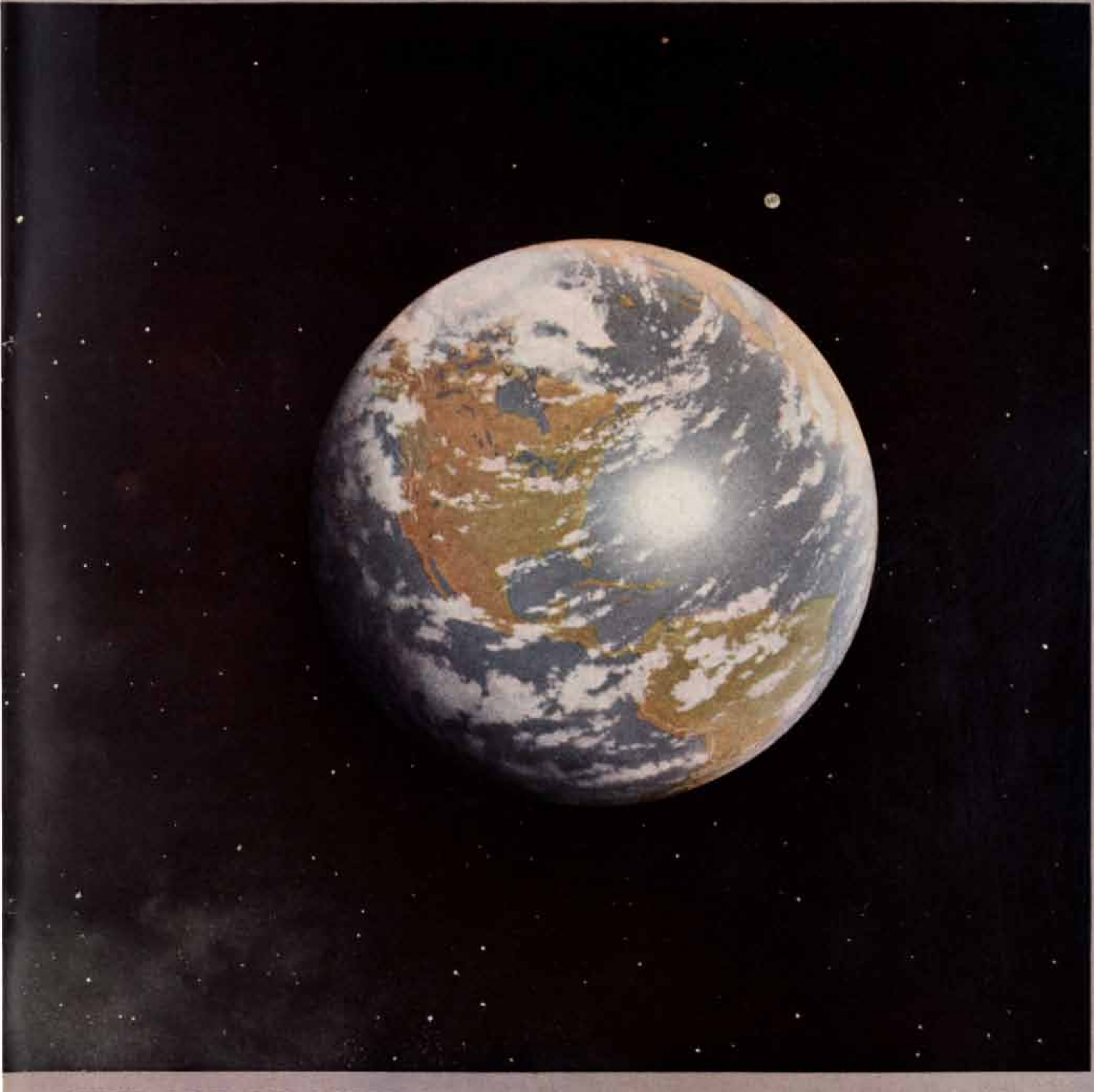
SCIENTIFIC AMERICAN



THE AGE OF SCIENCE: 1900–1950

FIFTY CENTS

September 1950

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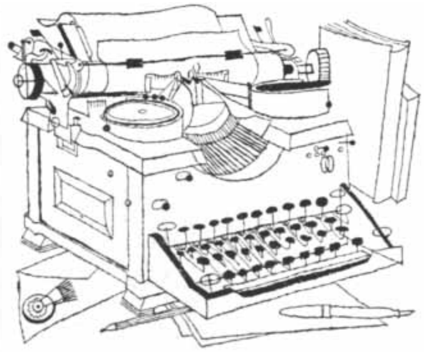

LETTERS

Sirs:

Professor Mangelsdorf's assumption, in his otherwise excellent summary of the most intriguing of ethnobotanical mysteries ("The Mystery of Corn," SCIENTIFIC AMERICAN, July), that the subject of pre-Columbian Old World maize is closed is no longer tenable in the light of recent evidence. Since Laufer, the great Sinicist, demolished the pre-Columbian argument with his linguistic researches some 40 years ago, those who continued to speculate about archaic corn in southeast Asia were regarded as mild cranks. Within the past decade, however, a small band of botanists and plant geographers, spearheaded by Edgar Anderson of the Missouri Botanical Garden, have come up with virtually unassailable proof that corn has been known in southeast Asia since prehistoric times, and the question of which hemisphere was the original source is now wide open.

The corn in question is scattered intermittently through southern Asia in Iran, Turkestan, the Himalayan regions, and as far as Hainan and possibly New Guinea, but it has been studied in greatest detail in Assam and northern Burma. Strains of rather non-vigorous corn, quite secondary to rice or millet in the agricultural economy, are raised here with much local variation in plant morphology and cultural significance. The fact of corn being grown by remote, conservative tribes and its absence among the more civilized peoples of monsoon Asia (who cultivate patently post-Columbian strains when corn is used at all) would make a 16th-century introduction most implausible. The absence of ancient written references is scarcely astonishing in view of the illiteracy and inaccessibility of the cultivators. Other lines of argument for the antiquity of corn in Asia are: 1) the primitive morphological characteristics of the Asiatic varieties, which are approached in the Americas only by extinct varieties or by certain rare and primitive popcorns, 2) the fact that the many local terms for corn are highly indigenous and were imbedded in the speech of these hill people many centuries ago, and 3) a diversity of uses indicating a long period of adaptation.

The possibility of an Asiatic home for maize, real proof of which awaits further field work in a quite unsettled part of the world, rests at present upon the fact that maize has many more possible botanical cousins among the Old World grasses than in the New, and upon the observation that it is more likely that the primitive and rather economically unimportant maizes of southeast Asia would be transferred across the Pacific by human agency several millennia ago, to be elaborated in the New World into the modern corns by relatively enterprising plant breeders, than that the reverse should occur. The early farmers of America were in dire need of good grain food; the people of Asia had their choice of several.

However vague this story of maize from across the Pacific may appear at present, it seems to me that there is the most promising prospect waiting to be explored, now that most of the leads in the New World have wound up in cul-de-sacs. The history of New World cotton (recently shown by genetic analysis to have been an ancient importation from Asia) is instructive, and it can be hoped that the combined efforts of specialists in genetics, ethnology, linguistics, archaeology and botany may finally prove or disprove the Asiatic ancestry of maize.

WILBUR ZELINSKY

University of Georgia
Athens, Ga.

Sirs:

I have not assumed, as Professor Zelinsky's letter suggests, that "the subject

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of pre-Columbian Old World maize is closed." In dealing with a problem as complex as that of the origin and evolution of corn, one does not arbitrarily exclude from consideration any possible solution, however unlikely it is to be the correct one. I have merely exercised my prerogative as an author to give greatest emphasis to those possibilities which in my judgment offer greatest promise. The statement in my article that "the evidence that corn originated in America is so overwhelming that it seems sensible to concentrate, if not to confine, our search for its wild ancestor to the Western Hemisphere" expresses quite accurately my present viewpoint on the possibility of an Old World origin of corn. Professor Zelinsky, a geographer, accepts as "virtually unassailable proof" some recent botanical observations and opinions on Asiatic corn about which I, as a botanist and long-time student of corn, am quite skeptical.

The observations in question are those of Stonor and Anderson, who found that the corn of Assam has several "unusual" characters and that it has many names and several uses among the native tribes, who believe it to be indigenous. Their hypothesis is that corn presumably "must either have originated in Asia or have been taken there in pre-Columbian times."

Actually the Assam corn itself is by no means unique. Some of its "unusual" characters—uniformly green leaves and stems, slender pendant tassels, colors of the endosperm and aleurone, small isodiametric kernels, and lack of vegetative vigor—are rather widely distributed in South American maize. One of the Assam varieties, called Late Sidewise, which is said to look "unlike anything previously reported for *Zea Mays*," has strong affinities, if not exact counterparts, among the living varieties of Colombia and will, no doubt, be found occurring elsewhere in South America when more extensive collections have been studied.

Other botanical criticisms of the article by Stonor and Anderson have recently been made by Elmer D. Merrill and by Paul Weatherwax.

The other evidence mentioned by Professor Zelinsky is in the same category (insofar as it has any bearing on the origin of corn) as the "unassailable proof" of Stonor and Anderson. Space does not permit a detailed discussion of it here. His statement on cotton will undoubtedly come as a shock to Hutchinson, Silow and Stephens, who several years ago developed a new hypothesis on the origin of cotton but who, I am sure, never foresaw that their hypothesis would be cited as an established fact to support an argument for the Asiatic origin of corn. Professor Zelinsky's statement that corn has "many more possible botanical cousins among the Old World grasses than in the New," although true,

is quite meaningless, since we are concerned not with numbers of relatives but with the closeness of relationship. The most important fact about the Old World relatives of corn is that they differ from corn quite profoundly in several fundamental botanical characteristics and, in spite of numerous attempts, none has ever been hybridized with corn.

It is at present true, as stated in my article, that "there is no evidence of any kind—archaeological, linguistic, ideographic, pictorial, or historical—of the existence of corn in any part of the Old World before 1492." If intuition or insight (the existence and importance of which I do not deny) point to Asia as the home of corn, then let the proponents of this thesis come forward, not with final proof, since this is perhaps too much to expect at this stage, but with the first tangible evidence in support of their thesis.

PAUL C. MANGELSDORF

Harvard University
Cambridge, Mass.

Sirs:

The article by Dr. Mangelsdorf on the ancestry of corn has given me a great deal of moral support by its conclusion that this useful food plant originated in the Andean region, rather than in Guatemala, as formerly believed. In my case, however, this conclusion is based on very different grounds from those advanced by Dr. Mangelsdorf.

In achieving its present degree of civilization the human species seems to have passed through three quite distinct stages—savagery, barbarism, which is characterized by the acquisition of domesticated herds, and finally agricultural civilization. Agriculture seems to have been undertaken originally for the purpose of providing fodder for domesticated herds; the use of cereal grains as a means of human sustenance seems to have been a secondary development.

It would therefore appear reasonable to suppose that the original development of corn would have been accomplished by those Indians who already had acquired herds of domesticated animals. At the time of the arrival of the conquistadores the only domesticated herds in America were those of the llamas in the Peruvian Andes. The occurrence of the domesticated llama in the same general area that is characterized by the greatest number of recognizable varieties of corn is too remarkable a coincidence to be attributed to fortuitous causes. It suggests that the development of corn was due to a deliberate attempt to secure a source of food supply for the llamas.

JOSHUA L. BAILY, JR.

San Diego, Calif.

SCIENTIFIC AMERICAN 50 YEARS AGO

1900. "Recent progress in the electrical world has been marked by steady advance along established lines. Perhaps the most striking development has been that of wireless telegraphy, a system which was shown for the first time in successful commercial operation in this country by Marconi himself during the international yacht races. During the summer wireless messages were successfully transmitted between ships of the British Navy which were separated by 80 miles of water; decipherable messages were also dispatched from Chelmsford in England to Boulogne in France, over 110 miles of land and water. Marconi has done enough to establish the practical value of his system for certain specified work, but its value will be enormously increased if he can discover some means to restrict the receipt of messages to the particular station for which they are intended, and prevent all interference by the waves sent out from other stations that may happen to be within range."

"M. Curie, in continuing his researches upon the rays given off by radium, has brought to light a remarkable phenomenon in connection with this form of radiation, namely, that these rays are possessed of an electric charge. They thus show a close relation to the cathode rays. Like the cathode rays, they are charged negatively. It must follow that the radioactive matter is the seat of a continuous emission of particles which are negatively electrified, and which will pass through a conducting or dielectric screen without discharging."

"Activity in the aeronautical world has been directed rather to the development of the airship than the aeroplane. Ever since Langley's brilliant success in achieving a flight of three-quarters of a mile with an experimental, steam-driven machine, we have heard but little either of the motor-driven aeroplane or the soaring machine. The balloonists, on the other hand, have been very active and fairly successful. By far the most ambitious attempt at the construction of an airship is that of Count Zeppelin."

"In the domain of Becquerel rays an addition to the number of radioactive substances has been made by A. Debierne. Up to the present we have had radioactivity exhibited by uranium, thorium, radium and polonium. The new substance is called actinium and belongs to the iron group."

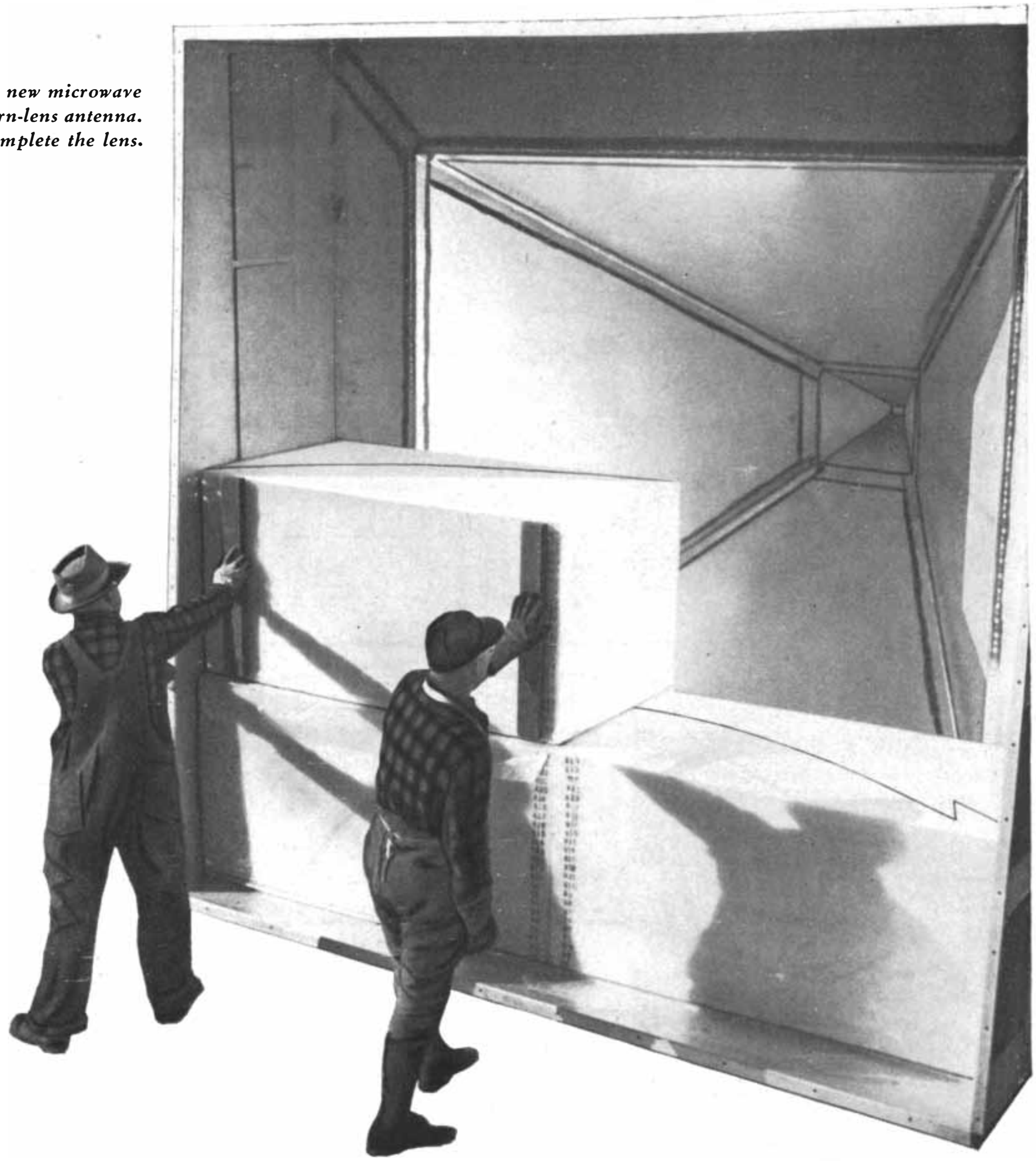
"Candidates for the Nobel prize for scientific achievements are being considered by the Swedish Academy of Science, at Stockholm, which must award the prize this year for the first time. Among the names already proposed are Prof. Roentgen, Marconi, Baron Nordenskjöld and Henri Dunant, the founder of the Red Cross Society."

"Prof. Haeckel, of Jena University, and David J. Walters, a law student, are about to start to find the pithecanthropus. Mr. Walters intends to pursue his investigations in Java and will arrive in that isle before the great evolutionist. The pithecanthropus if found will be of great value, as it will tend to supply the missing link in the evidences of evolution."

"Half a century ago the greatest hopes were entertained. The discovery of the conservation of energy and of its transformations had just revealed the unity of force; heat was explained by molecular movements; for light, the question seemed solved. Electricity, just annexed to magnetism, was farther behind, but no one doubted that it would take its place in the general unity, and for the molecular properties of solids, the reduction seemed easier. What do we observe today? First, an immense progress; the domains of electricity, light and magnetism now form but one. The optical phenomena enter as particular cases of electrical phenomena. While they remained isolated, it was easy to explain them, but now an explanation to be acceptable must enter into the domain of electricity; this is not without some difficulties. The theory of Lorentz is the most satisfactory. The irreversible phenomena are more intractable, but are brought into order by Carnot's principle. The role of thermodynamics has greatly increased, and we owe to it the theory of the pile and of thermoelectric phenomena. To sum up, the old phenomena become better classified, but new ones are constantly coming in, and we must now place the cathode and X-rays, those of uranium and radium, etc. No one can predict the place they are to occupy, but no doubt they will fit into the general unity."

"The Edison phonograph has become a familiar object in our modern life. The great growth in popularity of the phonograph, and the necessity for keeping the owners supplied with fresh 'literature,' has caused the mere work of manufacturing the records to assume truly enormous proportions. Evidence of this is shown in the storage room of the Edison Phonograph Works, in which are to be found tier upon tier of storage bins, whose contents represent records of

Mounting Bell's new microwave lens in a horn-lens antenna. Other blocks will complete the lens.



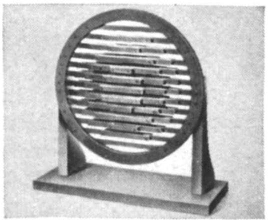
A focus on better, low-cost telephone service

In the new microwave radio relay system between New York and Chicago, giant lenses shape and aim the wave energy as a searchlight aims a light beam.

Reasoning from the action of molecules in a glass lens which focuses light waves, Bell Laboratories scientists focus a broad band of microwaves by means of an array of metal strips. To support the strips these scientists embedded them in foam plastic which is virtually transparent to microwaves. Rigid and light in weight, the plastic is easily mounted on relay towers.

This unique lens receives waves from a wave guide at the back of the horn. As they pass across the strips, the waves are bent inward, or focused to form a beam like a spotlight. A similar antenna at the next relay station receives the waves and directs them into a wave guide for transmission to amplifiers.

This new lens will help to carry still more television and telephone service over longer distances by microwaves. It's another example of the Bell Telephone Laboratories research which makes your telephone service grow bigger in value while the cost stays low.



Laboratory model of the new lens. A similar arrangement of metal strips is concealed in the foam plastic blocks in the large picture.

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"Prof. Dewar again holds a prominent place in current scientific progress. To the long list of his achievements has been added the liquefaction of hydrogen. Subsequently, at the Dover meeting of the British Association, he described the experiments by which he had succeeded in solidifying the same gas. In May Sir William Crookes informed the British Royal Society that he had found in a photograph of a spectrum a group of lines indicating the existence of a new element, which in honor of his Queen he named 'victorium.' "

"Prof. Loeb, of the University of Chicago, has made interesting experiments upon the artificial fertilization of the eggs of sea urchins, and the production of larvae after an immersion of two hours in a solution of magnesium chloride and sea water."

"Never was there a time when so many and so well-equipped expeditions were abroad in the effort to fill in the blank spaces in the geography of the world. Interest is divided pretty equally between the Arctic and Antarctic regions —with a preference for the former. Peary is well on his way to the North Pole. Profiting by his past experience, he is engaged in establishing the necessary line of communications before making his final dash for the objective point. He has an able competitor in Sverdrup, Nansen's old colleague, who has taken the *Fram* once more into Arctic waters, with the intention of combining Peary's and Nansen's plan of advance in a supreme effort."

"The progress of the South African war entrenched positions, as at Glencoe and Belmont, the repulses at Magersfontein and the Tugela, where the Boers had thrown up elaborate entrenchments, proved that direct assault on such positions, when held by such excellent shots as the Boers, are doomed to failure. The magazine rifle has put a heavy discount upon old-time valor, and the war of the future will be more than ever a war of the tacticians."

"Unquestionably the greatest advance in transportation is that recorded in the field of the automobile, which is evidently destined to enjoy a popularity as great as, and certainly more lasting than, the bicycle. There has been a noticeable and very gratifying improvement in the general appearance of the latest styles of automobile, and the constantly accumulating experience is leading to marked improvement in the motors. The speed and 'radius of action,' to borrow a naval term, of the automobile have seen a truly remarkable increase. A remarkable proof

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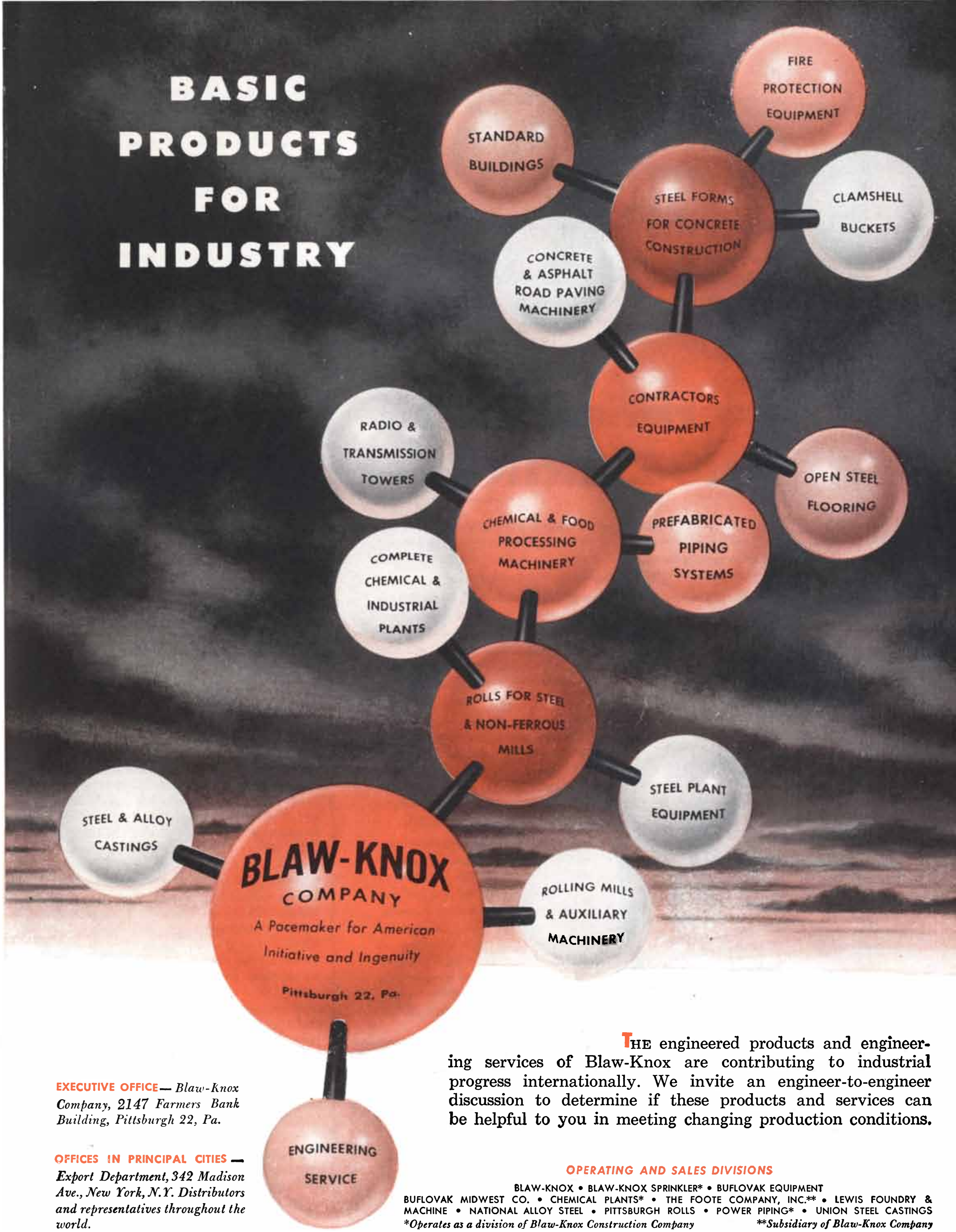

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"Prof. Percival Lowell and Prof. Todd have left New York with astronomical material to observe the eclipse of the sun in Algeria. Owing to the fineness of the climate of Algeria, it is a particularly good locality to observe the eclipse. There is an observatory in Algeria, the director of which recently went to Paris to take measurements with M. Loewey in order to observe the eclipse."

"In no period of human endeavor has the work of man been so built into tangible and enduring things of useful quality as in the century just about to pass into history. Ancient and medieval history dealt with bloody wars, limiting creeds, cunning politics and the greed of conquest. Modern history must leave these to a subordinate place, and substitute for them, as of greater importance, the genius of invention, the elements and agencies of industrial progress, and the arts of peace; and in so doing it marks the approaching millennium of happiness, good will and material prosperity which men have always longed for. The last decade of the century (1890-1900) is still so near to us, and is so filled with invented agencies of importance, that selection is rendered specially difficult, and only a few of the most important may be named. We find the Parsons rotary steam turbine, which in its applications in marine engines has raised the speed of smaller steam craft to that of an express locomotive; the Northrup loom, which acts almost with the discretion of a thinking mind; the Acheson process of making carborundum, the Yerkes telescope, Edison's kinetoscope, and the allied developments of the phantascope, cinematograph and biograph, whose moving and apparently living scenes fill the observer with wonder and admiration; the production of calcium carbide by Willson, and the electric furnace for making the same; the discovery and application of the X-rays by Roentgen, the Krupp armor plate, the developments in liquid air and apparatus for producing it by Linde, Tripler, Dewar, Ostergren, Berger and others; the mercerizing of cloth under tension to render it silky, the Schlick system of balancing marine engines, the improved disappearing gun, the practical development of the bicycle and automobile, the building and launching of the *Oceanic,* the largest steam vessel ever produced, and wireless telegraphy by Marconi."

BUSINESS IN MOTION

To our Colleagues in American Business . . .

Milk must be cooled quickly after milking, in order to lessen the growth of bacteria, and this has led to the development of various methods of reducing the temperature. On the non-electrified farm the dairyman may make use of a cool springhouse, or natural or artificial ice. Where electricity is available, however, mechanical refrigeration has become a virtual necessity. It might be thought that such an application of refrigeration would entail no particular problems, but that is not the case. The milk cooler presents its own special conditions of use, and hence requires specific, not general, consideration of those conditions.

In comparatively recent years the tank-type cooler has come prominently forward. This consists of a large tank of water, held close to or at freezing temperature by mechanical refrigeration. The 80-lb. cans of warm milk are immersed in the water until cooled. In some models, the tubes or pipes through which the refrigerant flows are within the tank itself, in order to avoid the insulating effect of the tank lining if the coils were outside. This location of the coils, however, subjects them to some possibility of mechanical injury, and complicates cleaning. Another problem that has arisen in connection with these coolers is the selection of the material for the lining. It has to be able to stand not only the weight of the cans, but the shocks of dropping them to the bottom, and, of course, must be made watertight. During the war the only practical material available was galvanized iron, which rusts quickly under such conditions. When restrictions were lifted on the use of copper and copper alloys, a large manufacturer of these coolers came to Revere with a number of ideas and suggestions. He claims to be the originator of the tank-type cooler, incidentally.

His basic thought was that it should be possible to line the tank with non-rusting copper. Then, since copper has the highest heat-conductivity of any commercial metal, he planned to attach the copper cooling coils to the outside of the copper lining. Could we furnish a copper that could be worked easily, yet be sufficiently strong to withstand the inevitable mechanical abuse?

Problems such as this challenge Revere. We worked closely with our customer, investigating the mechanical requirements of fabrication and of use, and the heat-conductivity needs. Two of our sheet metal specialists were assigned to the project, and went to work with their staffs. Tests showed that electrolytic copper was not mechanically feasible, and eventually a specially-modified copper was tried and found entirely successful. The Revere welding department developed a fast method of attaching the Dryseal copper tube to the outside of the special copper lining, and the project was finished. Today, the manufacturer is selling all he can produce of this type of cooler, and, profiting by our mutually-developed data, is expanding his use of special copper alloys in coolers for other industries.

Here is a case that is fairly typical, we think, of the manner in which American industry works together as it moves ahead. If you are a manufacturer and have an idea whose practical expression may require specialized knowledge, why not talk it over with your suppliers? You may go much further and faster with than without their collaboration.

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THE COVER

The painting on the cover shows the Earth as it might appear from a point 20,000 miles above the East Coast of the U. S. (*see* Preface *on page 19*). Some 258,000 miles beyond the Earth is its single satellite the Moon. At the lower left is a part of the Milky Way.

THE CREDITS

Cover by Chesley Bonestell

The portrait of the author with each article in this issue is by William Auerbach-Levy

Page	Source
20	U. S. Navy-The Johns Hopkins University
22-23	Wide World
26-27	Mount Wilson and Palomar Observatories
29	Bell Telephone Laboratories (*top*). C. D. Anderson, California Institute of Technology (*middle*). J. R. Dunning, Columbia University
31	Irving Geis
32-35	Roger Hayward, from *General Chemistry* and *College Chemistry*, by Linus Pauling. Published by W. H. Freeman and Company, San Francisco
37	Fairchild Aerial Surveys, Inc.
38	Eric Mose
39	Fairchild Aerial Surveys, Inc.
41	*Scripta Mathematica*
56	Eric Mose
57	Berwind P. Kaufmann, Carnegie Institution of Washington
58	E. M. Wallace
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71	Cambridge Instrument Company
72-73	B. W. Zweifach, Cornell University Medical College
74	Irving Geis
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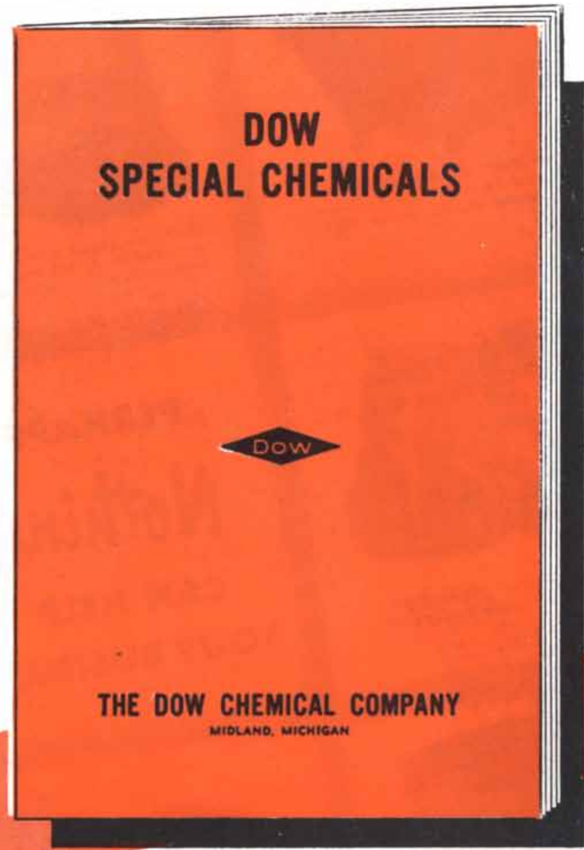
79	*Mental Testing*, by Florence Goodenough. Published by Rinehart & Company, Inc., New York
80	Eric Mose, after Carl J. Warden, Columbia University
82	Eric Mose
88	Douglas Oliver, Harvard University. (*top*). Margaret Mead (*middle*) and Harry Tschopik
90	Robert Broom, Transvaal Museum (*top*). G. Henri-Martin
109-110	Roger Hayward

DOW offers new Special Chemicals Catalog



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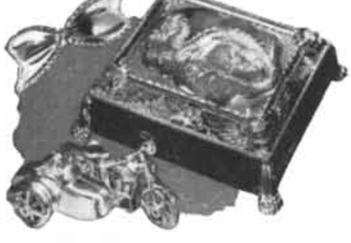

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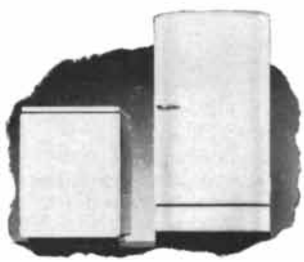

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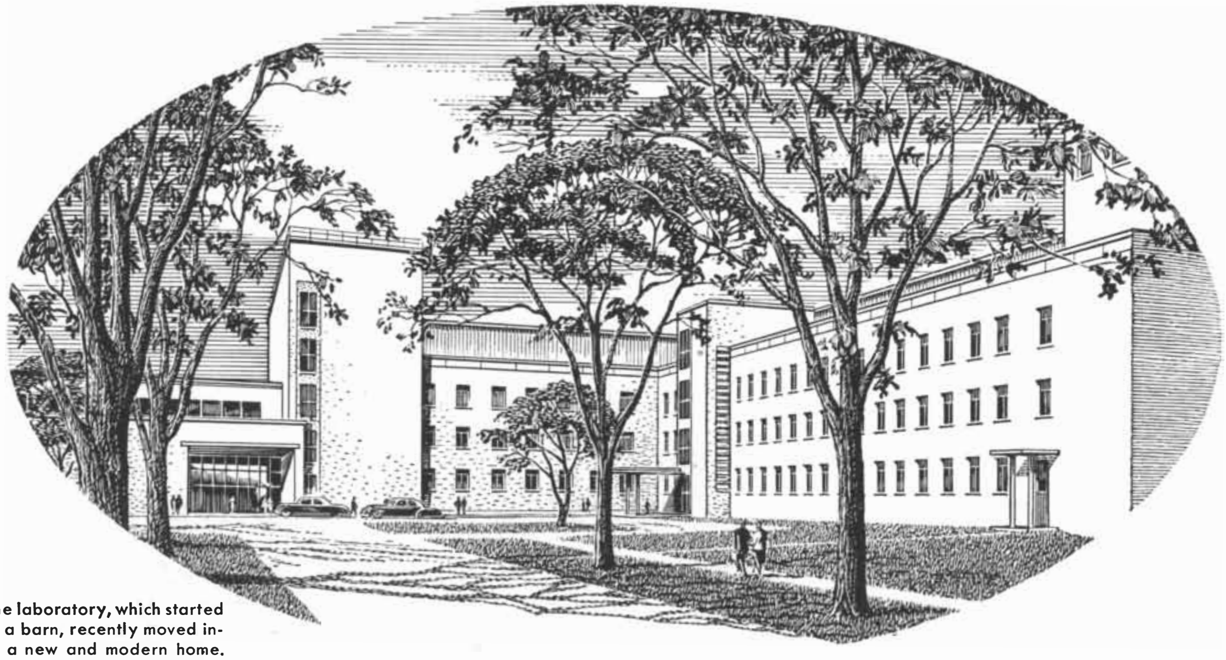
CONTENTS FOR SEPTEMBER 1950 VOL. 183, NO. 3

ARTICLES

DEPARTMENTS

50 YEARS of General Electric Research



The laboratory, which started in a barn, recently moved into a new and modern home.

It would be pretty hard to find an industry more closely associated with research than the electrical industry. And in the electrical industry the work of the General Electric Research Laboratory has played a major part.

It was established in 1900. At that time E. W. Rice, Jr., then vice president of General Electric, said:

Although our engineers have always been liberally supplied with every facility for the development of new and original designs and improvements of existing standards, it has been deemed wise during the past year to establish a laboratory to be devoted exclusively to original research. It is hoped by this means that many profitable fields may be discovered.

Many profitable fields *were* discovered—profitable not only for General Electric but also for industry, the American public, the world.

A half century ago the industrial experimental laboratory was itself an experiment. Today it occupies a firmly established and most important position in accelerating the progress of American industry.

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SCIENTIFIC AMERICAN

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Preface

THE OBJECT on the cover, basking in the sunny serenity of solar-system space, is the Earth in 1950, as it would be seen from a point 20,000 miles directly above the coast of North Carolina on the year's longest day, June 21. At that distance the Earth would have looked exactly the same, of course, on June 21, 1900; in the history of our planet 50 years is only an instant. Yet for the two billion-odd human beings who inhabit the Earth the past 50 years have been sufficiently eventful. What has distinguished this half-century from all previous ones is not wars, hunger, catastrophes or the clash of ideologies—from which no century in human history has been free—but a swift surge forward in man's knowledge and command of the physical forces of nature. Whatever else it may be, the 20th century is above all the age of science.

This issue of SCIENTIFIC AMERICAN seeks to summarize the progress of that incredibly full half-century in science—to chronicle some of the great events, to review the present state of knowledge in the various sciences and to look forward toward the future. It recounts the advances in 10 sciences covering the principal fields of man's scientific inquiry. The 10 authors of these accounts, each an outstanding authority in his field, have themselves been major participants in the 20th century's scientific revolution. Their collective review is not intended in any sense to be a definitive history of the half-century in science; rather, they have attempted to select and interpret some of the most significant discoveries and new ideas—ideas and discoveries that not only exemplify the progress of science but lie at the roots of the profound changes in man's way of life and ways of thinking that have taken place since 1900.

As J. R. Oppenheimer points out in his introduction to these 10 accounts, no scientist, let alone any layman, can be acquainted with more than a small part of the immense endeavor of modern science; the literature covering the work of the world's scientists during the past 50 years is so staggering, both in volume and diversity, as to defy even tabulation. Yet the basic questions to which this vast labor is addressed can be stated simply, and the essential findings of the scientists are well within the grasp of any literate nonscientist. Just as scientists in nearly every field now find themselves most in need of syntheses to make their mountains of facts intelligible, so the citizen who wants to understand what science has done and where it is going needs an over-all picture of the main outlines of the scientist's findings. To such a synthesis these articles make a contribution which this magazine is proud to publish.

The Age of Science 1900-1950

In the first half of this century man has vastly enlarged his understanding and control of nature. An introduction to the 10 articles in this issue

by J. R. Oppenheimer

THE SURFACE OF THE EARTH is photographed from a height of 18 miles by a camera in an Aerobee rocket. Man's deepest penetration of space by rocket: 250 miles by a two-step machine on February 24, 1949.

ONE EVENING more than 20 years ago Dirac, who was in Göttingen working on his quantum theory of radiation, took me to task with characteristic gentleness. "I understand," he said, "that you are writing poetry as well as working at physics. I do not see how you can do both. In science one tries to say something that no one knew before in a way that everyone can understand. Whereas in poetry . . ."

The 10 reports here, to which these words may serve as introduction, do indeed attest that science says things that no one knew before in a way we can all understand. They are reports, each written by a man eminent in his science, of what has happened in that science during the last half-century. They are diverse in style and in substance, reflecting the great diversity of the several sciences and the healthy and heartening diversity of the authors. Yet they all tell heroic stories. They all tell of a period of unparalleled advance of understanding, of new experience, new insight and new mastery. Indeed, for some of the sciences—for biochemistry, for physics, for genetics—the half-century now closing has been a time of splendor: of great men and great discoveries, of a real revolution in our knowledge of the world. For all it has been a time of extraordinary vitality and progress, extending and enriching what we know about the world, and unearthing, for every question answered, a host of new questions. Few of the authors, schooled by the surprises and wonders unfolded in the history of the last 50 years, hazard much of a preview of the history of the half-century to come; yet all speak with confidence of a future that will be worthy of a great past.

For truly science is a prototype of human progress. Its advances in experience and technique, in knowledge and understanding—these are never undone. Even its errors and its byways turn out, usually before many years have passed, to be an enrichment and not a perversion of knowledge. In its application to practice, in extending the resources available to mankind, as well as in its ever-growing contributions to human understanding, it has sustained and nourished the very ideal of the progress of human civilization.

All the reports are pervaded, though necessarily and properly with varying emphasis, by this sense of the dual role of science. The purpose and the fruits of science are discovery and understanding. Yet equally, though in a quite different sense, its purpose and its fruits are a vast extension of human resources, of man's power to control and alter the environment in which he lives, works, suffers and perishes. Some of the authors, perhaps notably Pauling, tend to speak of the future advances in terms of the triumphs of practice that further understanding will make possible. Kroeber speaks only most casually of practical benefits. Born, writing with the caution that experience has forced upon the physicists, refers briefly to the "formidable issues" that the advances in that science have raised. But perhaps the wisest, because most frankly paradoxical, words are those that conclude Meyerhof's brilliant report:

"Biochemistry has an important bearing on the progress of medicine. But because of this, it must remain a pure science, whose initiates are inspired by a craving for understanding and by nothing else."

With that surely most scientists will agree. We hope also for agreement and understanding from an increasing number of men who are not scientists, but who are nevertheless concerned that advances in science make the greatest possible contribution to human welfare.


Oppenheimer

YET AT THIS hour in history one cannot read these 10 reports, which constitute so substantial an account of heroic human achievement and so persuasive an example of the progress of civilization, without being sensible of a darker shadow, quite outside this serene and active workshop of the human spirit, and yet somehow touching it. Scientific progress, which has so profoundly altered both the material and the spiritual quality of our civilization, is not the sole root of its present grave crisis. But few men can be doubtful of its decisive part. Hand in hand, the growth of science and of the practical arts has produced, is increasingly producing, an unparalleled revolution in human resources, resources that in some part have altered, and in far greater part can alter, the material conditions of man's life.

Science, for all the brilliance of its contemporary development, for all the ingenuity of its technical invention, is still continuous with man's long history of rational life, of which it is a part; it is still the inheritor of the hope, so deeply founded in both Eastern and Western cultures, that, by reason and by open-minded efforts at understanding, man could not only enrich his life but better cope with the decisions that it fell to him to make. Those who are active, however modestly, in the work of science tend to feel themselves the inheritors of this tradition and of this hope. They see how vastly science, and the technology that is both its instrument and its consequence, have increased the range and difficulty and subtlety of the occasions on which decisions are required of men; they note how characteristic it is of these decisions that in one way or another they rest not with one man but with some community of men. They ask, as in all humility they must ask, whether in their own successful experience there may be any elements that could be helpful in the wider issues that confront mankind.

This is a wholesome question in the contemporary world: a world threatened with wars of vast destruction and countless particular cruelties, a world divided not only as to what constitutes truth but as to how truth can at all be established, a world overripe for the fruits of science yet in great areas destroying the essential conditions of its existence.

THE DAY is long past—if indeed it ever existed except in legend—when the whole of science was the expert province of any one man. These 10 reports are not addressed to the expert but to the interested layman. They attempt to tell, and I think for the most part with great success, of the high spots in the story of the last 50 years. There are of course important points of specific common interest between the sciences, where progress in one has made possible spectacular advance in another: so it has been with physics and astronomy, with biochemistry and physiology; so it will surely be with chemistry and genetics. The past decades have been marked by many such examples of the mutual fructification between sciences, and all signs point to its growth in the years ahead. In this happy sense a reader can discern evidences of the unity of science as he follows the reports here published.

