and other trespasses impose a constant vigilance upon coterie members, especially upon the coterie's dominant male. He is constantly running about the territory and identifying the individuals in it, climbing atop mounds and rocks and surveying the territorial boundaries, and keeping a wary eye on the activities of neighboring coteries. Through zealous guarding of boundaries, the coterie maintains a discrete area in a large town, and with its epimeletic (care-giving) behavior achieves a stable, cohesive and amiable society.

High on the list of benefits that accrue to the coterie and the individual prairie dog through such cooperative behavior is control of vegetation, with its encouragement of bountiful weeds and elimination of grass cover for predators. Equally high is the more effective defense afforded by the common watch for danger and, with this, the protective advantage of common access to all burrows in a coterie territory. The coterie system has another decisive, though not so immediately apparent, role in the prairie dog's adaptation to its environment. The division of the town into coterie territories secures a uniform distribution of population that minimizes overgrazing. Within the coterie, another social mechanism protects the group from the disaster of overpopulation.

In an area of some five acres in the Shirttail Canyon town the July population in three successive years went from 44 to 28 to 82. Much of this fluctuation can be accounted for by breeding habits. In contrast to other rodents, which reproduce throughout a long breeding season, prairie dogs deliver only one litter of about five pups each year of their three or four years of life. Indeed, some females, at least in the northern ranges, may not breed at all during their first year. As a result the age composition of a coterie, its reproduction rate and its total numbers will vary greatly from year to year. This was the case in the town I observed, where the young constituted only 10 per cent of the population one year and about 70 per cent the next; as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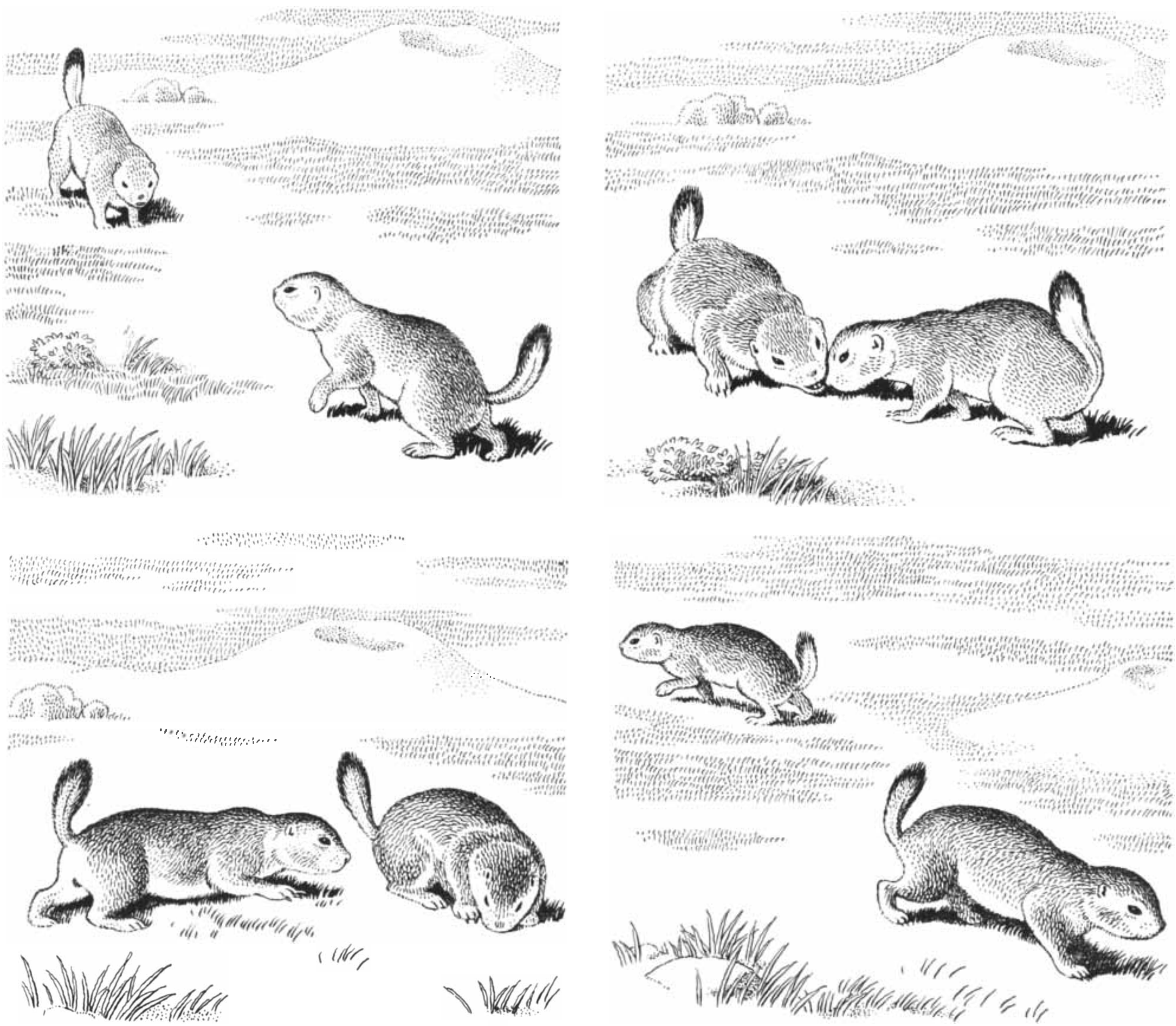
a result the population density increased from four per acre to 15 in three months. Such a population leap—almost fourfold in three months—might well seem a weakness in the prairie dog's social order; it could threaten both the food supply and the social order itself. But prairie dogs control population density by a singular mechanism: the emigration of the older generation from the coterie territory.

Though individuals may permanently depart from the coterie at any time, group emigration takes place less capriciously. Between March and May, the period of gestation and lactation, the coterie system breaks down and is replaced by individual nest-territories. The parturient females vehemently defend their nests against all intruders. They may associate with coterie members on neutral ground away from the nests, but the free access to all burrows that normally prevails in the coterie is now suspended. At this juncture some adults and yearlings begin to forage and construct burrows beyond the town's edge. They do this at intervals during the day, and at night return to their established homes. The daily migrations to the new suburbs continue through June. Then, as the young prairie dogs emerge from their burrows and require less care, the migrant adults spend more and more of the day at the new burrows and finally remain all night. They still come back into the old town occasionally, but the center of their activities has permanently changed. Not all such expansions are into unsettled areas. Emigrating adults may invade a neighboring coterie territory and take it over if its tenants are too few in number or fail to defend their rights. The expansion in population that I observed not only increased the size of the ward under my surveillance from five acres to more than seven; it also created new breeding assemblages as other prairie dogs, mostly yearlings, were attracted from the town's more remote sections. And the redistribution of population reduced the over-all density of the town from 15 to 11 prairie dogs per acre.

Population pressure was doubtless a factor in this emigration of coterie adults to new suburbs, though all the motivating factors are not yet clear. It may also be that the behavior of the young—their peculiar fondness for grooming and their tireless pursuit of attention from the



IDENTIFICATION KISS is exchanged whenever prairie dogs meet (*upper drawings*). If animals recognize each other, grooming encounters follow (*see drawings on page 134*); if they do not, the interloper usually turns and runs off. Here nonrecognition is followed by a tail-raising ritual in which the animals alternately sniff each other's anal glands (*lower left*), attempt to bite each other's rump, stalk off (*lower right*) and return to the ritual until one retreats a few feet. Rarely does either suffer more than a nip.

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GRAPHITAR® CARBON-GRAPHITE • GRAMIX® POWDER METALLURGY • MEXICAN® GRAPHITE PRODUCTS • USG® BRUSHES adults—played a part. Very rarely were the pups rebuffed. If disinclined to groom them, the adults walked away. But this was scarcely enough to discourage the overtures of the pups. Finally, with something that must border on exasperation, the adults started their emigration.

Such forbearance on the part of adults toward the young is an important feature of the social milieu that the young prairie dog enters when he leaves his burrow. Certainly it helps to account for the extremely low mortality-rate among the young (in one section of the town that I observed only one pup out of 58 died). Of equal consequence is the perpetuation of the prairie dogs' social habits. After leaving his birthplace the emergent pup meets his father and other members of the coterie and enters a pup paradise. He plays with his siblings and the other young. All the adults kiss and groom him as his mother does, and he responds to them as he does to her. He readily accepts foster mothers and may spend the night with their broods. He attempts to suckle adults indiscriminately—males as well as females. A female will submit quietly; the male gently thwarts him and grooms him instead, rolling him over on his back and running his teeth through the pup's belly fur. The pup's demands for this treatment increase as he grows. He follows the adults about, climbing on them, crawling under them, doing everything he can to entice an adult into a grooming session. Sometimes, if he fails to win attention, he may playfully jump at them, and they may enter into the game. Only on the rarest of occasions is he rebuffed by an importuned adult; seldom is he kicked or bitten or drubbed.

During these first pleasant weeks the pup may even meander into adjacent coterie territories with impunity. But as he begins to mature he wanders farther and his invasions meet with less forbearance. At first the receptions are mildly hostile, but they gradually grow more severe. Soon he comes to recognize the territorial boundaries and learns that not all prairie dogs treat him alike. At about this time he begins to originate and respond to territorial calls. When he utters them in foreign territory, the immediate reprisals soon teach him to confine them to his own territory. He learns further to associate the calls with safety and his own well-being. By this time he is more cautious when he enters strange territory, and if he is approached by a resident, he retreats to his own area. He begins to use the identification kiss to

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discriminate between coterie members and strangers. If his kiss is not returned by another animal in his territory, he treats it suspiciously, barks at it, runs up to smell it and then dashes off. As he grows older this behavior elaborates into the tail-spreading ritual.

By the end of summer the young prairie dog has become mature in the behavior that is essential to the social organization of the town. His fighting is less playful and more often resembles real hostility. His associations with adults are fewer because of their emigration to other areas. When he does encounter them, he may groom them as often as they do him. He keeps within his territory and invades only uninhabited areas. He guards his territory against invaders, particularly those of his own age, and when older prairie dogs invade, he barks as though calling for help. He has matured now, except in sexual behavior.

A yearling male that has not emigrated the year before may show interest in females during the breeding season, but he is probably checked by the adults. He may join with the migrating adults and leave his territory, or even try to go alone, and this may explain the high mortality of yearling males; their ratio to females, about 14 to 10 at birth, now drops to about six to 10. His sisters, probably not yet in heat, do not engage in sexual activities.

If the yearling male remains in the coterie until summer, his disputes with other coterie yearlings may increase, though he shows no antagonism to the adults or to the young pups now coming from the burrows. His restlessness grows and he invades other territories, constantly testing the combativeness of strange males. If he finds a weak neighbor, he may contest with him for the territory. Should he succeed, he dominates the other males in the new coterie, or they leave and try for new territories of their own.

In a newly settled area other prairie dogs may be attracted to his site. Yearling females, which have been crowded out of their old homes by the new crop of pups, or adult females departing from their young, may come to live with him. Other yearling males may immigrate. All bring the social order learned in their youth to the new territory. Strangers are repelled and acquaintances are recognized and cared for. By the next breeding season the male is sexually mature, and he mates with the females of his coterie. The social behavior and organization communicated to him as a pup he now passes on to the next generation.

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LICHENS

These humble incrustations of rocks, trees and soil are composed of two distinct organisms: a fungus and an alga. Together they are able to survive in some of the harshest environments on earth

by I. Mackenzie Lamb

Whenever we discuss the possibility that life exists in the harsh environment of the planet Mars, lichens enter the conversation. These humble plants occupy the most forbidding environments on earth: rocks just below the line of eternal snow on mountaintops, outcroppings not far from the North and South poles and, at the other extreme, sun-baked desert rocks too hot to place one's hand upon. Moreover, lichens are perennials *par excellence*, sometimes aptly described as "time stains." Certain lichen colonies have been estimated to be more than 2,000 years old—older than some of the oldest redwood trees. In keeping with their longevity and the poverty of their habitats, lichens grow very slowly. Members of a recent expedition to Antarctica noted that lichens observed on a cairn 30 years ago had not spread during that period to other exposed surfaces of the cairn.

The tenacity of lichens suggests that they must have an unusual biological makeup, a suggestion that is confirmed when they are examined closely. A lichen is not a simple plant, a single unit of plant life, but a duality. Two entirely different organisms—a fungus and an alga—associate to form a lichen. The teleological impulse is to call it a partnership. All available evidence indicates, however, that the fungus is a controlled parasite of the alga. Many fungi are parasites in any case; like animals they depend for their existence upon plants that can conduct the process of photosynthesis. Many live upon decaying vegetable and animal matter, all of which is ultimately derived from substances produced by photosynthetic cells. Most of the lichen fungi are more sophisticated parasites; they live in a remarkably stable biological equilibrium with photosynthetic plants, the algae, which they incorporate into their own structures. In this relationship the algal host usually suffers no appreciable harm, and in some cases it derives distinct advantages: it is shielded against excessive sunlight, desiccation and mechanical injury, and is supplied with inorganic substances necessary for its growth. As the alga grows in the lichen, some of the foodstuffs that it manufactures are diverted to satisfy the needs of the fungus.

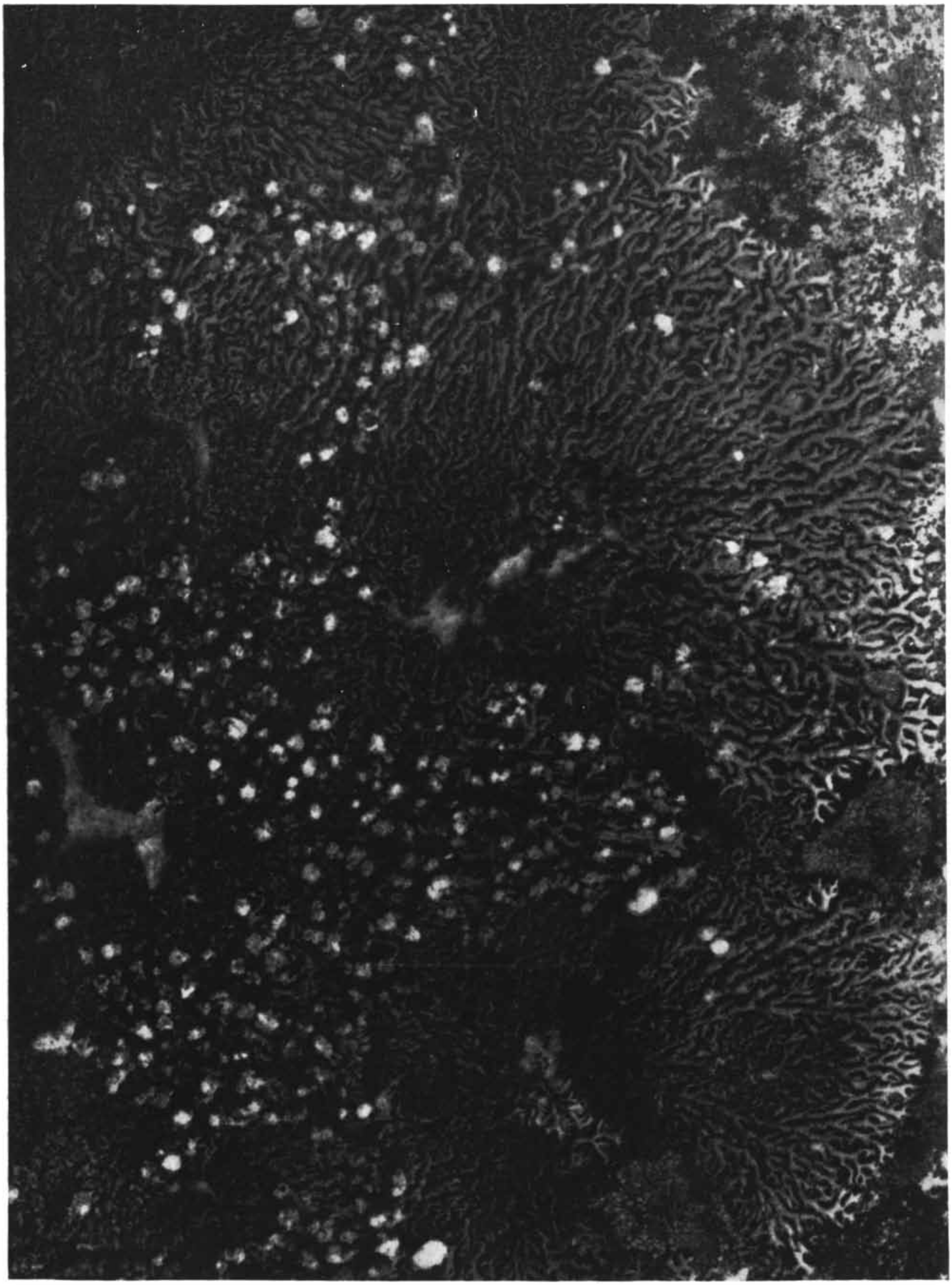
Of the two components of lichens, the algae have remained the least modified by the association. They belong to air-living groups of the blue-green algae (*Cyanophyceae*) or the green algae (*Chlorophyceae*). So far as is known, all lichen algae can, and many probably do, exist independently in nature. The lichenized fungi, on the other hand, have never been found in nature independent of their algae.

In a few tropical lichens the fungal member belongs to the group of mushrooms and bracket fungi (*Basidiomycetes*). These lichens form an insignificant group in comparison with those in which the fungal component belongs to the sac fungi (*Ascomycetes*). The sac fungi get their name from the club-shaped ascus, or sac, in which they form their reproductive spores. What role these spores play in the reproduction of lichens remains, as we shall see, one of the most intriguing mysteries in this realm of botany.

For all their obvious peculiarities lichens are really a highly specialized branch of the fungi. Unhappily the geological record can tell us little about how lichens evolved; lichens do not fossilize readily. From indirect evidence we deduce that they are not a primitive group. They seem rather to be a relatively recent product of evolution from the *Ascomycetes*, a fact that argues against their existence on Mars. Their radical evolutionary innovation—the employment of living algae to furnish them with the primary products of photosynthesis—has nonetheless enabled them to infiltrate ecological niches on earth where nothing else can survive. Liberated from dependence upon decaying organic matter, they proceeded to colonize bare rocks. Unlike other fungi, which die when their food supply is exhausted, the lichens became potentially perennial and even immortal. Subsequent evolution has slowed their rate of growth considerably below that of closely related fungi to bring it into equilibrium with the metabolism of their algal components. The development of tough, gelatinous tissue, microscopically attributable to a thickening and gelatinization of their cell walls, enables lichens to store enough water to survive prolonged periods of drought.

Hardy though they are, lichens have an Achilles heel. They are strongly susceptible to the substances with which man now pollutes the atmosphere. With the exception of a few inconspicuous "urban" species that grow on cement facings in metropolitan areas, lichens are disappearing from industrial regions. During the past century atmospheric pollution has wrought havoc with the lichen flora in Great Britain and the Low Countries, bringing about the local extinction of many species that were formerly abundant.

The dual nature of lichens was first propounded in 1867 by the Swiss botanist Simon Schwendener. Up to that time they had been regarded as simple organisms intermediate between algae and fungi, and many species had been described as such. Early taxonomists con-



LICHEN GROWING ON A ROCK has been enlarged about five diameters. This species, *Parmelia incurva*, has the branched structure typical of the foliose type of lichen. The pale outgrowths consist of dustlike particles that propagate the lichen asexually.

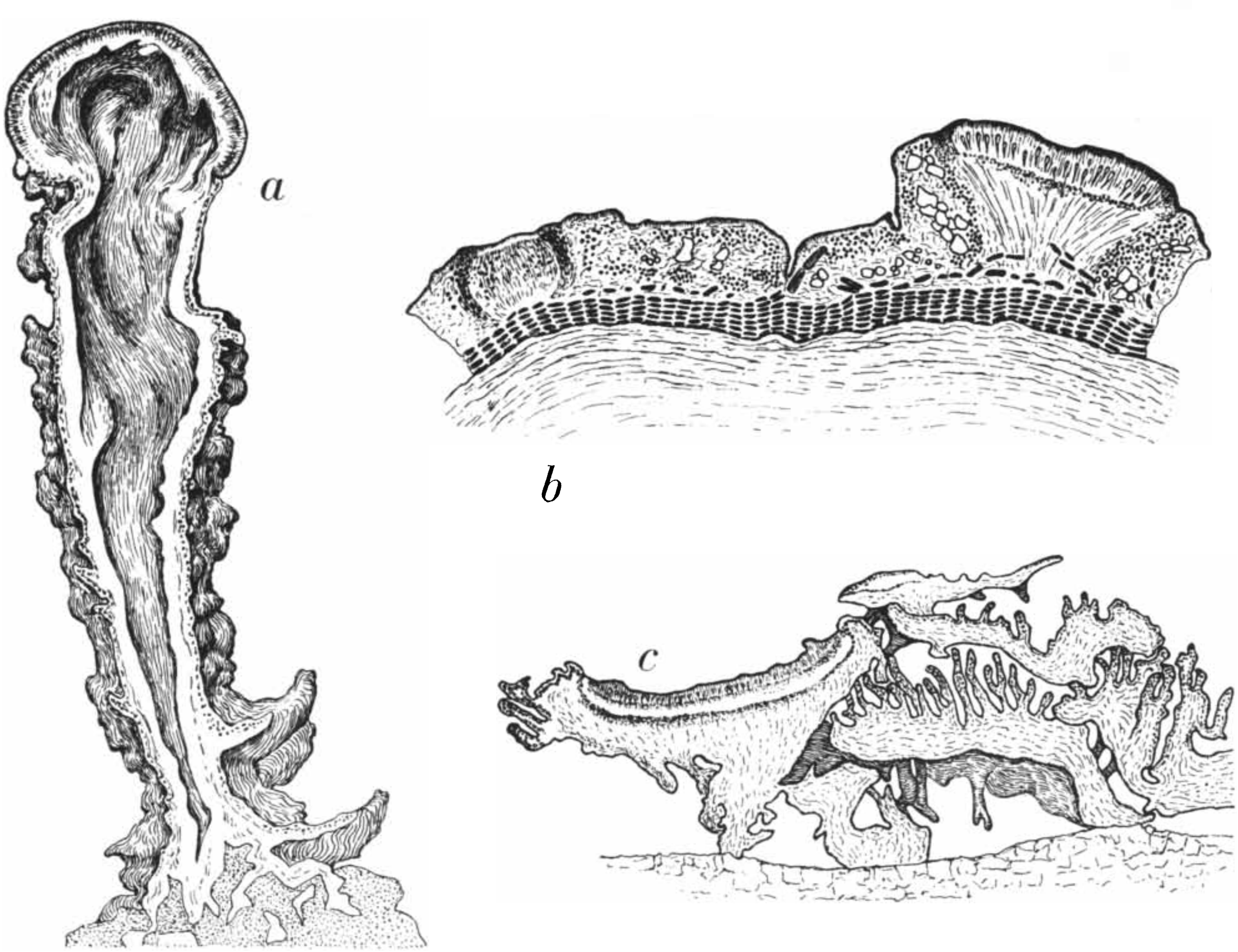
sidered the form and color of the algal cells as important criteria, and the use of these criteria in taxonomy persists even today. Some characteristics may indeed be attributable to the algal component. But there is logically no more justification for this method of classifying lichens than for the classification of other parasitic fungi by their host plants. The systematics of lichens are due for a radical overhaul in the next decade or so, with proper emphasis laid upon the fungal component.

In this connection some workers are troubled by a nice philosophical problem: Does the species name apply only to the compound organism? It is proposed by some that the fungal components, when isolated in laboratory cultures, should bear separate generic names, usually coined by adding the suffix *-myces* (from the Greek word for fungus) to the lichen name. Thus the fungal component of *Cladonia* would be *Cladoniomyces;* that of *Xanthoria, Xanthoriomyces,* and so on.

The relationship between the alga and the fungus in a lichen depends primarily upon the evolutionary status of the fungus. In primitive lichens fungal filaments actually penetrate the algal cells. In higher forms the cooperation of the two components is more subtle; the filamentary branches do not penetrate the algal cell wall but merely clasp it.

Among the more primitive lichens are those of the crustose type. They grow in flat patches that are firmly attached by their entire undersurface to soil, rock or bark, and they cannot be detached except in small fragments. Their thallus, or body structure, commonly cracks into bluish, greenish, yellow or gray islands, known as areolae, usually dispersed upon a basal black layer, the hypothallus. Some lichens take their form principally from their algal component, a filamentous blue-green alga (a species of *Nostoc*) which consists of chains of cells surrounded by thick mucilaginous sheaths. Among the algal chains the vegetative filaments of the fungus run in various directions. In dry weather such a lichen shrinks down to a wrinkled papery crust. When it is moistened by rain or dew, the algal sheaths quickly swell and the plant takes on a pulpy, gelatinous consistency.

