SCIENTIFIC AMERICAN

OCEANOGRAPHIC INSTRUMENTS

FIFTY CENTS

March 1954

BUSINESS IN MOTION

To our Colleagues in American Business . . .

Like other companies whose people do outstanding work, Revere receives many letters of appreciation. They are a source of great gratification, first because we want to render service, and second because good work shows that the way we select, train, and promote men to positions of responsibility is the right way. Let us quote from a recent letter.

"Thank you for bringing your welding engineer to assist us in solving our problems.

"On his visit to our plant last month, he helped us to establish sound procedures and in so doing, eliminated several expensive errors we were unknowingly making. We are especially grateful to him for the energetic way in which he went about his work, in spite of physical difficulties encountered due to our plant being in full operation. We appreciate his patience in answering all questions with which he was bombarded by operators, supervisors, and management alike.

"It was a real pleasure to have your welding specialist and a technical advisor with us, and we hope it will be possible for you to visit us again soon under less strenuous circumstances."

Our interest in welding stemmed originally from the fact that years ago it became evident that the market for Revere Metals would be expanded considerably if customers could be shown how to make perfect welds, quickly and at minimum expense. A Welding Section was set up within the Research and Development Department, where it was given full laboratory facilities. The activity was organized on both scientific and practical lines, with capable personnel who have solved many problems. In one case, two men were flown to a customer's plant, where they worked 20 hours a day over a weekend, and by Monday afternoon had the satisfaction of seeing the customer's operators turning out perfect welds, saving a substantial sum in penalties for delayed delivery.

The normal procedure whereby the Welding Section is called into action is simple. Usually a Revere Salesman uncovers a welding problem, and calls in the Technical Advisory Service. Often a Technical Advisor can provide the needed know-how. If additional help is needed, he can get it from the Welding Section people.

You may not be at all concerned about welding metals, and never expect to be. That does not matter. Whatever you make, or how you make it, you may have problems. Our suggestion is that you look around among your suppliers and see if one or more of them may not have just the special skills that you can use to good advantage.

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LETTERS

Sirs:

The short article "Too Many People" in "Science and the Citizen" [SCIENTIFIC AMERICAN, January] contains the erroneous statement that "the birth rate (of India), 27 per 1,000, is the highest in the world. . . ." For the period 1947-51, Costa Rica had an average birth rate of 45.1; Mexico, 45.2; El Salvador, 46.8; and Guatemala, 51.3.

Actually India's birth rate is only two per thousand higher than that of the U. S. India's terrible population problem arises from the fact that she cannot now afford any increase in her population at all—and her numbers are growing at the rate of five million a year. Despite the fact that India's rate of natural increase is lower than that of the world as a whole, her population will double in the next 56 years if the 1940-50 rate of increase continues—let alone rises.

It is true that in the past birth rates have dropped only in conjunction with rising standards of living. But today modern medicine and insecticides can and do cut the death rates of undeveloped countries in a very few years—thereby sending populations soaring. So ways must be found to cut birth rates in such countries more rapidly than they were reduced in the West; otherwise, all the benefits our Western "know-how" is bringing these countries will simply be swamped in an upsurge of numbers which the undeveloped countries themselves neither want nor can cope with.

WILLIAM ESTY

Planned Parenthood Federation
of America, Inc.
New York, N. Y.

Sirs:

In order to meet the space requirements for the article on "Radio Waves from Interstellar Hydrogen" [SCIENTIFIC AMERICAN, December, 1953], I was unable to include some general information that your readers might find of interest.

With regard to the radio astronomy program at Harvard, considerable credit is due the engineers of the Raytheon Manufacturing Corporation of Waltham, Mass., for their assistance which was provided free of charge in the interest of furthering the research program. In addition the National Radio Company of Malden, Mass., made the facilities of its model shop available to the Harvard project at a direct cost rate in order to expedite construction of several sensitive circuits requiring precise test equipment facilities.

The Harvard radio astronomy program under the direction of Bart J. Bok is supported by a grant from the National Science Foundation and by gifts from a friend of Harvard's Agassiz Station.

During the past few weeks the telescope has been put into full operation and has already provided a considerable amount of previously unpredicted information concerning the structure of our galaxy.

HAROLD I. EWEN

Harvard College Observatory
Cambridge, Mass.

Sirs:

I have read the elegant essay by Sir Edmund Whittaker on G. F. Fitzgerald [SCIENTIFIC AMERICAN, November, 1953] with more than ordinary interest. (Sir Edmund's exposition is *always* elegant and beautiful.) He speaks of the conception of the "Fitzgerald contraction" and writes: "He died in 1901, too soon to know that his notion led to the theory of relativity." It is on this point that I wish to comment.

These years (the days of Fitzgerald, Hamilton, Stokes, Maxwell, and the other "giants" of the late 19th century) were rapidly ripening for a revolution in physical thought. There is every evidence that relativity theory was *inevi-*

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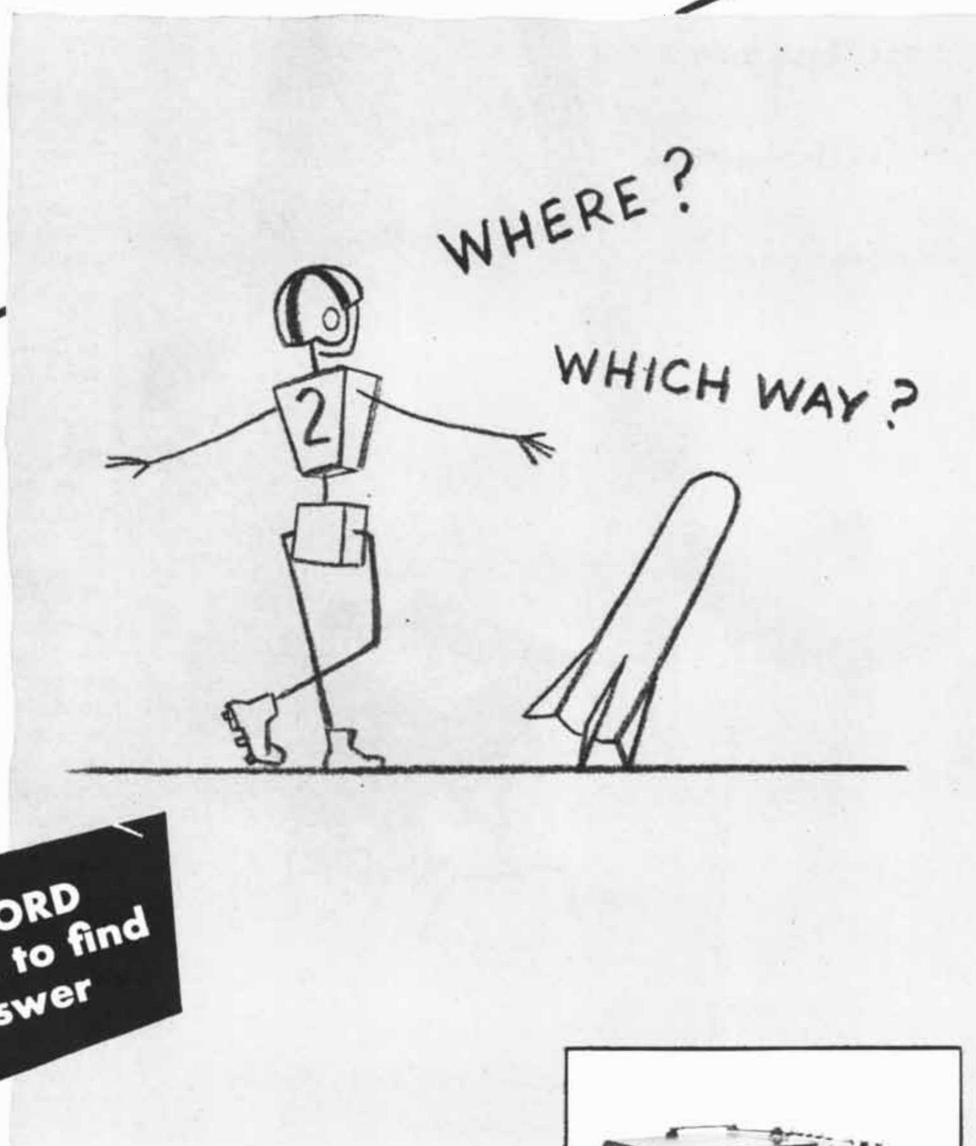
HOW TO KICK OFF A ROCKET in the right direction



...and FORD was asked to find the answer

Load! Aim! Launch! And off goes a rocket from shipboard . . . but not without precise devices that start the rocket in the right direction. Devices . . . such as Ford Instrument has manufactured for the Armed Forces since 1915. For from the vast engineering and production facilities of the Ford Instrument Company, come the mechanical, hydraulic, electro-mechanical, magnetic and electronic instruments that bring us our "tomorrows" today. Control problems of both Industry and the Military are Ford specialties.

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table and Fitzgerald's conception was most certainly a keystone in the new structure. One is convinced, when studying how things were pointing in these years, that the universe was about to be established anew. (Newton did it in one very acceptable fashion.) connection Einstein's remarks are exceedingly illuminating: "It appears to me as a foregone conclusion that he would have developed the Special Theory of Relativity, had that not been done elsewhere; for he had clearly perceived its essential aspects." Einstein's reference here happens to be to the French physicist Paul Langevin.

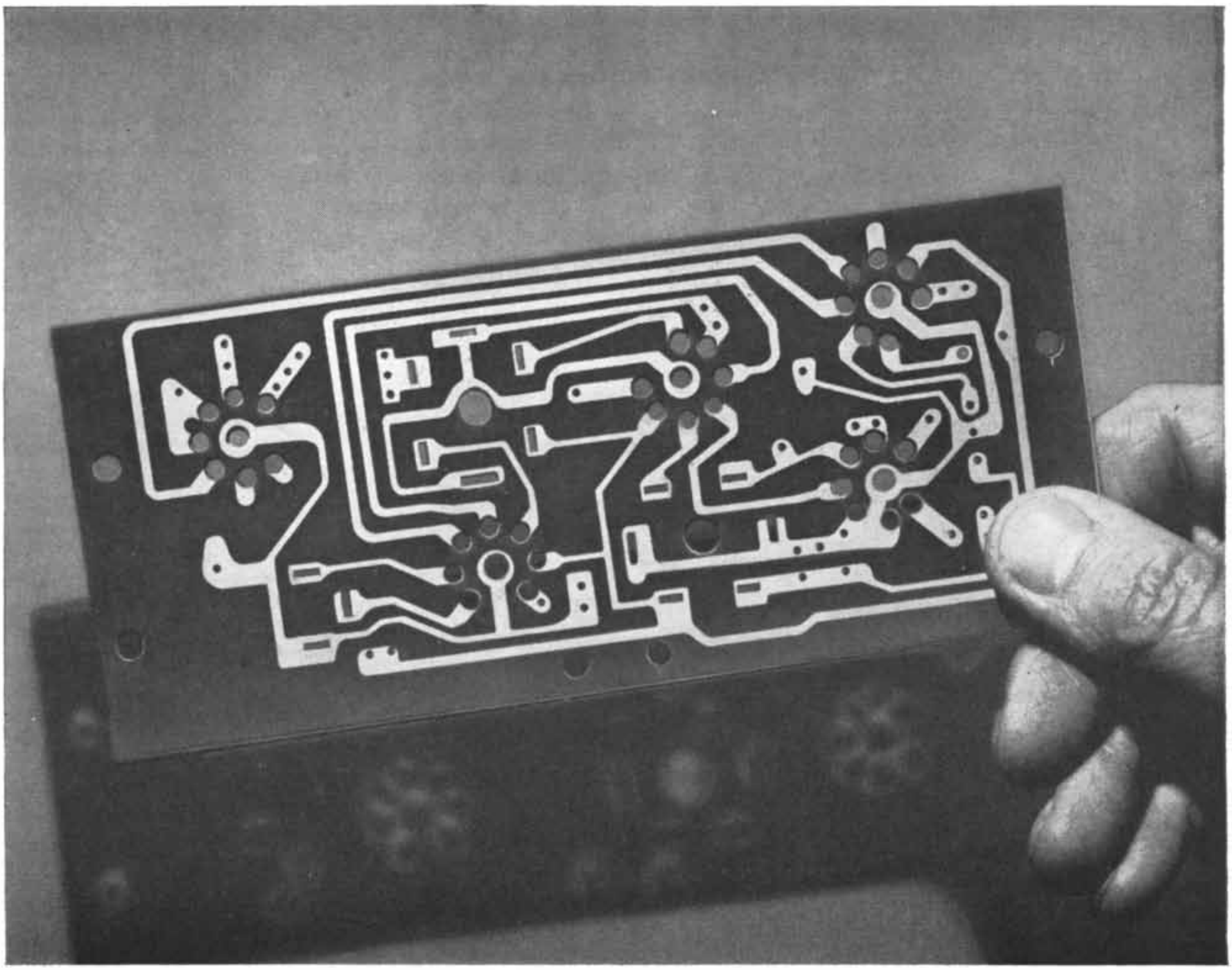
JULIUS SUMNER MILLER

El Camino College
Los Angeles, Calif.

Sirs:

In a letter in your November, 1953, issue Lloyd Espenschied commented on our article about Francis Hauksbee [SCIENTIFIC AMERICAN, August, 1953]: "I feel I must remonstrate against the practice . . . of maximizing the hero of the play by minimizing the supporting cast, in this case those upon whom the Hauksbee advance was built." We agree with this point of view, but we cannot agree, as Dr. Espenschied suggests, that Otto von Guericke was minimized by us when we pointed out that he was not the effective inventor of the triboelectric generator. The "many authorities" that Dr. Espenschied cites are unfortunately but one, for they are all the intellectual descendants of Joseph Priestley who, in looking back from the 18th century at Guericke's 17th-century sulfur globe experiments, realized that electrical phenomena were involved, and in his famous *History and present state of electricity* (1767) gave the story that many writers have since repeated. Fortunately we no longer have to depend upon Priestley's interpretation: a detailed modern study of Guericke's sulfur globe experiments has been made by the British historian of science N. H. de V. Heathcote. Interested readers may turn to his article in *Annals of Science* (1950, pages 293-305) to find why he concluded that "Guericke's sulfur globe was not devised as an electrical machine nor were the experiments made with it electrical experiments in the sense that they were investigations into the properties of electricity."

As for the review of Guericke's book in the *Philosophical Transactions* for 1672, it was hardly of such a nature as to en-



Pattern of things to come

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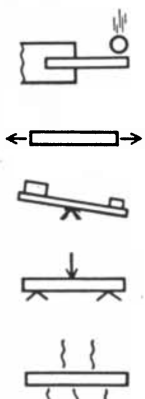

1. Impact strength. Synthane stands up in mechanical applications where jolts, jars and light shock loads are common. It does not splinter or break readily; will not delaminate.

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3. Light weight. Synthane has approximately half the weight of aluminum.

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5. Stable Over Wide Temperature Range. Synthane is thermosetting; does not flow as temperature rises, has a low coefficient of thermal expansion.

Here is one of the brightest ideas in electronics—and one of the materials which helped make it possible. The idea is the printed circuit; the material is a laminated plastic called *Synthane*.

For years radio sets were put together by laboriously soldering a forest of wires to terminals. It was a time-consuming and expensive operation. If one connection proved faulty, the whole assembly had to be rechecked.

Then someone came up with the idea of *printing* the circuit with an acid-resisting ink on foil bonded to a base—and etching away the metal not needed. It would be quick, easy and error-proof—if the right base material could be found.

Among many tested, *Synthane* was one sheet material selected. Synthane has the necessary strength, low moisture absorption, is an excellent insulator and can be punched easily. It bonds securely to metal foil and withstands the etching acid used to remove the excess metal.

The printed circuit is still in development—but it has zoomed into favor for radio, TV, hearing aids, and many other electronic devices. There are now a dozen ways to produce what are still called "printed" circuits. And Synthane is an accepted base material for every one of them.

Synthane laminated plastics are available in a variety of grades and colors—in sheets, rods, tubes, and fabricated parts. You are invited to write for information to Synthane Corporation, 2 River Road, Oaks, Pa.

SYNTHANE CORPORATION, OAKS, PA.

SYNTHANE
LAMINATED S PLASTICS

courage reading of the book, since rightly or wrongly it called attention principally to the reviewer's belief that practically all of the work published therein had been done by others before Guericke. The one paragraph devoted to the sulfur globe experiments makes no mention of electricity, rather skeptically noting that Guericke "affirms that the Impulsive, Attractive, Expulsive, and other vertues of the Earth, as he calls them, may be ocularly exhibited."

Robert Boyle knew of Guericke's work with air pumps. Yet Boyle in his own book on electricity, published three years after the appearance of Guericke's book, did not mention Guericke as an electrical experimenter, although he listed seven other 17th-century scientists—not all of them English—who had studied electrical phenomena.

As for Newton, there is nothing in his writings that we know of to indicate that he suggested the substitution of a rotating glass ball for one of sulfur, although several subsequent writers credited Newton with having made this suggestion.

Several decades after Hauksbee published his work, Dufay, in France, mentioned Guericke's book and, recognizing that the sulfur globe experiments were electrical in character, repeated and extended one in which the rubbed globe had been seen to repel a feather. But by this time there were other sources of information on electrical repulsion. The phenomenon had been observed as early as 1629, by Cabeo in Italy; and various striking experiments on repulsion were described by Hauksbee, with whose work Dufay was familiar. Indeed Dufay, in transmitting a summary of his electrical discoveries to the Royal Society of London in 1733, began by saying: "I owe this homage to that illustrious body, not only as a member thereof, but as a debtor to its works, in that the writings of Mr. [Stephen] Gray and of the late Mr. Hauksbee, both of that society, first put me upon the subject and furnished me with the hints that led to the following discoveries."

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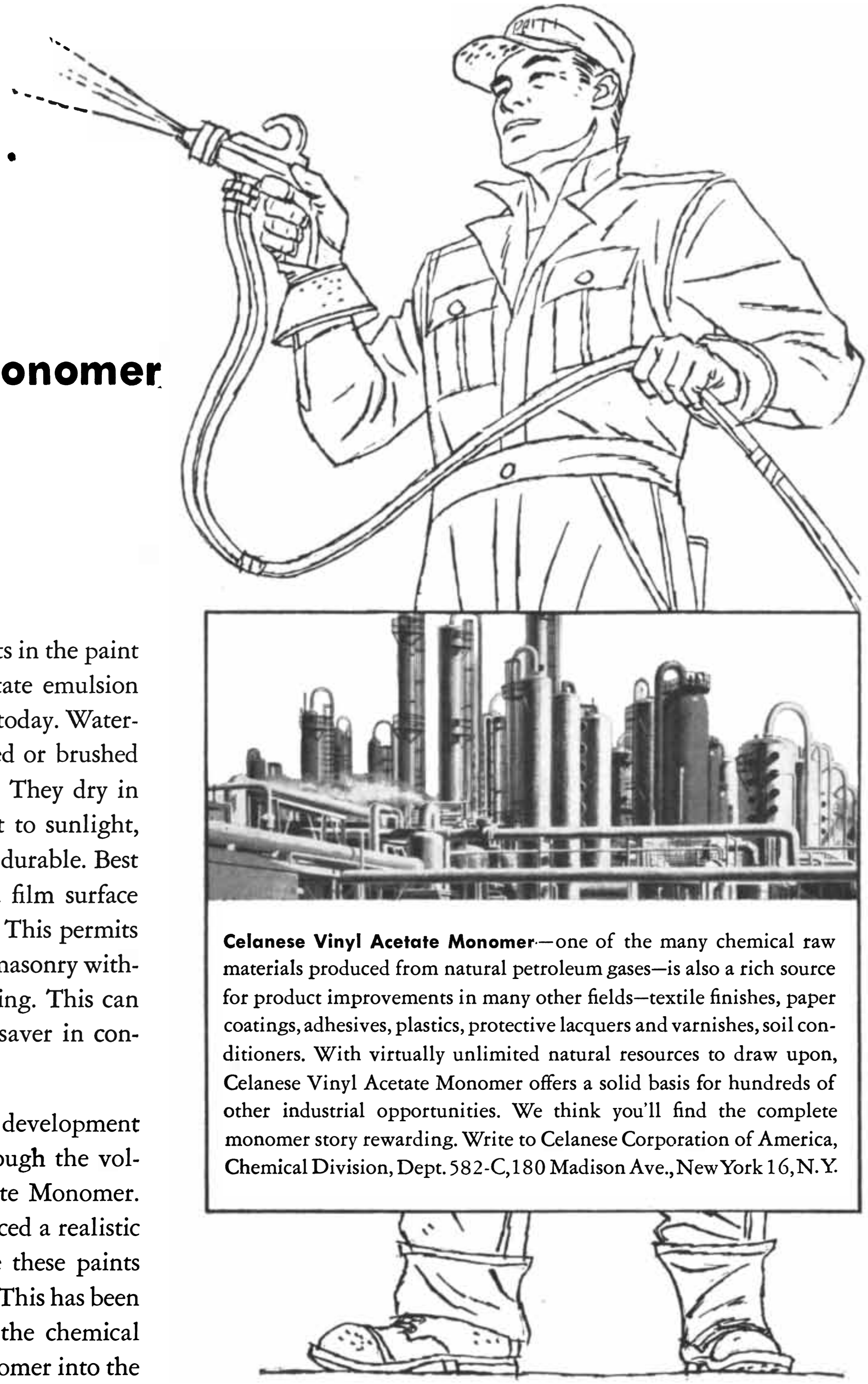
DUANE H. D. ROLLER

Harvard University
Cambridge, Mass.

New Paints that "breathe"... from Celanese* Vinyl Acetate Monomer



Of the many recent developments in the paint industry, the new polyvinyl acetate emulsion paints offer the greatest promise today. Water-based, they can be sprayed, rolled or brushed on any surface—indoors or out. They dry in less than an hour. They are fast to sunlight, alkali and weather resistant, and durable. Best of all, these new paints form a film surface that is porous to moisture-vapor. This permits application on fresh plaster and masonry without danger of blistering or peeling. This can prove to be a tremendous time-saver in construction and maintenance.

Celanese is contributing to the development of polyvinyl acetate paints, through the volume production of Vinyl Acetate Monomer. Celanese production has introduced a realistic price stability that should make these paints competitive in every application. This has been a spur to increased activity by the chemical companies who process the Monomer into the polyvinyl acetate resin emulsions for use by paint manufacturers.

Celanese Vinyl Acetate Monomer—one of the many chemical raw materials produced from natural petroleum gases—is also a rich source for product improvements in many other fields—textile finishes, paper coatings, adhesives, plastics, protective lacquers and varnishes, soil conditioners. With virtually unlimited natural resources to draw upon, Celanese Vinyl Acetate Monomer offers a solid basis for hundreds of other industrial opportunities. We think you'll find the complete monomer story rewarding. Write to Celanese Corporation of America, Chemical Division, Dept. 582-C, 180 Madison Ave., New York 16, N.Y.

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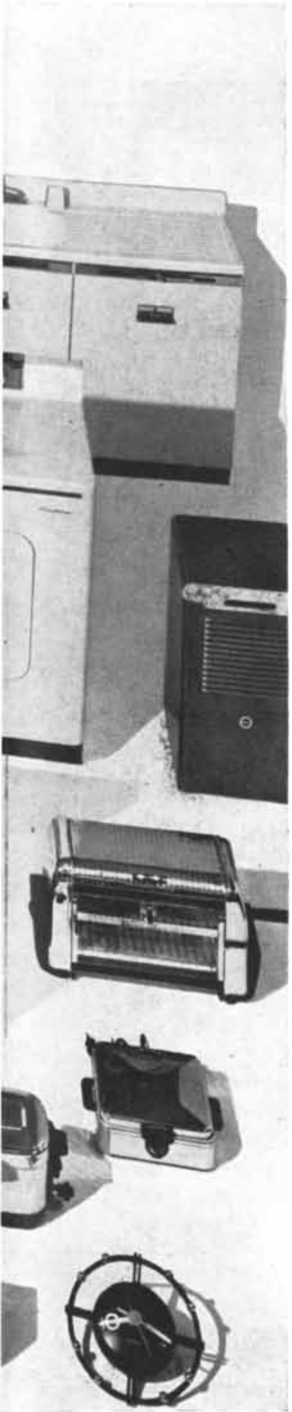
In Metals



It's an age of exciting new electrical appliances. But, despite warnings, our homes—and factories too—often suffer from "skimpy" wiring. Here's how Anaconda helps your electrician correct this situation for you.

IS YOUR house—or apartment—almost new? *Already its wiring may be dated.*

Our "electrical" needs have grown day by day. Electric light companies have been saying this for years. Now, as we buy dishwashers, grills and air conditioners at an amazing rate, these needs have become acute.

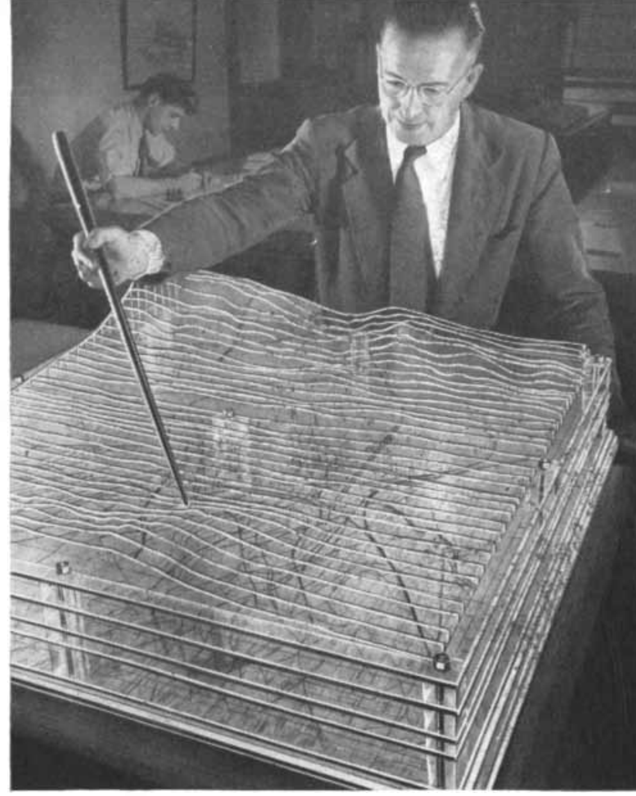
Wiring never seems to catch up. Even just after we build them, we sometimes find our homes *underwired*. We can't enjoy all the fun, comfort and freedom from work that electricity offers.

Our factories feel the same pinch. We install wonderful new machines. Only to find last year's wiring a bottleneck.

Best prescription: wire ahead—years ahead! It costs less in the long run. Anaconda Wire & Cable Company now offers your electrician a wide choice of many new wires and cables. Modern plastic and synthetic rubber insulations make it possible to replace outgrown circuits most economically.

Good products and modern production methods—to meet U. S. metal needs—are typical of Anaconda and its manufacturing subsidiaries. From their mills come products as varied as pre-formed *copper* tube grids for radiant panel heat, *stainless steel* flexible connections for jet engines, and *aluminum* cable, steel reinforced, for electrical transmission lines.

Leadership is a habit with Anaconda and its subsidiaries. Each is a part of a fully integrated business working with many metals. That's why each can serve you better . . . *today and tomorrow.* 53267A



3-D GEOLOGY SHOWS COPPER TREASURE. Since 1876 Anaconda's famous Butte Hill in Montana has yielded over 13 billion pounds of copper. For more than 50 years three-dimensional records of Butte's geological structure were kept. Recently, this precise geological mapping paid off. It showed vast resources of low-grade ores. Anaconda is now tapping a proved reserve of 2,600,000,000 *extra* pounds of copper from "the richest hill on earth." Much is already going into wires, cables and brass mill products for our homes, factories and electric companies.

WHERE WILL WE GET THE "EXTRA" ELECTRICITY WE NEED? In 10 years, electric companies have doubled their generating capacity, and in the next 10 years will doubtless double again. This year, the new Astoria plant of Con Edison will give New York City 360,000 kilowatts more power capacity. The American Brass Company, an Anaconda subsidiary, supplied thousands of "aluminum-brass" tubes which condense the steam that turns its turbines. Anaconda is well-equipped to help engineers select the best metals for such tubes. Its experience with copper and copper alloys goes back over a century.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1904: "In describing his successful experiments in powered flight, Wilbur Wright says, 'After the motor device was completed, two flights were made by my brother and two by myself on December 17 last. The first flight covered but a short distance. Upon each successive attempt, however, the distance was increased, until at the last trial the machine flew a distance of a little over a half mile through the air by actual measurement. We decided that the flight ended here, because the operator touched a slight hummock of sand by turning the rudder too far in attempting to go nearer to the surface. The experiments, however, showed that the machine possessed sufficient power to remain suspended longer if desired. According to the time taken of each flight a speed varying from 30 to 35 miles an hour was attained in the air.' "

"Sir William Crookes and J. Dewar have made some interesting experiments to determine whether the scintillations produced by radium on a sensitive blende screen are affected by cold. A 'spinthariscope,' a small screen of blende with a morsel of radium close in front, was sealed in a glass tube. On dipping the whole into liquid air, the scintillations grew fainter and soon stopped altogether. To test whether this was due to a cessation of the radio-activity or a cessation of the sensitiveness of the screen, two different cooling tubes were constructed, in one of which the radium salt adjoined the wall exposed to the liquid air, while in the other the screen was in that position. It was found that in the former case the scintillations remained as vigorous as before, while in the latter case they soon ceased. Hence the disappearance of the scintillations is due to loss of sensitivity of the screen and not to loss of radio-activity."

"The chemist of the old school objects scornfully to the new theory of electrolysis. The idea of the spontaneous dissociation of a substance like chloride of sodium appears to him to be absurd. He

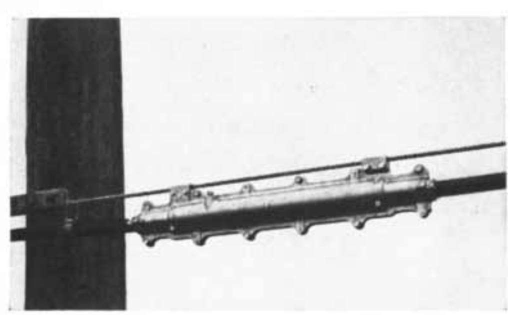
BOLTING VOICES TOGETHER

Adjusting casing over splice in polyethylene cable. Edges and ends are sealed with a new Butyl rubber compound that won't harden, dry out or lose adhesion even in extreme heat or cold.

More than ever, light, flexible polyethylene sheathed cable developed by Bell Telephone Laboratories is providing speedy answers to the demand for more telephone service.

But at thousands of splices, the sheath must be thoroughly sealed against moisture. Laboratories engineers developed a protective casing which is quickly and simply bolted in place. The edges and ends of the casing are *permanently* sealed with a new compound developed by Laboratories rubber chemists.

Now, economical polyethylene cable can be installed much faster and at lower cost. Here is another example of how Bell Laboratories continually finds ways to keep telephone service high in quality, while the cost stays low.



CLOSED CASING IN PLACE

BELL TELEPHONE LABORATORIES

EXPLORING AND INVENTING, DEVISING AND PERFECTING, FOR CONTINUED IMPROVEMENTS AND ECONOMIES IN TELEPHONE SERVICE knows chlorine as a gas exceedingly unpleasant to breathe. He knows sodium as a metal possessed of a remarkable energy, quite ready to cause explosions in the presence of water. He knows common salt as a perfectly harmless, indeed, salubrious compound, resulting from the combination of those two elements. Nobody has ever denied that a solution of salt in water is salt, that it tastes like salt, and that the solid salt can be recovered from the brine as many times as we desire. And now people come and tell him that, in brine, we have ions—whatever they be—of chlorine and of sodium roaming about, under certain restrictions, yet independently of one another. He declines to entertain these newfangled notions which pretend to explain phenomena that chemistry has duly labeled and shelved by an imposing array of new terms and arguments which become the more involved the further they are developed. These objections are not justified."

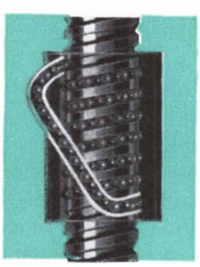
"Mr. E. W. Maunder has made experiments at the Royal Hospital School at Greenwich which, he believes, demonstrate that the Martian canal system, as figured by Schiaparelli and others, is an illusion. A class of about twenty boys, from twelve to fourteen years of age, were seated in four or five rows at different distances from a carefully-lighted diagram which they were told to copy. The diagram was reproduced from some published drawing of Mars, but in nearly every experiment the canals were omitted. The general result was striking. In several of these experiments nearly all the boys drew 'canals' on their copies, though there were none on the original from which they were copying."

"Regarding the airship contest at the coming St. Louis World's Fair, Leo Stevens, an American aeronaut, writes us that he has decided not to enter. 'The rules,' he says, 'call for a speed of at least 20 miles per hour. This is impossible. The prize is perfectly safe with the Exposition Company.' "

SCIENTIFIC AMERICAN

MARCH, 1854: "The opening lecture of the Royal Institution of London this season was delivered by Faraday to a very crowded audience. The principal point which Professor Faraday was anxious to illustrate was the confirmation

The way we change angles on 'Copter Blades puts a brand new slant on controlling power



One of these days, when you hop from home to the office in your personal helicopter, you'll marvel at the way you "shift gears"... from "straight up" to "full speed ahead"... from "side-winder" to "hover". It will be done fast, smoothly, accurately.

Today, helicopter builders are using Cleveland Pneumatic's friction-less combination of a screw and some balls to adjust the angle of the whirling blades on the 'copter. This device is called a "ball-screw actuator".

Ball-screw actuators are useful in many applications in either of two ways... to multiply the power of a drive... or to increase its speed. You also get the hair's-breadth accuracy of a metal-to-metal drive that eliminates merely-approximate positioning of other systems.

Somewhere in your product or your idea for a product, you may be able to use Cleveland Pneumatic ball-screw actuators. They've been engineered by us in all sizes... from tiny ones for 'copter blades to the giants that we make to raise and lower bomber landing gears.

If you wish to know more about Cleveland Pneumatic, write for our 16-page booklet.

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BALL-SCREW ACTUATORS • AUTOMOTIVE SHOP EQUIPMENT
AIR-OIL IMPACT ABSORBERS

World's Largest Manufacturer of Aircraft Landing Gears

To CUSHION SHOCK

CPT's shock absorber principle combines pneumatic and hydraulic cushioning. It can control minute vibrations or tons of impact. It is the shock absorber for the largest aircraft landing gears (CPT is the world's biggest manufacturer of landing gears), and the same principles are often adapted to finger-sized units. May we discuss with you how to take the shock out of stopping or the motion out of vibration?

which experiments on the large scale of the electric telegraph have afforded of the identity of dynamic or voltaic electricity with static or frictional electricity. Some interesting facts connected with the conduction of electricity have also been disclosed by the working of the submarine telegraph. It has been determined that the velocity of transmission through iron wire is 16,000 miles a second, whilst it does not exceed 2,700 miles in the same space of time in the telegraph wire between London and Brussels, a great portion of which is submerged in the German Ocean. The retardation of the force in its passage through insulated wire immersed in water is calculated to have an important practical bearing in effecting a telegraphic communication with America; for it was stated that, in a length of 2,000 miles three or more waves of electric force might be transmitting at the same time, and that if the current be reversed, a signal sent through the wire might be recalled before it arrived in America."

"At the present moment there are not over two—certainly not more than three—efficient steamships belonging to our navy. By late accounts from Europe it appears that the British steam marine amounts to 55,000 horse power—enough to match all the steam fleets of the world put together. We do not need such a large steam navy as this, but we certainly do need a better and much larger one than that which we have at present. We ought at least to have twelve or fifteen *first-class* steam frigates, whereas we have *not one*."

"Reports from both the Atlantic and Pacific expeditions across the Isthmus of Darien, to explore the country for a ship canal, have been received. The result of these observations is that the proposed route is a continuous chain of mountains, with summits of four thousand feet. One portion of the Atlantic party is still on the way to the Pacific. The construction of the canal, according to these reports, is utterly impracticable."

"In Boston they have a telegraph fire-alarm system by which, in a second of time, information is sent to almost every engine house of the exact situation of a fire when it breaks out, so that the firemen can dash off in an instant to the point of action. This system has been the means of preventing many disastrous fires in that city. Let it be adopted in New York and it will save the city some millions every year."

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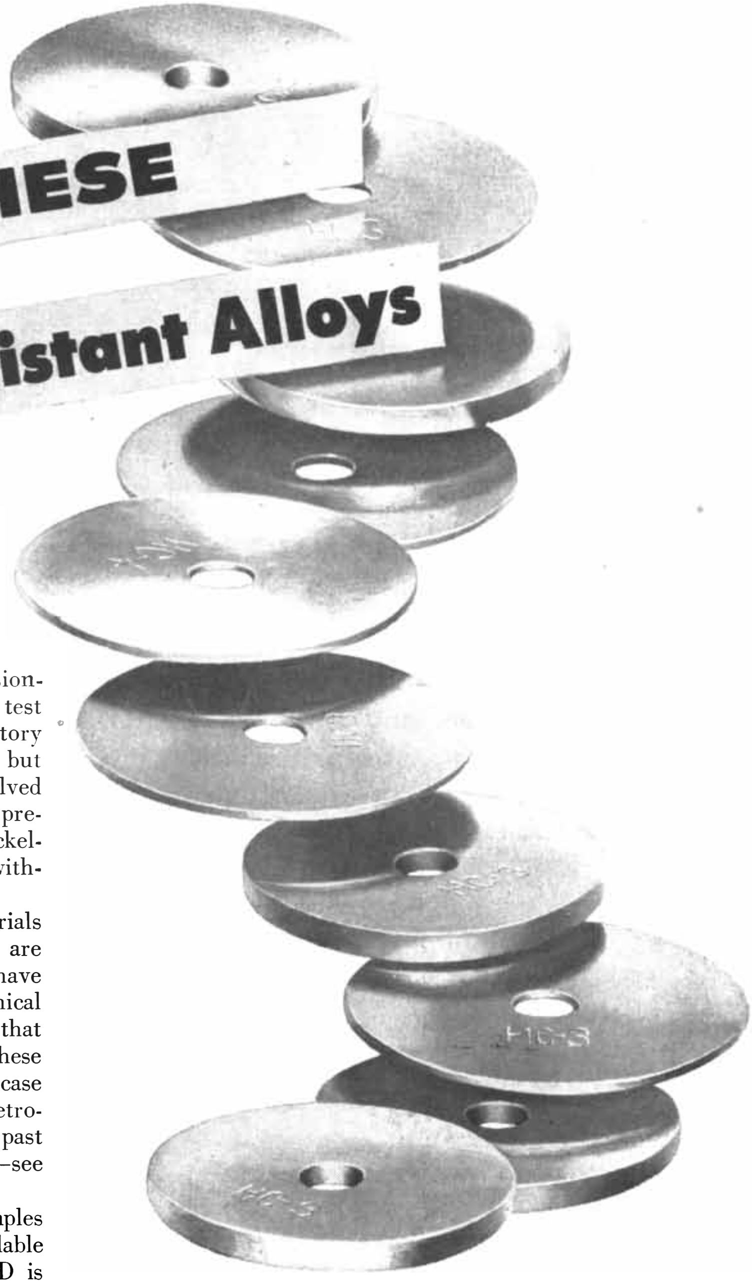

. . . and see for yourself how economical they are

The only way you can be sure that a corrosion-resistant material will work in your plant is to test it under actual operating conditions. Laboratory tests will give you some idea of what to expect, but they don't show the effects of the variables involved in production operations. That is why we have prepared standard test specimens of HASTELLOY nickel-base alloys . . . and they are available to you without cost.

Test these alloys yourself against the materials you are now using, or against others that you are considering using. Prove to yourself that they have exceptional corrosion resistance . . . high mechanical strength, even at elevated temperatures . . . and that they are economical to use. We can support these claims with records of laboratory tests and with case histories of actual installations in chemical, petroleum, textile, and metalworking plants over the past 20 years. But don't take our word for it—see for yourself.

Use the handy coupon below to order your samples of HASTELLOY alloys. Alloys B, C, and F are available in either cast or wrought forms, while alloy D is supplied as castings only. If the equipment you have in mind is to contain welded joints, be sure to advise us, so that we may furnish you with welded samples.