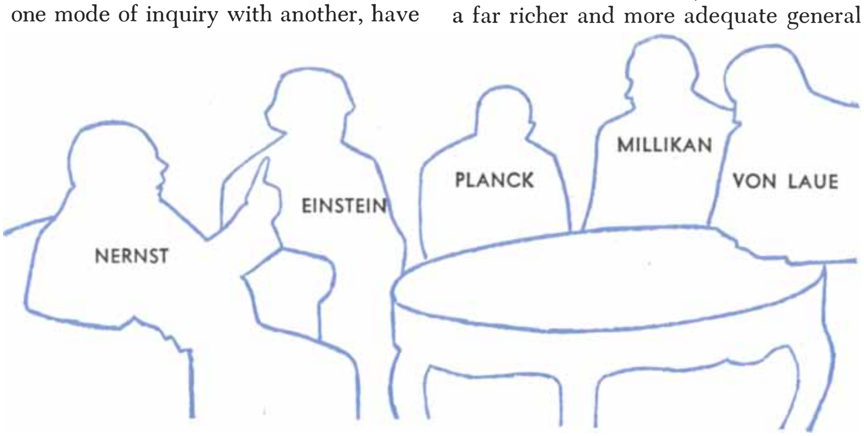
But even more striking is another almost opposite impression: that of an extraordinary diversification and specialization of the several sciences. They differ from one another, and their various parts differ from one another, by experimental techniques, by emphasis, by the kind of regularities that research reveals, by almost everything that might be codified as method. Most scientists will follow with pleasure what is written in the reports; few will fail to find something in them that is new, or newly clear; but none, I think, will recognize in himself any real technical competence, any basis for sound critical judgment, or for new discovery or new understanding, except in a very, very limited part of the broad field of contemporary science. This science is a land of extreme specialization and wonderful diversity, where the advances made by any one man rest, and necessarily rest, on the work of countless others, who characteristically have used techniques and ideas quite different from his own. This is a cooperative enterprise resting on specialization; its unity is based on the fullest exploitation and encouragement of diversity. The diversity is an appropriate reflection of the many-sidedness of our experience of nature; the unity, which we like to call the unity of nature, is in the first instance a result of the systematic application of the conviction that contradiction is a sign of error, a beginning for inquiry. The varied researches which in their totality make up contemporary science can never inhibit but only fructify one another: where their outcome appears to conflict, that conflict gives rise to new inquiry and the discovery of new truth.

Thus the order that characterizes the relations of one part of science with another is not primarily an hierarchal order. It is true that there have been attempts to sketch out possible hierarchies, designating, let us say, physics as more abstract than biology, or astronomy as more quantitative than anthropology. But it is doubtful whether such schemes have contributed much either to the growth of science or to its general understanding; certainly they do not describe at all the benign and tolerant symbiosis in which the sciences have flourished and nourished one another. Tolerance, open-mindedness and confidence in the resolution of conflict by further inquiry—these constitute the liberalism of the sciences in their relations with one another. These relations are rooted in many things, but not least in mutual respect and in a total, a deliberate candor.

OUR VIEWS on the relations of one set of researches with another, of one mode of inquiry with another, have been refined and deepened in an important way by the discoveries of the past half-century in one branch of science: atomic physics. It is probably true that in the past centuries physics led to the most nearly monistic, the least dialectical, the most hierarchal view of the order of nature. Yet it is just here that we have been most sharply taught by experience of the inadequacy of such syntheses. The discoveries in physics, which are described briefly in Born's article, revealed the inapplicability of causal, Newtonian physics to problems of individual atomic systems; they uncovered the universal duality between corpuscular and undulatory descriptions of atomic systems. Codified in the powerful formalism of the quantum mechanics, they were in the first instance given an acceptable epistemological formulation in Bohr's principle of complementarity. The basic finding was that in the atomic world it is not possible to describe the atomic system under investigation, in abstraction from the apparatus used for the investigation, by a single, unique, objective model. Rather a variety of models, each corresponding to a possible experimental arrangement and all required for a complete description of possible physical experience, stand in a complementary relation to one another, in that the actual realization of any one model excludes the realization of others, yet each is a necessary part of the complete description of experience in the atomic world.

It is of course not yet fully clear how characteristically or how frequently we shall meet instances of quite close analogy to the complementarity of atomic physics in other fields, above all in the study of biological, psychological and cultural problems. Yet it is clear, as has repeatedly been stressed by Bohr himself, that the discovery of complementarity has provided us with a far wider and more sophisticated framework for the synthesis of varieties of scientific experience. It has refined and extended the pluralism natural to science, and added new elements of subtlety to the idea of dialectic. Indeed, it seems to offer a far richer and more adequate general point of view for the comprehension of human experience than the misleadingly rigid and unitary philosophies that flowed so naturally from the experiences of Newtonian mechanics. It has also tended of course to emphasize the elements of analogy between the scientific tradition and the great traditions of Oriental philosophy, of Lao-tse and of Buddha—a circumstance which may hold some promise at this time, when understanding between diverse cultures seems more imperative than ever before.

The candor, the openness, of science is too well known to need elaborate emphasis. Yet it is basic. The most elementary student is taught to preserve and make available direct records of his experience. However obscure the findings or recondite the subject, the procedures of scientific investigation must be straightforwardly describable and communicable, so that work may be repeated at will. The mutual respect and the tolerance which ought to prevail, and so largely do prevail, in the sciences, rest in overwhelming measure on this complete accessibility. It is through this



FIVE NOBEL PRIZE WINNERS in physics met at Berlin-Zehlendorf in 1931. Walter Nernst had stated the third law of thermodynamics. Albert Einstein was the author of the special and general theories of relativity.

that a scientist, no matter how narrow his field of specialization, comes to be an equal member in a community: not because he shares the experience of all other workers or even a substantial part of it, but because no barriers have been raised and all efforts have been addressed to reducing the barriers to a minimum. Few of us can forget the delight of entering a new field of inquiry that appeared relevant at one time or another to our own work but had hitherto been unknown to us.

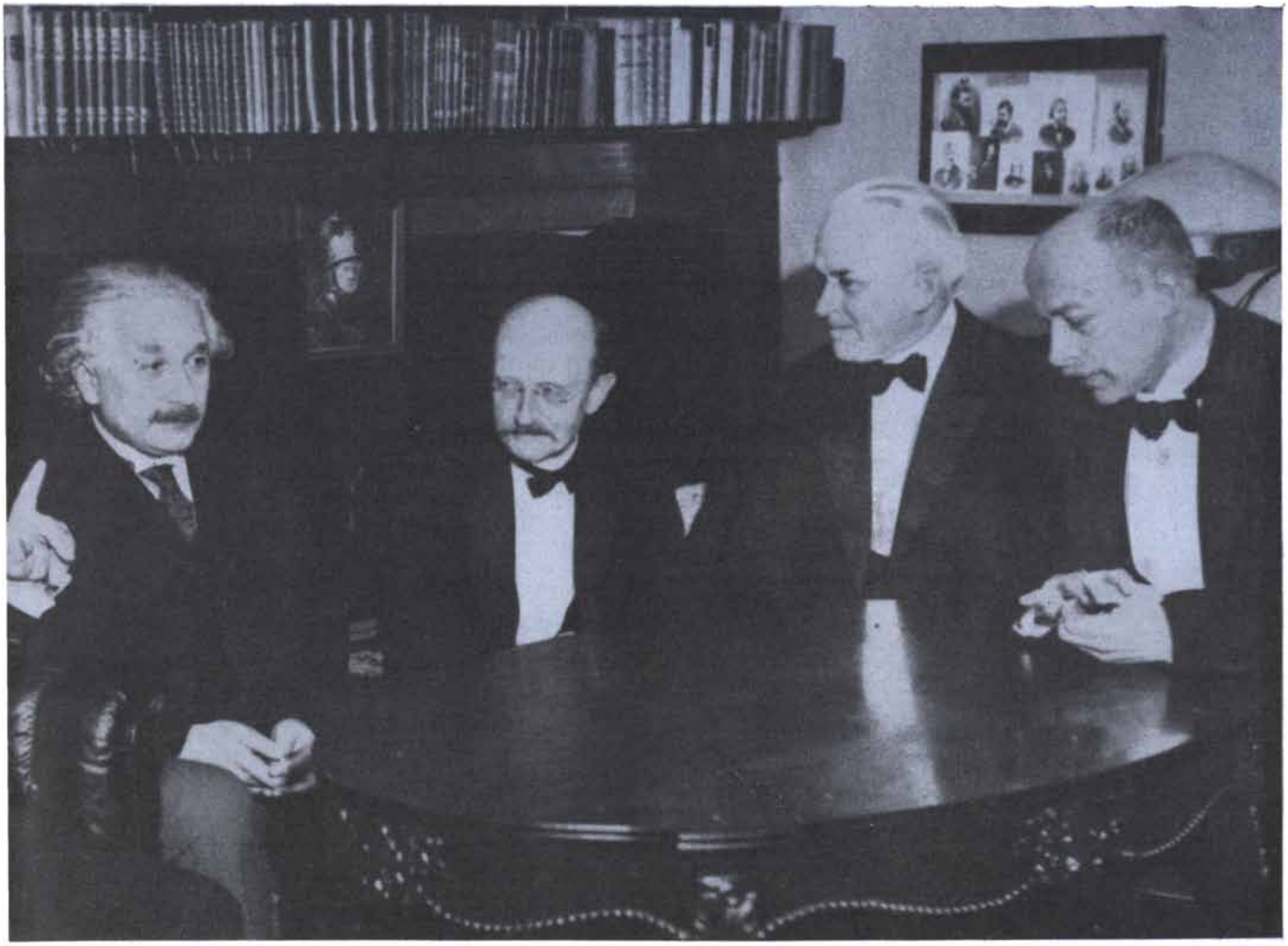
NO DOUBT there are elements of overidealization in this sketch of the relation of the individual scientist to his scientific community. Honor, prerogative and worldly pomp do sometimes, briefly and almost trivially, color and infect that relation. Yet there are few human institutions in which cooperation is more fruitful or the freedom of the individual conscience and taste more complete, where mutual respect makes for so great a harmony between the flourishing of the community and the liberation of the individual man.

This harmony, even in science itself, is being destroyed or threatened in vast areas of the world today. Terror, orthodoxy, recantation, hierarchy, secrecy—these words are full of grim omens for science and for liberty. A society which as a matter of principle invokes the measures for which these words stand betrays, whatever its protestations, science and the tradition that has nourished it. A society which invokes these measures (in the name of man's welfare, in fear or in folly) is in danger of death.

Increasingly, in these days of growing crisis, men have talked with earnest desperation of the application of scientific method to new areas, to problems of man's behavior and to human society. None of us knows or can foresee what progress individual genius and common effort may make possible in our understanding of these problems in the decades to come. Yet if the history of other sciences is a good guide, progress will come in only fitful and wayward response to man's needs, and will wait upon his insight, his patience and his invention. From this modest view, I think, neither Cantril nor Kroeber would dissent.

Yet science itself in its nature is, largely has been and in our hopes necessarily must be, world-wide. The need for the practical fruits of science is world-wide, as universal as man's striving to improve his lot on earth. The community of science is a limited but worthy prototype for that tolerant, open, open-minded community of men which alone can maintain the progress of civilization, which alone can contribute in these critical times to fulfilling the aspirations of mankind.

J. R. Oppenheimer, theoretical physicist, is perhaps best known as the wartime director of the Los Alamos Scientific Laboratory. Before the war he had been professor of physics at the University of California and the California Institute of Technology. He is presently chairman of the General Advisory Committee of the Atomic Energy Commission and director of the Institute for Advanced Study.



Max Planck had originated the quantum theory. Robert A. Millikan had measured the charge of the electron. **Max von Laue had suggested the application of X-ray diffraction to show the arrangement of atoms in crystals.**

ASTRONOMY

The big telescopes and subtler instruments have gathered and analyzed light from within the solar system to a frontier a billion light-years away

by Harlow Shapley

IN THE astronomical world of 50 years ago no reasonable dreamer could have foreseen what astronomy would grow into five decades later. Some weeks ago I assisted with doctoral examinations in astronomy. Scarcely a question asked of the candidates would have made sense to the giants of 1900—to Henri Poincaré, Simon Newcomb, Otto Wilhelm Struve, Sir David Gill, J. C. Kapteyn. They would have been baffled, helpless and perhaps suspicious in the face of inquiries concerning photomultipliers, quantum theory, solar spicules, the carbon cycle, shell stars, the expanding universe, radio "hot spots," the Schmidt reflector, Pluto, cosmic rays and other common topics of today's elementary astronomical studies. Pride in our advances and in the seeming superiority of today's workers should be mellowed, however, by contemplation of how much beyond us the astronomical world of 2000 A.D. is likely to be—in knowledge, theory and technical machinery. Will they at that date bother to use such interesting earth-anchored contraptions as the 200-inch telescope on Palomar Mountain, or be dependent on the photographic plate?

In 1900 Edward C. Pickering, my predecessor as director of the Harvard College Observatory, could have sketched in some of the infant century's promising trends, but he would have made only the poorest of predictions for 1950, largely because physics had not yet invented many of the instruments (*e.g.*, relativity theory, practical radio, photoelectric measurement) of astronomy's future accomplishments. Similarly any vision I may concoct for the future of astronomy can touch only on the most obvious trends of the next decade or two. It will probably not include, even sketchily, sensational advances in knowledge of the universe that will come from theoretical, mechanical, electrical or philosophical ideas that are now unimaginable.

In 1900 the celestial mechanics of the solar system was firmly in hand, as a result of two centuries of solid and occasionally inspired work, but knowledge of the mechanics of star systems was still embryonic. New techniques and developments were emerging, however, that promised much for the future. The many catalogues of star positions had laid the foundation for useful measurements of stellar motions, and photometric work (measurements of star luminosities) at Harvard and Potsdam had afforded a base for future studies of stellar variation and evolution. Two large refracting telescopes, at the Lick and Yerkes Observatories, were opening the era of great telescopic power in America. The *Astrophysical Journal* had recently been founded. The classification of stellar spectra on objective-prism plates had begun, pointing toward the building of the Henry Draper Catalogue of 1910-1925 and to the use of small-scale spectra in finding the temperatures, chemistry, distances and evolutionary trends of stars and nebulae.

BUT the most important tool bequeathed to the 20th century was the photographic plate. It was just 100 years ago (July 17, 1850) that the now obsolescent 15-inch refractor at the Harvard Observatory justified its standing as the then largest and presumably most important telescope in America by producing the first photograph of a star—a daguerreotype of the star Vega. In writing about this and other photographic adventures of the 1850s, the Harvard astronomer George P. Bond forecast the possible importance of photography in measuring the positions and brightnesses of the stars. He was rather eloquent about it, and correct in his surmises, but for the next 30 years relatively little happened in astronomical photography. First the dry plate had to be invented. Gradually silver halide emulsions replaced the human eye at the focus of telescopes. Yet in 1900 the Harvard collection had accumulated only 80,000 plates (it now has half a million), and elsewhere photography had not yet come into extensive use by astronomers.

At the beginning of the century, then, the recording of star and planet positions, solar-system observations and mechanics and the beginnings of mass photometry and spectroscopy were dominant. Among the chief operators in the U. S. were W. W. Campbell at the Lick Observatory, working with his spectroscopes on the line-of-sight motions of the brighter stars; Pickering at Harvard with large-field cameras and polarizing visual photometers, and Newcomb and George A. Hill in Washington, busy with orbits in the solar system. Comparably distinguished astronomers at Pulkova, Potsdam, Heidelberg and Paris were devoting themselves to the same or similar studies. In the U. S. the restless genius of George Ellery Hale was just turning to the promotion of the golden era of great observatories and telescopes, and in England two young mathematics students, Arthur S. Eddington and James H. Jeans, were preparing the careers that were to make England dominant in astronomical theory for the next 30 years. There were other serious young students, such as Henry Norris Russell in the U. S., E. Hertzsprung in Holland, K. Schwarzschild and Albert Einstein in Germany, who were destined to add much to the astronomical glory of the following decades. Let us proceed with them into the half-century that has seen general knowledge grow sensationally, thoughtful judgment decline and national and international morality tested by the fires of futile wars and baffling social revolutions.

IT WOULD perhaps be more than bold to attempt a list of the five outstanding developments, say the characteristic and dominant contribution made in each of the five decades since 1900; there have been so many basic contributions in the half-century. Nobody would be altogether satisfied with the five if I listed as the most significant: (1) analysis of stellar motions, (2) confirmation of the theory of relativity, (3) the concept of spiral galaxies, (4) the designing and building of great telescopes, (5) radio astronomy. One might find equal support for a different list: the birth of modern trigonometric parallax, the Henry Draper Catalogue, the exploration of stellar interiors, the development of the carbon cycle of stellar energy, the building of coronagraphs and birefringent filters. Or still another list: development of the quantum theory, globular clusters and the galactic center, the rotation of galaxies, researches on interstellar dust and gas, the rise of photocell astronomy. And even these listings do not include specifically such important discoveries as the period-luminosity relation, the Russell-Hertzsprung diagram, the prevalence and structure of dwarf stars and the mass-luminosity law.

In retrospect, developments in theory seem to be in the minority in these lists. Many of the theories have briefly served their makers (and the science) and then perished; whereas good observations, although frequently dull and laborious, have enduring characteristics.

However inadequately I have portrayed the highlights, we would all agree that it has been a wonderful half-century. Now where do we go from here? We are outfitted with excellent schools of astronomy, with telescopic power 100 times as great as 50 years ago, and with allies in the fields of electronic engineering, atomic physics, geochemistry, meteorology and statistical mathematics who should steadily enrich our inventions and interpretations. The public is effectively interested in astronomy. The Astronomical League is composed of more than 50 astronomical societies. The Schmidt type reflectors; the coronagraphs with filters that segregate narrow spectrum bands; the 200-inch Hale telescope on Palomar; the big telescopes that are building or contemplated in Australia, South Africa, Egypt, India, Sweden, Germany, France, Belgium, England, the U.S.S.R. and the U. S.; the microwave "dishes"; new electronic devices—all these implements will provide abundant discoveries throughout the next two decades.

WITHOUT reaching too far toward the unpredictable years around 2000 A.D., one can suggest that the major trends in the next decade or two may lie in the fields of cosmic physics, precise stellar spectroscopy, the unravelling of the detailed structure of the Milky Way, the mapping of the neighborhood of our galaxy, and the always fertile and generally futile speculation about the origin of the planetary system. These fields now appear most obvious for future development. They will demand much of the imagination and of instrumental ingenuity.

There are, of course, other rich fields. One bonanza lies near at hand in the upper atmospheres of the earth and of the sun. The intensive visual, photographic and microwave radio study of meteors, and the exploration of the peculiar radiations from the flares and the corona of the sun, will give us a rich return in our attempts to interpret fully the earth's upper atmosphere.

It is high time that astronomers do something significant about cosmic rays. The physicists now do practically all of the observing and thinking in this area, although astronomers have known for many years that a large portion of the energy of the universe is involved in these exceedingly high-frequency, penetrating rays. Where cosmic radiation originates is still a great question. Even if the cosmic rays received by the earth should turn out to be localized in the neighborhood of the solar system, we must remember the other billions of stars identical with the sun. In cosmic radiation we are dealing with a universal phenomenon that is energetic, basic and mysterious. We cannot afford in the years to come to neglect the extreme ends of the spectrum—either the long radio waves or the short cosmic rays with which the stars amuse themselves and confuse us mightily.

Shapley

Little foresight is required to see that microwave astronomy, using radiations in the wavelength range of one centimeter to 10 meters both for radar tracking and for listening to the broadcasts from space, will bring in highly significant data for the study of the Milky Way, the sun's surface, interplanetary space and meteors. The astrophysicists must actively join the electronic engineers in the development of this young branch of the science. On the basis of the work of the past few years we can also see that the magnetic properties of the sun and stars, and the newly discovered polarization of starlight, can be fruitfully explored in the next decade.

FROM the 20 new photoelectric photometers now posted in various parts of the world, half a dozen of them in the Southern Hemisphere, we should soon get a flood of information. For example, we should obtain precise light-curves of variable stars, measurements of star colors so accurate that "temperature variables" may become a common term, photometric records of the planets of such resolution that they can help us make practical topographic surveys of surface features, data on the rotations of ragged asteroids and on the internal structure of galaxies, and information for the development of new theories on the zodiacal light and the *Gegenschein*. Photoelectric operations in astronomy now enter a wide field.

But as I intimated earlier, it is likely that the outstanding astronomical contribution of the next half-century will occur in some unexpected activity. For example, the now dormant relativists may awaken to brave new concepts that will reorient us in the universe of matter and ideas much as quantum theory and relativity, radioactivity and photography have done in the past. We have solid foundations. What structures can we build thereon?

Astronomers must keep their eyes and ears open, watching and listening to the physicists, engineers, philosophers, geologists and chemists. They must dream of the impossible, and promptly design the best way to attain it. Already we see the glimmers of a strange dawn, of an exciting era. Perhaps space does congeal continuously into matter; perhaps the relativity theory is only the first approximation to something still simpler; perhaps the moon is "alive"; perhaps the other planets do have Saturnian rings that would be "visible" if we could devise the proper optics; perhaps the Milky Way is not one but several galaxies; perhaps elements or at least isotopes that do not exist on the earth are to be found on the red "flare" dwarf stars, or inside the supergiants; perhaps a trans-Plutonian shell of comets would reflect radio waves, or emit them; perhaps the sun, spectrographed from a 200-mile-high rocket, will not have any appreciable radiation at wavelengths shorter than 1,000 Angstroms (in the ultraviolet range), thus blowing up delightfully a number of inviolable theories.

The search demands patient work, imagination, freedom to inquire and skepticism about dogmas, about preliminary measures and especially about one's own hunches. For five decades we shall design, measure and think. In the summer of 2000 A.D. we shall ask, "Well, what were the answers, and what do *you* predict?"

Obviously the most interesting feature

of this science astronomy (and of all science) is our eager ignorance.

Harlow Shapley has passed his entire astronomical career with two institutions that are highly characteristic of the half-century in astronomy. From 1914 to 1921 he was at Mount Wilson Observatory, whose great 60- and 100-inch reflectors epitomized the trend toward giant telescopes. With the 60-inch Shapley did much work of first-rank importance, notably the use of pulsating Cepheid variable stars to measure the distance of globular star clusters. By this investigation he located the center of our stellar system, the Milky Way. Since 1921 Shapley has been director of the Harvard College Observatory, which epitomizes another significant trend: international coordination of astronomical research.

SIX PHOTOGRAPHS from Mount Wilson and Palomar Observatories illustrate some significant astronomical researches. The photographs were selected by Milton L. Humason.

1. SOLAR FLARE erupted from the surface of the sun on April 8, 1936 (A). The same region is shown 16 minutes earlier in B. At the time of the flare severe radio and magnetic disturbances were observed on earth. This was evidence of a connection between such disturbances and flares.

2. DWARF GALAXY N.G.C. 185 is an example of one of the two distinct types of stellar population that have recently been recognized. The stars in this galaxy, which resemble those found in globular clusters, form an almost pure Type II population. The same kinds of stars are found in the central regions of the Great Nebula in Andromeda and of the Milky Way. The outer regions of these galaxies, however, are characterized by Type I stars. This classification has opened new approaches for speculation on the evolution of stars and galaxies.

3. SUNSPOT SPECTRUM shows zigzagging of vertical dark lines due to the magnetic field of the spot. This displacement of lines, called the Zeeman effect, was evidence that revealed the magnetic field of sunspots.

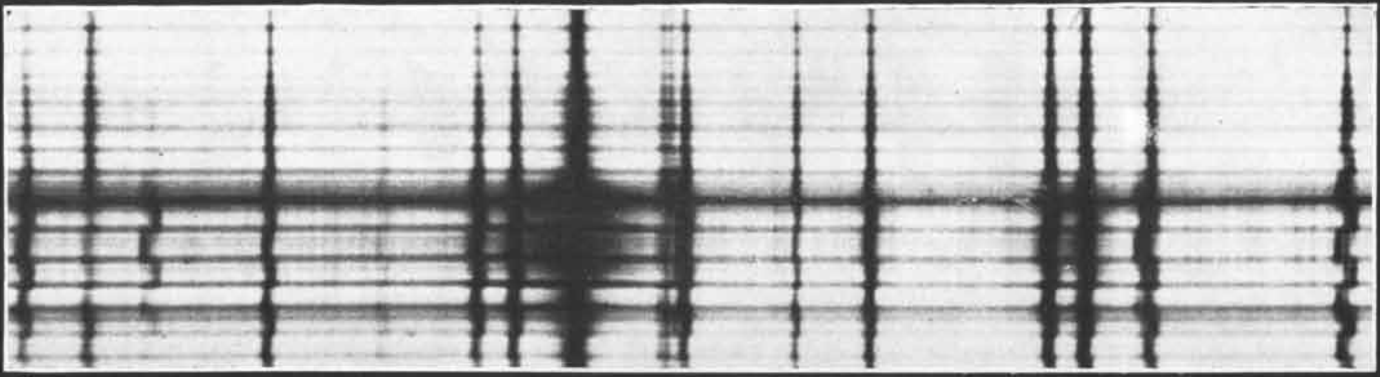
4. STELLAR SPECTRUM shows dark lines of interstellar dust and gas. Lines in A are from calcium; those in B from calcium and a molecular combination of hydrogen and carbon. The continuous background spectrum is from the star Zeta Ophiuchi.

5. FOUR GALACTIC TYPES appear in one cluster of galaxies. The galaxies are N.G.C. (New General Catalogue) 3185, 3187, 3190 and 3193.

1A

1B

2



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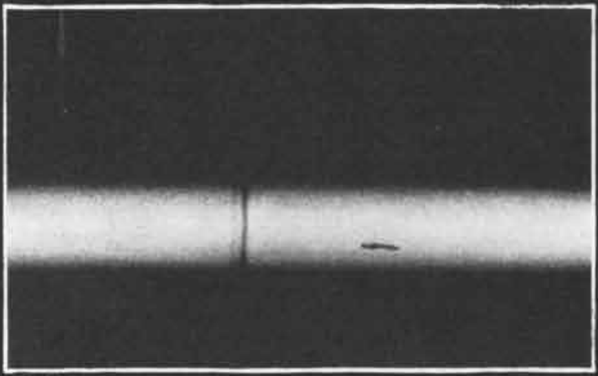
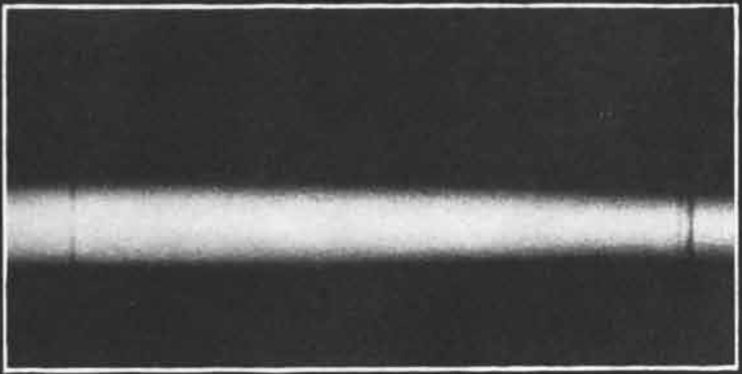


4A



4B

5

PHYSICS

The great experiments and heroic theories have revolutionized our view of the physical world and brought us closer to its underlying unity

by Max Born

NO OTHER half-century in history has witnessed so revolutionary a transformation in man's view of the nature of the physical universe as the one through which we have just passed. We have seen not only a vast accumulation of new facts but a profound revision of basic ideas and principles. Without attempting to review in detail the gigantic work of the past half-century in physics, one can indicate the nature of the transformation by describing some of the developments that most strikingly illustrate the contrast in the ideas held at the beginning and the midpoint of the century.

In 1900 Newton's concepts of space and time were still universally accepted. They imply a restricted relativity, the mechanical equivalence of an infinite number of "inertial systems" of reference moving with constant relative velocity. However, the propagation of light waves through interstellar space was believed to demand a substantial carrier of some kind—an "ether absolutely at rest." On the other hand, all experimental attempts, *e.g.*, those of A. A. Michelson and E. W. Morley, to measure the absolute motion of the earth had failed. This discrepancy between theory and observation could only be solved by a critical revision of our notions of space and time. This work, started by Henri Poincaré, H. A. Lorentz, G. F. Fitzgerald and others, was finally in 1905 reduced by Albert Einstein to a simple argument: The conception of absolute simultaneity of events at different places has no physical meaning, because the velocity of the fastest signals (light) is the same for all observers, irrespective of their motion. In 1908 Herman Minkowski established the adequate mathematical treatment of this theory; space and time were merged into a four-dimensional extension, where every point represents an "event," and where a generalization of ordinary Euclidean geometry holds.

The most important consequence of relativity is Einstein's law of the equivalence of mass and energy, expressed by the equation $E = mc^2$, c being the velocity of light. This law, first regarded as a matter of mainly philosophical interest, later turned out to have immense practical implications.

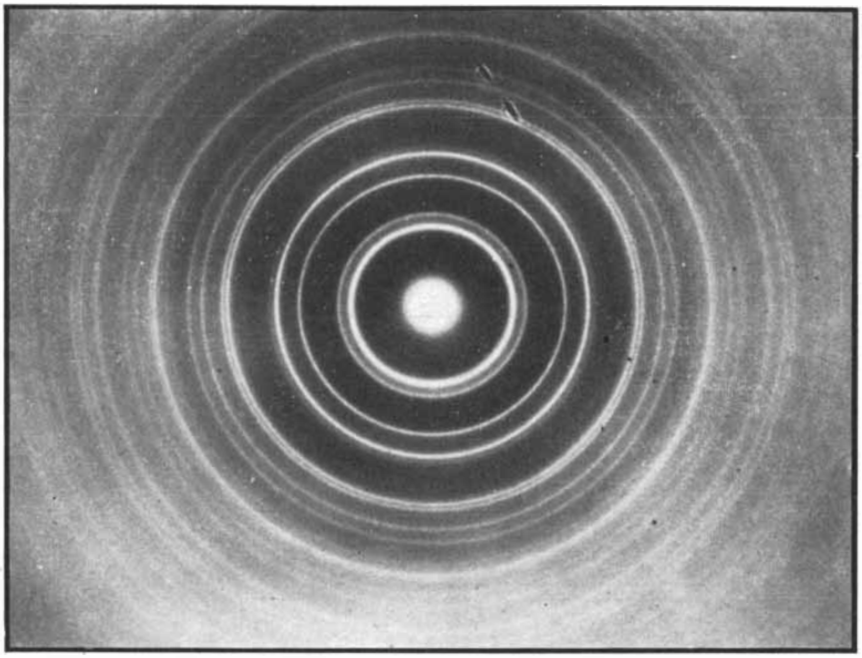
In 1915 Einstein extended relativity to accelerated systems and obtained a field theory of gravitation, which contained Newton's theory as a first approximation. Its greatest success was the prediction, and the verification during the total eclipse of 1918, that the light coming to us from stars is deflected when it passes near the sun. Einstein's general theory of relativity provided the foundation for a rational cosmology and cosmogony, of which in 1900 there had been hardly a trace. From the observational side astronomers developed the concept of the "expanding universe," based on the discovery that the distant nebulae or galaxies were moving away from us with velocities proportional to their distances. By 1927 mathematicians had worked out a modification of Einstein's equation which described a closed, expanding universe of "curved" spaces. This theory stimulated a vast number of investigations which widened our astronomical horizon more than had the work of all previous centuries.

IN 1900 physical research was still largely working with the concept of "continuous" matter; that is, it was concerned with the principles governing the behavior of matter in bulk, ignoring its atomic structure. For most practical applications these methods—the laws of classical physics—have continued to serve. The progress and achievements in this domain have been spectacular enough. One has only to remember that in 1900 the internal-combustion engine was in its infancy, the motorcar was just making its appearance and the airplane was still a dream. In response to the ever-increasing demands of technology, applied mathematics and mechanics acquired a new vitality. The results of the half-century's advances in thermodynamics, in hydrodynamics, in electricity, in aerodynamics, in acoustics (including the new study and applications of ultrasonics) are apparent in many aspects of our daily lives. Hydrodynamics, which in the 19th century was a beautiful mathematical theory, often in flagrant contradiction to experience, has become more realistic and tackles problems (*e.g.*, turbulence) actually occurring in daily life and technology. Aerodynamics has been able to explain the forces acting on aircraft in flight and to deal with problems of airplane stability, even at supersonic velocities. In acoustics ultrasonic vibrations have been used for studying the elastic properties of crystals, for signaling and for timekeeping; a clock constructed of a piezoelectric crystal and an electric resonator has turned out to be more accurate than ordinary pendulum clocks. In thermodynamics particular mention must be made of the progress in theory and in experimental observation of the behavior of matter at extremely low temperatures, close to the absolute zero, where such strange phenomena as the superconductivity of metals and the "degenerate" state of liquid helium were discovered. Spectacular also has been the progress of electrodynamics. Although Marconi had already sent the first wireless signals in 1895, electromagnetic oscillations and waves were not much more than a laboratory experiment; today there is hardly an aspect of our technology, from radio to automatic computing machines, in which they have not been put to use, with the aid of the electronic tube; and radio broadcasting has become a powerful factor in human affairs. Moreover, more and more of the electromagnetic spectrum has been brought under study and useful employment. In 1900 there was a large gap between the longest light or heat waves from incandescent bodies and the shortest known radio waves. Today the gap has been almost closed. Very short electric waves, down to about one centimeter in wavelength, have been put to use in radar, in exploring molecules and determining nuclear spins, in detecting meteor trails and even to reach out to the moon, from which radar echoes of man-made energy have been obtained. Especially important has been the development of the new science of radio astronomy, which is examining radio waves emitted from the sun and the stars.

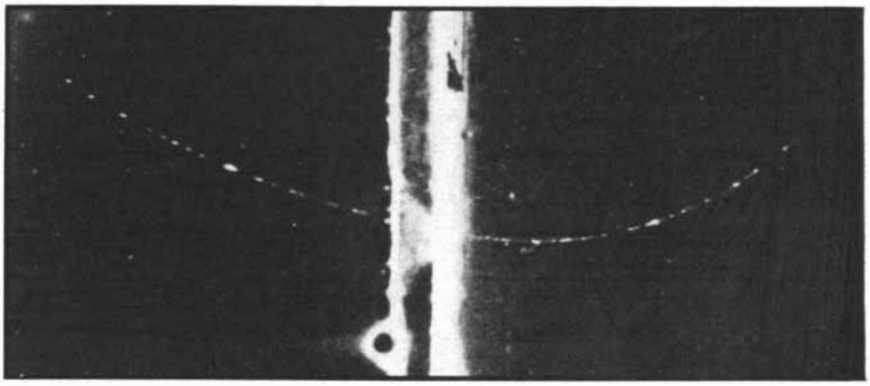
BUT in the final analysis the most striking difference between physics in 1900 and in 1950 is the complete victory of atomistics. The speculations of the ancient Greek philosophers and the dreams of the alchemists have come true. In 1900 the story of the atom was already beginning to unfold, although there were distinguished scholars who still denied the existence of atoms. The landmarks of this history are now familiar to almost every literate person: the discovery of the electron by J. J. Thomson in 1894, of X-rays by W. K. Roentgen in 1895, of radioactivity by Henri Becquerel in 1896 and of the enormously radioactive elements radium and thorium by Pierre and Marie Curie in 1898; the identification of the atomic nucleus and of alpha and beta rays by the brilliant researches of Ernest Rutherford and his school from 1902 on, and the decisive evidence for the reality of atoms that was derived from the Brownian movement of particles by Einstein in 1904 and Maryan von Smoluchowski in 1906.

Today we know beyond doubt that the atom is built up of (1) nucleons, *i.e.,* positively-charged protons and uncharged neutrons, and (2) electrons, negatively-charged particles about 1,800 times lighter than the nucleons. The nucleus of the atom, a densely packed cluster of protons and neutrons, is only a millionth of a millionth of a millimeter in diameter, and around it the electrons move, like the planets around the sun, in orbits whose diameters are about 10,000 times larger than that of a nucleus. Each atom has exactly as many electrons as it has protons, or positive charges, in the nucleus. All chemical and almost all physical properties depend only on the number of protons. Since the number of neutrons with a given number of protons may vary, there may be several atoms, or isotopes, of the same chemical type but different mass number. Chemical elements are mixtures of isotopes.

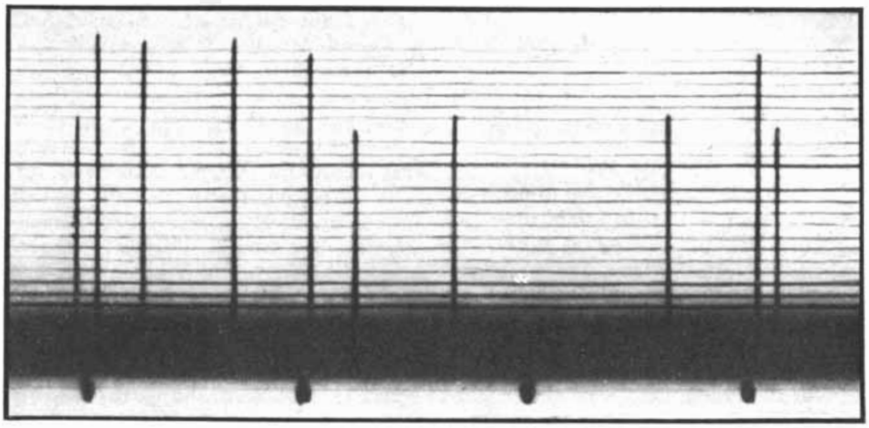
Yet this picture of the atom, simple though it seems, unfolded only slowly through incessant improvement of experimental methods and critical analysis of theoretical concepts. To explore the atom many ingenious instruments have



ELECTRON DIFFRACTION experiments of the 1920s indicated that these tiny particles are also waves. This pattern is produced by directing a beam of electrons through a metal foil and against a photographic plate. The electrons are diffracted like waves by the regularly spaced atoms of metal crystals.



POSITRON was discovered in 1932 by C. D. Anderson and Seth H. Neddermeyer. The evidence was this curved track in a cloud chamber. The curvature of the track in the magnetic field about the chamber was similar to that of an electron but in the opposite direction, indicating particle of opposite charge.



URANIUM FISSION was observed by several laboratories in Europe and the U. S. in 1939. The vertical lines on this oscillograph record show the energy of heavy and light fission fragments that were produced by bombarding a tiny sample of uranium 235 with deuterons in a Columbia University cyclotron.

been devised: the scintillation screen and later the Geiger counter for detecting and counting particles emitted from the nuclei of atoms, the Wilson cloud chamber and the photographic emulsion for recording the tracks of atomic particles, the mass spectrograph for separating isotopes and determining their masses, and so on.

With rather primitive instruments Rutherford and Frederick Soddy first analyzed the process of radioactive disintegration and found that it consists in a series of transformations of one atom into another. Thus the belief in the invariability of the chemical elements was shattered. At the same time ample proof of the existence of isotopes was discovered among the heavy, radioactive elements, all of which were found to decay in time into various isotopes of lead. When accurate mass determinations became possible through the use of the mass spectrograph, the masses of all isotopes turned out to be very nearly integer multiples of the mass of the hydrogen atom. The internal structure of atoms was explored by bombarding them with various kinds of radiation and observing how they absorbed or scattered these radiations. Rutherford, by accurate measurement of the scattering of alpha rays by atoms, gave convincing proof for the "planetary" model of the atom, and determined the nuclear charge that attracts the electrons and keeps them in their orbits.

But formidable difficulties arose. In the first place, it was impossible to explain the perfect stability of atoms by a Newtonian model. Nor could Newtonian laws account for the random character of radioactive decay. Newtonian mechanics requires that every physical event must be strictly determined—traceable to some cause. Yet in the case of the radioactive disintegration of atoms, say of radium, though the average rate of decay of a great number of atoms is perfectly determined, it is not possible to predict the moment when any given radium atom will disintegrate. At first this was thought to be due simply to a gap in our knowledge of the influences producing disintegration, but the difficulty turned out to be of a more fundamental character.

THE SOLUTION of these difficulties came from a quite different series of investigations and was much more radical than expected. It meant nothing less than the replacement of classical mechanics and its strict determinism by a new atomic mechanics which is essentially statistical and indeterministic.

It was from the study of radiant heat that the new mechanics started. In 1900 Max Planck had convinced himself that the observed spectrum of radiation from black bodies could not be accounted for by classical mechanics but only by the strange assumption that the radiated energy was given off in finite "quanta" instead of continuously. The quantum in each case, he found, is proportional to the frequency of the radiation; he calculated it to be the frequency times a fixed number that came to be known as Planck's constant.

The physical world received this idea with great skepticism. It seemed quite unreasonable to return to the old corpuscular concept of light. The wave theory of light had been well established by innumerable experiments, and the wavelengths of light could be measured with extreme accuracy. Nevertheless the corpuscular idea grew in weight. Einstein took it up and showed that the ejection of electrons from metals by light (the photoelectric effect) and the thermal properties of molecules and crystals could be explained in terms of Planck's quanta.

Born

In 1913 Niels Bohr applied the quantum hypothesis to Rutherford's planetary model of the atom with great success. The quantum theory at one blow solved the riddle of atomic stability and explained the mysterious regular series of spectral lines in the spectra of gases (such as the Balmer series of hydrogen) and some features of the periodic system of elements. Many of Bohr's predictions were soon confirmed by experiment, and the theory was extended by Arnold Sommerfeld and others in several directions. George Uhlenbeck and S. A. Goudsmit discovered the spin of the electron, and Wolfgang Pauli formulated the important "exclusion principle" relating to the orbits of electrons. This enabled Bohr himself to complete his interpretation of the periodic system of elements in terms of electronic orbits, and his new interpretation led at once to the discovery of one of the missing elements, hafnium. Even the most startling predictions arising from Bohr's theory, such as those concerning the orientation of atoms in magnetic fields, were found to be in agreement with observation. Meanwhile A. H. Compton's experiments on the scattering of light by electrons gave conclusive proof of the existence of light quanta or "photons."

Thus the paradoxical situation had to be faced that both the wave and the corpuscular theories of light were correct—in fact, Planck's formula $E = h\nu$ (the quantum of energy equals Planck's constant times the frequency) actually states a relation between these contradictory concepts. Louis de Broglie brought this challenge to reason to its most baffling climax: by applying the principles of relativity he showed that electrons may under certain circumstances behave as waves, and this was soon experimentally confirmed by diffraction experiments. In short, not only do waves behave like particles, but particles behave like waves.

SO stood matters at the midpoint of our half-century. The central problem of physics was to formulate a logically consistent theory that would account for the particle and wave aspects of light and matter. A satisfactory mathematical theory was soon developed. It was stated in several different forms: quantum mechanics by Werner Heisenberg, Max Born and Pascual Jordan; wave mechanics by Erwin Schrödinger; "symbolic" mechanics by P. A. M. Dirac. The new theory included classical mechanics as a limiting case and preserved some of its formulas, but differed profoundly from it in being essentially statistical and indeterministic. These features were strikingly formulated by Heisenberg in his so-called uncertainty principle, and were elaborated by Bohr in many examples. In 1928 Dirac showed that the adaptation of the theory to relativity led automatically to an explanation of the spin of the electron and to the prediction of the existence of positive electrons, which were soon actually found by Carl Anderson.

Today we have a complete theory of the electronic structures of atoms and molecules and of their relation to line and band spectra, to magnetism and to other phenomena. The explanation of the chemical bond in terms of quantum mechanics has made chemistry in principle a branch of physics.

Parallel to this investigation of the cloud of electrons in the outer part of the atom marched the exploration of the nucleus. Rutherford in 1919 was the first to break up the nucleus of an atom, by bombarding nitrogen with alpha rays from radioactive elements. By 1930 J. D. Cockcroft and E. T. S. Walton had begun to attack the nucleus with artificially accelerated particles, and two years later Ernest O. Lawrence invented for this purpose the cyclotron, the first of the huge modern machines for producing extremely fast particles. At the same time James Chadwick pushed our understanding of the nuclear structure a long step forward by his discovery of the neutron. Enrico Fermi then showed that neutrons, which are not repelled by the nuclear electrical charge, are most efficient weapons for disrupting atomic nuclei.