More highly developed from the evolutionary standpoint are the foliose and fruticose lichens. The foliose types are leafy structures less firmly moored to their place of growth than the crustose; sometimes they are attached only by a single central umbilicus. The fruticose lichens grow directly from their platform in elongated stalks and strands, upright or pendulous. Most lichens of these two types contain single-celled green algae of the order *Chlorococcales*. Their structure is more highly differentiated; the algal cells are confined to a definite



THREE TYPES OF LICHEN are illustrated by these examples drawn in cut section. *Cladonia cristatella* (*a*), one of the fruticose lichens, forms stalks bearing a fruiting body at the top and is firmly rooted at the base to decayed wood or soil. *Lecanora chlarona* (*b*), which forms a closely adherent layer on bark, is a crustose type. Its fruiting body (*right side of drawing*) is not stalked. Foliose lichens such as *Parmelia fuliginosa* (*c*) are many-branched and are loosely attached to bark, rocks or soil by means of rootlike growths.

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Management is actively looking for engineers who have the desire and ability to become administrators

by James M. Jenks

In a sense, this is the golden age for engineers. Once buried in corporate obscurity, many of them have emerged today as likely heirs apparent to the big jobs — and the big rewards — of business and industry. One impressive indication of this growth is that money spent in research and development over the past fifteen years has increased six-fold.

Despite this stepped-up activity, however, the once disorganized scramble for engineers seems to have ended . . . at least temporarily. And perhaps it's a good thing. Actually, the more perceptive engineers had always realized that unusually high starting salaries were often illusory. The gap between money being offered beginners and the incomes of experienced men was narrowing rapidly. Further, more and more thinking technical men concluded that even top engineering salaries are low when compared with the remuneration of highly placed general executives.

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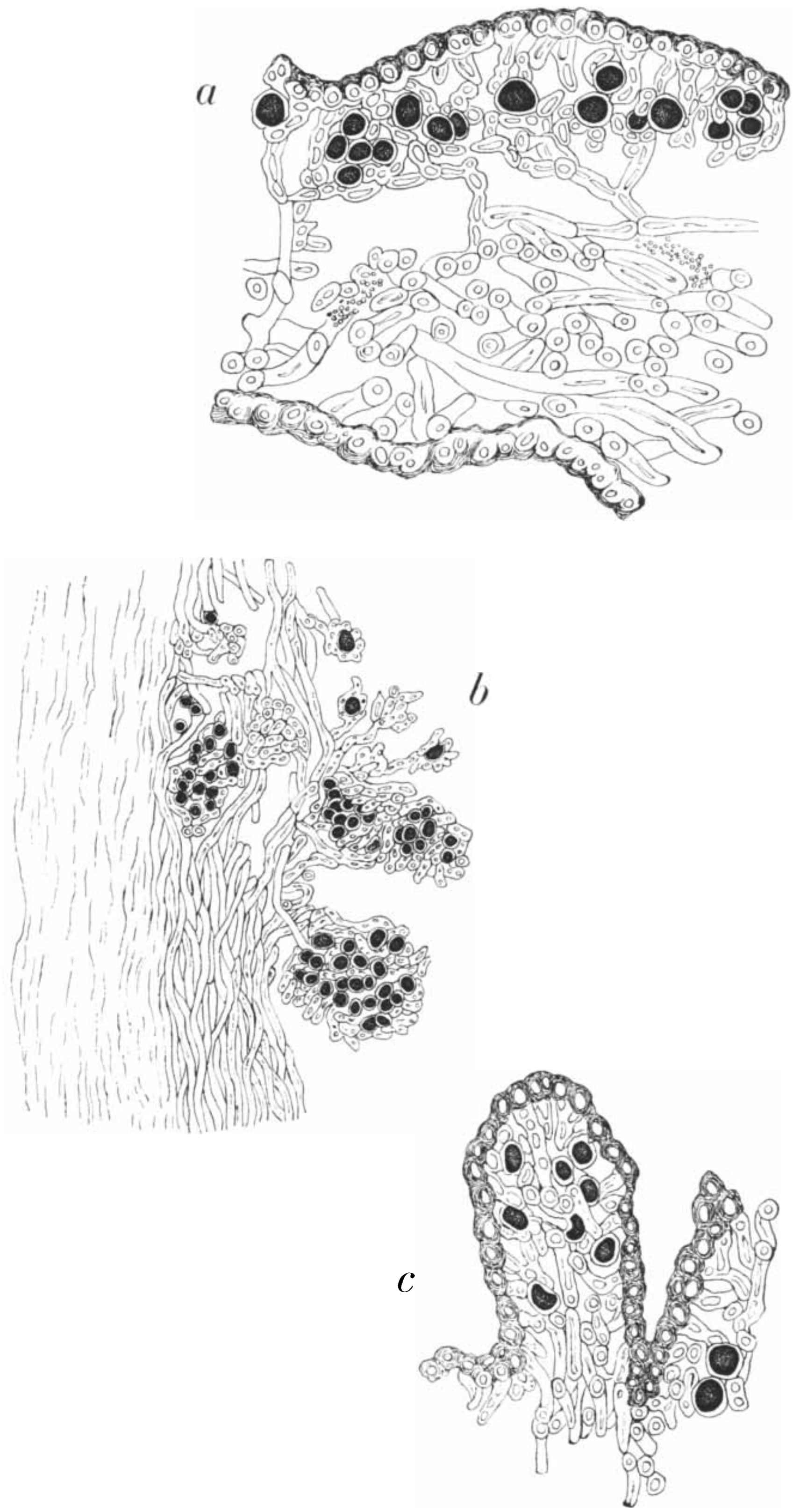

ASEXUAL REPRODUCTION is the principal method by which many lichens propagate. A broken portion of the lichen body or thallus (*a*) can grow into a new plant if it contains both algal (*black*) and fungal (*colorless*) cells. Some lichens produce special structures which are easily broken off and scattered. These may be particles formed by the dissolution of the outer layer of the lichen (*b*), or they may be small nodular outgrowths (*c*).

layer that is enclosed by fungal tissue and lies close to the outer surface of the plant. The fungal tissue also tends to differentiate into a tough outer rind and a loosely woven inner zone. The umbilicus that anchors some of the leafy lichens is produced by the fungal component. In the foliose and fruticose lichens only those fungal cells in contact with the algal component have the ability to assimilate the immediate products of photosynthesis. The other parts of the fungus serve primarily to protect and support the plant.

The spore-liberating reproductive sacs —if they can be called reproductive—resemble the asci of the corresponding nonlichenized species of *Ascomycetes*, and are borne in various types of fruitbody or receptacle. Some lichens bear globular or pear-shaped receptacles about a millimeter in diameter; the spores discharge through a narrow orifice at the top, often oozing out in a droplet of gluey slime. Others "fruit" with a larger saucer-shaped receptacle, blackish or brightly colored, in which rows of asci form the upper surface. In certain lichens these structures contain layers of algal cells and assimilative fungal cells, and so serve the function of photosynthesis as well as of spore-production.

The spores, coming from the fungal component alone, are liberated as fungal spores; they are accompanied by algae only in rare instances. If the spores are to give rise to normal lichen structures, they must encounter free-living algae of the appropriate kind. Such encounters, however, have never been satisfactorily observed. Algae of the appropriate species appear to be scarce outside of lichens. It is just possible that lichens, despite their prolific production of spores, no longer depend upon this process for reproduction. Are the spore sacs merely vestigial organs taken over from the free-living fungal ancestors of the lichens?

If this tentative suggestion (which is botanical heresy at present) corresponds with the facts, then lichens would have to possess some other means of propagation. This is indeed the case. The mechanical breakage of the thallus and the dispersal of its fragments by the wind and the feet of animals certainly accounts for much of the dissemination of lichens. Moreover, many lichens have accessory structures for vegetative propagation. Some produce cylindrical or branching outgrowths that contain all the necessary tissues of the fungus plus the symbiotic alga. Appearing on the surface of the lichen, these structures are actually lichens in miniature. They easily break loose when they are dry, and they

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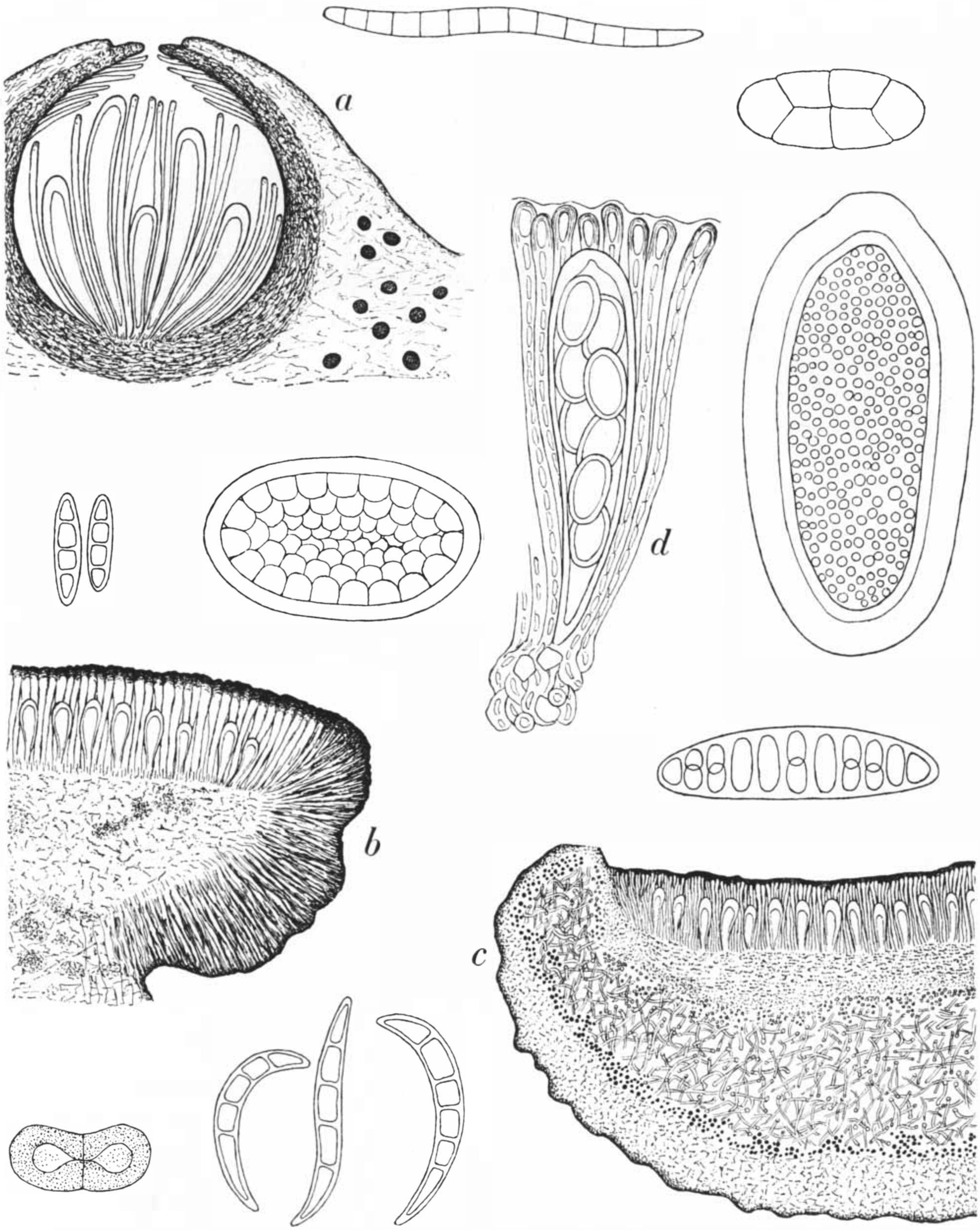


FRUITING BODIES of lichens produce spores only of the fungal component. The shapes of the fruiting bodies may vary from globular (*a*) to saucer-like (*b or c*). They may be formed entirely of fungal tissue (*b*) or may have algal cells (*black*) in their outer margins (*a and c*). The bulbous structures inside the fruiting bodies are spore sacs; a single spore sac with associated fungal filaments has been enlarged (*d*). Other structures in drawing are spores of various types, all highly magnified but drawn to same scale.

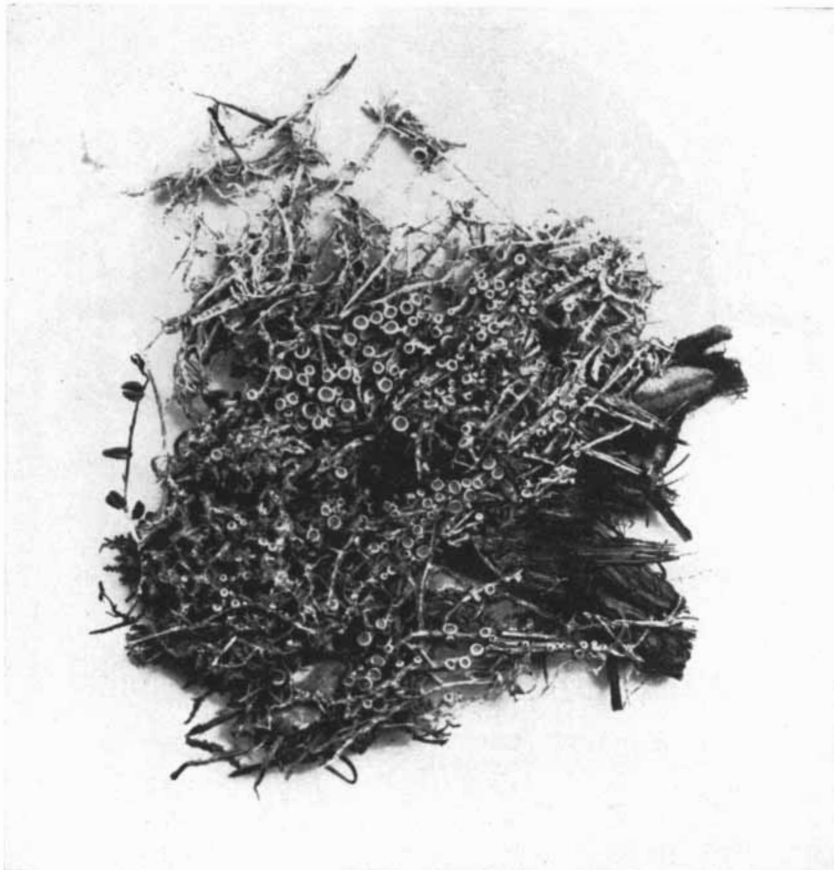
are capable of continuing their growth as soon as they come to rest in a suitable environment. Other lichens produce a less highly organized structure: minute powdery particles, each of which consists of a few algal cells enmeshed in a small weft of fungal filaments. They are borne in various ways on the thallus: on the surface in powdery mounds or furrows, or at the tips of lobes where, in some species, they are formed from internal tissue by the splitting open and eversion of the outer layer.

In spite of the obvious efficiency of these two accessory devices for vegetative reproduction, the lichens that possess them are not, on the whole, conspicuously more widespread in their distribution than those that do not. In fact, one of the commoner lichens found on rocks in eastern North America—the rock tripe (*Umbilicaria papulosa*)—has no such structure. Moreover, its spore sacs, which appear infrequently, contain spores which, at least under laboratory conditions, seem to be incapable of germination. The situation is enigmatic, unless we are to content ourselves with the notion that lichens are propagated by mere mechanical fragmentation and dispersal of the thallus.

It is possible to cultivate both the algal and fungal components of most lichens in the laboratory. This is not surprising in the case of the algae, for they or their close nonlichenized relatives can be found growing independently on stones and bark. Laboratory cultures show that they can also grow saprophytically, that is, by extracting organic substances from their environment without photosynthesis. In other words, they can thrive on nutrient media in total darkness and, surprisingly enough, retain their chlorophyll and green color.

The fungal component, never found alone in nature, presents a very different picture when cultured from spores in the laboratory. Such a culture is like the natural lichen only in the slowness of its growth. In most cases it otherwise exhibits no outward resemblance to the lichen thallus from which it came. No matter what sort of lichen produces the spores, they give rise to more or less undifferentiated mounds of dense whitish to brownish filamentous fungal tissue on the surface of the nutrient medium. These cultures have never been known to produce reproductive bodies with spores. They maintain only a slow and uneventful vegetative growth until the medium is exhausted or dries up.

Since each component can be grown



CRUSTOSE LICHEN of the genus *Ochrolechia* has cup-shaped fruiting bodies with algae in their pale outer margins. It grows on decaying plant matter in alpine and polar regions.

FOLIOSE LICHEN that has similar cup-shaped fruiting bodies belongs to the genus *Parmelia*. In some tropical species of *Parmelia* these fruiting bodies are up to an inch in diameter.

in the laboratory, the thought naturally occurs that it might be possible to synthesize or reconstruct a lichen by bringing its alga and fungus together in a culture. No one has really succeeded in doing so. Toward the end of the last century, it is true, the French botanist Gaston Bonnier claimed he had produced mature fruiting lichens of several species by sowing their algae together with their spores and nursing the cultures along for three or more years. But since his demonstration has never been duplicated, his claim is open to serious doubt, especially because he did not maintain pure cultures in any modern sense of the term.

More recent attempts, including some carried out in our laboratory at the Farlow Herbarium of Harvard University, have shown that one of the conditions necessary for the establishment of the first stages of lichen synthesis is starvation. Unless all organic nutrients, especially carbohydrates, are rigorously excluded, both fungus and alga continue to grow saprophytically. Even though they are intimately mingled, they show no tendency whatever to form an association. Accordingly we now commence a culture by placing a few green algal cells, all derived from one original cell, in a film of water on the underside of a thin glass cover-slip. The water contains only the necessary inorganic salts in very low concentration. In this medium we then sow a few spores from the same lichen, ejected directly from the spore sacs in a naturally aseptic condition. The cover-slip now forms the lid of a small, damp sterile chamber in which further developments may be followed under the microscope.

With suitable illumination the algae develop normally and reproduce themselves freely, both by nonmotile spores and by cells that swim actively by means of two whiplike flagella. Some of the motile cells may on occasion behave sexually, fusing in pairs. At the same time the fungal spores germinate and give rise to branching colorless filaments, which gradually use up the food reserves originally contained in the spores. Prior to the exhaustion of these reserves the filaments show no tendency whatever to seek out or become associated with the adjacent algal cells. There is no evidence that some hormonal substance diffused from the algae attracts the fungus. But after the fungal hyphae have lived a few weeks on air and water, starvation leaves its mark on them: they exhibit straggling, highly evacuated and often abnormally bloated segments. At this point they put out short side branches that

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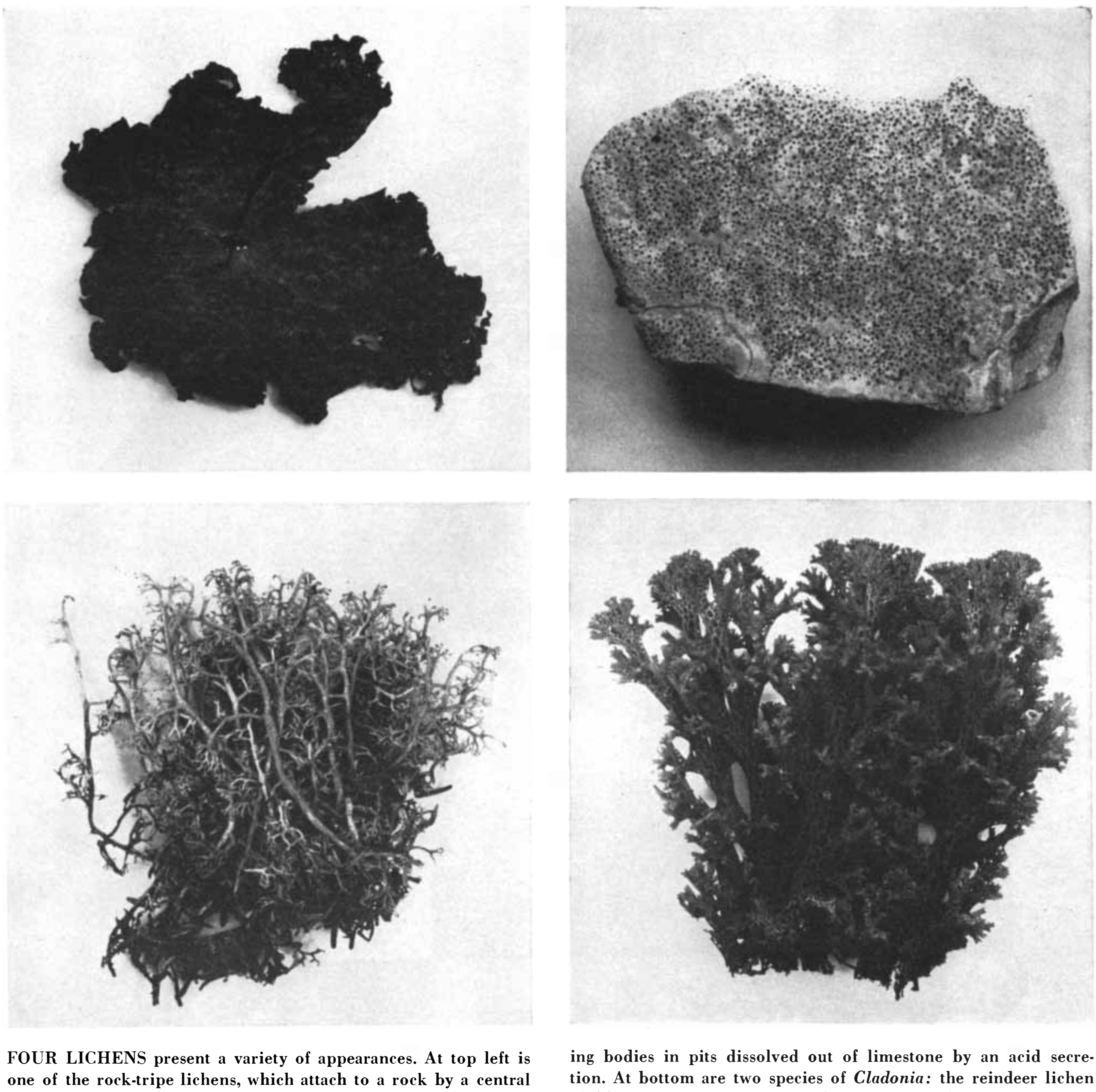
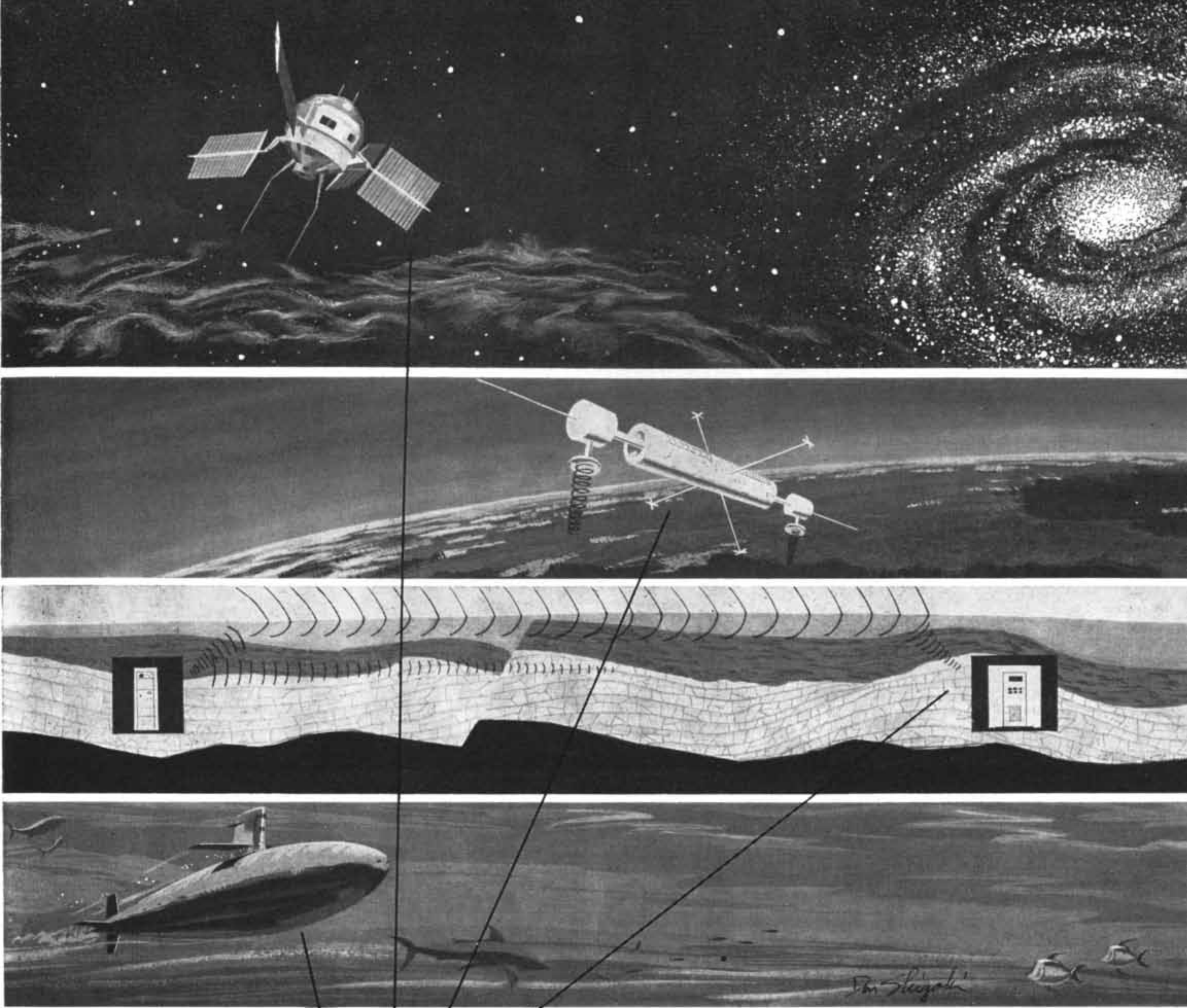
make close contact with the walls of the green algal cells. Such connections become progressively more frequent and begin to resemble those observed in the intact lichen. After a month or so a close weft of fungal filaments, with numerous connections to algal cells, takes shape, and there may even be signs of morphological differentiation in the fungal tissues.