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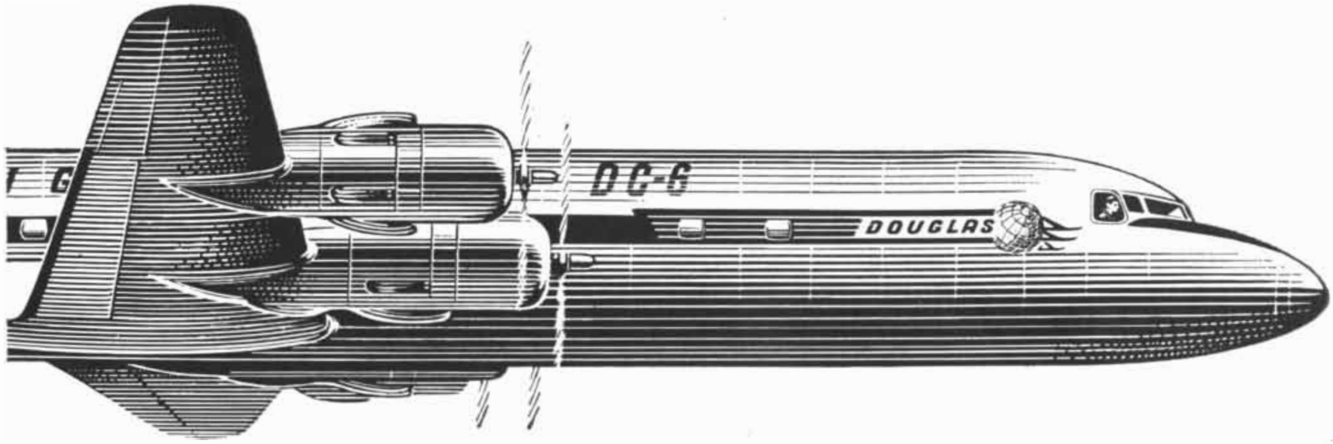

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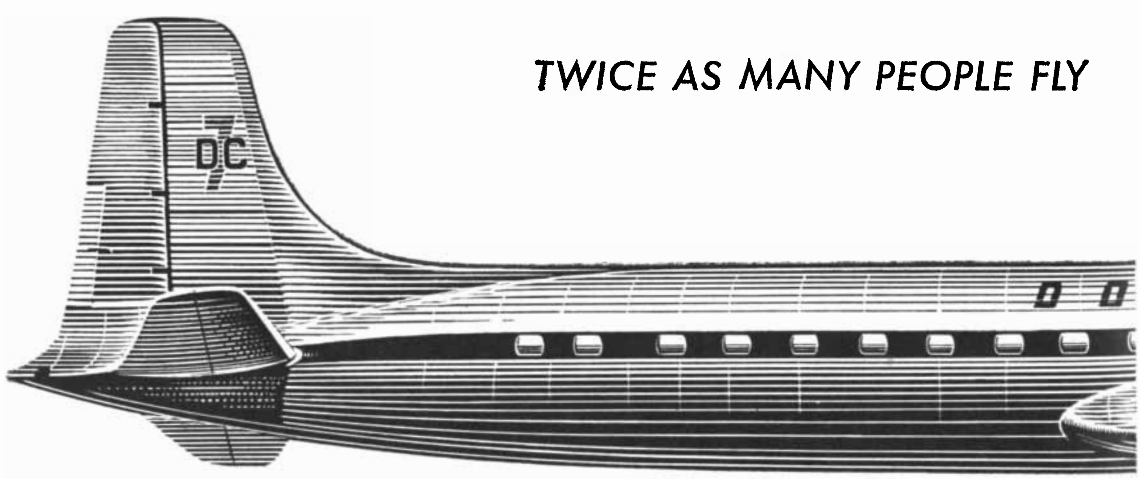

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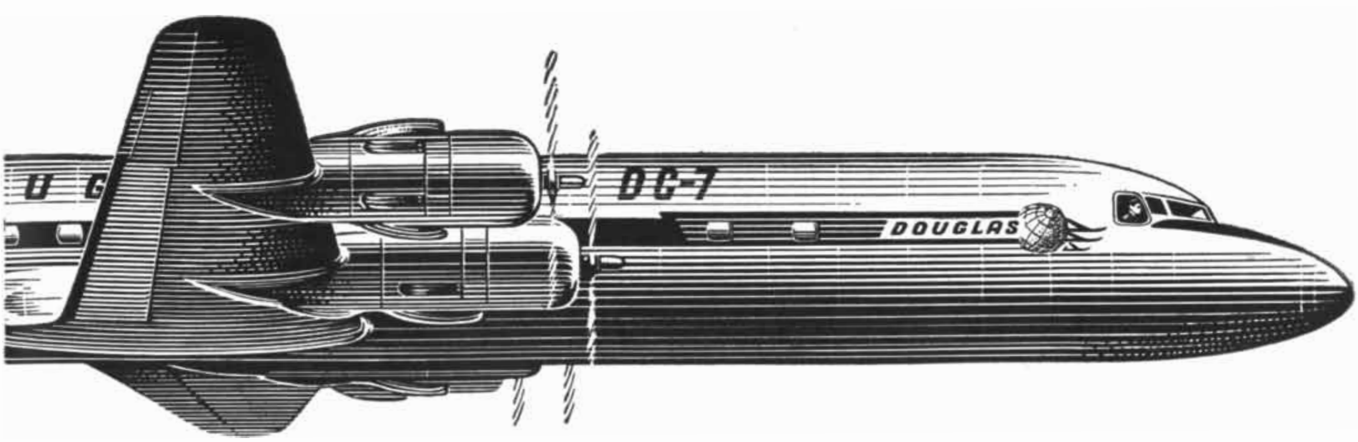
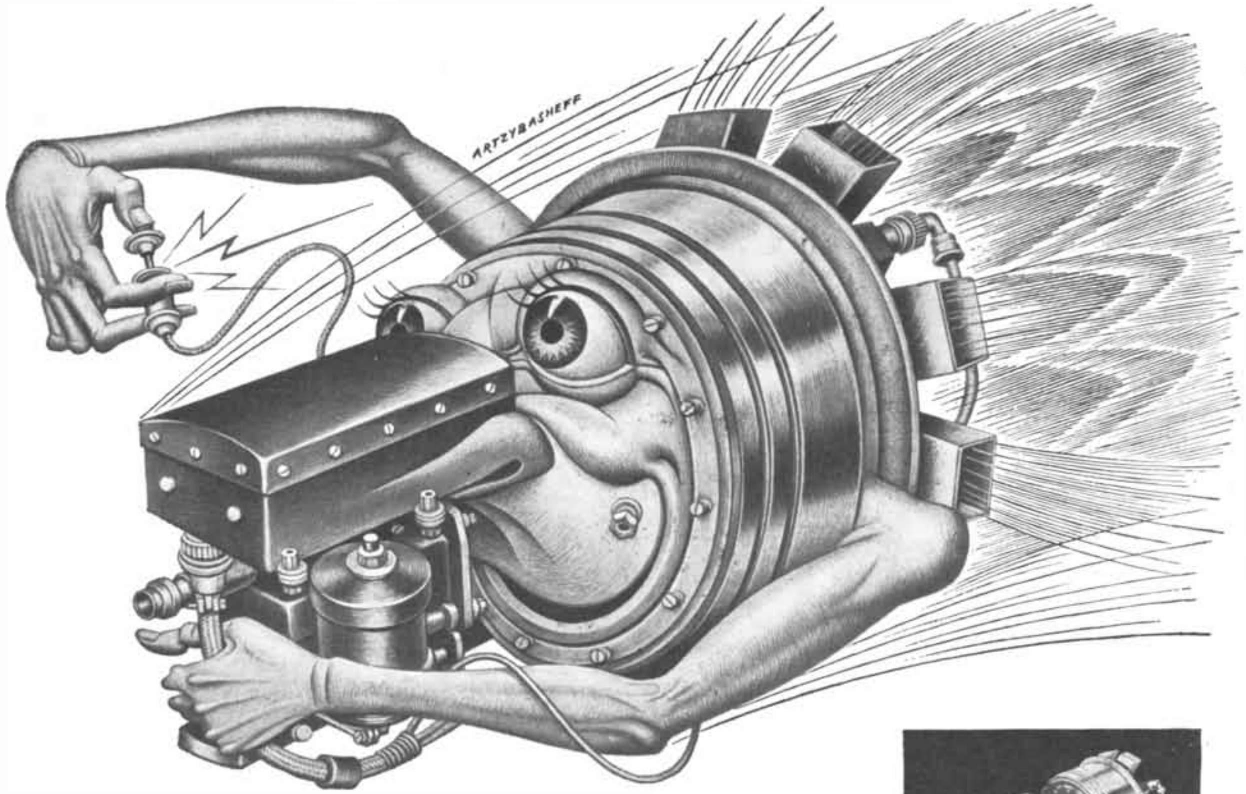


THE AUTHORS

LAWRENCE P. LESSING ("The National Science Foundation Takes Stock") is a member of the Board of Editors of this magazine.

ANDRÉ LWOFF ("The Life Cycle of a Virus") was educated at the University of Paris and is now head of the department of microbial physiology at the Pasteur Institute. His own capsule sketch of his career follows: "Dr. Lwoff has worked here and there on this and that. Has been fellow of the Rockefeller Foundation at Heidelberg and at Cambridge and Dunham Lecturer at Harvard. Is now visiting the U. S. for the sixth time, driving from one place to another, until, sooner or later, he returns to France. In 33 years of scientific activity has discovered some strange creatures and some unexpected phenomena which have been published in 250 papers (much too much) dealing with various aspects of microbiology. His activity since 1949 has been devoted to the study of lysogeny, which was put on a firm base by the discovery of prophage. Has produced a certain number of books. Is now preparing an *Essai de Biologie théorique* which will sometime be published somewhere and be, if it ever comes to light, a very remarkable book. As a result of that and this, is now a member of various scientific societies, here and there. Born in 1902, Dr. Lwoff seems to be one of the promising young French scientists." In an appended note Lwoff sympathizes with the task of a biographer of scientists: "Reduced to the essential, the life of those people is always of the same type." Of his spare-time activity he says, "When I do not work, I play."

ERNEST M. GRUENBERG ("The Epidemiology of Mental Disease") brings both a mathematical and a medical training to his studies of community mental health. He majored in mathematics at Swarthmore College, where he graduated in 1937, took his medical work at Johns Hopkins and also holds a degree in public health from Yale University. During World War II Gruenberg served as a medical officer with combat battalions and later as an intelligence officer in the Surgeon General's office. After the war he was for a time executive director of the New York State Mental Health Commission. He teaches courses in psychiatry and public health at Syracuse University, Columbia University



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and Yale. He is the son of Sidonie Matsner Gruenberg, past Director of the Child Study Association of America, and Benjamin C. Gruenberg, prominent educator and author.

GEORGE GAMOW ("Modern Cosmology") is professor of theoretical physics at the George Washington University in Washington, D. C. Born in Odessa, Russia, in 1904, he was educated at the University of Leningrad, taught and did research at the Academy of Sciences in Leningrad and at Göttingen, Copenhagen, and Cambridge universities, and came to the U. S. in 1934. He has done pioneering studies on the theory of radioactivity and the structure of the nucleus. When nuclear physics became "too crowded," he turned his attention to thermonuclear reactions in stars and to the field of cosmology and the origin of the elements. Most recently he has become interested in fundamental biology, believing that "new advances in this discipline are transforming it from a mostly descriptive into an exact science, thus opening new fields for theoretical studies." Gamow has written nine popular books on science, of which his own favorites are those devoted to the adventures of "Mr. Tompkins" in the fields of relativity, nuclear physics, physiology and genetics. He is a frequent contributor of articles to SCIENTIFIC AMERICAN.

GERALD S. POSNER ("The Peru Current") was a member of the Yale University South American Expedition of 1953, which explored ocean waters off that continent. He was born in New York City in 1927, graduated from the College of the City of New York and took a master's degree in marine biology at the Marine Laboratory of the University of Miami. He is now a candidate for a Ph.D. in zoology at Yale.

A. KATCHALSKY AND S. LIFSON ("Muscle as a Machine") are members of the Weizmann Institute of Science in Rehovoth, Israel. Katchalsky is head of the Research Council of the Institute, chairman of its department of polymer research and professor of physical chemistry at Hebrew University. He was born in Poland in 1913. His family fled before the German Army to the Ukraine, survived the Ukrainian pogrom of 1919-1920 and emigrated to Israel in 1925. His interest in the physical chemistry of biological systems dates from his student days at Hebrew University. One of the most prominent scientists in Israel, Katchalsky is a member of its Scientific Re-

search Council. He served as a lieutenant colonel in the Israeli Army. In 1951 he was invited by the American Chemical Society to be chairman of its section on polyelectrolytes and water-soluble proteins at a national meeting. He will return to the U. S. this summer at the invitation of the American Association for the Advancement of Science to lecture on ion exchange at the Gordon Research Conference to be held in New Hampshire. Lifson, born in Tel Aviv in 1914, is the senior physical theoretician in Katchalsky's department of polymer research.

DONALD R. GRIFFIN ("Bird Sonar"), professor of zoology at Harvard University, is a specialist in the sensory physiology of animal orientation. He has devoted much study to the radarlike navigation system of bats, and has written articles on this subject and on the navigation of birds for SCIENTIFIC AMERICAN. The investigation of oil birds which he describes in this issue was made as a side trip while he was on an expedition in South America to study the sounds made by tropical bats. Born in 1915, Griffin was educated at Harvard and took his Ph.D. in 1942. During World War II he did physiological research for the Government at Harvard. After seven postwar years at Cornell University he returned to Harvard last year. His chief hobby is sailing.

EDWARD L. GINZTON ("The Klystron") was one of the pioneers who helped develop the tube he describes. As a graduate student at Stanford University he worked under the late W. W. Hansen. Ginzton was born in the Russian city of Ekaterinoslav in 1915 and came to the U. S. in 1929. He took his undergraduate work at the University of California and his doctorate at Stanford in 1940. In the following year he and the other members of Hansen's laboratory transferred to the Sperry Gyroscope Company. As director of the Sperry department of microwave research he worked on various phases of radar and holds some 40 patents in the field. In 1946 he returned to Stanford, where he is now professor of applied physics and electrical engineering and director of the University's microwave laboratory.

FREEMAN J. DYSON, who reviews Sir Edmund Whittaker's book on the history of the theories of the aether in this issue, is professor of physics at Cornell University. A biographical sketch of Dyson was published with his article on field theory in the April, 1953, issue.

THE COVER

The painting on the cover depicts a group of instruments hanging from the rigging of the *Marise*, a 60-foot vessel sent by Yale University to study the Peru Current (*see page 66*). At the left is a fine net to filter plankton out of the water. Second from the left is a grab to take samples from the bottom. Third is a thermometer. Fourth is a bottle to take samples of water at various depths. Fifth is a reel which measures the length of cable paid out. Last is a bathythermograph, which records temperature and pressure.

THE ILLUSTRATIONS

Cover painting by Stanley Meltzoff

Page	Source
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34	Robley C. Williams and Dean Fraser
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DESIGNING WITH ALUMINUM

This is one of a series of information sheets which discuss the properties of aluminum and its alloys with relation to design. Extra or missing copies of the series will be supplied on request. Address: Advertising Department, Kaiser Aluminum & Chemical Sales, Inc., 1924 Broadway, Oakland 12, California.

NO. 6

THERMAL TREATMENTS

PROPER USE OF ANNEALING AND HEAT TREATMENT WIDENS SCOPE OF APPLICATION, DESIGN AND FABRICATION WITH ALUMINUM ALLOYS

FAMILIARITY with the thermal treatments which apply to aluminum and with their influence on metal behavior is frequently as important in design and alloy selection as in fabrication. This is especially the case in dealing with the wrought alloys, where forming of some sort is a regular concern; with the cast alloys the problems customarily revolve around such requirements as castability, machinability and strength, but not forming.

The major thermal treatments are annealing, and the solution and precipitation heat treatments which are often referred to singly or together under the general, but loose term "heat treatment." Their intelligent consideration in design and manufacture makes it possible in many cases to derive maximum advantage of aluminum's combination of desirable properties such as light weight with strength, corrosion resistance, conductivity, reflectivity and appearance.

The metallurgical aspects of the thermal treatments are quite complex, but it is possible to discuss their processes and effects satisfactorily in a general way insofar as they affect design problems.

Annealing Only Way To Remove Hardening

Annealing is a treatment to soften the metal and render it more ductile and susceptible to forming operations. It applies to both the non-heat-treatable and heat-treatable alloys although there is some difference in how the annealing treatment accomplishes its purpose.

Because cold working produces progressive hardening, it is frequently necessary in fabrication to anneal non-heat-treatable material after one or more sets of fabricating operations in order to proceed with further forming. With most of the group of alloys, annealing is carried out by raising the metal to a temperature of about 650°F although a higher temperature, 760°F, is required for the manganese-type alloy 3S that is so generally used for many formed articles. Normal air cooling to room temperature follows.

During the annealing process the grains which have been deformed by

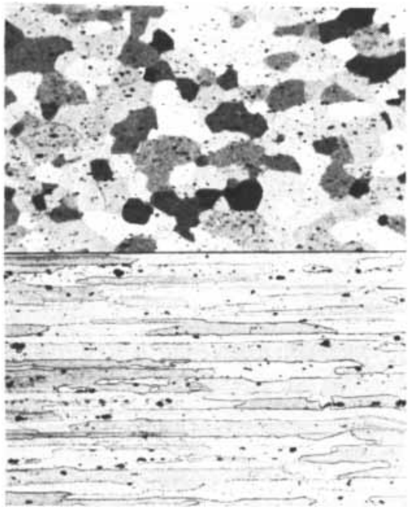


Fig. 1—TYPICAL GRAIN STRUCTURES
Photomicrographs show grain structures typical of non-heat and heat-treatable wrought alloys. Top: 50S-0 (anodic etch); bottom: 75S-T6 (phosphoric-Keller's etch).

cold working are recrystallized into new ones that are equiaxed, and the metal reaches a stable condition in which there is no strain. It is important that the material be brought to temperature as rapidly as possible and that it be exposed to heat only long enough to bring the entire part to temperature. Slow heating rates and overlong heating tend to create larger grains in the annealed metal, a structure that is usually undesirable.

When annealed, metal which has had only a small degree of cold work also tends to form larger grains than that which has been work-hardened considerably. With the non-heat-treatable alloys, of course, strength and hardness can be increased again, after annealing, only by further cold working. Therefore, where annealing is required at some intermediate stage in fabrication, careful consideration should be given to its exact location.

Cooling Rate Critical For Heat-Treatable Alloys

Annealing of the heat-treatable alloys removes the effects not only of any cold working the material has undergone but also of previous heat treatment, so that practice differs from that followed with the non-heat-treatable alloys. Precipitated particles of alloying elements must be coalesced, which reduces them in number and enlarges them in size, thus nullifying their hardening effect.

Higher temperatures, ranging between 750°F and 800°F, are therefore required, and the rate of cooling becomes of critical importance. It must be slow, no more than 50° per hour down to temperatures of at least 500°F, so that constituents taken into solid solution are precipitated as relatively large particles and heat treating effects are avoided. As with the non-heat-treatable alloys, excessive temperature and time may cause undesirable grain growth.

The annealed tempers of the heat-treatable alloys are used for forming purposes. Aside from the fact that there would be no reason for using them in a finished item, several of this group of alloys have lower resistance to corrosion resistance in the annealed temper as compared with heat-treated material.

The fact that a large class of alloys acquires optimum properties through heat treatment is a strong factor in extending the versatility and applications of aluminum. These alloys are heat-treatable because some of the elements and compounds go into solution with aluminum at elevated temperatures, and then after appropriate treatment are precipitated out at lower temperatures. This action promotes a structure that resists internal crystal slip and so increases the strength and reduces the ductility of the material.

Heat-treatable alloys include those of the highest strength, ranging up to 83,000 psi tensile strength for 75S. In general, they fall into three types, depending upon the chief alloying elements: the magnesium-silicide, copper (including copper-magnesium) and zinc-magnesium groups.

PLEASE TURN TO NEXT PAGE ➡

TABLE 1 • TYPICAL HEAT TREATMENTS (1)

Alloy	Solution Heat Treatment (2)		Precipitation Heat Treatment		
	Metal Temp. °F	Resulting Temper (3)	Metal Temp. °F	Time, Hours	Resulting Temper (3)
11S	935-970	11S-T4	325	12-16	11S-T6
14S	930-950	14S-T4 (4)	335-345	8-12	14S-T6
17S	935-950	17S-T4 (4)			
18S	950-970	18S-T4	340	8-12	18S-T61
24S	910-930	24S-T4 (4)			
25S	955-970	25S-T4	340	8-12	25S-T6
32S	945-960	32S-T4	340	8-12	32S-T6
A51S	960-980	A51S-T4	340	8-12	A51S-T6
53S	960-980	53S-T4	340	8-12	53S-T6
61S	960-1000	61S-T4 (4)	325-340	10-16	61S-T6
75S	860-925	75S-W	245-255	22-26	75S-T6
			or 210	4	
			followed by		
			310	4	
195 (5)	960	195-T4	310	3-6	195-T6
356 (5)	1000	356-T4	310	3-5	356-T6

(1) Figures are given as a guide only; more details may be obtained for specific applications.

(2) Solution heat treatment times depend on the section thickness, varying from 10 minutes for thin sections up to several hours for thicker sections. Soaking should be followed by immediate quench; in cold water for light sections, in boiling water for heavier, thicker sections.

(3) Addition of cold work would change tempers —i.e., 11S-T3, 11S-T8, etc.

(4) After aging at room temperature for approximately four days.

(5) Casting alloys. Soaking time at solution temperature for average casting is 12 hours—hot water quench.

Heat Treatment Consists of Two Phases

Heat treatment to attain maximum strength consists of two phases: solution heat treatment and precipitation or aging, which may be natural or artificial (the latter being termed precipitation heat treatment).

In solution heat treatment, the metal is heated to temperatures ranging approximately from 900°F to 975°F (see Table 1). At that point certain of the alloying elements go into solution, or dissolve, in the solid metal. When the temperature is quickly lowered by quenching, the alloying elements remain in solid solution.

Immediately after quenching, the metal is quite soft. But it is not in a state of equilibrium because the material is in a supersaturated solution—the solid solubilities of these alloying elements in aluminum being less at room temperature than they are at solution heat treating temperatures.

Within a few minutes, however, the alloying constituents begin to precipitate as extremely fine particles in the solid metal and the strength begins to increase. There is considerable difference between alloys in the rate of this precipitation, or natural aging, as shown by Figures 2a and 2b. In 24S it progresses rapidly and uniformly at room temperature and is virtually completed at the end of four days, with maximum strength and hardness then obtained.

In 75S, natural aging proceeds at a much slower rate: there is practically no increase in strength during the first hour and it is actually many months before 75S will attain maximum strength. Therefore, in practice this alloy requires a low-temperature thermal treatment after solution heat treatment to have adequate precipitation for desirable strength. This is the artificial aging process called precipitation heat treatment.

FIG. 2a • RATES OF NATURAL AGING OF SOME HEAT-TREATABLE ALLOYS

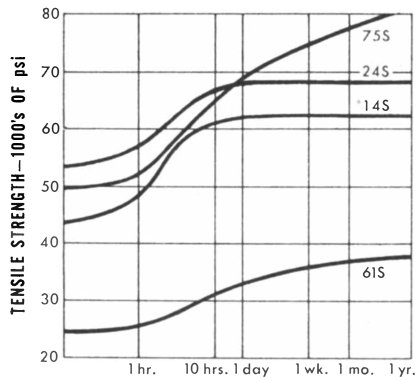
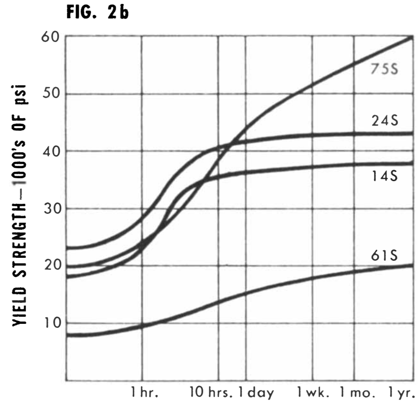


FIG. 2b



Another type of behavior is exhibited by 61S. It ages naturally at room temperature to one level of strength in four days, but can be given precipitation heat treatment (before or after natural aging) to T6 temper for maximum strength. It is quite common for a fabricator to obtain 61S material in the first condition (T4 temper) from the mill, do necessary forming and then achieve the full T6 properties by the relatively simple precipitation heat treatment.

Possibilities for Forming In Interim Condition

The behavior of the heat-treatable alloys as outlined above—especially the "delayed action" of varying duration between quenching and full precipitation—offers considerable opportunity in design and planning for forming operations.

For example, it is possible to solution heat treat and quench, do considerable forming while the metal is still relatively soft and then age the formed part either naturally or by precipitation heat treatment to maximum strength. This procedure can help avoid distortion problems likely to occur when forming the part entirely in the annealed temper and then heat treating, especially where light gauge material is being used.

Refrigerating material after quenching also slows down the rate of precipitation to such an extent that there is no increase in strength or hardness for an extended period of time. It is common practice to handle rivets made of heat-treatable metal in this manner, and the air-frame manufacturers have further developed the technique to a high degree for use in forming large parts and in bending large extrusions.

Other Thermal Treatments

Although they are of only minor interest to the designer, there are several other thermal treatments used with aluminum, such as stabilization and homogenization which are used in aluminum rolling mills and the treatment of some castings for stress relief and growth removal. Stabilization is a low-temperature treatment to establish the harder tempers of some of the magnesium-type non-heat-treatable alloys in a stable condition. Homogenizing consists of soaking the ingots of heat-treatable wrought alloys at elevated temperatures to distribute the alloying constituents uniformly before rolling.

More detailed assistance with design, alloy selection and fabrication and heat treatment procedure is obtainable through any of the Kaiser Aluminum sales offices located in principal cities. Or write to Kaiser Aluminum & Chemical Sales, Inc., 1924 Broadway, Oakland 12, California.

SCIENTIFIC AMERICAN

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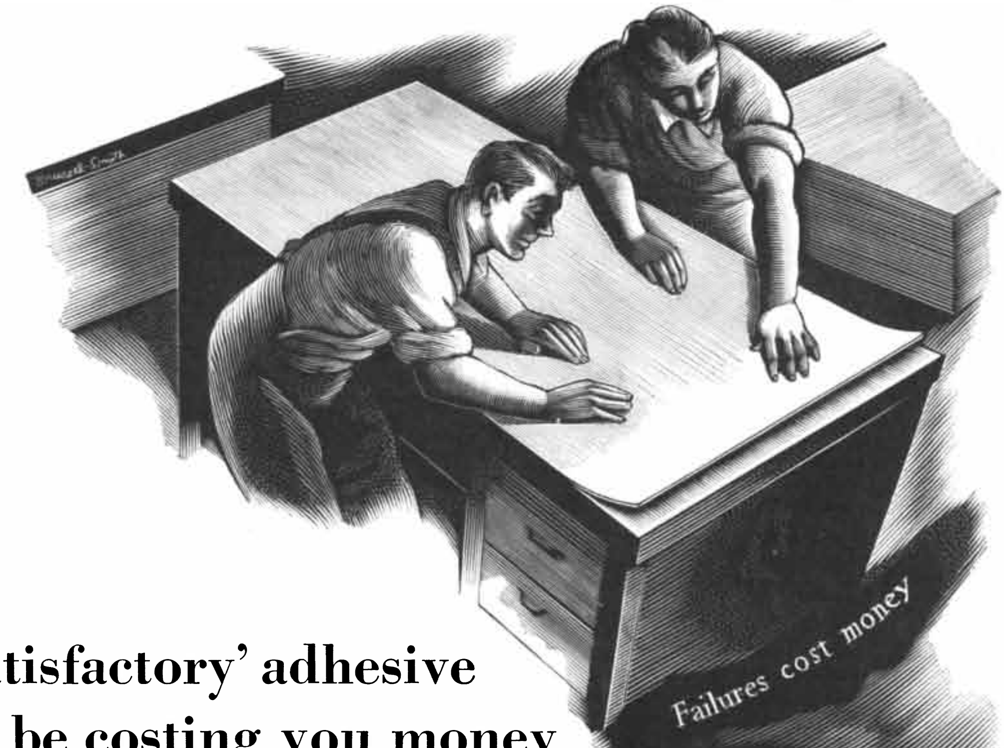
ARTICLES

DEPARTMENTS



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SCIENTIFIC AMERICAN
MARCH, 1954 VOL. 190, NO. 3

The National Science Foundation Takes Stock

Some $16 million in funds over three years and a mass of new statistics showing the need for more sum up the short, spartan history of the first U. S. agency for basic science

by Lawrence P. Lessing

The National Science Foundation is rarely noticed by Washington correspondents. This newest and smallest arm of the U. S. Government has a staff of 113, a current budget of $8 million and makeshift offices in the old Cosmos Club—a once fashionable but now decadent structure at 1520 H Street, N.W. On Washington's scale of values the NSF is about as piddling as a government agency can be—for all its great importance to the future of the nation.

Considering the central role of science in modern life, the grudging and spartan support given to this agency, belatedly set up to see that basic science is adequately promoted in the U. S., is not easy to understand. Despite the tremendous contributions of scientists to the winning of World War II, it took five years after the war to get through Congress an act establishing the Foundation. The act, as passed in 1950, put an unheard-of limit of $15 million a year on the new agency's activities. Before the NSF could be born, the outbreak of the Korean War, focusing Washington's attention on appropriations for military hardware, almost killed it in the womb. The NSF got a scant $225,000 for its first year. Its budgets of $3.5 million, $4.7 million and $8 million for the succeeding fiscal years have been less than half the amounts asked for and a smaller fraction of the actual needs for basic research.

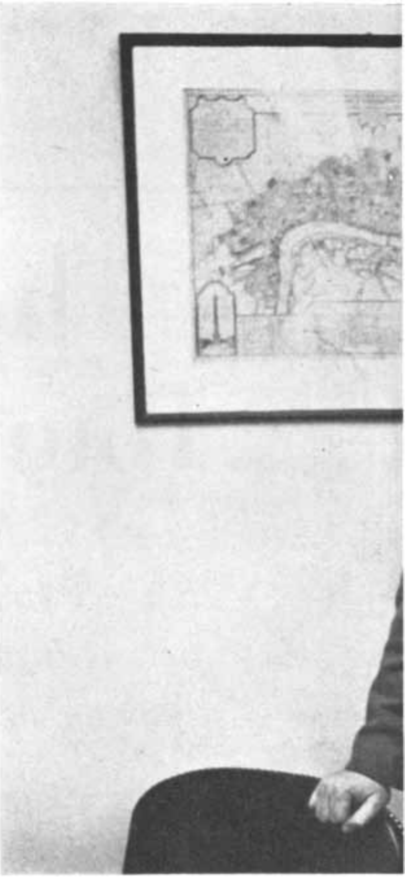
In the closing days of the 1953 session Congress erased the $15-million limitation, and the NSF enters its fourth year in a better position. The executive budget calls for $14 million for the fiscal year 1954-1955; how much Congress will actually allow remains to be seen. Whether the infant will be given the nourishment necessary to enable it to grow in a healthy manner is up to the national legislature.

Though Congress passed a reasonably lucid law giving birth to the NSF, and some members have given it intelligent support, most Congressmen have had to be constantly reminded or reconvinced of its purposes. It is not an agency for the development or engineering of new weapons; the military has budgets for this running to some $1.5 billion this year. It is specifically enjoined from supporting nuclear research; the Atomic Energy Commission is spending more than $265 million on that. It cannot build laboratories or carry on any research of its own, as is done in the National Bureau of Standards and in the Department of Agriculture to the tune of some $50 million a year. Nor is the NSF aimed at finding a cancer cure or a better way to make fuels or a preventive for the common cold. If it were designed for any or all of these things, it would have less difficulty getting funds. Ironically the huge sums given for military and other applied research have been the chief obstacle to obtaining adequate support for basic research.

The NSF Act declares the Foundation's prime purpose to be "to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences." In other words, the NSF is created to promote the increase of that pool of basic knowledge from which the whole U. S. technology must eventually draw sustenance. Any great new advances in industry, agriculture, medicine or even weaponry in the coming decades can come only from this source. That is a paradox of the "impractical" activity known as basic research.

A paradox which people not engaged in basic science find even harder to grasp is that in this age of the apparent supremacy of science, fundamental scientific work in the U. S. is actually in a state of declining support. College incomes and endowments, once the major support of basic science, are down 40 per cent from prewar days. Private foundation subsidies are drying up; for ex-

DIRECTOR Alan T. Waterman, former physics teacher at Yale, came to lead the Foundation from a solid administrative background as head of the Office of Naval Research and in the wartime OSRD.



DEPUTY DIRECTOR Charles E. Sunderlin, chemist and associate

ample, the Rockefeller Foundation, which almost alone financed the generation of scientists who performed so brilliantly in the last decade, has diverted most of its curtailed funds to emergency measures to raise agricultural and living standards abroad. Meanwhile the costs of basic research have risen sharply, not only in terms of equipment and manpower but also because of the new necessity for team research.

These were among the reasons that impelled Vannevar Bush and the scientists associated in the wartime Office of Scientific Research and Development to urge after the war a great, unprecedented national effort to extend and deepen U. S. basic research. After three years of trying to find itself and to examine the problem, the NSF now at least has some information and some modest progress to report.

The Foundation's active life dates from the 1951 appointment of Alan T. Waterman, former physics teacher at Yale University, as its director. Waterman, a thoughtful, able administrator, had been head of the Navy's well-run Office of Naval Research and before that a top staff member of the OSRD. The problems confronting him in the NSF were quite different from those of the military agencies. On one hand he had to parry political back-stabbings by established departments which inevitably took a fearful view of a new agency. On the other he had to quiet the fears of some scientists and universities that the NSF would grow into a bureaucratic colossus over science.

These fears have been largely dispelled by Waterman's tactful administration and by the operations of the NSF's main ruling body, the National Science Board. This unpaid panel of 24 eminent scientists, educators and businessmen, appointed by the President, is now headed by the noted telephone executive and former president of the Rockefeller Foundation, Chester I. Barnard. It represents a sufficiently broad, devoted cross section of regions and interests to hold a balance. It has been meeting about every six weeks, passing on all NSF business, with an attendance record of over 80 per cent.

The NSF has had to formulate its policies from scratch, for earlier agencies, devoted to supervising military or other applied research, offered few useful precedents. The NSF has four main functional areas: fact-finding, granting of funds for basic research and fellowships, dissemination of information and, most important, advising the President and Congress on matters of scientific import.

The largest accomplishment to date is in the first area. By fact-finding surveys the NSF has been plotting the dimensions of its problem, developing heretofore unavailable data on U. S. research. Some of the findings are presented in the charts with this article. Since 1940 Federal expenditures for research of all types have increased 20-fold: from $97 million in 1940 to some $2.2 billion last year. Nearly all the increase went to applied research and engineering, prompted mainly by wartime needs. This imbalance continues. Of last year's $2.2 billion, less than $125 million was spent for anything resembling fundamental research. When the $2.2 billion is broken down in other ways, even more remarkable imbalances appear. The physical sciences got nearly 95 per cent of the total; the biological sciences got less than 5 per cent, and the social sciences re-

professor at the U. S. Naval Academy, came over from the Office of Naval Research with Waterman.

ceived the remaining tiny fraction, most of that merely for statistical research.

The NSF began a series of detailed studies on the status of knowledge in the various sciences. It has completed the first, on certain fields in biology. It found the life sciences, though meagerly supported, in a state of ferment and nascent growth. Because the approaches of biologists are shifting, it has been necessary to classify the various life sciences in a new, more logical way. The sections into which they are now divided are: developmental, environmental, genetic, micro-, molecular, psycho-, regulatory and systematic biology.

The most active biological areas needing support were found to be molecular, regulatory and systematic biology. The first has to do with important molecules such as proteins and related substances in living tissue, particularly those involved in central life processes. The second has to do with the mechanisms by which life processes are controlled or regulated: studies of these have resulted in such applications as the use of insulin in diabetes and vitamin B_{12} in pernicious anemia. The third area—the description and classification of living species—is now being affected by so many accumulating discoveries and new techniques as to need thorough updating.

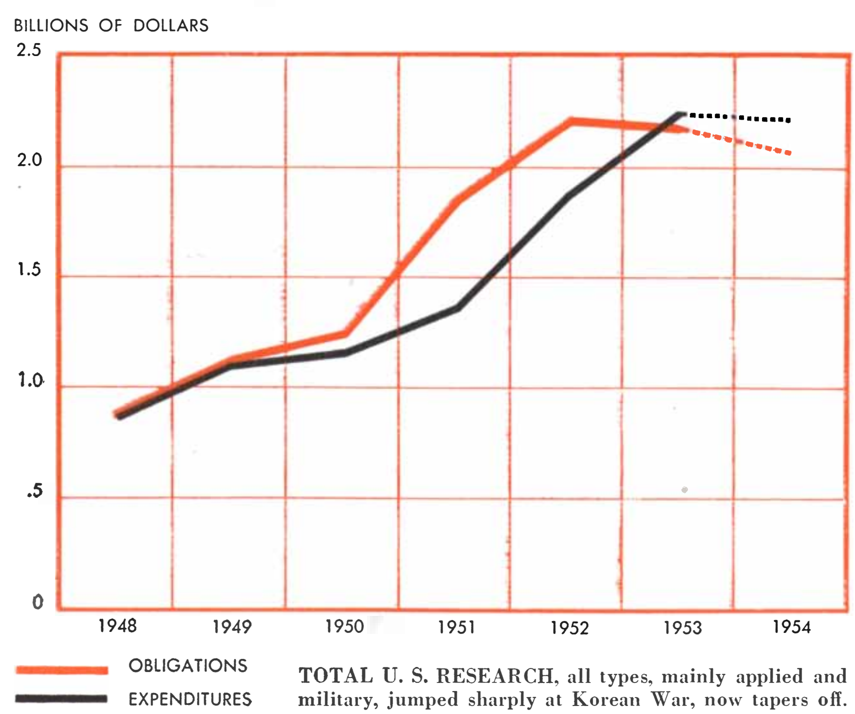
To make a start toward remedying the neglect of the biological sciences, as soon as research money became available to it (in 1952) the NSF gave most of the funds to that field. It distributed $763,000 for biological work in a number of institutions. One of the grants, for example, was $50,000 for five years to University of California geneticists for studying polygenetic variability in poultry; another was $41,000 to The Johns Hopkins University for a three-year study of antibody reactions. In 1953 a big part of the NSF's funds again went to biology, but its budget was large enough to make substantial grants in the physical and mathematical sciences also.

Surveys like those in the biological sciences already mentioned are now being made in the fields of physiology, psychology and applied mathematics. The NSF makes a grant to a scientific society in each specific field to carry out the survey. It plans to go through all the neglected sciences in the same way. By periodically repeating the survey of each field, it will keep a running inventory of the progress and lags in the various disciplines. Psychology, now in a period of chaotic growth and widespread application, will almost certainly show a lack of research on fundamentals, particularly in the psychiatric division. The mathematical survey already shows that applied mathematicians must have a deeper grounding in pure mathematics for future growth. Given this commanding view of the sciences, never before obtainable, the NSF will then do something about their needs.

The Foundation now has four major divisions: the biological sciences, including medical research; the mathematical, physical and engineering sciences; scientific personnel and education; and program analysis, or fact-finding.

Ultimately what the Foundation can do to promote basic research will be limited not by money but by men. The total number of persons in the U. S. capable of doing important original research in science (men and women with doctorates in science) today does not exceed some 35,000. Even if it had unlimited funds, the NSF could not use fruitfully more than about twice its present allowance of research funds in the next few years, according to its estimates. But in part this is due to the fact that people who might be doing basic research have been drawn into applied research. NSF surveys show that of the $338 million in Federal research funds going to universities and non-profit institutions in fiscal 1953, four out of every five dollars is for applied research and development, including the building of laboratories. Many scientists have been pulled by this big magnet into short-range, short-sighted work on "practical" problems.

This subversion of the universities, which by tradition are the fountainheads of long-range, fundamental sci-



TOTAL U. S. RESEARCH, all types, mainly applied and military, jumped sharply at Korean War, now tapers off.

ence, has so frightened many scientists and educators that the NSF is launching an exhaustive study of its effects on the standards, aims and operations of U. S. higher education. For this study it has assembled a committee headed by Chester Barnard and including Vannevar Bush, President Harold Dodds of Princeton University, J. A. Stratton of the Massachusetts Institute of Technology and other leading figures. When its report is in later this year, the NSF will have a key diagnosis of science's present deficiencies.

In its grants to workers in universities the NSF has been troubled by a wartime hangover. In order to get military research done swiftly the OSRD used a "no-gain-no-loss" contract which compensated universities for all costs, including overhead. The NSF, in contrast, has adopted the policy of giving funds as direct grants to reputable investigators, with a minimum of strings attached and no allowance for overhead. Its Board feels that, as a matter of principle, basic research, which should be a central function of universities, should not be made to pay for their general maintenance and housekeeping. Many college business offices do not like this arrangement, and some have resisted it. It is a policy that probably will be argued further.

In the training of new scientists the NSF has had to limit itself to graduate fellowships. It gave some 550 last year, ranging in size from $1,400 to $3,400 a year. The Foundation believes that to carry out its mission fully it will need to finance undergraduate scholarships also and even promote science in the secondary schools, where the heart of the problem lies [see "A Crisis in Science Teaching," by Fletcher G. Watson; Scientific American, February]. The NSF-supported Commission on Human Resources and Advanced Training forecasts that in the five-year period ending in 1957 the number of B.S. graduates will decline 30 per cent from the previous five years, falling to a rate of 66,800 per year. This decline will be followed by a fall in science doctorates—from a peak of 5,400 per year.

The NSF has other activities. It maintains a national register of scientific and technical personnel, underwrote some 10 scientific symposia and a number of smaller conferences in the past year, helped pay the traveling expenses of some 50 U. S. scientists to attend important foreign scientific meetings. It advised Congress on bills having to do with the complex subject of weather control, *i.e.*, rain-making. It set up for President Eisenhower a Committee on Minerals Research which is now investigating all known means of minerals ex-

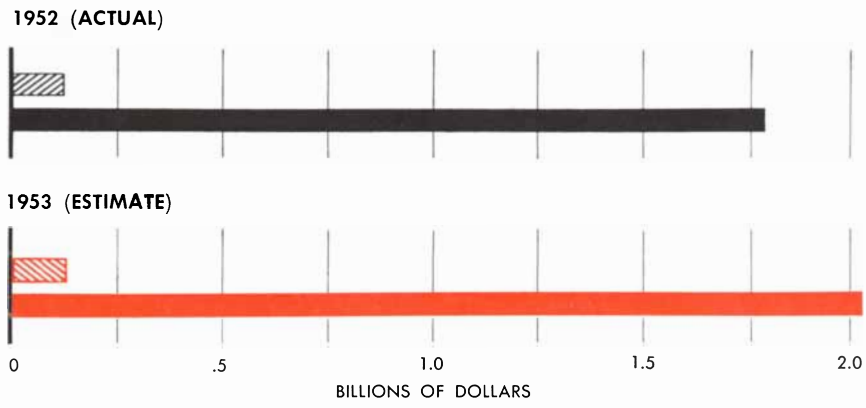
DIRECTOR AND STAFF stand before the fading elegance of Washington's old Cosmos Club where the NSF has makeshift offices. Left to right: Assistant Directors H. Burr Steinbach for biological and medical sciences; Raymond J. Seeger (acting) for mathematical, physical and engineering sciences; Harry C. Kelly for scientific personnel and education; Sunderlin and Waterman.

ploration in order to advise on future research in this critical field. It also, when consulted about the matter, vigorously advised the President to liberalize travel restrictions on foreign scientists seeking visas to attend U. S. scientific conferences. At least 50 per cent of all foreign scientists trying to enter the U. S. meet serious difficulties or delays, and some international societies have refused to schedule meetings in the U. S. The Foundation pointed out that the situation is inimical not only to the international traditions of science but also to scientific progress in the U. S.

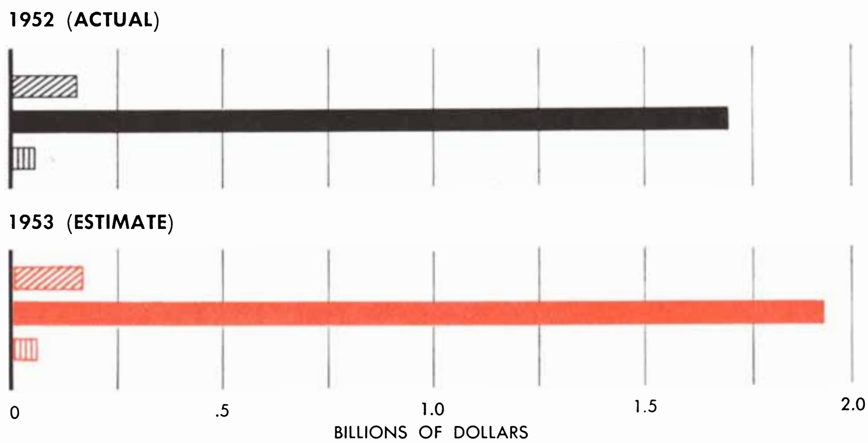
At the request of the National Academy of Sciences, the Foundation is preparing for participation by the U. S. in the Third Geophysical Year in 1957-58. In 1882 and again in 1932 many nations banded together to make a large series of important measurements simultaneously in many parts of the world to check such scientific constants as the speed of light, the positions of stars and so on. This time the measurements will be much more elaborate, with batteries of new instruments. So far 28 countries are behind the effort. If the U. S. is to participate, the NSF will have to obtain from Congress this year about a $10 million supplementary appropriation.