By means of these projectiles and the very fast cosmic rays (which had been discovered by Victor Hess in 1912) physicists began an intensive study of nuclear transformation. A kind of nuclear chemistry—modern alchemy—came into existence, using reaction formulas very similar to those of ordinary chemistry. The total binding energy of a nucleus is obtained from its mass by applying Einstein's equation $E = mc^2$. The results could be interpreted with the help of a simple model, where the nucleus is treated as something like an electrically charged liquid drop with surface tension. Thus it was shown that the nuclei of light atoms should exhibit a tendency to fuse, and heavy nuclei to disintegrate. Hence all matter except the elements in the middle of the periodic table, such as iron, is in principle unstable. Under terrestrial conditions nuclear reaction rates are so slow that no fusion or disintegration to speak of takes place. But conditions are very different in the interior of stars, and Hans Bethe showed in 1938 that one can account for the heat developed in the sun and the stars by a nuclear process that fuses four hydrogen nuclei to form a helium nucleus. The opposite phenomenon—the fission of the heavy nucleus of uranium into almost equal parts—was discovered on the earth by Otto Hahn and Fritz Strassmann in 1938. This process is initiated by the capture of a neutron and is followed by the emission of several neutrons. Thus a self-supporting chain reaction can be obtained by which enormous energies are released.

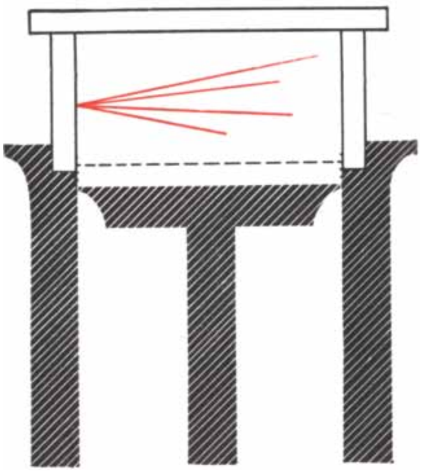
It is general knowledge how this discovery, under the pressure of war, led to the construction of a nuclear reactor or "pile" and finally to the production of the atomic bomb. This is not the place to enlarge on the technological problems connected with this development, nor on its economic and political implications and the formidable issues it has raised for mankind. We need only note here that peaceful science—physics, chemistry, biology, medicine—has greatly profited from the products of the pile. The remaining few gaps in the periodic table of elements have been filled, and six transuranic elements, some of them fissionable, have been created. Innumerable new isotopes of known elements have been produced. Some of these can be used as "tracers" in chemical and biological research, others in the treatment of cancer and other diseases.

THE LAST decade of our half-century has brought us to grips with a most fundamental problem—the nature of the forces that bind the nucleus of the atom. The nuclear forces differ, by their short range of action, from the electromagnetic forces which keep the electrons in their orbits. As Alexandre Proca pointed out, there exists a generalization of James Clerk Maxwell's electromagnetic equations which has such short-range solutions. By studying other solutions representing waves, Hideki Yukawa was led in 1935 to predict the existence of a new kind of particle called the meson, which is in the same relation to the nuclear field as light quanta are to the electromagnetic field. The mass of the meson was calculated from the range of forces to be about 300 times that of the electron. The actual existence of mesons was soon confirmed experimentally, first in cosmic rays, later by their artificial production in the University of California cyclotron. Two kinds of electrically charged mesons, one 300 and the other 200 times heavier than the electron, have been found; the first kind spontaneously decays into the second (plus a neutral particle). It is probable that other types of mesons, still undiscovered, exist.

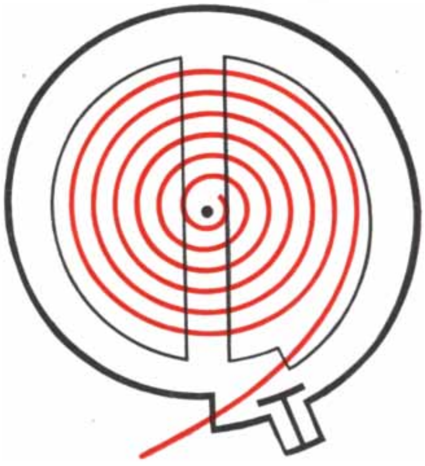
These discoveries open new vistas for the future. The electromagnetic field which has long dominated physics will very likely be found to be only one of many fields, each associated with a type of particle. The fundamental problem will be to establish the relations of all these entities and to unite them into one theory, not excluding gravitation.

SURVEYING this brief account of half a century, we find two remarkable facts: The fundamental—or metaphysical—concepts concerning space and time, matter and motion, cause and effect, which physics has inherited from a previous period, have not withstood the onslaught of new experiences and have had to be replaced by different, even opposite ideas. On the other hand, the actual physical theories, though strongly modified and extended, have never been quite discarded; the old ones are always preserved as limiting cases in the new ones. Thus in the midst of turbulent happenings and in spite of an incredibly widened horizon of facts and theories, the continuity of physical research has been perfectly preserved.

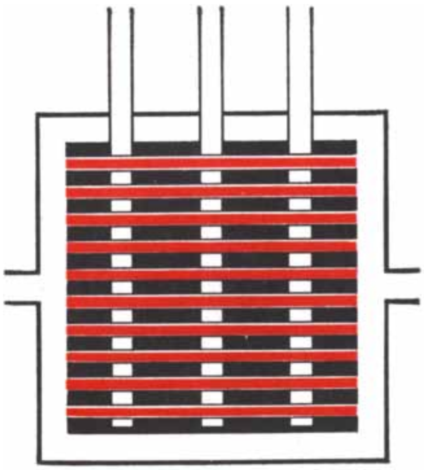
Max Born has been one of the active participants in the physical revolution of the past 50 years. He is one of the principal architects of quantum mechanics. His books include the recent Natural Philosophy of Cause and Chance *and the excellent popular account of physics* The Restless Universe. *He has been an influential teacher in Göttingen, Berlin, Frankfurt-am-Main, Cambridge and Bangalore. He is now Professor of Natural Philosophy at Edinburgh University.*



CLOUD CHAMBER, invented by C. T. R. Wilson, makes tracks of subatomic particles visible. When piston drops, droplets condense on tracks.



CYCLOTRON, invented by Ernest O. Lawrence, accelerates particles to high energies by whirling them in "dees" within a magnetic field.



ATOMIC PILE is an arrangement of moderator (*black*) and uranium (*red*) to produce slow neutron chain reaction. Vertical rods are controls.

CHEMISTRY

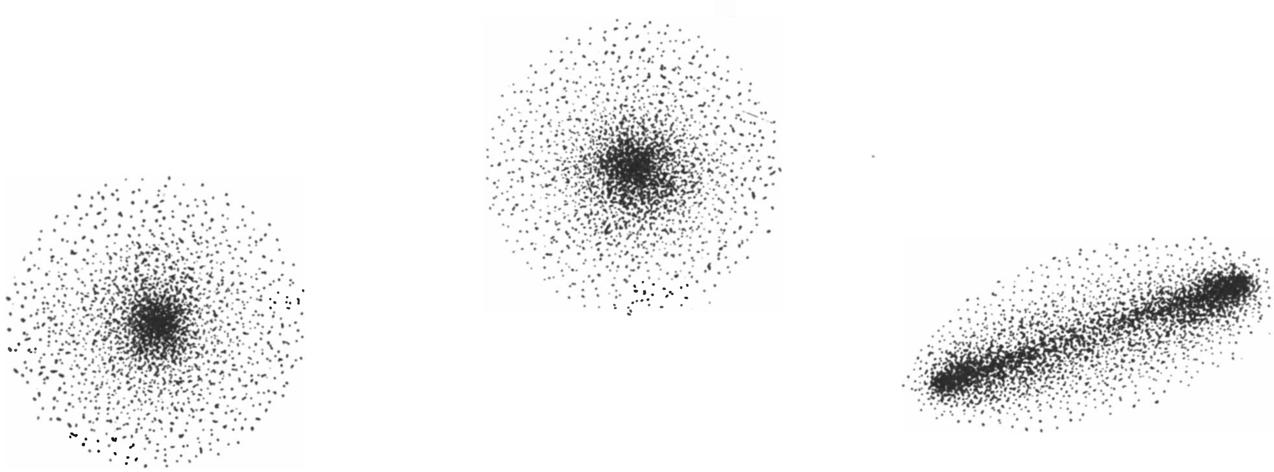
Aided by the new ideas of physics, the chemists have welded a huge body of facts into a unified system. Many of their fundamental advances have quickly become part of technology

by Linus Pauling

THE HALF-CENTURY we are just completing has seen the evolution of chemistry from a vast but largely formless body of empirical knowledge into a coordinated science. This transformation resulted mainly from the development of atomic physics. After the discovery of the electron and of the atomic nucleus, physicists made rapid progress in obtaining a detailed understanding of the electronic structure of atoms and simple molecules, culminating in the discovery of quantum mechanics. The new ideas about electrons and atomic nuclei were soon introduced into chemistry, leading to the formulation of a powerful structural theory which has welded most of the great mass of chemical facts into a unified system. At the same time great steps forward have been taken through the application of new physical techniques to chemical problems, and also through the continued effective use of the techniques of chemistry itself.

Chemistry is a young science. The chemical revolution took place only a little more than 150 years ago, when Antoine Laurent Lavoisier first clearly explained the role of oxygen in combustion and the nature of elementary and compound substances. Before Lavoisier chemical operations had been carried out according to recipes, and chemical reactions had been discovered only by haphazard trial. His new approach led to the rapid collection of a great amount of information about inorganic and organic substances. In 1828 Friedrich Wöhler achieved the first synthesis of an organic substance of animal origin (urea) from inorganic materials, and in the following decades many thousands of new substances were synthesized and their properties investigated. In 1852 Sir Edward Frankland formulated the theory of valence, and in 1858 Friedrich August Kekulé perceived that carbon has four valences; this insight gave great impetus to organic chemistry. Louis Pasteur's discovery of optical activity (the property, possessed by tartaric acid and many other substances, of rotating the plane of polarization of polarized light) and its explanation by means of the theory of the tetrahedral carbon atom by Jacob van't Hoff and Joseph LeBel effectively completed the classical structural theory of organic chemistry. Guided by this theory, and making use of many special techniques of analysis and synthesis, the organic chemist then investigated great numbers of natural substances and new substances made in the laboratory. Many of them were found to be valuable as dyes, as medicines, in foods and for special industrial purposes, and an immense organic chemical industry was developed, largely based on coal tar.

DURING the first half of the 20th century organic chemistry has advanced along an extension of this road. The theory of the structure of organic molecules has become more precise and more useful through the incorporation in it of the theory of resonance and the

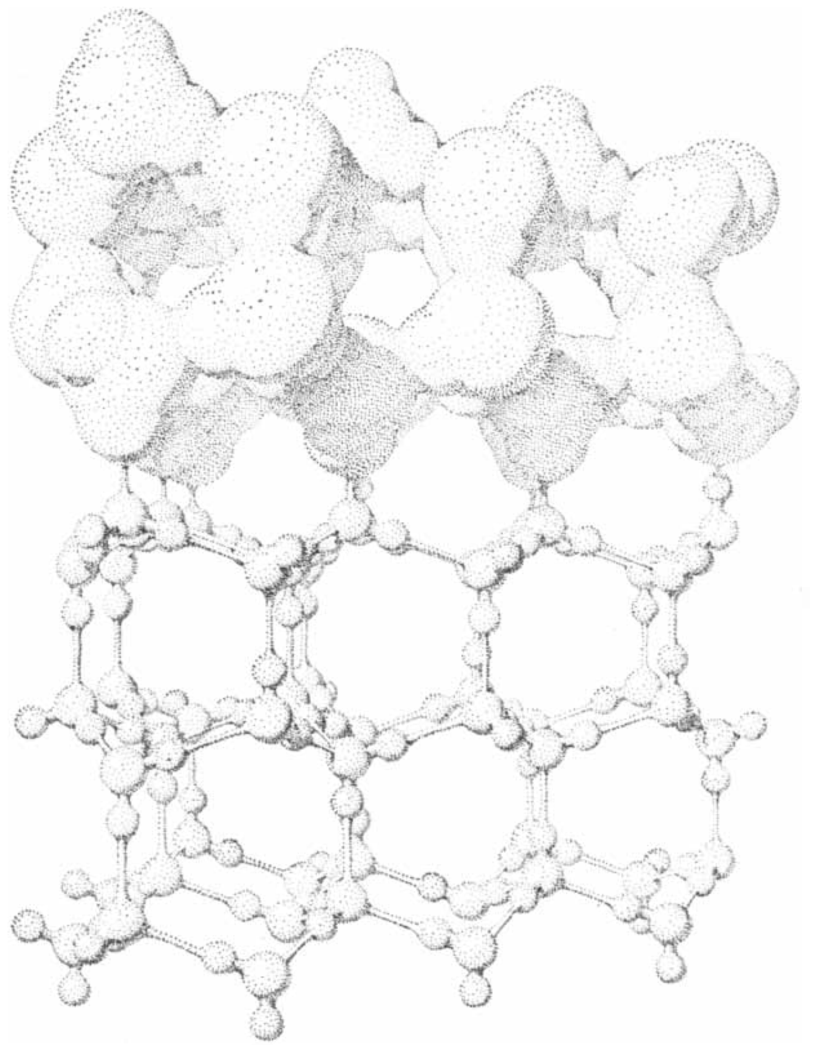


ATOMS AND MOLECULE illustrate the covalent chemical bond. At the left are two hydrogen atoms, each with an electron represented by the time average of its motion about the nucleus. At the right is the hydrogen molecule, in which two nuclei share two electrons. The drawings in this article are by Roger Hayward and are from Pauling's books *General Chemistry* and *College Chemistry*, published by W. H. Freeman and Company.

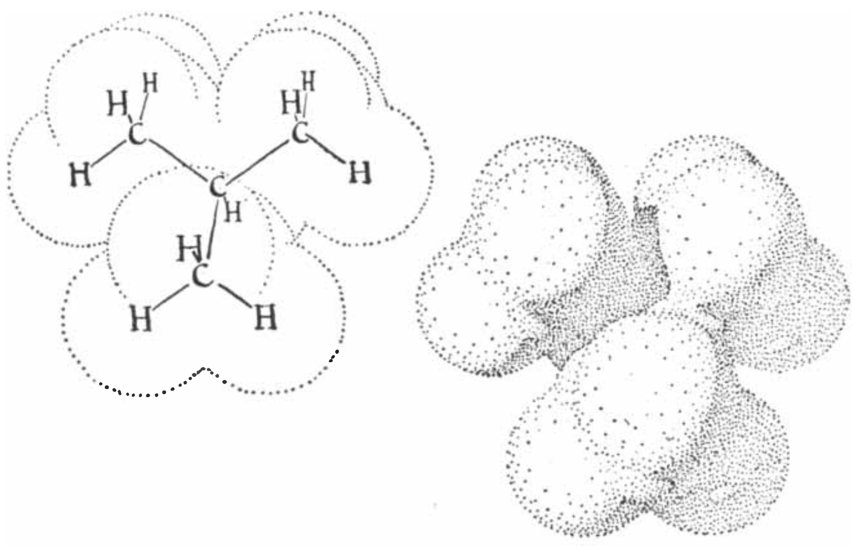
electronic theory of valence in general, and also of information about distances between atoms, bond angles and other features of molecular structure determined by spectroscopic analysis or by the diffraction of X-rays or electron waves. Many new synthetic procedures and analytical methods have been discovered. One of the most valuable new methods is the chromatographic technique for separating pure constituents from mixtures of substances, which was invented by Michael Tswett in 1906. In industrial chemistry we have seen an important shift: petroleum has to a great extent replaced coal tar as the raw material for the preparation of organic compounds.

Another striking aspect of organic chemistry in our century is the part played by special catalysts, both in the laboratory and in the industrial plant. This 20th-century development, which had its first success in the production of catalysts for the conversion of atmospheric nitrogen into ammonia and nitric acid, has risen to immense importance, especially in the manufacture of valuable products from petroleum. Great progress has resulted also from the expansion of the field of effective endeavor of the organic chemist to include giant molecules – molecules containing thousands or millions of atoms. In the 19th century the organic chemist could work confidently and effectively only with relatively simple substances. Then during the first decades of the 20th century he made effective headway in analyzing the structure and properties of macromolecular natural materials such as cotton, rubber and wood. Armed with knowledge obtained in this way, he essayed to synthesize new fibers, new elastomers, new plastics, and he succeeded not only in obtaining satisfactory substitutes for many natural materials but also in making many materials with far superior properties.

In inorganic chemistry there was a period of inactivity in the first part of our half-century, and then came a rebirth. The last two decades have seen the completion of the periodic table as far as atomic number 98, with the addition of technetium (43), promethium (61), astatine (85), francium (87), neptunium (93), plutonium (94), americium (95), curium (96), berkelium (97) and californium (98). Spectroscopic and diffraction studies of the structure of molecules and crystals have provided a penetrating insight into the nature of the interactions between atoms and molecules. This has been combined with quantum mechanics to yield a broad and powerful electronic theory of valence and chemical combination, permitting the correlation of the structure and properties of inorganic substances as well as of organic substances. The theory of resonance of molecules



CRYSTAL STRUCTURE of ice is based upon the geometry of the water molecule. The molecules at the top of this drawing are shown with their atoms and interatomic distances in the correct proportion. The atoms at the bottom have been reduced in size to clarify the structure of the crystal.



MOLECULAR STRUCTURE of the hydrocarbon isobutane is one of many of such structures worked out by organic chemists. At the right the atoms and the interatomic distances of the molecule are shown in their correct proportions. At the left is a diagram showing the skeletal geometry of the molecule.

among two or more valence-bond structures has found valuable applications in both inorganic and organic chemistry.

IN RECENT years practical inorganic chemistry has developed rapidly. Many new and important compounds of fluorine and silicon (fluorocarbons, silicones) have been made. The manufacture of plutonium and the controlled release of atomic energy have been accompanied by extensive chemical studies of uranium and the transuranium elements, of the rare-earth metals and of the elements formed as fission products.

Chemical thermodynamics—the study of the chemical effects of energy and temperature — is essentially a 20th-century development. It is true that the first and second laws of thermodynamics, dealing with heat transfer and entropy, had been formulated by 1851, and that Josiah Willard Gibbs had published his masterful series of papers on the application of thermodynamics to chemical phenomena in the period between 1873 and 1878. But the impact of this work on chemistry was not felt until after 1900. At the turn of the century Walter Nernst discovered the third law of thermodynamics, relating to the behavior of substances at low temperatures, and many chemists, among whom Gilbert Newton Lewis deserves special mention, labored to collect thermodynamic data and to weld them into a practical system. Quantum statistical mechanics has shown how the knowledge of interatomic distances and force constants obtained from spectroscopic and diffraction studies can be used in the application of chemical thermodynamics to practical problems. In the design of industrial plants the modern chemist — especially the petroleum chemist—may depend on thermodynamic information obtained by calculation from interatomic distances in molecules.

Information about the thermodynamic properties of substances, especially the absolute entropy, for application of the third law, often is obtainable only by measurements made down to very low temperatures. Early in the present century Kamerlingh Onnes, extending the pioneer work of Sir James Dewar, obtained temperatures slightly below 1 degree Kelvin by the evaporation of liquid helium. For some time it seemed impossible to achieve a closer approach to absolute zero; then William F. Giauque suggested in 1924 and later put into practice a new method—cooling by demagnetization. With this technique he and other investigators succeeded in reaching temperatures as low as about .001 degree K.

Thus chemical thermodynamics has rapidly developed to the point where it is possible for tables of the thermodynamic functions of chemical substances to be constructed. With the aid of these tables a reliable prediction can be made as to whether any chemical reaction involving these substances can be made to take place or is thermodynamically impossible. This prediction, however, does not satisfy the chemist; he wants also to know whether the reaction will proceed rapidly enough to provide a satisfactory yield of the product in the available time. The study of the speed of chemical reactions is another important branch of physical chemistry. In this field some progress has been made, but the goal of the formulation of a complete theory of reaction kinetics, analogous to the now essentially completed system of chemical thermodynamics, seems to lie far ahead.

WHAT will the next 50 years bring? How much greater understanding and mastery of chemical substances than we now possess will the chemist of the year 2000 have? We may hope that he will have obtained such penetrating knowledge of the forces between atoms and molecules that he will be able to predict the rate of any chemical reaction with reasonable reliability. In order to do this he will have to find out how catalysts work in accelerating chemical reactions. At the present time no one knows why a particular catalyst is effective for a particular reaction; the preparation of catalysts is essentially an empirical art. Perhaps in the next half-century chemists will succeed in preparing catalysts to order. In addition the chemist of the future may well be able to make use of new aids to cause desired chemical reactions to take place. One of these aids might be high-energy rays—alpha particles, electrons, positrons, gamma rays —made available by the uranium pile. As new materials capable of withstanding very high temperatures and pressures are developed, new chemical reactions can be made to occur. And the development of a greater understanding of the relation between the molecular structure and the chemical and physical properties of substances should permit predictions to be made as to the types of new substances that need to be synthesized for various special purposes.

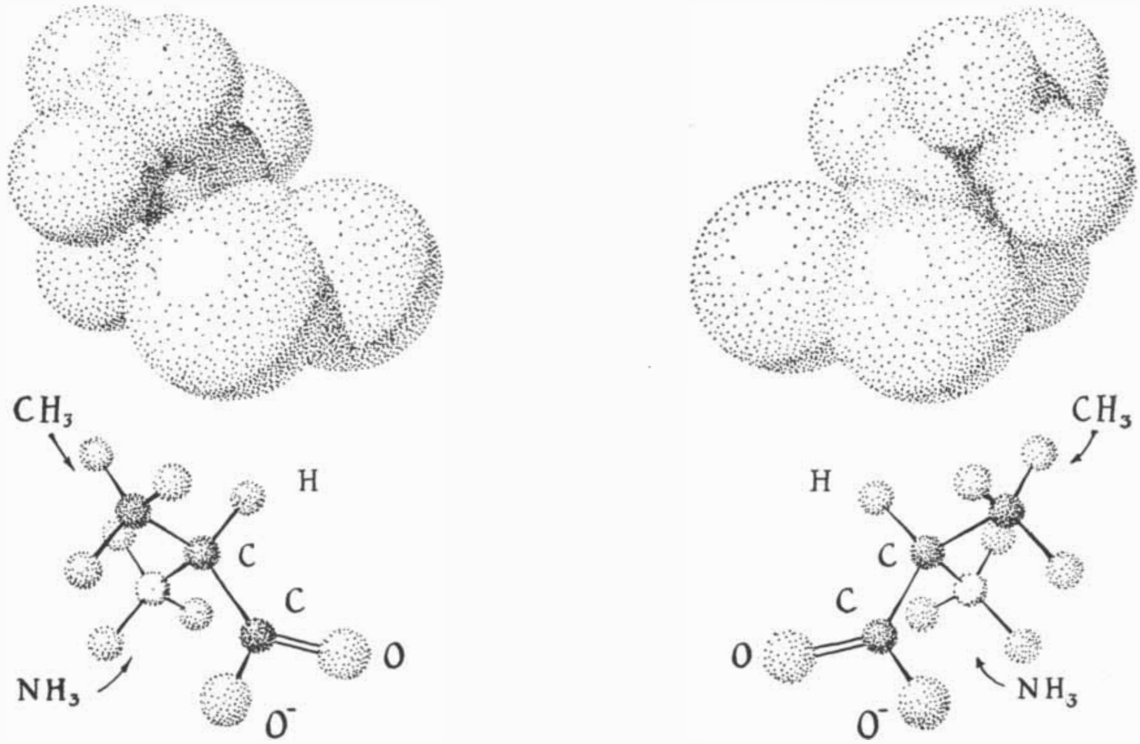
Pauling

The recent successful development of valuable new compounds of silicon and fluorine suggests that other elements too may be put to additional uses. The chemistry of very large inorganic molecules has been neglected. We may look forward particularly to progress in the study and use of compounds of elements that have a strong tendency to be present in large molecules, notably phosphorus, vanadium, molybdenum, wolfram and tantalum.

The metals constitute a great class of substances that deserves more thorough study by chemists. Organic and ordinary inorganic materials have been assiduously investigated year after year, but metals and alloys, including intermetallic compounds, have been neglected. The coming half-century should see the development of a sound theory of the structural chemistry of metallic substances. Metallography will thereby become a science, and the straightforward formulation of new alloys with special properties and valuable uses will become possible.

IN organic chemistry there exists a field with equally broad room for progress: investigation of the structure of physiologically active substances, especially vitamins and drugs, and the synthesis of new ones. This work has been handicapped by the lack of a theory of the molecular structural basis of physiological activity. The next half-century should witness the development of such a theory. This would involve also the solution of the problem of the structure of proteins, nucleic acids and other macromolecular constituents of living organisms, including enzymes and ultimately genes. When the mechanism of drug action has been elucidated, it will be possible for chemists to make greater and greater contributions to the problem of good health and the control of physical and mental disease. Instead of synthesizing great numbers of substances at random, the chemist will be able to plot the molecular structure of the most likely substance for each use and synthesize it for trial.

Linus Pauling is one of the principal figures in the application of the fruitful methods and theories of modern physics to chemistry. He has made important contributions to our knowledge of the chemical bond, of the structure of molecules and crystals, of immunochemistry. He is the author of The Nature of the Chemical Bond *and other books, and he has been president of the American Chemical Society. He is now head of the division of chemistry and director of the Gates and Crellin Laboratories at the California Institute of Technology.*



THE AMINO ACID alanine is one of the 20-odd amino acids that make up proteins. Like all the other amino acids except one, alanine has two stereoisomers or molecular mirror images: *d*-alanine (*left*) and *l*-alanine (*right*). Curiously only amino acids of the *l* configuration are found in proteins. Although the structure of the amino acids is well known, their arrangement in proteins is one of the fundamental problems of chemistry.

H 1	He 2

O	I	II	III	IV	V	VI	VII	O
He 2	Li 3	Be 4	B 5	C 6	N 7	O 8	F 9	Ne 10
Ne 10	Na 11	Mg 12	Al 13	Si 14	P 15	S 16	Cl 17	A 18

O	I	II	III	IVa	Va	VIa	VIIa	VIII			Ib	IIb	IIIb	IVb	V	VI	VII	O
A 18	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Kr 36	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Xe 54	Cs 55	Ba 56	La 57 *	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Rn 86	Fr 87	Ra 88	Ac 89 ♦	Th 90	Pa 91	U 92	Np 93	Pu 94										

*Rare-earth metals	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
♦ Uranium metals	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98					

THE PERIODIC TABLE of the chemical elements has in recent years been filled in and enlarged. Four elements have been inserted into the former table: technetium (Tc), promethium (Pm), astatine (At) and francium (Fr). The table has also been extended beyond uranium (U) by neptunium (Np), plutonium (Pu), americium (Am), curium (Cm), berkelium (Bk) and californium (Cf). Atomic number of each element is beneath symbol.

GEOLOGY

The search for the origin of major geological features has advanced further into the depths of the earth and time. A survey from the standpoint of physical geology

by Reginald A. Daly

GEOLOGY'S foundations were laid toward the end of the 18th century by a few lonely geniuses of western Europe. The scientific study of our planet naturally had to begin at the surface of the dry land. The pioneers in geology had only a few simple tools: hammer, compass, clinometer, collecting bag, notebook, topographic map and a good pair of legs. With such equipment, still indispensable to the field geologist today, they explored old sedimentary rock formations of western Europe, where streams cutting through steep slopes had exposed the strata, and by simple inspection they deduced the relative ages of these deposits.

The early geologists soon discovered that in each successive group of strata there were entombed certain fossils, chiefly of sea animals and plants, which were characteristic of their time. During the 19th century geologists proved that this marine life had gone through an irreversible evolution. Thus the "guide" fossils of Europe became a kind of calendar for reckoning the relative antiquity of the principal sedimentary rocks, not only in Europe but on every continent and large island where similar fossils were found. They made it possible to compose a rough time-scale for the infinitely varied events in the earth's history, insofar as these were registered in the accessible rocks.

The mapping of the earth's surface structure went on apace in an atmosphere of thorough international cooperation until 1914. Since then geological exploration and the pooling of ideas have been hindered by revolutions, world wars and the erection of an iron curtain around one sixth of the earth's land. The grievous retardation of progress by tribal insanities and lethal dictatorships has been somewhat offset by the development of the automobile and the airplane. With their aid sweeping geological reconnaissances have been made of wide stretches of the war-free portions of the earth—in Africa, Australia, Canada and even forbidding Antarctica, whose border reveals a belt of folded rock formations that appears to be part of the vast mountain belt rimming the Pacific—the greatest mountain system on the earth. Our half-century has also produced a number of more detailed local geological studies, notably in California and the adjoining Great Basin, the mid-Appalachians, British Columbia, Ontario, Hawaii, Samoa, the Dutch East Indies, New Zealand, the Bushveld of the Transvaal, the peerless Great Dike of Rhodesia, the Vredefort "dome" of the Orange Free State and the volcanic field of Natal.

Daly

DURING the first quarter of our century there were published two great syntheses of geological knowledge. One was a three-volume monograph on Switzerland by Albert Heim—the most thorough account ever made of the structure of a major mountain belt. The other was a four-volume work by two masters, Eduard Suess and Emmanuel de Margerie, who attempted to draw from the myriad literature of geology a picture of the main structural elements of the earth's crust as a whole. But these very syntheses made geologists more conscious of the rather terrifying complexity of their job. To read the record of the rocks—a record obscured and in many places all but obliterated by eons of erosion and by concealing covers of sediments, lavas and invading seas—is a formidable program. Here is a gigantic palimpsest written in hieroglyphs, and there is no Rosetta Stone by which to decipher it.

A truly scientific history of any phenomenon must explain it in terms of its origin; the geologist's problem is complicated by the fact that the origins of continents, islands, ocean basins, land basins, mountain ranges, high plateaus, volcanoes and mineral deposits are hidden in the depths of time as well as in the depths of the earth. The geologist cannot get far in this search without help, and so he has harnessed himself into a team with the geophysicist, the geochemist and the astrophysicist. The partnership is responsible for the major achievements of the past half-century in geology. This brief account will deal only with the principal advances in physical geology, since there is not space to go into the various other branches of the subject, such as paleontology, petrography and economic geology.

We delve first into the question of the earth's time-scale. The geologists of the 19th century demonstrated that our planet had a long history of leisurely change, with many successive cycles of erosion, sedimentation and mountain-building. They divided this history into four major eras: the Pre-Cambrian, the Paleozoic, the Mesozoic and the Cenozoic. Their estimates of the minimum age of the earth ran to hundreds of millions of years, but they had no means of making anything like a precise measurement either of the total age or of the length of the successive eras. In our century the physicist and the geochemist have provided geology with a remarkably handy clock for this purpose: the radioactivity of rocks.

From measurements of the decay of radioactive elements in the rocks the geologist-geophysicist-geochemist team was able to construct this time-scale: The oldest Pre-Cambrian rocks yet examined (themselves not the oldest in the earth) were crystallized about two billion years ago. The Pre-Cambrian Era lasted for at least three fourths of geological time. Half a billion years ago were deposited the earliest Cambrian strata, the first to carry abundant evidences of life on the earth, in the form of specific organisms. After the Cambrian came a series of periods measurable in terms of a unit of 10 million years. The last of these periods, the Cretaceous, closed the Mesozoic Era. In the Cenozoic Era, from the dawn of the Eocene Period to the present time, the periods have been shorter.

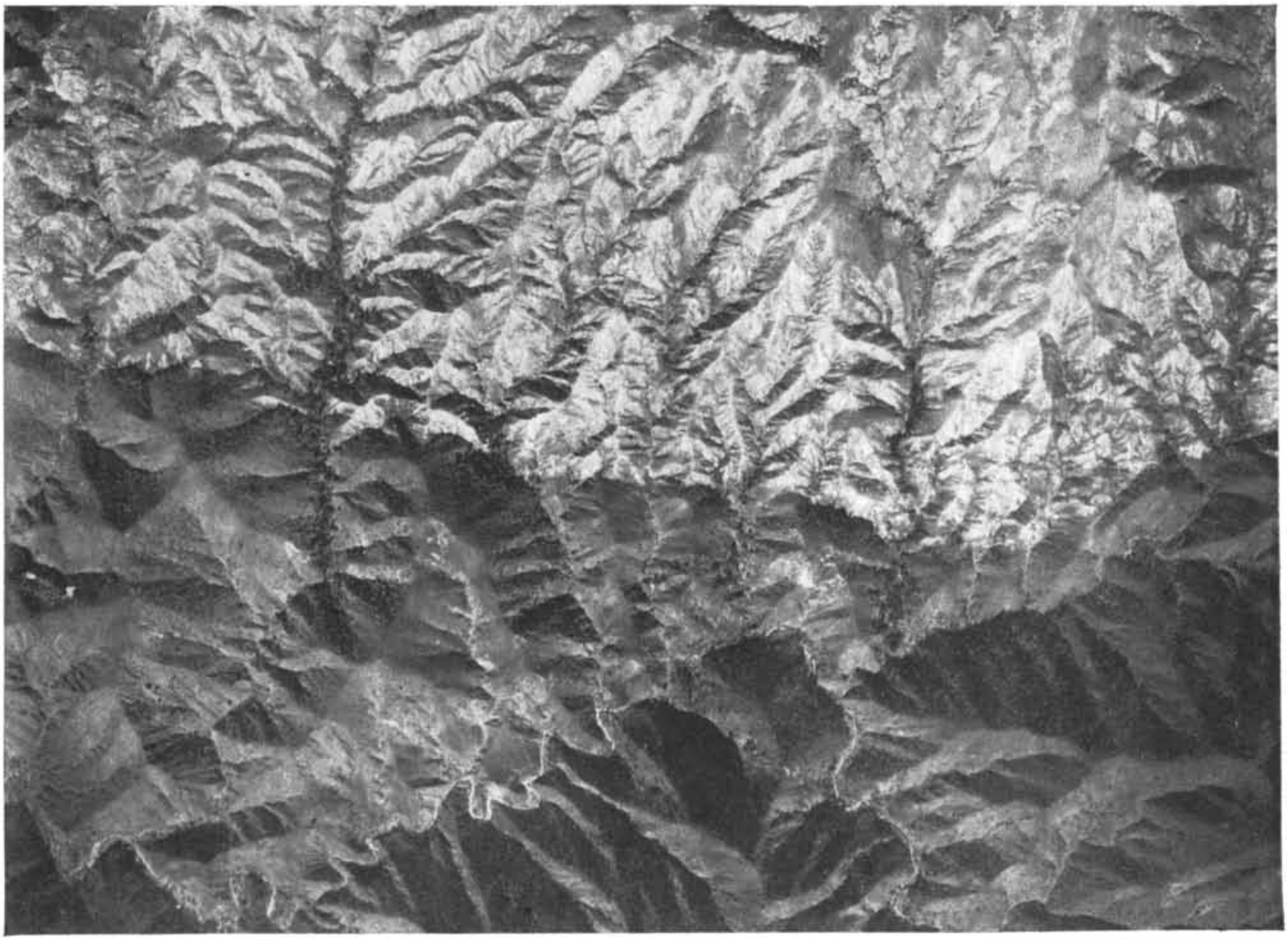
THIS time-scale is now one of the chief mental tools of the student of earth history. And the discovery of radioactivity led on to another finding of fundamental concern to physical geology. This has to do with the heat of the earth.

Before radioactivity was known, geologists had no reason to doubt that through all its history the earth had steadily been cooling off from an original molten state. But as studies of radioactivity were pursued into deep mines and tunnels, it soon became evident that considerable heat must be created in the earth by the spontaneous disintegration of atoms, chiefly of uranium, thorium and potassium. The earth, in short, is a true furnace.

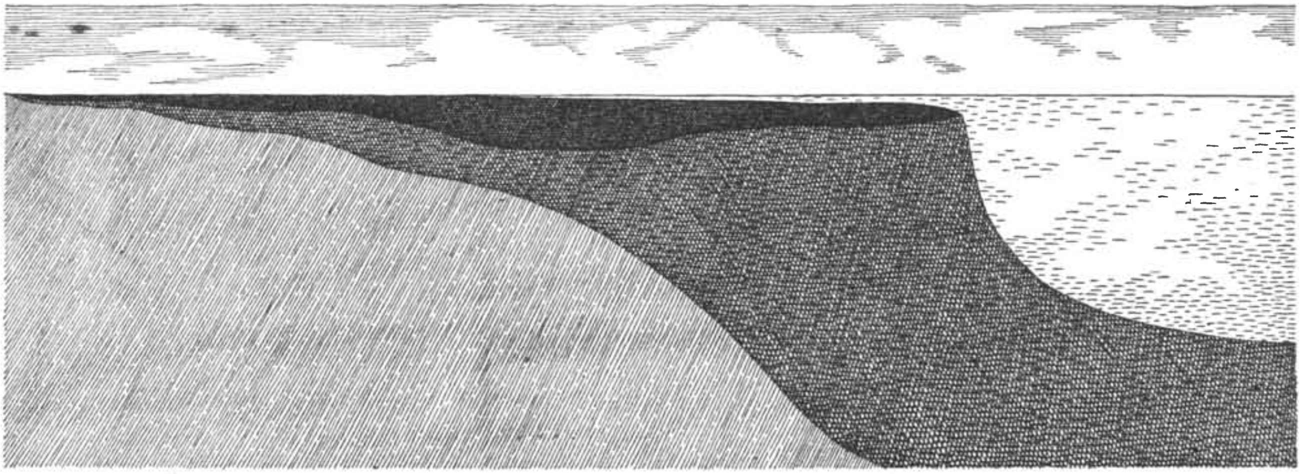
This discovery opened a world of new exploration, for it has a most important bearing on the problem of what forces and processes have molded the earth's main structural features. Since heat must play a key role in these processes, obviously our ability to find out what they are depends heavily on the investigation and correct interpretation of the temperature conditions down through various levels of the crust and the underlying material on which it rests.

During this century the temperature of the upper part of the earth's crust has been measured at hundreds of deep boreholes and mines in Europe, North America and South Africa. All of the measurements show that the temperature increases with depth. But there are good reasons for questioning whether the rate of this increase is the same at great depth as it is near the surface. One reason is some uncertainty about the distribution of radioactivity in the body of the planet. Another is uncertainty about how hot the infant earth was at the beginning. A third is uncertainty as to the possible effects on surface temperatures of localized convection currents that might have brought up especially hot material from great depth. Here, then, the geophysicist is in trouble, and he will do well to consider some relevant facts won by the geologists.

A vital discovery relating to the temperature of the material just below the earth's crust was made by geologists when they studied the reactions of the earth's body to heavy and extensive loads piled on its surface. Just such loads are represented by the existing Greenland and Antarctica ice caps. With the seismograph the geologists proved that these caps are thousands of feet thick. Other workers made it clear that the glacial ice caps that lay on northwestern Europe and northeastern North America during the ice ages of the Pleistocene Period must have had respective maximum thicknesses of about 9,000 feet and 12,000 feet. They showed that under



TWO KINDS OF ROCK adjoin in aerial view near Los Angeles. Lighter rock at top is igneous, *i.e.*, crystallized from a liquid state. Darker rock is metamorphic, *i.e.*, rock that has been altered from its original state. One problem of geology is to explain how large bodies of igneous granite find their way into mountain ranges.



CONTINENTAL SHELF is an undeciphered clue to the history of the earth's surface. Here the lightest tone represents the Pre-Cambrian "basement"; the darker tones, younger sediments. The vertical scale of this drawing is greatly exaggerated. One puzzling feature of continental borders is the deep canyons carved into their slopes.

these huge loads the crust of the earth was bent down as much as 1,000 feet in Europe and nearly 2,000 feet in America and, further, that these basinings of the crust continued even after the vertical excess pressure on the bottom of the crust had become small. This result of their field work shows that the material at and below the depth of a few tens of miles is extremely weak. The only good explanation of that weakness is that the material is made plastic by high temperature.

The cooperative studies of geologists and geophysicists have also established a convincing explanation of the reason why the continents and large islands stand an average of three miles above the ocean floor. The dry-land parts of the earth's crust, being predominantly granitic, are lighter than the crust beneath the open ocean. In consequence the continents are floating on the plastic layer which underlies the whole of the crust.

A related problem is the origin of the lava type of rocks, which have risen to the surface of the earth, and are still rising, as hot, liquid eruptions from the depths below. Geologists of the 19th century and early part of the 20th thought this could be explained in a comparatively simple way. They conceived the planet to have a crust of crystallized rock resting on a substratum of molten, gas-charged basalt; from time to time molten material from the substratum erupted through fissures in the crust, making piles of basaltic lavas and cther types of melts that were the products of chemical reactions between the liquid basalt and the invaded rocks. But doubt has been cast on this theory by recent geophysical evidence which makes it appear extremely improbable that any completely molten shell now exists near the surface of the earth. Some authorities have suggested that the lavas, including those of volcanoes, come from isolated pockets of hot liquid in the thick, solid crust, but this hypothesis also has its difficulties.

One of the major turn-of-the-century controversies that is still alive is the question of the stability of the continents. The continental-drift hypothesis, abhorrent as it is to many geologists today, has not yet gone to limbo, and it has gained some new support from the cumulative evidence of the plasticity of the depths below the crust. Over this weak underpinning, the drift theorists hold, floating continental blocks of the crust have migrated many hundreds of miles. But no one has yet suggested a generally convincing explanation of what forces made the continents move about, and some insist that the underpinning of the crust is not as weak as this hypothesis would demand.

EXPLORATION of the ocean depths by accurate echo-sounding methods developed during this century has added several new mysteries. One of these was raised by the discovery that the floor of the Pacific Ocean is ornamented with many "sea-mounts"—tall, conical hills whose tops are from a few hundred fathoms to 1,500 fathoms below the sea surface. They appear to be volcanic piles, but their tops have been beveled flat. It is not yet clear how and when they were so truncated.

A second mystery relates to the discovery of the surprising ruggedness of the continental slopes—the plunging undersea banks that are found off the shores of the continents. Geologists of the 19th century assumed, on the basis of sketchy soundings, that these slopes were smooth deposits built out by prolonged erosion from the continents. But this proved to be a serious error; more extensive and more accurate soundings made by the new methods in this century have shown that the slopes are cut by deep furrows like river valleys, now called "submarine canyons." How these remarkable fretworks on the flanks of the Americas, Europe, Asia and Africa developed is a matter of considerable debate. They seem to have been formed during the Pleistocene Period, *i.e.*, the last million years, and some geologists suggest that they were actually the sites of rivers during the long ice-age intervals when the sea level was lowered by the piling up of ice on the land. Others disagree, however; the arguments pro and con are too long to go into here.

This matter of the rise and fall of the sea level has been a subject of fruitful controversy among geologists; it may hold the answer not only to such questions as the origin of the submarine canyons and of the living coral atolls and barrier reefs of the Pacific but also to the broader problem of the stability of the earth's crust throughout the whole tropical belt of the planet during the last million years. Indeed, the history of the Pleistocene's ice ages has become a matter of great interest to biologists, anthropologists and geographers as well as geologists. The investigations of the past half-century have yielded convincing proof that the ice cap in the Northern Hemisphere made a series of advances and retreats during the Pleistocene, producing alternating periods of cold and warm climate, and the same sequence seems to have taken place in the Southern Hemisphere. The oceanographers have found evidence that these climatic changes were world-wide: in cores taken from the floor of the deep ocean at widely differing latitudes warm-water fossils alternate with cold-water species at successive levels. The computed duration of these alternate periods of warm and cold ocean temperatures matches well with the length of the glacial and interglacial periods on the lands.

BRIEF and incomplete as this review of the half-century has been, it illustrates the youth of physical geology as a true science. For every problem so far solved many new ones have arisen. The working out of the true story of the earth's evolution obviously still lies in the distant future. It is clear that the answers will require experiments and investigations by physicists, chemists, seismologists, oceanographers and geodesists as well as by the geologists themselves. Perhaps it is not too much to hope that ultimately the cosmogonists will be able to supply a crucial piece of knowledge on which the solution depends; namely, a reasonably assured description of what our planet was like in the beginning—its constitution and its temperature.

Of the requirements for further progress in geology, perhaps the most important is the restoration of one world in science. The geologist has a well-defined, and formidable, program of specific projects mapped out. Some of them are:

I. The making of detailed geological maps to cover more than 90 per cent of the land area.

II. More thorough exploration of the relief of the sea floor by echo-sounding.

III. Continued efforts to locate discontinuities in the depths of the earth by seismological methods.

IV. Further experiments on how heated rock glasses under high pressure transmit seismic waves, to help determine the physical condition of the rocks encountered by such waves in seismic explorations of deep layers of the earth.

V. A search for more data by which to test the continental-drift hypothesis.

VI. Investigation of a group of more or less related questions: Why is most of the earth's granite concentrated in the continents? How did the great granitic bodies in mountain ranges get there? How were massive strata of sedimentary rocks converted into crystalline schists?

