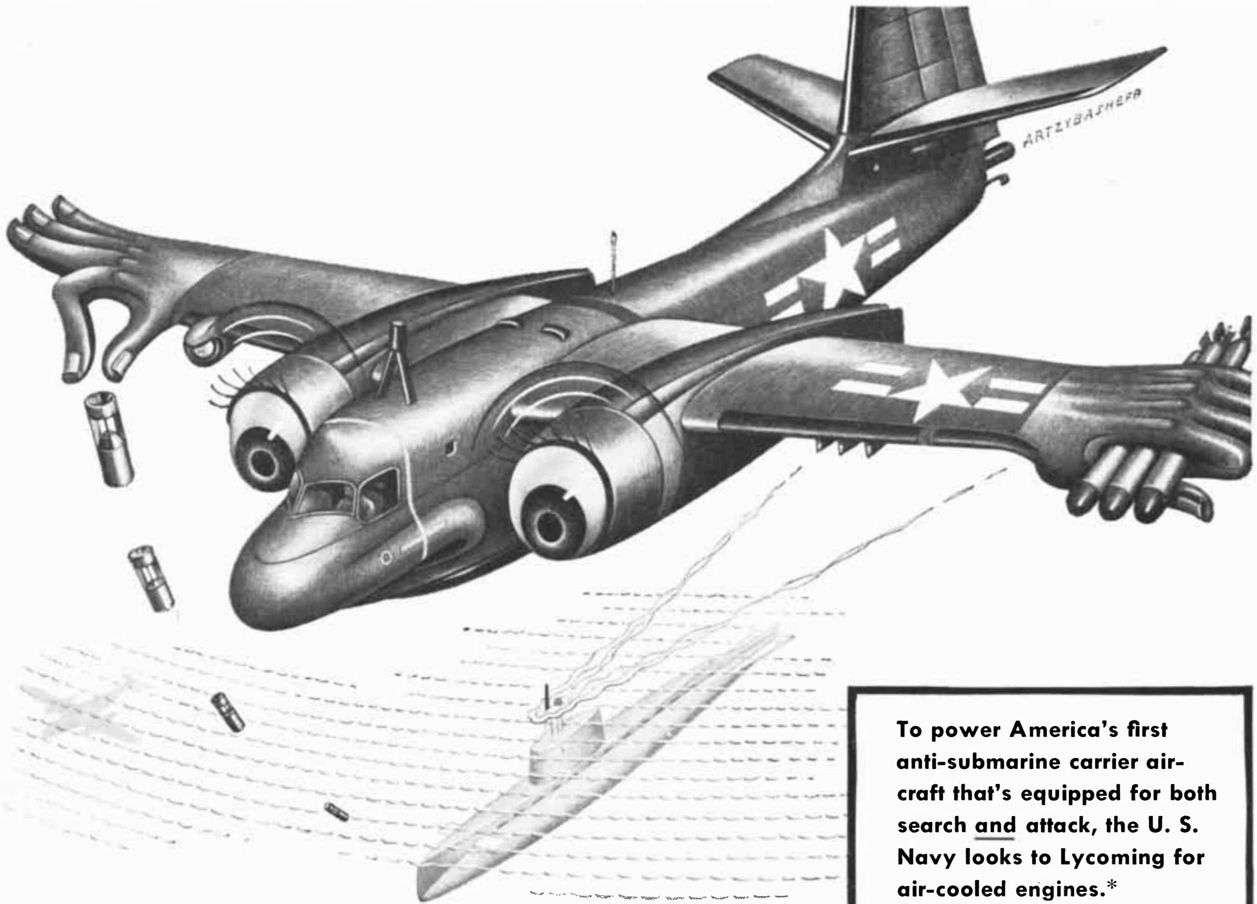
SCIENTIFIC AMERICAN

ANIMAL NAVIGATION

FIFTY CENTS

October 1954



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LETTERS

Sirs:

I found "The Origin of Life" by George Wald in the August issue very enjoyable reading. As I am a geologist, I know little of biochemistry, but Mr. Wald's arguments seemed very plausible.