So far the NSF has spent a total of some $5 million on nearly 500 grants for research and a slightly larger amount on research fellowships. The research supported ranges from important work on steroids, enzymes, radio astronomy, evolution, coals, probability, antibiotics, atomic masses and the metabolism of leaves down to projects on coal-ball flora and the biochemistry and nutrition of the bat—samples distributed over the whole fructifying range of knowledge that is basic science. But the NSF has been able to support only about half of the worthy projects proposed to it, and last year for lack of funds it had to turn away two thirds of the 2,000 qualified young applicants for its graduate fellowships. The names of those turned away were put on an honorable mention list and circulated to institutions which might consider them for fellowship grants. But undoubtedly many of these promising persons were lost to science.

At the moment the Foundation is in danger of being overloaded with political freight as a result of the new Administration's pressure for economy. Some people in the Budget Bureau and in Congress believe it would save money to concentrate all federal activities in basic science under the NSF. The new



BASIC SCIENCE'S PLIGHT is graphically shown in this breakdown of total U. S. expenditures for research between basic research and applied.



THE LIFE AND SOCIAL SCIENCES get the extremely short end of the stick in another breakdown of total U. S. research expenditures, all types.

budget transfers some $3 million for basic research from the Department of Defense to the NSF, and there is pressure to do likewise with basic research financed by the Atomic Energy Commission. The danger is that there may be a net constriction of the total available for basic science and injury to some programs. Some basic research is so closely associated with other work of a department that it should remain under that department's supervision. In basic science, unlike applied research, some duplication of effort is necessary. That is how science has grown in the past and continues to grow.

In a Reith Lecture for the British Broadcasting Corporation last fall J. Robert Oppenheimer observed: "We regard it as proper and just that the patronage of science by society is in large measure based on the increased power which knowledge gives. If we are anxious that the power so given and so obtained be used with wisdom and with love of humanity, that is an anxiety we share with almost everyone. But we also know how little of the deep new knowledge which has altered the face of the world, which has changed—and increasingly and ever more profoundly must change—man's views of the world, resulted from a quest for practical ends or an interest in exercising the power that knowledge gives. For most of us, in most of those moments when we were most free of corruption, it has been the beauty of the world of nature and the strange and compelling harmony of its order that has sustained, inspirited and led us. That also is as it should be. And if the forms in which society provides and exercises its patronage of science leave these incentives strong and secure, new knowledge will never stop as long as there are men."

THE LIFE CYCLE OF A VIRUS

What happens in the time between the infection of a cell and the appearance of new viruses? The behavior of bacteriophages suggests that this stage involves a new concept: the provirus

by André Lwoff

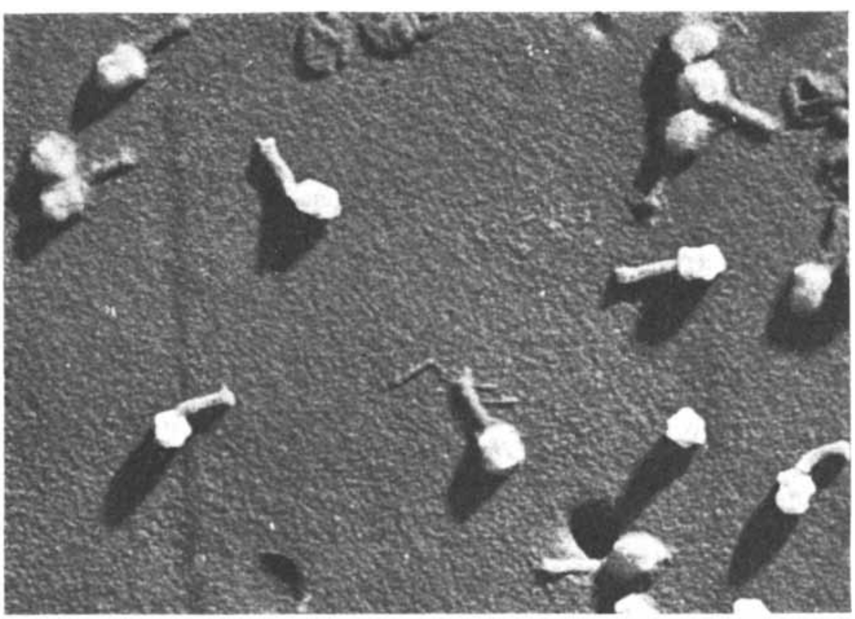
Close your eyes and look. What you saw at first is there no more; and what you will see next has not yet come to life.

—Leonardo da Vinci

We can apply these words very aptly to a virus—of the bacteria-infecting kind known as bacteriophage. When a phage particle enters a cell, it loses its infective power and its identity as a particle. Generally its entrance into the cell is followed within 15 minutes to an hour by the emergence of a new generation of infectious virus particles. Sometimes, however, there is no immediate pathological event. The genetic material of the virus that has passed into the cell combines with the genetic material of the cell itself. In doing so it is converted into something that has been named a "provirus," meaning before virus. Days or years afterward the provirus may suddenly develop into virus and the bacterium give rise to a group of virus particles.

The term provirus needs some explanation. The expression "proman" would certainly not evoke the idea of a human egg, from which *Homo sapiens* always develops, but rather that of an evolutionary ancestor of man which would have to undergo a genetic transformation to become man. A provirus may perhaps correspond to an evolutionary ancestor of a virus. But it is also much more than that.

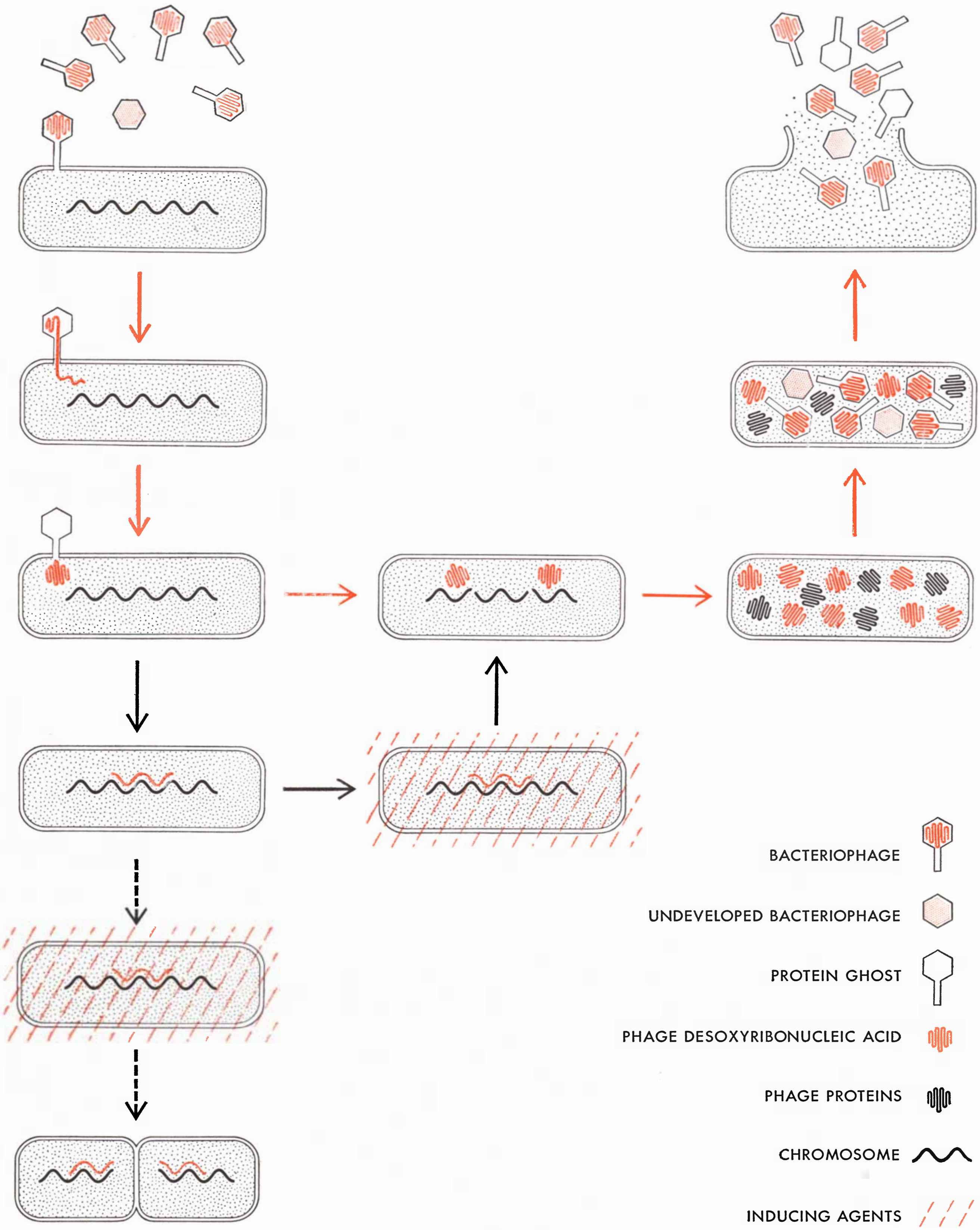
Before attacking the question of the nature of proviruses, we must know something about viruses themselves. What is a virus? We shall leave out of the discussion the much debated issue as to whether viruses are living organisms or not; our concern is to find out how they differ from "normal" organisms of the microbiologist's world. The two attributes that are usually thought to define viruses are their very small size and the fact that they can multiply only inside living cells—usually requiring a specific kind of cell host. But to learn more about their peculiarities let us go beyond this definition and compare viruses with other small biological units.



BACTERIOPHAGES of the T2 strain, which infects the colon bacillus *Escherichia coli*, are enlarged 65,000 times in this electron micrograph made by Robley C. Williams and Dean Fraser at the University of California. The short tails and hexagonal heads of the phages are brought out with unusual clarity by the method of freeze-drying the specimen.

First of all, how does a virus differ from a cell? Most cells are capable of reproducing themselves: they possess the genetic material which is the basis of heredity and the tools necessary to synthesize the essential building blocks and to organize these into a structure just like themselves. We can see three important differences between a cell and a virus, taking bacteriophage as a typical virus: (1) whereas cells contain both desoxyribonucleic acid (DNA) and ribonucleic acid (RNA), the phage contains only DNA; (2) whereas cells are reproduced from essentially all their constituents, bacteriophage is reproduced from its nucleic acid; (3) whereas cells are able to grow and to divide, the virus particle as such is unable to grow or to undergo fission. Bacterial viruses are never produced directly by division of an existing virus; invariably they are formed by organization of material produced in the host cell.

Next we must consider whether viruses bear any likeness to the particles within a cell, particularly the particles called plasmagenes. Here differences are less easy to find. The theory has been

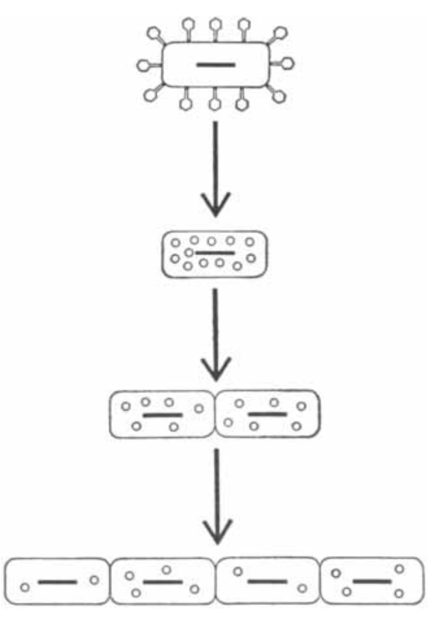


CYCLE begins when the phage, attached to a colon bacillus by the tail, empties its contents into the bacterium (*upper left*). Phage may then reproduce until it dissolves the bacterium (*upper right*), or it may remain harmlessly in the bacterium and its descendants as prophage (*lower left*). If bacteria containing prophage are treated with an inducing agent such as X-rays, either they continue to reproduce in the normal manner or the phage suddenly begins to multiply (*center*) until the bacterium dissolves.

proposed that viruses may originate as mutated plasmagenes. But we know that some plasmagenes (*e.g.*, the chloroplasts of green plants) can grow and divide. Furthermore, plasmagenes are not pathogenic or lethal to the cell, as virus particles are. Let us just note, for the time being, that nothing which resembles a bacteriophage in its properties, life cycle, shape or organization has been found in normal cells.

Let us now consider the peculiar behavior of the virus. The virus particle as such is only the beginning and the end of a life cycle. Its only physiological function is to obtain entry of the virus' genetic material into the host cell. After this occurs, what remains of the virus is devoid of infectious power. There follows a vegetative phase in which the specific constituents for new viruses are produced. Finally these constituents are organized into virus particles, which are liberated by lysis (dissolution) of the cell. The whole process usually takes from 15 to 60 minutes.

But a bacterial virus may multiply in another way, and this is where the provirus enters the picture. Ordinarily the virus nucleic acid passed into a cell proceeds promptly to multiply and to synthesize specific protein material for new phage particles. Sometimes, however, the nucleic acid may anchor onto a bacterial chromosome and act as if it were a normal constituent of the cell. It behaves as a bacterial gene, being replicated at each bacterial division and transmitted to each daughter bacterium. This is what we call a provirus. It is a potential virus; it may eventually give rise to virus particles. In the meantime the bacterial offspring go on growing and dividing as normal bacteria, and each daughter bacterium yields progeny capable of producing viruses. In other words, the ability to produce viruses is perpetuated inside the bacterium; no new infection from outside is needed.



IMMUNITY against infection by a related phage is conferred on a bacterium by prophage (*bar*). In the multiple attack depicted here, virus particles (*circles*) do not multiply but thin out with each generation.

Bacteria containing proviruses are called lysogenic. When a small number of such bacteria are broken down, no infectious particles can be found. This means that the provirus is not infectious. And yet in every large population of these bacteria some mature bacteriophage particles appear. From time to time a bacterium in such a culture suddenly disappears, and about 100 phage particles emerge. The probability of a lysogenic bacterium spontaneously giving rise to viruses varies from 1/100 to 1/100,000. In some systems the probability is apparently independent of external factors; it cannot be modified. In other lysogenic systems phage production may be initiated at will by inducing agents, such as X-rays, ultraviolet rays, nitrogen mustard and other substances—all of which are known to be capable of producing mutation. Within 30 to 60 minutes after exposure to one of these agents, practically all of the bacteria produce viruses and lyse.

How do lysogenic bacteria produce viruses? Before discussing this question we must know more about the proviruses. We are inclined to think that proviruses originally arose as mutants of normal bacterial genes. Whatever their origin, the reservoir of bacterial viruses seems to be the provirus-carrying bacteria. These bacteria may have perpetuated provirus, that is to say, the hereditary ability to produce virus, for many thousands of years.

The study of lysogenic bacteria has led to a clear picture of the provirus. Apparently it does not contain virus protein, for lysogenic bacteria do not cause the production of specific antibodies to phage protein in experimental animals. It is therefore tempting to visualize the provirus as a large molecule of nucleic acid. Secondly, the provirus is associated with a certain genetic character of bacteria and is located at a specific site on a bacterial chromosome. Thirdly, two genetically related proviruses in a bacterium may cross over and recombine. Fourth, a lysogenic bacterium is immune to infection by a phage particle related genetically to its provirus, though it can be killed by an unrelated phage. As long as the provirus remains in that state, a genetically related superinfecting phage is unable to develop into phage. Finally, the mere presence of the provirus may modify the properties of a bacterium: it may endow certain bacteria with the ability to produce a toxin they could not otherwise make, or it may change the typical appearance of bacterial colonies. Things happen as if the provirus either carries a specific gene or modifies the neighboring bacterial genes. From all these data it may be concluded that provirus is the bacterial virus' genetic material, bound to a specific site in the bacterium and responsible for a specific bacterial immunity.

Now it is difficult to imagine that this immunity is due only to the *presence* of the provirus. A particle cannot exert a specific action by its mere presence. The only way the provirus can make the bacterium immune—that is, prevent multiplication of a virus invader—is by modifying or blocking a specific activity of the bacterium necessary for that reproduction. And the provirus can do this only if it is present at a specific site. As a matter of fact, we can account for all the properties of proviruses and of lysogenic bacteria by the hypothesis that the provirus is the genetic material of the virus anchored at a given site in the bacterium. The genetic material of an infecting virus becomes a provirus when and because it becomes bound at that site to a specific receptor, which modifies the material. It then gives the bacterium immunity against genetically related infecting particles. An inducing agent such as ultraviolet rays destroys the immunity because it displaces the genetic material of the virus from its specific site.

For a long time virologists have concentrated on the virus particle itself. Yet the particle is only a prelude to the infection. During the longest and most important part of the life cycle, the pathogenic phase in a cell, no virus particle is present. As a matter of fact, disappearance of the virus particle is the *sine qua non* for the development of the cellular lesion. Indeed, there are cases in which all the bacteria in a lysogenic population die although very few of them produce bacteriophage particles; the cells are killed by a defective development of proviruses initiated by an inducing agent. One could even conceive of a condition in which the probability of the virus ever appearing would be infinitely small, that is to say, practically absent. Some bacteria actually carry a gene which can initiate the synthesis of a protein lethal to themselves. But that is another story.

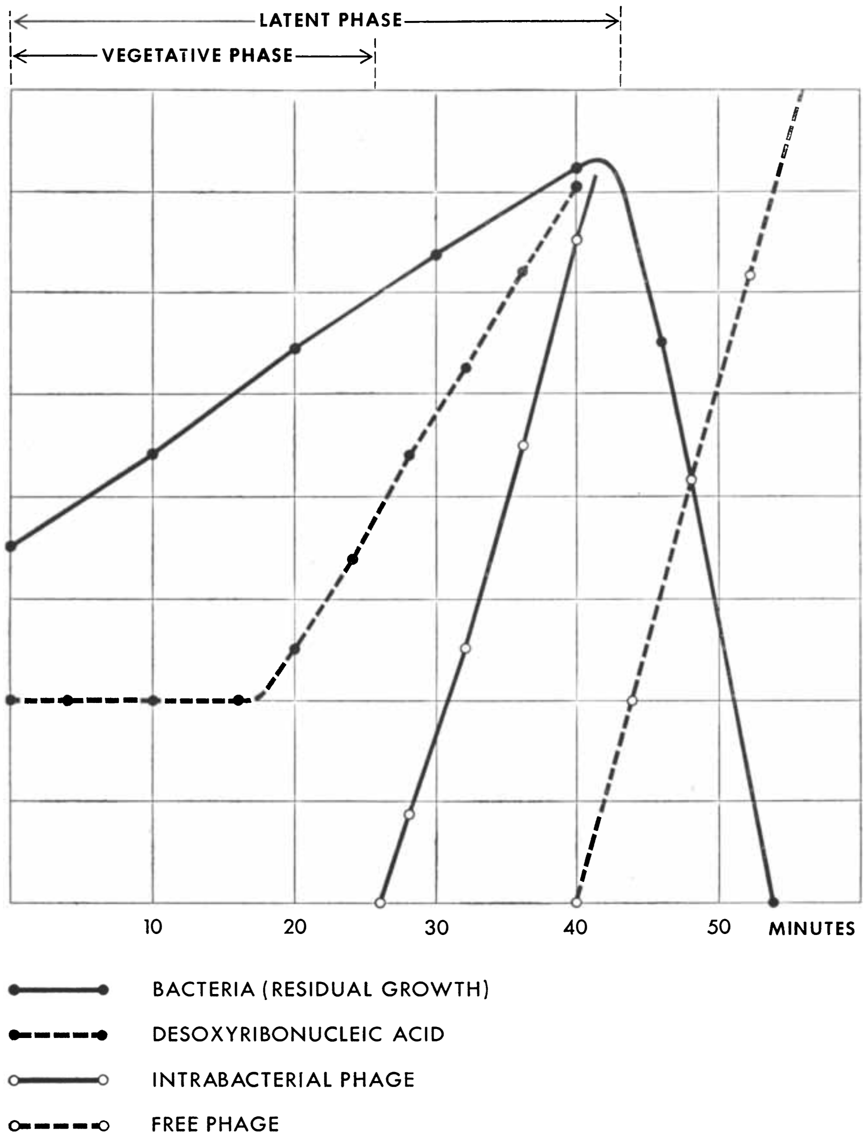
Biologists have long been accustomed to think of death in terms of the destruction or alteration of some vital structure. We have been less inclined to think of living cells as carrying the seeds of their own destruction, or of the possibility that lethal agents may kill in more than one way. For example, X-rays sometimes kill by destroying essential structures, but they may also destroy a cell by inducing a gene to express its lethal potentiality. This potentiality is sometimes the power to start a new synthesis which may or may not end in virus particles.

To what extent are the phenomena disclosed in bacteria valid for higher organisms? May animal or plant cells perpetuate proviruses? Are some viral diseases of man the result of the activation of a provirus? May immunity to virus diseases be explained in terms of proviruses? Do the findings concerning lysogeny have any bearing on cancer? Let us recall that the inducing agents which can trigger proviruses to give rise to viruses are all not only mutagenic but also carcinogenic—radiations, nitrogen mustard and so on. It is indeed tempting to theorize that carcinogens may induce malignancy by initiating the formation of a pathological structure from a provirus-like material. Many facts are in favor of the hypothesis that proviruses originate some animal diseases, but the problem cannot be discussed within the limits of this article. Suffice it to say that this is, at any rate, a working hypothesis.

I have tried to outline the concept of the provirus, to analyze its relations with the concept of the cell and of the virus and to show the impact of the newly acquired knowledge on our conceptions of cellular disease. The common denominator of the various phases of the life cycle of a virus is the genetic material—the nucleic acid—which may exist in three states: infectious, proviral and vegetative. Throughout these three states the genetic material apparently remains essentially the same in structure, but it changes radically in dynamic potentialities and behavior. The virus particle, the end product of the vegetative phase, is a quiescent nucleoprotein particle, unable to grow or to divide. The provirus is an integrated nucleic acid, which behaves like a gene and is replicated like the host genes. Neither the virus particle nor the provirus is pathogenic *per se*; their pathogenic property is only potential. The only pathogenic phase of the virus is the vegetative phase, during which the specific viral nucleic acid multiplies and during which the specific viral protein is synthesized. Things happen as if the synthesis of the protein is responsible for pathogenicity.

The provirus produces provirus; it is order. The vegetative particle produces virus particles and a disease of the host; it is disorder. The virus particle does not produce anything; it is an extremely conservative particle—the absence of any activity, that is to say, a kind of order. Thus the virus is an alternation of order and disorder.

As a result, my presentation of the subject may seem somewhat disordered. For this I had decided to apologize, when I came across an unpublished letter which Martin de Barcos, Abbot of Saint-Cyran, wrote to Mother Angélique in 1652: "Allow me to tell you that you would be wrong to apologize for the disorder of your discourse and of your thoughts, because, if they were otherwise, things would not be in order, especially for a person belonging to your profession. As there is a wisdom which is folly before God, there is also an order which is disorder, and in consequence, there is a folly which is wisdom and a disorder which is the true rule." This being exactly the case of the virus, I decided not to apologize.



INDUCING AGENT caused the effects plotted here for a colony of prophage-bearing colon bacilli. The time between the treatment with the inducing agent and the appearance of phage within the bacteria is called the vegetative phase. The time between the treatment with the inducing agent and the appearance of free phage is called the latent phase.

The Epidemiology of Mental Disease

The methods of investigating infectious disease in populations have recently been turned to the question of whether one group has a pattern of mental illness differing from that of another

by Ernest M. Gruenberg

Epidemiology is not the study of epidemics, as some dictionaries would have us believe, but the study of the distribution of disease. It is interested in the pattern of disease occurrence, in the factors that determine the pattern and particularly in how the factors can be modified to eliminate the disease from the population. An epidemiologist is a public health detective; he seeks to ferret out the factors responsible for specific diseases, and conducts experiments to establish their guilt and to find ways to bring them under control.

Epidemiological analysis generally proceeds according to a simple pattern: A factor, f, is suspected of playing a role in the production of a disease, d; populations having much f are examined to see if they have more d than populations having little f; through inferences based on all the relevant knowledge and on theories derived from clinical familiarity with the disease, the investigators obtain a picture of the chain of circumstances that leads to the occurrence of the disease; finally crucial links in the chain are attacked experimentally. The relationships are often indirect and highly complicated, but this general strategy has succeeded in bringing many animal and plant diseases under control.

If the germ diseases of man can be fought effectively in this manner, why not his mental illnesses? It is true that the scientific study of mental disorders is still very young, and some have doubted that epidemiological research can be helpful in this field. Indeed, the experts do not even agree on whether different populations have different rates of occurrence of mental disease. Nonetheless the epidemiological investigation of mental illnesses is now receiving much attention, and it is beginning to show promise.

A mental disease may flare up in a population for a time and then die out. A famous example is a disorder which began in Italy in the 13th century. It was recorded by many reliable writers, notably two physicians named Ferdinandus and Baglivi. The episode was reviewed recently by The Johns Hopkins University medical historian Henry Sigerist. The disease was called the Dancing Mania or Tarantism. Sigerist writes:

"The disease occurred at the height of the summer heat, in July and August, and particularly during the dog days. People, asleep or awake, would suddenly jump up, feeling an acute pain like the sting of a bee. Some saw the spider, others did not, but they knew that it must be the tarantula. They ran out of the house into the street, to the market place, dancing in great excitement. Soon they were joined by others who like them had just been bitten, or by people who had been stung in previous years, for the disease was never quite cured. The poison remained in the body and was reactivated every year by the heat of summer. People were known to have relapsed every summer for thirty years. . . .

"Thus groups of patients would gath-

A historic example

er, dancing wildly in the queerest attire. 'Sometimes their fancy leads them to rich clothes, curious vests and necklaces and suchlike ornaments [reported Baglivi]. They are most delighted with clothes of a gay color, for the most part red, green and yellow. On the other hand, they cannot endure black; the very sight of it sets them asighing and if any of those that stand about them are clad in that color, they are ready to beat them, and bid them be gone.' Others would tear their clothes and show their nakedness, losing all sense of modesty. . . . Some called for swords and acted like fencers, others for whips and beat each other. Women called for mirrors, sighed and howled, making indecent motions. Some of them had still stranger fancies, liked to be tossed in the air, dug holes in the ground and rolled themselves in the dirt like swine. They all drank wine plentifully and sang and talked like drunken people. And all the while they danced and danced madly to the sound of music.

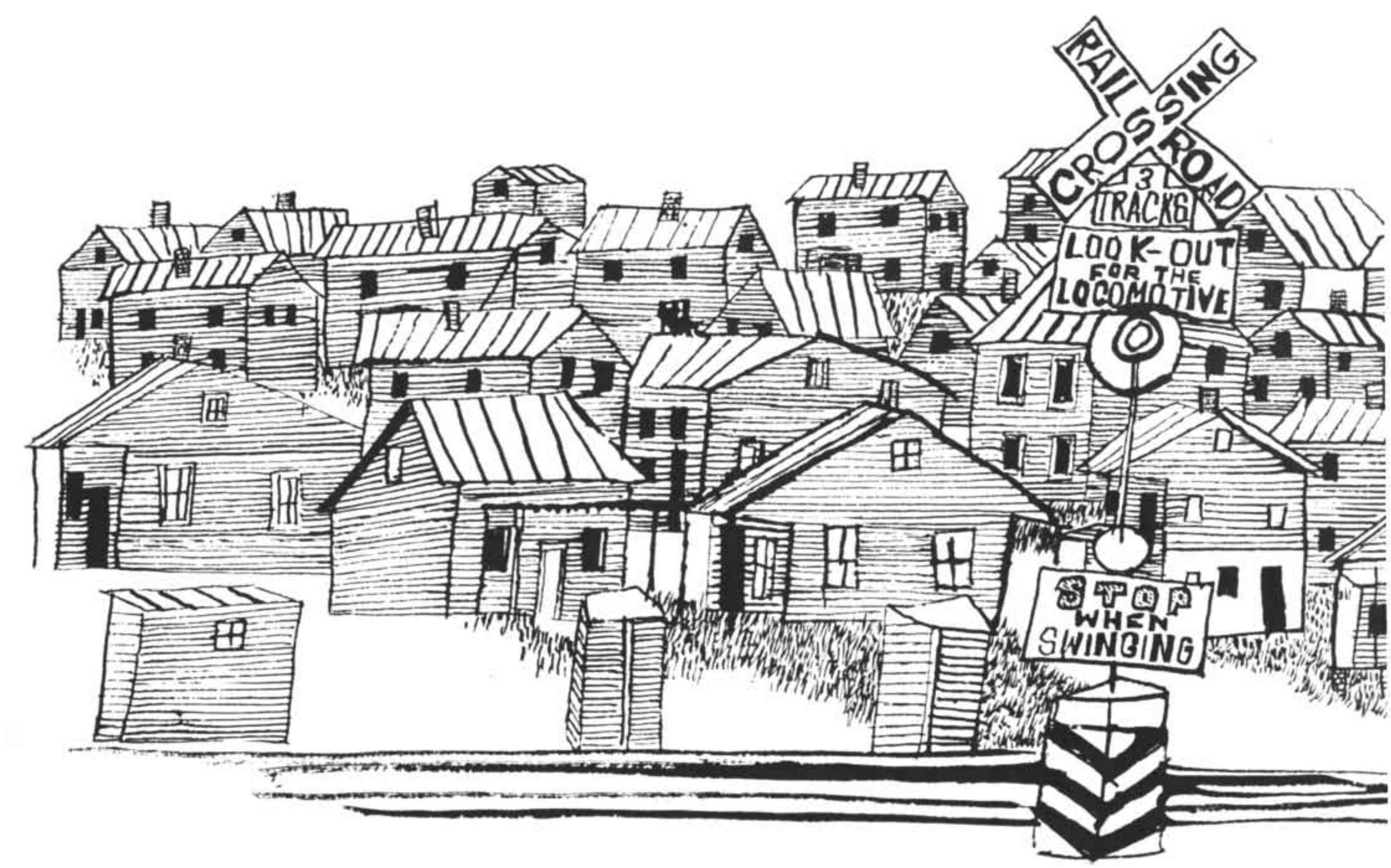
"Music and dancing were the only effective remedies, and people were known to have died within an hour or a few days because music was not available. A member of Dr. Ferdinandus' own family, his cousin Francesco Franco, died thus within 24 hours because no musician could be found after he had been stung."

Ferdinandus did not believe that the spider bite was the cause of the disease; he suspected that it was a form of insanity. Sigerist points out that the part of Italy where the disorder apparently originated, Apulia, had been a part of the ancient Greek empire. In this region Dionysus and other gods had been worshiped. Sigerist adds: "Orgiastic rites of a decidedly erotic character were performed. People danced madly to the sound of music, dressed in bright clothes with garlands of vine leaves, waving the thyrsus, uttering obscene words, tearing their clothes, whipping each other, drinking wine. The analogy between these rites and the symptoms of tarantism is striking. What is the connection?

"Christianity came late to Apulia and found a primitive and conservative population in which ancient beliefs and customs were deeply rooted. In competition with paganism Christianity had to adjust itself in many ways in order to win over the population. . . . There were limits, however, that the Church could not well overstep. It could not assimilate the orgiastic rites of the cult of Dionysus but had to fight them. And yet these very rites that appealed to the most elementary instincts were the most deeply rooted. They persisted, and we can well imagine that people gathered secretly to perform the old dances and all that went with them. In doing so they sinned, until one day—we do not know when but it must have been during the Middle Ages—the meaning of the dances changed. The old rites appeared as symptoms of disease. The music, the dances, all that wild orgiastic behavior were legitimized. The people who indulged in these exercises were no longer sinners but the poor victims of the tarantula."

The Dancing Mania spread through Europe for a few centuries and then disappeared. We have had somewhat similar outbreaks in our own time. The most comprehensive analysis of such a happening was the psychologist Hadley Cantril's study of the panic caused by Orson Welles's broadcast of an "invasion from Mars." Another study investigated an outbreak of hysteria in Mattoon, Ill. A man was reported to be spraying a paralyzing poison in women's bedrooms. The attacks were always reported by women who were alone. The outbreak had been preceded by com-

of a mental disease characteristic of a population was the Dancing Mania of medieval Italy



A study in Syracuse, N. Y., indicated that people who lived in one-family dwellings **(left)**.

munity alarm regarding possible German gassing of U. S. communities. The reports died down shortly after the mayor and chief of police became convinced that there was no prowler and began to disband posses.

Recently the child psychologist Fritz Redl made an epidemiological investigation of outbreaks of certain specific kinds of distressed group behavior—destructive forays, anxiety attacks, bullying and so forth—among the members of a camp for emotionally disturbed children that he operated near Detroit. He concluded that behavior can be contagious in a group, and that contagion is most likely when it is started by a popular individual, when the size, structure and atmosphere of the group favor the behavior, and when the behavior itself gives "vent to the suppressed needs" of many of the members.

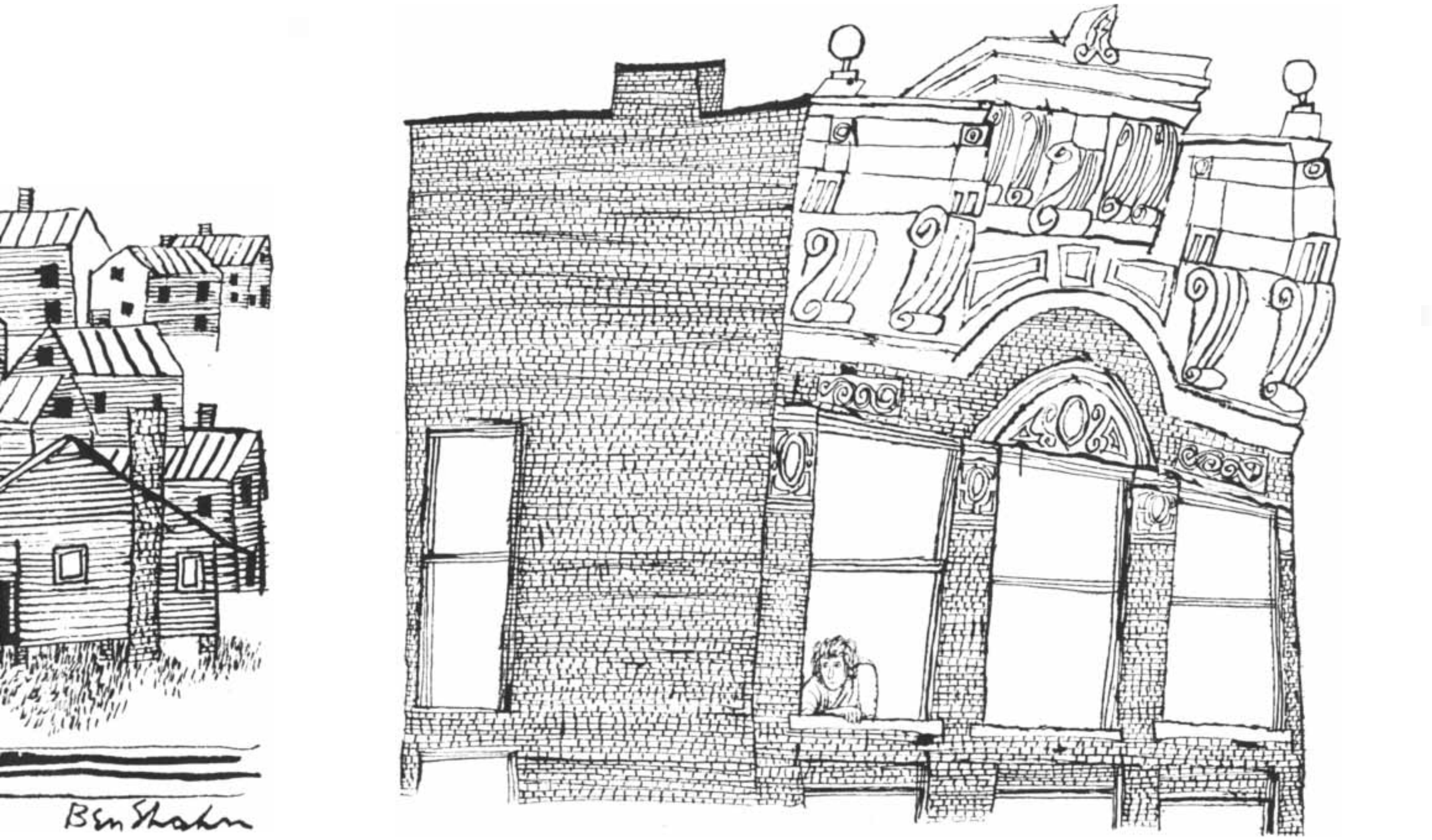
Some behavior patterns spread more readily in large groups, others in small ones. Division of the group into subgroups reduces contagion. High dependence of a group on adult leadership fosters contagion; experience in group initiative opposes it.

Redl also reported that one kind of disturbance may evoke a different kind in the responding group. For example, he placed a boy who had considerable tendencies toward masochism in a friendly group of boys who had had a year of club work in which they had developed group pride and the ability to discharge grievances and disputes harmlessly in group gripe sessions. The entry of the new boy, Al, into the group was carefully prepared, and the group attitude toward him when he entered was most favorable. But within a few days "the group was in an uproar." Al wanted to be chased, pushed and wrestled with; the youngsters began in a spirit of fun to gratify this wish, but he lured them into more and more aggressive behavior. After about a week, the boys "were like a bunch of sadistic bullies, . . . started to bicker and fight with each other." A gripe session and individual interviews confirmed that Al's display of extreme masochistic desires had stirred up within the boys "more sadistic pleasure temptations than they could cope with."

This kind of induction of a disturbance different from the one that evokes it is not unknown even in microbial diseases. For example, a mother who during the first three months of pregnancy has German measles, a virus disease, may transmit to her fetus a disorder which is not at all like German measles—it may be an encephalitis that results in mental deficiency. The mental deficiency of course is not contagious.

It is reasonable to believe that many personality disorders are produced by induction. There is a type of mother that some psychiatrists have called "schizophrenogenic"; that is, she is thought to induce schizophrenia in her children. These mothers are not schizophrenic themselves, but they suffer from severe emotional conflicts which make them vacillate between extremely affectionate play with their children and extreme rejection. This concept of a schizophrenogenic mother type has not been validated; it is mentioned only as an illustration of the postulate that one mental disorder may induce another.

In the early years of this century the great psychiatrist Adolf Meyer, then associated with the mental hospitals of New York State, directed attention to



had a lower rate of psychosis than those who lived in multiple-family dwellings (right)

the influence of social conditions in generating mental disorders. He found that some counties in the state had much higher rates of admissions to mental hospitals than others, and he attributed the differences to variations in social conditions. Unfortunately this study was not followed up. In the 1930s a group of sociologists led by Ernest Burgess at the University of Chicago became interested in the subject. The French sociologist Emile Durkheim had propounded the theory that in an industrialized community, the modern city, individuals suffer a loss of the sense of identity—he called this feeling "anomie." He had used the suicide rates in Europe as an index of anomie. The Chicago sociologists found that in Chicago anomie was highest in the central and socio-economically depressed sections of the city. Suicide rates and the rates of admissions to mental hospitals for schizophrenia were highest there. Hence there was a strong indication that schizophrenia has something to do with (a) socio-economic status, (b) anomie and (c) migratory patterns of life, for the high-rate areas had a mobile population.

Not until after World War II was the question pursued further. The war, of course, greatly heightened interest in mental hygiene, partly because of the large number of draft rejections and discharges from the armed services for psychoneurotic difficulties. After the war Herbert Goldhamer and A. W. Marshall conducted for the Air Force a very careful study to determine whether schizophrenia is increasing among young men. The study was based primarily on records of the Massachusetts state mental hospitals. It covered the first admissions to mental hospitals of all psychotic patients of both sexes and all ages for the past century. The two investigators found that the rate of admissions per 100,000 of population had not changed much in the age groups under 50, but that older people were entering mental hospitals at a rising rate. Goldhamer and Marshall searched for other locations to check their findings and lit on Oneida County in New York, where the first New York state mental hospital was built in 1843. Their findings for Oneida County were similar to their findings for Massachusetts.

On their face these figures failed to show that changing social conditions had had any effect on the incidence of psychoses among people under 50. However, Massachusetts and New York were the first states to develop state mental hospitals. It is at least possible that the social forces which produce high rates of psychoses are intimately connected with those which produce state mental hospitals, and that these forces had reached a plateau by the beginning of the period the investigators reviewed.

In 1949 Yale University began a study of the relationship between social class and prevalence of psychiatric disorder. The study was designed by the psychiatrist F. C. Redlich, the sociologist A. B. Hollingshead and myself. It surveyed patients under psychiatric care in New Haven. Redlich, Hollingshead and their colleagues have recently reported some of their findings. The prevalence of psychoses has proved to be much higher in the lowest socio-economic classes in New Haven than among those farther up the scale. These facts have opened up questions for further investigation which the Yale group is vigorously pursuing.

In 1950 the New York State Mental

Some mothers are thought to induce schizophrenia in their children

Health Commission set up a field unit to study the epidemiology of mental disorders. Studying admissions of elderly people to mental hospitals from Syracuse, it has shown that the sections of the city with the highest rates of new hospital admissions for senile and arteriosclerotic psychoses are low in socio-economic status. But other parts of the city just as low on the socio-economic scale do not contribute disproportionately large numbers of cases to the hospitals. It turned out that the areas producing more than their share of cases consisted mainly of multiple-family dwellings. In Syracuse the apartment areas have higher rates of psychosis than those made up of one-family houses. Possibly this is related to the fact that more of the people in apartments live alone, but there is no evidence yet on that point.

These and other studies make clear that mental hospital admissions do vary under varying social conditions. However, to identify the social conditions that make for a psychologically unhealthy life will take a great deal more research.

The Milbank Memorial Fund, which has long been a leading sponsor of new developments in the field of public health, organized in 1949 a conference of psychiatrists, epidemiologists and sociologists which gave great impetus to the epidemiological study of mental disorders. It brought research groups together again in 1951 for further discussion of common technical problems. Important research on these problems is being carried on by groups at Yale and in the New York State Mental Health Commission, at Cornell University under the psychiatrist-anthropologist Alexander Leighton, at the Cornell Medical School under the psychiatrist Thomas A. C. Rennie, at the Harvard School of Public Health under the psychiatrist Eric Lindemann and at Wayne University under the sociologist Joseph W. Eaton, who has been studying mental health among the Hutterites [see "The Mental Health of the Hutterites," by Joseph W. Eaton and Robert J. Weil; SCIENTIFIC AMERICAN, December, 1953]. Members of the staff of the National Institute of Mental Health and workers in other projects also have collaborated and consulted with one another. These consultations have been valuable in the planning and evaluation of studies.