VII. Continued study of the mechanism of volcanic action, already well begun at the volcanoes of Vesuvius, Kilauea and Parícutin.

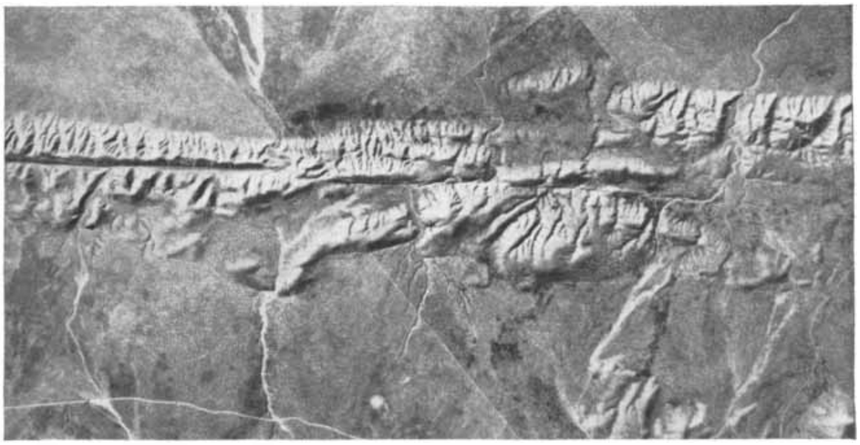
VIII. Studies of sedimentary rocks for further clues as to long-term changes in the composition of the oceans and their effects on the evolution of marine life.

IX. Investigation of the causes of the ancient changes in world climate.

In the words of a famous teacher of geology: "There is a world of work to be done!"

Reginald A. Daly has been one of the leaders of 20th-century geological thought. Among the subjects to which he has made notable contributions are the origin of igneous rocks, the nature of the earth's interior and the origin of oceanic islands. From 1912 to 1942 Daly was professor of geology at Harvard University. He is presently professor emeritus at Harvard.

ANCIENT LAKE SHORELINE in Nevada is a graphic record of the shrinkage of a glacial lake after the conclusion of an ice age. Higher ground is at top. The shoreline of the lake retreated slowly at first, then more rapidly.



SAN ANDREAS FAULT in California is a break in the earth's crust some 700 miles long. This aerial photograph of the fault was made in San Luis Obispo County. Periodically the crust drifts horizontally along the fault.

ENTRENCHED MEANDER of the San Juan River in Utah is evidence of a lifting of the land. Once the river meandered in a low valley. When the whole region was raised, the river cut downward in its original tortuous channel.

MATHEMATICS

Pure mathematicians have become more rigorous and applied mathematicians less inhibited. The interaction of mathematics and physics continues to enrich both

by Sir Edmund Whittaker

"MATHEMATICS," Bertrand Russell once wrote, "takes us into the region of absolute necessity, to which not only the actual world, but every possible world, must conform." This pithy statement is perhaps as good a summary as any of the relation of mathematics to the more mundane sciences, and it may also be taken as a description of developments during the first half of the 20th century – a half-century in which the theory of relativity and other exercises in mathematical logic have so drastically reshaped our world.

I shall not attempt here to review in detail the half-century's advances in mathematics, for the mathematician, as everyone is well aware, speaks a special tongue that is inscrutable to all but the initiated. But we can certainly consider some of the main concepts and problems on which mathematicians have been working.

At the end of the 19th century the two great personalities in mathematics were Henri Poincaré of Paris (1854-1912) and Felix Klein of Göttingen (1849-1925). Both of them created many new developments, but they were still in the tradition of the older analysts, and broadly speaking mathematics meant to them what it had meant to Newton, Euler and Lagrange. The new century saw some major changes. The first was associated with the publication of a new system of mathematical logic by two Cambridge men, Alfred North Whitehead and Bertrand Russell. This was the *Principia Mathematica,* a colossal work in three volumes published in 1910-1913.

One of the normal incidents of the development of human knowledge is that often a subject which has been regarded for centuries as a part of philosophy becomes emancipated and acquires an independent status. This happened long ago to physics, which is still known in the titles of the older university chairs as "natural philosophy," and it has happened within living memory to psychology and to logic. In the case of logic, much preparation for emancipation had been going on during the latter half of the 19th century, culminating in the work of Giuseppe Peano of Turin. Peano invented a new language consisting of symbols or ideograms for the expression of logical propositions; thus there were specific symbols to represent the terms "class," "and," "or," "is contained in," "there exists," and so forth. These symbols could be subjected to quasi-algebraic operations.

In 1900 Whitehead and Russell, while attending an international congress of philosophy in Paris, learned of Peano's system. Seeing at once that it was immensely superior to anything else of the kind that had preceded it, they resolved to devote themselves to creating a new syntax, so to speak, of mathematical logic, with the ideograms as the vocabulary, and to apply it to solve questions regarding the foundations of mathematics. They soon showed that the cardinal numbers 1, 2, 3, . . . could be defined in terms of purely logical concepts (such as "class," "not," "or") which could be represented by Peano's symbols. They asserted further that all pure mathematics could be built on this foundation, so that *mathematics was a part of logic.*

With this as a guiding principle, they opened up new fields of thought, concerned not only with the foundations of mathematics, but with problems of a more general character, such as the explanation of paradoxes arising from the defects of ordinary language, *i.e.,* contradictory conclusions developed by seemingly logical operations from the same set of premises. Many new paradoxes were discovered, and a theory known as "the theory of types" was developed to avoid them.

BUT the original outlook of the Whitehead-Russell theory was slightly modified when it was recognized that in order to provide a sufficient basis for mathematics, it was necessary to assume certain axioms which do not properly belong to logic, such as the axiom that the series of positive whole numbers is infinite. Then in 1931 Kurt Gödel of Vienna showed that some propositions of mathematics could not be either proved or disproved by the formal axioms of *Principia Mathematica,* or by any similar system. Some of the difficulties of the situation could be evaded by adopting what is known as the "intuitionist" theory of the foundations of mathematics, put forward by L. E. J. Brouwer of Amsterdam. This theory denies the unlimited validity of the logical principle of the excluded middle (*i.e.,* that every proposition is either true or false), and regards as invalid all existence-theorems which do not include a procedure for the actual construction of the entity whose existence is in question. In opposition to Whitehead and Russell, it takes the view that mathematics is not based on logic, but on the contrary is a presupposition for logic. The intuitionist system, however, has the drawback that it leaves a large part of the traditional analysis in ruins, and it has never been widely accepted.

It must be said that many professional philosophers, while admitting the power of the Whitehead-Russell methods, found the complicated Peano symbolism and algebra an uncongenial study, and complained that the real result, even of the *Principia,* was not to reduce mathematics to a branch of logic, but to reduce logic to a branch of mathematics. And, indeed, since the publication of the *Principia* logic has been widely regarded as a member of the group of the mathematical sciences.

While logic was thus developing as a subject in its own right, the question of its place within mathematics was occupying a great deal of attention. It was the ancient Greeks who first discovered that mathematical theorems might be proved by the methods of logic, and they attached so much importance to the matter that they had two different verbs, one of which was used when a theorem was simply believed to be true, and the other when a strict logical proof of it was forthcoming. The great mathematicians of the 18th and most of the 19th century were in the habit of offering proofs, but without taking overmuch trouble about their rigor. But in the latter part of the 19th century the pure mathematicians on the European Continent had begun to be more exacting.

NOW at the turn of the century there was in England a celebrated applied mathematician named Oliver Heaviside. He was entirely self-taught and had never been connected with any university, but he had a remarkable and indeed inexplicable ability (which was possessed also by Newton and Laplace, and in our own day by the Indian youth Srinivasa Ramanujan) to arrive at mathematical results of considerable complexity without going through any conscious process of proof. It was doubtless the awareness of this gift, coupled with the recollection of tedious hours spent on labored proof of the obvious in textbooks, that made Heaviside contemptuous of the "logic-choppers," as he called them. In his own writings he flouted their canons in the most outrageous way. Unfortunately the referees of the work he submitted to the Royal Society for publication thought that the time had come to offer up a sacrifice to the god of logic, and they rejected his papers, although it was shown later that the formulas he had obtained by unorthodox methods were perfectly correct.

Heaviside, however, was the last notable victim, for the curious sequel to this story is that although during the past 50 years pure mathematicians have become more and more rigorous, the restraints on applied mathematicians have been, in practice, altogether removed. For instance, P. A. M. Dirac of Cambridge introduced a "delta-function" which has the property of being infinite at one point and zero everywhere else but has a finite integral, and the applied men now make the most reckless use of it without incurring any censure. The reason for this situation is the increasing fragmentation of mathematics. The pure mathematicians are never asked to referee an applied paper, because they would be unable to understand what it was about, and consequently it escapes all criticisms on the score of rigor. Probably such a state of things is really quite healthy: first get on with the discoveries in any way possible, and let the logic be cleaned up afterward.

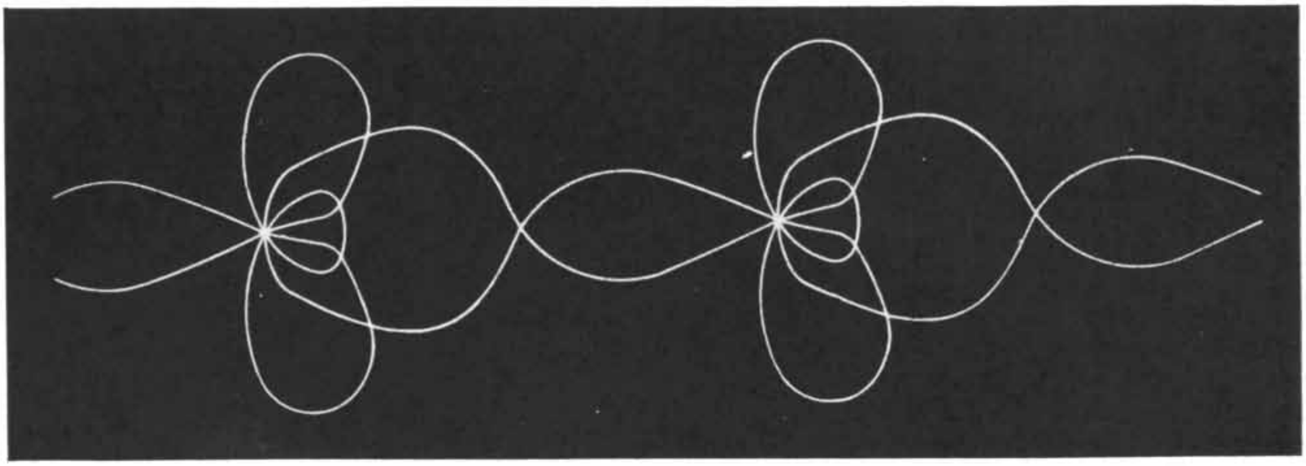
Throughout the history of mathematics progress has been achieved mainly by attacking the problems that are presented by nature to the applied mathematicians. This has been as true in the last 50 years as in any previous age. Let us take some conspicuous examples.

THE general theory of relativity, published by Albert Einstein in 1915, depends on the idea that the gravitational fields which exist all over the universe, and which up to that time had been described in terms of Newton's law of gravitation, can be more accurately described by introducing a new conception of space. Einstein abandoned the description of the geometrical properties of space set forth in Euclid's *Elements* and brought in the notion of curved space, which differs from Euclidean space in the same way as the curved surface of a sphere differs from the flat surface of a plane. The curvature of space varies from point to point, and its intensity at any particular place measures (broadly speaking) the intensity of the gravitational field there.

The working out of this idea, and the testing of it by comparison with observation, clearly depended on the mathematical theory of curved spaces. Now the geometry of curved surfaces had been studied in great detail for over a century, and the results were easily extended to curved spaces of any number of dimensions. But before long it became evident that something more was needed. Einstein's purpose was to explain all physical forces in terms of the geometrical properties of space. He succeeded in representing gravitation in this way, but electromagnetic phenomena still remained to be accounted for. It was found that these could not be brought into the scheme unless some radical innovation was made in the conception of a curved space. Such innovations first became possible when Tullio Levi-Civita of Rome and Gerhard Hessenberg of Breslau discovered in 1917 that what holds a space together, cementing its different volume-elements into a unity, so to speak, is its "parallel-transport," *i.e.*, the definition of the way in which a vector of the space can be moved for a short distance parallel to itself. This idea was applied by Hermann Weyl of Zurich and Arthur S. Eddington of Cambridge to furnish purely geometrical representations of the physical universe, including both gravitation and electromagnetic phenomena. Thus the physical laws became mere geometrical necessities, and geometry was enlarged from a mere system of measurement into a science embracing all that was known about the material universe.

Neither Weyl's nor Eddington's geometry was accepted as final, but their discoveries inspired a grand renaissance in differential geometry. The humblest research student was thrilled to feel that the novel and unprecedented types of geometrical form he invented might prove to be not the arbitrary and fanciful creations of a pure mathematician but a description of the actual universe in which we live.

ANOTHER example of the fruitful influence of theoretical physics on pure mathematics is provided by the dis-



MATHEMATICAL CURVE is a graphic expression of the complex transformation W=arg th w, which utilizes the inverse function of a hyperbolic tangent. The transformation was applied to a figure based on $Z=z^{1/5}$.

covery, made at Göttingen in 1925 by Max Born and his assistants Werner Heisenberg and Pascual Jordan, that quantum mechanics requires an algebra in which the commutative law $ba = ab$ does not hold. This law is of course valid whenever a and b are ordinary numbers, since the order in which numbers are multiplied makes no difference in the result. But in the newer kinds of algebra the letters can stand for entities other than numbers. For instance, let us take three axes at right angles to one another: Ox, Oy, Oz. Suppose that a denotes the operation of rotating any figure in space through a right angle about the axis Ox, while b denotes the operation of rotating any figure in space through a right angle about the axis Oy. Then ab means the combined operation of rotating first about Ox and then about Oy, while ba means the operation of rotating first about Oy and then about Ox. The results of these two compound operations are in general entirely different, so ba is not equal to ab. The first system of algebra with this "non-commutative" rule was developed by William R. Hamilton in 1843; it was called "quaternions." For quantum mechanics the necessary algebra was found in another system, also invented by Hamilton and called by him the "theory of linear vector operations." It is now known as "matrix algebra," and has been extensively developed in recent years, largely because of its value in applications.

Quantum mechanics has provided the stimulus for investigation in several other fields of pure mathematics. When a parallel beam of particles strikes a region containing a center of force which repels and scatters them, the solution of the problem depends on finding a certain function which satisfies a differential equation for the incident and scattered waves and which is finite at the scattering center, and then determining the behavior of this function at infinity. This is a problem in the pure-mathematical theory of asymptotic expansions.

The theory of the special functions of analysis has been developed also in connection with the problem of finding the energy levels corresponding to the stationary states of an atom (or of any quantum-mechanical system). For the hydrogen atom, the functions required are the confluent hypergeometric functions, and for the simple pendulum they are the Mathieu functions. Both these types of function have been named, and their properties discovered, in the last 50 years.

Still another part of pure mathematics which has owed much to its quantum-mechanical applications is the theory of "Hilbert spaces." The name commemorates David Hilbert (1862-1943) of Göttingen, who after the deaths of Poincaré and Klein was generally regarded as the greatest living mathematician, and whose work in the 20th century ranged over many fields of mathematics.

At the beginning of the century Hilbert was engaged in placing geometry on a secure foundation. It had long been recognized that from the standpoint of logical rigor Euclid's geometry was defective: many of his theorems tacitly presuppose axioms that are outside the list of those on which his system is supposed to be based. Hilbert constructed a complete axiomatic foundation, showing that his axioms were compatible with one another and were independent, and that from them all the theorems of Euclidean geometry could be obtained.

Hilbert's geometrical structure was practically completed in 1902, and his thoughts were now turned, by a lecture given in his own seminar by a visiting mathematician, to integral equations. In the years 1904 to 1912 Hilbert published a series of memoirs creating a complete theory of integral equations, with an

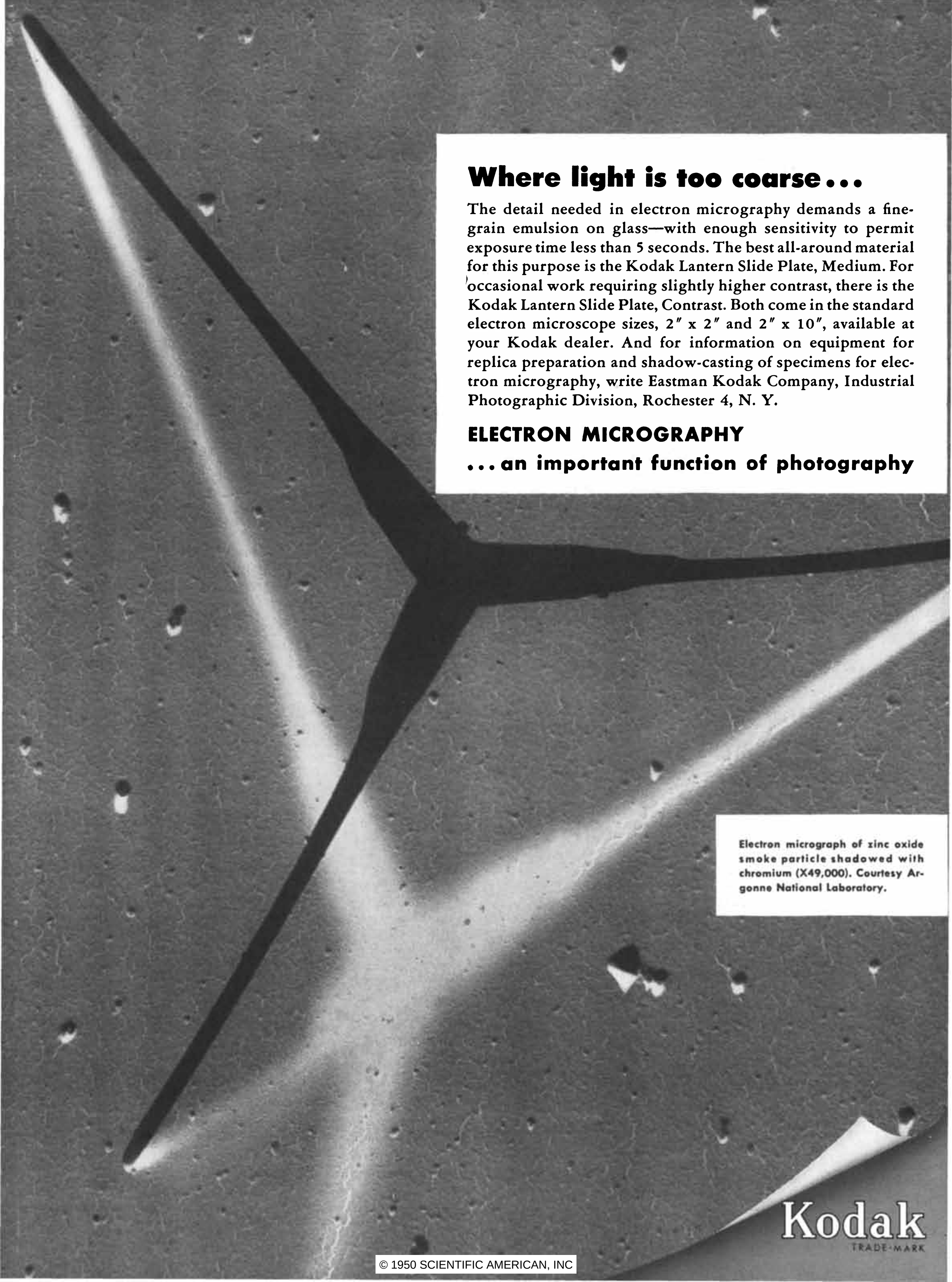
Whittaker

astonishing wealth of applications, both in pure mathematics and in such physical subjects as radiations and the kinetic theory of gases. It was in connection with integral equations that he introduced the notion of Hilbert space. This may be described as space of an infinite number of dimensions in which certain operations can be performed, namely the addition of vectors, the multiplication of a vector by an ordinary complex number and the formation of the inner product of two vectors. With this explanation, the fundamental theorem of quantum mechanics can be stated thus: *The various states which a physical system can take can be correlated to vectors of unit length in a Hilbert space, in such a way that the probability that the system will pass from a state represented by one vector to a state represented by another vector can be expressed in terms of the inner product of the two vectors.*

In 1909 Hilbert turned his attention to a problem in the theory of numbers. Edward Waring of Cambridge had asserted more than a century earlier that every positive whole number can be represented as the sum of at most four squares, or nine cubes, or 19 biquadrates. Waring seems to have arrived at his result by observation of a large number of particular cases. Hilbert now proved a general theorem: that every positive whole number can be represented as a sum of at most a certain number of k^{th} powers. But he gave no rules for finding this number. The problem was taken up in 1920 by the English mathematicians G. H. Hardy and J. E. Littlewood, and they succeeded in showing that the least number of positive k^{th} powers needed to represent all sufficiently large numbers is not greater than $(k-2)2^{k-1} + 5$. (For example, when k is 3, the case of the cube, this formula yields the number 9—*i.e.*, 9 cubes.) Their work has been followed by much activity in analytic number theory.

A small book published in 1940 by Hardy under the title *A Mathematician's Apology* attracted a great deal of attention. "Why," he asked, "is it really worth while to make a serious study of mathematics? What is the proper justification of a mathematician's life?" Hardy's own answer was that "if a man has any genuine talent, he should be ready to make almost any sacrifice in order to cultivate it to the full," and he justified his choice of a career by his consciousness of possessing great mathematical ability. But the critics asked: "If Hardy had been conscious of great agility in climbing drainpipes, ought he to have become a cat-burglar? If he had found that he had a great attraction for the other sex, ought he to have set up as a Don Juan?" The fact is that the problem he proposed really belongs to moral philosophy, and Hardy, who was a stranger to moral philosophy, had no principles available to deal with it. Curiously enough, I do not remember ever having seen a sustained argument by any author which, starting from philosophical or theological premises likely to meet with general acceptance, reached the conclusion that a praiseworthy ordering of one's life is to devote it to research in mathematics. Whatever the philosophical situation may be, it must be admitted that the 20th century would not have been the same without its mathematicians.

Sir Edmund Whittaker is one of the foremost mathematicians of the past half-century. He is author of the important mathematical works Analytical Dynamics *and* Modern Analysis. *From 1906 to 1912 he was Royal Astronomer of Ireland. Since 1912 he has been professor of mathematics at Edinburgh University.*



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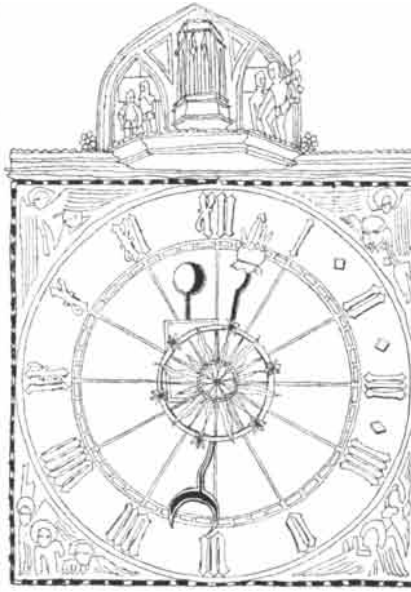

Effects of Atomic Weapons

THE long-awaited report on *The Effects of Atomic Weapons,* which has been under preparation by the Los Alamos Scientific Laboratory for a year and a half, was published by the Atomic Energy Commission last month. Intended mainly for the guidance of civil-defense planners, it is a readable account, containing much previously unpublished material, of the broad subject of atomic explosions. In a foreword Norris E. Bradbury, director of the Los Alamos Scientific Laboratory, says: "While the predictions of this book cannot be guaranteed to be precise, nevertheless they probably represent the most nearly quantitative approach to atomic bomb phenomenology which can be published at this time."

Five editors and 39 major contributors prepared the monograph. It includes detailed analyses of the physics and biological effects of shock waves, thermal and ionizing radiation and residual radiation; descriptions of the observed results of atomic explosions over land, under water and over water and the probable effects of an explosion underground; data on nuclear instrumentation, decontamination, personnel protection.

A few samples of the material covered:

Air Explosion. The radiation emitted by a bomb, covering a wide range of wavelengths, is absorbed in considerable part by the air immediately surrounding the bomb, with the result that the air is heated to incandescence. About a tenth of a millisecond after the burst this "ball of fire" has a radius of some 45 feet, and "the temperature is then in the vicinity of 300,000 degrees Centigrade." Its luminosity, as observed about five miles away, is approximately 100 times that of the sun as seen at the earth's surface. The ball of fire attains its maximum radius, about 450 feet, after the lapse of one second. Because of its low density, it rises like a gas balloon, reaching a maximum rate of ascent of 300 feet per second. About 10 seconds after the detonation the luminosity of the ball of fire has almost died out, the pressure of the shock wave has decreased to virtually harmless proportions and "the immediate effects of the bomb may be regarded as over."

Aftereffects. "Soon after the detonation a violet-colored glow is observed, particularly at night or in dim daylight, at some distance from the ball of fire. It is believed to be the ultimate result of a complex series of processes initiated by the action of gamma radiation on the nitrogen and oxygen of the air." Another phenomenon is a "cloud-chamber effect" in the air. If the air is saturated or nearly saturated with water vapor, the suction wave that follows the shock wave condenses the vapor and creates a cloud. The cloud is dispelled as soon as normal air pressure is restored and the water droplets vaporize. The whole effect is over in about a second or so.

Underground Explosion. The detonation of an atomic bomb underground would produce an earth shock which would have effects somewhat similar to those of an earthquake of small focal depth. A Hiroshima-type bomb would release energy comparable to that developed in a damaging earthquake of scale 5 on Richter's logarithmic scale. But whereas the focal point of the disturbance beneath the surface of the earth in an earthquake is of the order of scores or even hundreds of miles, in the case of an atomic explosion it would be effectively at the surface. The seismic waves generated by a bomb would have a shorter period and would decay somewhat more rapidly with distance than those of an earthquake. "It appears that the damage to be expected from an underground detonation is less than that from an air burst."

Probable Effects in the U. S. "The multi-story buildings in this country are generally designed to withstand a wind load of 15 pounds per square foot. On this basis, American reinforced-concrete buildings would be much less resistant to collapse than those designed for earthquake resistance in Japan. No firm conclusions can be drawn on this subject, however. . . . American steel industrial buildings would probably fare no better than those in Japan. The sawtooth roofs designed as rigid frames would be especially vulnerable to blast damage. . . . In Japan bridges withstood vertical blast loads quite well, and . . . it is probable that all bridges would be quite resistant to blast."

THE CITIZEN

Biological Effects. "Different types of cells show remarkable variations in their response to radiation. In general, it is the nucleus of the cell which reacts to radiation, whereas the cytoplasm is not so sensitive. Of the more common tissues, the radiosensitivity decreases in the following order: lymphoid tissue and bone marrow; epithelial cells (testes and ovaries, salivary glands, skin and mucous membrane); endothelial cells of blood vessels and peritoneum; connective tissue cells; muscle cells, bone cells; and nerve cells. . . . In connection with changes in the reproductive organs, it may be noted that the total body dose of radiation required to sterilize a man is believed to be from 400 to 600 roentgen, which would be lethal in most cases. Temporary sterility can occur with smaller doses, however, as happened among Japanese men and women. The vast majority of these have since returned to normal. It cannot be stated that all have recovered because it is not known how many were sterile from other causes, such as disease and malnutrition, before the bombings, but many afflicted with radiation sickness have since produced normal children."

Radiological Warfare. "An extreme case of contamination by radioactive isotopes would arise if such substances were used deliberately as an offensive weapon. This possibility is generally referred to as radiological warfare, the term being used to describe the employment for military purposes of radioactive material with the object of contaminating persons, objects or areas. The atomic bomb may be described as an indirect weapon of radiological warfare, for its main purpose is to cause physical destruction, the radioactive contamination being a secondary consideration. Perhaps the most important application of radiological warfare would be its psychological effect as a mystery weapon, analogous to the initial use of poison gas and of tanks in World War I. While it is impossible to predict, as in the case of chemical warfare, whether radiological warfare will be used or not, it is necessary to understand and be prepared for it. Only in the event of being unprepared are the consequences likely to be as serious as the destruction caused by an atomic bomb." (*For a more detailed discussion of radiological warfare, see below.*)

Effects on the Weather. "The suggestion has been made that certain destructive natural phenomena, such as hurricanes, tornadoes or cold waves, could be dispelled by a sudden release of the large amounts of energy provided by an atomic bomb. But it is very doubtful if this could be done, because the amounts of energy that appear to be necessary are of a higher order of magnitude than those at present attainable. A careful examination of all the available evidence leads to the conclusion that an atomic bomb burst has a negligible effect on the weather."

AEC's Progress Report

THE eighth semi-annual report of the Atomic Energy Commission, issued almost simultaneously with its monograph on weapons effects (*see above*), was devoted in the main to an account of its extensive researches and activities in the control of radiation hazards. In its general review of the "highlights of progress" during the past six months, the report announced that the production of fissionable materials, both uranium 235 and plutonium, had been increased to "a new record rate."

In its reactor program, which also has made substantial progress in recent months, the Commission has approved several new projects. One is a low-power, experimental "homogeneous reactor," where the fissionable fuel and the moderator will be combined in a homogeneous mixture. The Oak Ridge National Laboratory has been authorized to proceed with research on and the assembly of such a reactor. Another project is a design for a low-power research reactor of comparatively low cost—about $1 million—on which North American Aviation, Inc., is already working and which may eventually be a model for reactors to be built at university research centers.

In a separate announcement last month the AEC said that E. I. du Pont de Nemours & Co., which built and operated the Hanford Plutonium Works from 1942 to 1946, had been selected as the contractor to construct and operate a plant to produce hydrogen-bomb materials. A $260 million appropriation has been requested by President Truman for this plant. It was indicated that the plant, presumably a pile for making tritium from lithium, will be capable of conversion to the manufacture of plutonium if the hydrogen-bomb project fails.

RW

THE AEC's eighth semi-annual report contained a terse announcement that "studies on the feasibility of radiological substances as a method of warfare were continued." The subject of radiological warfare, which has had little public attention, was submitted to extended discussion for the first time in the U. S. in the July issue of the *Bulletin of the Atomic Scientists*. The physicist Louis N. Ridenour, dean of the Graduate College of the University of Illinois, there reviewed an earlier article on the subject in an Austrian journal by the physicist Hans Thirring.

The munitions of radiological warfare, authorities agree, would be the radioactive fission products, now mostly discarded, that are produced in a pile. From these, Thirring suggests, a "death sand" could be prepared by drying a water solution of salts of the fission products on a prepared carrier of sand or metal powder. Deposited on the level streets of a large city, this deadly dust would be picked up and blown about by the winds. Its victims would die from inhaling the dust. Thirring estimates that if the concentration of dust on the ground amounted to a radioactivity of two curies per square meter, a normal person would ingest a fatal dose by taking 500 breaths, which would occupy half an hour. A death sand containing one half of one per cent of active fission products by weight would have a radioactivity of 75,000 curies per pound, and a layer of this sand sufficient to produce the lethal surface concentration of two curies per square meter would be quite invisible.

Thirring calculates that from every 100 fissions of uranium atoms in a pile there is a yield of 61 fission-product atoms usable as a radioactive poison for military purposes. This means, says Ridenour, that "for each million kilowatts of reactor power—that is, for the original installation at Hanford—500 million curies of 'useful' fission products are ultimately produced. Each month's production amounts to some 250 million curies. Supposing that the presently existing Hanford installation runs at a power level of three million kilowatts—which seems a reasonable assumption—we are there producing, as you read this, 750 million curies per month of deadly poisons."

At this rate, "the three million kilowatts of atomic power that we taxpayers now have working for us in the State of Washington produce each month enough fission products to contaminate 144 square miles"—six and a half times the area of Manhattan Island.

Ridenour concludes: "The area that can be poisoned with the fission products available to us today is disappointingly small; it amounts to not more than two or three major cities per month. The problems presented by the proper use of fission products in war are very difficult. Despite these drawbacks, the novel and unique properties of the weapon may well make it useful in special situations. All in all, the official silence on radiological warfare probably is expressive of classification, rather than disinterest."

Roster Revived

THE wartime roster of scientific personnel, which was allowed to lapse in 1946, has been revived. The list is being brought up to date by a temporary agency called the National Scientific Register Project, headed by James C. O'Brien of the National Security Resources Board and responsible to the Office of Education of the Federal Security Administration. The agency will recommend measures to increase the number of workers in fields where manpower shortages develop. The National Academy of Sciences is cooperating with the project. When the new National Science Foundation is set up, it will take over the job.

2+2=5

ARE two drugs better than one? A controlled study of this current medical question has been made by bacteriologist Joseph W. Bigger of Trinity College, Dublin. The results are reported in *The Lancet*.

Bigger investigated the effects of adding antibacterial compounds in pairs to a culture of *Bacterium coli*. He used six compounds: sulfathiazole, penicillin, streptomycin, chloromycetin, boric acid and *p*-aminosalycilic acid. Most combinations, he found, had a synergistic effect: two drugs together produced stronger bactericidal action than either drug would give separately. For example, a combination of streptomycin and sulfathiazole at the right concentrations was more powerful than either drug alone at a concentration four times as high. Certain drugs are always antagonistic to each other, giving poorer results in combination than separately; an example is boric acid and sulfathiazole. Then there is a third type of combination that may have one result or the other depending on the concentration; *e.g.*, chloromycetin is antagonistic to sulfathiazole at a certain range of concentration of the latter but synergistic at other concentrations.

Bigger observes: "There is no great difficulty in advancing hypotheses to explain synergism. If the two substances interfere with the same constituent, cellular structure or metabolic process, they might be expected, in combination, to display an additive effect. If, however, the point of attack is different, such organisms as had survived the action of the first substance would become exposed to that of the second, and, if susceptible to it, would succumb. In this case much more than a merely additive effect might result."

Antagonism is a "more difficult" question. Bigger notes that unlike some bactericides, such as concentrated hydrochloric acid and sodium hydroxide, which are antagonistic because they react chemically with each other, the antagonism of the drugs he used is not chemical but physiological. Bigger suggests there may be some significance in the fact that, in the three examples of marked and permanent antagonism discovered, the antagonizer was either boric acid or *p*-aminosalicylic acid, both of which slow down the rate of multiplication of bacteria, and the substance

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against which antagonism was displayed was either sulfathiazole or penicillin, slowly acting substances which permit or perhaps require bacteria to multiply for several generations before they take action against these bacteria. The investigator believes that the antagonizer may cause some alteration in the cellular structure or metabolic processes of the bacteria, as a result of which the other substance is either prevented from entering the cell or, having entered it, is unable to bring about its death.

In clinical practice, Bigger concludes, it may be possible to eliminate the undesirable side-effects of a drug by using it in a combination that permits reducing the usual dose. "A more important advantage of using two drugs in place of one," he says, "is the probability that this procedure would tend to prevent the multiplication of mutants resistant to one of the drugs."

A group of physicians in the U. S. announced last month that the dosage of cortisone necessary to relieve arthritis could be reduced to one fourth by combining the drug with insulin. The combination was successfully tested with 12 patients at St. Barnabas Hospital, Newark, N. J. It eliminated the harmful effects of the larger doses needed when cortisone is administered alone.

Earthquake Patterns

WILL seismologists someday be able to predict earthquakes? Workers at the California Institute of Technology seem to have taken a step in that direction. They have found evidence that earthquakes throughout the world follow a rough pattern of recurrence and are related to a world-wide stress system.

Investigators at the Institute's Seismological Laboratory studied the 48 great earthquakes that have occurred all over the world since 1904, when reliable instrumental observations began. The study was limited to the highly destructive shallow quakes, which take place less than 45 miles below the earth's surface. All these quakes fell into a pattern "as orderly and regular as the cutting edge of a saw."

Major quakes used to occur in clusters, each period of activity being followed by a rest period. Thus there was violent activity between 1904 and 1907 and then quiescence for 10 years, except for two quakes in 1911 and 1912. Four more active periods, separated by quiet intervals, occurred between 1917 and 1948. But the periods of activity became progressively shorter and closer together. Since 1948 the pattern has entered a new phase, with approximately one great quake a year. Instead of accumulating over a period of years, strain in the earth's crust now seems to find release as fast as it is generated.

The nature of the "global force" that controls this orderly pattern is unknown. One speculation is that periodic increases in the earth's rate of spin due to slight changes in the tidal forces of the sun and moon may enlarge the earth, opening its seams sufficiently to release the accumulated tensions.

Langmuir on Rain-Making

IRVING LANGMUIR, Nobel prize winner and perhaps the world's leading theoretician on rain-making, has written an analysis and review of the new art which he helped originate. In an article in *Science* he presents the theory of precipitation on which cloud-seeding work is based and discusses various successful and unsuccessful rain-making experiments.

"Heavy natural rain from large supercooled cumulus clouds occurs only when both of two separate conditions are fulfilled," he says. "First, the weather conditions must be favorable. Second, there must be a concentration of sublimation nuclei to generate sufficient heat within the cloud to overcome the stability of the atmosphere and cause the clouds to grow rapidly and produce turbulence.

"Artificial seeding has many advantages. By properly choosing the point of seeding, effects can be produced that do not occur naturally. The cirrus-pumping mushroom clouds of semiarid regions ordinarily give no rain or are very slow in starting to produce rain. When nuclei, such as those from dry ice or silver iodide, are introduced into these clouds at elevations only a little above the freezing level, the cloud is completely modified within 10 or 15 minutes. Ice crystals are formed at low altitudes and grow rapidly to such size and number that they start the chain reaction long before the cloud reaches the minus 39 degrees Centigrade level, and thus the cloud becomes an efficient rain producer.

"The control of a system of cumulus clouds requires knowledge, skill and experience. Failure to consider the importance of the type of seeding, the place and the time, and also the failure to select the best available clouds, explain why the Cloud Physics Project of the U. S. Weather Bureau was not able to obtain rainfall of economic importance.

"I believe the time is now ripe for beginning an intensive study of tropical hurricanes," he adds. "It is highly probable that by using silver iodide generators at sea level in the regions where large clouds first begin to grow into incipient hurricanes, the hurricanes can be modified and even prevented from reaching land."

Longevity

THE theory that the offspring of young mothers tend to live longer than those of older mothers, suggested by some recent experiments with rotifers, has just received some support from

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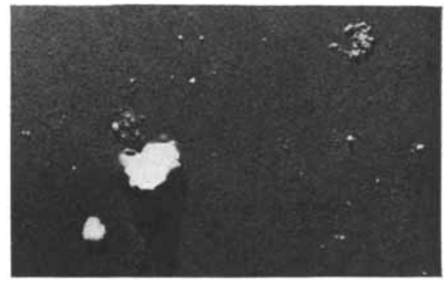

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a study of vital statistics by the physiologist Eeva Jalavisto of the University of Helsinki. She examined the birth and death records of 18,000 Swedes and Finns born between 1600 and 1850. In this large group the children born to mothers of 24 or younger lived six or seven years longer on the average than those borne by women of 40 or over. There was no correlation between longevity and the father's age.

Longevity is known to be influenced by heredity; Dr. Jalavisto found that long-lived mothers tended to have long-lived children. But the correlation between life expectancy and mother's age at birth cannot be explained by heredity. Dr. Jalavisto believes that some factor in the aging mother is responsible for shortening the lives of late children.

Dental Insurance

OF the great variety of voluntary health insurance plans that have developed in the U. S. in the last 10 years, none includes dental care in its coverage. Several months ago the House of Delegates of the American Dental Association urged its constituent societies to establish "experimental" prepayment plans. Now the first such plan has been announced in New York City.

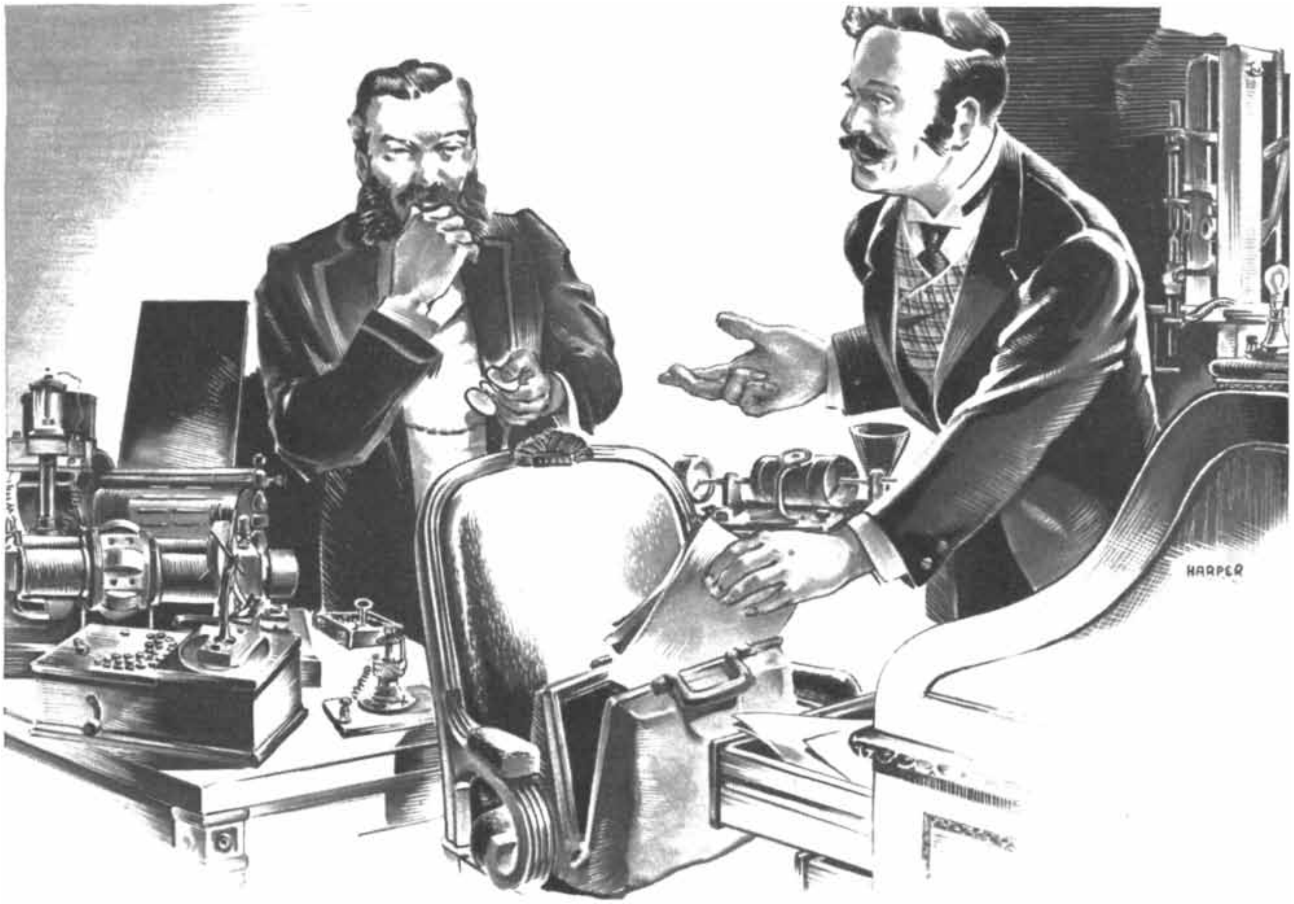
Group Health Dental Insurance, Inc., approved by the First District Dental Society of Manhattan and the Bronx, will begin operation in about six months. Subscribers will be enrolled in employee groups of 60 or more. Before admission they will be required to correct any existing defects. Thereafter, for a premium of $19.80 a year for individuals and $72 for families of three or more, they will receive all ordinary dental services. In most cases the subscriber will continue to use the same dentist as before he enrolled.

Dr. Oscar Jacobson, president of the First District Society, said: "This experiment is not intended as a final answer to all of the problems of distributing dental care to low-income groups. It is, however, an attempt, by voluntary means, to explore new methods of bringing dentistry, an essential part of health care, to families that do not now sufficiently use it."

Blood Fractions

TECHNIQUES for the separation and preservation of blood components have been further refined by work at Harvard University's Laboratory of Physical Chemistry Related to Medicine and Public Health. Last month Dr. Edwin J. Cohn, director of the Laboratory, opened it to visitors and disclosed a number of advances made in blood fractionating and storage since the end of World War II.

Some of the new techniques make it possible to keep blood components in



The mistaken young man who quit the patent office . . .