This is as far as we have been able to go at present. Further progress would seem to depend on our ability to simulate the varied and quite complex ecological factors necessary to the lichen in its natural environment. We may find that we must duplicate the surfaces on which lichens grow and somehow imitate the alternate wetting and drying to which most lichens are subjected in their natural environment. And we must of course provide ample time—half a human life-span if necessary—to allow the extremely slow-growing host and parasite to attain their full development. No crash programs can be scheduled in lichen synthesis. The experience in the laboratory certainly casts doubt upon the possibility of synthesis in nature through the accidental union of a spore and an algal cell.

Laboratory investigators are now looking for another challenging aspect of the lichen fungi. It may be that the pioneer activity of lichens in colonizing bare rocks plays a significant role in the formation of soil. The lichens as a group are distinguished from their nonlichenized relatives among the sac fungi by their capacity to produce a number of organic acids that are extremely rare in other plants and animals. Most of these lichen compounds have fairly complex molecules that comprise the familiar six-sided benzene ring. Some are brightly colored and give certain lichens a vivid yellow or orange-red tinge. These characteristic lichen acids seem in most cases to be secreted by the fungus alone, and some of them have been obtained in the



FOUR LICHENS present a variety of appearances. At top left is one of the rock-tripe lichens, which attach to a rock by a central holdfast. At top right is a pyrenocarp lichen, which embeds its fruiting bodies in pits dissolved out of limestone by an acid secretion. At bottom are two species of *Cladonia:* the reindeer lichen (*left*) and a perforated species that is found in Australia and Asia.



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ALGAL CELLS GROWING IN STERILE WATER are clasped by a fungal filament that has exhausted its food supply. This photomicrograph thus demonstrates that at least the first step in synthesizing a lichen from separated algae and fungi can be induced experimentally. In this case the investigator used the components of *Lecanora*, a crustose lichen.

laboratory from pure cultures of fungus without algae. Their significance in the economy of the lichen is not yet fully understood, and it is quite possible that they are merely by-products of the fungal metabolism. It is possible, however, that in nature these acids may disintegrate rock by the selective sequestration of the chemical elements of the rock.

Recent attempts to use the past growth of lichens as an indicator of climate and time have met with a considerable measure of success; lichens provide evidence on the age of glacial moraines, of lava flows and of ancient human monuments. On the whole, however, lichens have few uses for man. Reindeer lichens (*Cladonia rangiferina* and related species) serve as fodder for caribou and reindeer in arctic Canada, Scandinavia and Lapland. In times of famine various lichens have been ground up into meal and baked into "lichen bread," but their peculiar carbohydrates (mainly lichenin) are so indigestible that they make a poor substitute for other articles of diet. The "manna" of the Israelites is thought to have been a lichen of a type that becomes detached from its moorings and rounds up into balls that are blown by the wind for long distances over the deserts of Asia Minor. Lichens were once widely used as a source of dyes, but have now been largely superseded by synthetic aniline products. Litmus, used in the indicator paper familiar to chemistry students, and orcein, another reagent, are still obtained from lichens. The perfume industry continues to make use of lichens in various fragrances, the most widely employed species (*Evernia prunastri*) being known to the trade in France as *mousse de chêne* (oak moss).

What lichens lack in utility they make up in scientific interest. The biology of lichens abounds in unsolved problems of deep significance. They present a case, almost unique in the plant world, of highly controlled parasitism, maintained by the complementarity of the nutritional needs of parasite and host. The lichen is in fact a fungus that imitates a green plant by using another plant to make up for its own inability to conduct photosynthesis. Whether it exists on other planets or not, it presents a living monogram of life on earth.

creating controls

Descartes

This extraordinary Frenchman is principally remembered for his invention of analytic geometry, but he attempted far more. His aim was nothing less than to reduce nature to mathematical law

by A. C. Crombie

"I should consider that I know nothing about physics if I were able to explain only how things *might* be, and were unable to demonstrate that they *could not be otherwise*. For, having reduced physics to mathematics, the demonstration is now possible, and I think that I can do it within the small compass of my knowledge."

With these words René Descartes declared the viewpoint that placed him among the principal revolutionaries in the 17th-century scientific revolution. Against the "forms" and "qualities" of Aristotelian physics, which had proved to be a blind alley, he asserted the "clear and fundamental idea" that the physical world was sheer mechanism and nothing else. Because the ultimate laws of nature were the laws of mechanics, everything in nature could ultimately be reduced to the rearrangement of particles moving according to these laws. In analytical geometry, perhaps Descartes' most enduring achievement, he created a technique for expressing these laws in algebraic equations. He thus put forward the ideal program of all theoretical science: to construct from the smallest number of principles a system to cover all the known facts and to lead to the discovery of new facts.

All subsequent theoretical physics has been aimed at the realization of this ideal of a single theoretical system in which the last details of observable regularities should be shown to be deducible from a minimum number of fundamental equations, written perhaps on a single page. Blaise Pascal and Isaac Newton may certainly be said to have carried on in the 17th century the Cartesian program of looking for the explanation of the physical world in terms of its mechanism. In this century we have witnessed attempts at universal theories by Albert Einstein and Werner Heisenberg, among others. In the vision of Descartes, however, his indisputable first principles—"nearly all so evident that it is only necessary to understand them in order to assent to them"—were not the end but the beginning of the search.

There can be no doubt of the revolutionary character and influence of Descartes' theoretical insights and program. The paradox is that he should have exercised so profound an influence over men who found his approach essentially distasteful and who rejected some of the most important of his fundamental assumptions and detailed conclusions. Christiaan Huygens, the great Dutch mathematician and astronomer whose father had been an intimate friend of Descartes, admitted late in life that he could no longer accept any but a small part of Cartesian physics. But he said that it was Descartes' *Principles of Philosophy* that first opened his eyes to science. Descartes, he said, had not only exposed the failure of the old philosophy but had offered "in its place causes which one could understand for all that exists in nature." As is so often the case with revolutionists, the legacy of Descartes was not only achievement but also prophecy and vision.

Descartes himself came to recognize that his purely deductive, mathematical ideal for science had failed in the face of the complexities of nature and the enigmas of matter. This failure was especially apparent in physiology, the field into which he ventured most daringly. Out of failure and compromise, however, Descartes extracted another contribution to scientific thinking in many ways as important as the original theoretical program itself. Forced to turn to experiment and hypothesis, he showed himself to be the first great master of the hypothetical model. This has become an essential tool in all scientific investigation. In his theoretical models of physiological processes Descartes displayed the most ingenious exercises of his imaginative and experimental genius.

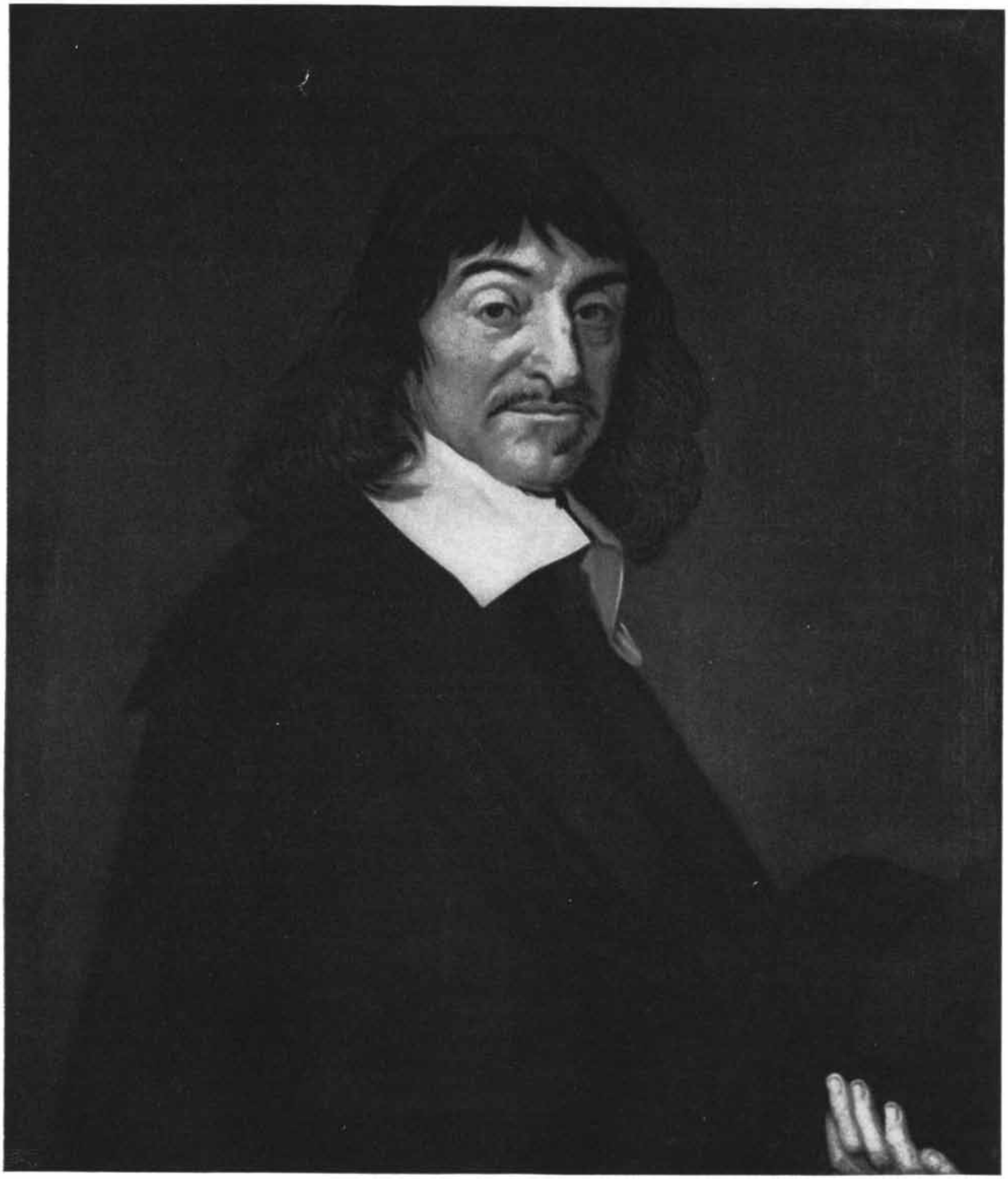
René Descartes was born on March 31, 1596, at La Haye, a small and attractive town on the river Creuse in Touraine. His family were of the *petite-noblesse*, long in government service; his father was counselor to the *Parlement* of Brittany. From his mother, who died a month after his birth, he inherited "a dry cough and a pale complexion," which he kept until he was over 20. He also inherited property from her that gave him complete financial independence. Because he was a delicate child, it was thought that he would not live long. But he used his enforced inactivity to indulge an early passion for study.

When he was 10, his father sent him to the newly established Jesuit college of La Flèche, where he remained for eight and a half years and received an excellent education that embraced logic, moral philosophy, physics and metaphysics, classical geometry and modern algebra, as well as an acquaintance with the recent telescopic work of Galileo. All the main characteristics of his mind appeared precociously at La Flèche. Introduced to the classics, he fell in love with poetry. Far from being a "geometer who is only a geometer" (Pascal's description of him), Descartes himself wrote in an early essay, the *Olympica:* "There are sentences in the writings of the poets more serious than in those of the philosophers. The reason is that the poets wrote through enthusiasm and power of imagination. There are in us, as in a flint, seeds of knowledge. Philosophers adduce them through the reason;

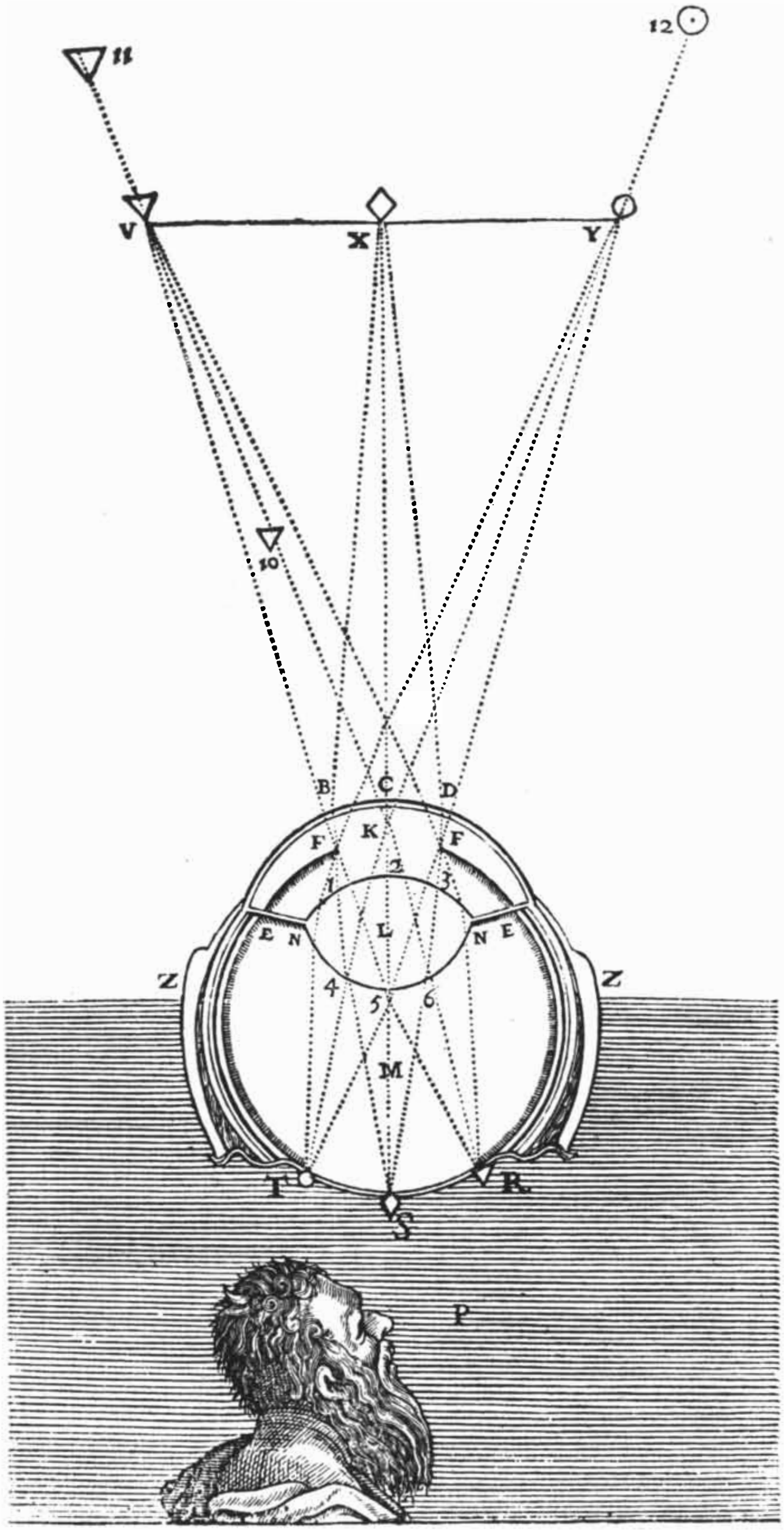
poets strike them out from the imagination, and these are the brighter."

Mental facility was one of Descartes' most striking and perhaps more dangerous gifts. A fellow pupil described his prowess in argument. He would first get his opponents to agree on definitions and the meaning of accepted principles, and then he would build up a single deductive argument that was very difficult to shake. At La Flèche he also acquired a habit that persisted throughout his life. He was excused from certain work and allowed to lie late in bed. Here he found it possible to indulge most fully his natural inclination to solitary concentrated thought.

When he was 20, having graduated in law from the University of Poitiers, Descartes went to Paris. Here he became a young man of fashion somewhat



PORTRAIT OF DESCARTES by Frans Hals hangs in the Louvre. Among the fields that he worked in were physiology, psychology, optics and astronomy. Many consider him the father of modern philosophy. He died in 1650 while tutor to the Queen of Sweden.



DESCARTES' EYE INVESTIGATIONS included removing the retina from the eye of an ox and replacing it with thin paper or eggshell so that he could study the image. This illustration is reproduced from Descartes' book *Dioptrics*, which was first published in 1637.

at a loose end. Soon, however, his thoughts returned to mathematics and philosophy. He was encouraged by his more serious friends, among them the Minim friar Marin Mersenne, whom Descartes had known at La Flèche. Mersenne was himself a competent mathematician and a skillful experimenter. His cell in the convent of the *Place Royale* was to become the meeting place of *savants*, an antecedent of the Academy of Sciences founded later in the century. Mersenne came to have a vast correspondence, of which only part has been published, and thus became a center of scientific intelligence in the days before there were any scientific journals. He also translated Galileo's *Dialogue* and *Discourses* into French, the former in 1634, the year after Galileo's condemnation. Until the end of his life Mersenne remained Descartes' principal friend, and after Descartes left France for good in 1628 Mersenne kept him posted with scientific news from Paris.

In 1618 Descartes joined the army of Prince Maurice of Nassau (later Prince of Orange) as a gentleman volunteer. He was sent to the garrison at Breda in the Netherlands, there being at that time a truce between the Franco-Dutch forces and the Spaniards, whose rule the Low Countries were throwing off. His scientific interests were such as were appropriate for an officer: ballistics, acoustics, perspective, military engineering, navigation.

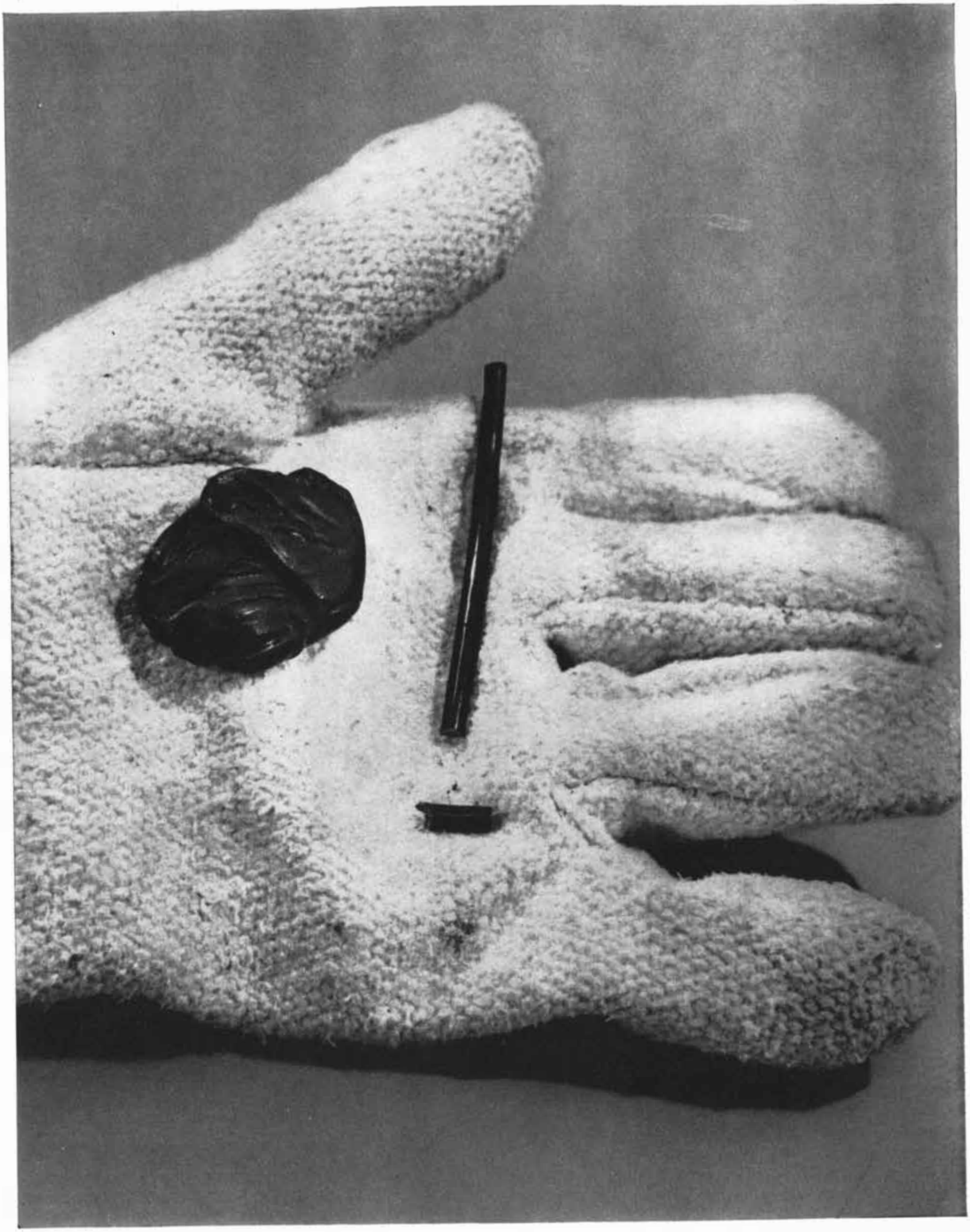
One day—November 10, 1618—he came upon a group of people gathered about a notice pinned up in the street. It was in Flemish, and turning to someone in the group, Descartes asked him to translate it into Latin or French. The notice proved to be a challenge inviting all comers to solve the mathematical problem that it proposed. The man whom Descartes had asked to translate it was Isaac Beeckman, one of the country's leading mathematicians. Descartes solved the problem and presented his solution to Beeckman, who at once recognized the young man's mathematical genius and set out to revive his interest in theoretical problems. During that winter Beeckman proposed that Descartes should find the mathematical law of the acceleration of falling bodies. Neither knew that Galileo had in fact already solved this problem; his solution was to appear in his *Dialogue on the Two Principal Systems of the World* in 1632. Descartes produced solutions based on different assumptions. That none of them described the way bodies actually fall did not concern him. He had not yet learned to unite mathematical analysis with experiment.

We are indebted to Beeckman's journal, discovered in 1905, for a flood of light on this period of Descartes' life. It was a time of self-discovery; the young man's mind moved with incredible speed over a broad assortment of questions. Descartes now got on the track of the method by which he was to attempt the unification of human knowledge upon a single, central set of premises.

On March 26, 1619, Descartes reported to Beeckman "an entirely new science which will allow of a general solution of all problems that can be proposed in any and every kind of quantity, continuous or discontinuous, each in accordance with its nature . . . so that almost nothing will remain to be discovered in geometry." This was Descartes' announcement of his discovery of analytical geometry or, as Voltaire was to describe it, "the method of giving algebraic equations to curves." Descartes' 14th-century countryman Nicole Oresme may have contributed something toward this idea. In the 17th century Descartes' contemporary Pierre de Fermat was to make the same discovery quite independently, but he did not follow it up. Descartes did not publish his "new science" until 1637, when he included in his essay *Geometry* both an exposition of the principles and several particular applications. Its generality is there shown in Descartes' demonstration that the conic sections of Apollonius are all contained in a single set of quadratic equations. Since conic sections include the circles of the ancient astronomers, the ellipses of Johannes Kepler, and the parabola used by Galileo to describe the trajectory of a projectile, it is plain that Descartes' first invention placed a powerful tool in the hands of physicists. Without it Newton himself would have suffered a crippling handicap.