One of the acute technical problems confronting all these investigators is to find some measure of community mental health more inclusive than mere hospital admission rates. It is not easy to devise a test of mental illness which will be equally reliable among people of different social groups and at different times. An X-ray picture or a Wassermann reaction is no respecter of persons, but mental-disorder epidemiology must be based on a deep respect for persons. Furthermore, the only present criterion for mental illness, in the last analysis, is the clinical judgment of psychiatrists. A psychiatrist cannot check his diagnosis with physical instruments such as microscopes, chemical reactions or an X-ray machine. The most sensitive instrument for detecting personality disorders is the clinician himself. His own perception and his way of relating to people is the instrument that must be standardized and calibrated.

Mental diseases need to be better defined and classified. Some people believe that all the psychiatric syndromes are variations on one basic theme. But the clinical pictures do vary, and it remains for epidemiological and other studies to relate the clinical patterns to the cause or causes.

More detailed and more scientific systems of reporting and recording personality disorders must be developed. Public health officers learned long ago that reporting of communicable diseases was necessary to lay the groundwork for combatting them.

Finally, there is a need to formulate theories in such a way that they can be tested. So far the most useful hypotheses have been provided by the sociologists and the eugenicists. But these hypotheses have been only distantly related to clinical observations or the ideas of psychiatrists. We are approaching a time when the views of psychiatrists, psychologists, sociologists, geneticists and physiologists will have to be brought into relationship with one another. In this epidemiology will play a key role.

Kodak reports to laboratories on:

identifying multicarbide phases by color photomicrography . . . high speed movie success stories . . . some things you can do with oxidized cellulose

Metallography in color

Meet Mr. Foster. Charles S. Foster is our ace photomicrographer. Charlie's function with us is to dole out individualized advice on how most expeditiously to get where you want to go with a photomicrographic or metallographic undertaking. Being the kind of chap he is, Charlie's advice is likely to be highly personalized.

A year or two ago the chief metallographer in the Powder Metals Research Department at Firth Sterling Inc. in Pittsburgh thought he would ask Mr. Foster for a little help on the problem of identifying constituents and phases in multicarbide mixtures through photomicrography in color. Worked out fine. Recently that hard-boiled publication, *Steel*, carried a short illustrated article on the results. It may turn out to be something of a landmark in metallography. Time will tell.

The technique is heat-tinting at 900 F for 5 minutes after careful polishing and electrolytic etching in 5% sodium carbonate. The various phases assume characteristic colors: grey for tungsten carbide grains, yellow for tantalum carbide, tan for the solution areas of tungsten carbide plus titanium carbide, deep purple for the eta phase formed by carbon deficiency, blue for the cobalt matrix, and so on. Though Mr. Foster is no metallurgist, he did prove helpful on the important matters of illumination and filtering to record these color nuances reproducibly on *Kodak Ektachrome Film, Daylight Type*.

Bulking large in making the project practical was the fact that this film can be processed on the spot to judge the results.

Perhaps life is not really that simple, but we like to think that in superior creep properties, better service in jet engine blades, etc., Firth Sterling products are now or soon will be reflecting the knowledge gained through heat-tinting.

Mr. Foster will be most happy to send you a reprint of the Steel *article if you want to see color reproductions of Firth Sterling's heat-tinted carbides at 1500 diameters. Also, if you have problems of your own in photography through the microscope, don't hesitate to write him about them. His address: Eastman Kodak Company, Industrial Photographic Division, Rochester 4, N. Y.*

High speed booklet

For only $1713.50 one may purchase from any Kodak Industrial Dealer a *Kodak High Speed Camera.*

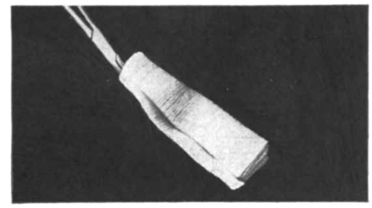
Some of the best-known typewriters, diesel locomotives, cigarette lighters, oil-drilling bits, breakfast foods, circuit breakers, printing papers, auto tires, beet pickers, casserole dishes, power looms, power tools, addressing machines, shotguns, vacuum cleaners, airplanes, and adding machines are being manufactured today on the basis of information their makers learned or confirmed by buying a *Kodak High Speed Camera* and submitting their products or processes to its quick and glassy gaze. (On the more academic side, we know of at least one diverted biologist who used the camera to find out how holes in fluids appear and disappear when a missile passes through.)

The subject is mentioned at this time because we have just published a new booklet which explains how the camera works and how it has performed some of its industrial research feats.

For a copy of "High Speed Motion Picture Making in Industry," *write Eastman Kodak Company, Industrial Photographic Division, Rochester 4, N. Y.*

Slightly degenerated cotton

Instead of oxidizing cellulose as man has done from time immemorial to take the chill out of his bones, cook his dinner, and dispel his gloom, we have a trick of oxidizing it only to a 10% to 22% carboxyl level. This we do by treatment with nitrogen dioxide. The product, called, surprisingly enough, "oxidized cellulose," looks like this:



It has the appearance and even some of the strength of ordinary cotton, along with some rather extraordinary properties. The most recent of these to come to light is its use in the diagnosis of congenital hyperplasia (enlargement) of the adrenal gland in children. This comes about from the remarkable affinity of oxidized cellulose for ACTH, which it absorbs quantitatively. ACTH is not detectable in the blood of normal children but does appear where this affliction exists. After cortisone treatment, no ACTH is detectable. One advantage of oxidized cellulose in ACTH assay is that the concentrates it yields are not toxic to the assay animal.

This is not the debut of the stuff as a tool in the healing art. Its first flush of prominence a few years ago was based on the surgically useful fact that it has the physical attributes of cotton gauze, yet is wholly absorbed in the blood stream after fulfilling its mechanical function.

Aside from its medical use, oxidized cellulose is an ion exchange medium, plucking cations out of aqueous solution to form metallic salts of cellulose. Plain cotton as far as the eye can see and the finger can feel, it bewitchedly vanishes into solution when popped into a 2% sodium hydroxide solution. When kept dry and cold, however, it survives indefinitely without change.

Trimming the cellulose chains with 10 to 22 percent of carboxyls drives the price of cotton up to $62.25 per pound, FOB Kingsport, Tenn. If you are interested in concentrating some ACTH, this may be a bargain for you right now, and, if you can develop some decent volume of demand for it, we'll probably drop the price. For the cold facts, write Eastman Chemical Products, Inc., Chemical Division, Kingsport, Tenn. (Subsidiary of Eastman Kodak Company).

Prices quoted are subject to change without notice.

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

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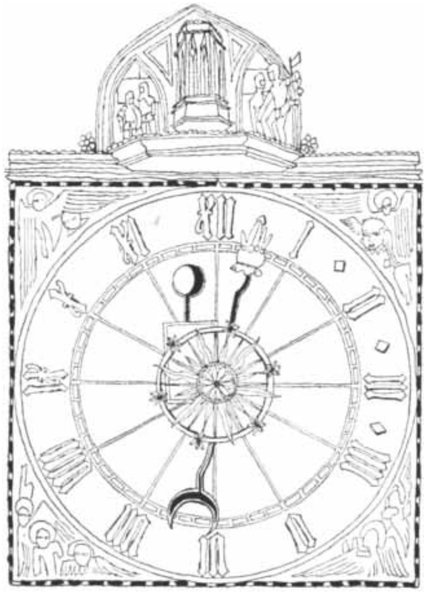

New Investigation

Congress is having another go at tax-exempt foundations, with hearings by a special investigating committee of the House of Representatives scheduled to begin this month. The committee chairman is B. Carroll Reece, Republican of Tennessee, a member of the Cox committee that investigated foundations last year.

The new investigation is the result of a speech in the House by Reece, who asserted that "an overwhelming portion of foundation grants for many, many years has been awarded for the propagation of the so-called liberal viewpoint and in some cases an openly communistic point of view."

The committee staff has already begun to interview a "sample" list of foundations and has sent a detailed questionnaire to members of the Association of American Colleges, professional journals and university publishing houses, asking for information about all foundation grants they have received since 1920. The institutions are asked to report, among other things, their religious affiliation. The college questionnaire states that the information requested will help determine "the manner in which certain types of schools are favored or ignored" by foundations. It lays special stress upon grants in the "fields of social sciences."

AEC Report

Perhaps the biggest news in the Atomic Energy Commission's Fifteenth Semiannual Report, published last month, was the announcement of some details of its first general power reactor, the design of which is "well under way." The announcement disclosed the surprising fact that both the moderator and the coolant in this nuclear furnace will be ordinary water. Although water absorbs neutrons, the Commission's researchers apparently have found that with slightly enriched uranium as fuel a reactor will be able to maintain a high-level chain reaction in a water medium. Earlier plans were based on graphite or heavy water as the moderator and a liquid metal as the coolant. The new design is called the Pressurized Water Reactor (PWR).

The report noted that estimates of what it will cost to build and fuel power reactors have continually been lowered. Nevertheless, the current estimates of cost still "exceed by a wide margin the $150 to $250 per kilowatt cost of installed capacity of conventional [coal] plants." Studies show that atomic power plants must cost no more than $300 per kilowatt if they are to produce power competitively with other sources, the Commission said. Nine industrial groups are now studying reactor technology.

The Commission made public the fact that it had established a "weapons research laboratory" at Livermore, Calif., in June, 1952. The New York *Times* reported that this laboratory was the site of the hydrogen bomb development. The laboratory is run by the University of California under the direction of E. O. Lawrence and Herbert York. It now employs 1,500 people. The report said that the California Research and Development Company, a subsidiary of the Standard Oil Company of California, is working at Livermore on a project "not related to the weapons effort of the University of California."

Summarizing the financial history of the atomic energy enterprise, the AEC said that at the close of the last fiscal year the U. S. had invested a total of $12.1 billion. Some $4 billion was spent in the year 1953, mainly on new plants. The Commission's net assets as of June 30, 1953, were $8.6 billion. Of the $900-million operating budget last year, $280 million went for source and fissionable materials, $236 million for weapons and $153 million for research.

Other highlights of the report:

The American Meat Institute has found that a "modest dose" of gamma radiation from fission products increases the shelf life of meats from three days to 15 days.

Brookhaven physicists believe that the so-called V particles may be excited states of a neutron, for a V particle produced in the Cosmotron decays into a proton and a *pi* meson.

AEC researchers have discovered evidence that spleen cells produce a substance which protects the body from radiation damage. A few cells from the spleen of a normal mouse, when transplanted to the anterior chamber of another mouse's eye, protected the second animal from fatal doses of radiation.

Bargain with Belgium

As part of the wartime agreement by which the U. S. obtained sole rights to the uranium output of the Belgian Congo mines, the U. S. promised to give Belgium technical information and assistance on atomic power when it was developed. This stipulation came to light last month when the New York *Times* reported that Pierre Ryckmans, president of the Belgian Atomic Energy Commission, had asked the U. S. to make good its promise.

Ryckmans called attention to a 1950 amendment of the Atomic Energy Act which empowers the U. S. Atomic Energy Commission to enter into "specific arrangements involving the communication to another nation of restricted data" on processing of source materials, reactor development, production of fissionable materials and research and development relating to these matters. He said Belgium had not yet received a reply to its request from the U. S. Government.

25 Billion Volts

The Brookhaven National Laboratory has received authorization to build a 25-billion volt "strong-focusing" synchrotron, the Atomic Energy Commision announced last month. The machine will cost some $20 million and will be finished in five or six years.

The strong-focusing principle reduces the weight of the magnet needed in an accelerator [see "A 100-Billion-Volt Accelerator," by Ernest D. Courant; Scientific American, May, 1953]. In the Brookhaven Cosmotron, which has attained energies of 2.3 Bev, the protons travel through a channel 32 inches wide, and the surrounding magnet weighs 2,000 tons. The channel in the 25-Bev machine will be only six inches wide and its magnet is expected to weigh no more than 2,500 tons.

Supersensitive Photography

A self-amplifying camera which produces strong, sharp pictures in very dim light has been developed at the Massachusetts Institute of Technology. It operates on the principle of the Geiger counter: light energy from the object to be photographed is made to trigger a large electrical discharge which in turn develops the emulsion. The instrument is described in the Office of Naval Research publication *Research Reviews* by its inventor, Kurt S. Lion, associate professor of biophysics at M.I.T.

The camera consists of a pair of parallel plates, one transparent to the radiation being used (Lion has been working chiefly with X-rays) and the other coated with a photographic emulsion. A high-voltage difference is maintained between the plates. When a single photon of radiation enters the instrument through the transparent plate, it releases electrons from the plate or from the gas inside. As in the Geiger counter, the high-voltage field quickly expands this initial ionization into an avalanche of ions and electrons rushing toward the negative and positive plates. The discharge produces a large amount of energy, mainly in the ultraviolet, which develops the photographic emulsion.

What is remarkable is that Lion has found a way to keep the discharge from spreading. Each avalanche runs as a pencil beam from one electrode to the other. It makes a small developed dot on the film. The picture, consisting of a huge number of dots, has high resolution.

The device is still in an early stage of development, and Lion sees many ways to improve it. His present electrodes are made of untreated metal which does not emit many electrons per X-ray photon. If the plate were covered with a luminescent substance, the X-ray energy could yield many more photons. In this way he expects to increase the sensitivity a thousandfold. It should also be possible to replace the ordinary emulsion with a substance in which the discharge leaves a permanent, visible trace, thus eliminating the need for development.

Doctor Bills

Last year U. S. families spent a total of $10.2 billion for medical care, and 16 per cent of them went into debt for their medical bills. This is the report of the Health Information Foundation, which has published the results of an extensive survey of medical costs for the year ending July 31, 1953—the first such study in 20 years.

Half of the nation's families spent more than 4 per cent of their income on medical care. A million families incurred illness expenses amounting to more than 50 per cent of their incomes and in half of these cases the medical bills were greater than their total income for the year. Almost eight million families are in debt for medical care; they owe a total of $1.1 billion.

The Foundation's report emphasized the importance of health insurance. Families with some sort of health insurance (58 per cent of the population) bought more than twice as much health service as uninsured families; the median for the insured group was $145 as compared with $63 for the uninsured. The report noted the "phenomenal" expansion of voluntary health insurance plans since 1940: coverage by hospitalization insurance has risen from 9 per cent to 57 per cent of the population; and surgical coverage, from 4 to 48 per cent. The Foundation said there is still debate over whether health service is really insurable. "Fire insurance does not necessarily increase fires . . . but health insurance does increase the utilization rate of personal health services."

Insurance coverage varies with income. Of families who earn less than $3,000, 41 per cent have some type of coverage; in the $3,000 to $5,000 group the proportion is 71 per cent; of those with incomes above $5,000, 80 per cent are insured. Employees in mining and manufacturing industries have the highest enrollment—80 to 90 per cent—whereas agricultural workers are only 30 per cent covered. Self-employed persons and those working in small groups have difficulty getting insurance with as wide coverage and at as low a cost as is available to members of larger groups.

Physicians' fees account for 37 per cent of the total medical expenditure, dental bills for 15 per cent, hospital charges for 20 per cent, medicines for 15 per cent and other medical goods and services for 13 per cent. Dental care especially is closely correlated with income: in the under-$2,000 income group 17 per cent went to the dentist during the year; in the over-$7,500 group, 56 per cent.

All the statistics in the report were obtained from interviews with 8,846 persons in 2,809 families, chosen by the same methods used by the Bureau of the

Census in its Current Population Survey. The survey was conducted by the National Opinion Research Center at the University of Chicago.

In a special health message to Congress President Eisenhower has requested a $25 million fund for reinsuring risks of voluntary insurance plans, to encourage them to "offer broader health protection to more families." A bill introduced in Congress would reimburse two thirds of each claim in excess of $1,000 paid by a private insurer to an individual in any 12-month period. To be eligible for reinsurance, plans would be required to put their premium charges on a sliding scale, geared to subscribers' incomes. Subscribers would have to pay part of all hospital and doctors' fees.

Drawing Conclusions

Is it possible to judge an individual's personality adjustment from his drawings of human figures? Some schools of psychologists think so. John W. Whitmyre, a psychologist with the Veterans Administration, decided to put the question to a test.

He obtained 50 drawings by psychiatric patients at a V. A. hospital and an equal number by a comparable group of veterans with no apparent psychological difficulties. After having all the drawings rated for artistic merit by art experts, he submitted them to panels of psychologists to judge them both for artistic excellence and for personality adjustment.

Whitmyre's findings:

Artists and psychologists agreed on the artistic ratings of the drawings.

The psychologists were unable to distinguish the psychiatric patients from the well-adjusted.

They ranked the pictures in very nearly the same order whether they were assessing art or psychological adjustment.

Reporting his results in the *Journal of Consulting Psychology*, Whitmyre concluded: "If it is not possible for the average clinical psychologist to differentiate those who are well-adjusted from those who are not on the basis of the human figure drawing, it appears that the use of the instrument to assay level of adjustment is questionable."

Scientists' Insecurities

The psychiatrist Lawrence S. Kubie, who has been studying the mental health of scientists, delivered another instalment of his conclusions in the January issue of the *American Scientist*. He wrote: "The idyllic picture of the innocent, childlike scientist who lives a life

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of simple, serene, peaceful, dignified contemplation has become an unreal fantasy. Instead, the emotional stresses of his career have increased to a point where only men of exceptional emotional maturity can stand up to them for long, and remain clear-headed and generous-hearted under such psychologically unhygienic conditions."

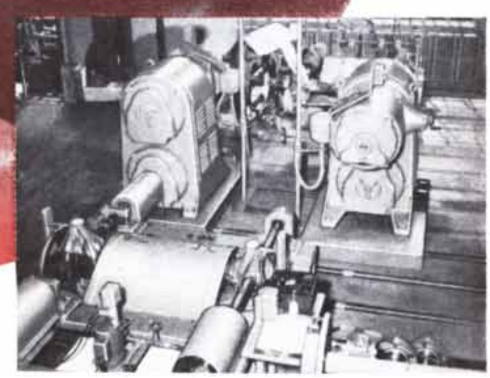
Dr. Kubie believes that young research scientists must have better psychological conditioning for their career. Few of them are prepared for the fact that the economic cards are stacked against them. "I do not remember one who had included in planning for his career a budget of reasonable living costs for a prospective family, compared with existing academic and research salaries. . . . There is the initial poverty and the crowded living quarters, . . . the pressure of anxiety about the future as these insecurities slowly come to be appreciated, . . . the consequent tendency to overwork, . . . the inadequate social life, the cramped and hampered sexual life, the increasing monastic absorption of the man and the wife's early fading and gradual loss of vitality and of confidence in herself as a woman."

Nor are young scientists prepared for the hazards of their work. For every successful and positive piece of research there are "hundreds which merely prove that something is *not* so. . . . A scientist may dig with skill, courage, energy and intelligence just a few feet away from a rich vein . . . but always unsuccessfully." Failing to realize that prestige and success are not entirely within their control, they find failure hard to take, and many have "nervous breakdowns" in middle age. Kubie compares the immature inability to see the hazards of the profession with "a serene but unrealistic fantasy of personal invulnerability" with which some soldiers go into battle. These are the soldiers, he says, who are most likely to break down under the stress of battle.

Immaturity may be on the one hand a reason for choosing a "sheltered" academic career, and on the other a result of the long, dependent student's life which scientists must undergo. "This protracted quasi-adolescence also stirs tides of conscious and unconscious rebellion." The long period of "subordination, insecurity and rebellion" and the desire to achieve rapid positive results may lead to a collapse of scientific integrity. "For many reasons," Kubie remarks, "I suspect (although I cannot prove) that we may be seeing today the birth of a new psycho-social ailment among scientists, one which may not be

New Laboratory

for New Departure



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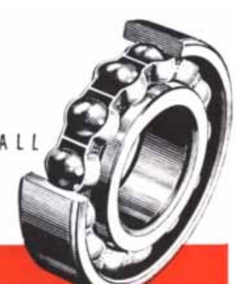

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wholly unrelated to the gangster tradition of dead-end kids." Growing up "hardened, cynical, amoral, embittered and disillusioned," some scientists today find an outlet for their feelings in "fashioning implements of destruction." It will be society's fault if the tendency continues and these men should turn to "even more disastrous channels of expression."

Apes and Bishops

In the history of science the story of what T. H. Huxley said to Bishop Wilberforce is a piece of folklore like what the Governor of North Carolina said to the Governor of South Carolina. At a famous meeting of the British Association for the Advancement of Science in 1860 Bishop Wilberforce debated Darwin's theory of evolution with Huxley. At the end of his long speech the Bishop turned and inquired whether Huxley claimed descent from an ape on his father's or his mother's side. Huxley made a devastating reply, but as to just what the reply was there have been many versions. The question has now been authoritatively settled. A British engineer, D. J. Foskett, recently unearthed a Huxley letter giving his own account of the incident. Said Huxley's letter, now published in *Nature*:

"When I got up, I spoke pretty much to the effect—that I had listened with great attention to the Lord Bishop's speech but had been unable to discover either a new fact or a new argument in it—except indeed the question raised as to my personal predilections in the matter of ancestry—That it would not have occurred to me to bring forward such a topic as that for discussion myself, but that I was quite ready to meet the Right Rev. prelate even on that ground. If then, said I, the question is put to me would I rather have a miserable ape for a grandfather or a man highly endowed by nature and possessing great means and influence and yet who employs those faculties and that influence for the mere purpose of introducing ridicule into a grave scientific discussion—I unhesitatingly affirm my preference for the ape.

"Whereupon there was unextinguishable laughter among the people, and they listened to the rest of my argument with the greatest attention. . . . I happened to be in very good condition and said my say with perfect good temper and politeness— I assure you of this because all sorts of reports [have] been spread about, *e.g.*, that I had said I would rather be an ape than a bishop, etc."

MODERN COSMOLOGY

Its theories utilize evidence from such things as the decay of atoms, the metabolism of stars and the flight of galaxies to describe the structure of the Universe in space and time

by George Gamow

The subject of cosmology is the study of our Universe's general features, its extension in space and its duration in time. With the great 200-inch telescope on Palomar Mountain man today can look over two billion light-years into space and see nearly a billion galaxies, spread more or less uniformly through that vast volume.

It is important to realize that we are looking not only far into distance but also far back in time. For instance, the present-day photograph of the great Andromeda Nebula shows that group of stars as it looked about two million years ago, for it has taken this time for its light to reach us. The most distant galaxies detected by the 200-inch are seen by us in the state in which they were more than two billion years ago.

The view of the Universe that we are seeing at this instant can be represented schematically by a cone-shaped diagram that takes the time factor into account [*see illustration on next page*]. At the apex of the cone is our own galaxy as it is now; down the surface of the cone are the other galaxies photographed by our telescopes as they were at dates in the past corresponding to their distance from us. A horizontal cross section through the cone would show the Universe as it was at a given date; this is known as a world map.

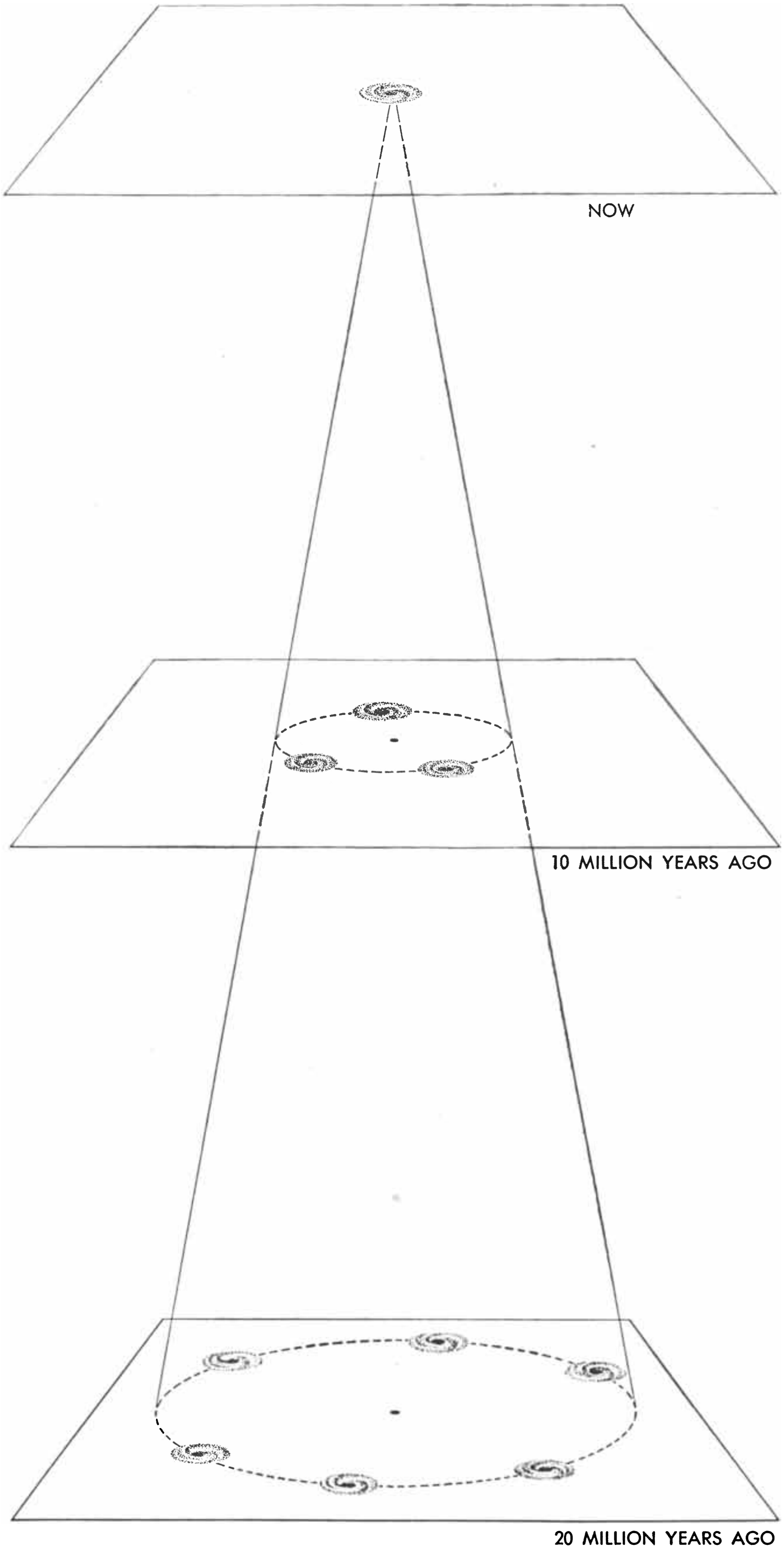
Theoretical cosmology attempts to correlate the observed facts about the Universe at large with known physical laws and to draw a consistent picture of the Universe's structure in space and its changes in time. In studying the structure we must accept the Copernican point of view and deny to man the honor of a privileged position in the Universe; in other words, we must assume that the structure of space is very much the same in distant regions as it is in the part we can observe. We cannot suppose that our particular neighborhood is specially adorned with beautiful spiral galaxies for the enjoyment of professional and amateur astronomers.

CLUSTER OF GALAXIES in Coma Berenices was photographed with the 200-inch telescope. It is 40 million light-years away.

The Paradox of Finite Light

To make clear the nature of the problems with which cosmologists must deal, let us begin with a paradox first pointed out by the German astronomer Heinrich Olbers more than a century ago. If stars are distributed uniformly through space, and if space is infinite, why, he asked, are we not blinded by their light? (Nowadays we must think of space as filled with galaxies, then unknown, but that does not affect the question.) Olbers' argument goes as follows: Suppose we think of space as a series of concentric spheres with ourselves at the center—imagine it as having the structure of an infinitely big onion. Each sphere is larger in radius than the next smaller one by a certain fixed amount; that is, the thickness of the onion layers, or shells, is uniform [*see illustration on page 57*]. Now the volume of each successive shell is greater than that of the next smaller one in proportion to the square of the increase in radius, and the number of galaxies in the shell is larger in the same proportion. On the other hand, the light reaching the center from galaxies farther and farther away decreases in proportion to the square of the increase in radius. Hence the two opposing factors—the increase in the number of galaxies and the reduction in light from each galaxy—cancel out, and we should expect the center to receive the same amount of light from every shell, no matter how near or how far. Therefore in an infinite universe any given point theoretically should receive an infinite amount of light! Actually, of course, the light sources partly screen one another and as a consequence of this interference the illumination could not exceed the surface brightness of an individual star. But this means that our night sky would be as bright as the sun's disk from horizon to horizon! In daytime the sun itself would be practically unnoticeable against the shining background of the galaxies in the heavens.

What is wrong with this reasoning? Early in this century the Swedish astronomer C. V. L. Charlier proposed an ingenious answer to Olbers' paradox. The visible stars in the Milky Way system altogether occupy so negligible a fraction of the sky area, and our galaxy itself is so limited—a droplet in the vast reaches of space—that all the Milky Way's starlight scarcely illuminates the earth at all. And the distances between galaxies are far greater than those between stars in our galaxy. Because of their distance from us and their great dilution in space, the total illumination of our night sky from the billion galaxies within the range of the 200-inch telescope is only a small percentage of the faint light we get from the Milky Way. This still does not invalidate Olbers' argument, if we assume that space is filled with the same density of galaxies for an indefinite distance beyond the range of our telescopes. But Charlier suggested that there may be a limit to this population: that we may be part of a giant cluster of galaxies which is surrounded by empty space at some distance beyond our telescopic range. If this is so, the



CONE-SHAPED MAP depicts our historical view of the Universe. At the vertex is our galaxy. The galaxies within 10 million light-years appear as they did 10 million years ago, and so on. The relative size of these galaxies has been greatly exaggerated for clarity.

total illumination at the earth from the cluster would indeed be negligible.

Of course we cannot stop there; we have to assume that there are other giant clusters, and that they are combined in superclusters, and these in turn in super-superclusters, and so on without end. It is apparent, however, that as we take in larger and larger volumes of space, the mean number of galaxies per unit of space becomes smaller and smaller, because of the increasingly large portions of empty space between the clusters and combinations of clusters [*see illustration on page 58*]. Since Olbers' paradox rested on the assumption that the number of galaxies per space unit remains the same no matter how large a volume is considered, Charlier's "hierarchy Universe" neatly solved the puzzle.

Expanding Space

Today we have a more direct answer to Olbers' paradox: namely, the shift toward the red end of the spectrum in the light reaching us from distant galaxies, which weakens or "dims" their light in proportion to their distance from us. The discovery of the red shift has had far more important consequences, however, than merely the solving of old puzzles; it has profoundly changed man's thinking about the cosmos [see "Galaxies in Flight," by George Gamow; SCIENTIFIC AMERICAN, July, 1948]. The chief change was to introduce the notion of the expanding Universe—an idea which has now become firmly established. One should remember that the expanding Universe theory finds support not only in the red shift but also in classical Newtonian mechanics. Because of the gravitational forces between the galaxies, the cosmic system cannot be expected to remain static, just as a tennis ball cannot hang motionless in midair. The system must either contract, under the forces of gravitational attraction, or expand, as the result of some dispersing force overcoming the attraction.

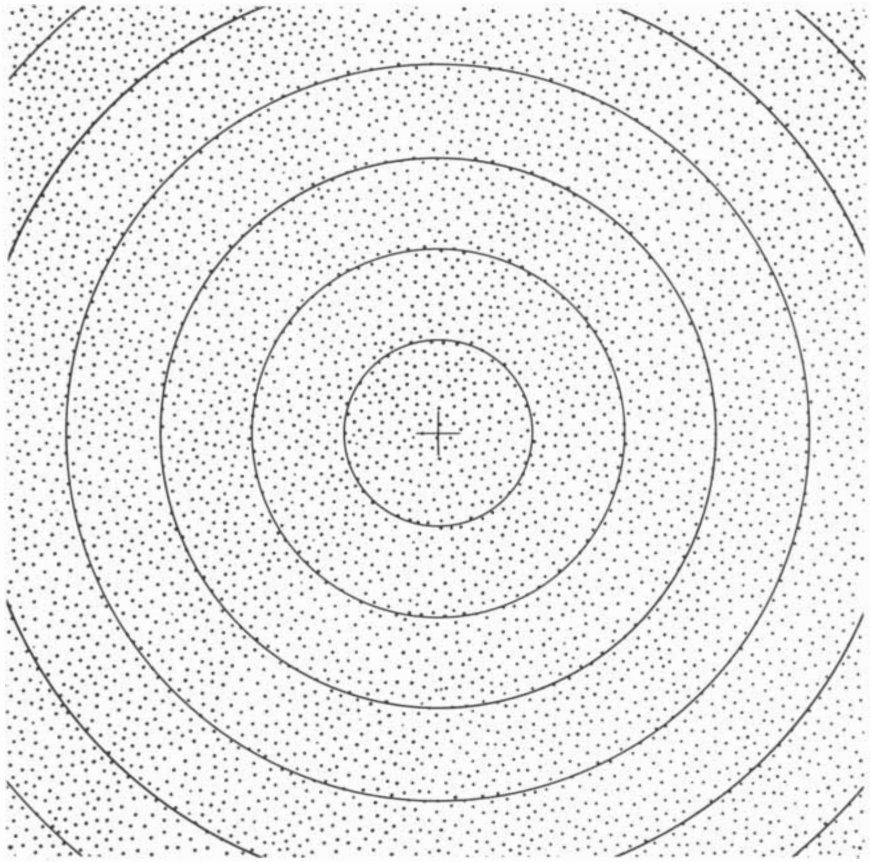
From the observed red shift one can calculate that the galaxies are fleeing from one another with a kinetic energy which is about 50 times as great as the potential energy of gravitational attraction between them. This means that the present expansion of the Universe will never stop, or, in mathematical language, that the expansion of our Universe is hyperbolic. Further, from the observed recession velocity and the distances between the galaxies one can also compute how long ago the Universe began to expand from its original compressed state.

On this basis Edwin P. Hubble and Milton L. Humason calculated a quarter of a century ago that the age of the Universe was 1.8 billion years. Until recently that estimate stood in serious contradiction to the estimates of geologists and astrophysicists, who calculated from the decay of radioactive materials in the earth and from the rate of burning of nuclear fuel by the stars that the Universe must be five billion years old. But the discrepancy was eliminated a little over a year ago when Walter Baade of the Mount Wilson and Palomar Observatories discovered that as a result of new observations the distances between galaxies, and therefore the age calculated on the basis of the red shift, must be multiplied by a factor of 2.8. This correction (2.8 times 1.8) raises the expansion age to five billion years, in perfect agreement with the geological and astrophysical estimates!

Curved Space

So far we have been discussing the properties of the Universe without reference to the so-called relativistic cosmology based on Einstein's general theory of relativity. The essential point of Einstein's general theory is the introduction of the notion of curved space, and the identification of the effect of gravitational forces with the change of free motion of material bodies in a curved non-Euclidean space. After the great success of his theory in predicting the deflection of light rays by the gravitational field around the sun, Einstein proceeded to apply the theory to the Universe as a whole. According to the cosmological principle of uniformity, one should assume that the curvature of space is the same throughout the Universe; in terms of a two-dimensional analogy, our Universe should be round like the surface of a basketball. There are two possible types of curvature for a curved surface: positive and negative. Positive curvature turns inward, like the surface of a ball; negative curvature turns outward, like a western saddle. Between these of course lies the surface of zero curvature, which is perfectly flat.

In complete analogy with these two-dimensional examples, three-dimensional space can be curved positively or negatively, with zero curvature representing ordinary Euclidean space. In Euclidean space the volume of a sphere increases as the cube of its radius. But in a positively curved space the volume increases at a less rapid rate, while in a negatively curved space it increases more rapidly.



OLBERS' PARADOX supposed an even distribution of stars in the Universe and concentric layers of equal thickness. The modern paradox substitutes galaxies for the stars.

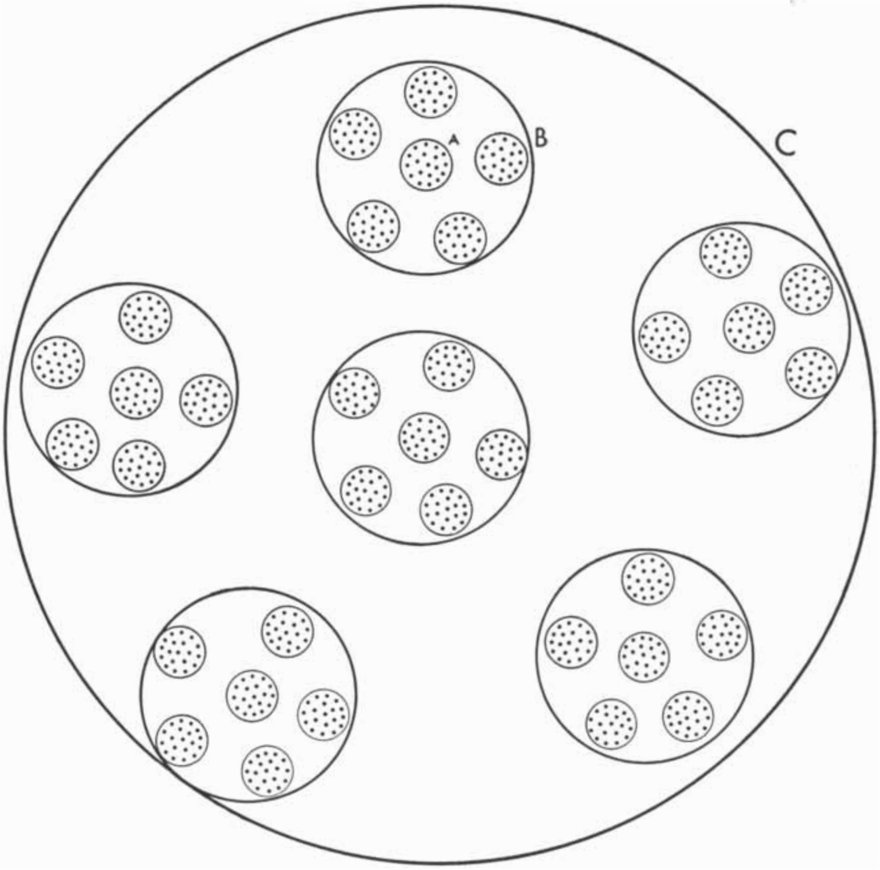
Now if the space of our Universe is curved either way, in principle it should be possible to find that out observationally by counting the galaxies within volumes of space of successively greater radius from us. If the number of galaxies increases more slowly or more rapidly than the cube of the distance, this would indicate a positive or a negative curvature. During the past two decades the late E. P. Hubble carried out such counts at the Mount Wilson and Palomar Observatories, but unfortunately with very indefinite results.

The difficulty is that we can expect to find noticeable curvature effects only at very great distances, and we cannot make reliable distance estimates for galaxies so far away. The only way we can judge their distance is by the faintness of their light. But we must also remember that we are looking far back in time. The intrinsic brightness of galaxies may change with time. Consequently we cannot be sure that a distant galaxy which is fainter than another is farther away; it may instead be at a different stage of evolution. Until we know more about evolutionary changes in galaxies, we shall not be able to reach any definite conclusions about the curvature of space from counts of the nebulae.

Models of the Universe

Relativistic cosmology went through several interesting stages. Due to an algebraic error in his calculations, Einstein concluded that the Universe must be static. (This was, of course, before the discovery of the red shift.) The only way to make such an idea work was to introduce some kind of repulsive force to counteract the gravitational one. This force, in contrast to any other known in physics, would have to be assumed to increase with distance. Einstein met this dilemma by introducing into his equations of general relativity the so-called "cosmological term," and that led to the famous spherical Universe—a finite cosmos closed on itself. But Einstein's static model failed to agree with astronomical observations: it was too small to represent the actual Universe.

Soon afterward the Dutch astronomer Willem de Sitter found another possible solution. His model of the Universe, however, turned out to be even less acceptable than Einstein's. It satisfied the



CHARLIER'S UNIVERSE supposed galaxies formed into clusters formed into larger clusters and so on. The dots are galaxies; the circles, clusters of galaxies or of clusters.

equations only if one assumed that space was completely empty and there was no matter whatsoever!

Then in the early 1920s the Russian mathematician Alexander Friedmann noticed the error in Einstein's computation. He showed that with this correction one could get solutions of basic relativistic equations which yielded models of a Universe that changed with time. The matter was further developed by the Belgian cosmologist Georges Lemaître. Associating Friedmann's dynamic Universe with the new red-shift observations of Hubble and Humason, he formulated the theory of the expanding Universe in the form in which we know it now.

Einstein's original equations of a static Universe related its curvature to the mean density of matter in space and to an *ad hoc* cosmological constant. The present dynamic equations of the expanding Universe connect its curvature with two directly observable quantities: the mean density of matter and the rate of expansion. With the observed value of these two quantities one can calculate that the curvature of our Universe is negative, so that space is open and infinite. It bends in the way a western saddle does. The radius of curvature comes out as five billion light-years.

About five years ago an entirely new idea was introduced into theoretical cosmology by the British mathematicians Herman Bondi and Thomas Gold. They started from the assumption that if the Universe is homogeneous in space, it must also be homogeneous in time. This would mean that any region of the Universe must always have looked in the past, and will always look in the future, essentially the same as it looks now. The only way to reconcile this postulate with the well established movement of the galaxies away from one another was to assume that new galaxies are continuously being formed to compensate for the dispersal of the older ones. If new galaxies are being formed, then new matter must be continuously created throughout space. Bondi and Gold calculated that the creation of new matter must proceed at the rate of one hydrogen atom per hour per cubic mile in intergalactic space. This idea of Bondi and Gold was soon extended by the British astronomer Fred Hoyle, who modified the original Einstein equations of general relativity so that they would permit the continuous creation of matter in space.

Besides circumventing the philosophical question as to the "beginning" of the Universe, the Bondi-Gold-Hoyle theory claimed to dispose of the painful discrepancy in the estimates of the age of the Universe that was still troubling astronomers at the time. If new galaxies were continuously being created, the Universe must be populated with galaxies of all ages, from babies to oldsters living on borrowed time. Bondi, Gold and Hoyle assumed that the average age of the population was about one third of the figure of 1.8 billion years that Hubble had arrived at for the total age of the Universe, that is, 600 million years. According to this point of view, since our own galaxy is estimated to be several billion years old, we are living in a rather elderly member of the population.

The recent revision of distances that eliminated the age discrepancy and placed the age of the Universe at five billion years does not disprove the Bondi-Gold-Hoyle theory of a steady-state Universe; it merely raises the average age of galaxies to about 1.7 billion years and makes our own galaxy three times instead of nine times as old as the average. Nevertheless the elimination of the discrepancy does deprive the steady-state idea of its main support. As far as observations go, the weight of the evidence at present is definitely in favor of the idea of an evolving Universe rather than a steady-state one such as is envisioned by Bondi, Gold and Hoyle.