However, Mr. Wald states that "all the carbon dioxide passes through the process of photosynthesis once in 300 years." He further states that all the oxygen and carbon dioxide are products of living organisms.

Any geologist knows this to be an erroneous statement. Carbon dioxide is added to the air from several sources: the combustion of fuels, respiration of animals, decay of organic matter, mineral springs, volcanoes. While a large amount of carbon dioxide is removed by photosynthesis, some is consumed in the weathering of rocks. No precise value has been given to either process as yet. T. S. Hunt states that in the weathering of a layer of orthoclase, 500 meters thick, to kaolin enveloping the globe, 21 times the present amount of carbon dioxide would be consumed.

DAVID A. HAACK

Washington University
St. Louis, Mo.

Sirs:

Interested in the origin and develop-

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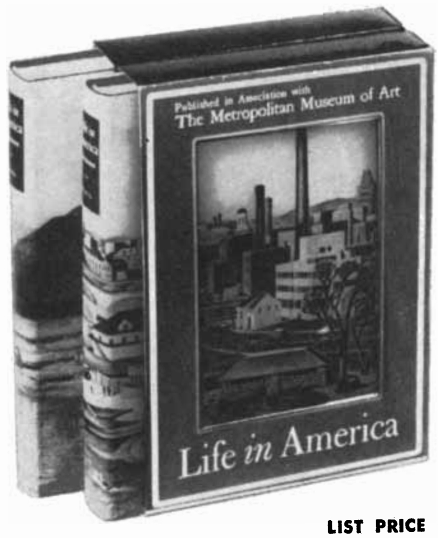

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ment of life on this planet, I read eagerly the article by George Wald. Apart from my generally favorable impression, I should like to point out what I consider an astonishing weakness in his argument for the inevitability of the spontaneous generation of life.

The theoretical phase of his argument concerning the increase of probability with the increasing number of trials is unsound, especially in view of the unfortunate illustrations he uses. The tossing of a coin is a fallacious analogy . . . for there is neither possibility nor impossibility for an appointed face of the coin to appear until there is a *trial*. And to have a trial, one must have a will toward the desired end. Every toss of the coin presupposes a "tosser" and an attempt (with an end in view, of course). Without the tosser and his trials, the rules of probability will mean nothing.

J. P. IRWIN

Philadelphia, Pa.

Sirs:

George Wald, in his thought-provoking article, claims that life was produced by chance organization.

This argument is not new. I believe Sir Arthur Eddington summed up this point of view in the following limerick:

There once was a brainy baboon
Who used to breathe down a bassoon,
For he said, "It appears
That in billions of years
I shall certainly hit on a tune."

Yet Lecomte du Noüy in his book *Human Destiny* reports the painstaking calculations made by Professor Charles-Eugène Guye on the mathematical probability of forming a simple protein molecule by chance. What conclusion did he reach?

"Indeed if we suppose 500 trillion shakings per second, which corresponds to the order of magnitude of light frequencies, we find that the time needed to form, on an average, one such molecule in a material volume equal to that of our terrestrial globe is about 10^{243} billion years. But we must not forget that life appeared about one billion years ago. . . . We are faced with an interval which is more than 10^{243} times too short."

I will admit that the scientist should try to explain events by natural causes, without bringing in the intervention of God, *as long as it is possible and reasonable to do so.* But science demands that a theory have some solid evidence sup-

porting it. Therefore, to hold that life has developed spontaneously by chance is not a scientific statement; it is a sheer act of faith, perhaps based on a prejudice against admitting the action of an agent outside of the material universe.

R. L. PROBST

College of St. Thomas
St. Paul, Minn.

Sirs:

In reply to the questions raised by our readers, let me take up first the atmospheric gases. It is true that there is a continuous, slow production of oxygen in the upper atmosphere, through the dissociation of water vapor under the influence of radiation and electric discharges; and a continuous emission of carbon dioxide from volcanic sources, the rate of which has never been adequately estimated. Both gases are also continuously bound, oxygen by performing oxidations, carbon dioxide by forming insoluble sediments.