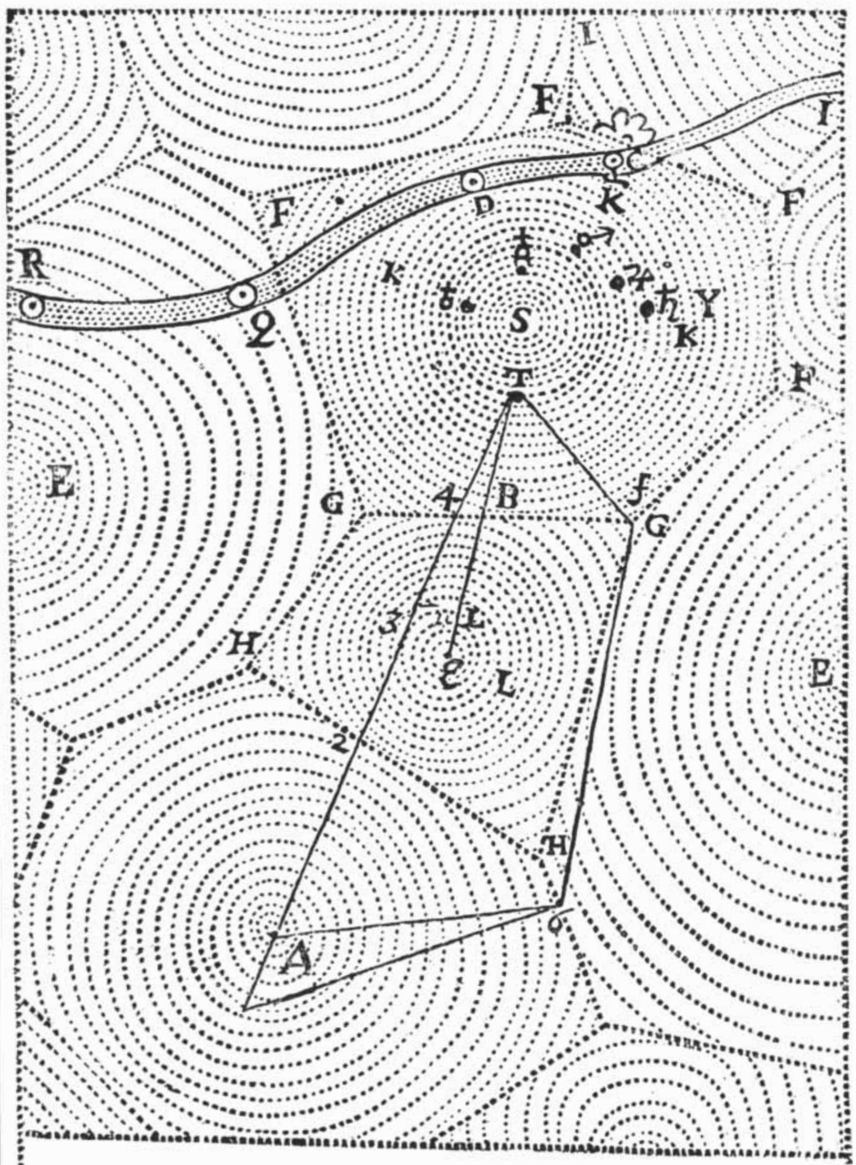
Exactly a year after his meeting with Beeckman, Descartes had a celebrated experience, perhaps the most important and certainly the most dramatic of his whole life. He had joined the army of the Duke of Bavaria, another of France's allies in the Thirty Years' War, and found himself in winter quarters at a remote place on the Danube. Much occupied with his thoughts, he spent the whole of November 10 shut up alone in the famous *poêle* (literally "stove," but actually an overheated room). In the course of the day he made two important decisions. First, he decided that he must

Solid Fuels are simple—



methodically doubt everything he knew about physics and all other organized knowledge, and look for self-evident, certain starting points from which he could reconstruct all the sciences. Second, he decided that just as a perfect work of art or architecture is always the product of one master hand, so he must carry out the whole of this program himself.

That night, according to his 17th-century biographer Adrien Baillet, Descartes had three dreams. First he found himself in a street swept by a fierce wind. He was unable to stand because of a weakness in his right leg, but companions near him stood up firmly. He awoke, and fell asleep again; he was reawakened by dreaming that he had heard a clap of thunder and had found the room full of sparks. He fell asleep once more and dreamt that he had found a dictionary on his table. Then, in another book, his eye "fell upon the words *Quid vitae sectabor iter?* [What way of life shall I follow?]. At the same time a man he did not know presented him with some verses beginning with the words *Est et non*, which he recommended highly to him." These words Descartes recognized as the opening lines of two poems by Ausonius. Even before Descartes had finally awakened he had begun to interpret the first dream as a warning against past errors, the second as the descent of the spirit of truth to take possession of



SYSTEM OF VORTEXES with which Descartes sought to account for the motions of the heavenly bodies consisted of whirlpools of "ether." In the case of the solar system the vortex carried the planets around the sun (S). Irregular path across top of the illustration is a comet, the motions of which Descartes believed could not be reduced to a uniform law.

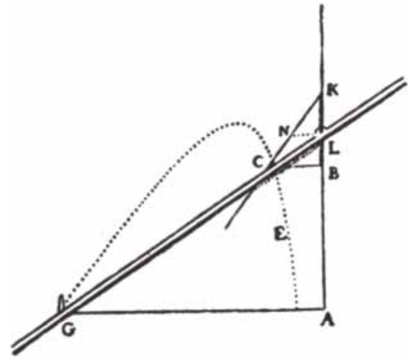
him, and the third as the opening to him of the treasures of all the sciences and the path of true knowledge. However this incident may have been elaborated in the telling by Baillet, it stands as a symbol of Descartes' certainty in the rightness of his approach to true knowledge.

He went on soldiering until 1622, seeing action at the battle of Prague and the sieges of Pressburg and Neuhäusel. Then for a few years he was a traveler, ranging over Europe from Poland to Italy and returning at last to Paris in 1625. There he rejoined the circle round Mersenne, worked at his "universal mathematics," and engaged in speculations on many subjects from moral psychology to the prolongation of life. From such pursuits he was distracted, in the fashion of his leisured contemporaries, by the social whirlpool and by music, idle reading and gambling. His father expressed the opinion that he was "not good for anything but to be bound in buckskin."

Then an incident occurred that turned Descartes' vision into his life's mission. He found himself present, along with a fashionable and impressive audience including his friend Mersenne and the influential Cardinal de Bérulle, at the house of the papal nuncio to hear a certain Chandoux expound his "new philosophy." Descartes alone did not join in the applause. Pressed to give his opinion, he spoke at length, demonstrating how it was possible for a clever man to establish an apparently convincing case for a proposition and also for its opposite, and showing that by using what he called his "natural method" even mediocre thinkers could reach principles that were found to be true. His hearers were astonished. When Descartes visited Bérulle a few days later, the cardinal charged him to devote his life to working out the application of his method in philosophy and in "mechanics and medicine."

In October, 1628, Descartes left for the Netherlands, where he remained for the rest of his life except for three short visits to France and his last journey to Stockholm in 1649. He avoided the company of everyone but his intimate friends and disciples, and dedicated his time to the application of his principles in philosophy, science and mathematics and to the dissemination of his conclusions. Within a year of finally leaving the Netherlands at the invitation of Queen Christina of Sweden, he died in Stockholm in February, 1650.

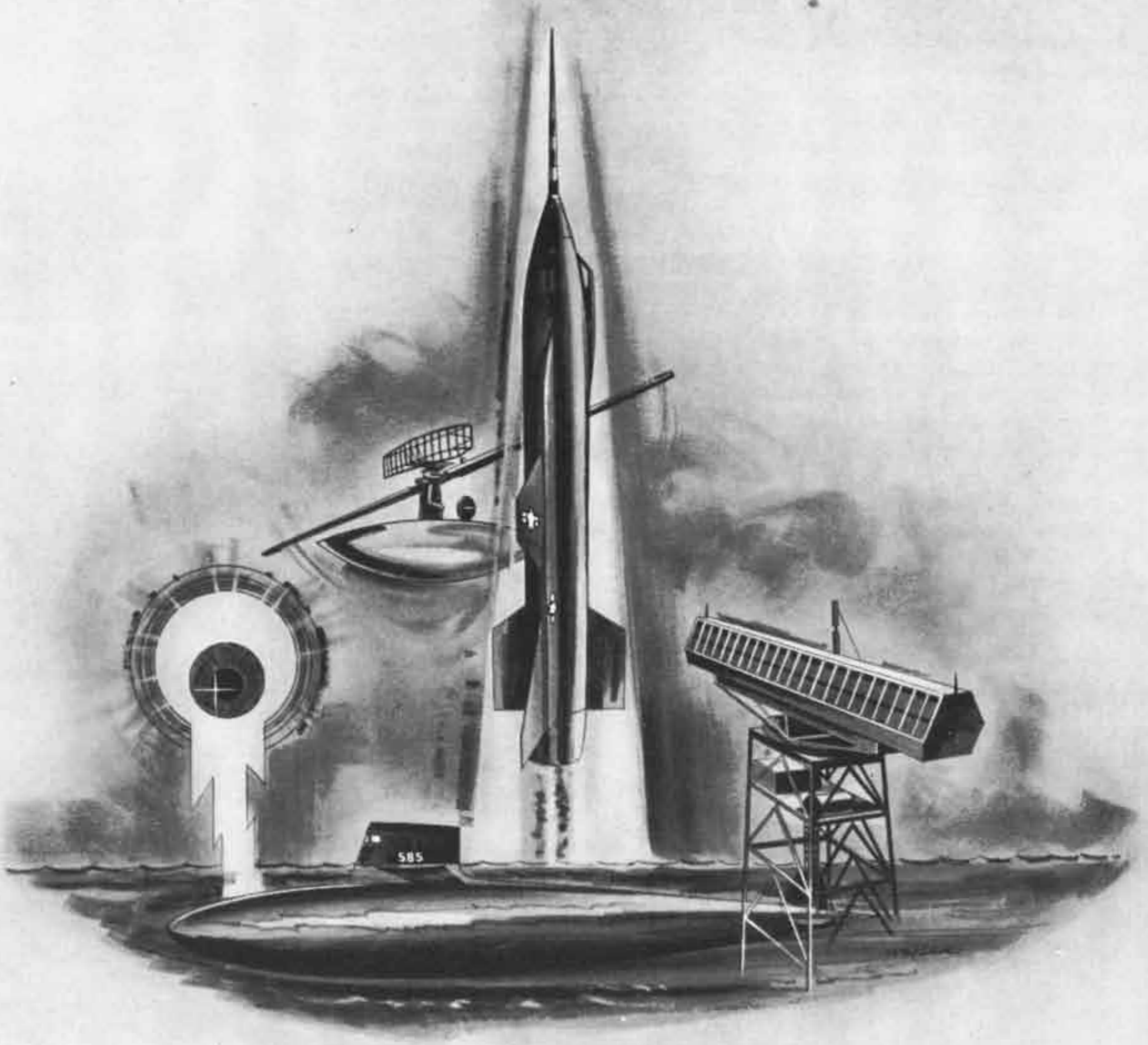
Descartes may be described as a centrifugal thinker: he moved primarily outward from a firm central theoretical point, in diametrical contrast to thinkers like Francis Bacon or Isaac Newton. The French writer and amateur of science Bernard le Bovier de Fontenelle, in the well-known *Eloge de Newton* written on Newton's death, drew an eloquent contrast between the methods of Newton and Descartes:



DESCARTES' GEOMETRY is, in Voltaire's words, "a method of giving algebraic equations to curves." Illustration is from a page in which equation for parabola is discussed.

"The two great men so placed in opposition had much in common. Both were geniuses of the first order, born to dominate the minds of others and to found empires. Both, being outstanding geometers, saw the need to carry geometry into physics. Both founded their physics on a geometry which they developed almost single-handed. But the one [Descartes] tried in one bold leap to put himself at the source of everything, to make himself master of the first principles by means of certain clear and fundamental ideas, so that he could then simply descend to the phenomena of Nature as to necessary consequences of these principles. The other [Newton], more timid or more modest, began his journey by leaning upon the phenomena in order to mount up unknown principles, resolved to admit them only in such a way that they could yield the chain of consequences. The one set out from what he knew clearly, in order to find the cause of what he saw. The other set out from what he saw, in order to find the cause."

The primary direction and movement of Descartes' philosophical and scientific enterprise are shown by the sequence in which he composed his major works. From 1618 to 1628, during the restless years of military life, travel and dissipation, he worked out his conception of true science and his highly rationalistic method for attaining it. These he de-



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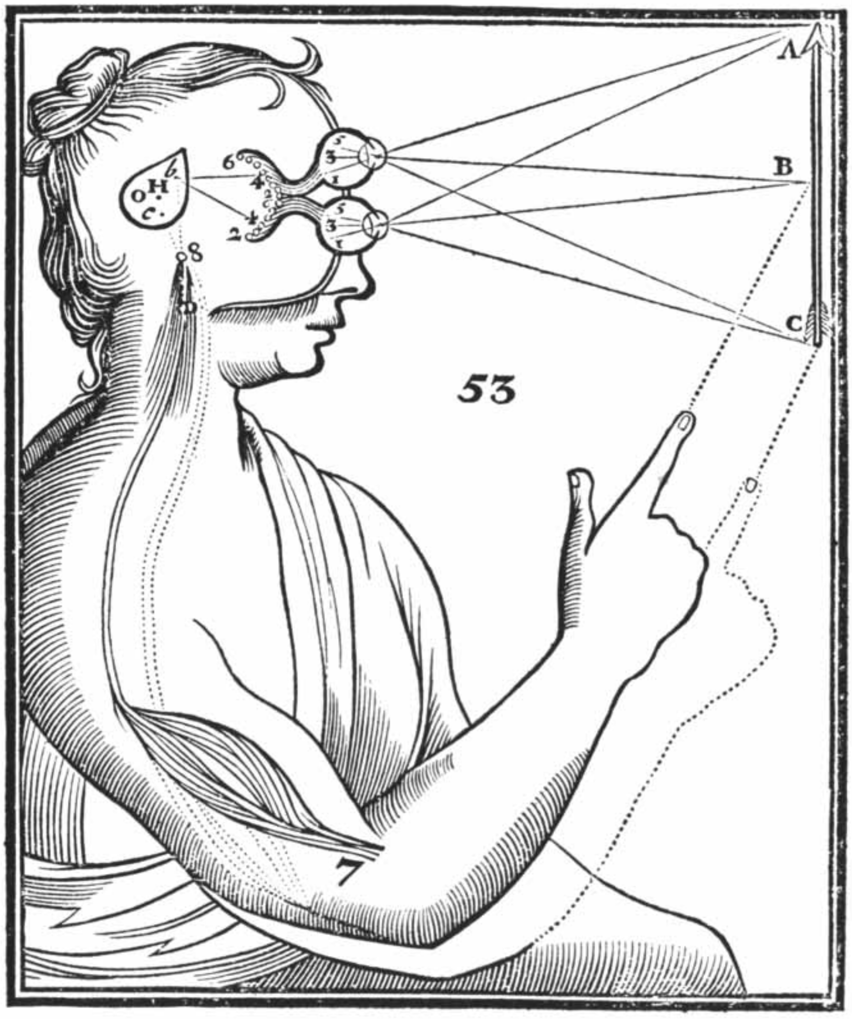
SUBMARINE SIGNAL | AIRBORNE ELECTRONIC | SYSTEMS MANAGEMENT | HEAVY ELECTRONIC | SANTA BARBARA scribed in his first work, *Rules for the Direction of the Mind*, finished in 1628 but published posthumously, and in the *Discourse on Method*, which he wrote after settling in the Netherlands. Before completing the latter he began work on the *Meteors*, the *Dioptrics* and the *Geometry*, which he presented as three illustrations of the power of the method applied to specific lines of investigation, when they were published with the *Discourse* in 1637. Meanwhile, by 1628, he had turned to the next stage of his investigations, the discovery of first principles. These he propounded in his *Meditations on First Philosophy*, published in 1641. From first principles he moved on quickly to the elaboration of his cosmology, which he completed in *Le Monde* in 1633, but withheld from publication upon the news of Galileo's condemnation. A revised version, with its Copernicanism mitigated by the idea that all motion is relative, was published in 1644 under the title *Principles of Philosophy*. At the same time Descartes was working out his conception of the relationship between the mind and the machinery of the body, and in his last work, *Passions of the Soul* (completed in 1649), he brought psychology within the compass of his system.

Perhaps the most revealing illustration of the power of his method is Descartes' *Dioptrics*. He characteristically announces at the outset that he intends to solve the problem of constructing a telescope on rational scientific principles. Accordingly he undertakes first an analysis of the nature of light: space is filled with fine contiguous globules of matter, forming a kind of "ether"; light is a mechanical phenomenon, an instantane-



CENTRAL ROLE OF THE PINEAL GLAND in Descartes' physiology is diagrammed in *l'Homme*. Images fall on retinas (*5, 3, 1*) and are conveyed to the cerebral ventricles (*6, 4, 2*); these then form a single binocular image on the pineal gland (*H*), the site from which the soul controls the body. Stimulated by the image, the soul inclines the pineal gland, activating the "hydraulic system" of the nerves (*8*), causing a muscle to move (at *7*).

ous pressure transmitted through this "ether" from a luminous source. Descartes then gives an elegant geometrical demonstration of the laws of reflection and refraction. Some years earlier the Dutch physicist Willebrord Snell had discovered the correct sine law of refraction, but he had not published it. Descartes' demonstration of what is now known as Snell's Law was almost certainly independent; he was the first to publish it.

Since the purpose of a telescope is to increase the power of vision, Descartes next makes a detailed analysis of the human eye in both its normal and its pathological states. For this, as his correspondence shows us, he conducted extensive studies and dissections. Repeating an experiment made by Christoph Scheiner, he removed the back of an ox's eye, replaced it with thin white paper or eggshell, and examined the reversed image cast upon it of an object placed in front of the eye. The whole investigation shows considerable anatomical knowledge and experimental skill; Descartes describes the functioning of the iris, the ciliary muscle, binocular vision, optical illusions and various forms of coordination and accommodation.

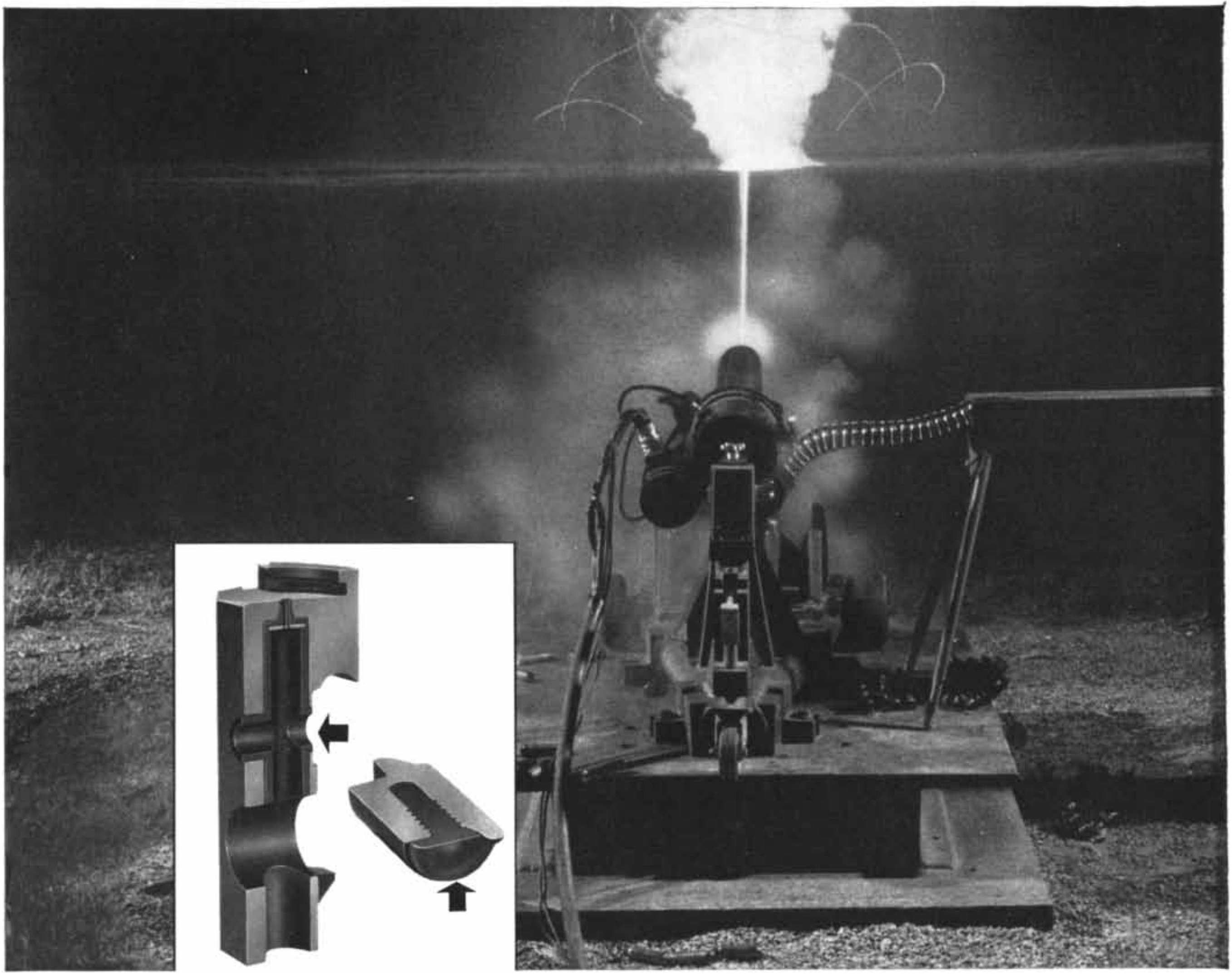
He now considered himself to be in a position, denied to Kepler and Galileo, to show scientifically what the curvatures of the lenses used in constructing a telescope should be. He concluded that their cross sections should be either hyperbolas or ellipses. He did not of course allow for chromatic aberration, a problem not then understood. Finally he gives a description of a machine designed to cut lenses on these scientific principles.

From a long correspondence between Descartes and a French spectacle-maker named Ferrier we know how this unfortunate man tried and failed to put Descartes' ideas into practice. In the end no actual telescope was constructed on Descartes' theoretical principles.

The essential structure and content of Descartes' physics and cosmology derive from the revolutionary conclusions at which he arrived soon after his retirement to the Netherlands in 1628. He found the basis for the possibility and certainty of knowledge in the fact of thought itself. This elemental fact, apprehended with "clarity and distinctness," became his criterion for determining whether or not anything else was true. The "qualities" of classical philosophy, apprehended by mere sensation, he found not to be clear and distinct. Thus he eliminated from the world outside everything but extension—the one measurable aspect of things and hence their true nature. This division of the world into the two mutually exclusive and collectively exhaustive realms of thought and extension enabled Descartes to offer what he regarded as a true science of nature. The task of science was now to deduce from these first principles the causes of everything that happens, just as a mathematics is deduced from its premises.

It was the very breadth of this program—which in effect declares that the whole of physical nature may ultimately be reduced to and comprehended by the laws of motion—that gave Descartes' work its revolutionary scientific importance. Descartes himself offered explanations, in terms of the motions of particles of various shapes and sizes, of chemical properties and combinations, taste and smell, heat, magnetism, light, the operation of the heart and nervous system as the source of action of the mechanism of the body, and many other phenomena that he investigated by sometimes rather naive experiments. The vastness of this program was its undoing; Descartes simply had no time to go into all these questions accurately and quantitatively. Coming from the author of a mathematizing program, Descartes' general physics and cosmology are surprisingly almost entirely qualitative. He was forced to fall back on speculation far beyond "the small compass of my knowledge," with the result that he came to fear that he had produced, to use his own phrase, nothing more than a beautiful "romance of nature."