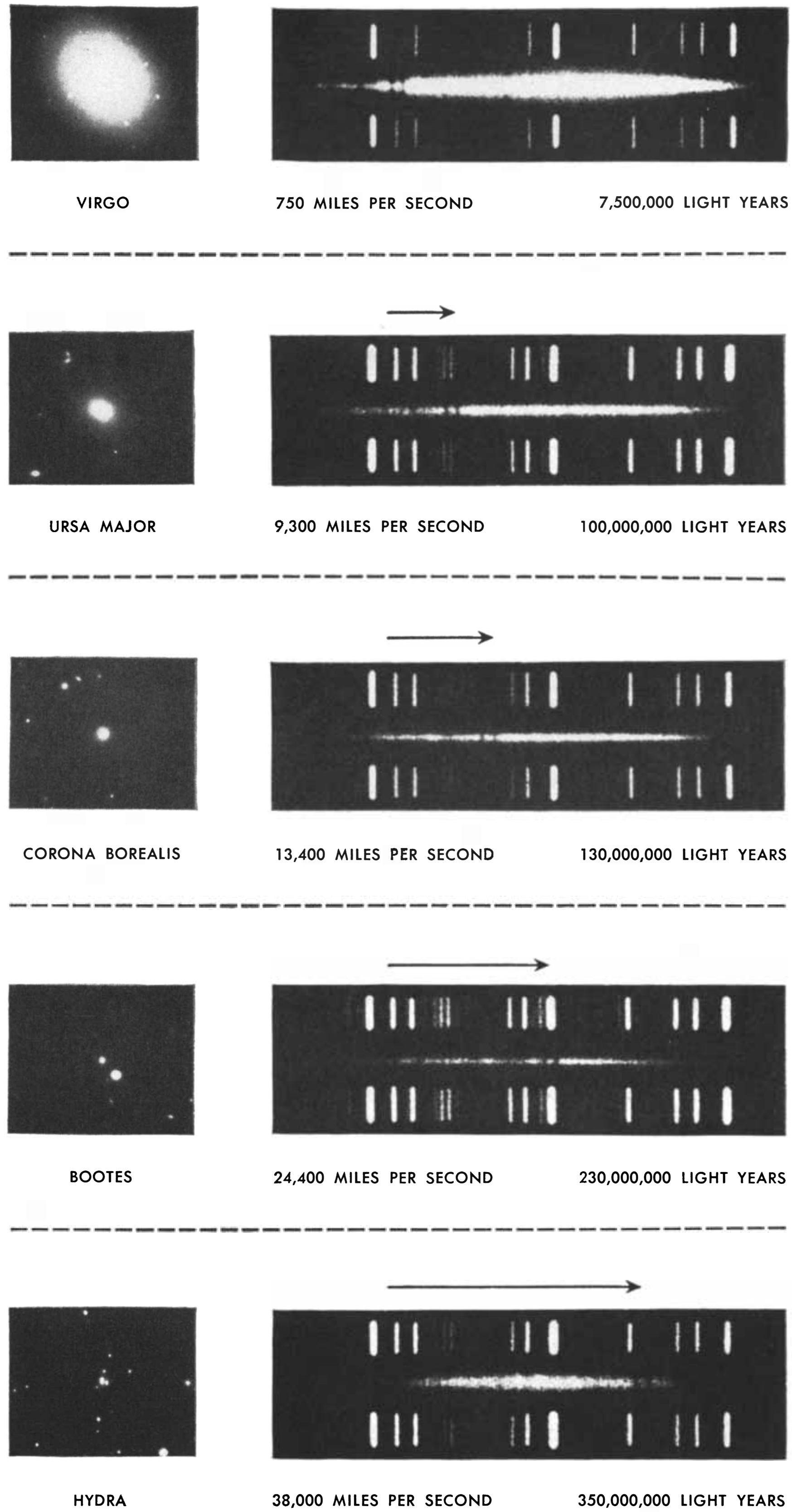
One of the most important recent pieces of evidence was a discovery made in 1948 by the U. S. astronomers Joel Stebbins and Albert E. Whitford. Using light filters of different colors, they measured the reddening of light from distant galaxies, and to their own and everyone else's great surprise they found the reddening to be about 50 per cent greater than could be accounted for by the red shift, or Doppler effect, due to the galaxies' movement away from us [see "Measuring Starlight by Photocell," by Joel Stebbins; SCIENTIFIC AMERICAN, March, 1952].

It is well known that light rays may be reddened by dust, which scatters and screens out the blue part of the light; the dust in the atmosphere is what makes the sun look red at sunrise and sunset. The excess reddening of the distant galaxies was therefore attributed at first to dust floating in intergalactic space. But when the investigators calculated how much dust would have to be present there to produce the observed reddening, they got an astounding result: the dust in intergalactic space would add up to 100 times as much matter as the total amount concentrated in the galaxies themselves! This finding not only contradicted all accepted views about the distribution of matter in the Universe but also played havoc with astronomers' distance scales and the theory of the curvature of space.

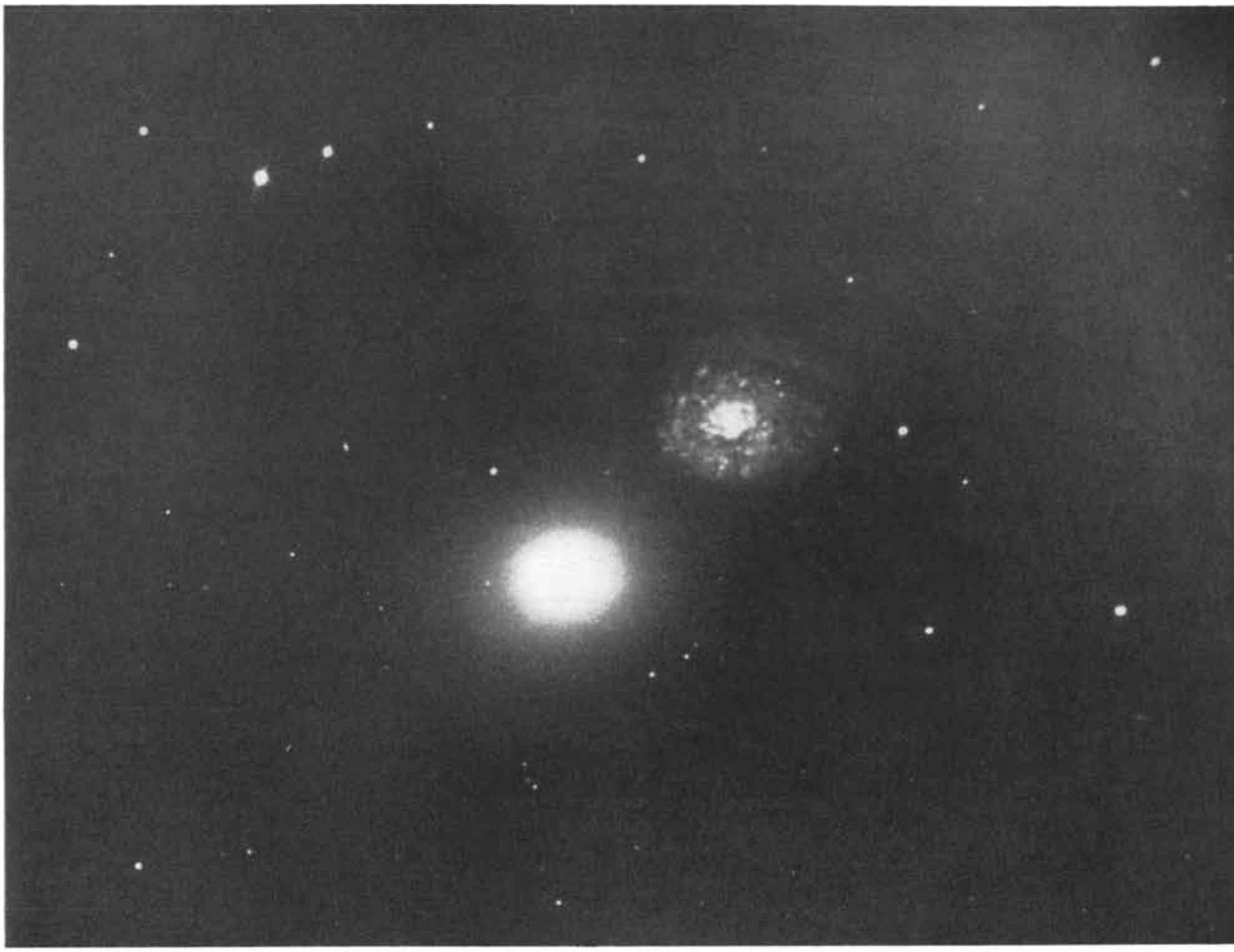
Fortunately further studies by Whitford extricated the astronomers from this impasse. To understand them we must look into the composition of galaxies. Baade has shown that there are two kinds of stellar populations: Population I consists predominantly of blue stars, with great clouds of dust and gas floating among them; Population II, mainly redder stars, has no dust or gas whatever. The spiral galaxies are made up largely of Population I, the elliptical ones of Population II. Since interstellar dust and gas afford material for forming new stars, one may assume that spiral galaxies are in a more or less steady state, with newborn stars replacing old ones that are slowly fading out. On the other hand, elliptical galaxies, lacking dust and gas, are producing no new stars to replace the dying population. The two types of communities may be likened respectively to the population of Cambridge, Mass., a dynamic community in which new births replace those who die, and to the Harvard University alumni of the class of 1925, a declining population.

Now Stebbins and Whitford had limited their original observations to elliptical galaxies. In his new studies Whitford included spiral galaxies, located in the same clusters. And he found that the light from the spirals showed no excess reddening! Thus the extra reddening of the light from the elliptical galaxies could not be due to any factor (such as dust) affecting it in its travel through space, since the elliptical and spiral galaxies observed lay side by side the same distance from us. The only possible conclusion was that the excessive redness of the distant elliptical galaxies is due to the fact that we see them now as they were in a distant past when they were intrinsically redder. This finding is one of the strongest evidences in favor of the idea that galaxies are evolving and against the theory of a steady-state Universe.

There are other arguments against that theory. For instance, if our own galaxy is older than the average, we should expect the stars in our system to be older and different from most of those in neighboring galaxies, but no such general difference has been observed. On the whole it appears that the steady-Universe theory, attractive as it may



RED SHIFT is illustrated by spectra. At the left are galaxies from five constellations. At the right are their spectra. Above and below each spectrum is the comparison spectrum of helium. The shift is indicated by the position of two faint dark lines: the H and K lines of calcium. Speed of recession and distance indicated by each spectrum is given below it.



THE PRINCIPAL KINDS OF GALAXIES appear in the same photograph made with the 100-inch telescope on Mount Wilson. At the right is a spiral galaxy. At the left is an elliptical galaxy, which presumably represents a later stage of galactic evolution.

seem from certain philosophical points of view, is neither necessary nor correct.

The Evolving Universe

Returning now to Lemaître's theory of the expanding Universe, let us try to explain how the cosmos evolved from the original highly compressed, very hot gas to stars, galaxies and matter as we know it today. First of all we must consider the relation between matter (represented by particles such as protons, neutrons and electrons) and radiation (represented by light quanta). In classical physics it was customary to regard matter as ponderable and radiation as imponderable, but we know now that radiant energy has mass, which is calculated, according to Einstein's basic law, by dividing the quantity of energy by the square of the velocity of light. On the earth the weight of radiant energy is negligibly small compared to that of matter: the total mass of all the light quanta passing through the atmosphere on a bright, sunny day is less than a thousandth of a millionth of a millionth of a millionth of the weight of the air. Heat radiation is slightly heavier than light, but its weight amounts to only one microgram per 10 billion tons of air in the atmosphere!

In interstellar and intergalactic space the ratio is not so large: the mass of matter there is only about 1,000 times the mass of the stellar radiation. Still, in the Universe as we know it today matter is everywhere more massive than radiation. But it need not always have been so. During the early stages of the Universe's evolution the mass density of radiation must have exceeded that of ordinary matter. The reason for that conclusion, which the writer first suggested several years ago, lies in the different behavior of matter and radiation. Imagine two cylinders, one filled with a material gas, the other a vacuum containing only thermal radiation. Both cylinders are sealed and thermally insulated, and the one containing the radiation has its inner walls made of an ideal mirror which does not absorb radiation. The cylinders have movable pistons. Now we pull the pistons, increasing the volume of space in each cylinder. In the cylinder filled with material gas, the density of the gas will be reduced in direct proportion to the increase in volume. But in the other cylinder, the mass density of the radiation will fall off more sharply, because the energy (and consequently the mass) of each quantum of radiation will be reduced by reflection from the receding piston. The laws of physics tell us the radiation's mass density will decrease in the ratio of 4/3 to the increase in volume.

Applying similar considerations to the Universe as a whole, we arrive at the conclusion that once upon a time in the distant past radiant energy had the upper hand over ordinary matter; there must have been pounds and pounds of light quanta for every ounce of atoms.

A Universe filled almost entirely with thermal radiation presents a rather simple case in the relativistic theory of expanding space. One can show that, starting from the time of maximum compression, all distances will increase in proportion to the square root of the elapsed time, and that the temperature of the radiation will decrease in inverse proportion to the square root of the elapsed time. The temperature of the Universe at any date is equal to 15 billion degrees absolute (degrees Centigrade above absolute zero) divided by the square root of its age expressed in seconds. Thus we get a chronological picture of the "changing climate" of our Universe: at the age of five minutes its mean temperature was about one billion degrees absolute; at one day it was about 40 million degrees (comparable to the temperature at the center of the sun or of an atomic bomb); at 300,000 years it was 6,000 degrees (the temperature at the surface of the sun) and at 10 million years it was 300 degrees (about room temperature).

Computing the mass densities of radiation and of matter at various epochs, we can find the date of the great event when matter took over from radiation, *i.e.*, surpassed it in mass density. The date was about the year 250,000,000 A.B. (After the Beginning). The temperature of space was then about 170 degrees absolute, and the density both of radiation and of matter was comparable with the present density of interstellar gas. The Universe, in short, was dark and cool.

The Genesis of Galaxies

The transition from the reign of thermal radiation to the reign of matter must have been characterized by a very important event: formation of giant gaseous clouds. From these "protogalaxies" the galaxies of today must have developed, somewhat later, by the condensation of gas into individual stars. During the period when matter had played only a secondary role in the infinite ocean of thermal radiation, it had had, so to speak, no will of its own; the particles of matter were "dissolved" in the thermal radiation, much as molecules of salt are dissolved in water. As soon as matter took the upper hand, however, the forces of gravity acting between the particles must have caused a growing inhomogeneity of the matter in space. The English astronomer James Jeans showed more than half a century ago that the size of the clouds into which a gas of particles will be collected by gravitational forces can be calculated from the density and temperature of the spread-out gas. Using Jeans's formula and the transition-period temperature and density values given above, we find that the primordial gas clouds must have been about 40,000 light-years across, and each cloud must have had a total mass about 200 million times that of our sun. These figures, derived purely from theory, are in quite reasonable agreement with the observed figures for the average dimensions and mass of the present galaxies. (The Milky Way and the Andromeda Nebula are considerably larger than the average galaxy.)

The protogalaxies were pulled apart by the general expansion process. Their material later condensed into billions of stars, presumably by repetition on a smaller scale of Jeans's accretion process. Planets were formed, and the Universe again became brightly illuminated, as a result of nuclear reactions taking place in the interiors of the stars. But these "secondary" processes are a topic in themselves, which we shall not discuss in detail here.

The Beginning

Let us now go back to the beginning—the earliest stages of expansion. According to our calculations, when our Universe was five minutes old its temperature was a billion degrees, and it must have been still higher before that. At such temperatures particles move with energies of millions of electron volts—energies comparable with those in modern atom-smashing accelerators. This means that nuclear reactions must have been going on at a high rate all through the matter of the Universe. It is natural to conclude that the chemical elements were formed, in the relative abundances that were to make up the Universe we know, during that early stage of evolution. This assumption is strengthened by the fact that the natural radioactive elements are calculated today, from the extent of decay, to be about five billion years old.

During the first few minutes of the Universe's existence matter must have consisted only of protons, neutrons and electrons, for any group of particles that combined momentarily into a composite nucleus would immediately have dissociated into its components at the extremely high temperature. One can call the mixture of particles *ylem* (pronounced eelem)—the name that Aristotle gave to primordial matter. As the Universe went on expanding and the temperature of ylem dropped, protons and neutrons began to stick together, forming deuterons (nuclei of heavy hydrogen), tritons (still heavier hydrogen), helium and heavier elements.

On the basis of what we know about the behavior of nuclear particles and of the assumptions about the rate of temperature and density changes in the expanding Universe, one can calculate the net result of all the possible nuclear reactions that must have taken place during those early minutes of the Universe's history. The time available for the formation of the elements must have been very short, for two reasons: (1) the free neutrons in the original ylem would have decayed rapidly, and (2) the temperature quickly dropped below the level at which nuclear reactions could take place. The mean life of a neutron is known to be only about 12 minutes; hence half an hour after the expansion had started there would have been practically no neutrons left if they had not been combined in atomic nuclei. Favorable temperature conditions lasted about the same length of time. Thus all the chemical elements must have been formed in that half-hour.

Many people would argue that it makes no physical sense to talk about half an hour which took place five billion years ago. To answer that criticism, let us consider a site, somewhere in Nevada, where an atomic bomb was set off several years ago. The site is still "hot" with long-lived fission products. It took only about one microsecond for the nuclear explosion to produce all the fission products. And simple arithmetic will show that a period of several years stands in the same ratio to one microsecond as five billion years do to a half-hour!

Early Matter

Calculations of the rate at which elementary atomic nuclei would have been synthesized under the assumed conditions were carried out by the writer a number of years ago and were later extended by Enrico Fermi and Anthony L. Turkevich. The composite nuclei whose production was estimated were deuterium (a combination of a proton and a neutron), tritium (one proton and two neutrons) and two isotopes of helium. By the end of 30 minutes free neutrons would practically have disappeared, and after that there would be no further change in the relative abundances of these elementary nuclei. At that time the Universe, according to these calculations, would have consisted of roughly equal amounts of hydrogen and helium, and about 1 per cent of the original ylem would have been converted into rare isotopes of hydrogen and helium which could combine to form the nuclei of heavier elements.

Now the fact that the amounts of hydrogen and helium come out approximately equal in these calculations is highly gratifying, because this is just about the relative abundance of these two elements in the Universe today. The result of the calculations gives good support to the expansion theory, for it can be shown that the Universe would have emerged from the ylem state consisting practically entirely of hydrogen or entirely of helium if conditions had been much different from those postulated.

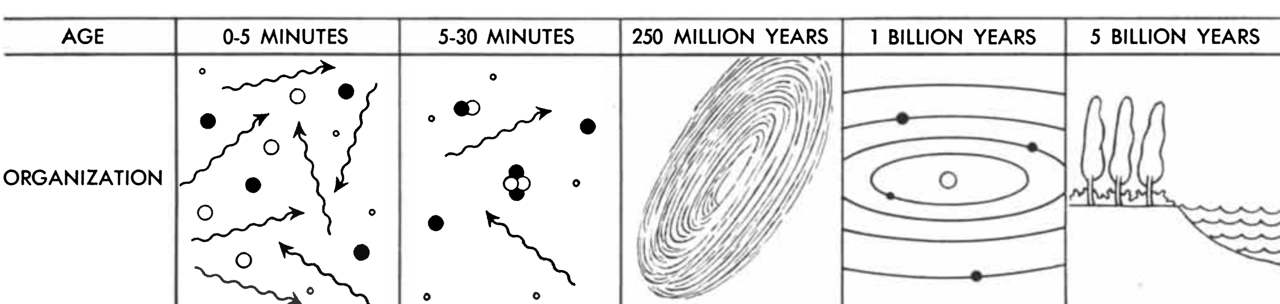
Beyond these first two elements, however, the theory runs into a serious and as yet unresolved difficulty. The theory assumes that the light elements combined in successive steps to form the heavier ones. Helium consists of four nucleons (nuclear particles); that is, its atomic mass is four. The next nucleus should have the atomic mass five, but the fact is that no nucleus of mass five exists; at least, none of any appreciable length of life is known. For some reason five nucleons simply do not hold together. After helium 4 the next nucleus is an isotope of lithium of mass six. One must therefore assume that helium was built up to the next nucleus either by the simultaneous capture of two neutrons (an extremely unlikely event) or by fusion with a tritium nucleus. But the rate at which such fusions could have occurred under the given conditions is much too low to account for the amount of heavier elements that was actually produced. No likely reaction that bridges the gap at mass five has yet been found.

Beyond mass five there is little or no trouble; once that gap has been bridged, one can account quite satisfactorily for the relative abundances of the elements from lithium up through the periodic table to uranium, as has been shown by calculations carried out by the writer, Ralph A. Alpher and Robert C. Herman. If no way is found to bridge the gap, we may have to conclude that the main bulk of the heavier elements was formed not in the early stages of the Universe's expansion but some time later, perhaps in the interiors of fantastically hot stars.

The Explosion

A theory which suggests that our Universe started from an extremely compressed concentration of matter and radiation naturally raises the question: How did it get into that state, and what made it expand? In his original version of the expanding Universe Lemaître visualized the beginning as a giant "primordial atom" which exploded because of violent radioactive decay processes. But this conception is quite out of keeping with the picture of early evolution that we have arrived at. The young Universe must have consisted almost exclusively of high-temperature thermal radiation, and atoms, radioactive or not, could have played only a negligible role in its behavior.

A much more satisfactory answer can be obtained by considering the operation in reverse of those same relativistic formulae that we have used to describe the expansion process. The formulae tell us that various parts of the Universe are flying apart with an energy exceeding



EVOLUTION OF THE UNIVERSE is symbolized at five stages. During the first five minutes of its expansion photons (*wavy lines*) outweighed solitary particles of matter such as protons (*black circles*), neutrons (*larger white circles*) and electrons (*smaller white circles*). Between five and 30 minutes matter had gained the upper hand and the fundamental particles had begun to coalesce into more complex nuclei such as those of deuterium (*proton and neutron*) and helium (*two protons and two neutrons*). After 250 million years the primordial gas began to break up into huge protogalaxies. After a billion years the matter in the protogalaxies had condensed into stars and planets. The present epoch is characterized here by the presence of life on at least one planet.

the forces of Newtonian attraction between them. Extrapolating these formulae to the period before the Universe reached the stage of maximum contraction, we find that the Universe must then have been collapsing, with just as great speed as it is now expanding!

Thus we conclude that our Universe has existed for an eternity of time, that until about five billion years ago it was collapsing uniformly from a state of infinite rarefaction; that five billion years ago it arrived at a state of maximum compression in which the density of all its matter may have been as great as that of the particles packed in the nucleus of an atom (*i.e.*, 100 million million times the density of water), and that the Universe is now on the rebound, dispersing irreversibly toward a state of infinite rarefaction.

Such motion is hyperbolic; it can be compared with the motion of a comet, which does not revolve around the sun as planets do but comes in from the infinity of space (in certain cases), sails around the sun in a bent path, developing a beautiful tail, and vanishes into infinity again without promise of return.

Before the Beginning

Any inquisitive person is bound to ask: "What was the Universe like while it was collapsing?" One might give a metaphysical answer in the words of Saint Augustine of Hippo, who wrote in his *Confessions:* "Some people say that before He made Heaven and Earth, God prepared Gehenna for those who have the hardihood to inquire into such high matters."

More recently a mathematical-physical answer was given by the Japanese physicist Chushiro Hayashi, and his idea has been elaborated by Alpher, Herman and James W. Follin of the Applied Physics Laboratory at The Johns Hopkins University. Considering the known facts about the behavior of fundamental particles, they came to the conclusion that the present chemical composition of the Universe is quite independent of its constitution before the state of maximum collapse. Transformations of particles must have occurred so rapidly during that state that the outcome was determined entirely by the conditions at the time rather than by what had gone on before.

Thus from the physical point of view we must forget entirely about the pre-collapse period and try to explain all things on the basis of facts which are no older than five billion years—plus or minus five per cent.

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THE PERU CURRENT

Although it flows through tropical waters, this oceanic stream is cool and rich in life. Sometimes it vanishes, a curious phenomenon investigated by a recent expedition

by Gerald S. Posner

Coastal Peru is a picture in contrasts and anomalies. On the one hand the land is barren, eroded and almost wholly infertile; on the other hand, the sea teems with an immense fish and bird life. Anomalous is the fact that the sea is cool although it is near the Equator.

These contrasts and peculiarities over a long stretch of the coast of western South America are due to the Peru Current, a great body of cold water which flows north from Valparaiso, Chile, to the region of Cabo Blanco in northern Peru, where it veers westward and loses its identity in the South Equatorial Current.

Cool, moist air from the ocean blankets the coast with perpetual haze and fog but gives no relief to the parched earth. In this land of calm and drought the fisherman leaves his adobe hut and goes far out to sea on a small balsa raft to take his food with a fishing line. There are fish in abundance for all—for the fishermen and for the millions of sea birds that darken the evening sky as they fly home to their nesting islands.

The bird islands are a rich source of income. The Peruvians annually collect from them some 5,000 tons of guano—an excellent fertilizer much in demand. The consumption of fish by these birds must be enormous. Indeed, on the basis of production of guano it is estimated that the birds in these waters annually consume about as much fish as the total commercial catch of all fisheries of the U. S.

In rare years—traditionally every seventh—the tranquil pattern of life on the Peruvian coast is interrupted by an event of sometimes catastrophic proportions. The Peru Current seems to disappear, and the temperature of the surface water rises rapidly. On land there are often torrential rains. At sea the fish are killed or move away, and the birds, too, must go or starve. This event has come to be known as *El Niño*, "the child," because it appears shortly after the Christmas season. Authorities differ about the meaning of the term. Some believe that *El Niño* is a current, but to avoid confusion and possible error it seems best to define it simply as a condition. During an

WATERS OF THE PERU CURRENT are often traversed by swarms of sea birds which feed on its teeming fish life. In the distance are the cliffs of the mainland, whitened by immense deposits of guano laid down by thousands of generations of birds.

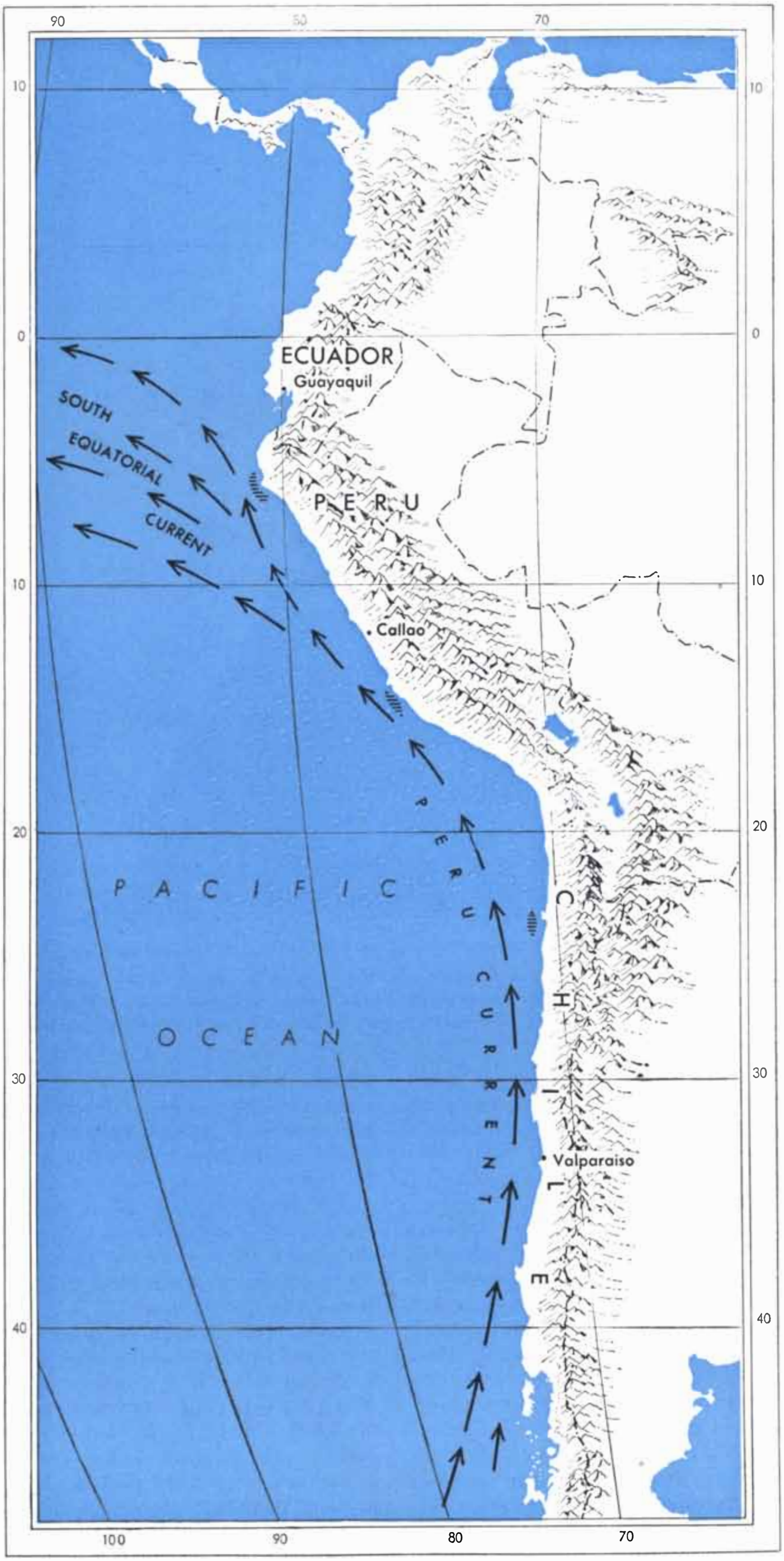
El Niño the surface water is much warmer and less salty than usual.

The Peru Current presents intriguing problems to an oceanographer. Generally speaking, tropical waters do not support large fish populations. Consequently no citizen of a "plundered planet" can fail to be interested in the reasons for the unusual productivity of the Peru Current. Of almost equally great interest is *El Niño*. Its causes are open to controversy, as indeed is every aspect of the Peru Current. Even the name of the current has been disputed. Some prefer to call it the Humboldt Current, after the renowned German naturalist [*see page* 78]. In his classic work on the phenomenon E. R. Gunther, the English oceanographer, argued that the name Peru Current rated preference on the ground of priority. It is hard to dispute this, and besides, it is sometimes confusing to associate phenomena or structures with the names of people. A good case in point is the Islands of Langerhans, which are found not in the Malay Archipelago but in your pancreas.

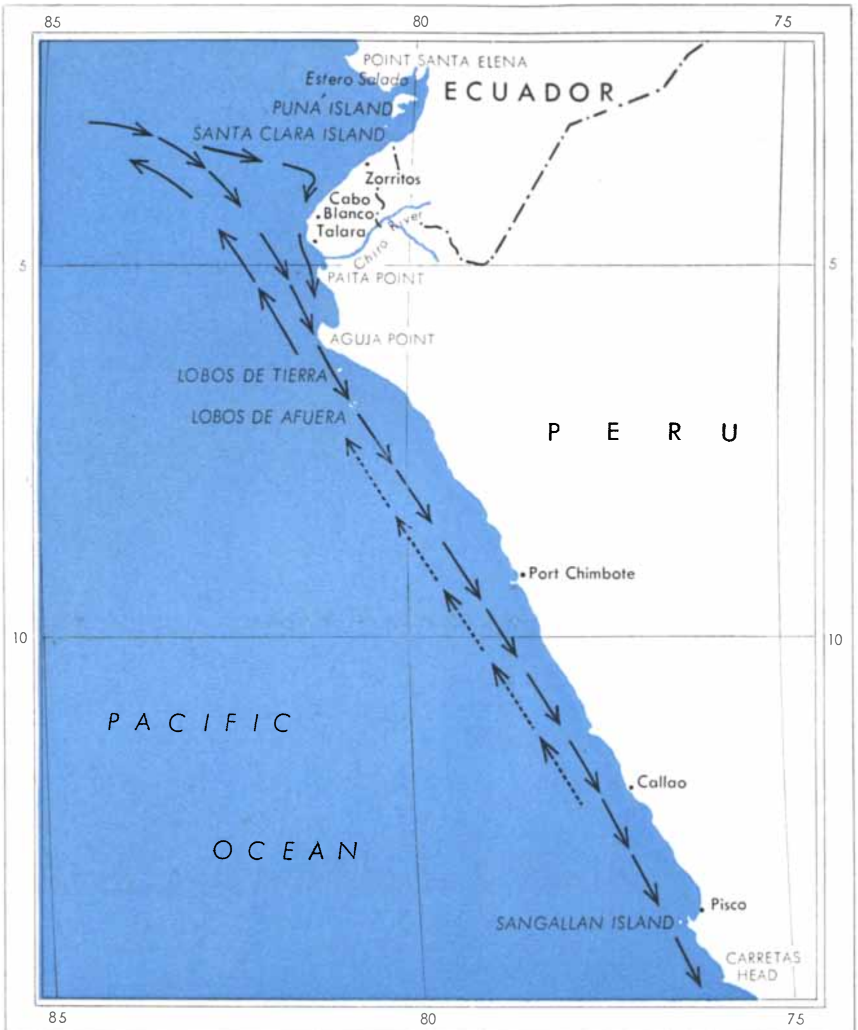
Increasing interest in the Peru Current has brought two oceanographic expeditions to Peruvian waters in recent years. In 1952 the Scripps Institution of Oceanography sent the Shellback Expedition south as far as Lima. In 1953 the Bingham Oceanographic Laboratory staffed the Yale South American Expedition, which made a study of the inshore waters of the Peru Current. The latter expedition was fortunate in having an opportunity to examine *El Niño* for the first time by standard oceanographic methods.

In normal years the surface temperatures in the Peru Current are always far lower than those of the open ocean at the same latitude. For example, at 3 degrees South latitude the water out at sea often has a surface temperature above 77 degrees Fahrenheit, while the Peru Current surface temperature at the same latitude does not exceed 71 degrees, even during the southern summer.

What makes the water so cold? It has been suggested that the cold water may come from the Antarctic or from the snows melting in the Andes, but these ideas have been disproved. The generally accepted explanation is that the prevailing winds blowing along the coast literally turn the water over: they drive surface water away from the coast, and cold bottom water rises (from a depth of 600 to 1,000 feet) to take its place. This phenomenon, termed upwelling, brings to the surface water low in dissolved oxygen but high in nutrients. It accounts



NORMAL COURSE of the Peru Current is up the coast of South America. It then flows into the South Equatorial Current. Three zones of upwelling are shown by cross hatching.



ABNORMAL CURRENT was charted by the Yale expedition. Dotted arrows indicate the probable displacement of the Peru Current by the Equatorial Countercurrent. Some think the source of the southward flow is the Estero Salado (*top*) in the Gulf of Guayaquil.

for all the properties of the Peru Current. Upwelling occurs in relatively few places in the seas of the world—off the coasts of lower California, Somaliland, West Africa and western South America.

The rise of nutrients from the bottom is primarily responsible for the high productivity of the Peru Current. To understand this it is necessary to look into the concept of the food cycle. In the sea, as on land, plants containing chlorophyll—the floating phytoplankton—convert carbon dioxide and water into organic matter in the presence of light and nutrient salts. The plants, chiefly algae, are then eaten by the zooplankton (small floating animals) and some fishes. The zooplankton fall prey to carnivorous animals which in turn are eaten by other carnivores, including birds. Any organisms that die before being eaten sink to the bottom, and are there consumed by bottom animals such as worms and crabs. This "natural death," involving all organisms from phytoplankton to fishes, is itself an integral part of the food chain. By bacterial action the phosphate, nitrate and other nutrient salts are returned to the water in a soluble inorganic form. If and when these nutrients reach the upper zones, phytoplankton can use them for further growth.

A marine biologist of today is far more concerned with the rate of production of living matter than he is with the number of organisms present at any given time. Obviously productivity is closely related to the food cycle. Since the food cycle is so dependent upon the phytoplankton, anything that affects phytoplankton production (or photosynthesis) will affect productivity. The quantitative effects of temperature and light in the Peru Current still await analysis. But one thing is clear: the bringing of nutrients to the surface by upwelling must increase photosynthesis. The abundance of sunlight in this region also must play a part in its high productivity.

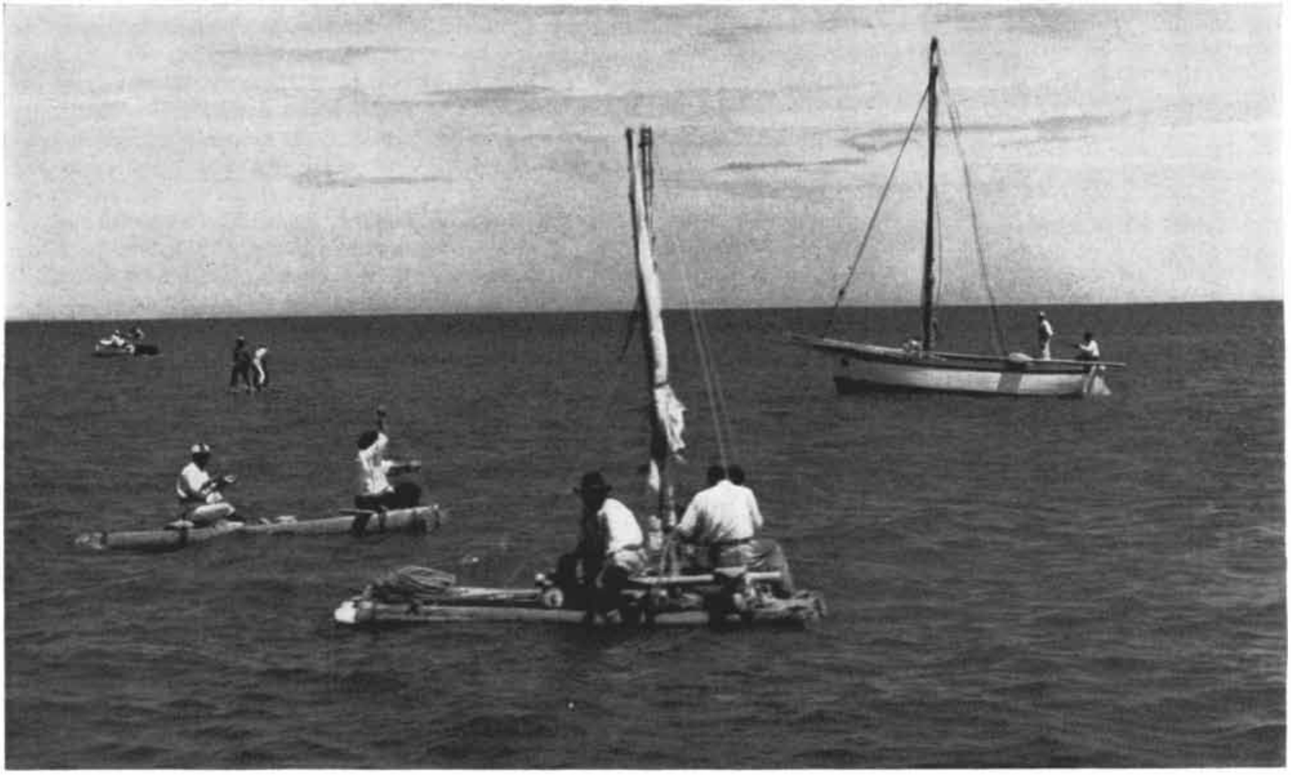
Every seven years, as we have noted, an *El Niño* covers the Peru Current. It is a layer of much warmer water about 75 feet deep. Just how it comes into being is a matter of debate; some hold that the warm water flows down from the equatorial Pacific, others that it comes from the Gulf of Guayaquil. In any event, no problem has been of greater importance to the shore-dwellers of Peru than that of predicting the occurrence of *El Niño*.

During the 20th century *El Niño* has held very well to the seven-year cycle; it has been traced back at seven-year intervals to 1911, skipping only the year 1946, when it may have occurred in unusually mild form. The question is: Will this regularity persist? The only way to find out is to determine the cause of *El Niño* and see if it has an inherent periodicity. Scientists have known for a long time that *El Niño* is associated with unusual rainfall. Most experts believe that it occurs in years when northeast winds of the North Pacific swing across the Equator and, because of the earth's rotation, become northwest in the Southern Hemisphere. These winds sweep equatorial countercurrent of high temperature and low salinity over the Peru Current. This theory of the winds has not yet been tested. Should the hypothesis be verified, it would be interesting to see if the atmospheric forces involved show a seven-year cycle.

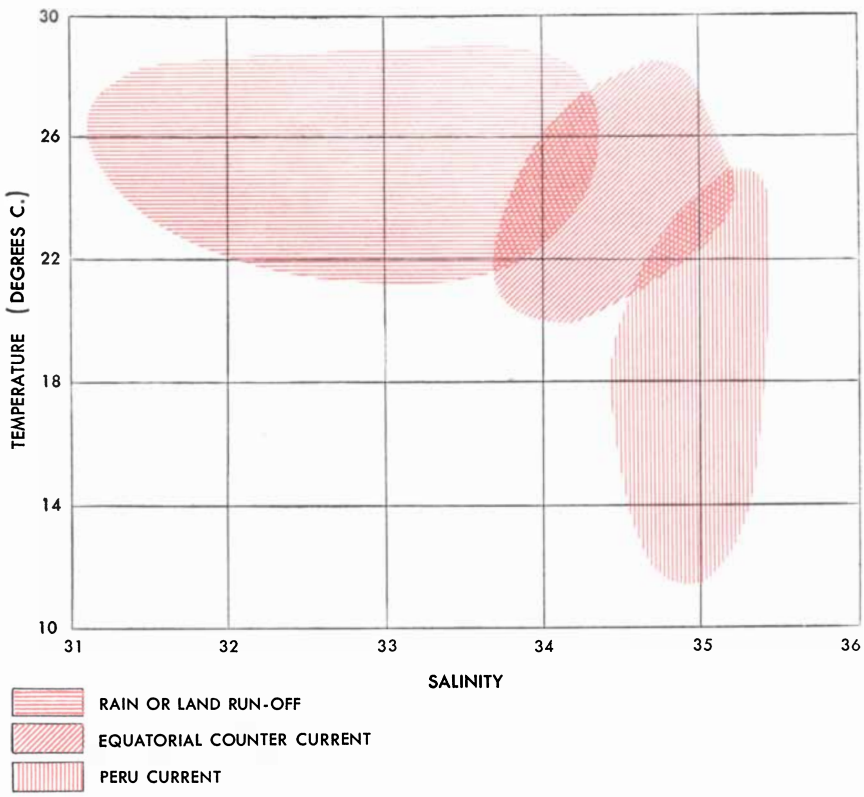
The Yale Expedition of 1953 came in a year when the Peru coast was experiencing an *El Niño*. Observations of the offshore water were made between March 10 and May 25. They showed that the Peru Current water had a salinity of 34.8 parts per thousand. Equatorial countercurrent water has less salt. The surface water in the upper 75 feet during *El Niño* was clearly of the equatorial countercurrent type, modified near the coast by water run-off from the land. Its temperature ran as high as 83 degrees F., and its salinity was often as low as 32 parts per thousand.