Back in the 1880's, a young man quit the patent office. It was a perfectly good job except for one thing: There wasn't any future in it. You could, as he explained, walk through the place and see for yourself that just about every possible thing had been invented.

He was, of course, just as wrong then as he would be today almost seventy years later. In a world where nothing is impossible and many things are still unknown, progress is limited largely by lack of imagination.

In electronics alone, a "normal" quarter of a century's development has been crowded into the past half dozen years. And patent requirements of this single industry probably equal the total work of the patent office when this mistaken young fellow resigned.

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exactly the same state as in the body. It was found, for example, that contact with any wettable surface destroys the white cells and other components. This meant that the rubber tubing and glass flasks used in extracting and storing blood were injurious to it. The problem has now been overcome by the substitution of silicone-coated glass, plastics and resin-coated stainless steel for rubber and glass.

Another finding was that the citrate and other anticoagulants employed to prevent the clotting of stored blood also injure the white cells. The Harvard workers therefore developed a new method for the prevention of clotting: by means of exchange resins they remove the calcium, which is necessary for clotting, from the blood and substitute sodium.

Red cells are now removed from the blood by sedimentation with fibrinogen instead of by centrifuge. This permits the subsequent separation without damage of the white cells and platelets. The remaining plasma is fractionated by new chemical reagents which make it possible to separate rapidly 98 per cent of the solid phases of the proteins. The reagents used are metals.

"Most plasma proteins," Cohn explained, "combine with zinc to form less soluble salts than their sodium salts. Others combine with calcium or magnesium to form salts of lower solubility than the sodium salts. Still others combine more readily with mercury or lead, with cobalt or copper or iron. But these are the metals which have long been known to have important influences upon bodily processes. Lead and mercury have been thought of as poisonous; iron, copper, and cobalt as essential for the active production of blood cells. It would thus appear that the reagents that are now proving so important in controlling the specific interactions of proteins in the laboratory are, in fact, the same reagents that have been known to have important influences on bodily processes."

Meteor Trails

EVERYONE who has watched a meteor flash through the sky has seen the faintly luminous trail it leaves. Such a trail—technically known as "the persistent train"—has been photographed for the first time by astronomers at the Dominion Observatory in Ottawa, Ontario.

The meteor was a bright Perseid visible to the naked eye. For 11 seconds its train "remained visible in the bright moonlight," reported Peter M. Millman of the Observatory. The spectrograph that was obtained confirmed previous visual descriptions of meteor trains. The elements responsible for the luminosity of the train are chiefly iron, magnesium, calcium and sodium.

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INSTRUMENT DIGEST

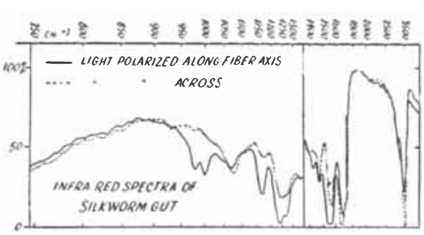
A condensation of some of the articles that have appeared in past issues of THE PERKIN-ELMER *INSTRUMENT NEWS*, a quarterly publication of The Perkin-Elmer Corporation, manufacturers of scientific instruments—Infrared Spectrometers, Tiselius Electrophoresis Apparatus, Universal Monochromator, Flame Photometers, Continuous Infrared Analyzer, Low-level Amplifiers—as well as Astronomical Equipment, Replica Gratings, Thermocouples, Photographic Lenses, Crystal Optics, and Special Instruments for the government. For further information, write The Perkin-Elmer Corp., Glenbrook, Conn.

Glenbrook, Conn. September, 1950 Vol. I, No. 12

POLARIZED SPECTRA SHOW CRYSTAL STRUCTURE

Polarized infrared spectra have aided in the determination of simple crystal structures. With added knowledge and data applied from other sources, these spectra will contribute further understanding of the structural patterns of proteins, hormones and complex organic compounds.

At Columbia University, crystals or crystalline materials were used whose molecular structures were known from other sources. Most frequently used were nitrates for which the various frequencies associated with the different modes of motion of the molecules were known. Independent sources (optical properties, x-ray diffraction data, etc.) all contributed data needed to interpret the polarized spectra. From these data, infrared spectra were predicted, and then actual spectra were checked against the theory.



Ammonium nitrate crystals grow in long needles, very elongate along the *c*-axis. The *a* and *b* axes are across the diagonals. To obtain polarized infrared spectra, it is necessary to slice, and polish off, thin sections of the crystals. The three fundamental spectra for the so-called "crystal modification IV" fulfilled theoretical expectations, except for experimental imperfections.

The number of systems that can be analyzed by this approach is limited, since there is only a limited number of molecular units whose modes of vibration can be identified with infrared absorption frequencies. The spectra above show well-defined differences and illustrate the potentialities of the polarized technique as applied to the most complex organic structures—proteins. Here, infrared observations are consistent with the Astbury model of fibrous protein structure, and with the further idea that in α-keratins as opposed to β-keratins, collagens and silk fibroin, the polypeptide chains may be folded.

These articles are digests from current and past issues of INSTRUMENT NEWS. You may receive this 8-page quarterly devoted to the latest advances in electro-optical instrumentation regularly by writing to The Perkin-Elmer Corporation, 535 Hope St., Glenbrook, Conn.

Here are some of the features of the Summer issue:

GROWING INSTRUMENT REVOLUTION SEEN IN RESEARCH, INDUSTRY

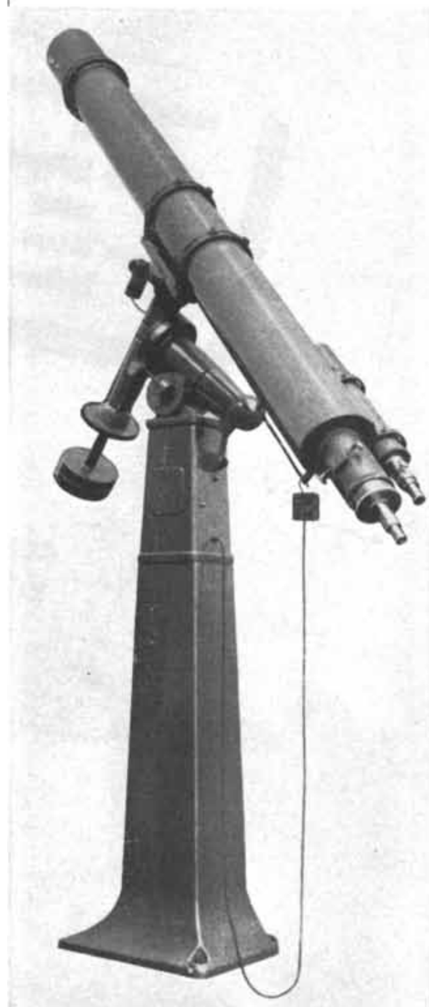
Today, the scientific and industrial world is in a period that might be termed the Instrument Revolution—a minor revolution perhaps, but one that, like its parent, the Industrial Revolution, will mark an acceleration of pace in man's material progress. The Instrument Revolution implies a recognition that many of man's prior functions of measurement, material handling, or calculation can now be done faster, more accurately, and automatically by an instrument. Or more simply stated, where the first thought used to be to hire a man for a job, it is now to buy an instrument.

Proof of Revolution

The proof is all around us—the term, "Physicists' War," for World War II to imply automatic weapon control; the instrumentation that made possible the production of the atom bomb, and represents the edge the United States has over other countries in this field; the trends in research from man-in-the-cupboard techniques toward research teams focused on results from a complicated apparatus; the tremendous increase in process control instrumentation, and the number of companies that have started in the last few years.

The Perkin-Elmer Corporation, which has always been in the vanguard of this revolution, is vitally concerned with the problem of converting a basic idea (which often originates outside the company) into a versatile, stable, commercial instrument of high quality. Its facilities are constantly being employed to develop new electro-optical instruments and increase the efficiency of existing ones.

NEW APOCHROMATIC 10-INCH REFRACTOR



A new 10-inch apochromatic refracting telescope has just been completed by Perkin-Elmer. Intended for the study of planetary detail, the new refractor's unusual degree of color correction will enable it to perform in this respect as well as much larger telescopes. To the best of our knowledge, this is the largest apochromatic lens yet constructed.

Apochromatizing was carried well beyond the limit which may be detected by the eye, to permit astronomical photography on films of different color sensitivity than the eye. The telescope is free from spherical aberration and coma.

GENETICS

The organized study of the mechanism of heredity and evolution began only with the 20th century and the rediscovery of the lost work of Gregor Mendel

by Theodosius Dobzhansky

FROM THE AGE of Galileo through the first half of the 20th century the scientific movement has been led by the physical sciences. These sciences still retain indisputable supremacy as wellsprings of technological progress. But in our age more and more of the intellectually and philosophically significant advances in knowledge appear in the realm of biology. Man's deepest urge, after all, is to understand himself and his place in the Universe—to fathom his own nature as a living organism and the interactions between heredity and environment that shape the development of his body and mind.

In this quest for self-understanding no investigation of the past 50 years has been more enlightening nor more dramatic than the study of heredity. The discovery of the basic laws of heredity is one of the major conquests of 20th-century science, and genetics has become a cornerstone of modern biology. Genetics, like nuclear physics, is peculiarly a science of our century. To be sure, its founder, the Austrian monk Gregor Mendel, reported his historic conclusions from his experiments with peas in 1865, but nobody then paid attention to them. It was in the year 1900 that Hugo de Vries in Holland, Karl Correns in Germany and E. von Tschermak in Austria rediscovered Mendel's findings and thereby initiated the growth of a new science. By then biology was prepared to appreciate the significance of Mendel's work, and from 1900 on the study of heredity developed very rapidly.

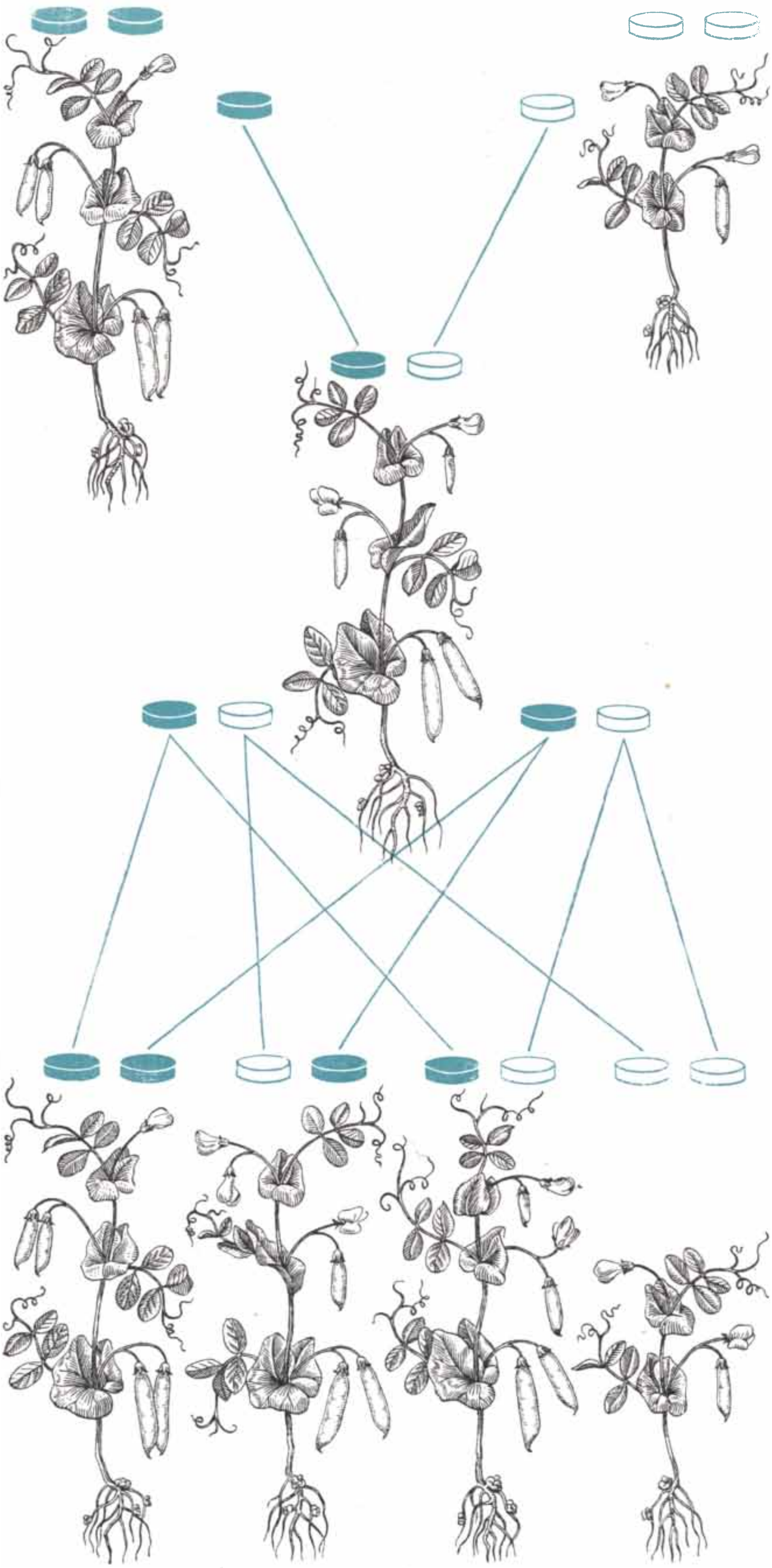
Mendel's experiments were remarkably simple. He crossed varieties of peas that differed in clear-cut traits, such as the color or shape of their seeds, their flower colors and so on. He found that ancestral heredities do not mix or blend in the progeny, but reappear uncontaminated in the second generation of hybrids. When yellow peas were crossed with green peas, some of the descendants were yellow and some green, but none of a shade in between. Mendel concluded that heredity was controlled by discrete units or particles of living substance transmitted by both parents to their offspring and reassorted in each generation.

Later investigators named these units genes, from the Greek *genos,* meaning race or stock. But in 1900 it was far from clear that all heredity is transmitted by genes. There was, for instance, the case of mulattoes—hybrids whose skin color is intermediate between that of their Negro and white parents. Did this not argue for a blending of "bloods" rather than segregation of genes? Biologists found in nature all sorts of refractory cases whose inheritance seemed to defy explanation in terms of the gene theory. But one by one they were all explained. In the case of mulatto inheritance, the answer was that skin color is determined not by a single gene but by the interaction of many genes. In general every trait and tissue of the human organism develops under the joint influence of the whole constellation of genes and of the environment.

Dobzhansky

IF THE ORGANISM was such a complicated product of heredity and environment, how could one even begin to distinguish between an individual's observable traits and his basic inheritance? In 1909 the Danish geneticist Wilhelm Johannsen proposed a distinction in terms which served to define the problem clearly. He suggested that the appearance and structure of an individual be called the phenotype, and that this be distinguished from the genotype, the endowment of genes inherited by the individual from his parents. The genotype determines how the developing individual will react to environment. The phenotype, say his size or stature, is the result of the interaction of the genotype with the environments the individual encounters during his lifetime.

The problem is to evaluate or measure the relative importance of genotype and environment in the formation of human phenotypes. This heredity *v.* environment question has fascinated biologists for half a century, but no generally convincing solution of the problem has yet emerged. The possibilities of experimentation with human beings obviously are severely limited. Almost the only way the question can be studied in the human realm is to observe the development of identical twins reared from early infancy in different environments. Horatio H. Newman of the University of Chicago and other investigators who have made studies of this kind have found that the normal environmental variations in an industrial civilization like that of the U. S. produce relatively little modification of physical traits, such as eye and hair colors, body build and the like. So we can conclude that variations in these traits are due mainly to genotypic differences. In the formation of psychic traits such as intelligence and temperament, however, environment plays a much more important role. We are still very far from understanding precisely



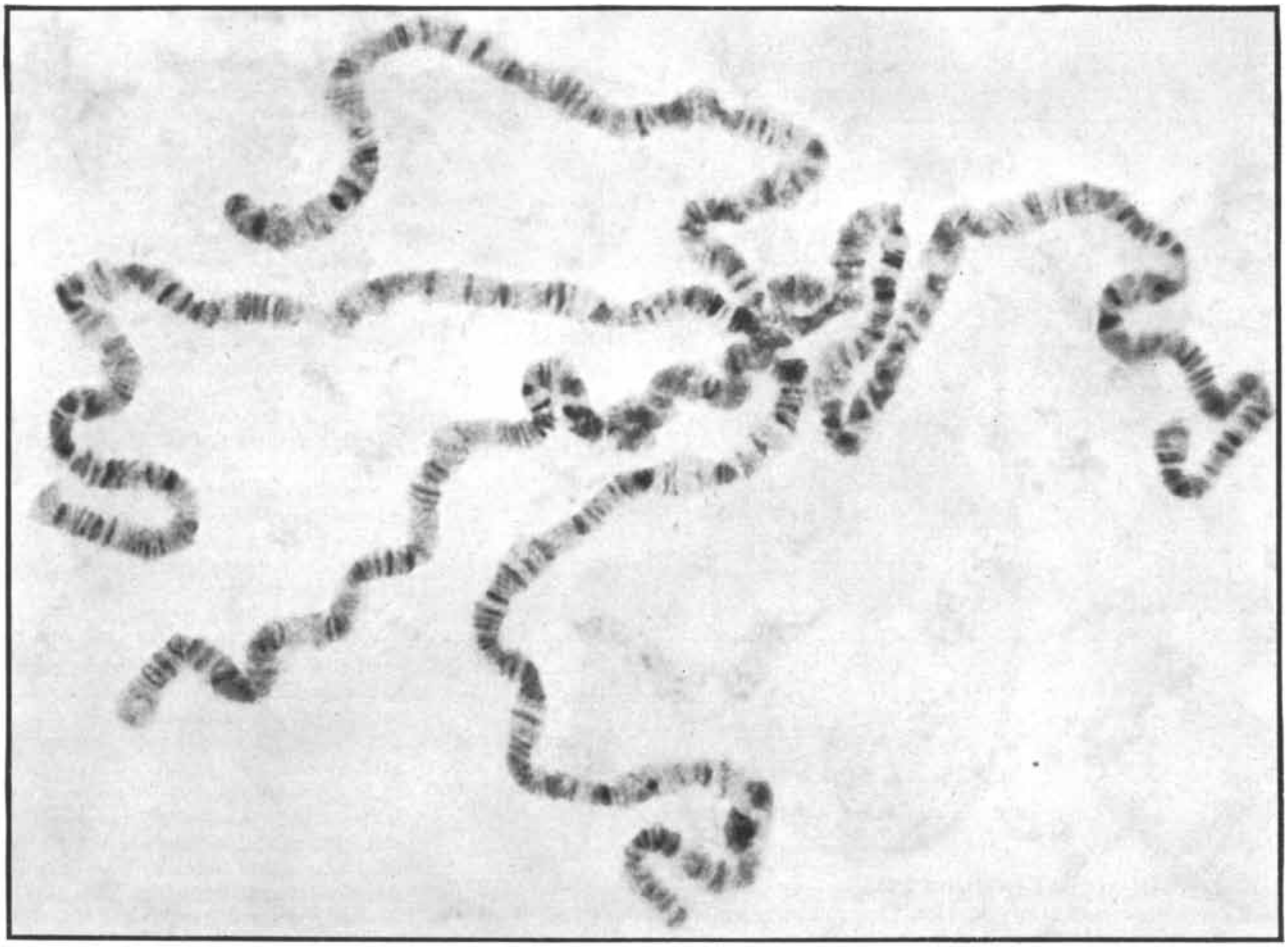
MENDEL worked with the pea plant. When he crossed a tall pea with a short, their offspring were tall. When the offspring were self-fertilized, their offspring were tall and short in a ratio of three to one. This Mendel explained on the basis of dominant factors (*dark disks*) and recessive (*light*).

how either heredity or environment influences these qualities, and during the next half-century genetics will certainly devote a great deal of attention to the problem—a problem of prime philosophical and sociological significance to mankind.

The investigation of the fundamental units of heredity—the genes—has made much greater progress; indeed these powerful particles have occupied the center of the geneticists' interest. The genes are extremely minute quantities of living matter, and they are transmitted from parents to offspring in sex cells which are themselves very small. The geneticist Hermann J. Muller, of Indiana University, has estimated that the egg cells from which the 2,200 million human beings now on the earth developed would about fit into a one-gallon pitcher, and the 2,200 million spermatozoa that fertilized them would occupy about the volume of an aspirin tablet. Within these cells the genes themselves—the bits of matter that account for the heredity of the entire human race—all together would make a small thimbleful. The powers of this hereditary substance are prodigious indeed!

ALMOST from the start geneticists singled out the nuclei of sex cells for special study. As early as 1903 W. S. Sutton of Columbia University and Theodore Boveri in Germany concluded that the genes are carried in the chromosomes, the nuclear structures which are visible under the microscope and were already well known at that time. In 1911 Thomas Hunt Morgan, then at Columbia University, inferred that the genes are arranged in a linear file, or row, on the chromosomes. He set up this hypothesis in order to make sense of certain results of hybridization experiments which would otherwise have been incomprehensible. His hypothesis soon received further support. In genetics, as in science generally, one frequently learns more from the abnormal than from the normal—the exception often proves the rule. In this case the earliest validation of Morgan's theory came from studies of certain aberrant cases of inheritance in Drosophila flies that seemed to break all the rules. It was found that whenever a trait appeared to break the usual rules of inheritance, the chromosomes showed a deviation from their normal conformation or behavior that explained the seemingly irregular heredity. And *vice versa:* deviations in the chromosomes always forecast corresponding abnormalities in the phenotype.

As the result of experiments suggested by the linear hypothesis, Morgan and others were able to construct genetic "maps," showing the relative positions of the known genes, of the chromosomes of the fly *Drosophila melanogaster*, which became the organ-



GIANT CHROMOSOMES of the fruit fly Drosophila have been one of the principal tools of the geneticist. These were prepared by B. P. Kaufmann at the Carnegie Institution of Washington in Cold Spring Harbor, N. Y.

ism most widely used for genetic research. More or less detailed maps of this sort now exist for several species of Drosophila flies, for corn and some other plants, for certain chromosomes of mice and poultry and for the sex chromosome in man.

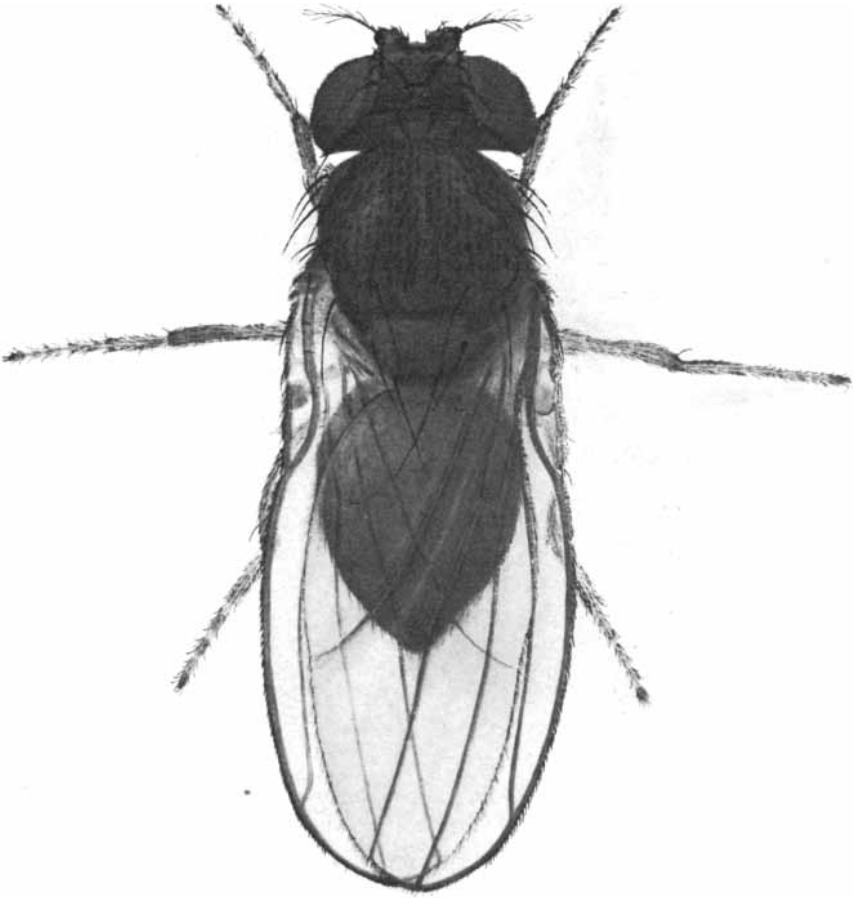
In 1933 and 1934 several investigators discovered a remarkably useful genetic material in the giant chromosomes in the salivary glands of the larvae of certain flies. Actually these chromosomes, like Mendel's laws, were a rediscovery: the extraordinary size of the salivary-gland chromosomes in a water midge, *Chironomus*, had been noticed by the Italian zoologist B. G. Balbiani as early as 1881. When, in the fullness of time, geneticists inspected the giant chromosomes closely under a microscope, they found them most revealing. In stained microscopic preparations these chromosomes appeared as cylinders or ribbons, composed of alternating dark and light disks. The patterns formed by these disks made it possible not only to distinguish the various chromosomes that a species possessed but also to recognize parts of the chromosomes. The linear arrangement of the disks suggested, and there now exists fairly convincing evidence to show, that each disk corresponds to a gene—though it would be incorrect to say that a disk *is* a gene.

Thus the gene was finally given a local habitation and a tangible existence—it was no longer some abstract unit of heredity; it was a material particle in a chromosome. What is the chemical nature of this particle? This question has been explored by a number of workers using various techniques. T. Caspersson of Sweden and Alfred E. Mirsky of the Rockefeller Institute for Medical Research have been particularly successful in applying ultraviolet spectroscopy and chemical extraction to the problem. The principal constituents of chromosomes are now known to be complex chemical compounds called nucleoproteins. It is probably more than a coincidence that the viruses, the smallest and simplest of all living beings, also consist of nucleoproteins. Indeed, quite aside from the chemical similarity, certain resemblances in the behavior of genes and viruses have led Muller to refer to viruses as "naked genes."

The British geneticist C. D. Darlington has recently speculated on the kinship between viruses, genes and "plasmagenes," viruslike particles in the part of the cell outside the nucleus which have been found in paramecia by Tracy M. Sonneborn and his students at Indiana University and in Drosophila flies by Philippe l'Héritier of France. Darlington speculates that there may be other particles intermediate between viruses, genes and plasmagenes. He also suggests that cancer may be initiated by a mutation which transforms a plasmagene into a particle of cancer virus with the power to change normal body cells into cancerous cells. The least one can say about this suggestion is that it is worth testing.

IN all probability a gene is a single complex molecule—a molecule that possesses the ability to reproduce itself. Since self-reproduction, in the opinion of many biologists, is the basic property that distinguishes living from nonliving matter, the genes represent life at the most fundamental level: they are basic units of life. But how do they exercise their control; by what power can a gene-molecule in a chromosome of a sex cell influence so profoundly the development of a whole organism consisting of billions of cells?

It is evident that the only way a gene



DROSOPHILA PSEUDOOBSCURA is one of several species of fruit fly that have been useful to genetics. This drawing was made by E. M. Wallace.

can influence development is through physiological, and ultimately physicochemical, processes in the body. A clear connection between the genes and some of these processes has been established by the beautiful experiments carried out on the bread mold Neurospora and on some other fungi and bacteria by George W. Beadle and his school at the California Institute of Technology. By treating this mold with X-rays, ultraviolet rays and other agents that changed its genes, Beadle produced defective varieties of Neurospora that could not grow on the medium of nutrients on which the organism normally thrived. In each case something had to be added to the usual nutrients, some specific vitamin or other substance, to enable the variant mold to grow. The defective organism had evidently lost the ability to manufacture this vitamin for itself. Beadle concluded that what was missing in each case was a specific enzyme the organism needed for normal metabolism; lacking this enzyme, the variant mold was unable to produce the vitamin or other nutrient in its own cells.

How a gene produces an enzyme is still a matter of speculation. One school of thought suggests that genes make enzymes as by-products during the process of self-reproduction; another conjectures that enzymes are actually genes that have been liberated from the chromosomes; still another that genes act as templates, impressing highly specific patterns on other molecules and transforming them into enzymes.

In any case, the immense effectiveness of the submicroscopic genes is, in the opinion of the eminent physicist Erwin Schrödinger, one of the most remarkable facts disclosed by science in the current century.

VERY early in the study of genetics biologists began to pay particular attention to the aberrations now known as mutations; this investigation was initiated by de Vries at the turn of the century and brilliantly developed by Morgan and his school from 1910 on. A gene, by definition, is a living particle that reproduces itself, and nearly always it does so exactly. But occasionally, probably under the influence of some outside agent, it forms an imperfect copy of itself. If this altered gene is able to reproduce itself in its new form, the result is a mutation, which is evidenced in a permanent change in some trait of the organism.

Thus mutation is the antithesis of heredity. Heredity insures the basic continuity and coherence of the organic form; mutation creates a diversity of genes, and thereby is ultimately responsible for the great diversity of living beings on the earth. The mutation process, in short, supplies the building blocks of evolution. With this discovery, the biologists of the 20th century started to unravel the mechanisms of that evolutionary process which Jean Baptiste Lamarck, Charles Darwin and their successors of the 19th century had suggested but only dimly understood.

The spontaneous mutations in nature that account for evolution occur relatively rarely. In 1927 Muller announced that the frequency of mutations could be greatly increased by exposing genes to X-rays. Since then it has been shown that the mutation rate can also be speeded up by other kinds of radiations, by high temperatures and by certain chemicals. But all these "mutagens" are nonspecific in their effects; they accelerate mutations in general, not exclusively in one particular gene or group of genes. Controlled mutation is a problem for the future.

Genetics is a fundamental or "theoretical" science; its value is before all else philosophical, in the sense that it strives to contribute toward man's understanding of the nature of life and of himself. Yet genetics will surely play a major role in the still infant technology of biological engineering. Already it has borne a huge harvest of "practical" results through improvements in breeds of food plants and animals. The development of hybrid corn in the U. S. has increased the average corn yield from 25.9 bushels per acre in 1932 to 36.5 bushels in 1946. In Sweden, with the aid of genetics, during the past half-century the average yield of winter wheat per hectare has been raised by 41 per cent, summer wheat 19 per cent, oats 9 per cent, barley 29 per cent and rye 19 per cent. In the field of medicine, the development of new strains of the mold *Penicillium* played a major part in making possible large-scale production of penicillin, and genetics steadily becomes more and more important as a tool for improvements in the prevention, diagnosis and treatment of many diseases.

THERE remains the ultimate hope that genetics will point the way to improving the human species. Some of the early attempts to apply eugenics in the human realm were based more on enthusiasm than on understanding. But as our understanding of the genetics of human populations grows, the possibilities for useful application of our knowledge doubtless will multiply.

Theodosius Dobzhansky is one of the principal contributors to the relationship between genetics and the study of evolution. Born in Russia, he came to the California Institute of Technology in 1929. Since 1940 he has been professor of zoology at Columbia University.

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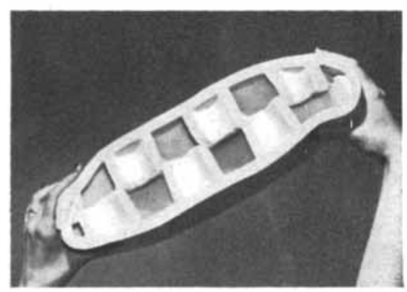

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BIOCHEMISTRY

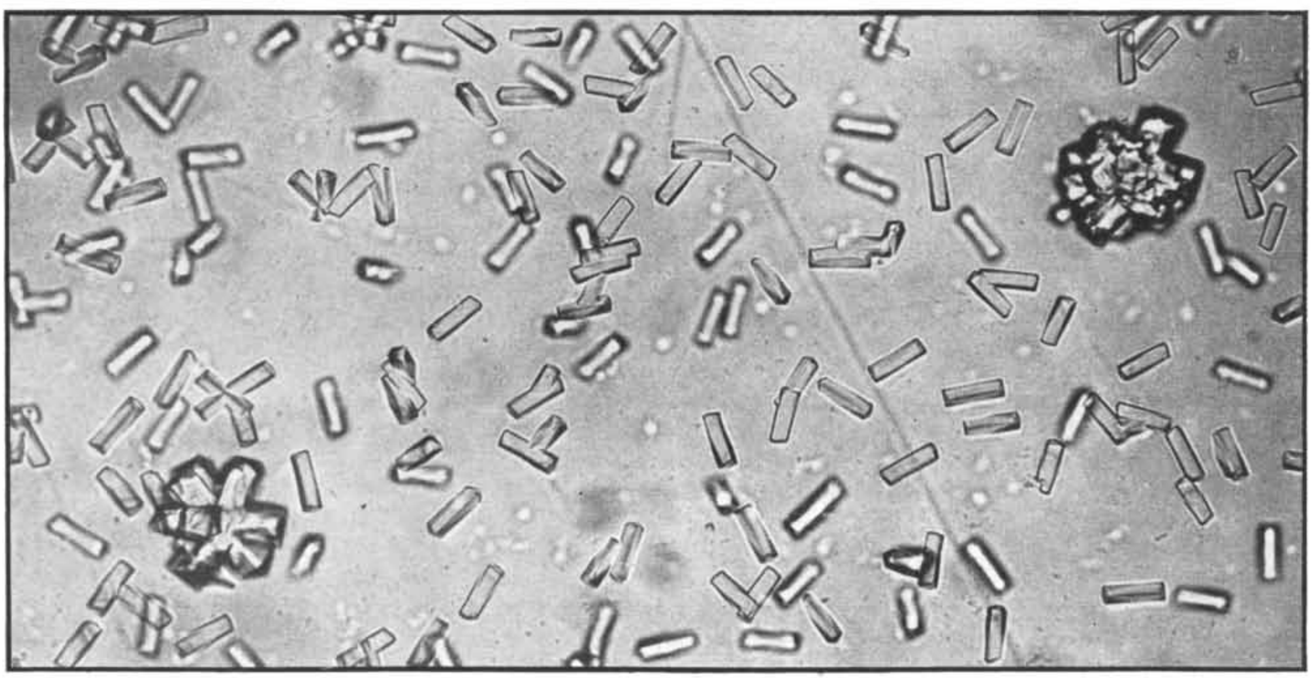
Another young science, viewing living things as dynamic processes rather than machines, has notably investigated the intricate chemical reactions common to all organisms

by Otto Meyerhof

THE HALF-CENTURY from 1900 to 1950 roughly spans the writer's personal scientific experience; he began his university study early in 1903 and now, in 1950, is not far from retirement. During this half-century he has seen biochemistry come of age as a separate branch of biology and medicine. Fifty years ago, in any review of progress in the major fields of science, no one would have been asked to write a separate account of biochemistry. The chemistry of life was then but a part of the study of physiology; it was taught in physiology classes and was called physiological chemistry. There was only one journal in the world (published in Germany) devoted to this special subject. The discoveries in biochemistry had been made by physiologists, by clinicians and, most of all, by organic chemists.

When the physiological chemists began to develop their study at the turn of the century, they started with a sound basis of knowledge, built by a few organic chemists, about the chemical composition of animals and of some of the nutrient substances on which they feed. Between 1882 and 1908 the penetrating genius and painstaking research of Emil Fischer of Germany had cleared up the molecular structure of the common sugars and carbohydrates; of many amino acids and peptides, the building stones of proteins; and of the purines and pyrimidines, which together with sugar and phosphate constitute the nucleic acids found in the nuclei of cells. Following the lead of organic chemistry, some physiological chemists have been and still are devoting themselves to disentangling the exact structure of all the important constituents of the body and of a variety of stimulating or depressing, activating or poisoning substances of plant and animal origin. An outstanding example is the work of the late Hans Fischer of Germany, who cleared up almost completely the chemical structure of the blood and bile pigments and of chlorophyll and related substances.

Considering that organic chemistry, founded from scratch around 1830 by Justus von Liebig and Friedrich Wöhler, is only some four generations old, these achievements in chemical analysis are stupendous. But in the last few decades biochemistry has developed aims and ideas which seem to us more important than mere continuance in the way of these elders and chemical wizards. Knowledge of the composition of the constituents of the body is not enough;



THE ENZYME desoxyribonuclease is one of a number of enzymes that have been isolated. This enzyme was crystallized by M. Kunitz of the Rockefeller Institute for Medical Research. Crystals are magnified 250 diameters.

we have become much more interested in a dynamic view which seeks to explain in chemical terms the functions and transformations in the organism.

THE CLASSICAL organic chemists liked to compare the living cell to an engine: it took in certain fuels, burned them and discarded waste products. Actually the cell is best compared, as Leonardo da Vinci compared it, to a burning candle. Da Vinci wrote: "If you feed a living body with so much food as has been internally consumed during the day, such an amount of living material will be rebuilt, in analogy to a burning light of a candle: The light is continually rekindled from below with the succour of the streaming wax, while above, it goes out and dies into black smoke." It is the continuous breakdown and rebuilding of living material that greatly interests biochemists today.

During the past half-century biochemistry has developed another fundamental change in point of view. The classical biology of the 19th century gave its main attention to whole organisms, and emphasized the differences between species and groups. Early in this century a movement headed by Jacques Loeb of the U. S. and Otto Warburg of Germany reacted against this specialism. They felt strongly that all living beings had much in common, and that the essential facts of the life process could best be studied by investigating the universal structures, functions and substances common to all living creatures. As a result of this shift in view, the study of mammals as a whole was largely replaced by intensive investigation of the metabolism and physical chemistry of homogeneous cells—sea-urchin eggs, yeast, bacteria, blood corpuscles, any cell that could reveal the physiological processes of life at the most fundamental and universal level.

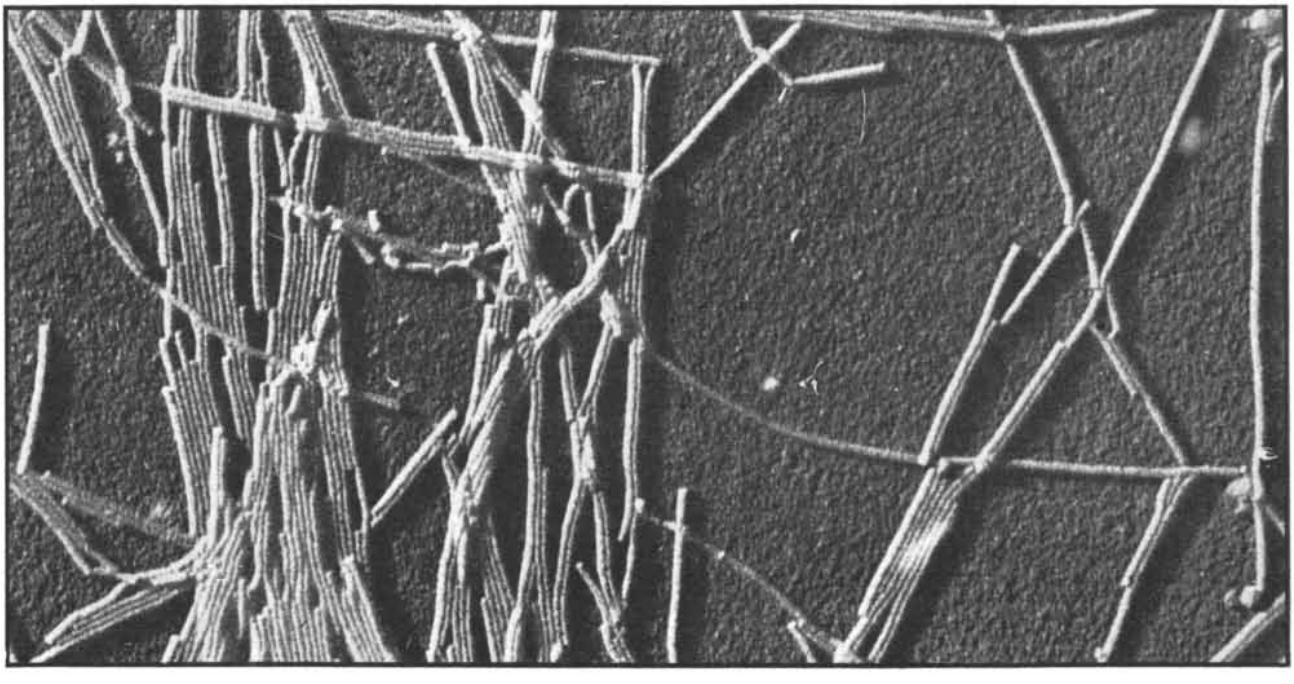
These two new outlooks, then—the dynamic view and the universality of life processes—have distinguished the more progressive elements of our science in the last few decades. Obviously it would be hopeless to attempt to summarize in one article the prodigious work of the half-century in biochemistry. I shall merely illustrate the problems and some of the important findings with a few specific examples taken from certain fields of research.

THE KEY AREA of biochemical research is the chemistry of enzymes, those vital catalysts on which every metabolic process depends. The idea of an enzyme or "ferment" originated in 19th-century studies of the alcoholic fermentation of yeast. Louis Pasteur regarded the whole yeast cell as a "formed ferment" which could decompose relatively unlimited amounts of sugar into carbon dioxide and alcohol: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$. But in 1897 the German chemists Eduard and Hans Buchner succeeded in completely separating the process of alcoholic fermentation from the living cell. They surprised the contemporary world by the demonstration that vigorous fermentation of sugar could go on in the presence of a cell-free juice pressed from yeast. With this yeast-juice enzyme system, which the Buchners called "zymase," modern enzyme chemistry starts. Since that time the Buchners' zymase has been found to consist of 20 or more enzymes which work marvelously in step, transforming sugar through more than 12 stable intermediates to the end products alcohol and carbon dioxide. Every single step is now chemically cleared up. Nearly all the individual enzymes have been isolated and many of them have been obtained as crystalline protein.

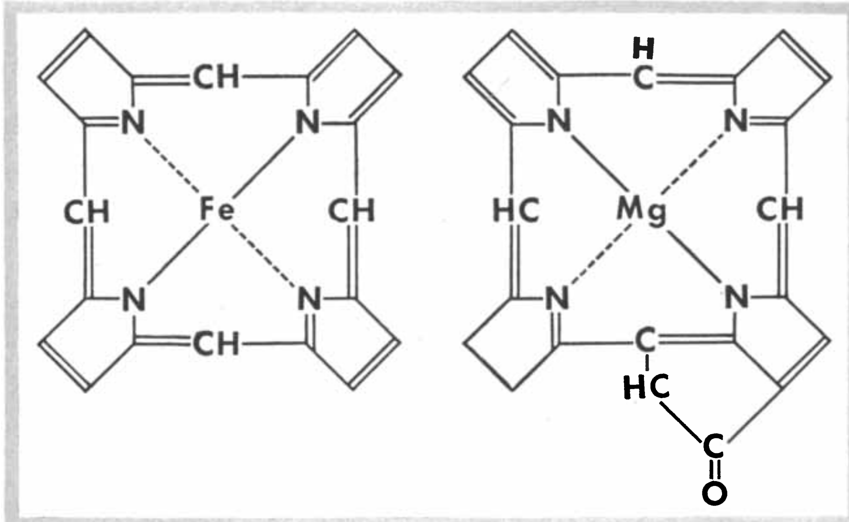
The intermediates formed during the fermentation of sugar to alcohol are mostly phosphate compounds. It was the English chemist Arthur Harden who discovered, around 1905, that sugar phosphates were formed and that inorganic phosphate was necessary for fermentation. He also demonstrated that the pressed yeast juice contained a complex which was named the "coferment of fermentation." This was later recognized to be a mixture of three different coenzyme systems, each necessary for one or more intermediate steps.

With further research it became apparent that the breakdown of sugar in the higher animals follows the same pathway as in yeast; indeed, various other types of metabolism, especially oxidative metabolism, were found to require either the same or very similar enzymes and coenzyme systems. As biochemists pursued their studies of metabolism, they found these enzymes and coenzymes of fermentation to be important in many biological activities of the organism.

How one discovery led to another may be illustrated by some of the findings that flowed from the identification of the three coenzyme systems mentioned above. These three coenzyme systems, which are necessary not only for alco-



THE VIRUS of tobacco mosaic disease was isolated by W. M. Stanley of the Rockefeller Institute. This electron micrograph of some 70,000 diameters was made by R. W. G. Wyckoff of the National Institute of Health.