All of this, however, scarcely influences two primary considerations. First, oxygen seems to have entered the earth's atmosphere originally in substantial amounts as the product of plant photosynthesis. If a geologist's testimony is wanted on this point, R. T. Chamberlin, in discussing the evolution of the earth's atmosphere, says, "Goldschmidt, along with most geologists, considers the photosynthetic action of plants to be the chief source of atmospheric oxygen." Second, the cycles of passage of both oxygen and carbon dioxide through living organisms are at present so rapid that virtually all of these gases in our atmosphere are products of organisms, and have passed through organisms again and again. Indeed in my article I grossly understated the speed of the carbon dioxide cycle. According to Eugene Rabinowitch, it is estimated that the land and aquatic plants together could bind all the carbon dioxide of the atmosphere in about three years.

As for Mr. Irwin's comment, I used the term "trial" with no intention to imply a trier. By a trial I meant only an event to whose outcome one might attach a probability. As I said, such trials in the present instance may have consisted largely of collisions among molecules—perhaps also between molecules and catalytic surfaces; and the associated probabilities should have depended upon the species of molecules colliding. I see no reason to abandon the consideration that with time an outcome, though

very improbable initially, becomes virtually inevitable.

This brings us to Professor Probst's letter. I have not read du Noüy's book, nor any other account of Guye's calculations. I think, however, that I can assure Professor Probst that no adequate basis exists for such a calculation. We are concerned here with the probabilities associated with a series of stepwise reactions and aggregations, none of which perhaps exceeds the bounds of what may happen in a two-body collision.

I wonder how one might have assessed the probability that a mixture of water vapor, methane, hydrogen and ammonia, passed for a week over an electric spark, could form a variety of amino acids in relatively high yield. Yet in 1953 Miller showed that this happens, and our entire conception of its intrinsic probability is revised accordingly.

If you will permit me a moment of nonsense, this is much the way I feel about the probability of living organisms. If they did not exist, I would regard them as impossible. Yet here we are; so we must be much more probable than appears on the surface.

I have no strong personal prejudice against invoking God's intervention in the origin of life, certainly no prejudice that keeps me from wondering what Professor Probst has in mind. The Jesuit priest, John Turberville Needham, a great champion of spontaneous generation, believed that God created matter initially with the potentiality of spontaneously generating life. Indeed, as pointed out in my article, this belief is consonant with the relevant passages in the Book of Genesis. If Professor Probst is dissatisfied with this view, where does he believe that God intervened? Was it to create the first protein? Or the first living cell? Or a man?

Dr. Garrett Hardin has brought to my attention a notable contribution to the argument for spontaneous generation which I neglected in my article. In an essay published in the 1920s J. B. S. Haldane wrote:

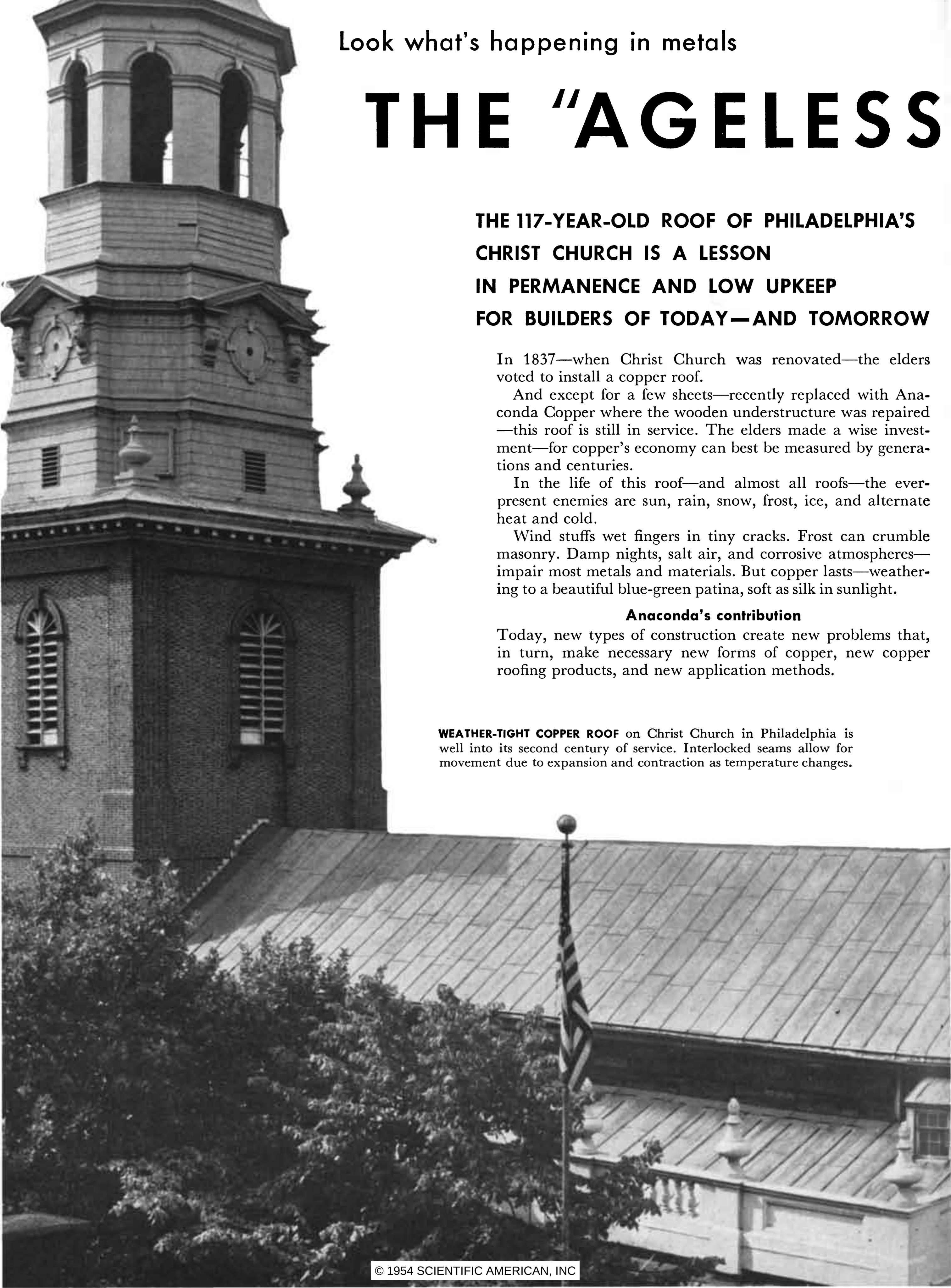
"In this present world such (organic) substances, if left about, decay—that is to say, they are destroyed by microorganisms. But before the origin of life they must have accumulated till the primitive oceans reached the consistency of hot dilute soup. Today an organism must trust to luck, skill, or strength to obtain its food. The first precursors of life found food available in considerable quantities for existence."

GEORGE WALD

Woods Hole, Mass.

Look what's happening in metals

THE "AGELESS



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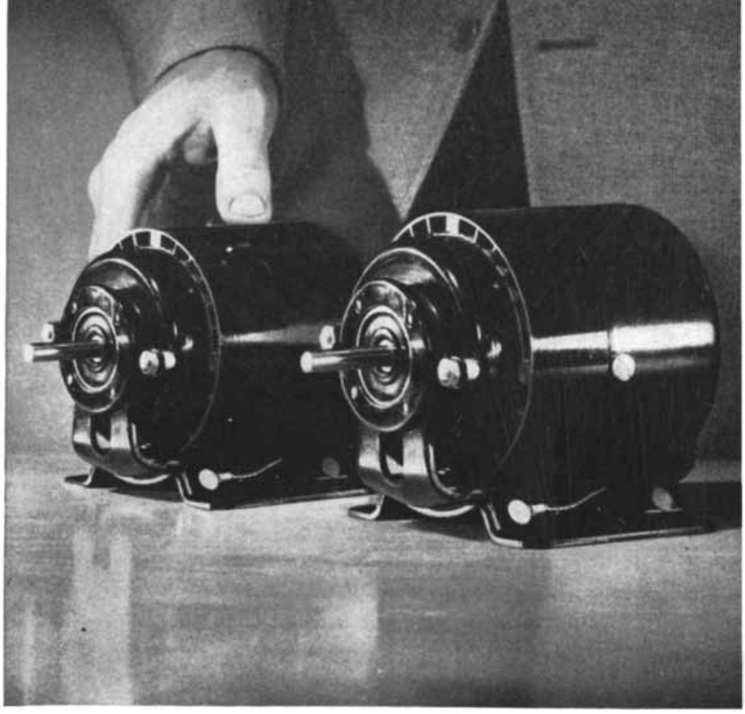