The surface temperatures rose and fell in cycles. For 10 days after March 10 the temperature was high; then for 12 days it was low, and this was followed by a high-temperature period which lasted 13 days. Assuming that the low temperature was normal, the conclusion is inescapable that water of high temperature and low salinity invaded the area at least

EXPEDITION BOAT was the 60-foot *Marise.* This former fishing craft was refitted for oceanographic purposes and sailed by the members of the expedition from Mystic, Conn., to Peru. Usually it stayed close to the shore, but once it ventured out 100 miles.



PRIMITIVE RAFTS are used by some of the men who fish in the waters of the Peru Current. They are made of balsa logs in the manner of the famous *Kon-Tiki.* When the Peru Current is abnormal, its content of plankton diminishes and fishing is poor.



WATER MASSES are distinguishable by their temperature and salinity characteristics. The data plotted from several expeditions, taken between Cabo Blanco and Aguja Point, show the overlapping of equatorial and land run-off waters over that of the Peru Current.

twice, probably from the north. The high-temperature invasions coincided with northerly winds from the Equator. Moreover the air temperatures were also noticeably higher (average: 79.9 degrees F.) during these periods.

Instead of the normal northward flowing current near the shore, during March and part of April there was a southward current roughly 20 miles wide. This reversal of current flow was noted as far south as Aguja Point.

The occurrence of *El Niño* has a number of interesting biological and chemical results. For example, at a station in Pisco Bay we found that although the surface water had plenty of phosphate and nitrate for phytoplankton growth, the populations were small. It is possible that another nutrient, such as iron or manganese, was deficient. However, the explanation could be that the surface water had been very recently enriched with nutrients by upwelling and that the phytoplankton had not yet had sufficient time to respond to the enrichment. In short, this situation might simply mean incomplete recovery from the *El Niño* condition. At another station close to an island heavily populated with birds, phosphate was more abundant at the surface of the water than 15 or 30 feet down. This may have been because the birds were replenishing the surface with their droppings.

In general both the phytoplankton and zooplankton populations during the period of our observations were smaller than one would expect in a highly productive area. As no information on plankton fluctuations within the year is available, it is impossible to say whether this was due to *El Niño* or simply a seasonal drop.

El Niño is not the only marine catastrophe that occurs on the west coast of South America. The most obvious fact about any body of water, aside from its wetness and temperature, is its color. The Peru Current displays many colors—all the way from blue through green to red and orange. The color blue is a tattletale of a deficiency of life. In the sea the desert color is blue, as on land it is yellow. The color of a fertile sea, as of fertile land, is green. The color red may mean death. Everyone remembers the "red tide" that darkened the waters off Florida in 1947 and the vast numbers of dead fish that washed ashore. The color was due to the sudden bloom of large numbers of tiny organisms called dinoflagellates, which produced a substance toxic to the fishes. Such blooms are now thought to be attributable to unusual physical or chemical properties of the water. Regions of red tide have been reported for many years in the Peru Current. During April and May of 1953 several patches of red tide were sighted, and there proved to be a great abundance of dinoflagellates in the water.

The color scheme of bright salmon pinks, oranges and browns that sometimes is seen in the sea is believed to be the result of the meeting of cool coastal water and shoreward-moving warm oceanic water. It may produce a mass slaughter of marine organisms and great putrefaction. The large amounts of hydrogen sulfide produced by the decaying organisms react with the lead of ships' paints to form a black coating. This is called "Callao painter," after the harbor of Callao, where it often occurs. The suggestion has been made that "souring" of the water by red tide, Callao painter or some other agency is responsible for the catastrophes that sometimes accompany *El Niño*. This theory does not seem likely, because it would require a souring of the water over a distance of 600 miles or more to explain the catastrophic deaths of 1891.

Whether the animals are killed by the warm water or by the reduced food supply accompanying an *El Niño* can only be answered by close observation of a catastrophic year. The *El Niño* of 1953 came slowly and hesitantly. There was no catastrophe. Perhaps it takes a rapid, sudden invasion of the warm water to raise havoc with the sea life.

As for the cause of *El Niño*, it seems that we shall have to look to the atmosphere rather than the sea itself for the answer. Very possibly the causes will be found to be exclusively meteorological. The southward movement of the equatorial countercurrent that produces *El Niño* apparently is associated with meteorological conditions whose basic nature is only now beginning to be explored. We do know that it is accompanied by unusual rainfall: the seven-year cycle in rainfall records has been traced back to 1864. Before that the rainfall shows no regularity, which may indicate that the cycle was established fairly recently.

Obviously much work remains to be done to clarify the normal and abnormal aspects of the Peru Current. This much is clear: one could scarcely imagine any marine area in the world that holds more interest, from the standpoint both of pure science and of finding ways to increase man's food resources.

Muscle as a Machine

The contractile tissue converts chemical into mechanical energy with remarkable efficiency. The authors study this significant process by making gels with similar properties

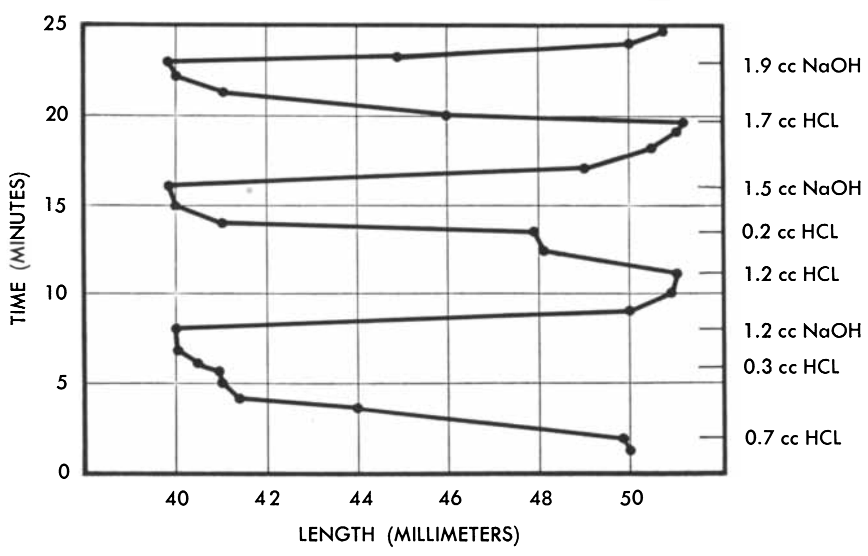
by A. Katchalsky and S. Lifson

Two years ago some excitement was aroused by a newspaper report that synthetic muscles were being made in Israel at our Weizmann Institute of Science laboratory. Amputees and cripples wrote letters asking us to replace their missing limbs and paralyzed muscles; a gentleman wondered whether we could make a quiet and efficient muscle engine to take the place of the noisy gasoline job in his motorcycle; another offered to fit synthetic muscles to the wings of Leonardo da Vinci's flying machine. Regretfully we had to inform our correspondents that their requests were premature. It would be many years before anything like true muscle could be developed from the simple mechanochemical systems under investigation.

There is a strong imaginative appeal in the possibility of imitating the movement of living beings with synthetic models. It is clear even to a layman that natural motility, such as is shown in the whiplike lash of protozoan flagella or in the contraction of muscle, uses mechanisms and energy transformations radically different from those found in a Diesel engine or an electric motor. To be sure, living and nonliving motor systems have one thing in common: both use energy stored in chemical substances and liberated by chemical reactions. But a living muscle transforms this chemical energy directly into mechanical power, whereas a nonliving device first converts it into heat or electricity.

The study of the direct mechanochemical process is tempting even from a practical point of view, for the efficiency of living "engines" compares favorably with the best heat engines. The muscles of an athlete, for example, convert almost 45 per cent of the energy stored in foodstuff into useful work, while a modern steam turbine has no better than 40 per cent efficiency.

More than half a century ago the great Dutch physical chemist J. H. van't Hoff analyzed the conversion problem. He showed that in any chemical reaction a certain amount of energy, called "free energy," is available for conversion into mechanical work. He also suggested a system of osmotic cells with pistons which might apply this energy directly to work. But van't Hoff's theoretical osmotic engine did not simulate what actually takes place in living tissue. In muscle the motive power is supplied not by the fluids that cross the membranes of the osmotic cells but by the solid matter of the muscle itself, which contracts and expands as the consequence of a chemical reaction. We shall confine our discussion to this elastic type of system.



CONTRACTION AND EXPANSION of a synthetic gel immersed in an alternately acidic and basic solution is illustrated by this chart. When hydrochloric acid (HCl) was added to the solution, the gel contracted. When sodium hydroxide (NaOH) was added, gel relaxed.

Many natural and synthetic gels have the property of contractibility. The word "gel" may suggest to a layman only soft jelly, but to a biologist and colloid chemist it also denotes some of the strongest living structures, including muscles, tendons, hair and skin. The fundamental structure of any gel is a submicroscopic network of large molecules or very small crystals, joined together at numerous cross-linking points. Within this mesh is entrapped a liquid that permeates the material. The network endows a gel with elasticity and tensile strength. In certain gels, which are of particular interest for mechanochemistry, the network is made up of threadlike molecules, sometimes consisting of thousands of atoms, linked together in a long chain. Such molecules are very flexible and tend to coil up under the impact of the thermal movement of neighboring molecules in the gel. When held in a gel network they are as elastic as rubber, which has, in fact, a similar structure.

Now let us imagine that the molecular chains of the network carry chemical groups able to combine with a substance dissolved in the liquid that permeates its meshes. If the reaction causes the chains to uncoil, the network will expand and the gel as a whole will swell. On the other hand, if the molecules are already extended by some internal force, certain chemical reactions may cause the chains to coil up and the gel to contract. When a weight is attached to the gel, this contraction will lift the weight, thus performing work.

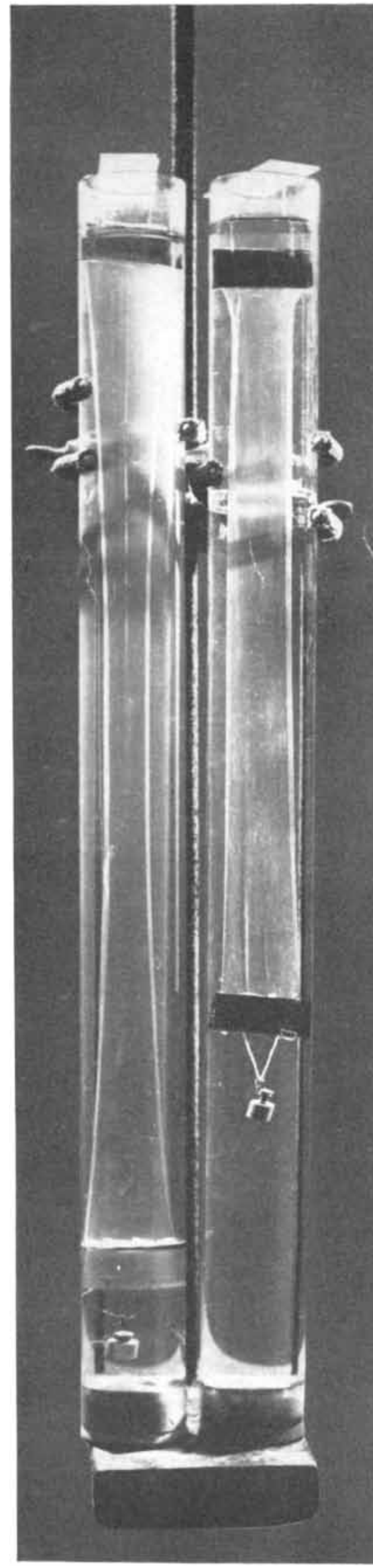
It is possible to reverse the chemical reaction so that the gel undergoes a cycle of alternate contractions and expansions. In such a cycle the chemical compound that reacts with the gel must enter it in the first half-cycle and leave it during the second half. Evidently it must be a compound initially rich in chemical energy; *i.e.*, it must have a higher chemical "potential" when it enters the gel engine than when it leaves. Thus the mechanochemical engine works on a chemical potential difference in the same way that a turbine operates on pressure differences or a heat engine on temperature differences. Its efficiency depends on its ability to work on high chemical potential differences, converting the chemical forces between the reacting groups into contractile forces in the gel network.

Consider a well-investigated example of a chemical reaction which may cause a gel to perform work. When immersed in certain solutions (*e.g.*, thioglycollic acid or mercury potassium iodide), hair, wool and animal tendons will contract like muscle. The details of the contraction process can be observed by X-ray analysis of the changes in the structure of a tendon thus treated. Before immersion the long threadlike molecules of the tendon are straight and parallel to one another. The threads are kept stretched straight by the mutual attraction between them, which in turn is due to the interaction of their reactive groups. Upon immersion, the reactive groups in the threads combine with the solution, thus breaking the crystalline structure and liberating the long-chain molecules. The molecules now coil up, in response to the thermal impact of the surrounding molecules, and cause the tendon to contract.

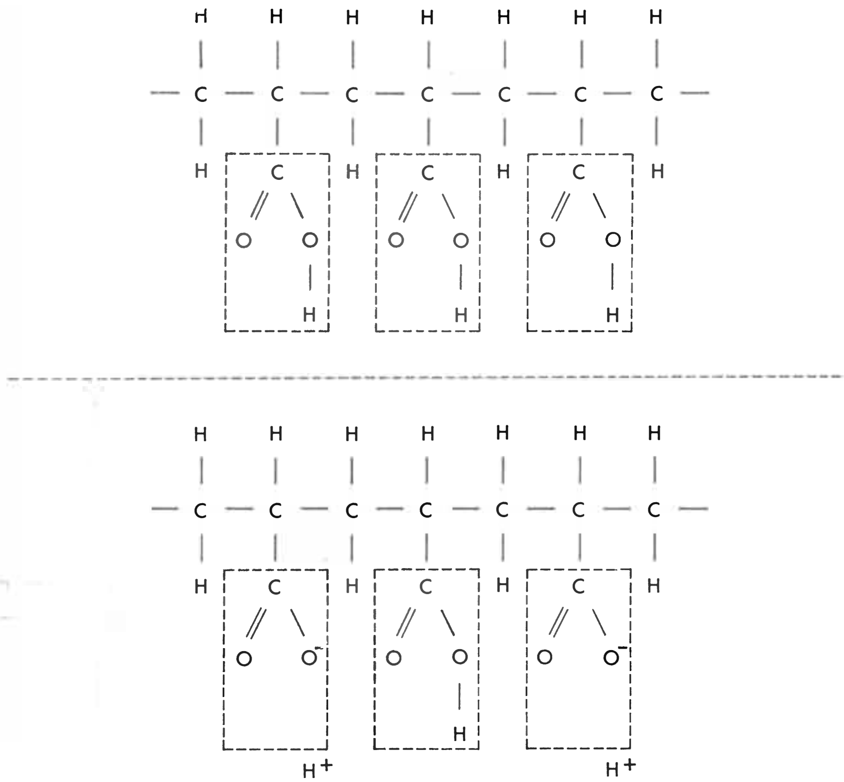
Such a reaction is not sufficient, however, to drive a mechanochemical engine. It gives us only half of the cycle: namely, a chemical reaction that makes a fiber contract (as in this case) or expand. To complete the cycle we need to reverse the process: that is, find a reaction in which contraction or expansion brings about a change in the chemical reactivity of the material. A good example of this kind of reaction is the behavior of a certain synthetic plastic in water. The substance is polyvinyl alcohol—a long molecule consisting of a carbon chain with an alcohol group (OH) attached to every other carbon atom. Since alcohol groups are strongly attracted to water, polyvinyl alcohol is highly soluble. But a fiber made of this plastic will not dissolve in water if it is stretched. X-ray analysis shows that stretching orients and crystallizes the long fiber molecules in a structure like that of the parallel fibers in a tendon. In this arrangement the alcohol groups are so strongly bound by their mutual attraction that they are not free to react with the water molecules, *i.e.*, to dissolve. But as soon as the stretching force is released and the alcohol groups are freed, the fiber dissolves instantly.

It was the study of certain water-soluble plastics that led to the synthesis of the first mechanochemical system. These plastics are known today as "polyelectrolytes," and we must consider the properties of polyelectrolytes to understand how a mechanochemical engine can work. The essential property of any electrolyte (a general term for acids, bases and salts) is that, when dissolved in water, its molecules split into ions—electrically charged particles. A polyelectrolyte is a chain of electrolyte molecules hooked together. It may contain many thousands of acidic or basic groups, and may therefore carry a high concentration of electric charges. The degree of ionization of a polyelectrolyte is variable; for example, the ionization of a weak polyacid may be increased by adding a strong base or decreased by adding a strong acid.

The electrostatic charges on polyelectrolytes produce a force which may be used in a mechanochemical process. To see how this force operates, let us start with an uncharged polyelectrolyte molecule. Like any other threadlike molecule, it coils up freely under the thermal impacts of the molecules around it. But as soon as the molecule is ionized, the groups of atoms that compose the chain strongly repel one another. The force of



WEIGHT IS LIFTED by a synthetic gel. The vessel at the left contains a basic solution; the vessel at the right, an acidic one.



MOLECULAR STRUCTURE of the polyelectrolyte polyacrylic acid is a coiled hydrocarbon chain with carboxyl side groups (*dotted rectangles at top*). When the molecule is in solution, hydrogen atoms are removed from it, leaving charged carboxyl groups (*left and right rectangles at bottom*). Because charged groups repel one another, the molecule uncoils.

repulsion tends to stretch and straighten the molecule. Two opposing forces are at work: the contractile force of thermal impacts and the stretching force of electrostatic repulsion. We can strengthen the stretching force by chemically increasing the degree of ionization, or strengthen the coiling force by reducing the ionization. Thus in the ionization of polyelectrolytes we have a reversible reaction which can be employed as a true mechanochemical process. Amplified in a gel network, the coiling and stretching of the molecules can perform work. The gel will contract when loaded with a weight and expand when unloaded. The driving force for the alternate contraction and expansion is supplied by the addition of acids or bases, which changes the system's acid-alkaline balance in one direction or the other.

Working systems of this kind were developed independently and simultaneously five years ago in three laboratories: in Vienna, in Basel and at the Weizmann Institute. Each used a fiber or film made of a polyelectrolyte gel network which expanded on the addition of an alkali and contracted on immersion in a mineral acid. In our laboratory we were especially delighted with the performance of polyphosphate gels: they contracted to about a third of their length and in a manner strikingly like that of muscle.

A thin strip of suitable material can lift a fairly heavy weight and operate reversibly for many cycles. Such a system is illustrated on the preceding page; it is made of polyacrylic acid and polyvinyl alcohol cross-linked together, and the strip is dipped alternately into mineral acid and a strong base. The principle makes possible the construction of a continuously working mechanochemical engine, and Moshe M. Zwick and Saul Gassner of our laboratory have built such a machine [*see photograph on page 76*]. Its operation is rather sluggish and its efficiency low, but it proves the feasibility of the idea and suggests that when technical difficulties are overcome, better devices may be developed.

The most beautiful and efficient mechanochemical system known is, after all, a living muscle. Recent investigations have shed much light on how a muscle contracts. Thanks to the brilliant researches of Albert Szent-Györgyi and others, we know that the contracting substance in muscle fiber is the slightly soluble protein actomyosin and that the energy of contraction is supplied by the

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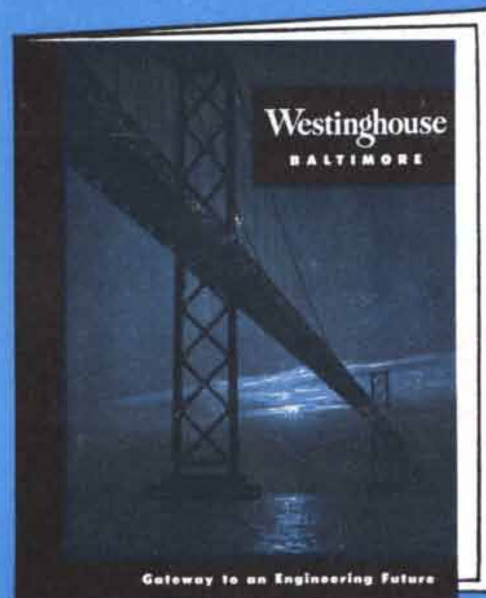

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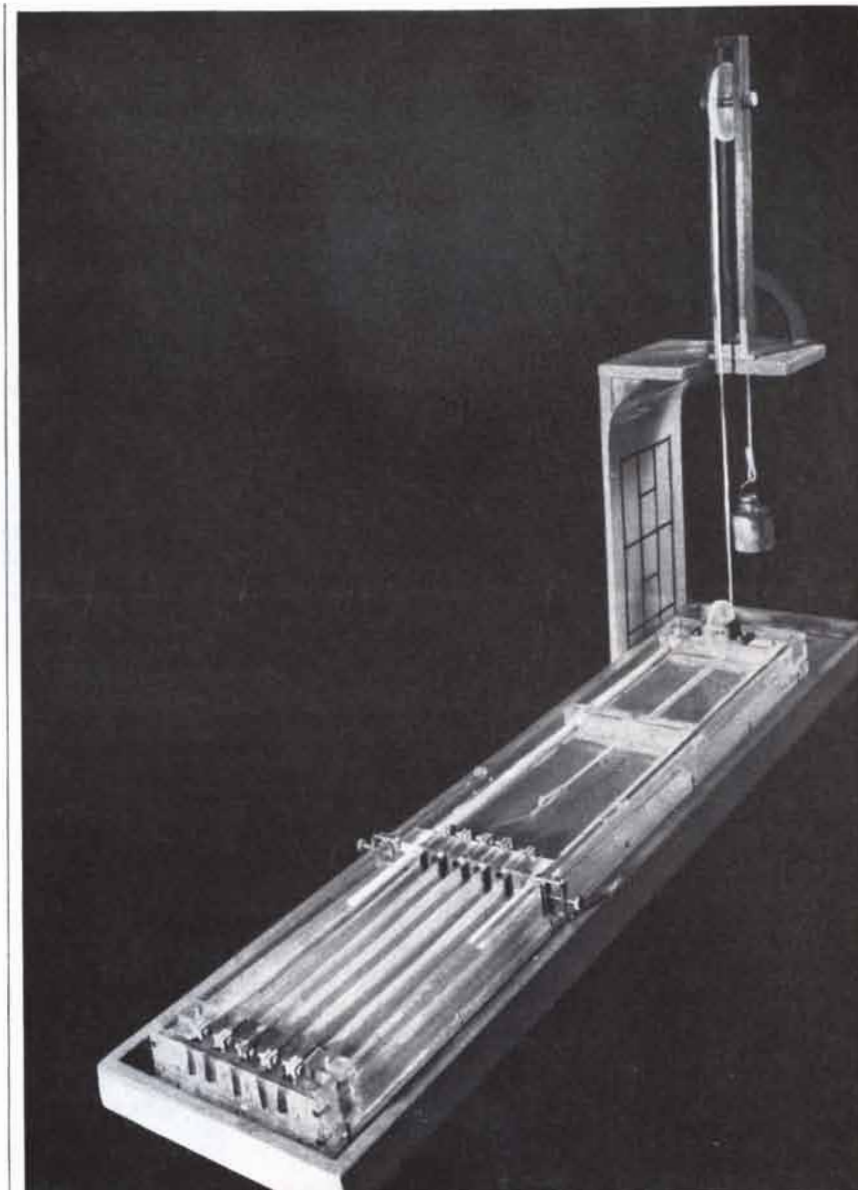
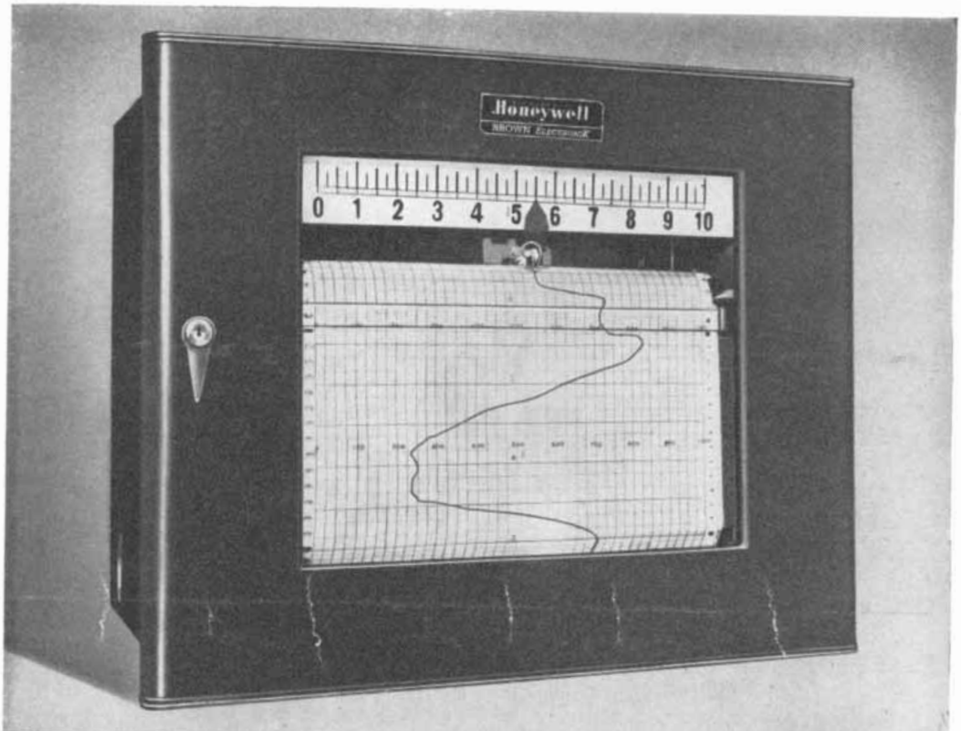


MECHANOCHEMICAL ENGINE made in the laboratory of the authors consists of five polyelectrolyte strips connected to a heavy weight by means of two pulleys. When the solution in the shallow pan around the strips is acid, the strips contract and lift the weight.

energy-rich substance adenosine triphosphate (ATP). Fibers made from actomyosin solutions shrink and contract violently on contact with ATP.

The detailed chemical process by which the metabolic energy of ATP is transformed into work, and the mechanism of the mechanochemical coupling, are still not clear. M. G. M. Pryor of Cambridge University has suggested that the basis of muscular contraction is similar to the situation observed in tendons: that is, in the expanded state muscle fibers are straight and parallel in a crystalline structure; the addition of ATP breaks the crystallization points and causes contraction by liberating the actomyosin chains. Other workers prefer a polyelectrolyte model: they believe that ATP may change the electrostatic charge density of the protein molecules. Indeed, ATP is itself a highly charged molecule, and its absorption by actomyosin may initiate an electrostatic contractile cycle.

The decisive experiments for arriving at the correct explanation of muscle contraction have still to be made. When the explanation is worked out, man may not be able to outfit himself with synthetic wings, but he will have the greater satisfaction of approaching an understanding of the marvelous process that gives living things the power to move.



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CAVERN OF THE GUACHAROS near Caripe in Venezuela is totally dark 2,000 feet from the entrance, yet the guácharos are able to fly from perch to perch without difficulty. These birds were photographed with high-speed flash by Guillermo Zuloaga.

Bird Sonar

How the great Humboldt, by describing the melancholy shriek of strange nocturnal birds called guácharos, brought a modern naturalist to a cavern in Venezuela to study their navigation

by Donald R. Griffin

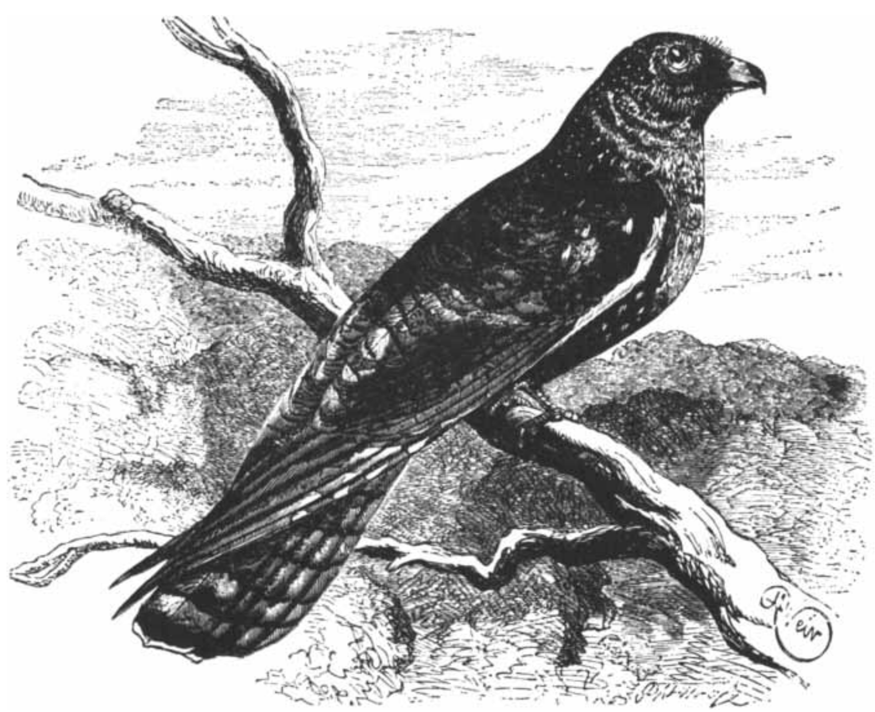
In his account of his explorations in South America 155 years ago, the German scientist Alexander von Humboldt described a remarkable cave-dwelling bird he found there. The bird is called the guácharo (Spanish for "one who cries and laments"). Humboldt visited the great Cavern of the Guácharos near the town of Caripe in the highlands of Venezuela.

The guácharo, he reported, was "the size of our chickens," with a wingspread of three and a half feet, and had "the mouth of a goatsucker, the bearing of a vulture . . . an extremely strong beak furnished with a double tooth" and blue eyes which were "dazzled by the daylight." A nocturnal bird, it quit the cave at nightfall to feed on fruit. The bird is covered with extensive deposits of fat, and it was and still is prized for its oil—a transparent, odorless, butter-like food that was said to keep for a year without becoming rancid. (Humboldt named the bird *Steatornis caripensis*—the oil bird of Caripe.) Once a year the Indians went into the cave with long poles, knocked down the guácharo nests from the high roof of the cave and killed several thousand of the nestlings. Then they extracted the oil by melting down the squabs in clay pots over brushwood fires outside the cave.

One of the most remarkable attributes of the guácharo, as Humboldt observed, was the great "volume of its voice." He wrote: "It is difficult to convey any idea of the frightful noise which thousands of these birds produce in the dark portions of the cavern. . . . The sharp and piercing sounds of the guácharos are reflected from the rocky vault, and the echoes reverberate from the depths of the cavern."

This part of Humboldt's account has intrigued me for some time. Here is a bird that flies about in dark caves uttering sharp cries. Bats, which also live in caves, have an echo system of navigation based on high-pitched cries inaudible to human ears [see "The Navigation of Bats," by Donald R. Griffin; SCIENTIFIC AMERICAN, August, 1950]. Does the guácharo guide its flight in the darkness by means of a similar sonar-like system in the audible range? I resolved to find out, and so a year ago I retraced Humboldt's footsteps to the Cavern of the Guácharos in Venezuela.

The trip was made possible by the generosity of William H. Phelps, Jr., the well-known ornithologist of Caracas. We took along a portable tape recorder and the same apparatus that we use to detect and analyze the high-frequency sound of bats. In 1953 we had a much more gentlemanly trip to the cave than that described by Humboldt in 1799. Humboldt and his botanist companion Aimé Bonpland had been obliged to climb through a heavy tropical forest, criss-crossing a raging torrent on the way up. We debarked from an airliner at an airport 50 miles from Caripe. Near Caripe was a pastel-tinted "Hotel El Guácharo." We were driven in an automobile up a gravel road to the very mouth of the cave. There we were greeted by a custodian and a crew of

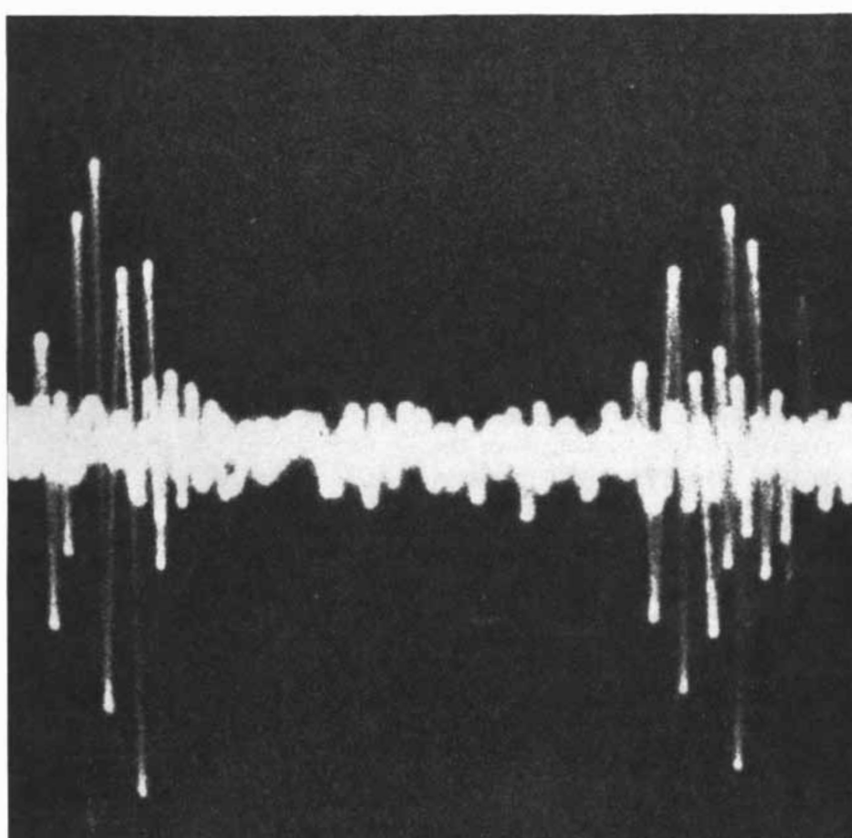


GUACHARO was depicted in A. Brehm's *Illustrirtes Thierleben*, published not long after Humboldt's 19th-century description. The bird has a wingspread of three and a half feet.

guides eager to lead us through the cavern. Indeed, we were told that electric lights were soon to be installed in the cave to save tourists the inconvenience of carrying flashlights.

The oil birds were still there in considerable numbers, now protected by the government. Our first concern was to determine the degree of darkness in which the birds could fly. We therefore walked deep into the cave, past a twilight zone full of nesting birds to a place where turnings in the passage shut out the daylight. Humboldt had described his penetration into the cave in the following words: "We had had great difficulty in persuading the Indians to pass beyond the anterior part of the cavern, the only part which they visit annually to gather fat. . . . The natives attached mystical ideas to this cave inhabited by nocturnal birds. They believe that the souls of their ancestors reside at the bottom of the cavern. . . . To go to join the guácharos is to rejoin one's fathers, is to die. . . . We walked in a thick mud to a point where we saw with astonishment the development of a subterranean vegetation. The fruits which the birds carry into the cave to feed their young germinate wherever they fall into the mould which covers the calcareous incrustations. Blanched stalks provided with some rudiments of leaves grew to a height of as much as two feet. . . . These traces of organization in the midst of darkness aroused a lively curiosity in the natives, otherwise so stupid and so difficult to excite. They examined [the blanched shoots] in silent contemplation inspired by a place which they seemed to dread. . . . The missionaries, despite their authority, could not persuade the Indians to penetrate farther into the cavern. As the roof of the cavern became lower, the cries of the guácharos became more piercing. It was necessary to give in to the pusillanimity of our guides and retrace our steps."

We also found ourselves walking through a meadow of white shoots, just as Humboldt had described. About 2,000 feet from the entrance we arrived at a large chamber called *El Barrial*, which Humboldt apparently did not reach. Picking reasonably dry and comfortable rocks to sit down upon, we turned off all our lights and waited for our eyes to adapt to the darkness so that we could tell whether there was any natural light here. I also set up a camera facing the direction of the entrance, with its en-



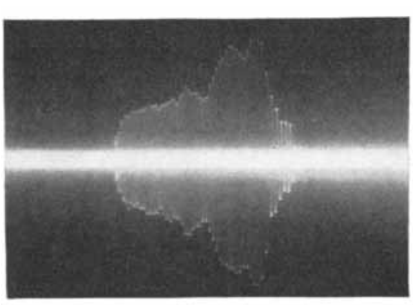
CRIES OF GUACHARO AND BAT are compared by oscilloscope. At the left is the trace of the guácharo's cry. Its pitch is about 7,000 cycles per second, well within the range of human tire lens mount removed and its Super XX film directly exposed to whatever daylight might possibly penetrate to *El Barrial.*

Over our heads guácharos circled noisily and called back and forth to one another from ledges 75 to 100 feet high. We waited 25 minutes to assure complete dark adaptation of our eyes. I must admit that this wait in the clamorous darkness was an uneasy one, and I am sure more than one finger wandered wishfully toward a flashlight switch. I could only feel the deepest sympathy for the Indians of Humboldt's party and wonder what their reactions would have been if he had ordered them to extinguish their torches and listen to the guácharos in total darkness.

At the end of 25 minutes we were all agreed that no light was to be seen in any direction. Furthermore, the film, which had been exposed for nine minutes, later confirmed this by showing no evidence of light upon development. Our first question was thus conclusively answered: the guácharos did fly in total darkness.

Now we had to determine whether the squawks and shrieks the birds gave forth almost constantly were used for orientation. Bats employ very brief bursts of ultrasonic sound for their echolocating system. Some of the sounds uttered by the guácharos were rather sharp, short clicks, but these clicks formed only a small part of the sounds we heard during our stay in the cave.

Phelps had noted on a previous visit that the birds made particularly striking noises as they flew out of the cave for their night's hunting. We therefore set up a microphone at the cave entrance. We had to place it on the pinnacle of a rock 15 or 20 feet high, because the birds generally flew near the ceiling some 75 to 100 feet above our heads. Lower down on this rock were arranged amplifiers, a variable electronic filter, a cathode-ray oscillograph, a tape re-



hearing. At the right, on the same time scale, is the trace of a brown bat's ultrasonic cry.

BLANCHED PLANTS sprout in the dark Cave of the Guácharos. They grow from seeds in the droppings of the birds. These plants would grow to a height of 50 feet in the light.

corder, a 16-millimeter camera to photograph the cathode-ray traces and a storage battery plus vibrator to provide 60-cycle power.

At twilight the guácharos began to fly out. I could scarcely believe these were the same birds we had heard inside the cave that afternoon. For now there were no squawks, clucks or screeches. Instead there came out of the gathering darkness a steady stream of the sharpest imaginable clicks. Each click had a duration of only one to two thousandths of a second—about the same length as the ultrasonic signals of bats. Well into the night the stream of birds and the barrage of clicks continued undiminished. During the whole evening we heard no more than half a dozen of the longer calls and screeches that had predominated inside the cave during the day.

We still lacked any direct evidence that these clicks were actually emitted to locate objects in the birds' path by the echo. Perhaps the clicks were only call notes or symptoms of some other avian emotion the nature of which we could not guess. Accordingly we trapped three birds in a net and took them to an improvised darkroom to make further tests.

The first test was to plug their ears. When both ear canals were tightly stopped with absorbent cotton and cellulose acetate cement, the birds were completely disoriented. In the dark they banged into the walls whenever they took wing. But when the plugs were removed, they were again able to fly about in the dark room without colliding with anything. They also flew without difficulty when the light was turned on even if their ears were plugged.

Even these limited tests were sufficient to show that these birds, like bats, use clicks to avoid obstacles in the dark by echo-location. Unfortunately we were not able to carry the tests much further, and many interesting questions are still unanswered. For example, we do not know how small an object the oil bird can detect. Since the wavelength of its clicks (about five centimeters) is much longer than that of a bat's ultrasonic sounds (less than one centimeter), the guácharo must fail to detect obstacles which a bat could easily locate.

The oil bird's sounds have a frequency of about 7,000 cycles per second—well within the range of human hearing. The question arises: If the oil bird can use such sounds to guide it in the dark, could not a man develop the same skill? The highly perfected human hearing apparatus would appear quite capable of achieving the type of sound analysis necessary for echo-location.

Blind men do indeed achieve a considerable skill in finding their way about, and this ability is often called "facial vision." But the skill is largely lost if the blind man's ears are tightly stopped or if loud noises interfere with the hearing of faint echoes. Very possibly man could develop the echo-locating ability by using short pulses of sound. Since sound travels roughly one foot per millisecond, the pulse should be no longer than one or a few milliseconds to return a distinguishable echo at a distance of a few feet. Perhaps properly designed click generators or similar sources of pulsed sound could enhance the ability of blind people to find their way about.

The pragmatic experience of blind men, unconsciously using the taps of a cane, footsteps or other sounds to guide them, may already have produced as much skill in echo-location as the human auditory mechanism allows. But it might not be amiss to see what we can learn from the guácharo and other flying animals which have developed more precise systems of echo-location.

THE KLYSTRON

Long overshadowed by the famous magnetron, this ingenious radio tube has now come into its own as a broadly useful means of generating, receiving and amplifying microwaves

by Edward L. Ginzton

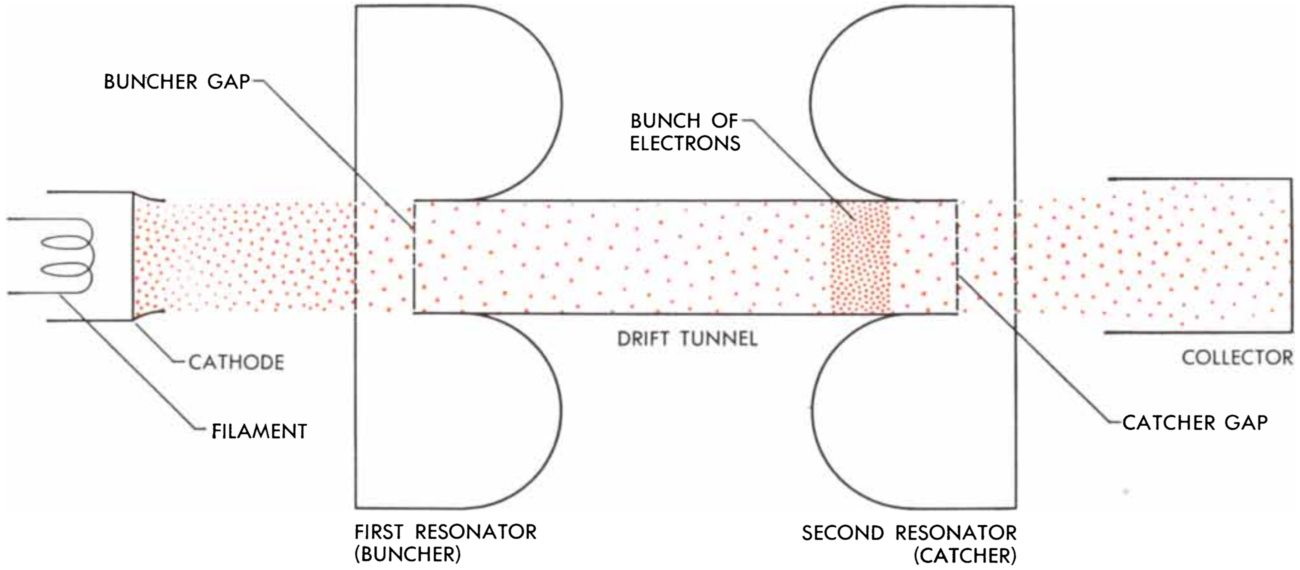
Just before World War II there was a brief blaze of publicity about a new vacuum tube called the klystron. The klystron was celebrated as an invention that would open up a whole new region of radio frequencies and make possible the development of radar. It lived up to its promise, and it played a very important role in the war. But it was overshadowed by another new tube, the magnetron, and the klystron faded from public attention.