His most disastrous failure occurred in fact at the very center of his program, in the laws of motion themselves. He had reached his conclusion that the essential property of matter was extension in space by a process of purely rational analysis. Since his method *a priori* ruled out other possibilities, it did not leave the question open to empirical test. From this supposedly firm basis he then proceeded to construct a system of mechanics that left out important facts, notably those included in what became the Newtonian notion of "mass." His mechanics certainly contains some valuable conclusions; for example, his account of the conservation of motion and his enunciation of an equivalent of the principle of inertia. But geometrically identical bodies of different masses do not behave identically when they collide or interact in other ways. Descartes' treatment of this subject was disastrously wrong because his antecedent analy-



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sis of matter into mere extension was itself mistaken.

In order to explain how the planets were kept in their orbits, Descartes put forward his famous vortex theory, according to which the fine matter of the "ether" forms great whirlpools or vortexes round the stars and the sun. The planets are carried about in the sun's vortex, rather like a set of children's boats in the celestial bathwater, and the moon is carried round the earth in the same way. The astonishing thing is that Descartes did not bother to check whether or not this very important part of his physical system agreed with the facts as expressed by Kepler's laws of planetary motion. It was Newton who destroyed Descartes' famous vortex theory. In fact, he may have chosen the title *Principia Mathematica* to give point to his polemic against Descartes' *Principia Philosophiae.* Newton treated the vortex theory as a serious problem of fluid dynamics and utterly demolished it.

Descartes' subsequent reputation as a mere speculator has been kept going largely by historians of mechanics writing under the influence of Newtonian polemics. But if we turn from Descartes' mechanics to his physiology we can observe him at work in a field where the qualitative hypotheses on which he had fallen back in dealing with other subjects yielded results more worthy of him.

Descartes is rightly ranked with William Harvey as a founder of modern physiology. Harvey was a master of experimental analysis, but Descartes introduced the master-hypothesis on which all subsequent physiology has been based. Having divided the world into extension and thought, Descartes was able to regard biology as a branch of mechanics and nothing else. In modern terms this view asserts that living organisms are in the last analysis explicable in terms of the physics and chemistry of their parts. In man, according to Descartes, the realm of thought makes contact with the extended body at a single point: the pineal gland in the brain.

Descartes' correspondence shows that during his long residence in the Netherlands he spent much time in making anatomical dissections. He found biology the most defeating of all the fields into which he tried to carry his explanations by means of mechanical principles. It is in this field that he found experiment most necessary, both to acquire information and to choose between different possible explanations of the same phenomenon. Although he accepted Harvey's discovery of the circulation of the blood, he engaged somewhat unsuccessfully in a controversy with him over the mechanism of the heart's action, each bringing forward a crucial experiment to establish his explanation. Descartes was wrong in fact, but he made the essential point that a full explanation of the heart's action cannot simply start with the fact that it is beating, but must try to account for this fact in terms of the underlying mechanism—ultimately in terms of the laws of motion common to all matter.

Although Descartes' mechanistic explanation of this still-obscure phenomenon now seems rather naive, the method by which he attacked it and the working of the machine of the body as a whole introduced one of the most powerful tools of all modern physiological research. This was the hypothetical model. Descartes' physiological writings contain many good observations and some brilliant mechanistic explanations of such phenomena as automatic actions like blinking and the coordination of different muscles in complicated movements such as walking. He was inclined to sacrifice real anatomy to the hypothetical anatomy demanded by his mechanism. But he always said explicitly that he was describing a hypothetical body to imitate the actions of the real body, just as a modern investigator will build an electronic machine to imitate the processes of the brain.

Descartes set out to produce a true science of nature in which everything would follow mathematically from self-evident first principles. Modern physicists, of course, reject the idea that the principles of physics can be self-evidently certain. Even in the 17th century Pascal and Huygens made the same criticism. They pointed out that there is an essential difference between physics and abstract mathematics in that the principles of physics, which explores the unknown in the concrete world of fact, are always exposed to complete or partial invalidation by the discovery of new facts.

Descartes, moving outward from his central principles, had himself come to appreciate the point made by Pascal and Huygens, and to realize that his mathematical ideal of unilinear deduction had broken down because of the difficulty of connecting abstract general principles with the particulars of fact. Yet as a positive scientific thinker he was perhaps not so different from his successors in our time. His search was for the causes and meaning of no less than everything that occurs.

MATHEMATICAL GAMES

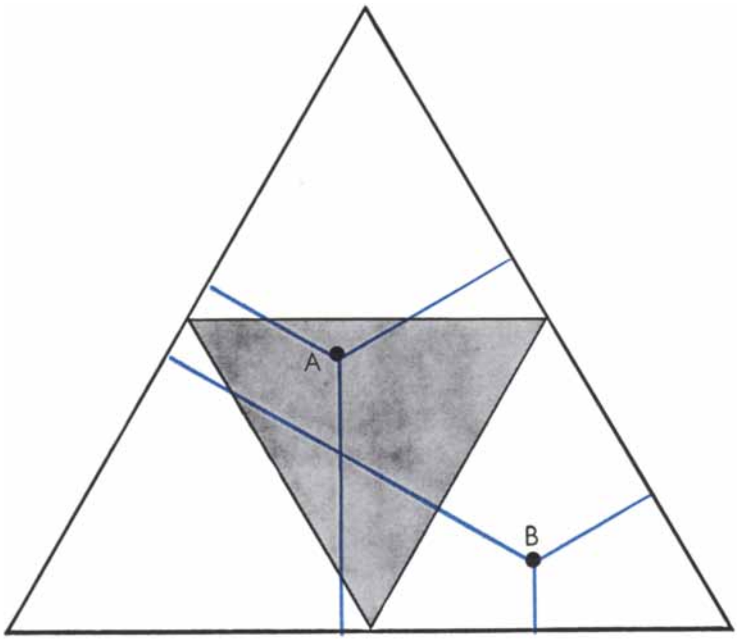
Problems involving questions of probability and ambiguity

by Martin Gardner

Charles Sanders Peirce once observed that in no other branch of mathematics is it so easy for experts to blunder as in probability theory. History bears this out. Leibniz thought it just as easy to throw 12 with a pair of dice as to throw 11. Jean le Rond d'Alembert, the great 18th-century French mathematician, could not see that the results of tossing a coin three times are the same as tossing three coins at once, and he believed (as many amateur gamblers persist in believing) that after a long run of heads, a tail is more likely.

Today probability theory provides clear, unequivocal answers to simple questions of this sort, but only when the experimental procedure involved is precisely defined. A failure to do this is a common source of confusion in many recreational problems dealing with chance. A classic example is the problem of the broken stick. If a stick is broken at random into three pieces, what is the probability that the pieces can be put together in a triangle? This cannot be answered without additional information about the exact method of breaking to be used.

One method is to select, independently and at random, two points from the points that range uniformly along the stick, then break the stick at these two points. If this is the procedure to be followed, the answer is 1/4, and there is an elegant way of demonstrating it with a geometrical diagram. We draw an equilateral triangle, then connect the midpoints of the sides to form a smaller shaded equilateral triangle in the center [*see illustration below*]. If we take any point in the large triangle and draw perpendiculars to the three sides, the sum of these three lines will be constant and equal to the altitude of the large triangle. When this point, like point A, is *inside* the shaded triangle, no one of the three perpendiculars will be longer than the sum of the other two. There-



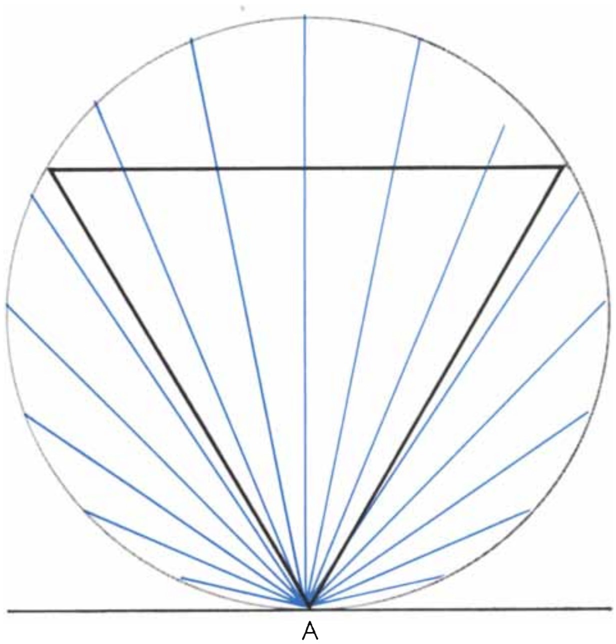
If a stick is broken in three pieces, probability is 1/4 that they will form a triangle

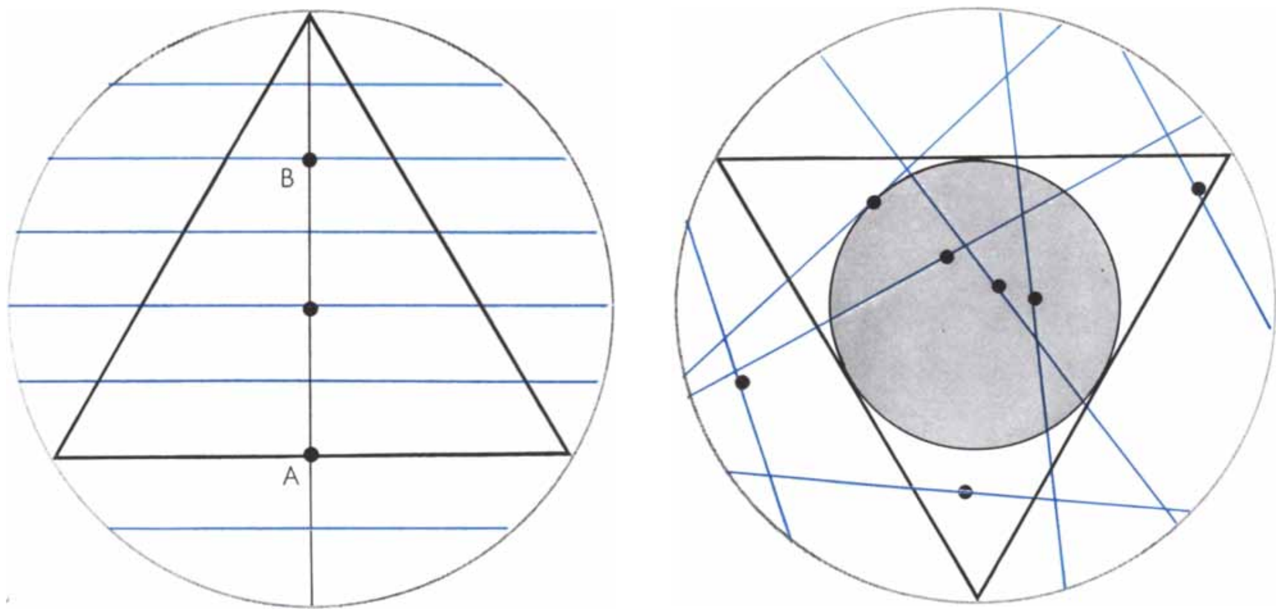
fore the three line-segments will form a triangle. On the other hand, if the point, like point B, is *outside* the shaded triangle, one perpendicular is sure to be longer than the sum of the other two, and consequently no triangle can be formed with the three line-segments.

We now have a neat geometrical analogy to the problem of the broken stick. The sum of the three perpendiculars corresponds to the length of the stick. Each point on the large triangle represents a unique way of breaking the stick, the three perpendiculars corresponding to the three broken pieces. The probability of breaking the stick favorably is the same as the probability of selecting a point at random and finding that its three perpendiculars will form a triangle. As we have seen, this happens only when the point is inside the shaded triangle. Since this area is one fourth the total area, the probability is 1/4.

Suppose, however, that we interpret in a different way the statement "break a stick at random into three pieces." We break the stick at random, we select randomly one of the two pieces, and we break that piece at random. What are the chances that the three pieces will form a triangle? The same diagram will provide the answer. If after the first break we choose the smaller piece, no triangle is possible. What happens when we pick the larger piece? Let the vertical perpendicular in the diagram represent the smaller piece. In order for this line to be smaller than the sum of the other two perpendiculars, the point where the lines meet cannot be inside the small triangle at the top of the diagram. It must range uniformly over the lower three triangles. The shaded triangle continues to represent favorable points, but now it is only one third the area under consideration. The chances, therefore, are 1/3 that when we break the larger piece, the three pieces will form a triangle. Since our chance of picking the larger piece is 1/2, the answer to the original question is the product of 1/2 and 1/3, or 1/6.

Geometrical diagrams of this sort must be used with caution because they too can be fraught with ambiguity. For example, consider this problem discussed by Joseph Bertrand in a famous 19th-century French work on probabili-





Probability that random chord is longer than side of inscribed equilateral triangle is proved to be 1/3 (top), 1/2 (left) and 1/4 (right)

ty. What is the probability that a chord drawn at random inside a circle will be longer than the side of an equilateral triangle inscribed in the circle?

We can answer as follows. The chord must start at some point on the circumference. We call this point A, then draw a tangent to the circle at A, as shown in the top illustration on page 176. The other end of the chord will range uniformly over the circumference, generating an infinite series of equally probable chords, samples of which are shown on the illustration as colored lines. It is clear that only those chords that cut across the triangle are longer than the side of the triangle. Since the angle of the triangle at A is 60 degrees, and since all possible chords lie within a 180-degree range, the chances of drawing a chord larger than the side of the triangle must be 60/180, or 1/3.

Now let us approach the same problem a bit differently. The chord we draw must be perpendicular to one of the circle's diameters. We draw the diameter, then add the triangle as shown in the illustration at bottom left on page 176. All chords perpendicular to this diameter will pass through a point that ranges uniformly along the diameter. Samples of these chords are again shown in color. It is not hard to prove that the distance from the center of the circle to A is half the radius. Let B mark the midpoint on the other side of the diameter. It is now easy to see that only those chords crossing the diameter between A and B will be longer than the side of the triangle. Since AB is half the diameter, we obtain an answer to our problem of 1/2.

Here is a third approach. The midpoint of the chord will range uniformly over the entire space within the circle. A study of the illustration at bottom right on page 176 will convince you that only chords whose midpoints lie within the smaller shaded circle are longer than the side of the triangle. The area of the small circle is exactly one fourth the area of the large circle, so the answer to our problem now appears to be 1/4.

Which of the three answers is right? Each is correct in reference to a certain mechanical procedure for drawing a chord at random. The problem as originally stated is ambiguous. It has no answer until the meaning of "draw a chord at random" is made precise by a description of the procedure to be followed. Apparently nothing resembling any of the three procedures is actually adopted by most people when they are asked to draw a random chord. In an interesting unpublished paper entitled "The Human Organism as a Random Mechanism"

Oliver L. Lacey, professor of psychology at the University of Alabama, reports on a test which showed the probability to be much better than 1/2 that a subject would draw a chord longer than the side of the inscribed triangle.

Another example of ambiguity arising from a failure to specify the randomizing procedure appeared in this department last May. Readers were told that Mr. Smith had two children, at least one of whom was a boy, and were asked to calculate the probability that both were boys. Many readers correctly pointed out that the answer depends on the procedure by which the information "at least one is a boy" is obtained. If from all families with two children, at least one of whom is a boy, a family is chosen at random, then the answer is 1/3. But there is another procedure that leads to exactly the same statement of the problem. From families with two children, one family is selected at random. If both children are boys, the informant says "at least one is a boy." If both are girls, he says "at least one is a girl." And if both sexes are represented, he picks a child at random and says "at least one is a . . .," naming the child picked. When *this* procedure is followed, the probability that both children are of the same sex is clearly 1/2. (This is easy to see because the informant makes a statement in each of the four cases—BB, BG, GB, GG—and in half of these cases both children are of the same sex.) That the best of mathematicians can overlook such ambiguities is indicated by the fact that this problem, in unanswerable form, appears in one of the best of recent college textbooks on modern mathematics.

A wonderfully confusing little problem involving three prisoners and a warden, even more difficult to state unambiguously, is now making the rounds. Three men—A, B and C—were in separate cells under sentence of death when the governor decided to pardon one of them. He wrote their names on three slips of paper, shook the slips in a hat, drew out one of them and telephoned the warden, requesting that the name of the lucky man be kept secret for several days. Rumor of this reached prisoner A. When the warden made his morning rounds, A tried to persuade the warden to tell him who had been pardoned. The warden refused.

"Then tell me," said A, "the name of one of the others who will be executed. If B is to be pardoned, give me C's name. If C is to be pardoned, give me B's name. And if I'm to be pardoned, flip a coin to decide whether to name B or C."

"But if you see me flip the coin," re-

plied the wary warden, "you'll know that you're the one pardoned. And if you see that I don't flip a coin, you'll know it's either you or the person I don't name."

"Then don't tell me now," said A. "Tell me tomorrow morning."

The warden, who knew nothing about probability theory, thought it over that night and decided that if he followed the procedure suggested by A, it would give A no help whatever in estimating his survival chances. So next morning he told A that B was going to be executed.

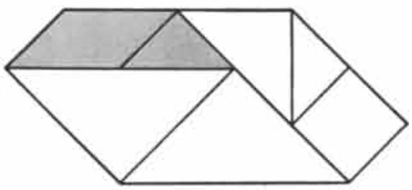
After the warden left, A smiled to himself at the warden's stupidity. There were now only two equally probable elements in what mathematicians like to call the "sample space" of the problem. Either C would be pardoned or himself, so by all the laws of conditional probability, his chances of survival had gone up from 1/3 to 1/2.

The warden did not know that A could communicate with C, in an adjacent cell, by tapping in code on a water pipe. This A proceeded to do, explaining to C exactly what he had said to the warden and what the warden had said to him. C was equally overjoyed with the news because he figured, by the same reasoning used by A, that his own survival chances had also risen to 1/2.

Did the two men reason correctly? If not, how should each calculate his chances of being pardoned? An analysis of this bewildering problem will be given next month.

The tangram hexagon, usually the hardest to find of the 13 possible convex tangrams that readers were challenged to find last month, is depicted in the illustration below. The solution is unique except for the fact that the two shaded pieces may be transposed.

The peg-jumping puzzle is solved in 46 moves as follows: 10–8–7–9–12–6–3–9–15–16–10–8–9–11–14–12–6–5–8–2–1–7–9–11–17–16–10–13–12–6–4–7–9–10–8–2–3–9–15–12–6–9–11–10–8–9. At the halfway point the black and white counters form a symmetrical pattern on the board. The remaining moves repeat in reverse order the pattern of moves in the first half.



Answer to last month's tangram problem

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Arthur Shef, Chief, Advanced Design Section, Missiles and Space Systems, irons out a problem with Arthur E. Raymond, Senior Engineering Vice President of DOUGLAS

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THE AMATEUR SCIENTIST

A transistorized drive for a telescope, and a sundial that keeps accurate time

Conducted by C. L. Stong

The slow parade of stars across the night sky appears to be greatly accelerated when it is observed through a stationary telescope of high power, because the instrument magnifies apparent motion as well as size. In consequence objects drift across the field of view and disappear in a matter of seconds unless some arrangement is made to keep the instrument trained on them. If the telescope is mounted so that it can turn, objects can be kept in view most of the time by moving the tube manually. Hand guiding is not precise enough, however, for many types of observation. The instruments used by astronomers and a large number of the telescopes made by amateurs are therefore equipped with a mechanism to keep celestial objects automatically in view.

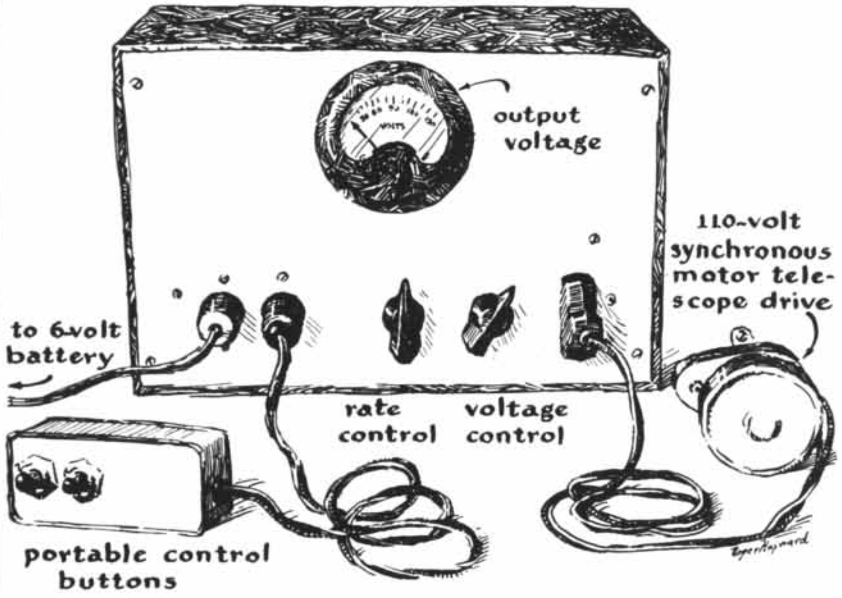
Most of the apparent motion of a celestial object is caused by the rotation of the earth, which amounts to one revolution in 24 hours with respect to the sun, and to one in about 23 hours, 56 minutes with respect to the stars. The fact that the hour hand of a clock turns at approximately twice this rate suggests that a clockwork could be modified to serve as an automatic drive by coupling it to the shaft of the telescope through a set of simple reduction-gears. This approach has been tried by many amateurs. Ordinary clocks, however, fall considerably short of meeting the requirements for an ideal drive. Few of them deliver enough power to overcome frictional losses in bearings of the type used by amateurs, and they do not provide enough range in speed. To track the moon accurately as it crosses the meridian a clock must run about 5 per cent slower than normal, a rate which in the latitude of New York would cause the clock to lose about an hour per day. This rate is beyond the range of the "fast-slow" adjustment of most clocks. Another serious limitation of clocks as drives for telescopes arises from the property to which they owe their usefulness as instruments for measuring time. Clocks run at constant speed, but the apparent motion of a star varies. Light from stars low in the sky passes through more of the earth's atmosphere than does light from stars higher in the sky; the light of a star near the horizon is so strongly refracted by the atmosphere that the image of the star can be seen several seconds after the star has passed below the horizon. Accordingly a drive that freezes an object in the field of a telescope pointed at the zenith permits the image to drift increasingly as the telescope is pointed at lower angles. In the most satisfactory drives provision is therefore made for continuously altering the tracking speed through a narrow range above and below its average value. Moreover, the best systems are equipped with a coarse control for changing the tracking rate by at least an order of magnitude so the tube can be quickly centered on a selected object.

All of these requirements are met in an inexpensive electrical drive utilizing transistors which was constructed last year by George W. Ginn, an engineer of Lihue, Hawaii. "Much of my observing," writes Ginn, "which has included a lot of photography, has been done at elevations above 10,000 feet on Mauna Loa and neighboring volcanic peaks, where seeing is exceptionally good nearly every night of the year. Most of these locations are reached by car and on foot by roads carved from lava, which is scarcely an ideal pavement. This means that my equipment must be light, portable and rugged enough to retain its accuracy during rough trips.

"The camera and guide telescope are supported on a tripod by a mounting of German manufacture which I acquired from the University of Hawaii in exchange for adapting one of their instruments for portable use. The mounting is of the equatorial type—one shaft turns in the plane of the earth's equator and the other in elevation—and is equipped with worm gears coupled to hand wheels for following objects in right ascension and declination as well as with clamps for locking the tube in any desired position. The arrangement is adequate for casual observing and even for making photographs of short exposure. But fine visual measurements and extended exposures require more precise guiding.

"Mechanical drives, such as those built around spring-driven clocks, are not satisfactory for use with portable instruments. The mainspring of most small clocks is not powerful enough to overcome frictional losses in the mounting, so an arrangement of weights must be added to supplement the energy stored in the spring. A clutch must also be inserted between the clockwork and mounting so that the tube can be disengaged for shifting the field of view from one region of the sky to another. In addition, the system must include a set of differential gears, a screw adjustment or some comparable means for making small corrections in the position of the tube without interrupting the basic motion of the clock. All this adds up to a cumbersome mechanism which is costly to make, inconvenient to use and difficult to maintain in satisfactory working order.

"Most of these difficulties can be overcome by substituting electrical parts for the springs and gear trains—with a distinct gain in the precision of tracking My present drive consists of a small synchronous motor of the type used in electric clocks which is energized by an oscillator-amplifier using transistors. The oscillator converts direct current into alternating current of a precisely known frequency. In effect it measures time and corresponds to the escapement of a clock. Power for the unit is taken from my automobile storage battery, which is thus analogous to the mainspring of a clock. The motor, somewhat smaller than a pack of cigarettes, is mounted on and geared directly to the mounting. A plug-in cord connects the motor to the oscil-



Transistorized drive for a small telescope

lator-amplifier. The unit is about the size of a miniature radio-receiver. Another plug-in cord from the oscillator-amplifier is connected to the battery by spring clips, and a third cord runs to a control box equipped with push buttons for changing the speed of drive as desired. The control box is held in and operated by one hand during observation. The complete system, less battery, weighs five pounds. It requires no lubrication or other maintenance, is unaffected by dust and retains its calibration over wide changes of temperature.