IRON PORPHYRIN is the nucleus of hematin, which with a protein forms the oxygen-bearing pigment of the blood. At each blank corner in this structure is a carbon atom. The similar skeleton of chlorophyll (*right*) possesses a fifth ring and contains magnesium (Mg) instead of iron (Fe).

holic fermentation but also for lactic-acid fermentation, a feature of the metabolism of most animal tissues, are: 1) the adenylic system, also known as the phosphorylating coenzyme; 2) cozymase, a pyridine nucleotide; 3) cocarboxylase. They are needed for three stages of fermentation. The adenylic system serves as the necessary catalytic agent whenever an intermediary takes up phosphate or is split off from it—the process called phosphorylation. Cozymase is the agent for oxidation or reduction of intermediaries; its pyridine ring and phosphate group accept two hydrogen atoms to accomplish this. Cocarboxylase is the catalyst responsible for splitting off carbon dioxide—one of the final steps in the fermentation.

IT WAS the study of the first of these coenzymes—the adenylic system—that brought to our knowledge a certain special type of phosphate bond which stores much of the chemical energy of the living body. This "high-energy" phosphate bond liberates about 10 times as much energy, when it is split off from an organic compound, as the bond of an ordinary phosphate ester. Especially important as a source of energy is adenosine triphosphate (ATP). The Hungarian biochemist A. Szent-Gyorgyi showed that the contraction of muscle probably is brought about by a direct reaction between ATP and the muscle proteins actin and myosin. Thus the phosphorylating coenzyme plays the key part in liberating the energy that enables an organism to perform its functions.

The role of the other two coenzyme systems was found to be equally dramatic. From studies of them came answers to the questions: What are vitamins, and what are they for? The existence of vitamins had been discovered around 1906, and they had become recognized as essential elements of nutrition, the lack of which causes such deficiency diseases as rickets, pellagra, beriberi and scurvy. Now when the chemical formulas of the two coenzyme systems were worked out, it developed that both contained vitamins as functional groups. The special pyridine compound in the oxidation-reduction coenzyme, the diphospho-pyridine nucleotide, is the vitamin nicotinamide, whose absence produces pellagra. Similarly cocarboxylase is a diphosphate compound of thiamin or vitamin B_1, the lack of which produces polyneuritis and beriberi. Following up this lead, investigators have found that every vitamin, as far as can be determined, is part of a coenzyme. Our knowledge about the functions of vitamins as parts of coenzymes is still not complete, but their chemical relations are well established.

Out of the knowledge of the chemical structure of specific vitamins has developed, in turn, a subtle chemotherapy. We have learned that a slight alteration

Meyerhof

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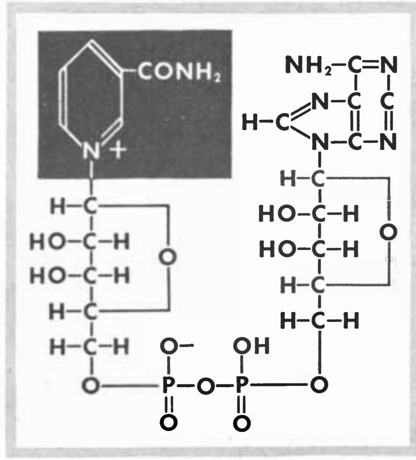
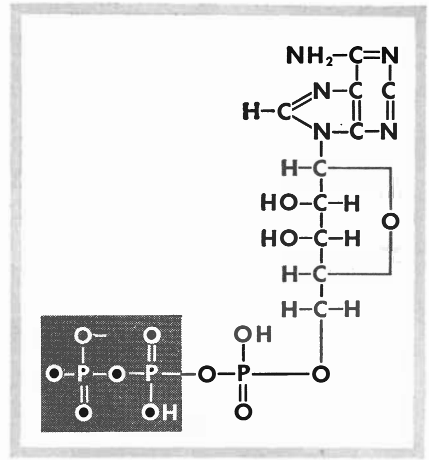


COZYMASE is a coenzyme containing the B vitamin nicotinamide (*black rectangle*). As far as is known, all the vitamins are part of coenzymes.



ATP, or adenosine triphosphate, contains three phosphate groups, two of which (*black rectangle*) can be split off to release large amounts of energy.

in the configuration of a vitamin will produce a substitute substance that competes with the vitamin itself. It can react with metabolic enzymes in place of the true vitamin and thereby block the enzymes' activity. If this pseudo-vitamin blocks the action of metabolic enzymes of disease-producing bacteria without affecting the cells of the host, it can be a very useful tool for treatment of infections. This is the principle of the sulfa drugs, which simulate para-aminobenzoic acid, one of the vitamins of the B group.

Enzyme chemistry has many other interesting aspects. While there is no space here to describe the physical chemistry and the reaction mechanism of enzymes, the great progress in the complete purification and crystallization of many enzyme proteins must be mentioned. For decades there was dispute as to whether enzymes were proteins at all. When, at the end of nine years of work, James B. Sumner of Cornell University in 1926 succeeded in crystallizing the first enzyme, urease, and proved it to be a protein, the crystallization of many more enzyme proteins followed. In 1936 came the remarkable discovery by Wendell M. Stanley at the Rockefeller Institute for Medical Research that plant viruses, such as the tobacco mosaic virus and several tomato viruses, could be crystallized in the same way as enzymes. Because a virus behaves like a living organism, this was one of the most startling biochemical discoveries of our time. These viruses are high molecular nucleoproteins, containing materials similar to the genetic substances in the nuclei of ordinary cells. Indeed, we must assume that they are very like the genes in chemical constitution. (*For a discussion of the chemistry of genetics, see page 55.*)

From the foregoing we are prepared to look at the metabolism of a cell from two different angles: we can consider either the causal mechanism that makes it go or the materials and intermediate steps involved in the process.

The first point of view demands that we unravel the chemical nature of the active enzymes. Otto Warburg has made great strides in explaining oxidative metabolism—the oxidation and reduction of body substances. He found that the oxygen taken by an animal from the air reacts first with an enzyme containing as an active group an iron-porphyrin which is closely related to hemoglobin, the oxygen-carrying blood pigment. But the iron in this enzyme behaves differently from that in hemoglobin. In hemoglobin the iron remains bivalent and the oxygen is bound reversibly: the hemoglobin can release molecular oxygen as well as take it up. In the enzyme an irreversible reaction takes place: when it takes on oxygen the bivalent iron is oxidized to trivalent iron. This iron is then consecutively reduced by three other iron porphyrin pigments of the cells—the cytochromes A, B and C. The oxidation of the combustible material of the cell, on the other hand, is actually a dehydrogenation: hydrogen is withdrawn from the organic substances by specific enzymes. Generally the next step after the oxidation of the iron of the cytochromes is a reaction with a yellow enzyme containing as an active group the phosphate ester of riboflavin, or vitamin B_2, which can add hydrogen to nitrogen rings.

WE CANNOT enter here into a detailed description of the other aspect of cell metabolism—the materials and intermediary steps. But one baffling finding should be noted. This is the surprising discovery, made with the help of tracer isotopes, that carbon dioxide is not only an end product of metabolism in animals, as has long been known, but actually is used by an animal in some of its building-up reactions. When carbon dioxide labeled with isotopic carbon is injected into an animal as bicarbonate,

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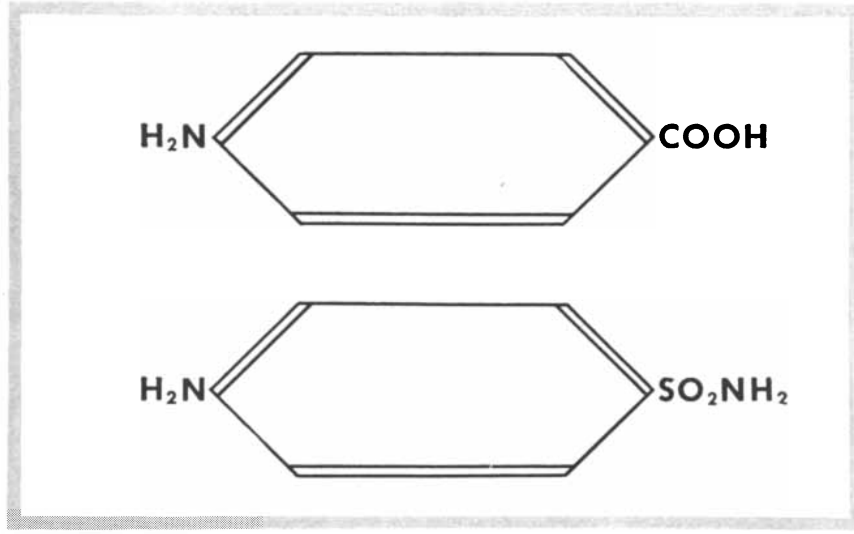


SULFANILAMIDE (*bottom*) **has a structure analogous to that of the B-vitamin para-aminobenzoic acid** (*top*)**. The drug can thus enter into and inhibit reactions involving the vitamin. Other drugs similarly imitate vitamins.**

some of the labeled carbon is later found incorporated in the glycogen of the liver. Most of the individual steps of this remarkable reaction are now known. They have given us a great deal of information on the probable pathway by which plants assimilate carbon dioxide in photosynthesis. We know that plants require light to produce hydrogen for reducing their carbon compounds, but the formation of these compounds in the first instance is probably brought about by a reaction identical with the reversible assimilation of carbon dioxide in animals.

The use of tracer isotopes to study metabolic reactions, started as early as 1936 by the chemist George Hevesy, has of course become a great stimulus to biochemistry. The most valuable biochemical tools are radioactive phosphorus 32 and the isotopes of carbon, especially radioactive carbon 14, with a half-life of 5,000 years. These studies reveal in a most impressive way the speed with which all the constituents of the body are "rejuvenated" by decay and resynthesis. Studies with isotopes show also the specific ways in which complex substances are synthesized in the body from simpler ones, and what intermediaries are formed during the turnover. One may say that the use of isotopes has added a new dimension to biochemical studies: it allows us to see reactions which cannot be seen by purely chemical means. An example of new information of this kind made available by isotopes is the rate of exchange of phosphate between inorganic and organic compounds in the presence of enzymes. Such reactions can now be used for the diagnosis of malignant tumors in the human body.

LOOKING ahead to the next half-century, we must be clear that the most important discoveries cannot be planned or predicted. They stem from genius and creative intuition; techniques and skills play no other role than they played for Michelangelo in painting the Sistine Chapel or for Beethoven in composing the *Ninth Symphony*. The only means by which society can assist fundamental scientific progress is to protect and appreciate scientific talent.

In biochemistry the time is undoubtedly ripe for illuminating discoveries that will give us an understanding of the structure of proteins; the new techniques of chromatography and the electron microscope should help greatly toward that end. By systematic research on the competitive inhibition of vitamin analogues we should arrive at a universal rational chemotherapy for many diseases. The mechanism of the transformation of chemical energy into work in muscle and into electric currents in brain and nerve will be cleared up. Research in these directions is well under way.

Biochemistry has an important bearing on the progress of medicine. But because of this, it must itself remain a pure science, whose initiates are inspired by a craving for understanding and by nothing else.

Otto Meyerhof, awarded the Nobel prize in physiology and medicine for 1922, has been one of the most creative investigators in the young science of biochemistry. The subjects of his principal studies have been the chemistry and thermodynamics of muscle, for which he received the Nobel prize, the metabolism of carbohydrates and enzyme chemistry. Meyerhof began his career at the University of Kiel in Germany, and during the 1920s and 1930s he taught in Berlin, Heidelberg and Paris. Since 1940 he has been Research Professor of Biochemistry at the School of Medicine in the University of Pennsylvania.

PHYSIOLOGY

The earlier physiologists were principally concerned with the general organization of the body. Today their interest has shifted toward its physics and chemistry

by E. D. Adrian

THE AIM of physiology is to describe the events that take place in the body, and incidentally to help the doctor by doing so. But what events, and in what terms shall it describe them? About this there has been, during the past half-century, a change of view. Today it is generally agreed that although physiology is concerned with living processes, it must in the end bring its descriptions within the framework of physics and chemistry.

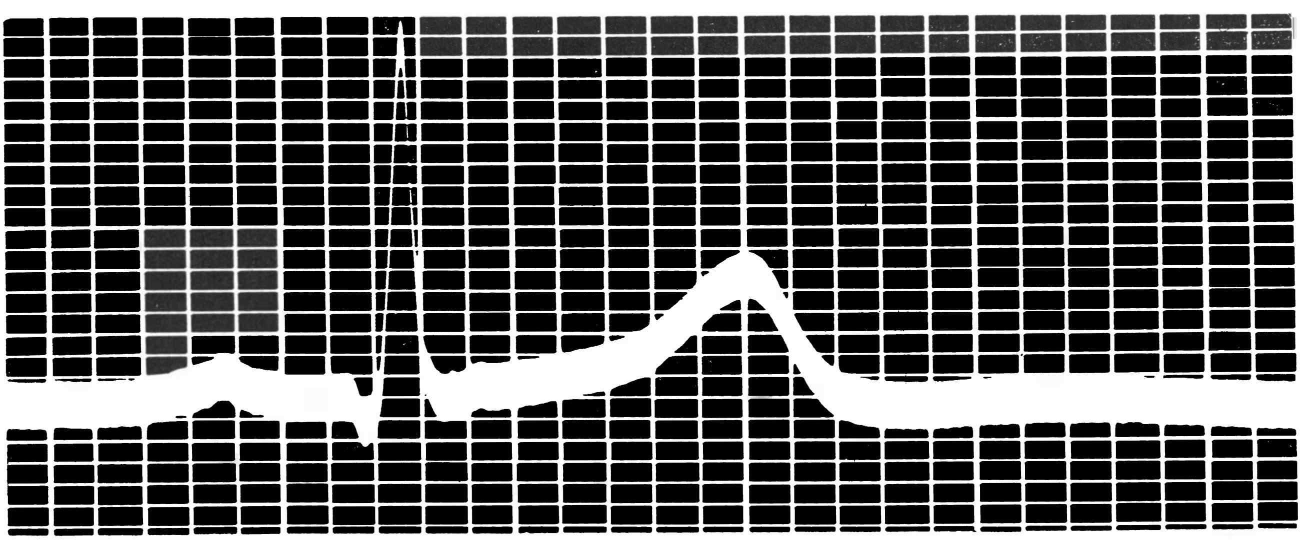
In the 19th century physiology could be less ambitious. There was so much to find out about the structure and large-scale activities of the various organs without attempting to measure the physical and chemical changes in them, for which there were, in any case, few methods of exact measurement available. Physiologists were fully occupied in analyzing the movements of the stomach and gut, the nervous control of the blood vessels and the cycle of pressure changes in the heart. They could speak rather vaguely of anabolism, tonic influences, nervous energy.

That early phase is now over. The general organization of the body has been cleared of its more obvious problems. Physiologists have borrowed many new techniques from the exact sciences, and their interest is shifting in the direction of biophysics and biochemistry.

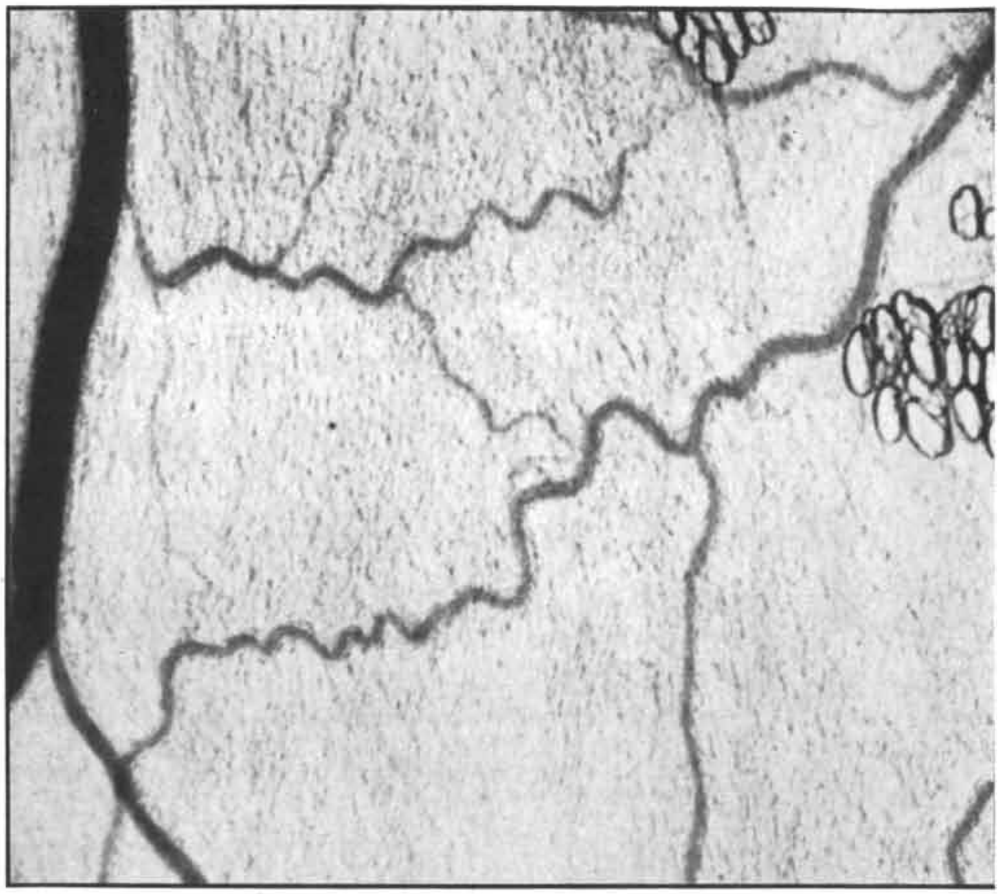
In the first 10 years of our century the whole working plan of the body became much clearer. Sir Charles Sherrington, studying the spinal reflexes, revealed an illuminating picture of the central nervous system as the main integrative apparatus of the body, responsible for all its rapid adjustments to the world outside. During the same period other investigators, employing new methods of investigation, uncovered the nature of many of the internal adjustments.

The chief interest of that time was in the physiology of the digestion, circulation and respiration. Research on digestion had flourished since the 1890s. Ivan Pavlov's new surgical methods had permitted the alimentary canal to be explored from one end to the other. Walter Cannon began to use X-rays to reveal the movements of the stomach. J. N. Langley had mapped the complicated pathways and distributing stations of the sympathetic and parasympathetic nerves, and the nervous regulation of the viscera was already understood. In 1902 William Bayliss and Ernest Starling made the startling discovery of a new kind of regulation—by chemical signals instead of nervous ones. They showed that the flow of pancreatic juice was started by a chemical substance that was formed in the gut in the process of digestion, was absorbed into the blood and was brought to the pancreas by way of the circulation. This substance, "secretin," was the first of the hormones (and is still one of the most dramatic in its effects). It was already known that the ductless glands were essential to health, but the discovery of secretin opened to view their importance as the chemical integrative system of the body.

LANGLEY'S work was to have other consequences: it laid the basis for the modern operation in which the sym-



STRING GALVANOMETER record has been characteristic of many physiological studies. This record from a string galvanometer electrocardiograph plots action current through the heart during a single contraction.

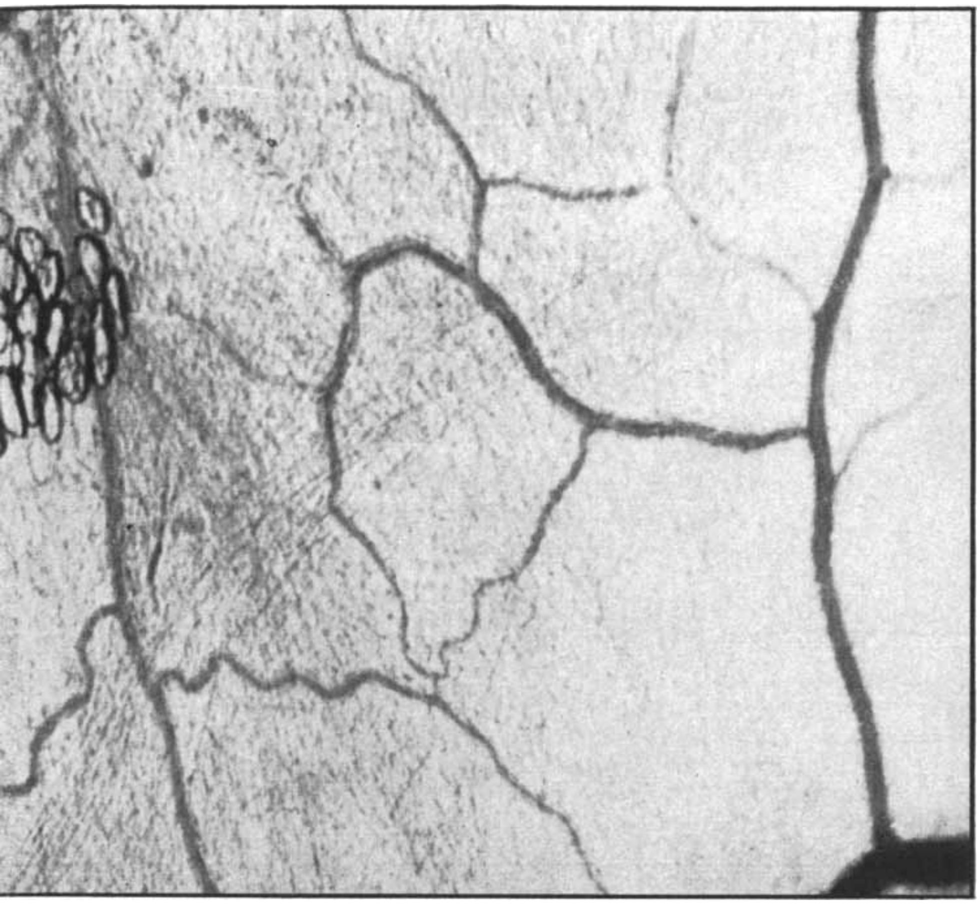


CAPILLARY BED has been the site of numerous studies. This photomicrograph of a rat's mesentery by B. W. Zweifach of Cornell University Medical

pathetic nerves, one of whose functions is to constrict the blood vessels, are cut at their origin to improve the blood flow through the limbs. But it was to be 20 years before physiologists could bring themselves to believe that the sympathetic nerves might sometimes have harmful effects (causing too much vasoconstriction), and before surgeons became so bold as to sever these nerves as a treatment for arteriosclerosis and high blood pressure.

In 1903 came the invention of a new instrument that was as potent for research on the heart as were the X-rays for research on digestion. It was the string galvanometer, designed by W. Einthoven of Leyden to follow the brief electric changes in living tissues. Its moving part, a fine thread of silvered quartz held in a strong magnetic field, was rapid enough to give a faithful record of the currents generated by the beating heart, and sensitive enough to record these currents from the surface of the body. For the first time the activity of all the different chambers of the heart could be clearly followed in man, and the progress of the wave of excitation could be seen. Einthoven's instrument changed the fashion in heart disease. Heart specialists wrote papers on irregular rhythms and damage to the conducting tissues of the heart, and were less concerned with leaking valves and the murmurs peculiar to them. For 25 years the string galvanometer held the field. It was used to record the action potentials of muscles and nerves as well as of the heart, and it showed the way to all the recent work on the electrical activity of the nervous system. When electronic amplifiers were developed, it became unnecessary to use such a sensitive recorder as the string galvanometer, at least for laboratory work, and the instrument lost its unique position. It is still going strong, however, in clinical practice.

NEW METHODS of gas analysis made a corresponding advance in the physiology of respiration. At the turn of the century the great issue was whether breathing was regulated by the need to absorb more oxygen or the need to expel more carbon dioxide. Then in 1905 J. S. Haldane and J. G. Priestley devised a beautifully simple method of obtaining samples of the air in the alveoli of the human lung. They found that the pressure of carbon dioxide remained nearly constant in spite of great variations in breathing. They were able to conclude that the important controlling factor was the concentration of



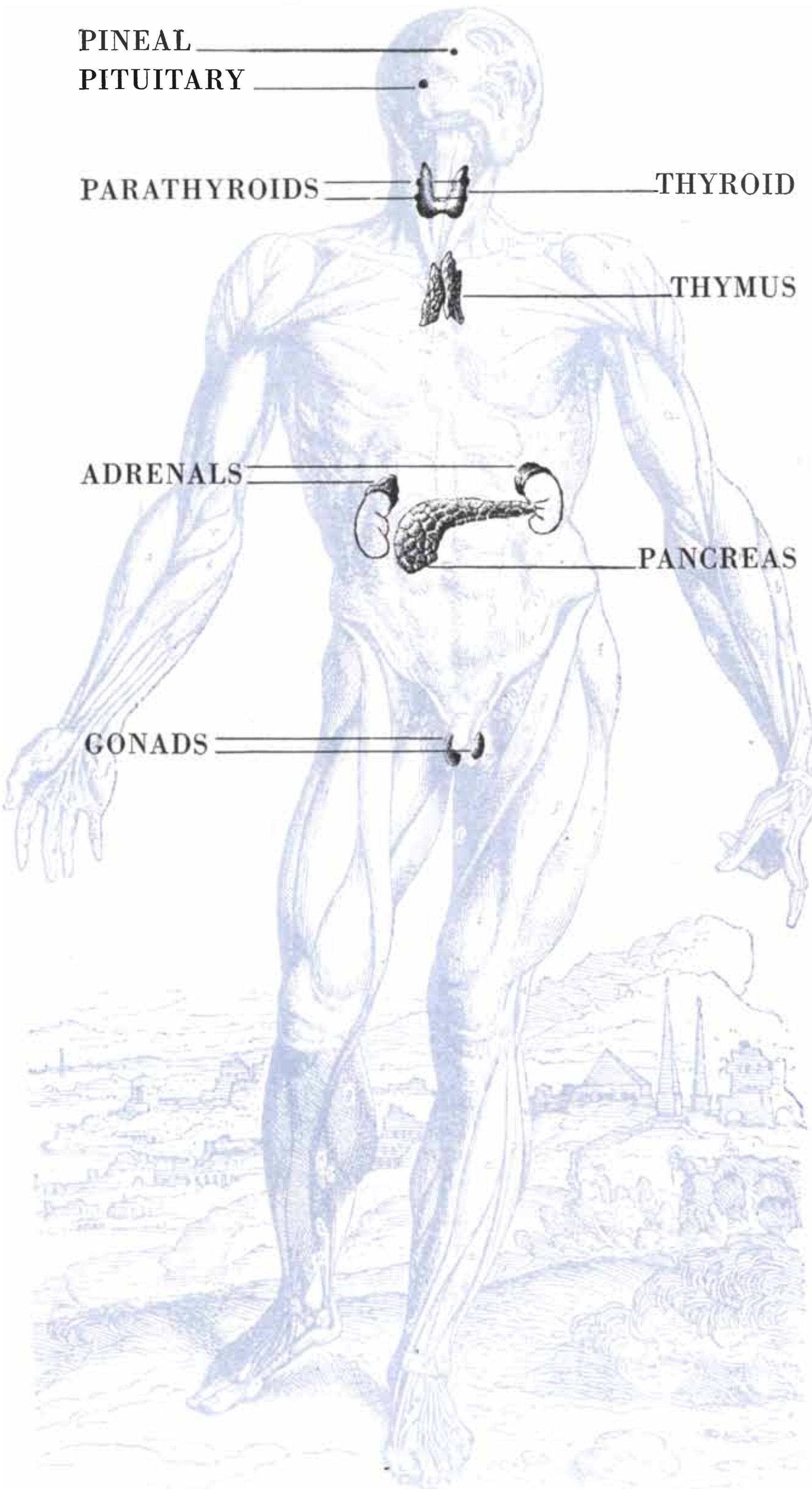
College shows the venules (*left and right*) and arterioles (*left center*) connected by thin capillaries. The round structures in center are fat globules.

carbon dioxide or carbonic acid in the blood.

Their work started what has become a special subdivision of physiology. Disorders of respiration were shown to depend on disturbances in the acid-base equilibrium of the blood. Thus interest was focused on the blood's physical chemistry. There emerged a host of questions as to how carbon dioxide was transported and how oxygen combined with hemoglobin, the oxygen-carrying pigment. Forty years' work by Joseph Barcroft, L. J. Henderson, Donald Van Slyke, Hans Fischer and August Krogh—to name only the protagonists—has not exhausted the interest in this field of blood chemistry. It has given us a far better understanding of the molecular structure of hemoglobin than of any other protein.

Most of the major lines of advance in physiology, then, received their great push in the first decade of the century. In the physiology of the endocrine glands the most spectacular leap ahead came later: this was the discovery in 1922 by F. G. Banting and C. H. Best of the pancreatic hormone insulin, which resulted in the immediate saving of thousands of lives. The complex functions of the pituitary gland took longer to unfold; our knowledge of them is still incomplete. More recent is the exploration of the adrenal cortex, source of the cortical hormones, whose story is mostly yet to come.

MEANWHILE still another story has developed from the much earlier discovery of adrenalin, the secretion of the medulla, or interior part, of the same adrenal gland. Adrenalin, a fairly simple molecule, produces all the effects that follow stimulation of the sympathetic nerves: constriction of blood vessels, acceleration of the heart, and so on. This posed the question: Is there a corresponding glandular secretion that acts as agent for the other set of visceral nerves, the parasympathetic? No such secretion was found. But in 1926 Otto Loewi discovered that when the parasympathetic nerves were stimulated, a chemical substance did come out of the nerve endings. This substance proved to be acetylcholine. Like adrenalin, it affects the viscera directly and is in fact responsible for the effects produced when the nerves are stimulated. And adrenalin or something like it comes out of the sympathetic nerve endings and is responsible for their effects. In fact adrenalin and acetylcholine are both chemical or "humoral" transmitters by which the nerve fibers influence the mus-



THE ENDOCRINE SYSTEM is made up of eight kinds of gland that secrete their hormones into the common pool of the blood and lymph. Of particular interest in recent years has been the relation between the pituitary and the adrenals involving the widely discussed hormones ACTH and cortisone.

cles or gland cells to which they are distributed.

Both substances have aroused sharp controversy and still do so. If the visceral nerves act by chemical transmission, we must look for such transmission in other parts of the nervous system as well. There is strong evidence that acetylcholine is the transmitter between motor nerve and muscle, and some evidence for its activity in the central nervous system. Evidence of chemical transmission in the brain and spinal cord would be of the highest importance. But direct evidence is hard to get, as any chemical transmitter that may exist must be destroyed almost as soon as it is liberated by the nerves.

It has, however, become far easier in recent years to get evidence as to the transmission of the signals along the nerve fibers. The messages that go into the brain from the sense organs and out to the muscles are made up of repeated impulses, each marked by a brief electric effect due to a change of potential at the surface of the fiber. These effects were too small to come within the range of the string galvanometer, but the whole position was changed by the advent of the electronic amplifier after the First World War. We can now record the smallest electric effects and can analyze the nervous signaling in detail.

The analysis has given us valuable information about the sense organs, the different kinds of nerve fiber and so forth, but it has not yet told us much about the higher levels of nervous activity. The central problem still to be solved is what happens in the brain when something new is learned. Pavlov's work on conditioned reflexes gave us many of the rules governing habit formation, but there is still a great gap between our knowledge of the observable behavior of an intact animal and of what is happening in the restricted area of its cerebral cortex. Until that gap is reduced we can only collect all the information we can about the nervous apparatus, knowing that a good deal of it may be irrelevant.

FINALLY there are the problems of the conduction of nerve impulses and how they bring about muscular contraction. These have engaged physiologists for centuries and have come to form a recognized subdivision of the science. Here we are dealing with the biophysics and biochemistry of individual cells, and not with the way in which the cells are organized in the body. For further understanding of what happens in a contracting muscle fiber we must therefore depend on advances in knowledge about the physical and chemical state of living matter, about protein structure, about enzyme action and about surface chemistry. We are still very far from a complete picture; in fact our picture of mus-

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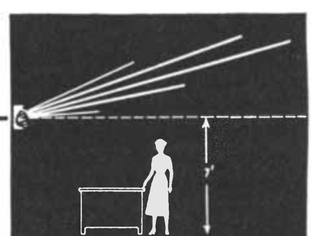

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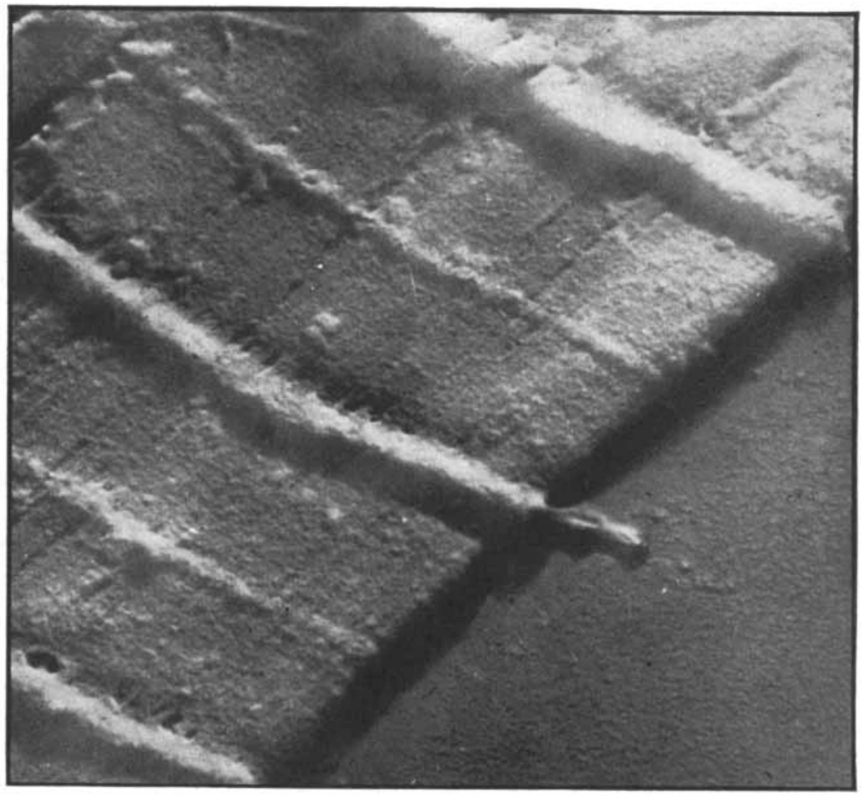

MUSCLE FIBRIL of a dog is magnified 42,000 diameters in electron micrograph by R. W. G. Wyckoff of the National Institute of Health. Fine structure of fibril is made up of filaments running from lower right to upper left.

cular contraction is like a jigsaw puzzle awaiting assembly. A great deal has been found out about the heat production and the chemical changes during contraction, but the different parts of the puzzle have not yet been fitted together.

In nerve there is less to explain and the outlines of the picture are clearer. The realization that the nerve impulse is an "all-or-nothing" reaction at each point in the fiber has focused attention on the surface membrane as the trigger mechanism. This investigation has been greatly assisted by studies of giant nerve fibers from invertebrates such as the squid. In these large fibers physiologists have been able to examine the properties of the membrane in rest and activity, and with the help of radioactive tracers they have determined how the different ions pass in and out through it. The nerve membrane is alive and seems to undergo surprising changes, but these are no longer beyond the reach of experiment. If they can be understood, we shall have mastered one of the most important properties of the living cell: its power to react suddenly to changes in its surroundings.

In the future we may expect dramatic advances in the field of cell physiology. There will remain a great many problems which are neither pure biophysics nor pure biochemistry, particularly those of the endocrine system and of the brain. They will keep some of us occupied for many years to come. But physiologists have always been eager to borrow all they can from the physical sciences in the way of new ideas and instruments, and at present these seem to lead to the study of the cell rather than to that of the organism.

Adrian

E. D. Adrian, awarded the Nobel prize for physiology and medicine in 1932, has been concerned principally with the physiology of the brain and the nervous system. He is the author of The Mechanism of Nervous Action *and* The Physical Background of Perception. *Since 1937 he has been professor of physiology at Cambridge University.*

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PSYCHOLOGY

Faced with problems of discouraging complexity, its workers tried to fractionate them. Now the trend is toward placing the problems in their natural context

by Hadley Cantril

THE GOAL of psychology is to improve our understanding of experience and behavior. To account for the interplay of man's capacities, his hopes and fears, his aspirations and frustrations, his ceaseless striving, his manipulation of symbols, his unconscious value-judgments—to explain all these abstractions in naturalistic terms is clearly a task of unsurpassed complexity. The range of phenomena with which a psychologist can legitimately deal extends all the way from the chemical activities involved in the transmission of a nervous impulse to the search men make for the kingdom of God or the wars they wage in defense of ideologies. Psychologists today are actually trying to cover this whole range of phenomena.

Perhaps the best way to summarize briefly the development of psychology in the past half-century is to consider three major trends that appear to have taken place during that period. First, there has been a trend away from an atomistic approach toward the integrated study of the whole man. Second, there has been an increasing tendency to consider man and his environment together rather than as separate absolutes. Third, psychologists have sought more and more to simulate actual life situations in their laboratory experiments for the study of behavior.

IN 1900 psychology, the stepchild of philosophy and physiology, was only about 40 years old. As a late arrival among the sciences, it tried to model itself on the older disciplines. Much of the psychological research around the turn of the century appears to have been guided by a conscious attempt to apply methods that had proved successful in the physical sciences. The eagerness of psychological investigators to be "scientific" led many to follow rather blindly the scientific procedures that had gained status and acclaim elsewhere. There was an intense interest in separating experience and behavior into events that could be handled experimentally and were amenable to quantitative treatment. Thus Wilhelm Wundt of Leipzig, generally regarded as the founder of psychology, was carrying on an attempt to analyze experience into various elements, to determine the attributes of sensation and to discover laws of psychical relationships among the components of experience thus analyzed. The Wundtian tradition was transplanted to American soil by Edward B. Titchener at Cornell University. The methods pioneered by these two men had a tremendous impact on the development of experimental psychology in the U. S. and Europe, and for a long period psychologists devoted themselves to fractionating experience, taking the pieces apart, examining them and then fitting them together again.

Ultimately this approach led into a blind alley, and it is not hard to see now why it did: the investigators were taking apart what really belongs together. We now know that the elements of experience become meaningless when taken out of the total experiential process.

INK BLOT of the Rorschach Test is one of several techniques for the projective testing of human personality.

Early in the century the Würzburg school of psychologists in Germany showed that the thought process could not be accounted for solely in terms of bundles of sensations and images; it seemed to be directed largely by the set or attitude of the individual. Later the Gestalt psychologists demonstrated that perception—the process involved in our awareness of the world in which we live —was more than the sum of its parts; that it depended upon the total pattern of relationships with which the organism was confronted at any one time.

Similarly in the study of the learning process experimental psychologists started with an atomistic approach but eventually outgrew it. Hermann Ebbinghaus, in his classical studies on memory which used nonsense syllables to rule out meanings, never got beyond the psychology of simple rote learning. The early experiments of Edward L. Thorndike and John B. Watson on the conditioning of white rats, which attempted to account for learning in terms of connections, also proved to have limited value in explaining the kind of learning that occurs in everyday life. Gradually larger segments of behavior were included in learning theory, as investigators saw more and more how much was being left out and were forced to expand their interpretation of what constituted learning. Today the more sophisticated learning theories in one way or another face the problems of consciousness, of unconscious wishes, of cognition and of the particular purposes of the organism involved in a particular situation.

It is significant that while psychologists have gradually been freeing themselves from their original ideal of scientifically "objective" experiments devoid of personal value-judgments, the physical scientists have been giving increasing recognition to the role played by human understanding and interpretation in research. Thus the psychologist, who has tried so hard not to let meaning or his own interpretation affect his results, is now being pushed by his former model, the physical scientist, to tell how the design of experiments and the interpretation of results in physics itself are affected by the personal outlooks that inevitably permeate all research. The physicist Percy W. Bridgman, for example, argues that scientific proof is an individual matter, that there is a "private component" involved in all creative science. It is the business of the psychologist to investigate the nature and function of this private component.

LET US consider now the second trend in psychology—what might be called the trend away from dichotomies. In every science one of the marks of progress has been emancipation from absolutes, generally juxtaposed against other absolutes as independent constructs existing in their own right. In the past few decades psychology also has gradually become aware of the extent to which its own progress was being hamstrung by clinging to such dichotomies. We may mention four illustrations.

Subjective v. objective. Much of the early work in the psychology of perception was based on the explicit assumption that "subjective" factors could be disregarded and experience measured solely in "objective" terms. If we could learn enough about the stimulus "out there," and about the nature of the physiological reaction to it in our sense organs, we would have an understanding of our subjective experiences. Apparently this guide to investigation was adopted because it offered the easiest way to follow traditional scientific methods: the stimulus "out there" could be rigidly controlled and measured and the physiological processes themselves were amenable in some degree to laboratory investigation and control, whereas the so-called "subjective" factors, such as past experience, purpose or expectancies, were not amenable to scientific controls except in a very crude way. As a result, there was a widespread assumption that stimuli somehow existed in their own right, and that all we had to do was to study the effects of controlled changes in the stimulus on experience as reported.

But this naive separation of "subjective" from "objective" was increasingly seen to be false. The development of psychiatry, clinical psychology and social psychology showed that "subjective" factors, such as fixations, phobias or stereotypes, radically affected the meaning an individual could give to a stimulus. Hence the emphasis was reversed: it became essential to study the effect of "subjective" factors on what was experienced as "objectively" given. There is now a growing recognition that "subjective" factors and the stimuli outside the experiencing organism are not independent entities but each depends on the other for its very existence. For example, even the simplest perception, *e.g.*, the perception of a sphere, is in a large measure our own creation based on sets of assumptions which we have built up from past experience and which give the stimulus a certain meaning. It has become clear from recent laboratory experiments that we cannot tell *where* a thing is until we make some assumptions about *what* the thing is. The two perceptions are completely interdependent; neither would exist without the other. The total perception of a sphere, for example, depends on certain assumptions we bring to bear on the particular stimulus pattern that innervates our sense organ, *i.e.*, an assumption that the sphere is a ping-pong ball, a billiard ball, the moon or the sun.

Stimulus v. response. Rather early in this century John Dewey and James R. Angell pointed out the futility of regarding a stimulus as something different from and independent of a response. They emphasized that in order to understand behavior, the total activity

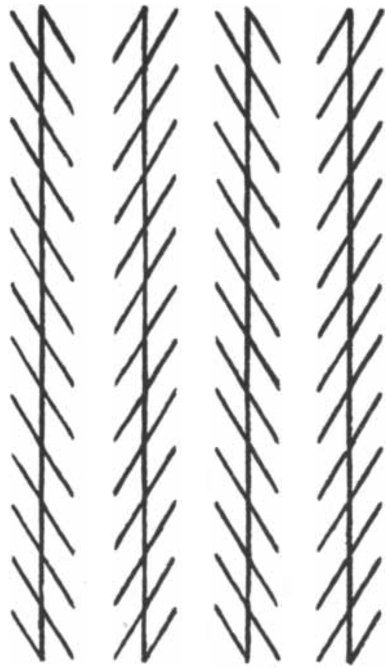
PROBLEM BOX is one of classical techniques of measuring animal intelligence. Animal must learn pattern of pressing switches to get food.

of the organism, including the goal toward which that activity is directed, must be considered. Their point of view, which became known as American functionalism, stood in sharp contrast to the structuralism of Wundt and Titchener. More and more the realization has grown in psychology that both the stimulus and response are part of a total ongoing activity, and that the activity can be understood only by considering the purposes of the organism, its past experience, temperamental and genetic factors, and the particular meaning the situation has for the organism at a particular time and in a particular place.

Nature v. nurture. The turn of the century found a number of psychologists discussing the nature of human nature. The most important thinking on this subject was taking place in a seminar of medical students in Vienna led by Sigmund Freud. Freud, whose brilliant insights had discovered the operation of man's unconscious psychic processes, posited certain basic human instincts as the dynamic motivations of these processes. In England, and later in America, William MacDougall vigorously championed another theory of instincts. For a number of years a battle raged as to how much of man's behavior was due to his innate nature and how much to the environment around him. Eventually this debate was made meaningless by the accumulating studies of actual human societies. The documented accounts of behavior in various cultures by Bronislaw Malinowski and other cultural anthropologists forced serious questioning of any doctrine that assumed that instincts determined the specific directions of man's behavior. Psychologists were compelled to take into account a cultural relativity. This concept, together with the evidence from biology of the complete interdependence of the organism and the environment, has brought psychologists to a more sophisticated search for the interrelations of behavior and environment. Many psychologists today are using a "field theory" concept in their accounts of learning, purposive behavior, group dynamics and so on. But physicists are likely to be considerably puzzled by the way the concept of "field" is currently employed in psychology. They will probably notice that the psychologist has not yet rid himself of the habit of considering separate entities reacting "in" or "to" a field. Psychology, in other words, has not yet completely emancipated itself from an elementarism that considers the environment as something outside the organism.