It may surprise many people, though it will certainly not surprise radio engineers or physicists, to hear that the klystron not only is still around but is flourishing more brilliantly than ever. From radar, in which it still plays its important role, it has branched out to other uses in the military field, in television, in telephony, in navigation and in physics research—with the promise of more services to come in the future. Since the end of the war the klystron has been developed to powers undreamed of when it was first conceived.

The klystron works in the domain of microwaves [see "Microwaves," by J. R. Pierce; SCIENTIFIC AMERICAN, August, 1952]. In that region it performs the same functions that ordinary electronic vacuum tubes do at conventional radio frequencies; that is, it can generate, receive and amplify radio signals or energy. The klystron was invented because the ordinary triode tube cannot handle microwaves effectively. Let us look at the reasons it cannot—at the problem which the klystron solved so beautifully.

A triode radio tube, as almost everyone knows, consists of three elements: a filament that emits a stream of electrons, a grid that stands in the path of the stream, and a plate that attracts the electrons and catches them after they pass through the grid. The grid acts like a valve, opening or closing to the passage of electrons according to the voltage on it. Radio waves intercepted by an antenna come to the grid as a weak alternating current oscillating with the radio waves' frequency. The oscillating voltage thus applied to the grid modulates the flow of the electrons crossing the tube to the same frequency. The electron stream then delivers at the catching plate an alternating current which reproduces with great amplification the weak signal on the grid.

Now the time it takes an electron to



PRINCIPLE OF THE KLYSTRON is outlined in this diagram of a tube with two resonators. Electrons are produced by the cathode at the left and accelerated toward the collector at the right. As they pass through the oscillating electric field of the first resonator, some of the electrons are speeded up and others slowed down. Then, as the electrons proceed down the drift tube, the faster ones catch up with the slower, forming a bunch. When the bunch passes the second resonator, an oscillation is excited in it.

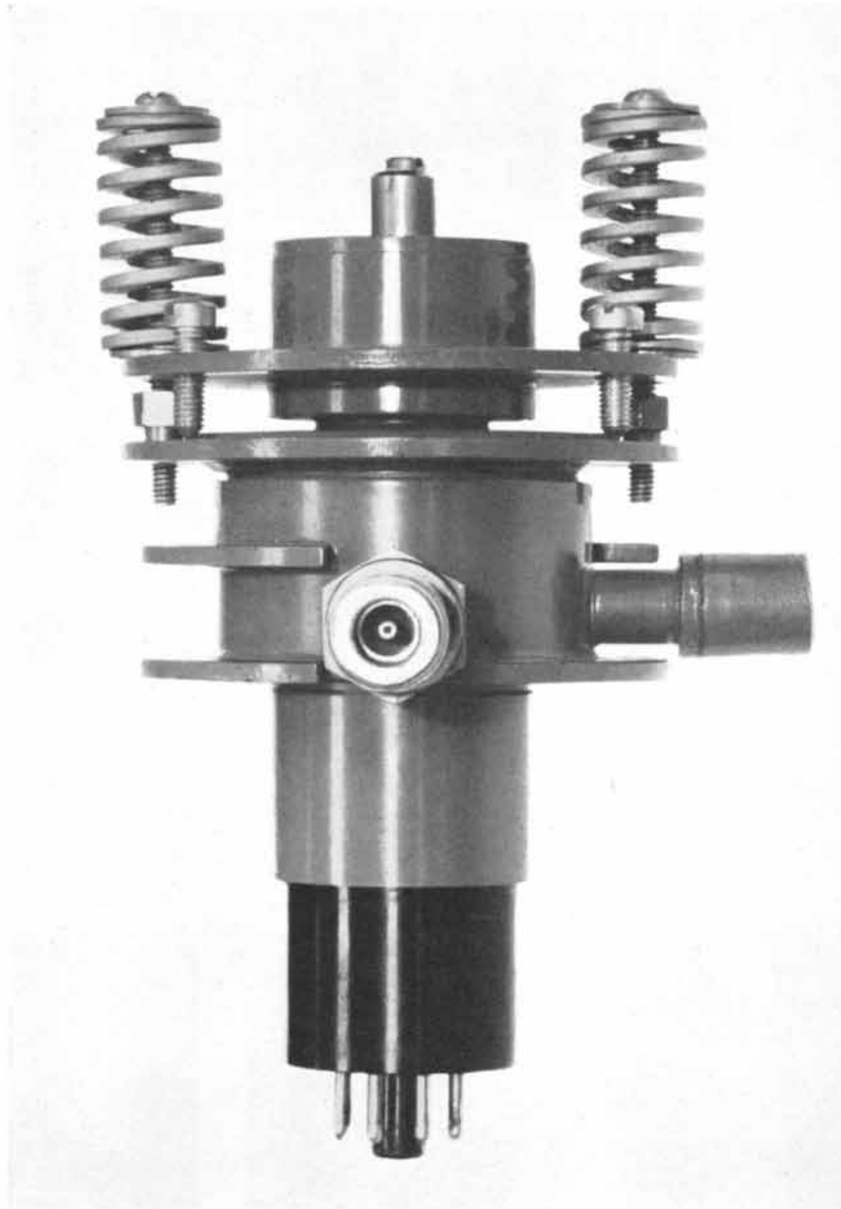
cross the tube is something of the order of a billionth of a second. This transit time is short compared to a cycle of a long radio wave (around a millionth of a second); hence the electron is slowed or speeded by the voltage on the grid at one moment of the cycle. The flow of electrons therefore can follow the voltage fluctuations. In the case of microwaves, however, the oscillations are so rapid (*i.e.*, the cycle is so short) that the voltage on the grid may go through several complete oscillations during an electron's travel across the tube. In other words, the grid voltage changes too fast and produces only chaos among the electrons. It no longer can impose the signal pattern on their flow.

There are other reasons why the conventional triode tube fails in the microwave range, but this is the most fundamental one. Several new types of tube have been invented to overcome the difficulty—the magnetron, the "close-spaced" triode, the traveling-wave tube. With the possible exception of the traveling-wave tube, none of these is quite as simple or versatile as the klystron.

The klystron tube makes a virtue of the very thing that defeats the triode—the transit time of the electrons. What it does is to "modulate" the velocity of electrons so that as they travel through the tube they sort themselves into groups and arrive at their destination in bunches, thus delivering an oscillating current of controlled frequency.

To take the klystron in its simplest form, picture a long vacuum tube consisting of several sections, of which the most important are two chambers enclosed in metallic shells [*see illustration on opposite page*]. At one end a cathode, as in any electronic tube, feeds a stream of electrons into the tube. The electrons are pulled toward the opposite end by a positively charged plate and are focused into a beam by a magnetic field applied from outside.

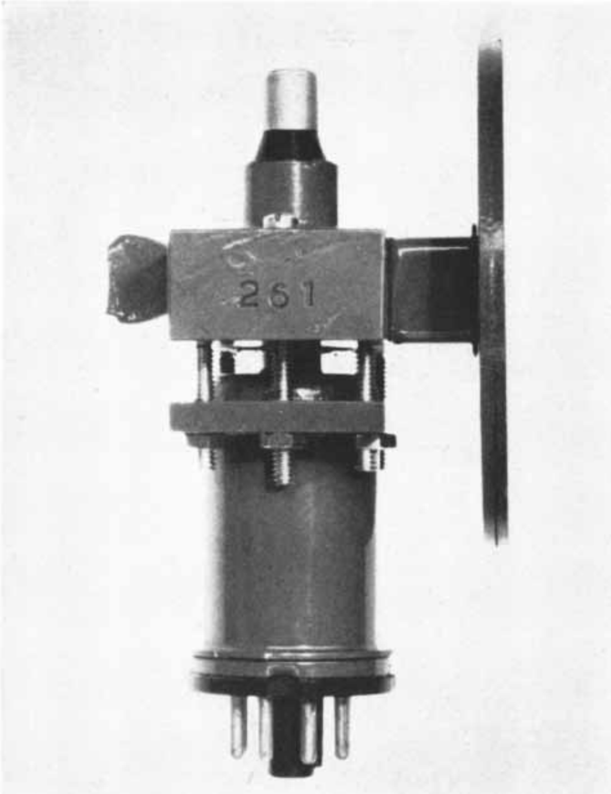
When the electrons pass through the first chamber, crossing what is called the "buncher gap," they encounter an oscillating electric field analogous to the oscillating voltage on the grid in a triode tube. This metal-enclosed chamber, known as a cavity resonator, is the crux of the device. The electric field within the cavity is produced by the microwave signal to be amplified. When the cavity is a certain size, it will resonate to microwaves of a certain frequency, which thereby set up an oscillating electric field within the enclosure. The cavity can be tuned to various microwave frequencies simply by adjusting its size by some mechanical means. A crude analogy to the cavity resonator would be a glass goblet which resonates at a certain pitch depending on the level of the water in it—that is, the size of the air cavity.



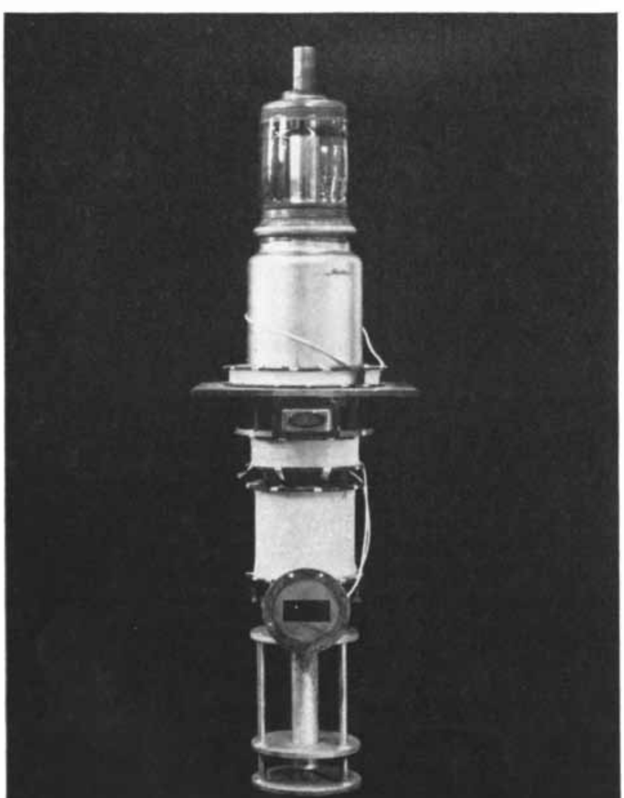
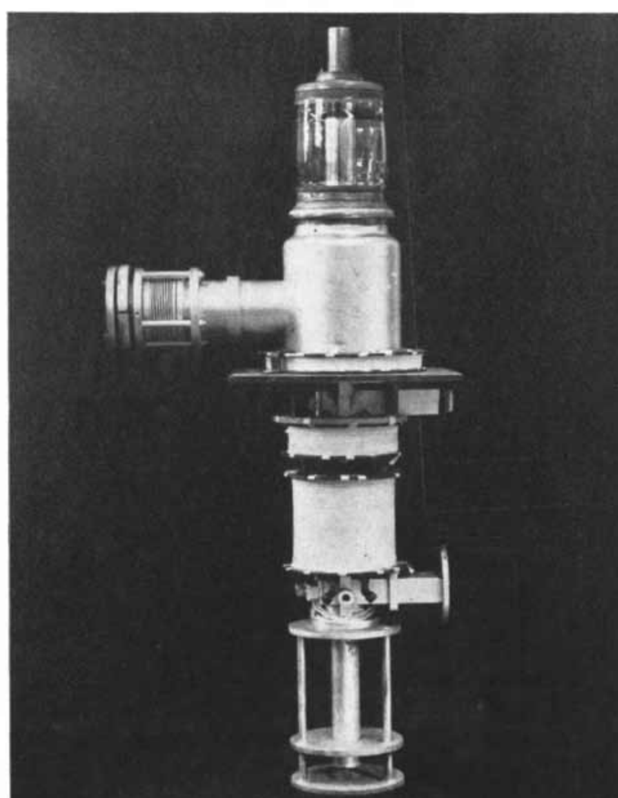
REFLEX KLYSTRON has only one cavity (*see diagram at the top of page 88*). This tube, made by Varian Associates of Palo Alto, Calif., generates microwaves 15 centimeters long. Its output of 10 watts is conducted along a coaxial cable, a cross section of which is in the center.

The oscillating field alternately gives the ends of the gap a negative and positive charge. As a result some of the electrons are slowed down as they pass across the gap and others are speeded up. In the next stage of their journey, through a so-called "drift tunnel," the faster electrons catch up with the slower ones and bunches are formed. Just when the bunching has become sharpest, the electron groups reach the second gap, also a cavity resonator. If this cavity is tuned to the frequency of their arrival, the electron bunches will excite electrical oscillations in it, just as hitting a pendulum with periodic strokes timed to its natural frequency will keep it swinging. The electrical energy delivered at this "catcher gap" is taken off by some suitable transmission line. After the electrons have passed beyond the gap, they are caught in a collector bucket and their remaining kinetic energy is spent in the form of heat.

This simple klystron tube, like a conventional triode tube, acts as an ampli-



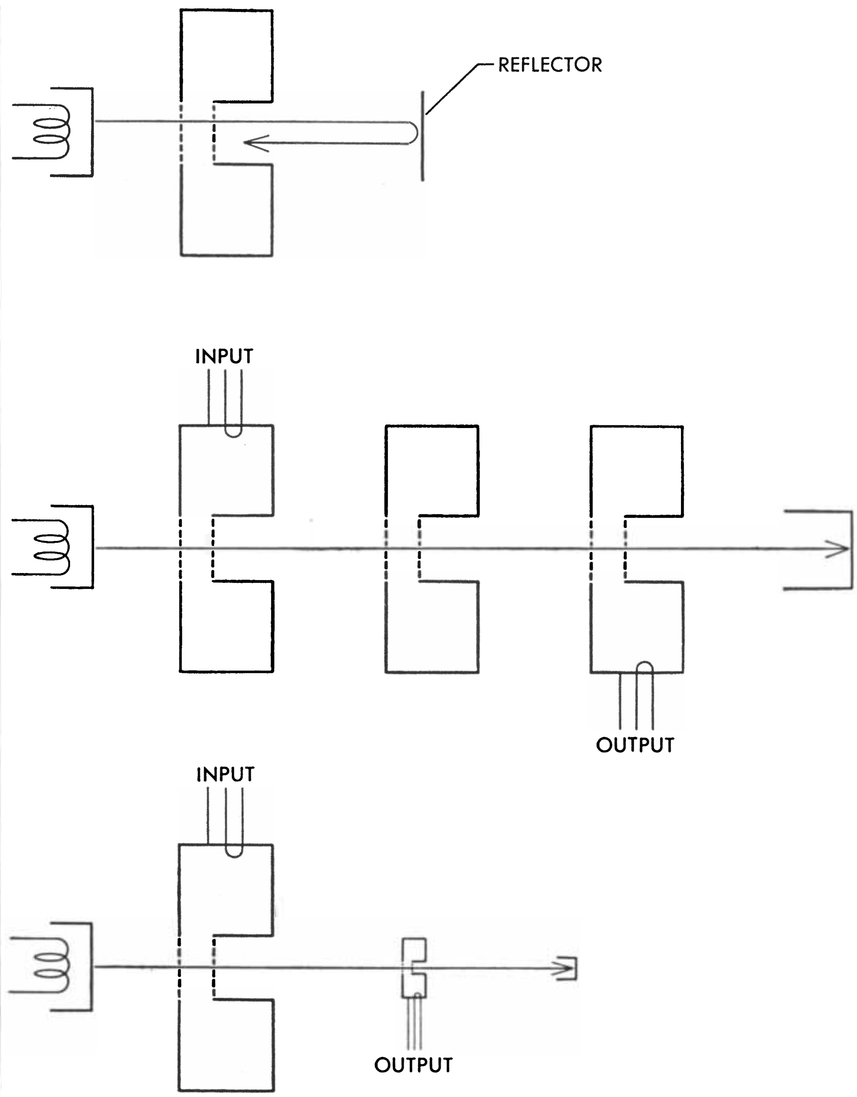
ONE-WATT KLYSTRON made by Varian Associates is shown from two sides. It is a reflex tube which generates microwaves five centimeters long. The oblong opening in photograph at right is coupled to a wave guide, the pipe used to conduct microwaves.

THIRTY-MILLION-WATT KLYSTRON made at Stanford University is similarly shown from two sides. Its output is used to propel electrons in the new Stanford linear accelerator. Standing about three feet high, it is the most powerful radio tube ever made.

fier: it uses a weak microwave signal to convert the power of the electron beam into microwave power. The same tube can be employed to generate microwaves, feeding part of the power from the second cavity back to the first. Many other variations of the klystron are possible. For instance, it can be made with only one cavity resonator, which serves both as the buncher and the catcher [*see diagram at top of next page*]. After the electrons have crossed the cavity, they are reflected back into it by a negatively charged plate; on their return they arrive in bunches and boost the power of the electrical oscillations in the resonant circuit. This reflex klystron, as it is called, is very handy because there is only one cavity to tune, and it was used by the millions in radar sets during the war. Another version of the klystron has three or more cavities in series; this improves the bunching of the electrons and enhances the efficiency of the tube. Still another variation is the so-called "frequency-multiplier" klystron. The catcher gap is made resonant not to the frequency of the arrival of bunches but to some whole multiple of that frequency—as if a pendulum were pushed not at every swing but at every second, third, fourth or even 20th swing. The tube then puts out a higher frequency than is fed into it. This klystron is especially valuable in applications where it is important to hold a transmitter to a given frequency with great precision.

The simplicity of the klystron, both in principle and in practice, is its most attractive feature. It contains no wires to dissipate and lose electrical energy. Its three basic functions—formation of an electron beam, generation of microwave power and disposal of the heat of the spent electrons—are physically separated and nearly independent of one another. This makes it easy to design new variations of the tube and to understand their operation. And the klystron's efficiency in converting electrical energy into microwave power is comparatively high—usually between 25 and 40 per cent and sometimes as high as 50 per cent. In its early years the klystron was not believed capable of putting out much power, and it was used mainly as a receiver tube, with the magnetron taking over transmitting jobs. But its development since the war has dispelled that idea; today there are klystrons which generate much more power than has ever been achieved with a magnetron or any other radio tube. A klystron developed at Stanford University for use in linear accelerators can put out, in short pulses, a peak



VARIATIONS use resonators in different ways. In the reflex klystron (*top*) the electrons pass through a single resonator twice. In the cascade amplifier (*middle*) the electrons pass through three or more resonators. In the frequency multiplier (*bottom*) the second resonator is tuned not to the frequency of arriving bunches but to a multiple of it.

power of 30 million watts—a level that approaches the power consumption of a small city.

The klystron is now 15 years old. The principle of the velocity modulation and bunching of electrons was conceived independently by A. Heil and O. Heil in Germany in 1935 and by W. C. Hahn and G. F. Metcalf and the Varian brothers, Russell and Sigurd, in the U. S. in 1939. Meanwhile W. W. Hansen of Stanford University, who was seeking ways to accelerate electrons to higher energies, discovered the principle of the cavity resonator. The first klystron was built in 1938 by the Varian brothers, Hansen and other collaborators at Stanford. During the war the U. S., England and France independently produced klystrons which were nearly identical in appearance and performance. This is not surprising, for the fundamental principles are simple and the original papers on them were sufficiently clear to point the way to development of various klystron devices.

After the war many of the laboratories that had been working in the klystron field dropped this effort; only two or three in the U. S. and a similar number in England and France continued research. At Stanford the Hansen-Varian group reassembled to develop the klystron further, and one of their interests was to use it to generate unprecedented amounts of microwave power for accelerators in nuclear physics. The tube they devised for the Stanford linear electron accelerator is the most powerful vacuum tube ever made. It operates at a wavelength of 10 centimeters. The

klystron can put out its great power of 30 million watts only in pulses, for the equipment would quickly overheat if the output were continuous. Altogether the klystrons in Stanford's billion-volt accelerator will provide about 400 million watts of power.

The high-power klystron has been turned to many other uses, and several manufacturers now produce it commercially. It is believed to have promising possibilities in moderate-sized electron accelerators for treating cancer, sterilizing food and drugs, deinfesting grain and fruit and so on.

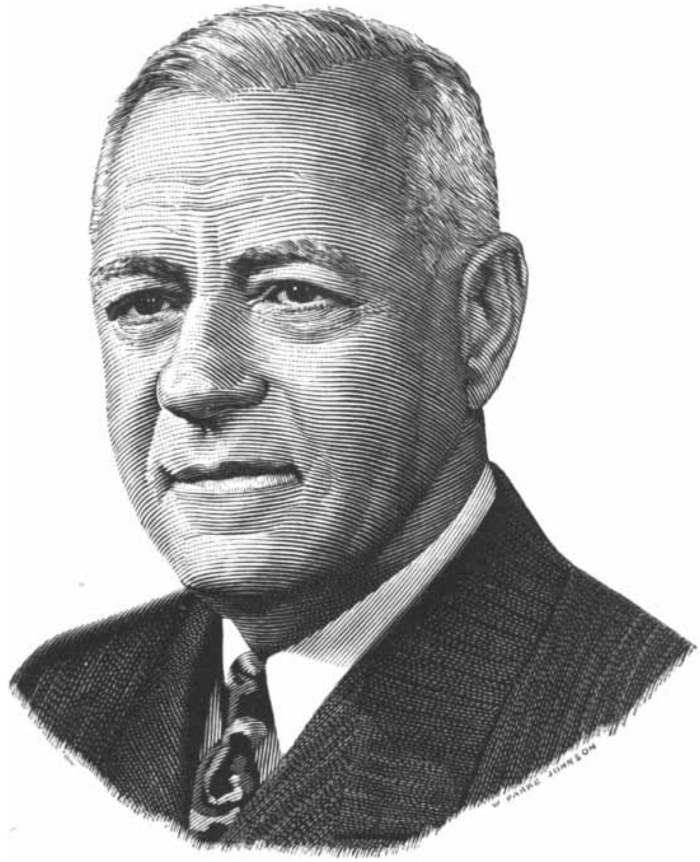
In radar sets the klystron is still giving wide and rugged service. Reflex klystrons as small as one or two inches in length have been made for aircraft sets. Larger ones are serving as transmitters in microwave relay systems, not only for television but also for other communications. One tube of this kind can generate as much as 10 watts of power. In the new ultrahigh-frequency television broadcasting region klystrons will be invaluable. One large klystron especially designed for transmitting service in that band is nearly as tall as a man. It is a three-cavity amplifier, capable of delivering more than 15 kilowatts of power continuously. A high-power klystron must be large so that it can dissipate the heat produced by electrons straying from the stream in the tube.

The magnetron, the close-spaced triode and the newly developed traveling-wave tube will be competitors of the klystron in certain fields, but the klystron will certainly more than hold its own in its large sphere of usefulness—as a transmitter where large amounts of power are required, as a source of local oscillator power in nearly all microwave receivers, as a laboratory tool for studying microwaves and matter.

Recently there have been suggestions that the transistor, the new solid-state device for controlling the flow of electrons, may do away with vacuum tubes altogether. The fact is that neither the klystron nor the other microwave devices is likely to be supplanted by the transistor. For theoretical and practical reasons it seems improbable that the transistor can be made to operate at microwave frequencies.

The klystron has come into its own because it is a relatively simple device which can perform at high frequencies nearly every function required of a radio tube: it can amplify signals, multiply frequencies and generate small or large amounts of power.

"... More than 6,000 of our employees are now participating ..."



MELVIN H. BAKER
Chairman of the Board, National Gypsum Company

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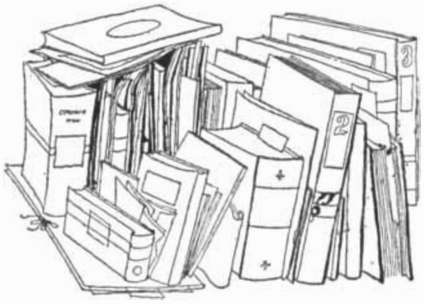

BOOKS

Physics 1900-1926: a review reflecting upon how past theories shape those of the future

by Freeman J. Dyson

A History of the Theories of Aether and Electricity, Vol. II, by Sir Edmund Whittaker. Philosophical Library ($8.75).

Englishmen still speak of January and February of 1947 as "the bad winter." It began with a blizzard which disrupted communications, and it continued with five weeks of unceasing frost and biting east winds. Industry was at a standstill, and animals died of cold in the zoology laboratories at Cambridge University. Twice a week all through this time, Sir Edmund Whittaker delivered a series of public lectures. For each lecture he traveled from Edinburgh to Cambridge (eight hours by train in good weather) and back again. He was then 73 years old. The inhabitants of Cambridge, of whom I was one, crawled out of their unheated rooms and groped along dark and icy streets to the big lecture hall to listen to him. There we were warmed, not only by the physical presence of a big crowd packed together, but by the mental vigor and enthusiasm of the old man on the rostrum.

With such memories of Whittaker, I was not surprised to find him at the age of 80 publishing this ambitious work, which is a rather complete and copiously documented history of the whole of theoretical physics during the period 1900 to 1926. The first volume of his history, dealing with the classical theories up to 1900, was originally published in 1910, and was reissued in a revised and up-to-date version in 1951. He said in the new preface to Volume I that he had long intended to write a second volume, but had had no time for it while he was a professor at Edinburgh, a position which he held from 1912 to 1946. When, after this interlude of 34 years, he took up the task again, he found that so much had happened in the meantime that three volumes rather than two would be required. So Volume II goes only up to 1926, and Volume III will take the story up to 1950. Knowing Whittaker's pertinacity and indestructibility, I feel confident that Volume III will appear in due course and will be as thorough and informative as its predecessors.

The second volume is necessarily very different in style from the first, because the history it records is of a different character. Up to 1900 the rate of progress in physics was determined mainly by the rate of discovery of new experimental facts. A theory, or an argument between two conflicting theories, could hold the field for a hundred years, as new discoveries came slowly. For example, for a hundred years after Newton no essentially new optical experiments were done, and so Newton's corpuscular optics could neither be proved nor disproved. In the meantime the physicists, who in those days correctly called themselves "natural philosophers," could discuss the nature of light only in general philosophical terms. Thus the history of this period is the story of the exceptional geniuses who discovered, often accidentally, new facts, and the story of the gradual assimilation of the new facts into the leisurely scientific speculations of the time.

But toward the end of the 19th century the pace quickened, and after 1900 new experimental knowledge concerning light and electricity accumulated rapidly. Now the rate of progress in physics was set by the speed with which observations could be understood and expressed in exact mathematical terms. The leaders of physics were a group of mathematically trained minds, working consciously toward the creation of a theory which should explain the wide totality of known facts. The history of the period 1900-1926 is therefore the story of a concerted and sustained intellectual effort, giving birth to ideas of a highly technical and mathematical nature. There is probably no other period of history in which so much prolonged hard thinking was done. At the end of it the two great new ideas of modern physics had been born—the Einstein theory of gravitation and quantum mechanics.

Whittaker's two volumes reflect faithfully the different climates of science in the two periods they cover. The first volume is dominated by personalities, the second by logic. The first volume describes historical accidents by which individuals were able to change the way of thinking of their times; there is also much discussion of the connections between the physics and the general philosophical ideas of each century. The second volume, like the physicists of today, is more limited and professional in its scope. It gives a clear, logical account of the sequence of events in the intellectual struggles which led up to relativity and quantum mechanics. Whittaker not only describes each stage of the struggle but explains the necessary mathematics and writes down the equations. The volume thus in a sense is a mathematical textbook in which the theories of relativity and quantum mechanics are outlined with emphasis on their historical development. If the author had not changed his style in this way for the second volume, he could not have written so useful a book.

For us who have grown up after 1940 and have accepted quantum mechanics as a *fait accompli*, it is extremely difficult to imagine the state of mind of the men who were creating the theory before 1926. It is especially difficult for me, for I had my first introduction to the subject by way of the highly polished and completely unhistorical lectures of P.A.M. Dirac.

It is much easier to understand the finished product than to examine critically the steps by which it came into being. Still it is important that we do make the effort of imagination to put ourselves in the position of the men of the 1920s. We must do this because we must expect changes in the theory in the future. If a theory is taught and learned dogmatically as it stands, without regard to its origins, then it is in danger of becoming fossilized and of being finally an obstacle to further progress. Science, and even quantum mechanics, is not a body of revealed truth to be piously preserved. We must understand what is essential in the theory and what is not, and the best way to reach such understanding is by studying its history.

The most striking fact that Whittaker's book brings out is the steady and continuous nature of the development that led up to the big jumps. The actual discoveries of relativity and quantum mechanics were indeed big jumps, but not so big or so miraculous as they seemed to us of the younger generation. For example, Whittaker quotes passages from papers of Henri Poincaré written in 1904. If I had been asked to identify these passages without knowing their author, I would unhesitatingly have placed them in Einstein's historic paper of 1905, in which he announced the discovery of special relativity. To say this does not detract from the achievement of Einstein. It only means that the story of Einstein's discoveries as it has taken shape in the public mind is oversimplified. Just because Whittaker emphasizes the continuity of the over-all development, and reduces the size of the big jumps, his book is an enormous help to anyone who wishes genuinely to understand the state of mind of the men who made the jumps.

Whittaker himself lived as a working scientist through the whole of the development he is describing. He made significant, though not leading, contributions both in quantum mechanics and in the field of general relativity. Whittaker has references in this volume to about a thousand original papers, which he presumably studied at the time they were published. These are advantages which hardly anybody now living shares with him. I am not able to pass judgment upon his historical accuracy, but I think it likely that this is the most scholarly and generally authoritative history of its period that we shall ever get.

The book starts with a chapter describing the growth of experimental atomic physics from the discovery of radioactivity by Henri Becquerel to the artificial transmutation of atoms by Lord Rutherford. The facts revealed by these experimenters—that each atom consists of a nucleus with a definite number of electrons attached to it by the electric attraction of unlike charges—were basic for the detailed theories of atomic structure which came later. The rest of the book is concerned mainly with theoretical and mathematical developments. Two chapters are devoted to special and general relativity, three to the "old quantum theory" of Max Planck and Niels Bohr, and two to the "new quantum theory" of Werner Heisenberg and Erwin Schrödinger, which we now call quantum mechanics.

The central paradox in the physics of our time is shown very clearly in this history. Namely, the developments which led to general relativity and to quantum mechanics started out in opposite directions and have never been brought together again. General relativity is a theory of the gravitational effects produced by large masses of matter. Quantum mechanics describes the behavior of individual atoms and electrons. There is no practical overlap of the two theories, because the gravitational effects produced by individual atoms are exceedingly weak—many, many times below the limit of observability. Each theory appears to be correct within the domain to which it applies. And still the two theories are formally incompatible; that is to say, both cannot be exactly true in their present forms.

General relativity is built upon the hypothesis that our space-time does not possess any special coordinate systems put into it *a priori* by the creator. By a coordinate system we mean a system of attaching to each space-time point a set of four numbers which act as a label, so that given the four numbers we know what point we are talking about. For example, the coordinate system that locates points upon the earth consists of these four numbers: latitude, longitude, height above sea level and Greenwich mean time. It is impossible to write down any mathematical laws of physics at all without assuming some kind of coordinate system in terms of which the positions and velocities of material objects may be specified. The principle of general relativity asserts that the laws of physics must be of such a kind that they hold good in *any* coordinate system. Nature shall have no intrinsic preference for one coordinate system over another.

As a consequence of this principle of relativity, geometry becomes a branch of physics. We cannot take a region of empty space with a given geometrical size and shape, and then imagine some piece of matter to be put into it. The matter will change the measurements of distances and angles, and so will change the geometry of the space. If the geometry of space could be defined independently of the matter in it, this would enable us to construct a special, preferred coordinate system. So the Einstein law of gravitation describes the motion of matter through space, and the changing geometry of the space, as two aspects of the same thing.

In contrast to general relativity, quantum mechanics starts from the hypothesis that the position of a material particle is not something that exists in nature independently of our attempts to observe it. The particle has a definite position only at the instant when we bring it into contact with a piece of apparatus designed to measure its position—for example, a photographic plate. A moment after the measurement is made, the position is again uncertain. The result of a later measurement of its position cannot in general be predicted from the result of the first measurement. Therefore in quantum mechanics there is no way to speak about a distribution of matter in space-time as something existing precisely and objectively without our having to observe it.

To write down laws of nature in quantum mechanics we still need coordinate systems. The points of space-time must be labeled in some way, and the labels must be definite numbers independent of our measuring apparatus. The space-time with its coordinate system appears as a fixed framework, not subject to the uncertainties of quantum mechanics. The equations of quantum mechanics describe how particles move over the coordinate framework. But the equations do not fix the movements of a particle precisely; they only determine the probability of seeing the particle at a given position at a given time, if its position has been found by observation at an earlier time. As the coordinate framework is supposed to be fixed, while the particle motions are uncertain, there is no way in which we can allow the particle motions to react back upon the geometric properties of the space-time. The geometry is assumed to be known *a priori*, and the particles travel through space-time in waves of probability without disturbing the geometry in the least.

It is by no means clear that it will always be impossible to find laws of nature which are quantum-mechanical and yet are valid in all coordinate systems. But nobody has produced any promising suggestion of how to do it. All our existing quantum-mechanical equations presuppose a space-time with a definite geometry, and this geometry defines a preferred set of coordinate systems.

There are three possible ways out of this dilemma. First, one may reject the idea that the principle of general relativity is universally valid. Second, one may believe that quantum-mechanical indeterminacy will disappear in the physics of the future. Third, one may believe in both principles and look to the future to reconcile them. Let us briefly examine what is implied by each alternative.

The first alternative is preferred by a substantial number of present-day physicists. As Einstein has always stressed, the observational evidence for general relativity is by no means conclusive. The advance of the planet Mercury's perihelion and the other two effects which to some extent confirm the theory could if necessary be explained otherwise. To most people who believe in the theory strongly, the convincing argument is an esthetic one. The theory explains in such a simple and natural way the basic facts of universal gravitation, especially the equality of gravitational accelerations for all masses at a given point of space, that it seems stupid to look for another explanation. The principle that God created the world without any special built-in coordinate system seems in harmony with the ideal of avoiding unnecessary hypotheses; to deny the principle seems by comparison uneconomical and ugly. Esthetic arguments of this sort may convince you or they may not. The important point is that if you believe in general relativity for such reasons, then you must believe that the principle holds universally, on the atomic as well as on the astronomical scale. If you believe this, as I do, then the first alternative is unacceptable.

The second alternative is the one followed by Einstein himself. He believes that quantum mechanics is correct as far as it goes, but that it gives an incomplete description of nature. He expects the physics of the future to be a deterministic theory, in which motions of particles are exactly predictable. The equations of quantum mechanics will describe then the incomplete knowledge of the future of a particle that would follow from an incomplete knowledge of its past. If such a deterministic theory could be found, the difficulty of harmonizing quantum theory with general relativity would disappear. But few people besides Einstein place solid hopes in this direction. The acceptance of indeterminacy as a basic law of nature is supported by arguments of simplicity and esthetics which most physicists find as compelling as the arguments for general relativity.

There remains the third alternative: that we may be able eventually to construct a quantum mechanics without special coordinate systems. Probably most physicists, if forced to choose, would call this the most promising alternative. But it must be admitted that there has been absolutely no progress in this direction during the past 20 years. The difficulties are clear. We must suppose a space-time to be given *a priori*, completely devoid of geometrical features. The equations of quantum mechanics must somehow be written without the help of previously defined notions of distance and time interval. Then the distances and time intervals between physical events will be defined in terms of the solutions of the quantum-mechanical equations. These distances and time intervals, like other physical quantities, will be subject to quantum-mechanical uncertainties. So the geometry of space-time will finally appear as part of the physics; it will be a quantum-mechanical geometry quite different from anything we have seen up to now. It is not clear whether the notion of a space-time point will any longer have a meaning.

It is perhaps the strongest guarantee we have of future progress in fundamental physics that this big jump of reconciling general relativity with quantum mechanics lies ahead of us. If this big problem is solved, a host of smaller problems will be solved with it. The time may already be ripe for a great theorist to construct by pure thinking and mathematical insight a quantum-mechanical world geometry, and from it to deduce many of the puzzling features of our actual world. More probably the time is not yet ripe, and we face a rather long period of accumulating experimental information and groping for a piecemeal understanding of it. In any case, it is good for us occasionally to look over the past and the future, as Whittaker does, with a longer perspective than the exigencies of day-to-day research allow to us.

Short Reviews

THE COMMON SENSE OF SCIENCE, by J. Bronowski. Harvard University Press ($2.00). This sensitive, searching book is concerned with the nature of science and the relation of its central creative ideas to other human activities. The ideas of order, of causes and of chance have played immensely important parts in the growth of scientific thought. Yet none of these ideas, Dr. Bronowski points out, is peculiar to science; they are common-sense ideas which we all use "to help us run our lives." In the history of science the decisive moments occur when these common-sense ideas are reappraised and reformulated. In the 18th century, science, as well as other branches of thought, was dominated by the idea of order; the 19th century was ruled by Laplace's belief "that everything can be described by its causes"; in our century the concept of chance and the conviction of the underlying uncertainties of all knowledge have made possible the most spectacular advances in knowledge. Bronowski, who is

an able mathematician, an imaginative director of practical research, a gifted man of letters (he has written a first-rate biography of William Blake) and a perceptive and witty commentator on the problems of society, is uncommonly well equipped to treat the broad theme of his essay, to give it unity and clarity. His small book, like a fine glass of brandy, is a rich and satisfying distillment.

Animal Biochromes and Structural Colours, by Denis L. Fox. Cambridge University Press ($11.00). A 14th-century Chinese writer, Li Hai Chi, marveling at the processes of nature, observed: "As for eggs, they have white on the outside and yellow on the inside. But when the development of form is accomplished, the yellow is changed to the outside and the white to the inside. How can this be?" Li Hai Chi ascribed the transformation to the interaction of Yin and Yang, the male and female principle. A more reasoned explanation of the colors and pigments of animals is presented in this fascinating book by Dr. Fox, professor of marine biochemistry at the Scripps Institution of Oceanography. Color may arise from two fundamentally different sources: "chemical or pigmentary compounds on the one hand, and on the other, purely physical structures of such fine dimensions as to interrupt visible light waves and disintegrate the spectrum." Fox discusses specific examples of structural colors, the pigmentary compounds and the chemical, distributional and physiological features of colored bodies throughout the animal world. His survey is remarkable in bringing together the researches and interests of biologists, biochemists, physiologists, anatomists, cytologists, pathologists, geneticists and naturalists. The book is illustrated by numerous text figures and three stunning color plates.

The Papers of Thomas Jefferson, Vol. VII, edited by Julian P. Boyd. Princeton University Press ($10.00). During the 11 months of Jefferson's life spanned by this volume (March, 1784, to February, 1785), he produced some of his greatest papers. The writings include reports on the national debt, surveys of the commerce and agriculture of the several states, recommendations for the establishment of a land office for disposing of lands in the national domain, model drafts of international treaties, and his famous *Notes on Coinage,* which persuaded Congress to adopt the dollar as the U. S. money unit and to apply to coinage the decimal system of reckoning. The correspondence between Jefferson and his many friends is, as always, of the widest interest. He advises George Washington to force the Society of the Cincinnati to abandon the principle of hereditary membership, lest this feature create an élite within the state; he presses inquiries about recently discovered fossils and receives a report from Ezra Stiles, president of Yale, on monsters, four-pound teeth and giants "antediluvian and postdiluvian." From Paris, where he went with Benjamin Franklin and John Adams to negotiate treaties of "amity and commerce," he reports various scientific discoveries, among them the phosphorus match, a new cylindrical lamp and one of the earliest of self-regulating machines—a windmill "which offers itself to the wind in whatever direction that is."

Jane's All the World's Aircraft, 1953-54, compiled and edited by Leonard Bridgman. The McGraw-Hill Book Company, Inc. ($23.00). In 1909, the year *Jane's* first appeared, Louis Blériot made the first flight over the English channel. The annual's 1953-1954 edition, coinciding with the 50th anniversary of the Wright brothers' first flight, reports advances over Blériot's time. In 1952 the world's airlines flew more than a billion scheduled miles, carrying 45 million passengers and 925 million metric tons of cargo. But the dominant theme of this edition is military. Every self-respecting air force now possesses craft that fly faster than sound. The British have Venoms and Javelins and Swifts and Furies and Ghost turbojet engines, also Chipmunks and Doves and Fairey Fireflies and Rotodynes. The pride of the French air force is the Mystère, clocked at supersonic speeds. The fastest U. S. planes include the Bell X-5, Boeing's Stratojet, Convair's XB-58 bomber, Douglas' Skyrocket, North American's F-86. Data about the U.S.S.R. are meager as always, but there is ample evidence that the Mikoyan, the Lavochkin and the Tupolev are keeping up with the latest products of the West.

An Essay on Man, by Ernst Cassirer (75 cents); Modern Science and Modern Man, by James B. Conant (65 cents); Man on His Nature, by Sir Charles Sherrington (85 cents); Socrates, the Man and His Thought, by A. E. Taylor (65 cents); History of England, Vol. II: The Tudors and the Stuart Era, by G. M. Trevelyan (85 cents); The Seventeenth Century Background, by Basil Willey (85 cents). Doubleday and Company, Inc. These volumes appear in an excellent new series of paper backs (Doubleday Anchor Books) designed to make available at moderate price books of merit but not necessarily of mass appeal. Cassirer's study, an introduction to a philosophy of human culture, is a major work completed shortly before his death and first published in 1944. Sherrington's famous essay, originally delivered as the Gifford Lectures at the University of Edinburgh in 1937-1938, is a profound analysis of the physical basis of life, stressing the view "that man is a product, like so much else, of the play of natural forces acting on the material and under the conditions past and present obtaining on the surface of our planet." Taylor's biography affords an attractive and authoritative introduction to Socrates' life and thought. Conant's discussion of the role of modern science has been well received—though it must be admitted that this book scarcely measures up to its companions in the series. Trevelyan's chronicle and Willey's survey of the thought of the 17th century in relation to religion and poetry are recognized as outstanding contributions to historical literature.