"The oscillator-amplifier circuit was designed for transistors instead of vacuum tubes primarily because I wanted to learn something about transistors. Perhaps the use of vacuum tubes would have been wiser at this stage of transistor development; the choice of circuit components designed expressly for transistors is still rather narrow, particularly in the case of transformers. On the other hand, the impressive reduction in size, weight and power consumption of apparatus which is made possible by the use of transistors more than compensates the builder for time spent in modifying parts.

"With the exception of the motor and the controls, the system contains no moving parts. During operation the oscillator draws direct current from the battery and converts it to alternating current at any desired frequency from 55 to 65 cycles per second. The frequency is controlled by a knob that corresponds to the fast-slow adjustment of a clock. The control covers a range of something more than 5 per cent, which is adequate for guiding telescopes and cameras less than five feet in focal length. The frequency can be doubled instantly by operating one of the two push buttons in the control box. The other button stops the oscillator. The action of the buttons corresponds to that of a set of differential gears and is used as a slow-motion traverse. By pressing the appropriate button the telescope can be moved forward or backward with respect to the stars at the rate of .25 degree per minute. The amplifier portion of the circuit steps up the output power of the oscillator to four watts at 115 volts for driving the motor, which is rated at 3.8 watts.

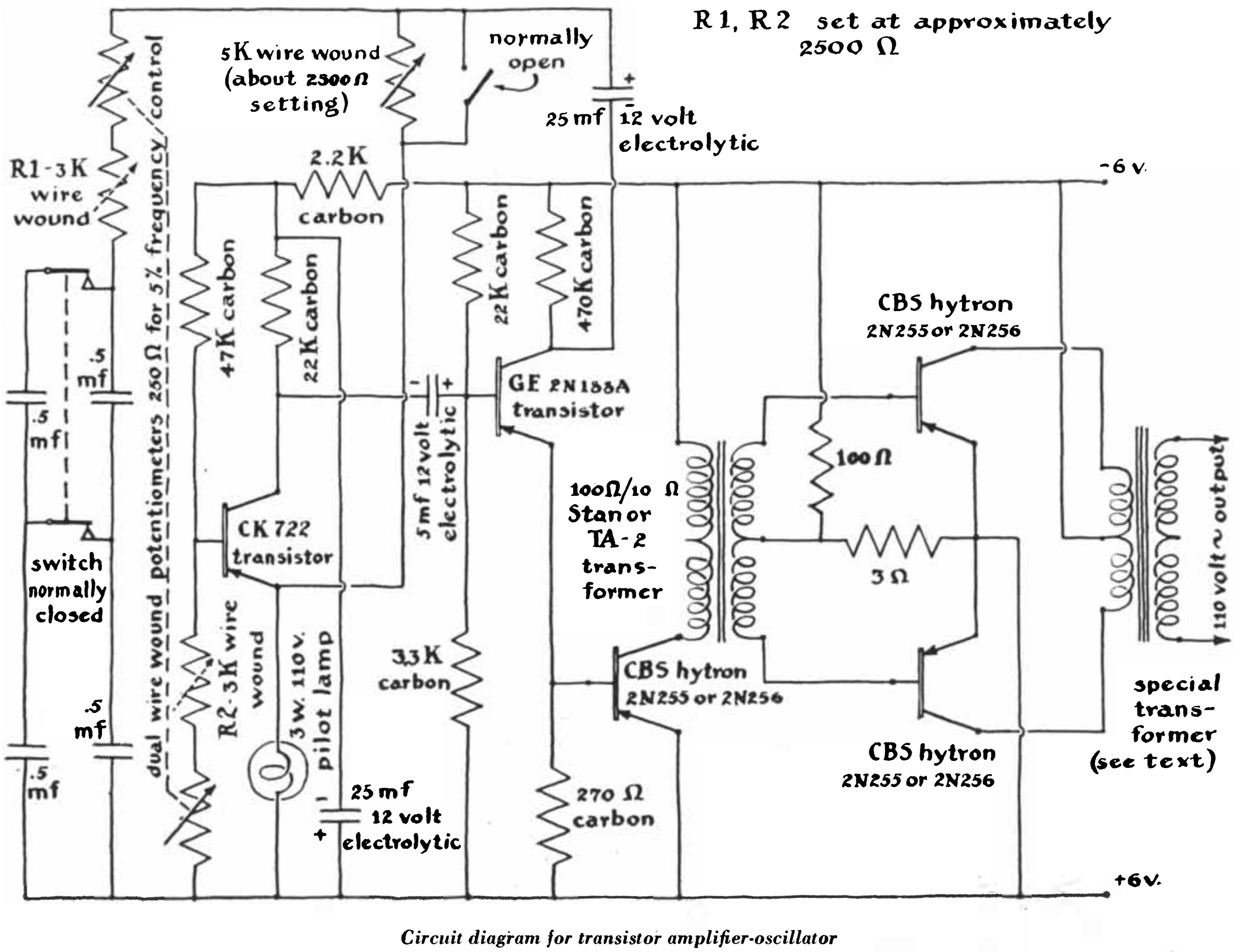
"The oscillator circuit is of the Wein bridge type and has excellent stability. The frequency is adjusted through the 5-per-cent range by dual potentiometers and is doubled by switching out half of the .5-microfarad capacitors shown at the far left in the accompanying circuit diagram [*page 188*]. Stopping the oscillator is accomplished by short-circuiting the 5,000-ohm (5K) variable resistor shown at the top of the diagram. This resistor controls the amount of energy fed back in reverse polarity from the output of the oscillator to its input and is normally set to the lowest resistance at which the oscillator will start and maintain stable operation. Switching is accomplished by relays, the coils of which are energized by the push buttons.

"The circuit includes a ballast lamp for stabilizing the output voltage. The

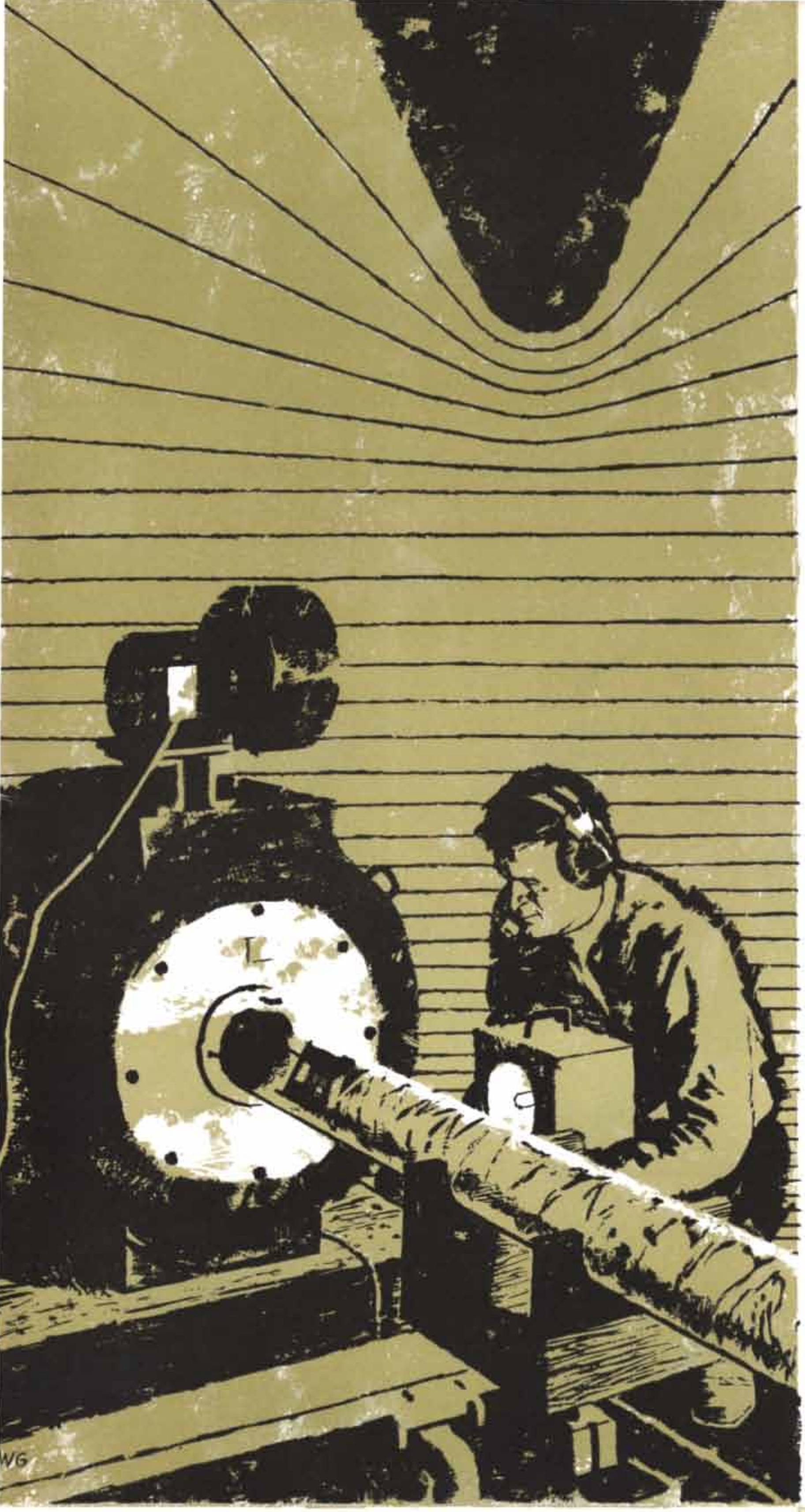
filament is connected in series with the feedback resistor so that the voltage of the circuit is divided between them. When the voltage rises, the filament warms up and the resistance increases. This has the effect of increasing the negative feedback, which in turn reduces the voltage to its normal value.

"Standard construction and wiring were used. The housing of the oscillator-amplifier unit is five inches wide, six inches deep and nine inches long and is available from most radio dealers. The aluminum panel and chassis were cut to fit the case. The small transistors were mounted along with the resistors on a strip of Formica by drilling small holes in the strip for the leads and making connections on the back. The cases of the power transistors function as 'collectors,' counterparts of the 'plate' electrode in vacuum tubes. Voltage is applied to the cases, so they must be insulated from the chassis. Kits are available for mounting power transistors which include mica washers and silicone oil to aid in the transfer of heat to the chassis. I did not use the oil because in this circuit the units operate substantially below their rated capacity for dissipating heat. Do *not* solder connections directly to the power-transistor terminals; transistors are easily damaged by high temperature. Clips for connecting transistors into the circuit can be made from contacts salvaged from miniature vacuum-tube sockets. Connections to the emitter electrodes of the power transistors must be tight because a peak current of two amperes flows in this circuit. Two other precautions are worth mentioning. First, transistors, unlike vacuum tubes, can be damaged by applying voltage of incorrect polarity to the terminals. Second, the output stage must not be operated without a load.

"The power transistors of this amplifier deliver about 4.3 volts on each side of the center tap. This must be stepped up by a transformer to 115 volts for driving the motor. Unfortunately dealers do not stock a suitable transformer. I tried to modify a conventional filament-transformer for the job by leaving the 117-volt winding intact and rewinding the 6.3-volt secondary for the lower input voltage. Sad to relate, only 50 volts came out of the high side. After stewing over this development for a day or so, and consulting *Radio Engineers' Handbook* for data on transformer design, it became apparent that heat losses in the iron core caused by the high density of the magnetic field were eating up the profits. Apparently 6.3-volt filament-transformers are designed with a minimum of iron and copper, adequate performance being achieved by operating the iron core at a high magnetic-flux density. If 25 per cent of the energy is wasted in heating the core, nobody cares because the energy is being taken from the 110-volt power line and amounts to only a few watts. After calculating the losses for several values of flux density and wire size, I picked the best combination and rewound both coils of the transformer. The primary was replaced



Circuit diagram for transistor amplifier-oscillator



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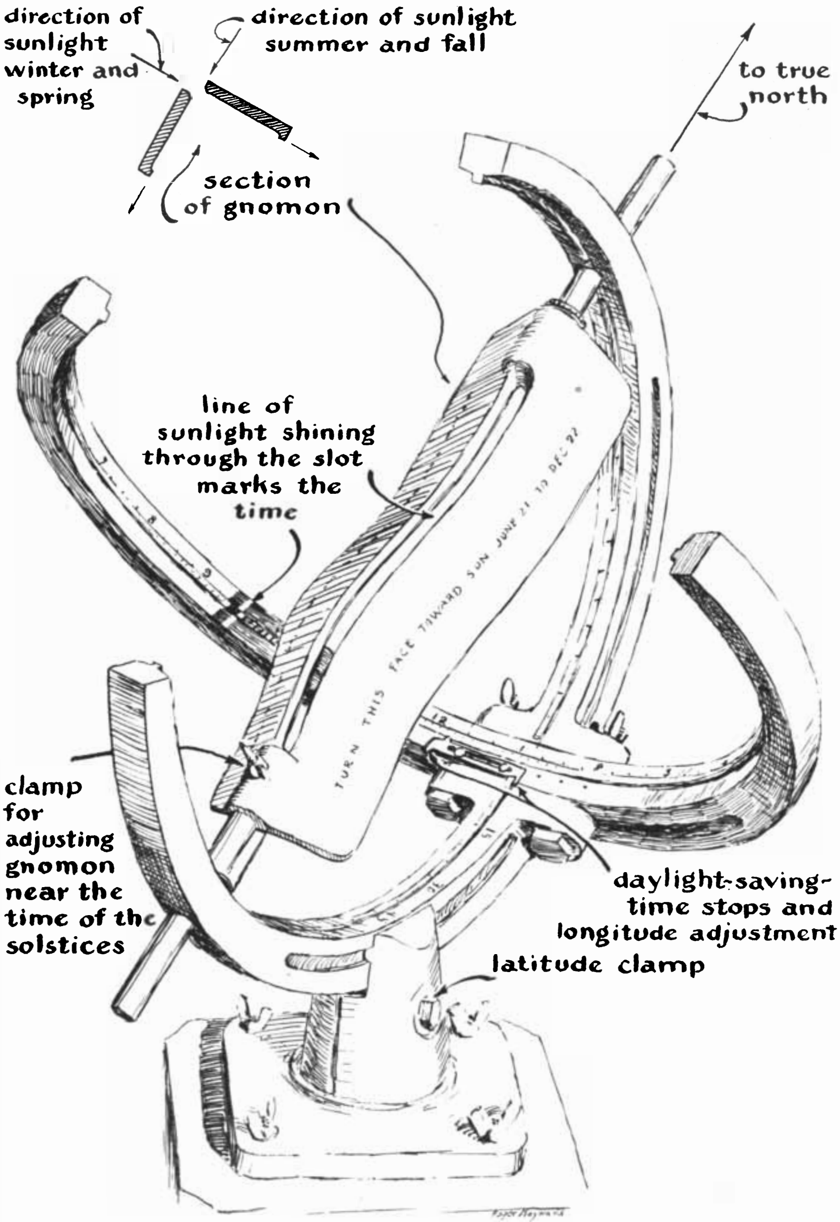
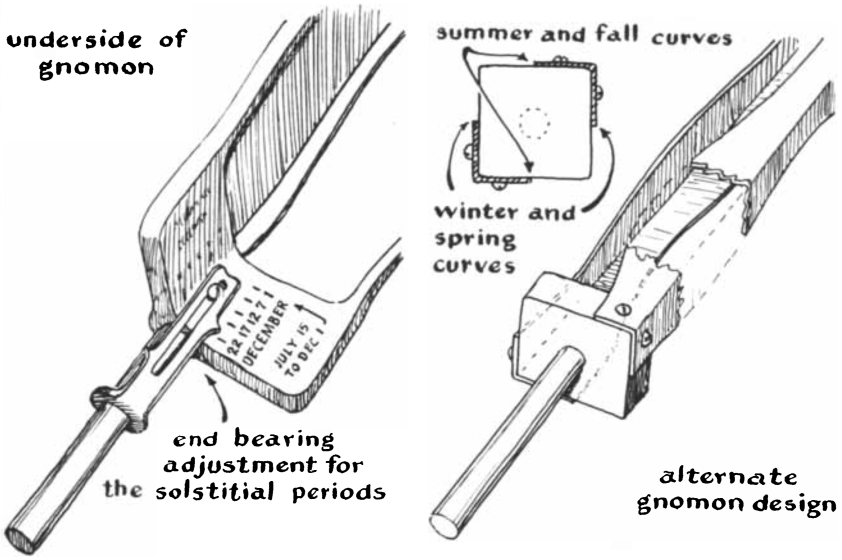
with 48 turns of No. 18 enameled magnet-wire on each side of the center tap; the secondary, with 1,560 turns of No. 32 wire. This reduced the flux density from 98,000 lines per square inch to 41,000 lines and reduced the core loss from four watts to one watt. The core weighs 10 ounces and has a cross-sectional area of 7/8 square inch. Any core of about this size and weight should work satisfactorily. Smaller cores would require more turns. The losses are proportional to the weight of the core and the square of the flux density. The core of an audio-frequency transformer would doubtless perform better because the laminations are thinner and are made of the highest quality magnetic iron.

"The power transistors operate alternately, so only half of the primary coil carries current at one time. If the transformer were operating from a conventional alternating-current source of four volts, the primary coil could be a single winding of 48 turns. If 12-volt operation is desired, the number of primary turns must be doubled. The output in this case would be about nine watts, so the wire size of the secondary winding would have to be increased to No. 30,



An amateur's sundial that indicates clock time



Detail of gnomon for sundial

and a larger core would be required to provide additional space for the larger wire size.

"The new set of coils delivered an output of 90 volts, as measured by a meter of the rectifier type. Further investigation disclosed that the low indication was caused by the irregular shape of the voltage wave, a response induced by the motor. A .5-microfarad capacitor connected across the output coil of the transformer corrected the wave form and raised the indication to 110 volts. The voltage rises somewhat when the frequency is doubled, but this is not a disadvantage because the torque of the motor would normally drop at the higher frequency. The higher voltage tends to maintain constant torque.

"A few bugs remain in this pilot model. The oscilloscope shows some highly unconventional and mysterious wave forms here and there. Other builders will doubtless find ways to improve the circuit, and I will welcome a report of their results. But the bugs have no discernible effect on the operation of the unit. When I compare its output with that of the 60-cycle power line, the power frequency varies most. Operation in the field is simplicity itself. Set up the telescope, plug in the cords, adjust the speed and you are in business.

"It is assumed that amateurs who undertake the construction of this drive will have some experience with electronic circuits. Others are urged to solicit the cooperation of a neighboring radio 'ham.' Some reading is indicated for those inexperienced with transistors; I can recommend the booklet on 2N255 and 2N256 transistors published by CBS Hytron of Lowell, Mass. Similar booklets covering equivalent transistors made by other manufacturers are available through most radio dealers. Should problems arise during the construction of this apparatus which cannot be solved by reference to current literature, I will try to answer them. My address is: Box 669, Lihue, Hawaii."

"In *The Amateur Scientist* for August," writes Richard L. Schmoyer, an engineer of Landisville, Pa., "you raise the question of why a man who owns an accurate watch and several clocks will go to the trouble of building a sundial. Few will disagree with your conclusion that he is motivated in part by the intellectual charm of a device which, without moving parts, can convert the sun's changing position directly into time. But sundial-making holds other attractions for its enthusiasts. In the course of developing a sundial one is exposed to a fascinating and well-defined mixture of mathematics, geometry, geography and astronomy. The design of a sundial challenges our creative talents, and its construction puts our craftsmanship to an exacting test. Finally, the designer who permits the primary time-telling function of the sundial to control its form adds spice to the project. Hardware in pleasing though strange and unexpected shapes often emerges from the equations which describe the ever-changing slant of the sun's rays.

"These inducements led me to design a sundial last year which has become a continuing source of pleasure both to me

and to my neighbors. With only a few simple settings during two seasons of the year the sundial can be made to indicate accurate clock time. It can be adjusted to the latitude and longitude of any point in the Northern Hemisphere, including those areas where clocks are changed for daylight-saving time. Clock time can be read from it to an accuracy of about one minute, even when the sky is covered by a light overcast.

"Most people find sundials attractive, so one must not altogether dismiss their ornamental properties. The structure of my dial was derived from the armillary, a traditional form which continues to enjoy wide popularity. Those primarily concerned with the appearance of a sundial admire the geometric perfection of the armillary's nested rings, representing latitude, longitude, tropics, celestial equator and the ecliptic. Much the same pleasing quality is found, however, in the unsymmetrical crescent of the early and late moon. The armillary can be converted to this form by eliminating all except the rings representing latitude and longitude and opening these at one of the sides where they join at right angles. When tapered and strengthened, these rings become nested crescents, as shown in the accompanying illustration [*page 190*].

"The transformation from armillary to nested crescents demonstrates how a pleasing shape can emerge from a functional necessity. A good time-telling device should always fulfill its mission. The armillary falls short of this ideal. During part of each day its pattern of ornamental rings casts shadows on the time-scale, which is carried on the inner face of the equatorial ring. Worse, in the seasons of the equinoxes (March 21 and September 23) the scale lies in continuous shadow because the plane of the ring then parallels the sun's rays. By eliminating the useless rings and opening the functional pair into crescents the time-scale is exposed to the sun without obstruction.

"The structure of a sundial which indicates clock time is simple in concept if not in the making. The crescents are supported at their edges by an arrangement of bolts, slots and clamps so they can be rotated in their respective planes. The latitude crescent is made in two parts with a flange at the inner end of each. Bolts pass through the flanges and through a slot in the longitude crescent. When the nuts are tightened, the assembly becomes a rigid unit. Similarly, the edge of one member of the latitude crescent is clamped between the jaws of a split pedestal which extends up from the base. By loosening a single wing-nut the whole assembly can be rotated in the plane of the latitude crescent and in azimuth.

"A pair of holes are drilled in the latitude crescent on the diameter which coincides with the axis of the equatorial crescent. These holes serve as bearings to support the gnomon. It is to the unique shape of the gnomon, which compensates for the effect of the eccentricity of the earth's elliptical orbit and the tilt of its axis, that this sundial owes its property of keeping clock time. If the earth followed a circular orbit around the sun, and if its axis were perpendicular to the plane of the ecliptic, the straight gnomon of the conventional sundial would indicate clock time. The time shown by clocks is that of a fictional sun which leads the real sun by as much as 16 minutes or lags behind it up to 14 minutes, depending upon the observer's location and the season. This difference is known as the equation of time and is shown graphically as the analemma on globes, a closed curve in the form of a figure eight.

"The gnomon of my dial is related to the analemma but differs from it in that halves of the figure are separated and the ends have been stretched somewhat. Structurally the gnomon consists of a strip of cast metal bent at a right angle along its length. The apex of the angle is opened to form a thin slot. It is supported at the ends by shafts which turn in the bearings of the latitude crescent. The halves of the gnomon are bent into almost symmetrical compound curves with respect to the long axis and are therefore complementary. When either half is turned to face the sun, the curved ribbon of light which passes through the slot corresponds with the equation of time for half of the year, the remaining six months being represented by the other half. Time is indicated by the thin line of light from the slot which falls on the time-scale between shadows cast by the halves of the gnomon.

"The portion of the curved slot through which the rays pass to the time-scale depends on the declination of the sun. In summer, sunlight falls on the dial at a high angle and reaches the time-scale through the upper part of the slot, where the curvature just compensates for a 'slow' sun. The reverse is true in the fall, when the sun is low. The winter sun is also mostly slow, and in the spring the sun goes from slow to fast to slow to fast again. Whatever the season, the sun's declination selects an appropriate portion of the curve to offset the equation of time.

"Some difficulty is encountered during

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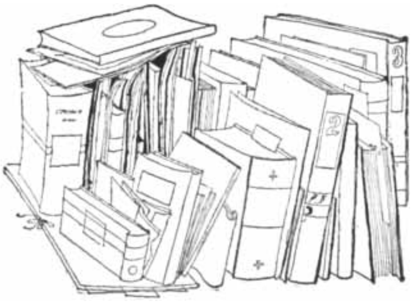
the period from about December 1 through January 15, when the sun lingers close to its lowest path across the sky. During this same period, however, it speeds up with respect to the fictional sun. A lag of some 11 minutes becomes a lead of about nine minutes. The simultaneous change in declination is very small. A similar event takes place in reverse during the weeks preceding and following the summer solstice on June 21, when the real sun falls behind the fictional one, again accompanied by little change in declination. To accentuate the sundial's response during these periods, the curvature of the slot is stretched out. The gnomon must also be moved axially in its bearings, the amount of shift being determined by a stop on the shaft. The adjustment is made by hand according to a scale of dates engraved on the gnomon, as shown in the accompanying detail drawing [*page 192*].