Individual v. social. In the area of social and political psychology the century was ushered in with a controversy as to whether man's social behavior and political institutions could best be understood through a study of the individual human being or a study of the institutional and ideological structures themselves. As we look back on the controversy now, it seems clear that each side was fighting a straw man. The painstaking investigations of such men as G. H. Mead, C. H. Cooley, Karl Mannheim, Jean Piaget and F. C. Bartlett made it apparent that it was meaningless on the one hand to think of an individual divorced from social institutions and group loyalties, or, on the other, to try to separate these from their concrete components, which consisted of the common assumptions and actions of groups of individuals.

THE THIRD trend we have to consider is the recent return of many psychologists to the laboratory, this time to study much more inclusive problems than the fragmentary ones that occupied psychologists at the beginning of the century. The piecemeal approach of early experimental psychology generated a widespread impatience with experimental methods. Experimentation



OPTICAL ILLUSION shows effect of experience upon sensory perception. Vertical lines which appear to slant toward each other are parallel.

was not leading to an understanding of man's anxieties and aspirations, his loyalties, his persistence in the face of obstacles. Many psychologists therefore turned to methods other than those of the laboratory: case studies, clinical diagnosis, attitude and opinion testing, the construction of tests to shed light on man's capacities and temperament, the study of communications, of group structure, of propaganda and so on. From these investigations many valuable hunches and theories were formulated and more adequate problems were posed. But as the data obtained from investigations of actual life situations accumulated, there developed an urge to systematize the data and to verify formulations and observations in some experimental way. A number of psychologists have therefore returned to the laboratory with new problems. They are trying to bring into the laboratory situations comparable to those encountered in life, to keep in rather than to rule out those aspects of experience and behavior that characterize lifelike occurrences. New quantitative methods, such as factor analysis and the analysis of co-variance, have been devised to handle these more complicated situations.

Psychology has of course found applications in many fields and on an increasing scale in our half-century. The tests of the clinical psychologist have been of enormous usefulnesss to the psychiatrist; the Rorschach Ink Blot Test and the newer Thematic Apperception Test developed by H. A. Murray and his associates have become standard diagnostic instruments. Psychology has en-

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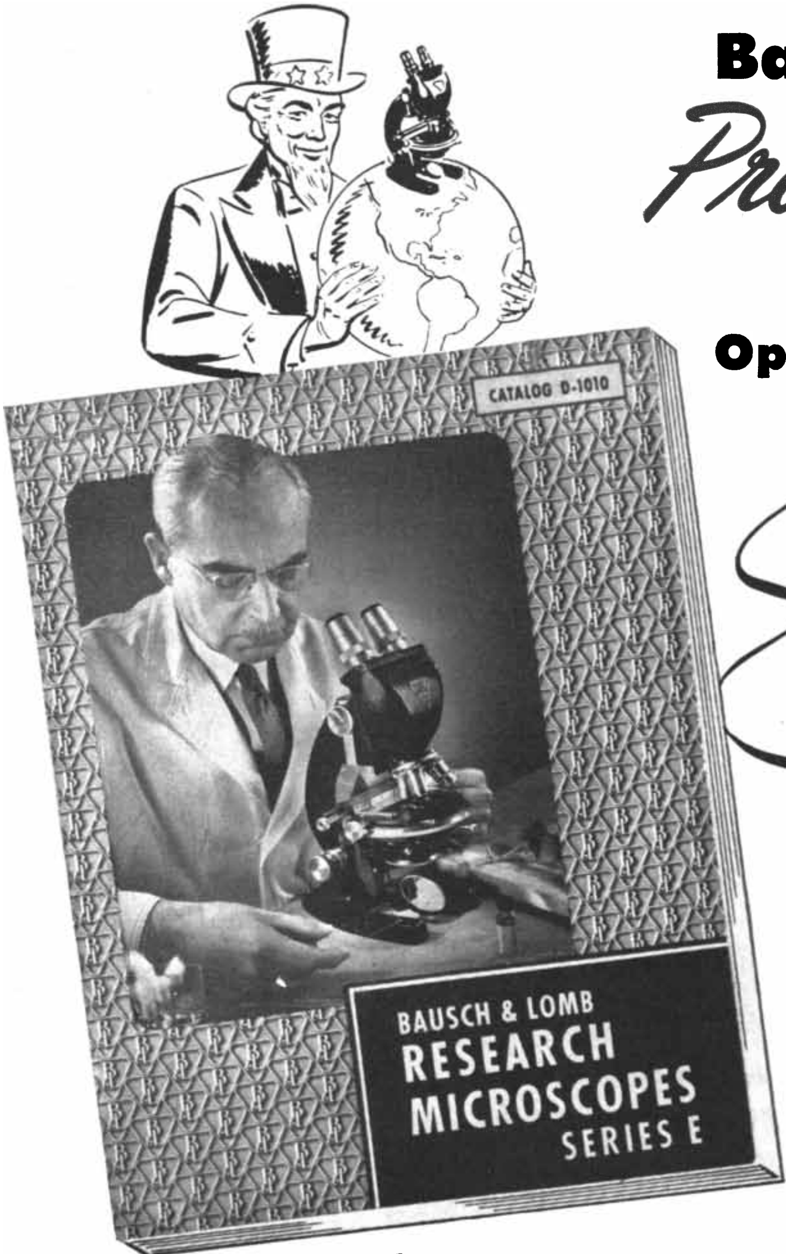

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tered industry through studies of human relations, of efficiency and of machine design; a special field of market research has grown up; surveys of public opinion are now standard devices employed by governments, industry and labor; institutes for personnel counseling and guidance have had a mushroom growth. Some indication of the rapid development and acceptance of psychology can be obtained by a comparison of its use in World War I and in World War II. In the First World War psychology was almost entirely concerned with testing the intelligence and a few other capacities of military personnel for purposes of placement. In World War II, psychologists of one kind or another played a role in nearly every military operation in most of the belligerent countries: the selection and training of personnel for specific activities; the solving of problems in communication; the adaptation of implements of war to human physical limitations; clinical and psychiatric work; testing of the interests and morale of troops; propaganda analysis and psychological warfare.

THE TRENDS cited in this review, and others that could be mentioned, seem to indicate that psychology is undergoing a revolution. Its culmination is likely to be an acceptance of the view that any experience or any behavior is what Dewey and A. F. Bentley have recently called a "transactional" process. The psychology of the future will, I believe, become increasingly aware of the necessity of investigating all behavior and experience as transactional processes involving the total organism-environment situation, including within the "now" the effects of the past and the expectations of the future.

Hadley Cantril has worked in the fields of social psychology, the psychology of personality, sensory perception, public opinion and mass communication. He has served as director of the tensions project of UNESCO. He is now professor of psychology at Princeton University.

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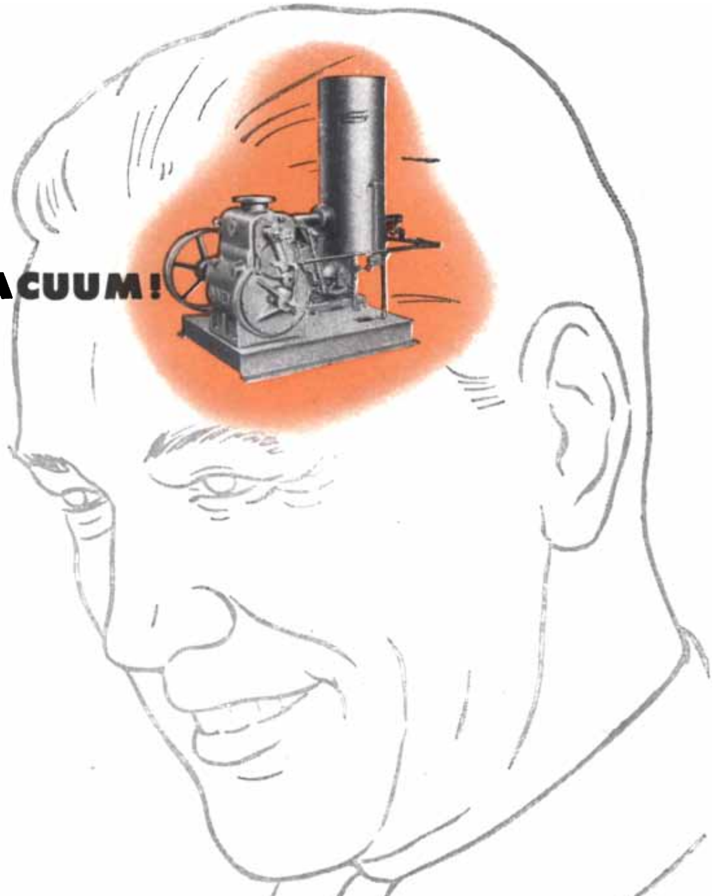

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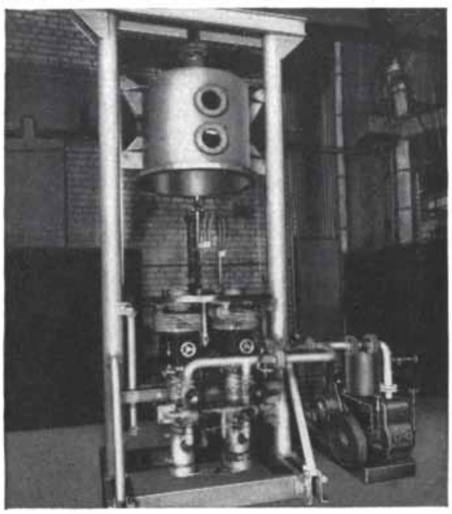

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ANTHROPOLOGY

The powerful concept of culture has been extended to explain much of human behavior and to eliminate some artificial distinctions among groups of men

by A. L. Kroeber

THE most significant accomplishment of anthropology in the first half of the 20th century has been the extension and clarification of the concept of culture. The idea that culture—a society's customs, traditions, tools and ways of thinking—plays the dominant part in shaping the development of human beings, and therefore ought to be the central concern of anthropology, did not originate in our century; its importance had been recognized by the great English anthropologist Edward B. Tylor in 1871. But during the past 50 years the concept has been given a wide and consistent application which has immensely advanced the growth of anthropological science.

The outstanding consequence of this conceptual extension has been the toppling of the doctrine of racism—that bland assumption of race superiority which is so satisfying emotionally to most people and so unwarranted. We have learned that social achievements and superiorities rest overwhelmingly on cultural conditioning. Racial heredity has not been totally ruled out as a factor in social accomplishment, but clearly it is a tiny factor in comparison with cultural influences. The racist illusion rests on a naive failure to distinguish fixed biological processes from essentially variable cultural processes. Once the nature of the cultural process is clearly grasped, the racist illusion is bound to melt away rapidly. Hitlerism represented its last, die-hard, desperate lashing out as an organized national creed, just as the Dayton trial proved to be the final stand of anti-biological literalism in theology.

The comparative study of culture has similarly helped to diminish ethnocentrism—the parochial conviction of the superiority of one's own culture—from which so much intolerance springs. The widespread social and emotional drift in this more liberal direction has certainly been given intellectual support by the anthropological analysis and comparison of various cultures. Anthropologists now agree that each culture must be examined in terms of its own structure and values, instead of being rated by the standards of some other civilization exalted as absolute—which in practice of course is always our own civilization. This anthropological principle leads, it is true, to a relativistic or pluralistic philosophy—a belief in many values rather than a single value system. But why not, if the facts so demand? The domain of life is certainly pluralistic, what with a million species on our own small planet. I have not heard of biologists bewailing the diversity of species. Rather, they try to find some kind of order in it. Quite correspondingly, anthropologists try to treat all cultures, including our own civilization, as parts of nature—without preferential and partisan priorities. This may be distasteful to partisans, but it is certainly the only way of science.

THE staunch adherence of modern anthropologists to this principle has brought about a growing conviction that anthropology holds promises of importance for the world's future. Yet anthropology offers no pat answers to our problems: I do not believe it has even one specific categorical remedy to contribute to the world—let alone a panacea. Its contribution is an attitude of mind. This attitude holds that cultures—each of which contains a value system—need not be viewed as rallying points for rival emotional loyalties but can be studied as natural phenomena by methods of natural science.

The growing recognition of culture as a force has had repercussions in other fields of science, especially in personality psychology and psychiatry. Freud attempted to annex the whole of culture at one blow, contending that it was all derived from the Oedipus complex. Some later psychoanalytic theorists have tried to maintain this claim in a different form; they have proposed less simplistic mechanisms, such as "basic personality structure," as the foundation of culture. But as these mechanisms are admittedly dependent on the culture, the culture cannot really at the same time be derived from the personality. On the whole in this field of culture-personality relations it is culture that has so far proved to be the active and molding force, and personality the molded element.

FIFTY years ago anthropologists still were remarkably ready to look for simple, fundamental causes of behavior and to come up with them—but often each man came up with a different pearl of speculation. The commonest theory then was that primitive culture and high civilizations alike emanated spontaneously from "human nature" or the "unity of the human mind." Sir James Frazer took that point of view in *The Golden Bough.* He influenced more of his contemporaries than any other anthropologist. By the sheer weight of his comparative examples he helped to liberate their minds from ethnocentrism. But he was innocent of what constituted a soluble scientific problem; he simply made whatever assumptions were necessary. By now we have become more humble. Human nature certainly exists, but we recognize it as a heaving jumble of gene effects tremendously elaborated and distorted by cultural pressures. And we no longer venture to define what human nature is, except that we may sometimes indicate certain sketchy limits within which, common-sense experience tells us, this nature generally manifests itself.

Somewhat later came the pseudo-historical explanations. Thus Elliott Smith suggested that everything in higher civilization could be traced to an origin in ancient Egypt, from where it was spread over the world by Phoenician treasure seekers. No, objected F. Graebner, there were six origins: the boomerang culture, the totemistic, the matrilineal, and so on; spreading from their respective birthplaces in various parts of the world, they eventually were all mixed together. We had only to learn how to unscramble the world's cultures to reduce them to the six original blocks.

The answers are more limited and hesitant nowadays, since we realize that answers are the end product of investi-

NEGRITOS of Bougainville, photographed by Douglas Oliver of Harvard University, compete for prestige by giving extravagant feasts. The expense of such feasts delayed the naming of the boy at right until he was six.

BALINESE, studied by Margaret Mead and Gregory Bateson, suppress their feelings. At the left a Balinese father plays unemotionally with his son. At the right a dancer maintains ritualistic nonchalance before demon.

AYMARA of Peru and Bolivia, studied by Harry Tschopik, adopted elements of Spanish culture 400 years ago but retain many features of their own. At left: a Catholic procession. At right: a blood-sacrifice ceremony.

gation, not what one starts with and then fights for. In the investigations of the past half-century many things have come out in the wash quite unexpectedly. In 1912 Charles Hose and W. MacDougall published a book on the pagan tribes of Borneo. They had found that the Borneans made blood sacrifices of domesticated animals to their gods, consumed the victims at worshipping festivals and divined the future by signs in the liver and gall of the sacrificed animals. A reviewer pointed out how much some of the Bornean customs smacked, in a primitive way, of the social and religious practices of the Greeks and Romans. Could there be an actual connection? Or was it a case of the same old X, human nature, spouting forth the same old similarity spontaneously—somewhat as life used to generate spontaneously in the naive days of biology? We know now that there was indubitably an historical connection between these similar customs, with Mesopotamians and Hindus and Chinese as connecting links between the Indonesians and the Greeks and Romans. Wherever Christianity, Islam or Buddhism became established, this set of customs was forced out of use as pagan; but at the remote edges in the interior of Borneo and of the Philippines it survived. It never penetrated to Australia nor to America. These conclusions, which would have seemed revolutionary 50 years ago, were arrived at by induction—a piece of inferred instead of documentary history. But they are supported by consistent, unselected bodies of distributional fact, both positive and negative, and by the parallel of dozens of other disseminations that are documentarily proved—such as, to name just one example, the diffusion of the art of papermaking from China to Europe.

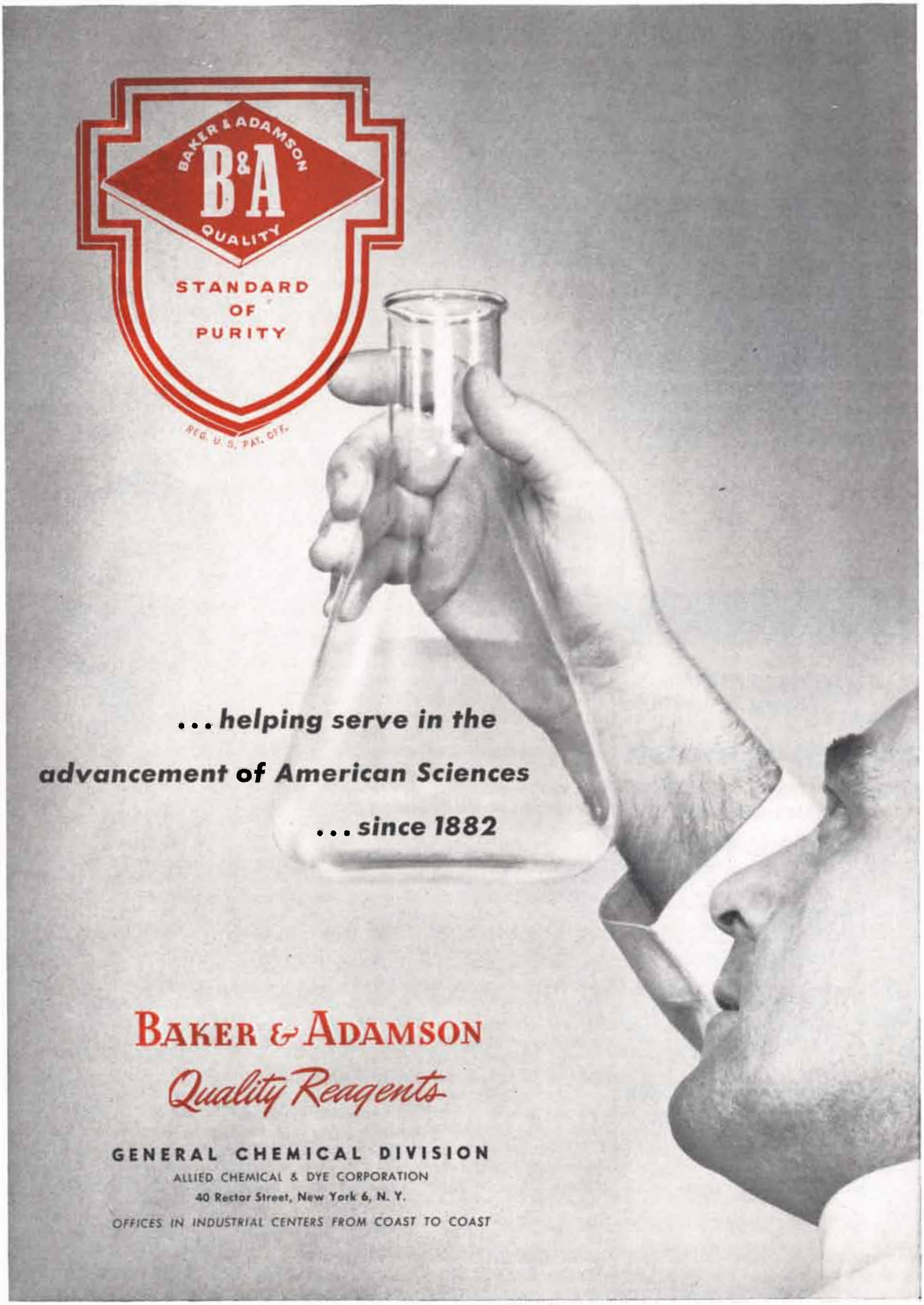
EVEN greater has been the increase of knowledge due to archaeological exploration and discovery. Before the 20th century archaeology, apart from concern with the Stone Age in western Europe, dealt largely with early civilizations rather than with prehistoric times. In Egypt, in Mesopotamia, in China, in the Mexican and Mayan area, archaeologists looked for antiquities that bore inscriptions and dates and thus supplemented and extended the written records that had been transmitted to us in documentary history. No profound skill was involved in dating the inscription of an 18th-dynasty Egyptian king as later than that of a fourth-dynasty ruler. But to put the antiquities that *predate* writing into a reliable time sequence, and to bridge their gaps by new explorations —this was an adventure that called for real ingenuity and refinement of techniques. It is during the past 40 or 50 years that the overwhelming bulk of knowledge of this sort, for all the world except western Europe, has been accumulated and interpreted. This new knowl-

PLESIANTHROPUS is one of a whole group of man-apes discovered in South Africa by Robert Broom and others. This specimen is *P. transvaalensis*.

edge includes a huge amount of material on the pre-farming stage and Stone Ages in Egypt and Mesopotamia, in Turkey, Syria, Iran, North Africa, India, China and other Far Eastern regions. In the Americas the search for remains of cultures that predated writing commenced around 1920. The archaeologists' satisfaction in dealing with things that were old began to give way to a new interest in *how* old the remains were—and this of course included the question of which were the more or the less old. In the eastern U. S., in the Southwest, in California, in the Caribbean, dependable sequences were worked out and filled in. For Mexico and the Maya, the chronologies suggested by the early investigators are being worked out anew on a sounder basis. For Peru, collaborating investigators determined a succession of culture stages extending back about 2,000 years before the Incas whom Pizarro found in control; then in 1946 this span was perhaps doubled by discovery of remains of a society that was pre-metallurgical, pre-ceramic, pre-maize-growing, but already cultivating the soil.

Most of the known biological history of man and his immediate fossil ancestors also has been discovered since 1900. Four principal findings sum up much of this exciting quest. First, we now have solid information on Pithecanthropus and his close twin Sinanthropus. They were low-grade men, but they definitely were men, and they lived at least as early as the middle of the Pleistocene, the last geological period. The second major finding is the South African Australopithecines, including Plesianthropus and Paranthropus, which essentially had the

CHARENTE MAN is represented by broken brain pan found in France. Its age shows that relatively modern men were contemporary with Neandertalers.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teeth, jaws, hips and posture of men, along with brains the size of gorillas and big chimpanzees. We do not yet know when they lived. Third, there is the famous Neandertal man, the slightly brutalized sideline outcome of an experiment conducted by nature in what we call the course of human evolution—but we now recognize that he was neither very primitive, very early, nor very brutal. Finally, there is fairly strong evidence, still strengthening, that true human beings—actual members of our living species *Homo sapiens*—were already in existence well back in the Pleistocene, and that long before them their ancestors must have been pretty thoroughly set off from all other forms, living or extinct. That great mysterious X of a generation ago, the famous "Missing Link," has become quite outmoded. The story leaves him stranded and forgotten, and its path is all the more intricate and dramatic for it.

THE study of living human races has unfortunately been unable to profit much from the half-century's greatest biological development: genetics, the quantitative study of heredity. This is so for various reasons: because human chromosomes, and probably their genes, are numerous, and our heredity is therefore complex; because human lives are long and generations grow up and pass slowly, and because we cannot experiment with large-scale controlled breeding of men as we can with fruit flies or pollinated plants. The few human traits that work out according to calculable rules of heredity are either abnormalities or relate to laboratory-revealed blood factors which are seemingly without influence on man's general functioning or capacity.

At present all except the most obvious groupings in race classification still depend essentially on subjective judgments. For instance, the Hottentots and Bushmen, who undoubtedly have some relationship with Negroes (frizzy hair, wide noses) and possess some distinctive features peculiar to themselves (hollow backs, fat buttocks, flat ears, wrinkly skin), also tend to have an eye-fold like that of the Mongolian race. Is the Mongolian-like eye-fold of the Bushmen due to their having at some time in the past experienced contact and admixture with Mongoloids? Or is it just a specialty they happened to develop as an independent variation in their isolation? In short, have we here a case of inherited contamination or of an inherited mutation?

The authorities can give only personal judgments in situations of this sort. But if we can accumulate race data on enough blood-type and similar genotypic factors—not only the known blood types O-A-B-AB, A_1-A_2, Rh and M-N but a lot of new factors in addition—it will be possible to determine from the percentages of these inheritances whether the Bushmen ever really experienced a significant Mongoloid admixture. If hereditary links do not appear in these factors, the eye-fold will be demonstrated to be an independent local development. Similarly, enough knowledge of demonstrably genotypic factors might reveal whether the Bushmen were a deviant derived from the Negro stock or the remnant of an old, coordinate, primary race. These minute, simple-unit traits of heredity are a bit like fingerprints—rather insignificant in man from the standpoint of the total organism's functioning, but sometimes quite telltale as to who contacted whom in the past.

FINALLY there is the important contribution that the comparative study of languages can make to anthropology. Most linguists are also philologists, and accept their customarily assigned place in the humanities. However, the philologists and the anthropological linguists now agree that the structure of every language needs description and understanding first of all in terms of its own phenomena and plan—not by any absolute standard. This is of course the anthropologist's basic principle of relativism all over again, merely accentuated a bit more for that part of culture—speech—which is the most outrightly symbolic, the most nearly autonomous and the most rigorously patterned.

Kroeber

Linguistic anthropologists have differed from other linguists only in the accident that they have dealt mainly with wholly unwritten languages that consequently had no known history or preserved ancient forms. Thus linguistic anthropologists have had to operate comparatively rather than by directly historical methods; they have had to frame their alphabets and grammars while making their investigations, instead of proceeding from given languages. Under the leadership of Franz Boas and Edward Sapir, special techniques for this were developed. When World War II

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came and it was important to teach exotic foreign languages rapidly, these techniques proved their practical value as an educational device for attaining quick spoken control of Chinese, Japanese, Russian, Arabic and other languages in which a totally foreign and often elaborate script—or a badly formulated conventional grammar—makes acquisition by the old book methods usually a matter of years.

WHAT the past half-century has accomplished above all for anthropology is to transform a loose collocation of separate physical, social, cultural and linguistic interests, ancient and modern, primitive and civilized, into an integrated attack on the biological, the sociocultural and the linguistic phenomena presented by man—an attack held together by a common attitude. This attitude is expressed by the principle of the relativistic approach. It might equally be called the naturalistic approach. It insists on treating the customs and histories, the ideals and values, the societies and languages of man as being phenomena of nature to exactly the same degree as the biology of men, or for that matter of animals and men.

This may seem a simple and trite program. Perhaps it is simple conceptually, but operationally it has been difficult and hard-won. How far are men and their activities actually treated as a part of nature in most economic and sociological study, in most history and philology? Hardly at all; in these fields human activities are consistently set apart from nature, and primary emphasis is given to what is within one's own culture, rather than to the broad and varying panorama of total human behavior through time and space. That is why in the organization of universities and of the great research councils of national scope these fields of study are assigned to the social sciences or to the humanities. Anthropology, on the other hand, is represented not only in the social sciences and the humanities but also in the natural sciences. This is not so much because in its so-called "physical" branch anthropology includes a concern with human biology. Rather it is because in everything that anthropology touches—cultures, societies and languages as well as physiques—it aims to proceed wholly with the broad attitudes of natural science, plus such special methods and techniques of its own as may be called for in each situation confronted.

A. L. Kroeber is one of the leading generalizers of modern anthropology. He has worked in the fields of ethnology, cultural anthropology and archaeology. From 1901 to 1946 he taught at the University of California. He is now professor emeritus at California and professor of anthropology at Columbia University.

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BOOKS

The 50 years and the popularization of science: a listing of 20 good examples

by James R. Newman

"FRUITFUL entertainment and agreeable recreation" is the sovereign good to be derived from a well-chosen stock of books—so the 17th-century librarian Gabriel Naudé advised his patron Henri de Mesme in counseling him on the establishment of a library. This is a measure of selection difficult to improve upon, and I have kept it in mind in assembling a list of 20 of the leading science books of this century accessible to the common reader. My standards must, however, be more fully explained. Anyone rash enough to embark on the making of a book list should see to it that his escape hatches are well placed and in working order.

The elementary requirements for a popularization of science may, though important, be disposed of quickly. Clarity, honesty, disinterestedness, unpretentiousness are of course indispensable. The author must tell a story that will keep the reader awake. There should be drama—it will appear inevitably in describing the struggle for discovery—but not at the expense of accuracy, reasonable accuracy within the leeway of understandability and sound instruction. The aim of nontechnical books, said Eddington, is "to convey exact thought in inexact language." This is only partly true. Inexact language, while often unavoidable, creates pitfalls of which the writer must warn the reader. It is essential that the writer not pretend that an exact thought has been conveyed when it has not been. The well-known English philosopher Susan Stebbing made the charge against Eddington and Jeans that they repeatedly created the illusion of describing a set of circumstances with precision where in fact they read into them their emotions, philosophical theories and religious predilections.

Technical terms should be held to a minimum and where used carefully defined; on the other hand the writer ought certainly to avoid what Whitehead called "misty profundities," however easily they may go down. Well-chosen photographs, imaginative and skillfully executed diagrams, graphs, charts, cartoons are not only invaluable aids to instruction but help to offset the second-handedness of book learning by giving the eye the opportunity to substitute for the hand. Only a small beginning has been made in utilizing graphic methods for the popularization of science. Lancelot Hogben is among those who have suggested new ways of using pictorial devices for communicating ideas; the illustrations in *Mathematics for the Million,* drawn by the English artist-journalist James F. Horrabin, are unsurpassed in their field.

Recently I. Bernard Cohen of Harvard called to my attention an interesting paper issued last year by UNESCO. It is "The Theory and Practice of Popular Science," by David S. Evans, a young Welsh astronomer now working at the Radcliffe Observatory in South Africa. Evans divided popularizers of science into three main groups: the "commercial," the "axe-grinder" and the "flesh-creeper." His classification invites discussion.

The quality of a book is of course not reduced simply because its author writes it to sell; nor is a potboiler less a potboiler because it happens to catch the vogue. But it is not altogether an accident that the great majority of the leading works of popularization were written by scientists with some leisure and security rather than by harassed journalists or other professional writers.

In the case of axe-grinders the real question is whose axe is being ground. Every informed person objects to the "crank-theorists," the mystics and other hokum peddlers who turn the prestige of science to their special purposes. On the other hand the popularizer who either fails to recognize the social importance of science or delicately avoids reference to it on the ground that it is controversial, also does a disservice to his subject and his audience. (Several of the choices below, it must be admitted, exhibit this defect; I include them with apologies, trusting that their merit outweighs the defect.) One may lay it down as an axiom that intellectual enlightenment in science, as in other spheres of thought, must be informed by the liberal spirit. Culture has no value unless it be for action, action directed to social good. Whitehead, among others, has reminded us that knowledge for its own sake is not enough; the curiosity spurring its acquisition is itself impelled by the fundamental desire to extend man's control over nature. The spread of understanding not only of the material benefits of science but of the connection between science on the one hand and social, economic and political circumstances on the other, should be a primary objective of nontechnical writing for the general reader. The popularizer incapable of grasping this fact should turn his talents to the writing of chess books.

Few popularizers are able entirely to resist the temptation to be flesh-creepers. Nor is the practice necessarily an evil—when used in moderation. Its purpose admittedly is to make the reader goggle by the use of striking analogies, prodigious figures and astonishing facts. The desired effect may be obtained by comparing the vastness of interstellar space or the minuteness of the atomic world with the dimensions with which the reader is familiar, or by references to the ominous equation $E=mc^2$, or to the inexplicabilities of the social organization of ants, the concept of entropy, the strange habits of the platypus, the principle of indeterminacy or the homing instinct of pigeons. All this may enthrall the reader, but sometimes it also confuses him.

Evans suggests that the practice stems from a lack of faith in scientific knowledge itself. Writers think it necessary to add a touch of the terrifying, the marvelous or the inscrutable to make the fare more palatable. But if in truth the instruments and insights of science lay open to view a most astonishing universe, why should the popularizer refrain from so describing it? Why should he not be permitted the right to marvel and to share his wonderment? Herodotus was a brilliant popularizer of this kind; unfortunately he was also a brilliant liar. Archimedes, in his famous letter to King Gelon about big numbers, showed himself a flesh-creeper in the highest tradition; in the same class were Strabo, Pliny, Galileo, Laplace, Fontenelle, Huxley, Tyndall and, more recently, Wells, Fabre, Jeans, Eddington and Russell—to name only a few of an honorable company.

When analogies are invoked they should be constructed carefully and used sparingly, for they can be tricky and misleading. Personal religious interpretations or the reading of God or mind into nature are altogether out of place in a scientific popularization. Apart from the fact that such excursions snarl up the story, they take unfair advantage of the reader. He has the right to expect that a science book will be about science and that he will not be victimized by a sermon. Moreover there is the danger that he will accept as scientific truths opinions which are no more scientific and no more related to truth than the author's opinions about a musical composition, a painting or a rare cheese.

Certainly any literary, didactic or psychological artifice that supports the exposition without unduly compromising its accuracy or carrying the odor of condescension ought to be permissible, so long as it is made clear to the reader that he is an onlooker who sees only "the best of the game," with its complex rules, drudgery, fumbles and mistakes artfully concealed. The touchstone of an effective exposition is whether it enables the reader to share in some small measure the incomparable experience of tackling hard problems and discovering their solution. There are three books that come to mind as particularly illuminating, each from a different standpoint, on the nature of scientific research and the conditions of scientific progress. They are Michael Faraday's *Researches in Experimental Electricity,* a superb working journal which describes how a great experimenter went about his business; Herbert Butterfield's *The Origins of Modern Science,* reviewed in the July issue of SCIENTIFIC AMERICAN, and William Dampier's elegant little anthology, *Cambridge Readings in Science,* a superior achievement in condensation and selection.

Some contend that there are subjects which cannot be popularized. Evans places the theory of relativity and other cosmological speculations in this class, either because of their complexity "or because they have acquired connotations in the public mind which will almost automatically bring in mysticism and confusion." I am not convinced that any subject is too difficult to be made accessible to the general reader. Of course, a complex scientific idea cannot be explained until it has been mastered sufficiently to permit its translation into familiar terms. No one has yet succeeded in popularizing Einstein's field theory; nor for that matter is there a wholly satisfactory general account either of relativity or of the much earlier electro-

magnetic theory of James Clerk Maxwell. Yet when I see how successfully my old teacher Edward Kasner of Columbia University, one of the world's leading mathematicians, explains the concept of infinity and other advanced mathematical concepts to children of kindergarten age, I dismiss all doubts as to limitations of subject matter.

Difficult subjects can be explained if those with the necessary knowledge and a gift for popularization, scientists especially, think the job worth doing. We live in an age when it becomes increasingly obvious that the job needs to be done, and that the range of subjects must be expanded steadily. I see no pressing need for a popular account of Lebesgue integration or the ergodic hypothesis, on which the public is not well informed. On the other hand, concerning certain other matters no less difficult to comprehend, such as mass-energy equivalence, neutrons, capture cross-sections and tritium, there seem to be more interested and knowledgeable persons than Dr. Smyth could have dreamed of five years ago or than the Atomic Energy Commission apparently dares contemplate.

Mysticism and confusion need not invariably follow in the train of popular cosmology. There is, to be sure, a steady hunger for irrationalism. The more afflicted and uncertain the times, the greater the appetite, and there is always a du Noüy or a Velikovsky to satisfy it. But it would be most unfortunate if the rational treatment of complex subjects were to be frightened off by the best-seller standing of claptrap.

I recommend the works in the following list as good books, some of them excellent, but I do not mean to suggest that they are the *only* good books in their field. I am painfully aware of many omissions and no doubt unaware of others of equal importance. I have confined myself almost exclusively to American and English books. My list is pitifully inadequate as regards the social sciences; it is purposely overloaded on the subject of scientific method, which is less popularly attended to yet more important than any of the individual sciences. I regret having had to neglect anthropology, geology, biochemistry and some other major areas in science.

Ernest Nagel has suggested to me that the leading popular-science books might appropriately be divided into three classes: 1) those of intrinsic merit but small influence; 2) those of small merit but considerable influence; 3) those both excellent and influential. The first and third categories are here well represented; the second has deliberately been omitted. There will be differences of view, of course, as to how soundly this sound principle has been applied. The books in the list are arranged not in any ranking but in the alphabetical order of the authors' names. From all of them I have derived "fruitful entertainment and agreeable recreation."

MATHEMATICAL RECREATIONS AND ESSAYS, by W. W. Rouse Ball. The Macmillan Company. First edition 1892; eleventh edition, revised by H. S. M. Coxeter, 1939.

A modern classic packed with information on such matters as games, arithmetical and geometrical recreations, chessboard recreations, magic squares, map coloring, mazes, Kirkman's schoolgirls' problem, calculating prodigies, cryptography and cryptoanalysis. Properly speaking, the work belongs to the 19th century, but it can be included here by grace of Professor Coxeter's able revision (though I cannot forgive him for omitting the fascinating chapter on Strong Figures that appeared in earlier editions). In the same field I recommend for its excellent illustrations also Hugo Steinhaus' *Mathematical Snapshots,* soon to be reissued by the Oxford University Press, and the admirable German study by Wilhelm Ahrens, *Mathematische Unterhaltungen und Spiele.* Ball's work exemplifies Leibnitz' famous comment: "Men are never more ingenious than in the invention of games; the spirit there finds itself wholly at ease."

MEN OF MATHEMATICS, by Eric T. Bell. Simon and Schuster, 1937.

For all its limitations, which are not negligible, this collection of biographies of leading mathematicians is of interest to anyone who enjoys delving into the history and development of the queen of the sciences. On the biographical side it is only rarely an original study, Bell having drawn heavily on the work of others; a number of its anecdotes are of doubtful authenticity and specialists have found not a few errors in details; the author's penchant for debunking and the form of racy journalism to which he is addicted wear a little thin after six- or seven-hundred pages. Nonetheless this is a highly readable, entertaining book, independent in outlook, and Professor Bell's popularization of the various phases of mathematics from elementary geometry and algebra through Riemann surfaces and groups is masterly. Many fine portrait plates and diagrams.

THE MIND OF PRIMITIVE MAN, by Franz Boas. The Macmillan Company. First edition 1911; latest edition 1938.

A distinguished pioneering work demonstrating the theses, still not widely comprehended today, that there is no fundamental difference in the way of thinking of primitive and civilized man, that there is no connection between race and personality, that the concept of racial type as commonly used is misleading and requires logical and biological redefinition, that several races have contributed to our civilization, that the rise and long dominance of the Old World were due to chance and not the superiority of any one race, that neither cultural achievement nor outer appearance is a safe basis on which to judge the mental aptitude of the different races. The book is written with clarity and in a quiet tone that intensifies the force and significance of its argument.

Among the popularizations of anthropology another book that must be mentioned is *Patterns of Culture,* by the late Ruth Benedict, one of Boas' noted pupils. Her study, dealing with the problem of understanding the meaning of a culture as a whole, examines three societies, each permeated by one dominant idea: the Pueblos of New Mexico, the Dobuans of the South Pacific and the Kwakiutl Indians of Vancouver Island. A celebrated section of Benedict's book describes the extent to which Kwakiutl culture—with its cruelty, self-glorification, fanatical sense of property and encouragement to asserting one's superiority and humiliating one's enemy by the most conspicuous forms of waste and self-destruction—is a parody of our own society. Also highly recommended in the fields of anthropology and sociology: William Graham Sumner's *Folkways;* Bronislaw Malinowski's *The Sexual Life of Savages* and *Argonauts of the Western Pacific,* Robert S. and Helen M. Lynd's brilliant study *Middletown,* William W. Howells' *The Heathens,* Ralph Linton's *The Study of Man,* Lewis Mumford's *Technics and Civilization.*

WHAT IS SCIENCE?, by Norman Campbell. Methuen and Company Limited, London, 1921.

A concise, lucid exposition by a British physicist who was comparatively unknown in the U. S. (he died last year). In his chapters on measurement, the use of mathematics, the explanation and discovery of scientific laws, Campbell gives a first-rate summary of the rules of science and the purpose and meaning of scientific method. This is not a book for semi-somnolent readers. Campbell's view was that "all experience shows that mere difficulties of thought are no bar to success in adult education; the enthusiasm of a leader is all that is necessary to sustain interest." Campbell was also the author of a remarkable original work on the foundation of modern physics called *Physics, the Elements.*

THE WISDOM OF THE BODY, by Walter B. Cannon. W. W. Norton and Company, 1932; revised 1939.

This work by the eminent Harvard scientist is one of the classics of exposition in modern physiology. Its main theme is "homeostasis," *i.e.,* the means by which that amazingly contradictory complex of durability and instability, the human body, keeps normal in spite of powerful disturbing forces. With great clarity Cannon describes how our bodies keep a constant supply of water, salt, sugar and protein, call for more of these substances when the supply is depleted, maintain a constant temperature, repair themselves after illness or injury, make antitoxins and generally keep functioning despite their extreme sensitivity. For example: the sensory surface of the nose will detect one part of vanillin by weight in 10 million parts of air; the eye is sensitive to five trillionths of an erg of light energy—one 3,000th of the amount of light required to affect the most sensitive photographic plate.

WHAT HAPPENED IN HISTORY, by V. Gordon Childe. Penguin Books, Inc., 1946.

An original, stimulating and attractively written account of the record of mankind from Paleolithic times to the decline and fall of the ancient world. In this and other writings *(e.g., Man Makes Himself, The Dawn of European Civilization, Prehistoric Communities in the British Isles),* Childe not only makes available to the layman a fascinating survey of prehistory and of man's making of himself but affords a brilliant example of scientific reasoning and reconstruction in the difficult field of archaeology.

INTRODUCTION TO LOGIC AND SCIENTIFIC METHOD, by Morris R. Cohen and Ernest Nagel. Harcourt, Brace and Company, 1934.

"I envy the youth who sit at your feet" was the felicitation Justice Oliver Wendell Holmes sent to Morris Cohen on his 60th birthday. This work by Cohen and another distinguished American philosopher is a masterly textbook, but actually much more than a textbook. There are chapters on the scientific method, probability, the meaning of logic, formal logic, applied logic and related topics. Together they present a conspectus of the rules of scientific thought comparable in quality and style to the notable studies by William Jevons and J. M. Keynes (the late Lord Keynes' father) in the last century.

THE HORMONES IN HUMAN REPRODUCTION, by George W. Corner. Princeton University Press, 1943.

A world-famous embryologist gives a lucid account for the general reader of hormone function in the processes of sex and reproduction. An absorbing description of an intricate and most important branch of biological and medical research. Fine photographs and diagrams. In the related field of biochemistry I recommend *The Stuff We're Made of,* by W. O. Kermack and P. Eggleton, and Ernest Baldwin's *Introduction to Comparative Biochemistry.*

THE NATURE OF THE PHYSICAL WORLD, by Arthur S. Eddington. The Macmillan Company, 1937.

At this date little needs to be said about this famous book, based on the author's Gifford Lectures in 1927. (I prefer his earlier *Space, Time and Gravitation,* but that is not a book for the general reader.) Susan Stebbing, to whom I have already referred, said of Eddington and Jeans in her brilliant polemic *Philosophy and the Physicists:* "Both these writers approach their task through an emotional fog; they present their views with an amount of personification and metaphor that reduces them to the level of revivalist preachers." This book of Eddington's nonetheless remains one of the notable modern works of scientific understanding, offering a superb survey of every fundamental concept of physical science. Eddington clearly ranks ahead of Jeans, both as an original thinker and as a popularizer. But Jeans also has given us, in *The Mysterious Universe, The Stars in Their Courses, Through Space and Time,* exceptionally lucid accounts of astronomical and physical knowledge. Among other outstanding books in the heavily populated fields of physics and astronomy are Max Born's *The Restless Universe,* Sir William Bragg's *Concerning the Nature of Things* and *The Universe of Light,* Sir C. V. Boys' *Soap Bubbles* (a delightful little work), Percy Bridgman's *The Logic of Modern Physics* (difficult but good), H. Levy's *The Universe of Science,* Frederick Soddy's *Matter and Energy,* Bertrand Russell's *The ABC of Atoms* and *The ABC of Relativity* and Hans Thirring's *The Ideas of Einstein's Theory.* Russell's and Thirring's books on relativity are, in my judgment, the best of the many that have appeared on this subject. Finally, there is Louis de Broglie's masterpiece *La Physique Nouvelle et les Quanta;* unfortunately it has not been translated.