World Population and Production, by W. S. Woytinsky and E. S. Woytinsky. The Twentieth Century Fund ($12.00). An invaluable survey of the world's economy and an almost incredible achievement of scholarship. The authors' 1,268-page, closely printed, double-column volume deals with migration, cities, births, deaths, marriages and divorces, health, consumer needs and consumption, human resources, agriculture, livestock and animal products, forests and forest products, fisheries, mining, minerals, coal, petroleum, the economics of energy and power, manufactures in the world economy, the food, drink and tobacco industries, the textile industry, the iron and steel industry, the machinery and transportation equipment industry, the chemical industry and so on. There are several hundred charts, maps, graphs and statistical tables, extensive notes and source references and a meticulous index. The authors say that the book represents five years of "intensive work," but apparently only on a half-time basis, for they are also publishing this year another behemoth on world trade, transportation and government. The Woytinskys, it is clear, have learned to eclipse the bee by improving the nonshining as well as the shining hours.

The Major Features of Evolution, by George Gaylord Simpson. Columbia University Press ($7.50). In a 1944 work, *Tempo and Mode in Evolution,*

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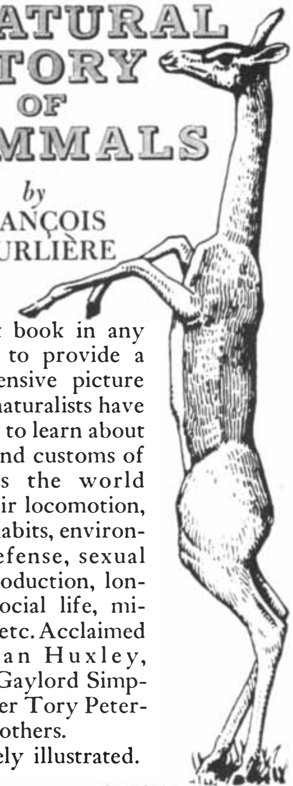
Dr. Simpson attempted "to apply population genetics to interpretation of the fossil record and conversely to check the broader validity of genetical theory and to extend its field by means of the fossil record." This new idea was hailed at the time as a notable contribution to evolutionary theory. In the past ten years a "veritable revolution" has taken place, says Simpson, not only in the knowledge of evolution but in the breadth and nature of the approach to evolutionary theory. This volume, though drawing on its predecessor, is completely rewritten and greatly enlarged, and reports fully the progress made in combining the findings of paleontology with other branches of biological research—genetics, systematics and related sciences. An important book for students and specialists.

ENERGY IN THE FUTURE, by Palmer Cosslett Putnam. D. Van Nostrand Company, Inc. ($12.75). In 1949 the Atomic Energy Commission asked Putnam, a consulting engineer, to make a study "of the maximum plausible world demands for energy over the next 50 to 100 years." This book embodies the results of the study. The "maximum plausible" world population in 2050, says Putnam, will be six to eight billions. Coal, oil and gas, the low-cost fossil fuels, will have been depleted. It is essential, therefore, to accelerate the development of atomic power, "explore nuclear reactions other than the fission of uranium and thorium" and "explore all ways to obtain income energy from sunlight in more useful forms and at lower costs than now appear possible."

JAPAN'S NATURAL RESOURCES, by Edward A. Ackerman. The University of Chicago Press ($25.00). This valuable assessment of Japan's resources is based upon field studies made by the author, a University of Chicago geographer, with other members of the Natural Resources Section of the Supreme Command of the Allied Powers in Tokyo. Ackerman's study was originally published by General Headquarters in an edition of 57 copies, in which the author's name and all text credits to him were deleted, as well as the foreword and the conclusions of the last chapter. Apparently this was an instance of the high-handedness of SCAP, about which journalists and other visitors to Japan have complained. The topics discussed include Japan's food resources and requirements, its hydroelectric, coal, petroleum, lumber and mineral resources, possible advances in the efficiency of their use, its scientific research and technical



competence. The author's treatment is thoughtful and supported by a wealth of statistical detail, photographs, charts, maps and the like. While stressing the serious gap between Japan's requirements and production, Ackerman makes it clear that an intelligent development policy can go far towards overcoming the deficiency. But, he says, many "policy-makers" in the U. S. and other member countries of the United Nations "for one reason or another consistently have opposed those regional development projects which subordinate profits to public welfare. One day the existence or absence of such projects may mean the difference between a democratic and an autocratic Japan."

OXFORD JUNIOR ENCYCLOPAEDIA, VOL. V: GREAT LIVES, edited by Laura E. Salt and Robert Sinclair. Oxford University Press ($8.50). This encyclopedia is in general an attractive and useful reference for young readers, but it is not always easy to perceive the basis of the editor's policy of selection. It is puzzling, for example, to find no article on Gauss, Laplace, Ampère, Huyghens, Claude Bernard, Helmholtz, Apollonius, Galen, Virchow, Tycho Brahe, Hooke or Hobbes. One would gladly trade the long articles on Andrew Carnegie, John Constable, Admiral Hawke and similar figures for a little space on the scientists and philosophers so sadly neglected.

Notes

AUGUSTINE TO GALILEO: THE HISTORY OF SCIENCE A.D. 400-1650, by A. C. Crombie. Harvard University Press ($8.00). This book, reviewed here in January, was first published in England. It is now available in a U. S. edition.

SAMPLE SURVEY METHODS AND THEORY, by Morris H. Hansen, William N. Hurwitz and William G. Madow. John Wiley and Sons (Vol. 1, $8.00; Vol. 2, $7.00). A comprehensive work on the theory of sampling and the application of its methods.

THE MACHINERY OF THE BODY, by Anton J. Carlson and Victor Johnson. The University of Chicago Press ($5.50). A fourth and revised edition of a clear, accurate and attractive introduction to human physiology. The authors have added material on radiation injuries and the use of radioisotopes, biological warfare, gamma globulin, blood banks, artificial respiration, hormones, effects of tobacco, traumatic shock, pregnancy tests, emotional factors in disease.

THE AMATEUR SCIENTIST

About snakes, the other side of the moon and unusual telescopes to follow rockets

Conducted by Albert G. Ingalls

"And the Lord God said unto the serpent, Because thou hast done this [beguiled Eve] . . . I will put enmity between thee and the woman, and between thy seed and her seed; it shall bruise thy head, and thou shalt bruise his heel."

Despite this curse in Genesis some people like snakes. A well-known commercial artist once raised a young constrictor as a pet in his studio. Another acquaintance of ours rarely goes anywhere without carrying along a garter snake or two in his coat pocket.

Most people develop in childhood an all-or-nothing attitude toward snakes. You either like them a lot or you don't—a lot! If you belong to the exclusive little band of those who do, the chances are good that you are a herpetologist, amateur or professional, and have been one for as long as you can remember.

Herpetologists find the average person's aversion to snakes hard to understand. Snakes are not only useful and beautiful but most species are harmless. According to the excellent field guide *Reptiles and Amphibians*, by Herbert S. Zim and Hobart M. Smith of the University of Illinois, of 250 species and subspecies of snakes found in the U. S. only 36 produce poison that can harm man, and these are rare except in a few localities. Snake bites account for fewer than 150 deaths a year in the U. S. Snakes are clean, are easy to tame, live well in captivity, need little care and are lovely to look at.

Herpetology offers to amateurs broad opportunities for original research. Zim and Smith emphasize that the life histories of many species of snakes are still unknown. Most of the adults have been described, but data on their eggs and young are far from complete. Snakes' eating habits, hibernation, mating, diseases and patterns of hunting remain relatively unexplored.

An enthusiastic amateur herpetologist who has written much about snakes is D. F. Munro, professor of modern languages at Kansas State College. He says: "Prejudice against snakes, it seems to me, stems from the same source as most other prejudices. The attitude vanishes with a little firsthand knowledge. No one could ask for a more attractive or well-behaved companion than I had in Lulubelle, a garter snake that used to share my lot. If a snake and a human being can have rapport, Lulubelle and I had it. I used to carry her around in the sleeve of my uniform when I was in the Army (left arm, to avoid jostling her when saluting). She went everywhere with me, just sticking her nose out far enough to watch the world go by. In the evenings when I was in charge of quarters I would put her in a cloth sack and leave it lying open on the desk. She would poke her head out and get in on the act no matter what I was doing. When I used the typewriter, it seemed as if the rhythmic movement of my fingers lulled her into a contented bedazzlement. I note the same effect on the copperhead on my desk just now. He has the freedom of the desk top as I write these lines to you.

"Experiments have shown that babies and young monkeys do not fear snakes until 'taught' to do so by their elders. If you can overcome this imposed revulsion to snakes, you could hardly find a field of study more fascinating or one in which it is easier to make worthwhile contributions."

Munro has written many articles for *Herpetologica*, the official organ of the Herpetologists' League. He has based them on observations of Lulubelle and various other snake pets.

"I never learned to fear snakes," he writes. "Small animals, including snakes, have always interested me. Living in Nova Scotia, a region free of venomous reptiles, I was brought up with the same regard for snakes as for other creatures in the wild. During fishing and hunting trips my father was doubtless glad to have me off exploring the meadows and hillsides for snakes and other animals because he was a most exacting and expert fisherman and gunner.

"From these trips I brought many snakes home and released them in our garden, always wondering afterward why I never saw them again. Now I realize they must have made a beeline back to the tall timber.

"The fascination of snakes dwindled after I got into baseball, language study and other activities in high school and college. But it revived during World War II military service, when, paradoxically, I had the leisure for an avocation. While on a leave in Kansas City I wandered into a bookstore one day and chanced to thumb through *Snakes of the World*, by Raymond L. Ditmars. The striking illustrations caught my eye, and I could hardly wait to get back to camp. The volume was absorbed in a single session.

"I had had no formal training in biology, hence the story of snakes came to me as a revelation. It had never occurred to me that so much work had been or could be done in this relatively humble region of the animal kingdom. I was particularly stimulated by the emphasis Ditmars' book placed on the gaps in our knowledge of reptilian ways.

"As spring approached, I made plans for acquiring a few snakes as pets, though the idea appeared awkward because I was still in the Army and living in barracks. Nevertheless, I built a couple of cages and pinned my hopes on an understanding War Department.

"Kansas and its environs is good snake country. I quickly picked up specimens, only to release them in favor of others more interesting. From the very beginning the snakes proved endlessly diverting. Gradually I learned to recognize each individual by variations in color, scalation, mood and pattern of behavior. For some months the snakes were little more than pets. I tended and fed them. In return they amused me.

"In the summer of 1945 I captured an exceptionally beautiful female garter snake, and she bore a litter of young immediately afterward. But with one exception all of them were stillborn. 'Why?' I wondered. I decided to give Lulubelle, as I had named her, another chance. The next spring I found her a fine young mate. By this time I was so familiar with Lulubelle's behavior that the slightest departure from normal was strikingly apparent. This helped uncover some facts about the mating behavior of garter snakes not previously recorded.

"According to the books, the male snake takes all the initiative during courtship and mating. Lulubelle proved that the female is far from passive. As soon as the pair were placed in the same cage, the male approached the female, slid along her back and wriggled. The female seemed indifferent to this advance, and the male retired to a corner. A few minutes later the female began to crawl and loop over the male and arch her tail in an obvious mating gesture. But the male now ignored the female's advances and showed considerable timidity, as if disturbed by captivity.

"I placed him in another cage and the next day brought Lulubelle another newly caught male. The pattern of behavior was repeated. When this second male failed to respond to the female, I replaced him with the first. The pair immediately approached each other. The male stroked the female with his chin and the female simultaneously arched her tail. The union was consummated at once. From the moment of mating an obvious change came over the female. Whereas for several days she had been restless and sensitive to any touch in the anal region, she now became almost sluggish, apparently content to lie in a loop without moving. Four months later she produced her young, all born alive this time.

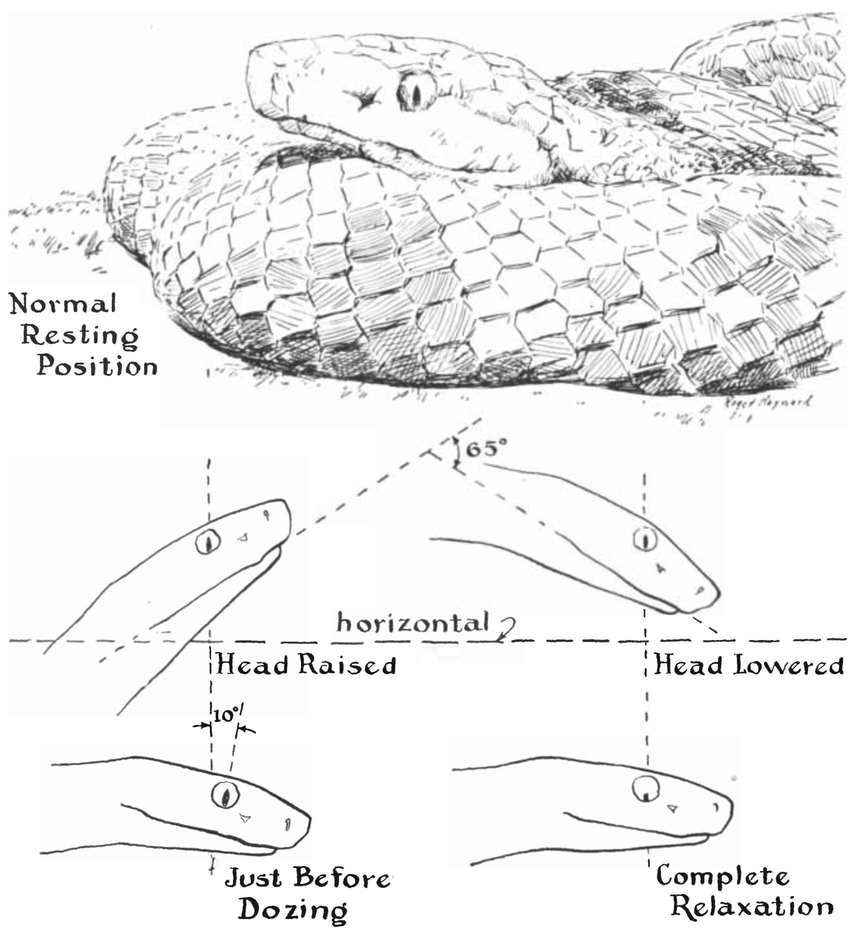
"The same summer I found Lulubelle I also caught a newborn copperhead which likewise stimulated my interest in serious snake study. When you spend a lot of time watching snakes, small details of their behavior catch your attention. The copperhead, for example, has a way of staring at you with an intensity that cannot be ignored. You find yourself staring back. After a few hours of this, I became conscious of a unique characteristic of the pit viper's eye.

"Like the eye of a cat and many other nocturnal creatures, the pupil of the pit viper takes the form of a vertical slit. But in one very remarkable respect it behaves differently from a cat's eye: instead of turning with the tilt of the snake's head, the slit stays vertical, as if the pupil were under the control of an internal gyroscope! However the snake's head moves, the pupil retains its perpendicularity like a plumb line [*see Roger Hayward's drawings below*]. The only exception is that when the snake is on the verge of dozing off and its head droops the pupil may tilt forward. But if the snake is aroused by a camera flash, the pupil immediately snaps into the vertical position. The snake's eye can rotate not only in a forward and backward direction but also in the sidewise direction; in sleep the slit turns under so that part of it is hidden [*drawing at lower right in illustration below*].

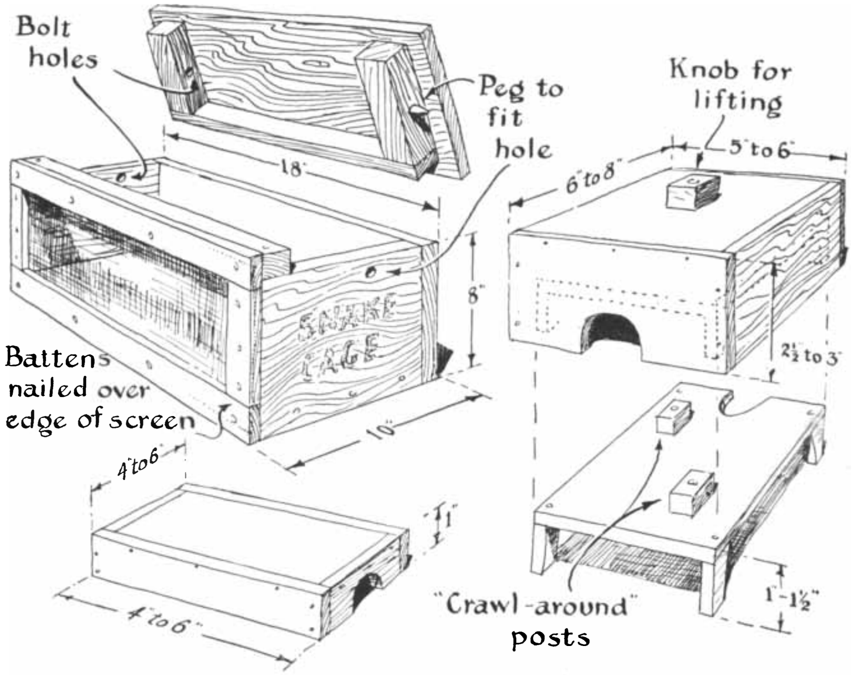
"When I sent a photograph of the viper's remarkable pupil adjustment to the vertical position to *Herpetologica*, it was a great satisfaction to receive word from Major Chapman Grant, the publisher, that I had a 'scoop.'

"Herpetologists also welcome notes on the hatching and behavior of young snakes—an area of investigation that has not been well covered. I made a careful watch of a clutch of eggs laid by a hognosed snake. When laid, the 11 eggs weighed about three quarters as much as the snake did. They had a smooth, soft, rubbery feel. During incubation they were kept in covered glass jars with damp paper to prevent them from drying out. I weighed and measured each egg at intervals during the two-month period. The eggs had gained about 50 per cent in weight by the time they hatched.

"Young snakes, like birds, are equipped with an egg tooth which enables them to cut their way out of the shell. Each emerging snakelet first made a slit in the egg shell and then enlarged the opening by forcing its head through. During this phase its tongue flicked in and out. The head emerged from the shell upside down—a position which had brought the egg tooth into play against the uppermost part of the shell. After about an inch of the body was exposed, the hatching process slowed down. Occasionally the snake appeared to writhe and squirm inside the egg, as if disentangling itself or straightening out kinks. The first snakeling escaped from the shell at the end of a 55-hour struggle. The remainder of the clutch followed a similar hatching pattern, the time ranging from 40 to 60 hours. The plump,



An amateur's study of the constantly vertical pupil of the copperhead



How to make a snake cage

newly hatched snakes averaged seven inches in length and were perfect miniatures of the mother.

"Immediately after hatching, the snakeling began crawling in an effort to shed its skin. It was dipped in water. The body skin came off easily. The fledgling's tiny, thornlike egg tooth also seems to be shed soon after birth. This tooth is a special structure in the upper part of the mouth. An eight-power magnifying glass shows it to be forward-pointing and white. The tooth does a disappearing act that would challenge the detecting prowess of Philo Vance. I was unable to find a single egg tooth in the debris of cast skin. I kept a close scrutiny over one snakelet placed in a small bare cage by itself, and when it dislodged the scale from the end of its snout, I examined the material immediately. The egg tooth had vanished! I can only surmise that the snakelet had swallowed it."

If Munro can get your ear, he will go on for hours about his pets. "Lack of time and facilities," he says, "has reduced my stock of snakes to seven. Still among them, however, is one of the early specimens from Army days, the copperhead, now a veteran of over eight years of cage life. Lulubelle died three years ago after presenting me with several fine litters. I still miss her, of course.

"One can't help being amazed that so many otherwise rational people feel an aversion for snakes. For a busy person, or one who must be away from home occasionally, they make ideal pets. Many practical considerations make it convenient to keep snakes in situations which would prohibit other pets. The reptilian tempo of life is slow, so that a study of their ways need not be based on daily contact. More important, snakes require feeding only once a week or so, and if necessary they can be left a month or so in safety if they are provided with a dish of water.

"Cages are inexpensive and easy to build [*see illustration above*]. Only one precaution need be taken in their construction: the screening should be securely attached and its rough edges covered so the captives will not injure themselves. Cleanliness is easily maintained. Snakes abhor dirty cages. Lulubelle used to insist on being taken out in the yard for excretion. She would crawl back and forth against the wire of the cage to attract my attention, and accidents happened only when I was too stupid to understand what she was trying to tell me. On these rare occasions she would meticulously avoid the soiled area until I cleaned her cage.

"Snakes do not sing, purr or dance for you, but that does not mean they are unresponsive. Even when they just lie about like crooked sticks, they are watching you and will respond to attention in their own way. Different as they are from human beings, these silent creatures throw light upon many essentials of animal behavior."

Lives there a person who has never wondered what lies on the other side of the moon? H. P. Wilkins, director of the lunar section of the British Astronomical Association and the foremost selenographer of our time, has sought for years to elucidate this mystery. He has prepared an advance guide map for the space explorers who in the not distant future will visit the moon and become the first human beings to see its farther side.

Because of the moon's libration we get glimpses of about 9 per cent of that half of the lunar sphere facing away from us. Each month the Man in the Moon nods a little and shakes his head a little. He nods (libration in latitude) because the moon's axis is tilted so that we can see 6½ degrees over one pole and two weeks later the same distance over the other pole. He shakes his head (libration in longitude) because the moon's elliptical motion around the earth is not uniform, while its axial rotation is. This difference enables us to look about 7¾ degrees (more than 100 miles) around each of its sides. In addition, each day the viewing position of an observer on the earth shifts by about 8,000 miles because of the earth's rotation. This diurnal libration adds about another degree to our field of view of the moon.

Wilkin's map of the back of the moon [*see drawing on the next page*] shows around the edges the portions we can see during the various librations. It also shows rays like those on the moon's side facing us; these lines are not theoretical, for they are projections of sections of rays that can actually be seen in the zones of libration. Wilkins extends the rays to the centers, presumably large craters, from which they radiate. The shaded areas on the map are his surmises as to topographical features on the other side of the moon.

On the earth and Mars each large upland mass is balanced by a large depressed region—an ocean or plain. Wilkins therefore supposes that the depressed "sea" visible in the northern part of the moon side that faces us is balanced by a mountainous portion diametrically opposite it on the other side. This area is left white on his map. Similarly he imagines that the mountainous region in the southern portion of the side that faces us is balanced by a depressed plain on the other side. The big shaded area on his map represents a large plain or "sea" similar to the great Mare Imbrium on the earthward face. A dark area which may be one end of this region is just visible to us; it has been named Mare Incognito. Wilkins throws in three smaller plains, also shown as shaded areas, on the probability that such depressions exist in the mountainous area on the other side as they do on the earthward face. Four such depressions are visible in the zone of libration.

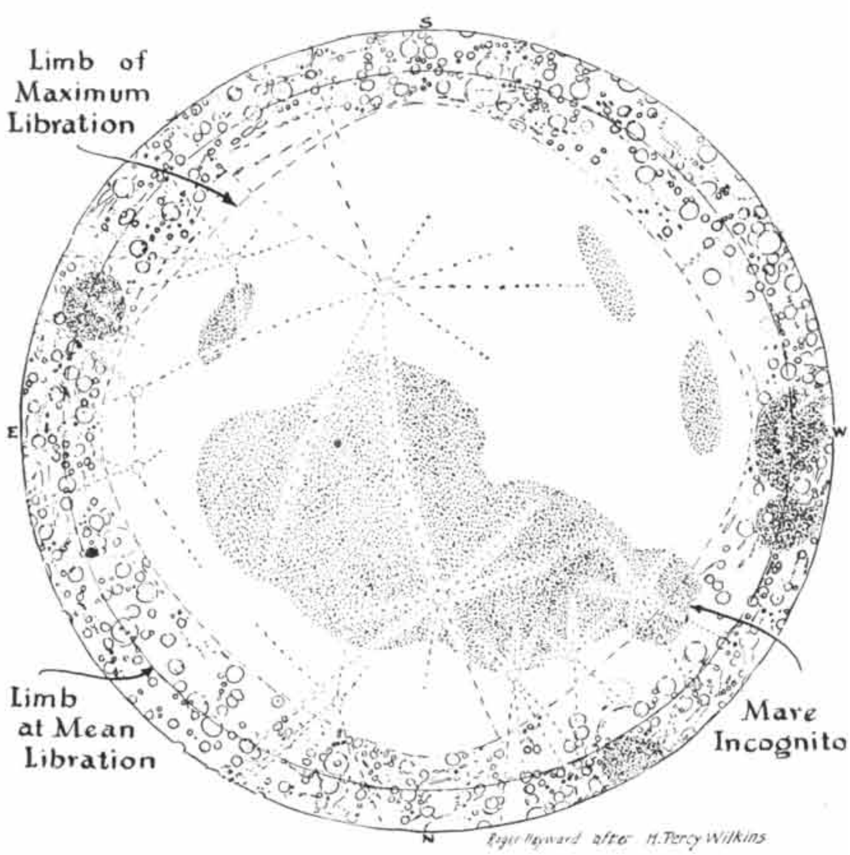
No doubt when the first space ship circumnavigates the moon a selenographer broadcasting from it will report to the great listening earth audience that the back of the moon has about the same kinds of mountains, plains, craters, pits and clefts that we can see on our side, but he will nonetheless have a large and excited audience when he comes back to earth with his slides to tell the details.

To compute the path of a projectile from a gun one must measure the projectile's greatest velocity, which occurs just after it leaves the muzzle. In the case of a rocket missile the problem is different, for a rocket continues accelerating clear up to the point where it has burned all its fuel. Near that part of the flight velocity measurements must be made at two or more points in the trajectory. For this a missile-tracing telescope is needed. Because rocket missiles have exceedingly high velocities, the telescope must work photographically. The motion-picture cameras used make 16 to 64 exposures per second with exposure times of 1/10,000 second.

When Clyde Tombaugh, optical staff physicist of the Flight Determination Laboratory at the White Sands Proving Grounds, set out to design the optics of telescope cameras for tracing missiles, he realized that the optical system must be fast. The smallness of the missile and its great height above the ground would require a scale of images that could be obtained only with a focal length of about three feet. He hoped that this focal length might also make it possible to determine absolute positions of points in the trajectory by the most precise of all methods: graphing the missile with two cameras against the background of the stars. By this method the points can be determined with an accuracy of one inch in three miles.

To obtain images of enough brilliance to be photographed in the necessary 1/10,000 second at this focal length, the focal ratio must be at least $f/3$. Refracting telescopes of this short focal ratio would be impracticable to make. Paraboloidal reflectors, though relatively inexpensive and easy to make, would not be satisfactory because of their excessive coma and astigmatism at this focal ratio. However, Schmidt cameras of 12-inch aperture and 16.5-inch mirrors would give the necessary speed if suitably modified.

In a normal Schmidt camera [*drawing at left in illustration on page 106*] the light rays enter through a thin lens or



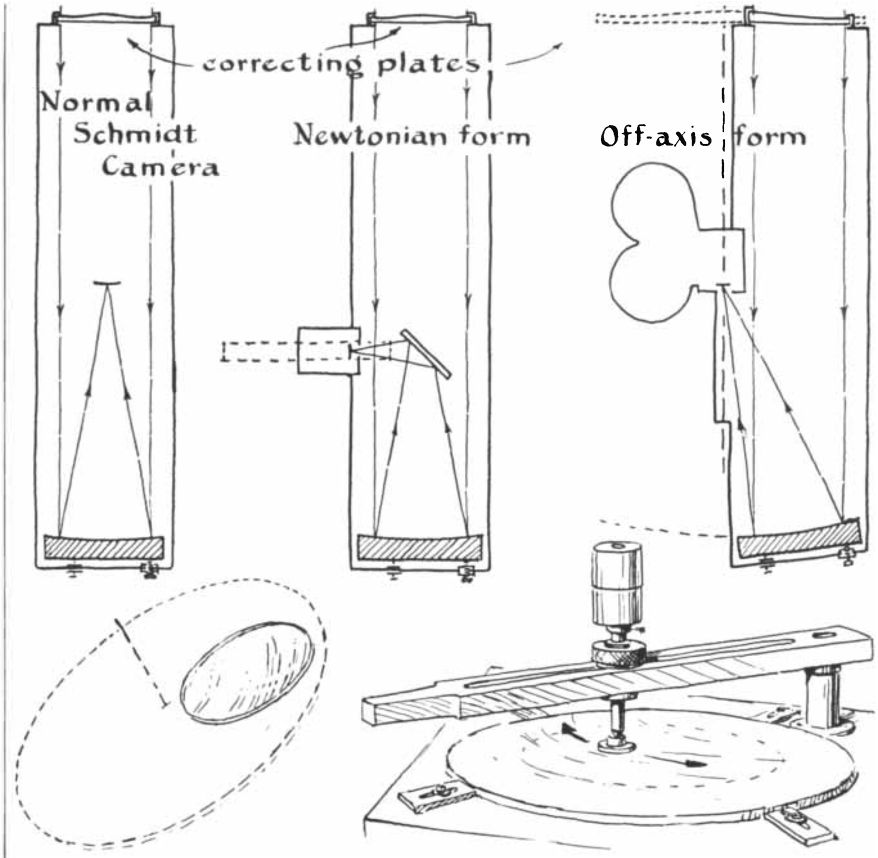
Wilkins' map of the other side of the moon

correcting plate with its surface ground to a very shallow double curve (greatly exaggerated in the drawing). This curvature bends the incoming light rays just enough to neutralize the spherical aberration that will be caused later by the spherical mirror. The corrected rays from the mirror are then focused as a spherically convex image at a point midway between the mirror and the correcting plate. Here Tombaugh might have inserted a diagonal mirror similar in principle to the one in the Newtonian form of telescope [*drawing in middle*], which reflects the rays to a film holder outside the telescope. Unfortunately this diagonal mirror would cut off 40 per cent of the light—even more than a film holder. The decrease in light would increase the necessary exposure time from 1/10,000 second to 1/7,000 second, causing prohibitive travel blur in the images of the missiles.

The solution of the dilemma was the off-axis form of the Schmidt camera [*drawing at right*]. Here the mirror is tilted to reflect the rays to one side of the telescope. After they pass through a small plano-convex field-flattening lens, which brings the convex image into coincidence with the flat film of the camera, they enter the motion-picture camera. This solution is not as simple as it may seem. The correcting plate used in the normal type of Schmidt is no longer suitable. The plate must now have the curvature shown in the right-hand drawing: the curve is a section of a hypothetical Schmidt corrector of the diameter indicated by the dashed lines.

The off-axis Schmidt was proposed in this department in August, 1939, by D. O. Hendrix and William H. Christie of the Mount Wilson Observatory in a classic article on uncommon variations on the original Schmidt.

One method of making an off-axis correcting plate is to make a normal one of full hypothetical size and then cut a circle from one side [*drawing at lower left*] with a rotating glass saw or cookie cutter. This method tempted Tombaugh and his associates, the physicist William C. Braun and the mechanical engineer Clyde R. Dennon, especially because it would afford two correcting plates for the two cameras they needed. Tombaugh writes: "We were hesitant to attempt it, because the ¼-inch correcting plate would have been 32 inches in diameter, and we had no means of supporting it adequately during grinding and polishing to keep it from flexing. Hence we elected to make a correcting plate off-axis by the use of a special jig [*drawing at lower right*]. The lever arm has a long,



Figuring an off-axis Schmidt correcting plate

carefully machined slot through the middle, which permits a small grinding tool bolt to be clamped anywhere along a radius from the centered king bolt. The grinding tool is designed to slide up and down freely, so that variations of force on the grinding arm by the operator cannot cause variations in pressure of the tool on the correcting plate. Various weights can be put on this bolt to regulate the rate of grinding. The grinding is done by arc strokes with small tools (one to three inches in diameter) to scoop out the various zones."

Off-axis optical surfaces have been figured by professional and amateur opticians for a number of years. Most of these workers regard a mechanical jig as too inflexible; it confines the abrasion too closely to separate zones without the necessary blending effects. Norbert J. Schell of Beaver Falls, Pa., who with his co-worker T. J. Beede of Youngstown, Ohio, had made off-axis telescopes as early as 1939, said then that in figuring off-axis mirrors "no machine work or mechanical controls were used, although a mechanical control was first tried and discarded, as it was found unsatisfactory." Today Schell adds: "Everybody who gives this any thought comes up with this lever method of control. Beede and I found that there was so much more to it that the machine we tried was a nuisance. We wouldn't use it as in the drawing but only to control the central position of the stroke, which would be zigzag *across* the zone to give blending. The optician Daniel E. McGuire has used a large lever in much this manner, but with a smaller lever to make local arcs."

The principle of this method was devised independently and used by the Ferson Optical Company in 1946. Fred B. Ferson says: "This method can be readily used by hand by a skilled optician with off-axis mirrors of $f/5$ to $f/9$, and if the departure from the axis is not too great. It involves only rubbing the longest where most needed, and grading the figure to that part of a larger parabola. The figure can be determined in collimated light with the Ronchi test at the off-axis position. It can likewise be tested at the center of curvature with the Foucault test, which will exhibit the figure of that part of a hypothetical larger mirror. True correction will give straight bands with the Ronchi test in collimated light. This is the whole story."

So far as this department knows, instructions for figuring an off-axis mirror have never been published before.

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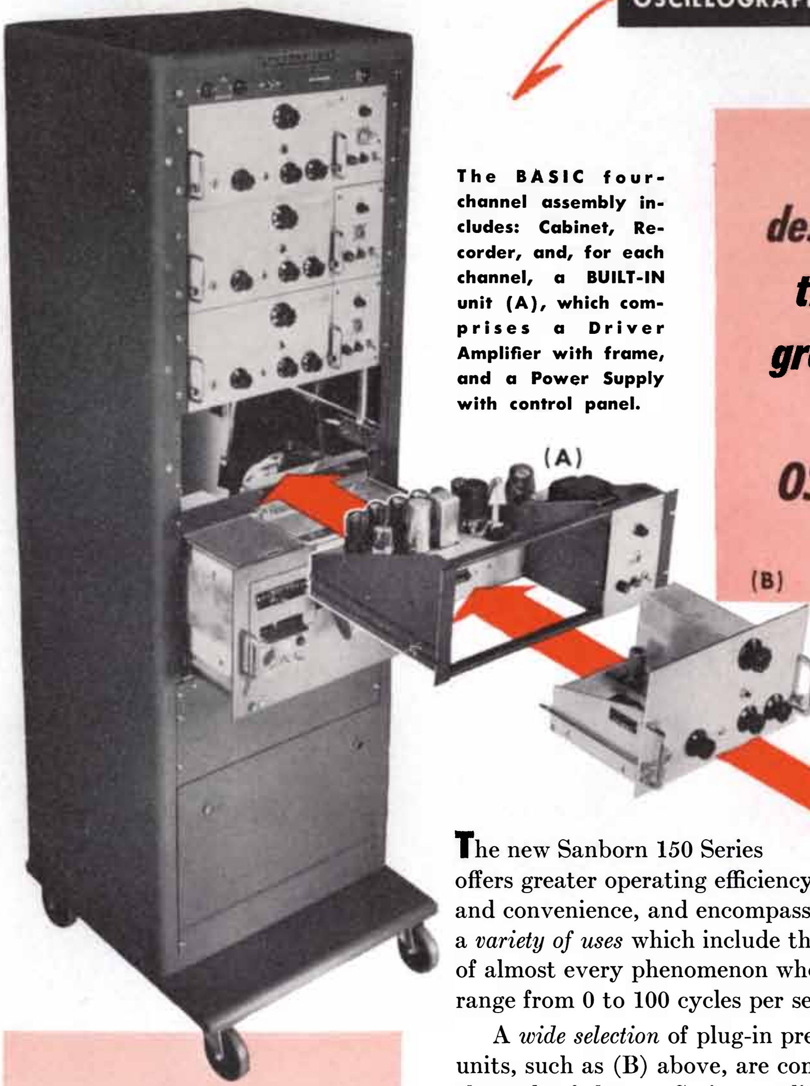

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A *wide selection* of plug-in preamplifiers, or "front end" units, such as (B) above, are completely interchangeable in any or all channels of the 150 Series amplifier section, where they simply plug in to the driver amplifier and power supply, (A) above, which are already in place.

Available plug-in Preamplifiers include: AC-DC, CARRIER, SERVO-MONITOR, DC COUPLING, LOG-AUDIO, and LOW LEVEL. Blank plug-in assemblies are also available for users to make input circuits for special measurement problems.

And, there are the popular Sanborn advantages: a high torque movement (200,000 dyne cms per cm deflection), direct *inkless* recording in *true rectangular coordinates*, and provision for code and time markings.

A new catalog on Sanborn Oscillographic Recording Systems and their components will be sent gladly on request.

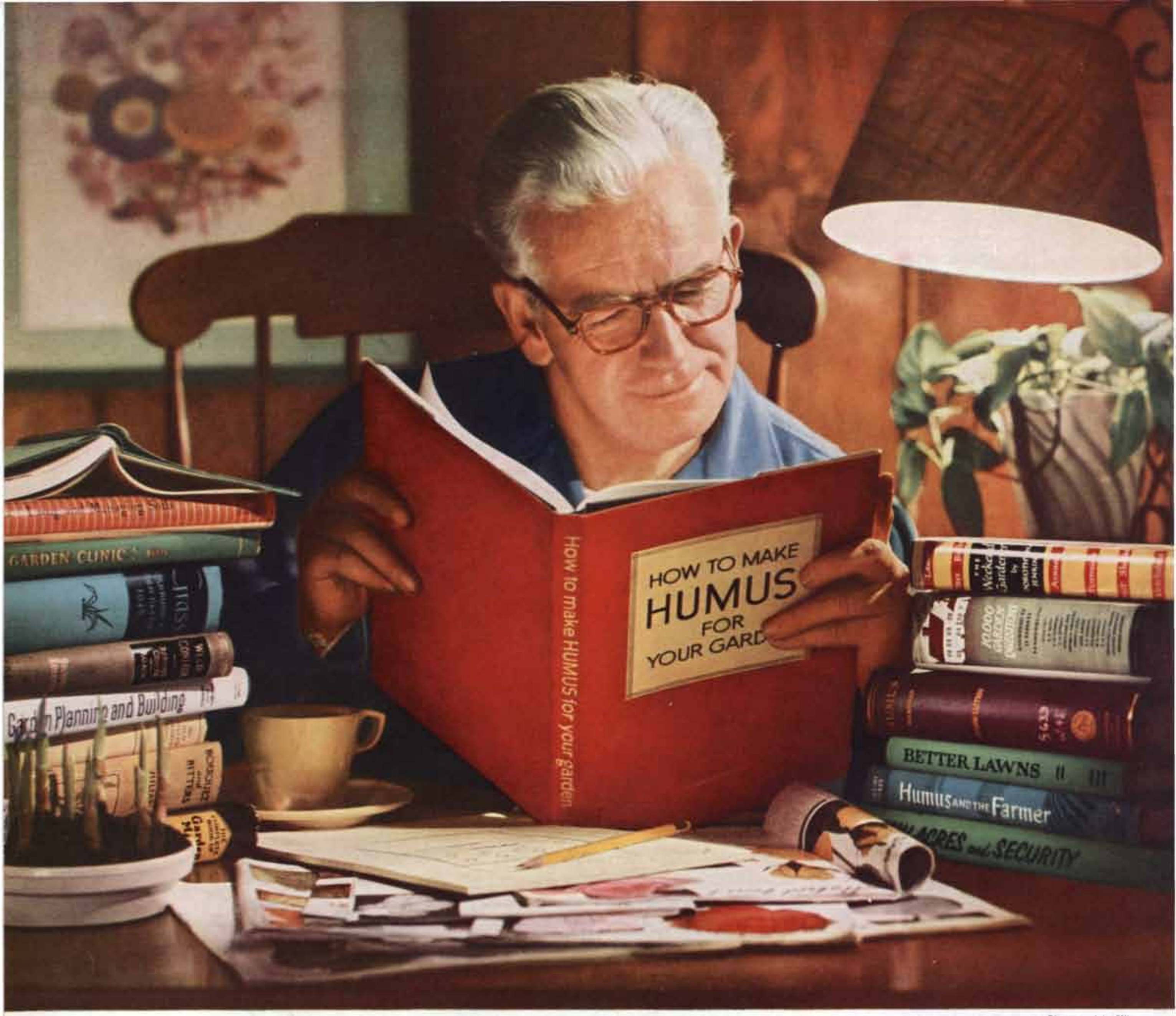
OTHER SANBORN IMPROVEMENTS

- Extended frequency response.
- Improved regulated power supply.
- Individual stylus temperature control for EACH channel.
- Improved, single control, paper speed selector. Nine speeds — 0.25 to 100 mm/sec.
- Recorder slides out, if desired, for better view of recorded events, or for notations on record (illustrated at right).
- Improved control of input signals by use of 1, 2, 5 ratios on attenuator.

Be sure to see the 150 Series at BOOTHS 455–457, I.R.E. Convention, Kingsbridge Armory, Bronx, N. Y. March 22–25, 1954.

SANBORN COMPANY
INDUSTRIAL DIVISION

195 MASSACHUSETTS AVENUE
CAMBRIDGE 39, MASS.



Photograph by Viles

Here's GOOD NEWS for gardeners!

Millions of home gardeners have a pleasant surprise in store for them this year. For the first time "Cyanamid," agriculture's most useful form of nitrogen, is available for home garden use.

Lawn and Garden Cyanamid, as this product is known, offers many advantages to the home gardener. It enables him to turn spaded-in plant refuse into humus in the soil . . . build humus in a compost pile . . . kill weed seeds in the soil for new lawns . . . or repair old lawns. At the same time, Cyanamid supplies long-lasting nitrogen and soil-sweetening lime . . . both essential to sturdy and season-long plant growth. In fact, this is the way commercial growers have achieved outstanding results for many years with flowers, vegetables and turf. Cyanamid is now available in 10, 25 and 50-pound bags and will be on sale at garden supply outlets as rapidly as distribution can be completed.

Lawn and Garden Cyanamid is a granular form of calcium cyanamide, the astonishingly versatile, basic material from which American Cyanamid Company has developed many chemicals for agriculture, industry and the home.

AMERICAN *Cyanamid* COMPANY

30 ROCKEFELLER PLAZA, NEW YORK 20, N. Y.