"The designing of the gnomon, though tedious, is not difficult. One first determines the rate at which a ray of sunlight moves across the time-scale. This depends on the diameter of the crescent on which the scale is engraved and on the related distance between the scale and the gnomon. Multiply 3.1416 by the diameter of the equatorial crescent and divide the product by the number of seconds in a day. In the case of a 13-inch crescent the result is .000473. This number is used for computing the distance and direction by which the curved slot must depart from a straight line for successive weeks of the year. This procedure can be illustrated by constructing a graph of the curve for one face of gnomon. First draw a straight line equal to the radius of the proposed crescent and erect a perpendicular of about the same length above and below one end of the line. The base line represents the sun's mean elevation (0 degrees) on September 23. Next, with the end of the base line as the point of origin, extend a line to the perpendicular at an angle of 21 degrees, 34 seconds *above* the base line. This represents the sun's elevation on July 15. Now make a similar angle of 21 degrees, 47 seconds *below* the base line. This corresponds to the sun's elevation on December 1. Angles above the base line are regarded as positive and are designated 'plus'; those below are considered negative. Next, draw in angles at weekly intervals for all intermediate dates. A table showing the sun's angular elevation throughout the year can be found in any ephemeris and in many almanacs. These references also carry a table for the equation of time and list the difference between solar time and clock time in minutes and seconds. The curve for one face of the gnomon is plotted from these values. (If the thickness of the material from which the gnomon is constructed exceeds .01 inch, the curvature of the trailing edges must depart from that of the faces to avoid shadow. The same basic procedure is used in computing all curves, however.) For September 23 the equation of time has a value of —7 minutes, 35 seconds, which is equal to —455 seconds. Multiply this interval by the rate at which the ray of sunlight moves across the time-scale of the dial. In the case of my dial the computation is: $.000473 \times -455 = -.215$. This product represents the distance in inches by which the curve of one edge of the slot in my gnomon departs from the perpendicular. (In plotting the curves all negative values are directed to the left of the perpendicular and positive values to the right.) The remaining points of the curve are similarly plotted for all intermediate dates at weekly intervals.

"The ends of the curve must be stretched out, as mentioned earlier. To accomplish this a perpendicular line is drawn through the point of origin and divided by a series of four points spaced a quarter of an inch apart both above and below the base line. With these points as successive origins draw in the sun's declination *above* the base line for the dates July 8, July 1, June 26 and June 21 and *below* the base line for the dates December 7, 12, 17 and 22. Similarly draw in the sun's declination on the other half-face for June 1 to 21 and December 22 to January 15. The ends of the curves are then plotted from the equation of time by the method described. The full-scale drawing is then ready for translation into hardware. All major parts of my sundial were cast in aluminum. The layout was drawn directly on the wood from which the patterns were made. The time-scale is divided into hourly intervals of 15 degrees each and subdivided into minutes as desired. The graduation representing noon lies in the plane of the meridian."

This department will forward a copy in reduced scale of the layout of Schmoyer's gnomon upon receipt of a self-addressed, stamped envelope. Schmoyer advises that the patterns used in making the parts for his dial, including the gnomon, have been preserved. He has volunteered to have duplicate castings made by the local foundry upon request by those who wish to purchase a ready-made set. His address is Landisville, Pa.



BOOKS

C. P. Snow and Sir Eric Ashby on "the two cultures": scientific and nonscientific

by Asa Briggs

THE TWO CULTURES AND THE SCIENTIFIC REVOLUTION, by C. P. Snow. Cambridge University Press (75 cents). TECHNOLOGY AND THE ACADEMICS, by Sir Eric Ashby. St. Martin's Press ($3.25).

There are surely very few men in the 20th century who have practiced both as scientists and as novelists. C. P. Snow is one. He is best known for his impressive sequence of Lewis Eliot novels, particularly *The Masters* (published in 1959), which described coolly, carefully and sometimes caustically the events leading up to the election of the head of a Cambridge college. As a writer Snow is interested not only in people but also in power, particularly in the effects of power on personal relationships and in the "corridors of power" that run through the 20th century. One of the more recent novels in the sequence, *The New Men* (1954), is specifically concerned with the reactions of his characters to atomic power: Chapter 23 is called "Events Too Big for Men." Snow has also been concerned with power as a scientist, notably with manpower. As a young man he won a research scholarship to the University of Cambridge, worked on molecular physics and became a Fellow of his college at the age of 25. During World War II he became a civil servant engaged in selecting people for scientific jobs, and since the war he has continued to serve as scientific adviser on the Civil Service Commission. Many people in London think of him as "Mr. Science," the spokesman of the needs and claims of science in the corridors of power. It would be more accurate to call him "Sir Science," since in 1957 he received a knighthood for his services to industry and government.

Given this background, Snow has unique personal qualifications to examine and discuss the place of science in contemporary society, and it is not surprising that he chose as the title of his recently delivered Rede Lecture at Cambridge "The Two Cultures and the Scientific Revolution." It is the circumstances of his own life that have led him to ruminate on what he calls the polarity of "two cultures," not only in Britain but in the entire West—at the one pole the culture of literary intellectuals, at the other the culture of physical scientists. Between the two poles there is "a gulf of mutual incomprehension," sometimes of hostility. Nonscientists think of scientists as brash, boastful, overoptimistic; scientists think of nonscientists as at best decorative, at worst dotty. There is no place where the cultures meet. Thirty years ago "they managed a kind of frozen smile across the gulf"; today they do not always bother to glare.

After discussing the experiences of his own life that have forced him to reach this conclusion, Snow goes on to look for historical explanations for the existence of the two cultures. The main reason has been the lack of interest in, concern for and understanding of the industrial revolution and of the more recent scientific revolution. Subsidiary reasons have been educational specialization, and, in Britain at least, "the tendency to let our social forms crystallize." The major reason subsumes the minor. "Intellectuals, in particular literary intellectuals, are natural Luddites." Even if they do not try to smash machines, they shudder at the sight of them. Whenever possible they try to avoid seeing them. They thus combine a complete lack of knowledge of pure science with a horror of technology. The educational and social systems in Britain reflect the dominant attitudes of the nonscientific elite, and even in other Western countries there is a lack of insight into the scientific revolution. At this point Snow brings in the experience of the U.S.S.R., and claims not only that Russians are as ready "to cope in art with the processes of production as Balzac was the processes of craft manufacture" but that they have properly judged what kind and number of educated men and women a country needs if it is "to come out top in the scientific revolution." He ends his lecture with a powerful plea for "closing the gap between our two cultures," suggesting that it is essential that the gap should be closed if the social and political gulfs of the world are to be bridged. It is technically possible, he claims, to carry out the scientific revolution in India, Southeast Asia, Latin America and the Middle East within 50 years. "There is no excuse for Western man not to know this; this is one of the situations where the worst crime is innocence." Literary intellectuals, he implies, may be innocent; scientists cannot be. The sooner we all pull together, the better. There is not much time—less than we think. If we do not pull together in time, the Communist countries will take over.

This summary does not do full justice to Snow's thesis or to his occasional qualifications and asides. He notes, for example, that the idea of only two cultures is somewhat crude, that there is a basic difference between the British and the U. S. educational systems, that not only many literary intellectuals but many scientists are devastatingly ignorant of productive industry, and that problems of politics are at least as important as problems of science in weighing the prospects of a world-wide scientific revolution during the next 50 years. Nonetheless, for all the qualifications and asides, two elements are missing from the thesis: a continuously rigorous scrutiny of the argument and a searching examination of history. The lecture stands as a lively and intensely personal contribution to current debate, which makes efficient use of contemporary conversational themes; for example, "the race with Russia" and the perils of educational specialization. As a plea for action it carries moral conviction and personal authority, but the action recommended is extremely vague. "The best one can do, and it is a poor best, is to nag away, but that is perhaps too easy a palliative for one's own disquiet. Though I don't know how we can do what we need to do, or whether we shall do anything at all, I do know this: that if we don't do it, the Communist countries will in time." This all-too-honest admission leaves the argument not on the ground—certainly not in the laboratory—but in the clouds, perhaps where the literary intellectuals belong. Scientific optimism, tempered with vague disquiet, is no more sustaining or potent than scientific education decked with a few literary frills. We need to look at the world not only with "fresh eyes," as Snow recommends, but with clear minds.

How important is the polarity? Because of his special circumstances Snow knows the London literary world as well as he knows the world of science. It is not difficult to believe that in that world you do not meet many people who could define the second law of thermodynamics. Snow describes the question "What is the second law of thermodynamics?" as the scientific equivalent of "Have you read a work of Shakespeare?" This might pass in a questionnaire, but it is fair to add that as a subject of conversation at parties the second law of thermodynamics has limited possibilities. Doubtless it would be encouraging if more science could be injected into polite conversation, but even if there were to be one shared culture, it is doubtful whether science would be more than an injection. Polite conversation in any society steers more or less amicably between (usually) safe tittle-tattle and (sometimes) disruptive controversy. In a shared culture there would presumably be more scientific tittle-tattle (to add to the rest) and more critical and imaginative awareness of both scientific discovery and scientific controversy. The second consequence would be a gain, but it might not greatly improve conversation. In the meantime, there will probably be a great deal of polite conversation not about science but about Snow's views on the two cultures and the scientific revolution. This too will be a gain.

The London literary world, however, is not the place where victories will be fought and won. At best they will only be registered there. The polarity looks less alarming—although it still exists—if academics are substituted for novelists and the provinces are substituted for London. In recent years the history of science has been advanced by historians as well as by scientists, and slowly—all too slowly—the advance is influencing the teaching of undergraduates and even of children. Furthermore between science and "nonscience" lie the growing territories of the social sciences, studies that Snow leaves completely out of the picture. There is already room for fruitful collaboration between the "natural" and the "social" sciences, and for constructive arguments between them both about the points that they have in common and the significant differences of approach and technique. There is scope for the development of a working alliance between social scientists and technologists, more universally fostered than the existing but still imperfectly operating alliance between philosophers and pure scientists. Technologies are directly concerned with the application of science to the needs of men and societies, and technologists are always faced with human as well as technical problems whether they like it or not. Cooperation between social scientists and technologists can be natural, not forced. Already, then, there are bridges across Snow's gulf, some of them precarious, others carrying traffic. Already there are areas of common concern and even of common exploitation. Perhaps the most effective means of bringing the two cultures closer together is to increase the number and strengthen the structure of the bridges, to extend the areas of common exploitation. The transformation of the London literary world or of any other literary world can wait.

It was, after all, a favorite complaint of the provinces in 19th-century Britain that London always received too much attention. The important things that were happening in the country were happening somewhere else. "Londoners," wrote one sturdy provincial, "are the lapidaries of the nation. They polish the diamond found in the counties, and sometimes, if no one challenges them, they take credit for producing the jewel." Snow himself was born in provincial Leicester, and knows this well. In the industrial areas of 20th-century Britain it is no more possible to ignore the industrial revolution and its legacy than it is to ignore the natural landscape. Not all intellectuals are concentrated in London, nor is more than a small section of the university population concentrated in Oxford and Cambridge. To generalize about the provincial intelligentsia on the basis of London literary circles or about universities on the basis of Oxford and Cambridge is already misleading. There is a geographical gulf here. When I was a Fellow of an Oxford college for 10 years after the end of the war, I used to ask my students how many of them had ever been inside a factory. Only a tiny minority ever had. In Leeds, a large industrial city, I ask my students how many of them have ever been in a cathedral. There are rather more. The problem in Oxford was how to help history students to understand the industrial revolution (Snow's problem in London); the problem in Leeds is how to help history students to understand the Renaissance. In both cases history students, not scientists, were the victims of cultural deprivation.

Snow claims, when he turns from his own personal experiences to history, that intellectuals have never tried, wanted to or been able to understand the industrial revolution and that far too little attention has been paid to its achievements and its problems. Both statements are inadequate as they stand. The attitude of intellectuals to scientific and technical advance in the 18th and early 19th centuries was complicated, not simple, and there have been few subjects more generally discussed by historians of every kind in recent years than the impact of industrialization.

The early scientific advances of the 18th century attracted writers rather than repelled them. Wordsworth, for example, when he was 24 wrote enthusiastically of:

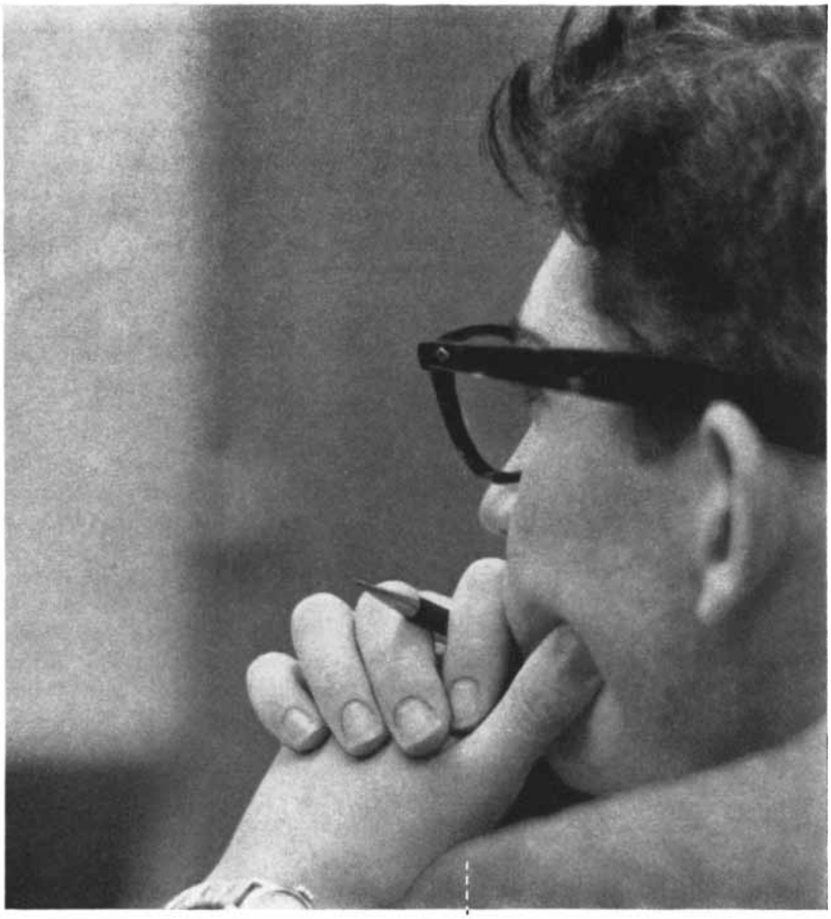
. . . those to whom the harmonious doors
Of Science have unbarred celestial
stores,
To whom a burning energy has given
That other eye which darts thro' earth
and heaven.

As Francis D. Klingender showed in his stimulating book *Art and the Industrial Revolution* (1947), there was a brief period of enchantment when science and art were thought of as two joint keys unlocking the same door. The coincidence in time of the industrial revolution and the upsurge of the romantic movement led to many statements like Wordsworth's. There was no nostalgia or regret in a letter written in 1787 to Samuel Oldknow, the cotton spinner, stating that Cartwright, the inventor of the power loom, "had left the Barren Mountains of Parnassus and the Fountain of Helicon for other Vales and Streams in Yorkshire . . . to work in the wild, large and open field of Mechanics." B. R. Haydon, the romantic painter, exclaimed with zest that "so far from the smoke of London being offensive to me, it has always been to my imagination the sublime canopy that shrouds the City of the World." Finally, as late as 1847 Edward FitzGerald, who 12 years later produced his version of *The Rubáiyát of Omar Khayyám*, wrote "it is not the poetical imagination, but bare Science that every day more and more unrolls a greater epic than the Iliad; the history of the World, the infinitudes of Space and Time! I never take up a book of

Geology or Astronomy but this strikes me."

An anthology of reactions of writers to the industrial revolution would reveal a more complex pattern than Snow suggests, nor can its effects on the sensibility either of the artist or of the scientist be reduced to a formula. The main reason why the initial enchantment did not last had more to do with society than with science. The industrial revolution began clean but continued dirty. Very soon the facts of the exploitation of people had to be set against the facts of the conquest of nature. It is interesting to contrast the first panegyrics of steam power with later writings about its social consequences. All revolutions, including the industrial revolution, have an element of violence about them. Snow overlooks this when he writes that "of course, one truth is straightforward: Industrialization is the only hope of the poor." There has often been a divergence between short-run and long-run, and it has taken time for the significance of changes to become clear. Social history seldom deals in "straightforward truths." The response of the poor to the pressures of industrialization has usually been ambivalent, and it has only been after struggle and pain that golden ages have shifted from the past to the future. If the British industrial revolution is taken as the prototype, it is not surprising that many sensitive artists and writers began to recoil in the early 19th century from many of the things that they saw. Haydon, for instance, who had written so fondly of London smoke, complained that he was "not happy in Manchester. The associations of these hideous mill-prisons for children destroy my enjoyment in society. The people are quite insensitive to it." The insensitivity seemed even more alarming than the conditions of work. When considered alongside the grimmest physical facts of the new society and the social contradictions that seemed implicit in it, this led many romantic writers to brood on the "mechanization of man" and the "thralldom of the cash nexus." Some became rebels; others tried to contract out of society altogether. The story of the British reactions to these experiences has recently been examined in detail, and with great insight, by Raymond Williams in his *Culture and Society: 1780-1950*. Snow does not seem to have pondered on it.

It is because the effects of scientific and technical changes cannot be separated from the whole context of a changing society that the study of social history is so important to scientists and



technologists, and the study of science and technology is so important to students of society. Given a genuine interchange of views and experiences, we could all realize, as Snow wishes us to realize, that in some sense (though not in every sense) the industrial revolution was "where we came in." Oddly enough, although he rests his case on something more than personal experience and makes more than one appeal to history ("History," he writes, "is merciless to failure"), he never refers to the mounting piles of material that historians have prepared on topics concerned with science and the industrial revolution nor considers the serious claims of history as a key subject in a "one-culture" curriculum. Yet at two particular points in his argument these claims are directly relevant. First, in describing the so-called optimism of the scientist—his impatience to see if something can be done now and in the immediate future—he does not consider whether or not even a brief study of the past might modify the scientist's perspective. Second, in asserting the superiority of Russian education as an instrument of adaptation to the scientific revolution, he does not examine to what extent (if at all) Marxist theories of the historical evolution of society (a past-present-future philosophy) shape the ways in which Russian education is organized, pure science is encouraged and applied, and economic action is taken in other parts of the world. The vagueness of his own conclusion about what the West could and should do to foster scientific revolutions in the underdeveloped countries of the world contrasts sharply with the precision of Marxist answers to the same questions. Instead of relating techniques to values, Snow chooses to dwell on "the egotisms, the weaknesses, the vanities, and the power-seekings of men" and, as a ray of hope, the fact that "they are sometimes capable of more."

We are back once again in the fascinating world of the Snow novels and his own personal quest. He rightly encourages his fellow novelists to learn something about the world which is so familiar to him, to look more closely at "personal relations in a productive organization." They are, he says, "of the greatest subtlety and interest." The Russian novelists, he goes on, are much better at dealing with industrial themes than are writers in the West. "An engineer in a Soviet novel is as acceptable, so it seems, as a psychiatrist in an American one." He does not go on to ask why, yet the question would lead him back into history and toward other themes "of the greatest interest and subtlety." He mentions that the Russians share his grandfather's "passionate belief in education." They share much more. There was no generation more proud of its engineers than the Victorian generation; they turned them into the heroes of society. There was no generation that displayed a greater *voluntary* interest in technology. Of course, even then a section of the London literary world stood apart. Even then the rebels talked of what they did not like instead of the forces that had made Britain rich and great. In a free world they will always stand apart. Even in a one-culture society they could claim that they have no more reason for liking managers or backroom researchers than their predecessors had for liking mill-owners in Manchester.

Some of Snow's themes are firmly placed in their historical context in a rewarding little book to which he refers: Sir Eric Ashby's *Technology and the Academics.* Chapter 4 of this book is called "Split Personality in the Universities." Like Snow, Ashby is concerned about the adaptation of universities to the world of the scientific revolution. As a biologist, it is natural that he relies on biological metaphor throughout his survey; as a university administrator, he has rich experience of both formal and informal relations between "the two cultures." He knows the provincial universities well, and has recently been president of Queen's University in Belfast. In autumn he will span what I have called the geographical gulf, when he takes up appointment as elected head of a Cambridge college. Moreover, he has one other valuable qualification in studying "the two cultures." He is an authority on adult education, the missing or at best imperfect component of education both in "developed" and underdeveloped countries.

Ashby describes the clash of doctrines in a university as an opportunity and not a calamity, but he rightly regards the debate on the humanities versus science as silly, unprofitable and tedious. It has now petered out, he claims, for bad reasons as well as good ones, partly because scientists no longer regard science as an alternative to humanism or as inconsistent with it, and partly because much teaching and research in the humanities could not by any stretch of the imagination be described as humanism. Later in his book he returns to the question of teaching and research, and makes fruitful suggestions not only about "bridge courses" but about work in the humanities themselves. "Instead of contributing to the university what the Victorians understood by a liberal education, some of them [the humanities departments] are doing with grammar and documents what scientists and technologists can already do with formulae and instruments. This is doubtless profitable for the progress of scholarship in the humanities, but one cannot escape the consequence that the humanities cease to be humanities when they are treated in that way." This statement marks a considerable shift in emphasis not only from Snow's Rede Lecture but from the arguments hitherto advanced in this review. The bringing together of the "two cultures" demands not only contact but domestic reform. Professors of technology need to be persuaded that the pattern of the curriculum under which they themselves were trained is quite inadequate for their students, while professors of humanities need to be persuaded that the development of science and technology in universities places them under an obligation to reconsider the emphasis in their own humanistic studies.

A second and more drastic shift of emphasis follows the first. Whereas to Snow educational specialization, particularly premature specialization at school, is a minor but significant cause of the polarity between "the two cultures," Ashby dismisses the debate on specialization versus a liberal education as just as unprofitable as the older debate on the humanities versus science. He challenges the assumption that specialization and a liberal education are antithetic, and argues boldly that "in order to adapt itself to an age of technological specialization, the university must use specialist studies as the vehicle for a liberal education." Around the core of the specialism should be grouped all those studies that are relevant to a full understanding of it. "The path to culture should be through a man's specialism, not by bypassing it."

Insofar as Snow is concentrating on school education and Ashby on university education, their views do not necessarily clash. It may be reasonably argued that the prerequisite of an enlightened approach to specialist studies in a university is a broad education at school. Both writers would probably agree that there are grave weaknesses in the contemporary British pattern. Nonetheless their difference of approach should not be minimized. Ashby dislikes as much as Snow what he calls "the intellectual curtain separating faculties of science and faculties of arts," but he would begin to tear down the curtain by persuading the people on each side of it, scientists and nonscientists, to abandon the limited approaches to their subjects which most of them share. It is not primarily a question of subject matter at all: scientific and humanistic knowledge are two different sides of one and the same process of human thinking. "The fault (at present) lies in what Alfred North Whitehead called 'a celibacy of the intellect which is divorced from the concrete contemplation of the complete facts.' It is a preoccupation with abstractions from reality, and escape from the whole of reality." This seems to me to be a more rewarding approach to the creation of "one culture" than that of Snow. Specialists would pursue their specialties, but most of them—there would always be a cluster at the poles—would also travel freely in common territory. Given such a change in the universities, there would still be the problem of science and society in the world outside. As Snow says, "Young scientists now feel that they are part of a culture on the rise while the other is in retreat." Both their outlook and "life-styles" would change if there were to be big changes in education, but they would still be separated from the rest of the community as well as drawn closer into it. Economic as well as educational factors are involved, and although Snow touches on these neither he nor Ashby is directly concerned with them.

There is one final difference in emphasis between Ashby's book and Snow's lecture. Ashby does not like thinking in terms of manpower. He admits that it is convenient for certain clearly defined purposes to do sums in which scientists and technologists are considered as so many units of scientific or technological manpower, but he emphasizes that there is a serious danger in educationists and administrators thinking in these terms. No one, except as a joke, he reminds us, talks of classical manpower or philosophical manpower. The advocates of "one culture," like the advocates of "traditional culture," must think always in terms of individual men. At this point he provides an alternative philosophy to that which lies behind many of the developments in Russia: he does not leave values out. Moreover he draws on history to place recent changes in the West in proper perspective. "A century ago the scientist was as much an individual as a poet is. . . . More recently he has been regarded as 'one of A's team' or 'a product of B's laboratory.' There is now a risk that he may become simply a unit of scientific manpower." It would be the central feature of "one culture," as he envisages it, that it would enhance individuality, encourage variety and breed dissent. All this, and a scientific revolution too!