A General Introduction to Psycho-Analysis, by Sigmund Freud. Liveright Publishiing Company, 1935.

These renowned lectures delivered by Freud at the University of Vienna in 1915-1917 are confined to three topics: psychopathology of everyday life, dreams and neuroses. I select them, rather than other writings of Freud or of those who came after him, for several reasons. First, in substance and style they are by far the best introduction to psychoanalysis, and afford a profound insight into the workings of Freud's mind. Second, they have had great influence upon laymen as well as professionals (though it must be granted that among laymen Freud, like Marx, is a thinker much talked about but rarely read). Third, Freud, for all the narrowness and dogmatism of his theories, was so much the ablest exponent of psychoanalysis that the discipline he founded would almost certainly have expired had the defense against its detractors, second raters though most of them were, depended on the writings of the dreary pedantic gabblers and voluble mediocrities who with variations claim to be his disciples. This is not to deny that psychoanalysis has been considerably enriched by the work of a few men in the last quarter-century.

Explaining the Atom, by Selig Hecht. Viking Press, 1947.

An enlightened book by the late biophysicist of Columbia University. Hecht was a clear thinker and wrote with precision, wit and sincerity. I suggest as close competitors E. N. da C. Andrade's *The Atom and its Energy* and Thirring's *Die Geschichte der Atombombe.*

The Principles of Psychology, by William James. Henry Holt and Company, 1890.

This is one of the great psychology textbooks, but it was necessary to make a foray into the 19th century to find it. I was unable to uncover a modern book on psychology of comparable quality, *i.e.,* relatively jargon-free, readable, stimulating and wholly within the grasp of the common reader. The distinction and modernity of this work lies in its adherence to the viewpoint of natural science. James was among the first to reject the metaphysical and adopt the positivistic approach to mental phenomena. I suggest also his *Varieties of Religious Experience,* a wonderful study of human behavior, and his *Psychology,* a human, witty, delightful work.

Karl Menninger's *The Human Mind,* a popular study of personality with emphasis on psychiatry, is well written, temperate and enlightening. Other basic books in the field of psychology that can be recommended are R. M. Hart's *The Psychology of Insanity* and John Dewey's *How We Think.*

The Nature of Mathematics, by P. E. B. Jourdain. Published by T. C. and E. C. Jack, London, 1912, and Dodge Publishing Company.

"The purpose of this little volume," says the author, "is not to give—like a textbook—a collection of mathematical methods and examples, but to do, firstly, what textbooks do not do; to show how and why these methods grew up." A book of 90 pages which cost only sixpence (in a regular binding) when it appeared—*eheu fugaces*!—this is the best primer I have read. Jourdain was a talented mathematician and logician, with wit, a clear style and a genuine feeling for popularization. Other attractive books include Whitehead's *Introduction to Mathematics,* E. C. Titchmarsh's *Mathematics for the General Reader,* J. E. Littlewood's *A Skeleton Key to Algebra;* Richard Courant's and Herbert Robbins' *What Is Mathematics?* (somewhat advanced but an exceptional text); Lancelot Hogben's *Mathematics for the Million* (good, but not as good as its reputation); Edward Kasner's and James Newman's *Mathematics and the*

Imagination (primarily concerned with the higher branches); Tobias Dantzig's *Number, the Language of Science,* and of course G. H. Hardy's *A Mathematician's Apology.*

THE FOUNDATIONS OF SCIENCE, by Henri Poincaré. Science Press, 1913.

A magnificent book by one of the giants of mathematical physics. Many of the essays are out of the general reader's reach, but there are several, including the famous chapter called "Mathematical Creation," which are comparatively nontechnical and of rare originality and lucidity. Poincaré presents absorbing discussions of number, space, mathematical reasoning, probability and the value of science. Also highly recommended, though somewhat dated, is Karl Pearson's *Grammar of Science.*

THE SCIENTIFIC OUTLOOK, by Bertrand Russell. Allen and Unwin, London, 1931.

It is hard to make a choice among Russell's popularizations—there are so many good ones. To the one selected here and the ABC books, already mentioned, I would add *Mysticism and Logic,* the *Outline of Philosophy* and, for more intrepid amateurs, *Introduction to Mathematical Philosophy. The Scientific Outlook,* though less well known, is an excellent example of Russell's style and his power and fertility as a thinker. It is gay, disrespectful and penetrating in its discussions of scientific knowledge, scientific technique and the "scientific society."

YOU AND HEREDITY, by Amram Scheinfeld. Frederick A. Stokes & Co., Inc., 1939; Garden City Publishing Company, 1945.

An unpretentious, straightforward account of the complex subject of genetics written by a layman "looking into the laboratory." For the nonspecialist it seems the most satisfactory treatment that has yet appeared. Good plates, diagrams and tables. The nature-nurture problem is presented exceedingly well in *Heredity, Race and Society,* by two leading geneticists, L. C. Dunn and Theodosius Dobzhansky, in the valuable Penguin series.

CREATIVE CHEMISTRY, by Edwin E. Slosson. The Century Company, 1919.

A lively, informative work which, though far from up to date, is still the classic among popular chemistry books. Worthy competitors—and more recent—are *This Chemical Age,* by William Haynes, and *The Romance of Chemistry,* by William Foster. Bernard Jaffe's *Crucibles* is a very interesting story of the lives of the great chemists. *Prelude to Chemistry* by John Read is an attractive historical survey by a talented writer and scientist. He has also written a more specialized but readable introduction to organic chemistry, *A Direct Entry to Organic Chemistry,* which in 1949 won a large Italian prize for the best work of popular science in the past five years.

THE SCIENCE OF LIFE, by H. G. Wells, Julian Huxley and G. P. Wells. Doubleday and Company, 1934.

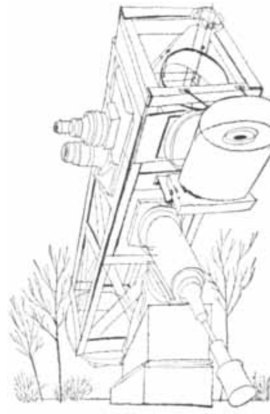
A comprehensive work of 1,500 pages dealing with almost every phase of the life sciences. Clearly and attractively written, profusely illustrated, this is an extraordinary panorama of biology, analogous, in the sphere of science, to Wells' *Outline of History.* As a tiny but worthy companion to this tome I suggest Erwin Schrödinger's intriguing *What Is Life?* There is also the popular *What Is Life* (sic!) by the noted geneticist J. B. S. Haldane. Unquestionably the best general book on evolution, consistently rational in outlook and lucid in style, is *The Meaning of Evolution,* by George Gaylord Simpson, based on the Terry Lectures delivered by this noted paleontologist in 1949. And I cannot leave this subject without mentioning the fascinating, encyclopaedic *On Growth and Form,* by the late D'Arcy Wentworth Thompson, a lavishly illustrated study of the forms of living organisms, their development and the remarkable geometry and algebraic functions which govern their growth. This is a book of endless riches by a distinguished scientist and classicist.

SCIENCE AND THE MODERN WORLD, by Alfred North Whitehead. The Macmillan Company, 1925.

One of the outstanding and most influential works of modern thought. It discusses, among other things, mathematics as an element in the history of thought, the origins of modern science, science and philosophy, religion and science, the requisites for social progress. The key to the book is the sense of the overwhelming importance of a guiding philosophy. Whitehead's concept of philosophy as the most effective of all intellectual pursuits is expressed in the famous passage: "It builds cathedrals before the workmen have moved a stone, and it destroys them before the elements have worn down their arches. It is the architect of the buildings of the spirit, and it is also their solvent . . . ."

A HISTORY OF SCIENCE, by William Cecil Dampier. The Macmillan Company, 1944.

The best one-volume general chronicle of science, notable for its readability, clarity and scope. It emphasizes throughout the evolving relations between science, philosophy and religion. It should be pointed out, however, that the book's treatment of the ancient period, especially of Babylonian and early Greek science, has been criticized by experts as inadequate and is undoubtedly inferior to its exposition of later periods.



THE AMATEUR

Conducted by Albert G. Ingalls

THERE is a great deal of truth in the cliché that the day of significant contributions by amateurs in science has passed, but it is probably less true in astronomy than in most other sciences. In astronomy, perhaps more than in any other field, the dividing line between the amateur and the professional is still rather thin and hard to define. Amateurs and professionals hobnob in the same organizations, work on some of the same kinds of problems and often are equally innocent of remuneration for their work, or *vice versa*. It is also a fact that amateurs have made many important contributions to astronomical knowledge in the past half-century. Nearly everything we know about the moon's surface and that of the planet Jupiter is due to the work of amateur observers; they have also been responsible for the discovery of many comets, meteor showers and novae. In addition, as regular readers of this department know, amateurs have contributed in no small way to telescope optics, astronomy's servant.

The history of amateur astronomy is summed up in the history of a few amateur societies. One of the earliest was the Astronomical Society of France, founded in 1887. It set a pattern for such organizations by admitting professionals as well as amateurs; it now has several thousand members. In 1889 a group of professionals and amateurs in the Pacific Coast States organized the Astronomical Society of the Pacific. This society became increasingly professional, however, and today its 800 members include many specialists, and its journal, called *The Publications*, is largely technical.

The most active and serious-minded of the amateur groups is the British Astronomical Association, founded in 1890. From the outset it carried on organized, systematic observations. Within 10 years of its founding it had 1,169 members and had already published 32 "memoirs" on the sun, planets and moon, with many detailed drawings of sunspots and planetary and lunar features. Today its 1,800 members are divided into more than a dozen working sections, each specializing in a particular investigation such as the sun, the moon, a planet, comets, meteors, the aurora and zodiacal light, variable stars, photography, instruments, computations and astronomical history. Although amateurs cannot do difficult astrophysical research, the members of the British group have published a great number of memoirs describing long, patient investigations of astronomical subjects within their reach; notable among them are minutely detailed maps of the moon by the late Walter Goodacre and more recently by H. P. Wilkins.

The founding of the British association was followed in 1903 by the formation of the Royal Astronomical Society of Canada, a federation of amateur astronomers' clubs in 11 Canadian cities. These clubs do little organized observing but meet to hear lectures by professional astronomers or the reading of members' papers, and the Society publishes a periodical called *The Journal* and an annual *Observer's Handbook*. There are now 1,700 members, including 300 in the U. S.

In the U. S. amateur astronomy made a slower start. The early files of *Popular Astronomy*, a publication founded in 1893, show that for many years professional astronomers worked hard but without much success to build up a body of amateur astronomers in this nation. Then in 1911 the American Association of Variable Star Observers was founded to help the professionals keep watch on some of the 600 variable stars. Since 1911 the diligent members of this group have provided astrophysicists with more than a million observations of variable stars—one of the most solid contributions by amateurs to astronomy. Recently the Association has sponsored organized observation of sunspots and a lookout for bright novae. It has also done cooperative observing with the American Meteor Society, another amateur group founded in 1911.

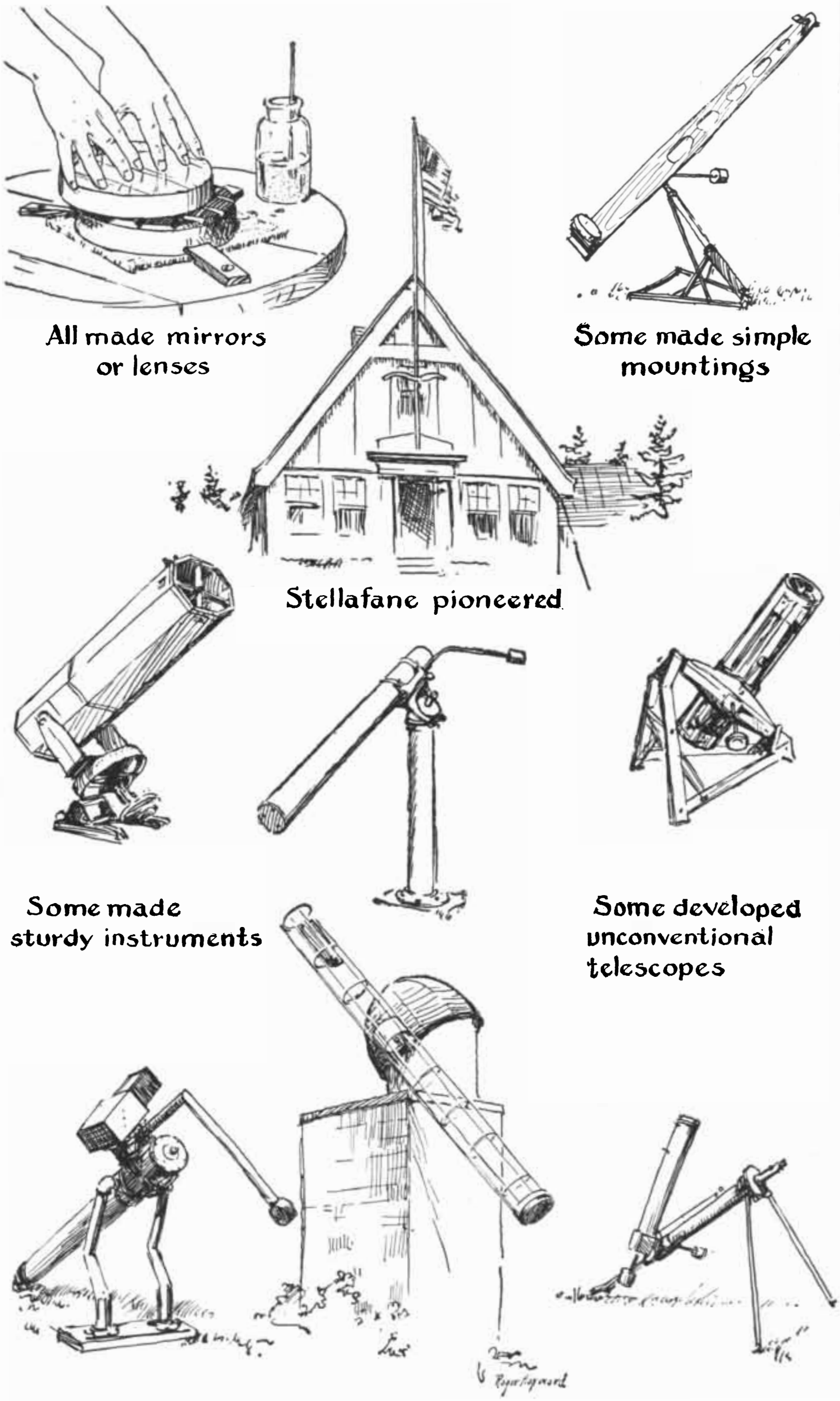
Since 1925 local groups of amateur astronomers have been forming all over the country, and after World War II Charles A. Federer, Jr., of Harvard University, who had long been active in popular education in astronomy, organized these groups in a federation called the Astronomical League. It now has 56 member organizations and 3,389 members. In 1947 another new society, the Association of Lunar and Planetary Observers, was formed to make systematic observations of the moon and planets; it publishes a periodical called *The Strolling Astronomer*.

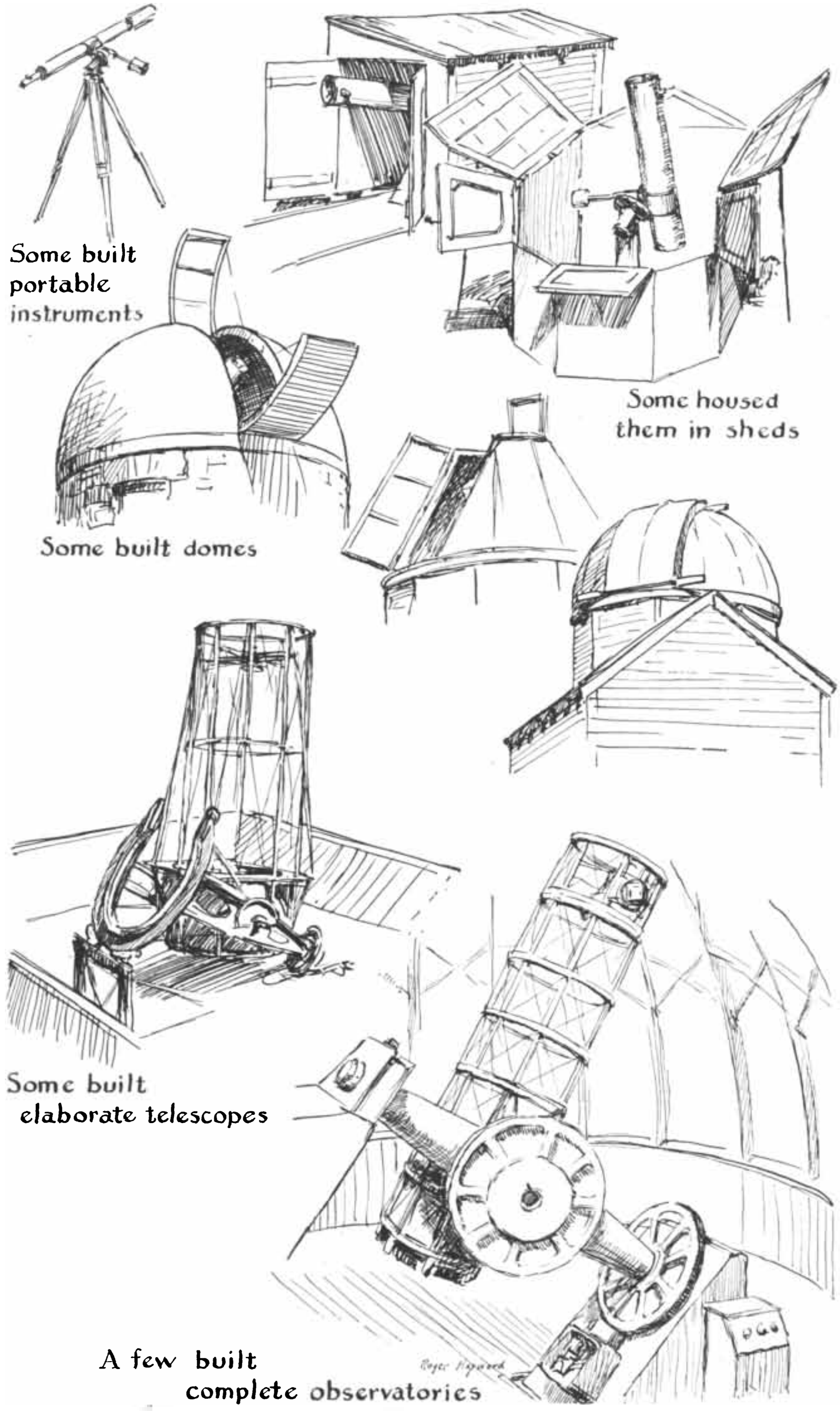
It would be misleading to suggest that

ASTRONOMER

the principal purpose of the amateur-astronomy movement is to contribute important new research and discovery to the science. Although the amateurs' observations have been helpful to the professionals, few amateurs are equipped to make basic discoveries of new knowledge in modern astronomy. The amateur in this field, as in any other, finds sufficient justification in the pleasure and personal enlightenment afforded by the pursuit of his hobby, whether at the eyepiece of a telescope, at the workbench, in an armchair or in the sociable company of colleagues with a kindred interest.

This is particularly true of the many thousands of amateur astronomers whose chief interest is in making their own telescopes, and who for a quarter of a century have been the special concern of this department of SCIENTIFIC AMERI-





CAN. Few of the amateur telescope makers have yet discovered new worlds with them. Probably most have found more satisfaction in making telescopes than in using them; the first telescope is barely started before they are already planning the second. By and large the telescope maker is not an observer. This may be regrettable, but the work of the telescope makers has not been without profit to astronomy. It has made an appreciable indirect contribution to the science through its contributions to precision optics. Some of the amateurs have gone on to become professionals, and to design new types of optical instruments for astronomy.

The history of the amateur telescope-making movement may be of some interest to all who are interested in science and in broadening the understanding of science among laymen by enlisting a more widespread amateur participation. The fascinating but latent possibilities in the art of telescope making were discovered quite accidentally by this magazine just 25 years ago. Before that time the art had never had more than a handful of followers, but as information about it was made widely available through the pages of SCIENTIFIC AMERICAN and the book *Amateur Telescope Making*, tens of thousands of persons eagerly seized upon it as a most absorbing pastime and ultimately developed it to a full-fledged nationwide movement.

Had an unknown borrower in the New York Public Library one day in 1925 deposited Volume 29 of *Popular Astronomy* on the book-return desk one minute earlier or one minute later, this history of telescope making might not have been written, at least not by this author. As it was, the writer, who happened to be present at precisely that moment, idly picked up the volume before it could be returned to the library's stacks and came upon an article by Russell W. Porter on the making of reflecting telescopes. He recalled that his father, Charles W. Ingalls, had once said many years before that there were not 10 men on earth capable of making telescope mirrors and lenses. The writer sat down and read the article with fascination. He went home determined to attempt to make a telescope of his own, and therefrom grew an unforeseen sequel of events.

The seed had actually been planted many years earlier. Porter himself had discovered telescope making in 1911 through a copy of *Popular Astronomy* sent to him by a friend. The periodical had a short note about a telescope made by Leo Holcomb of Decatur, Ill. (who in turn had been prompted to undertake his project by reading an article with some scanty instructions for telescope making by John Mellish in *Popular Mechanics* in 1907). Porter wrote to Holcomb for further information, and with the help of a book on glass working began to make reflecting telescopes. By 1925 he had made 10 mirrors. The writer, after reading Porter's article, purchased a mirror blank and communicated with Porter, then living in Springfield, Vt. Porter soon announced that he was coming to New York on business and suggested a meeting.

At six o'clock one spring evening in 1925 we sat down to two-inch mutton chops in Brown's Chop House on Broadway. We arose from our chairs only in time for Porter to catch a midnight sleeper to Vermont—after six solid hours of talk about telescopes! Porter became so absorbed in the subject that in the midst of dinner he stood up in the crowded restaurant, thronged with theatregoers, and gave me a demonstration of mirror grinding with the makeshift tools at hand. Using two inverted saucers on the dinner table, he demonstrated various grinding and polishing strokes, ordinary and extraordinary, with a quiet running commentary. While the fascinated restaurant diners, to whom Porter was completely oblivious, stopped dining to watch, uneasy floor managers hovered indecisively over the performance, apparently wondering what kind of emergency vehicle should be summoned.

During the evening Porter proposed that an attempt be made to spread the telescope-making virus through SCIENTIFIC AMERICAN. Soon after he returned to his Vermont home, he renewed the suggestion, writing: "I have held a meeting of the telescope makers of Springfield to set a date for your visit. We have, after due consideration of the moon's phase, configuration of the planets' horoscopes and astrological incantations, found that the 13th of June seems the most auspicious for the night at Stellafane on the mountain. A little grinding experience before then will give you more appreciation of the stuff you will hear discussed here."

A somewhat overdramatized account of the events of that June night was published in the November, 1925, issue of SCIENTIFIC AMERICAN. We thought that perhaps half a dozen readers might show some interest. Actually we had 368 immediate requests for instructions in the art of telescope making. Early in 1926 the magazine began to publish articles of instruction by Porter, and eager readers all over the country fell to work grinding their first telescopes. A series of accidental events, which had brought together a reliable source of instruction, a means for its dissemination and a catalytic agent, had revealed an unsuspected hunger for creation to which about 50,000 amateur-made telescopes have since been fed without reducing the hunger.

Very soon all amateur telescope makers with known addresses in the Northeast States received printed invitations to a meeting at Stellafane on July 3, 1926. A group photograph still in existence reveals that on that date 17 guests assembled behind Porter's Springfield telescope in front of Stellafane, shown in one of the drawings on page 109. This was the first of 17 such conventions, some of which brought as many as 400 pilgrims to the crowded mountaintop at imminent risk of mutual suffocation, for Stellafane is only a little wooden house on top of a mountain that is only a hill. Unfortunately the conventions eventually outgrew the capacity of the Stellafane retreat, nestling in a grove of aromatic black spruces, and the amateur astronomers now convene in cities or on campuses.

The invitations to the second Stellafane convention in 1927 read: "No formal program but a chance to talk over your problems." It had been recognized that the amateurs wanted most of all to become acquainted, hence no attempt was made to weary the visitors by aping the formal programs of established societies, and this set the keynote for future Stellafane conventions.

By 1928 the movement was well amarch. In that year this department, then called "The Back-yard Astronomer," was started as a regular feature of the magazine. The first, 103-page edition of *Amateur Telescope Making* had vanished and 6,000 copies of a second edition of 285 pages were printed. Clubs of amateur astronomers were being formed in local communities. The skill of the amateur telescope makers did not yet match their enthusiasm; most of their products were too light and shaky, but progress was being made.

When in 1930 the Lowell Observatory in Arizona announced the discovery of the planet later named Pluto, the press stated that its image had been found on the plate by Clyde Tombaugh, "who once had made a telescope." This hint led to the disclosure that Tombaugh had started as an amateur. The telescope referred to, his third, had been mounted by his father on parts adapted from a straw spreader, a cream separator and an old car. "Its optical performance," according to Tombaugh, "was most gratifying." Appointed as a professional to the staff at the Lowell Observatory and assigned to the search for an outer planet, Tombaugh examined two million images with the blink microscope and within a year succeeded in finding Pluto. Tombaugh is one of several professional astronomers now at large observatories who graduated from the ranks of the amateur telescope makers.

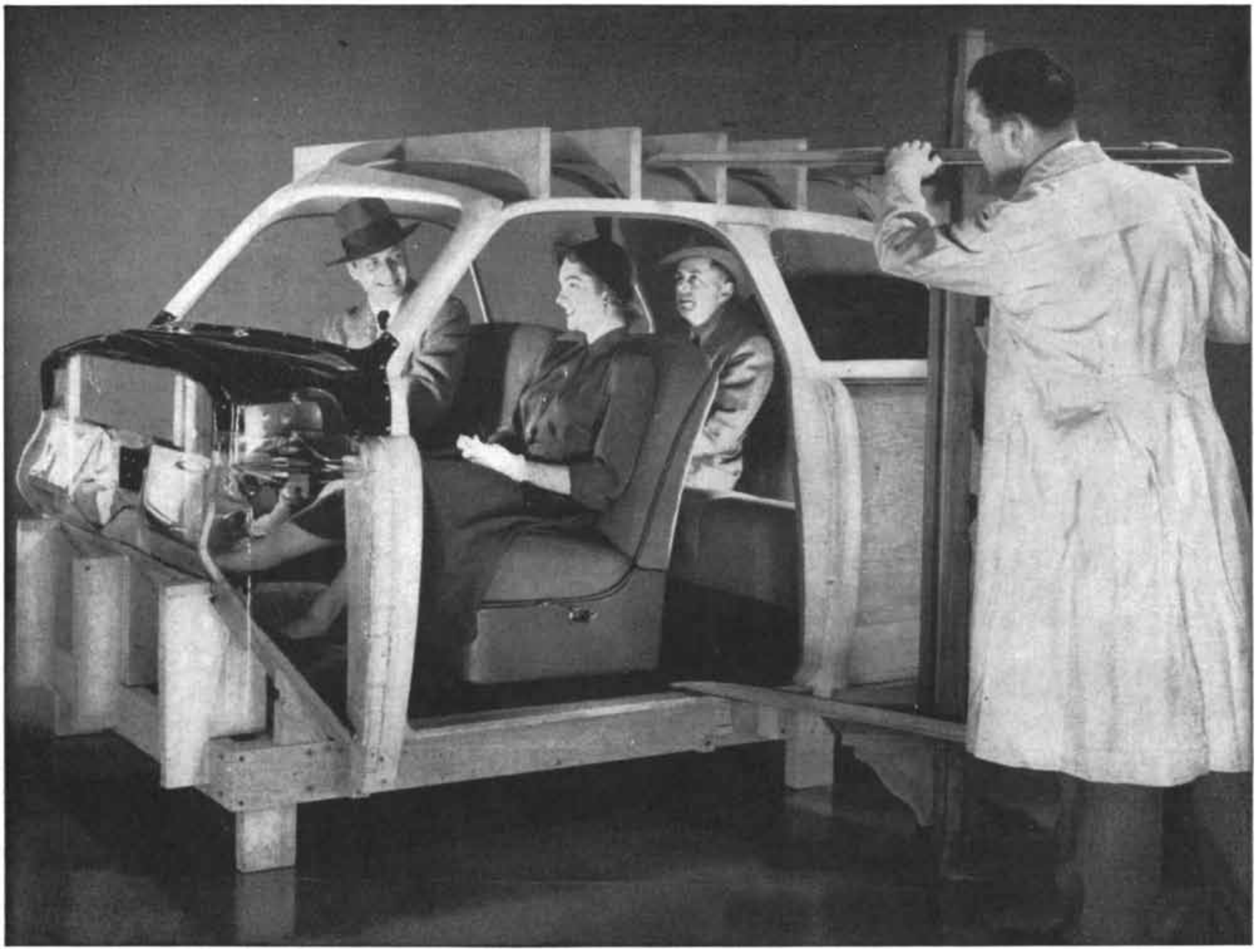
In the depths of the economic depression of the 1930s men who were out of work turned to telescope making as an inexpensive form of fun and as a morale-preserver. And in World War II the amateur telescope making movement made a material, practical contribution to our military needs. The war found this nation short of roof prisms for gun sights—one of the most difficult prisms to manufacture—and even of trained personnel who could make them. An amateur telescope maker, Fred Ferson of Biloxi, Miss., who had mastered the difficult art, undertook to instruct other amateurs. Through this magazine, which coordinated the project and distributed his instructions, he taught 100 advanced amateur telescope makers how to make roof prisms. Working in spare hours in their home workshops, about 15 of these amateurs produced more than 30,000 roof prisms. And in Texas a graduate of the amateur telescope making hobby produced another 30,000 in his plant. It turned out that the amateurs' prisms excelled those of professional manufacturers by a wide margin in quality of workmanship, no doubt because of the amateurs' pride in their skills and the fact that large manufacturers could not arouse equal pride of workmanship in their employees.

Amateur telescope making is now in its second generation of followers. It is clearly destined to a permanent place as a hobby that attracts those who enjoy the challenge of its exceptional difficulties.


THE SUN

INDEX OF ADVERTISERS

SEPTEMBER 1950



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Many readers of SCIENTIFIC AMERICAN *may wish further information about some of the topics discussed in the 10 articles that appear in this issue. There are of course numerous books and articles that treat with these topics at the level of the educated layman. A few of the books are listed in the review of the best popularizations of science during the past 50 years* (pages 97-107). *A larger number of articles on these topics have appeared in* SCIENTIFIC AMERICAN *since its reorganization in May, 1948. They are listed below with the title of each article in this issue and in the order of their publication.*

ASTRONOMY

THE DUST CLOUD HYPOTHESIS, by Fred L. Whipple. May, 1948.

GALAXIES IN FLIGHT, by George Gamow. July, 1948.

A NIGHT ON PALOMAR, by Albert G. Ingalls. August, 1948.

THE SUN, by Armin J. Deutsch. November, 1948.

RADIO ASTRONOMY, by Grote Reber. September, 1949.

FIVE HISTORIC PHOTOGRAPHS FROM PALOMAR, by E. P. Hubble. November, 1949.

THE ENERGY OF STARS, by Robert E. Marshak. January, 1950.

THE MILKY WAY, by Bart J. Bok. February, 1950.

PHYSICS

DAVISSON AND GERMER, by Karl K. Darrow. May, 1948.

THE ULTIMATE PARTICLES, by George W. Gray. June, 1948.

RADIO WAVES AND MATTER, by Harry M. Davis. September, 1948.

COSMIC RAYS, by George W. Gray. March, 1949.

LOW TEMPERATURE PHYSICS, by Harry M. Davis. June, 1949.

THE LIMITS OF MEASUREMENT, by R. Furth. July, 1950.

CHEMISTRY

THE CHEMISTRY OF SILICONES, by Eugene G. Rochow. October, 1948.

FLUOROCARBONS, by J. H. Simons. November, 1949.

HOT ATOM CHEMISTRY, by Willard F. Libby. March, 1950.

THE SYNTHETIC ELEMENTS, by I. Perlman and G. T. Seaborg. April, 1950.

PROTEINS, by Joseph S. Fruton. June, 1950.

GEOLOGY

SUBMARINE CANYONS, by Francis P. Shepard. April, 1949.

RADIOACTIVITY AND TIME, by P. M.

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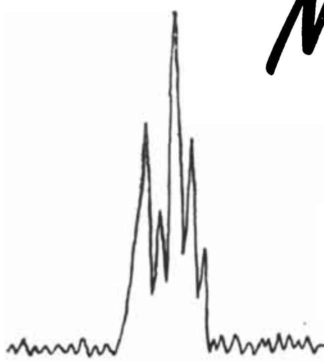

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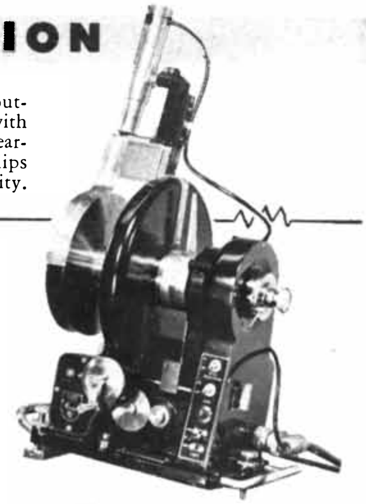

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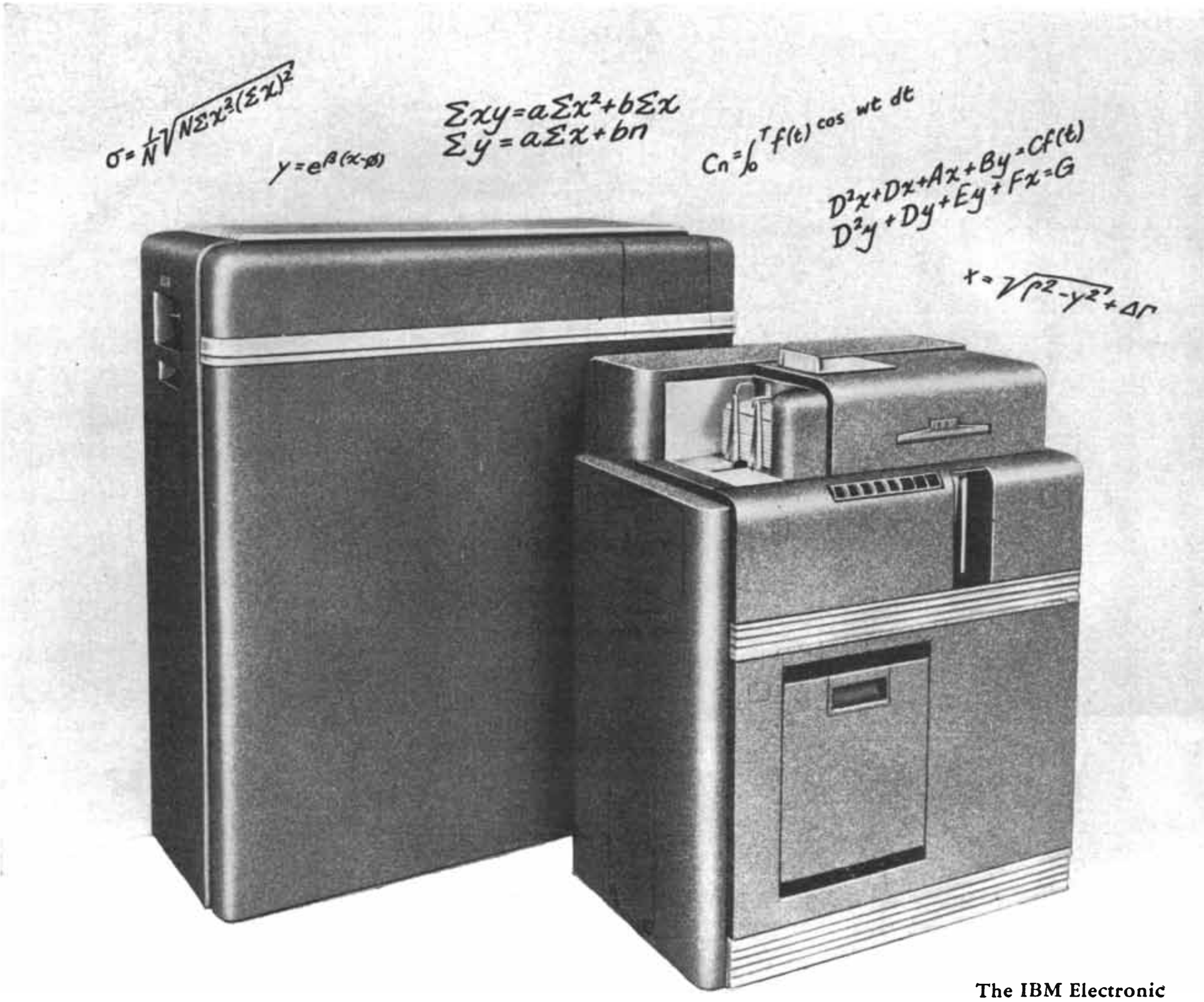

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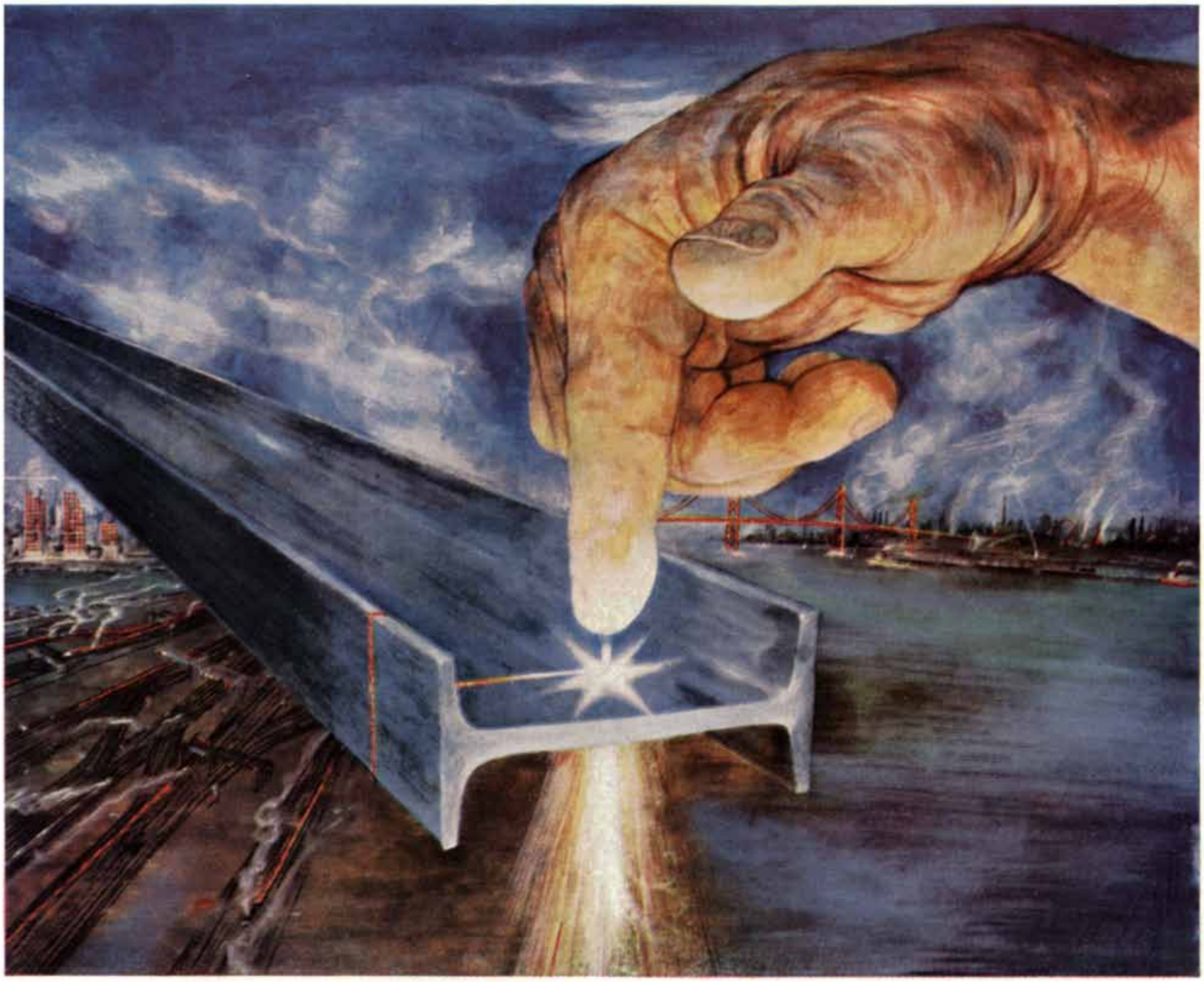

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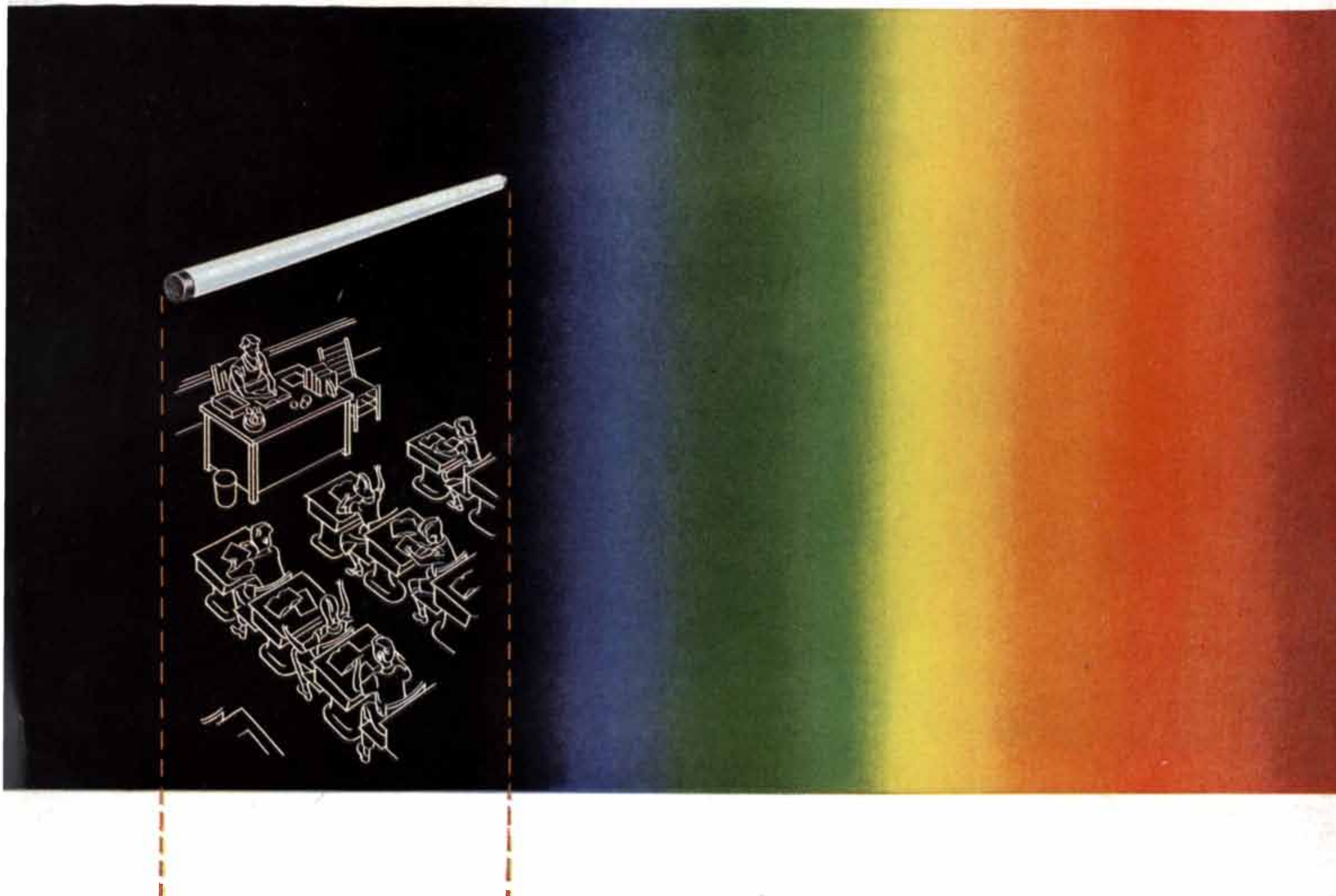

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