The only difficulty, as Snow so rightly concludes, is "that we have been brought up to think as though we had all the time in the world, and we have very little." The note of urgency in his lecture still sounds loud and clear when we have listened with thoughtful admiration to the note of urbanity in Ashby's book. It is a note that should command general attention. "Closing the gap between our cultures is a necessity in the most abstract intellectual sense as well as in the most practical. When those two senses have grown apart, then no society is going to be able to think with any wisdom."

Short Reviews

THE LIFE OF SIR ALEXANDER FLEMING, by André Maurois. E. P. Dutton & Co., Inc. ($5). "Fortune," in Pasteur's celebrated phrase, "favors the prepared mind." Like Becquerel, who would not throw away a fogged photographic plate until he had discovered what had fogged it through its light-proof wrappings, Fleming looked sharply at a queer patch of mold in a petri dish and instead of washing it out insisted on finding an explanation. The years he had spent in his tiny cluttered laboratory at St. Mary's Hospital were the preparation for this moment of inspired stubbornness. Chance of course played its part: a single spore of *Penicillium notatum* floated in through his open window, looking out upon a dingy London street, and conveniently settled on a hospitable culture. "All the same," he said later, "the spores didn't just stand up on the agar and say 'I produce an antibiotic, you know.' " The well-known biographer André Maurois presents a finished example of his art in this life of the tongue-tied Scotsman (when his first wife lay dying, she predicted he would marry again, but "She'll have to do the proposing"; when he proposed to his student Amalia Coutsouris, his strangled words were unintelligible and she was forced to inquire: "Did you say anything?").

Fleming's achievement was as much a tribute to his perseverance and single-mindedness as to his imagination and skill. He was the not rare example of the poor country boy who climbs up the hard way. He came from a family of farmers who respected learning and decided that he should have an education and do better for himself than he could on the land. At the age of 13, after primary schooling, he journeyed to London to join his brother Tom, who was an oculist. He enrolled in a high school to follow the commercial course and later found employment with a shipping line. He joined up to fight the Boers but the war was over before his regiment was called; by now his brother had a flourishing practice and it was agreed that Alec should study medicine. At St. Mary's he was a superb student who finished first in every competitive examination he took. It was his good fortune to come under the influence of the celebrated bacteriologist Almroth Wright, an immensely gifted, learned, opinionated, tyrannical teacher and investigator. He took to Fleming from the start, stimulated and bullied him, made him his assistant, and lived to see his "son in science" gain international fame.

To write this book Maurois took a course in bacteriology at the Institut Pasteur in Paris and persuaded a scientist friend to repeat for him all of Sir Alexander's principal experiments. This preparation has had a happy result, for the chief merit of the account is the lucid description of the researches that went into the successful preparation of penicillin as a therapeutic tool. Fleming's main interest was the study of communicable diseases. In the early 1920's he made the important discovery that his own nasal mucus, discharged during a cold, was a potent microbe killer. Tear fluid, he found, had the same effect, the common ingredient being a substance he called lysozyme, which is present also in saliva, white blood cells, egg white and so on. Experiments on this inhibitory substance occupied him for more than five years and were a prelude to his master stroke. He recognized very soon after examining the mold from the spore wafted in from Praed Street that it produced a substance which, like lysozyme, stopped the growth of certain pathogenic microbes. Other molds, he was able to show, did not have the same power, and the next step therefore was to make a great quantity of this special "mold-juice" and test it. With his assistant Stuart Craddock he applied himself to the task for months and was finally able to make 200 to 300 cubic centimeters of the mysterious fluid a day. But this was only the beginning. The juice was not toxic, and yet it was clear that it could not be used for injections until it had been freed from foreign proteins (the protein injections would have caused incidents of anaphylactic shock). For therapeutic purposes it was essential to extract the active principle. This was a job for a chemist or biochemist, but Fleming had no such knowledge, nor did anyone else on Wright's staff.

For a few months in 1928 and 1929

Craddock and another young physician, Frederick Ridley, sought a solution to the chemical problem. They had no funds for equipment; they worked over an old sink in a narrow passageway so as to have running water; they made do with apparatus they built for themselves from odds and ends. They did not realize how extraordinarily difficult the problem was they were trying to crack; what is astonishing is that they came "within measurable distance of success," though this too they did not realize. After a while they became discouraged and the work lapsed. Fleming read a paper on penicillin to the Medical Research Club. He delivered it in his half-hearted, self-deprecating style; the listeners were bored; not a single question was asked. (One recalls that Gregor Mendel had a similar experience.) The paper was published in the *British Journal of Experimental Pathology;* the scientific world remained calm.

In the early 1930's a leading British chemist, Harold Raistrick, studied Fleming's strains together with other molds, but for various reasons the investigation was dropped before much progress had been made. There were other small flurries which came to nothing. The years passed and Fleming himself half-abandoned his darling child. Then in 1935 two men who were to provide the brilliant climax to the enterprise converged upon the University of Oxford from two points very distant from each other on the earth's surface. One was the Australian Howard Florey, who came to take up the chair in pathology, the other was the biochemist E. B. Chain, a refugee from Nazi Germany who, at the suggestion of Sir Frederick Gowland Hopkins, came to work with Florey. Chain had read Fleming's paper and saw the enormous possibilities of a nontoxic microbe killer. With Florey's help he got the Rockefeller Foundation to put up $5,000 for the necessary research. He thought that penicillin must be an unstable enzyme and attacked the problem of extraction and purification on this basis. By the ingenious technique of freeze-drying—by which the culture liquid could be eliminated by sublimation and the solid substances which formed the dry residue could be preserved without destroying their activity—Chain was able to obtain a brown powder: a concentrated, stable, partially purified penicillin product. After further purification, this substance was shown to be free of toxicity and to possess astonishing antimicrobial powers.

With Florey and other colleagues, Chain made crucial tests on May 25, 1940, on three groups of infected mice. Through the night, as the Oxford group watched, one after another of the controls died, while the treated mice survived. It was one of the high moments of science. Fleming first learned of the triumph in *The Lancet*, and immediately went to Oxford to see Florey and Chain. The latter was taken completely by surprise: he had thought that Fleming was dead. The later chapters of Maurois' biography describe the U. S. development of penicillin which made possible large-scale production (including the delightful episode of the rotten Peoria supermarket cantaloupe which became the ancestor of most of the penicillin strains used today) and the abundant, well-deserved rewards that finally came to the laconic Ayrshire farm boy whose discovery is perhaps the single greatest life-saver of modern medicine.

THE ANCIENT MARINERS, by Lionel Casson. The Macmillan Co. ($5.95). The story of what the ancients accomplished on the sea, beginning with the first sailing vessels of about 3,000 B.C. The author, a classicist and a yachtsman, has drawn upon the very considerable findings of hundreds of archaeological excavations of the last half-century or so, including the objects of trade, documents and records on stone and papyrus, and the remains of ancient wrecks explored in underwater archaeology. He is therefore able to give a well-connected story of the development of maritime trading, warfare, piracy and exploration. An enjoyable book which, while wholly acceptable to specialists—there is no book in any other language, Casson says, that covers the field—will please the general reader. Glossary, photographs and selected bibliographies.

D'ARCY WENTWORTH THOMPSON, by Ruth D'Arcy Thompson. Oxford University Press ($4). *Hunc tantum virum* (this great man): Thus the public orator introduced him at a convocation in 1945 when the University of Oxford gave him its highest degree, Doctor of Civil Law. D'Arcy Thompson was an "aristocrat of learning," vastly endowed in his knowledge of man's work and nature's forms and remarkable in his ability to use and impart what he knew. He was a classicist, a mathematician, an eminent naturalist, a beloved teacher who held important chairs for 64 years, a brilliant lecturer and the author of the incomparable *On Growth and Form*—a literary masterpiece of science. He was, as P. B. Medawar has said, a natural philosopher in the proper sense of that term. This biography by his daughter (not, under the circumstances, an excessively adulatory work) describes the 88 years of his life in its daily setting. It traces his career at Dundee and St. Andrews, his researches and travels, his activities on the Bering Sea Commission and the Fishery Board for Scotland, his literary labors. It conveys a sense of his infinitely varied curiosity, his enormous energy, his foibles and eccentricities (which must have been more endearing to outsiders than to his family), his Victorianisms, his joy in living, his generosity and sympathy. Fame came to him very late, but the span of his years was exceptionally long and no one ever enjoyed more being a patriarch. A most interesting postscript by Medawar assesses the scientific value of *On Growth and Form*, and concludes that despite its imperfections and limitations, its influence upon biological science both in Great Britain and the U. S. has been very great.

A California Flora, by Philip A. Munz in collaboration with David D. Keck. University of California Press ($11.50). A comprehensive manual of the more than 6,000 flora of the third largest state in the Union, whose size, exceedingly diverse topography and wide range of physical conditions (*e.g.*, the lowest and highest points in the country—276 feet below sea level in Death Valley and 14,405 feet above at the top of Mount Whitney—are within a few miles of each other) contribute to a remarkably large and interesting variety of plant species. Descriptions of each species give habitats, plant communities (a new system is used of grouping species according to these communities rather than the conventional family order), altitudinal and geographic distribution, flowering dates and chromosome numbers. There is also a section on the early geologic history of the state and the fossil floras. A valuable compendium for specialists.

Robert Boyle and 17th Century Chemistry, by Marie Boas. Cambridge University Press ($5.50). The argument of this book runs as follows. Progress in chemistry in the 17th century has been seriously undervalued. It is true that the advances were minor compared to the brilliant surge in physics, and that the great revolution in chemistry waited for Lavoisier; yet there were significant accomplishments in theoretical ideas as well as in practice, that must be acknowledged to have paved the way for the breakthrough in the next century. Robert Boyle was a major figure in the 17th-century contribution. He championed the corpuscular theory of matter, and this view, supported by his great prestige, helped steer chemistry away from mysticism and alchemical cookery into more rational paths; he studied the mechanism of chemical reactions, conducted extensive experiments and developed systematic tests for alkalis and acids, salts and metals. While he was unable to rid himself entirely of many prevailing misconceptions, his researches and writings had an enormously quickening effect on the development of chemistry. All this could have been said in an essay of 30 or 40 pages, but Miss Boas has stretched it out to 239 pages, embedding her thesis in pedantries and repetitions, and imparting the whole in singularly resinous prose. What is it about the history of science, that intrinsically fascinating subject, that so often invites such abuse?

THE NATURE OF MATHEMATICS, by Max Black ($1.50); FIVE TYPES OF ETHICAL THEORY, by C. D. Broad ($1.75); SCIENTIFIC THOUGHT, by C. D. Broad ($1.95); THE LOGICAL SYNTAX OF LANGUAGE, by Rudolf Carnap ($1.95); BENTHAM'S THEORY OF FICTIONS, by C. K. Ogden ($1.75); PHILOSOPHICAL STUDIES, by G. E. Moore ($1.75). Littlefield, Adams & Co. This new series of paperbacks is a happy idea. It makes available inexpensive reprints of standard works originally brought out in the famous International Library of Psychology, Philosophy and Scientific Method. All the above volumes are too well known to students and philosophers to require comment; many other titles are promised.

AMUSEMENTS IN MATHEMATICS, by Henry Ernest Dudeney; THE CANTERBURY PUZZLES, by Henry Ernest Dudeney. Dover Publications, Inc. ($1.25 each). Henry Dudeney, who died almost 30 years ago, was perhaps the greatest—some connoisseurs prefer Sam Loyd—of modern puzzle-makers. His jokes are not so funny as they used to be (in fact they never were), but his logical riddles; arithmetic, algebraic and geometrical problems; chessboard, weighing, point-and-line, river-crossing unicursal and other puzzles, are still ingenious, fiendish and baffling. He not only put fresh garments on old problems, but contrived new ones. These illustrated paperbacks consist of two of his best-known collections. The first is a gathering of some 400 different brain-teasers; the second presents its puzzles not as individual problems, but as incidents in connected stories.

ANCIENT LANDSCAPES: STUDIES IN FIELD ARCHAEOLOGY, by John Bradford. G. Bell and Sons, Ltd. (84 shillings). Air archaeology is the search for and study of ancient sites by aerial photography. The techniques and equipment have come largely by way of modern warfare, with adaptations to meet special needs. An enormous number of air photographs has been taken in national surveys and under private auspices; many are too small to be of much use archaeologically, but a large residue, which often covers little known areas, is of major interest to those concerned with antiquities. The author has spent more than 10 years in researches of this character, and his book, based on courses of lectures given at Oxford, gives a detailed, splendidly illustrated account of the purpose and practice of air archaeology, together with reports of several field studies in Mediterranean countries. It is gratifying to accompany the trained observer, to discover how much can be learned from small signs, faint markings, barely perceptible differences of color and shading. An ancient farm enclosure is revealed by crop marks, because the vegetation deeply rooted in a 2,000-year-old ditch is darker than that of the adjacent area and forms a border which, though unnoticeable from the ground, stands out clearly in an aerial photograph. Crop and soil marks delineate ritual sites, buried roads and tracks, ancient terracing, abandoned fields, burial mounds, hidden fortifications, foundations of buildings, the street networks of lost cities. Sometimes a vertical photograph is best to bring out the telltale signs, sometimes an oblique picture provides the necessary shadow-relief; often stereoscopy is required to make certain effects intelligible. Assemblages of stones which appear meaningless when viewed from the ground form significant patterns in aerial photographs; examples include a Roman military road with associated structures in Iraq, Roman centurial squares in Dalmatia, the site of a buried port in Greece. Chalk lines, parch markings on grass, a light snowfall with accompanying drifts can point up otherwise invisible remains. Interpretive readings call for considerable skill because it is easy to be deceived; geological features have to be distinguished, as well as comparatively recent furrows and field boundaries. In England, France and elsewhere tank-ditches of the last war have been filled in and are overgrown; thus aerial photos may show

markings that promise antiquities but are in fact mere military scars. Air archaeology has already fully proven itself, Bradford clearly shows, not only as a tool of discovery but as a means of enriching archaeological understanding. Townsites, the topography of entire road networks or agricultural systems, the growth of whole regions in periods when civilization was younger can be seized by the eye and grasped by the mind in full perspective, thereby furthering the ultimate aim of archaeology: "the overall picture of a human community, its economy and setting—societies as 'going concerns.' "

ANCIENT EGYPTIAN AND CNIDIAN MEDICINE, by Robert O. Steuer and J. B. de C. M. Saunders. University of California Press ($3). This footnote of medical history examines the influence of ancient Egyptian medicine on the medical practice of Cnidus, a Greek colony on the coast of Asia Minor; in particular, the relationship of their aetiological concepts of disease. Putrefaction was believed to be a major cause of disease; just as the embalmer knew that he had to prevent the process from consuming the dead body, the physician knew he had to counteract it in the living one. The very word used for "embalm" in *the Book of the Dead* was also used, in medical contexts, to mean medical treatment in general. The skillful sleuthing in the documents and the reproduction, with accompanying translations, of hieroglyphic passages from ancient papyri make this an engrossing little essay.

EXPLORERS' MAPS, by R. A. Skelton. Frederick A. Praeger ($12.50). The Keeper of the Map Room of the British Museum presents some episodes and phases in the history of geographical discovery for which the evidence of contemporary maps is especially interesting or accessible. Among the subjects of the essays are the European discovery of the Far East from the 13th to the 16th centuries, Portuguese voyages to the Indies, the New World in the 16th century, the search for the Northeast and Northwest passages, European rivalry for the Spice Islands, South Sea exploration by the Spanish and the Dutch, James Cook and the mapping of the Pacific, the mapping of North America, the rivers of Africa, and the polar regions. The text provides a summary of geographical ideas and events associated with maps and views. Despite inevitable loss of clarity due to reduction in size, the maps are well reproduced. Altogether Skelton's book makes a handsome and informative pictorial companion to general histories of exploration.

Notes

GENESIS AND GEOLOGY, by Charles Coulston Gillispie. Harper Torchbooks ($1.75). A most welcome reprint of a delightful, too-little-noticed study of the impact of scientific discoveries upon religious beliefs in Great Britain in the decades before Darwin.

PARIS SYMPOSIUM ON RADIO ASTRONOMY, edited by Ronald N. Bracewell. Stanford University Press ($15). A collection of research papers presented at the Paris Symposium in 1958. The volume also contains excerpts from discussions and a number of summaries of the background and current state of major fields of radio astronomy.

CREATIVITY AND ITS CULTIVATION, edited by Harold H. Anderson. Harper & Brothers ($5). A strikingly uncreative group of addresses presented at the "Interdisciplinary Symposia on Creativity" held at Michigan State University in 1957 and 1958. It is remarkable that so many speakers can say so little at such length; and even more remarkable that anyone should take the trouble to give permanent form to such vaporings.

THE HUMAN MEANING OF THE SOCIAL SCIENCES, edited by Daniel Lerner. Meridian Books, Inc. ($1.45). This paperback consists of original essays on the history and application of the social sciences by Margaret Mead, Paul Samuelson, Clyde Kluckhohn and others.

METASCIENTIFIC QUERIES, by Mario Bunge. Charles C. Thomas ($6.75). Essays on various problems in the philosophy of science: complementarity, interpretations of quantum mechanics, the space-time approach to quantum electrodynamics, the nature of computers, the reducibility of physics to mechanics, the meaning of scientific laws, the method of science.

THE THEORY OF THE POTENTIAL, by William Duncan MacMillan. Dover Publications, Inc. ($2.25). Paper-back reprint of an extensive text, long unavailable, on an important tool of theoretical mechanics, invented by Laplace and since extended to an ever widening range of physical problems.

GROWTH AND PERFECTION OF CRYSTALS, edited by R. H. Doremus, B. W. Roberts and David Turnbull. John Wiley

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THE MANY BODY PROBLEM, edited by C. M. Dewitt. John Wiley & Sons, Inc. ($15). Papers presented at a summer session of the School of Theoretical Physics, University of Grenoble, in 1958.

GROUP THEORY AND ITS APPLICATION TO THE QUANTUM MECHANICS OF ATOMIC SPECTRA, by Eugene P. Wigner. Academic Press, Inc. ($8.80). The original German version of this important monograph on the quantum mechanics of atomic spectra, which was stimulated by the investigations of Werner Heisenberg and P. A. M. Dirac on the quantum theory of assemblies of identical particles, was published in 1931. It has now been expanded to report on Racah coefficients, time inversion and other developments since the first publication, and has been translated into English by J. J. Griffin.

CONCRETE: THE VISION OF A NEW ARCHITECTURE, by Peter Collins. Horizon Press ($12.50). An account of the development of concrete architecture from the end of the 18th century, and a rather detailed study of the work and theory of the modern French architect Auguste Perret, whose concrete frame structures—dwellings, theaters, factories, arsenals, laboratories and churches (Notre Dame de Raincy is a celebrated example)—mark him as a 20th-century leader in this field.

METHODS OF EXPERIMENTAL PHYSICS; VOL. I, CLASSICAL METHODS, edited by Immanuel Estermann. Academic Press, Inc. ($12.80). The first volume of a projected six-volume guide presenting papers on the most important methods, or general principles, of experimental physics, with basic references for further reading. The topics treated are evaluation of measurement, fundamental units and constants, mechanics of solids and fluids, sound and vibration, heat and thermodynamics, optics, electricity, magnetism.

THEORETICAL ELASTICITY, by Carl E. Pearson. Harvard University Press ($6). This volume in the series of Harvard Monographs in Applied Science discusses modern methods in the theory of elasticity.

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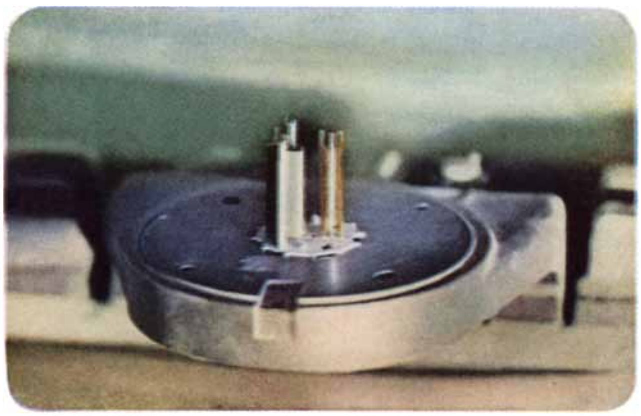

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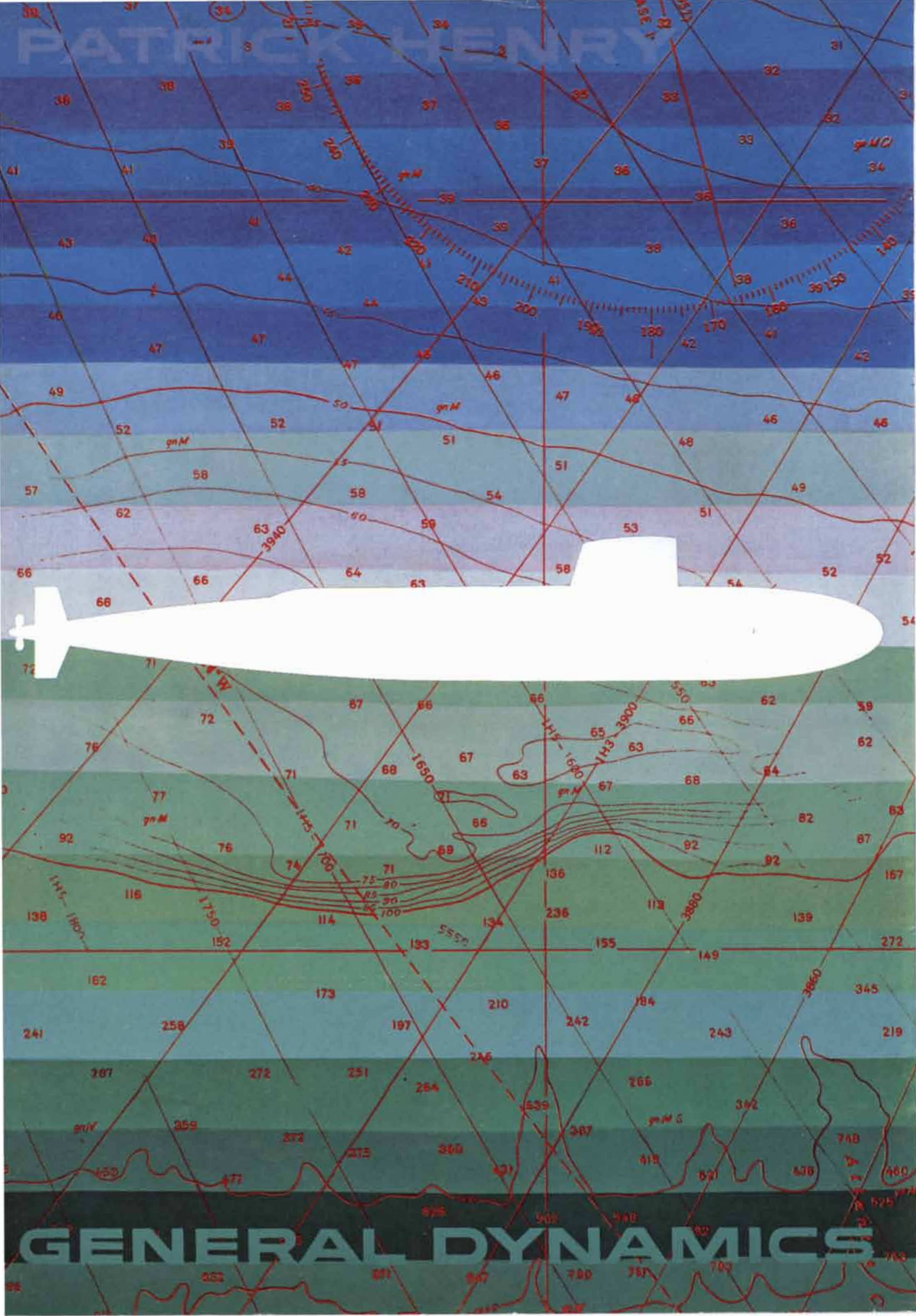

Launched September 1959, the ballistic-missile-firing Patrick Henry SSB(N)599 is the seventh nuclear-powered submarine designed and built by General Dynamics Electric Boat Division.