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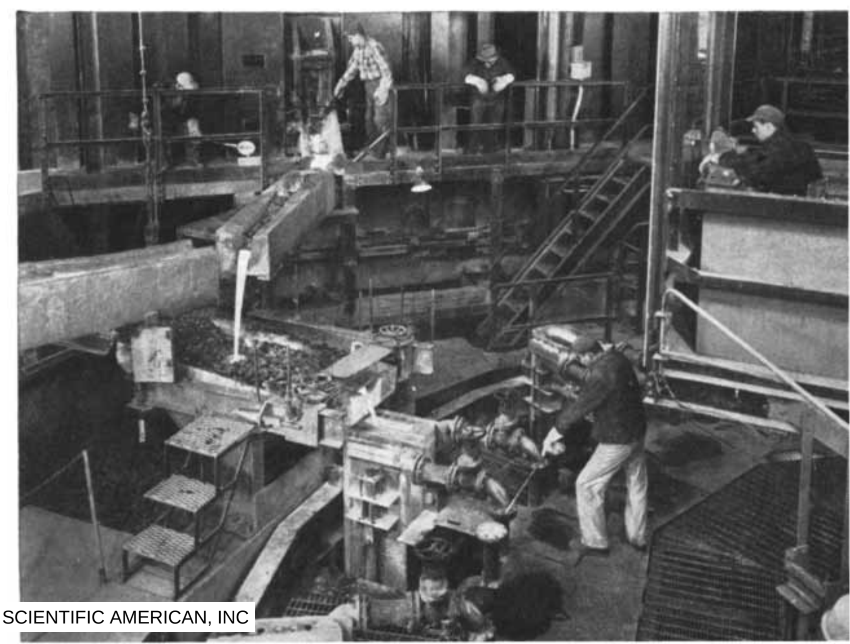
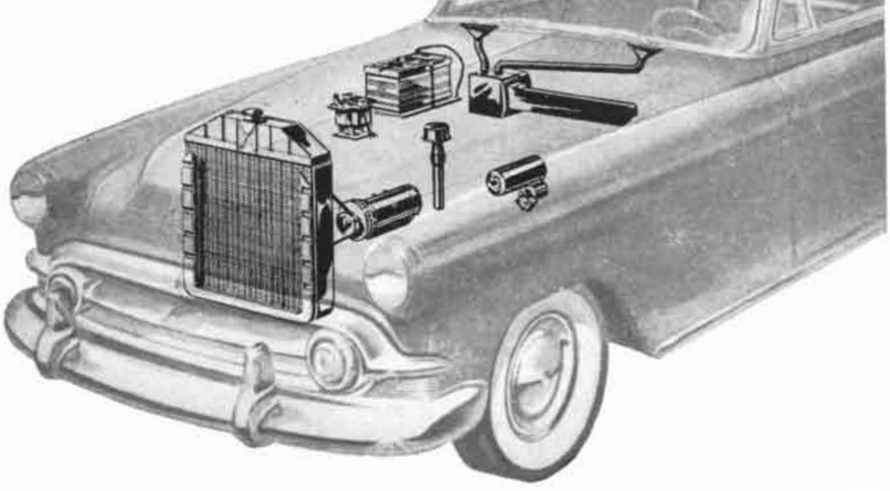
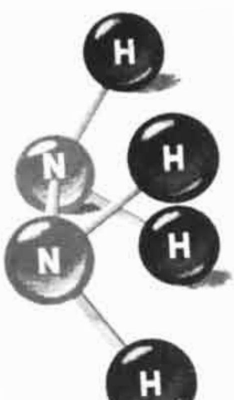




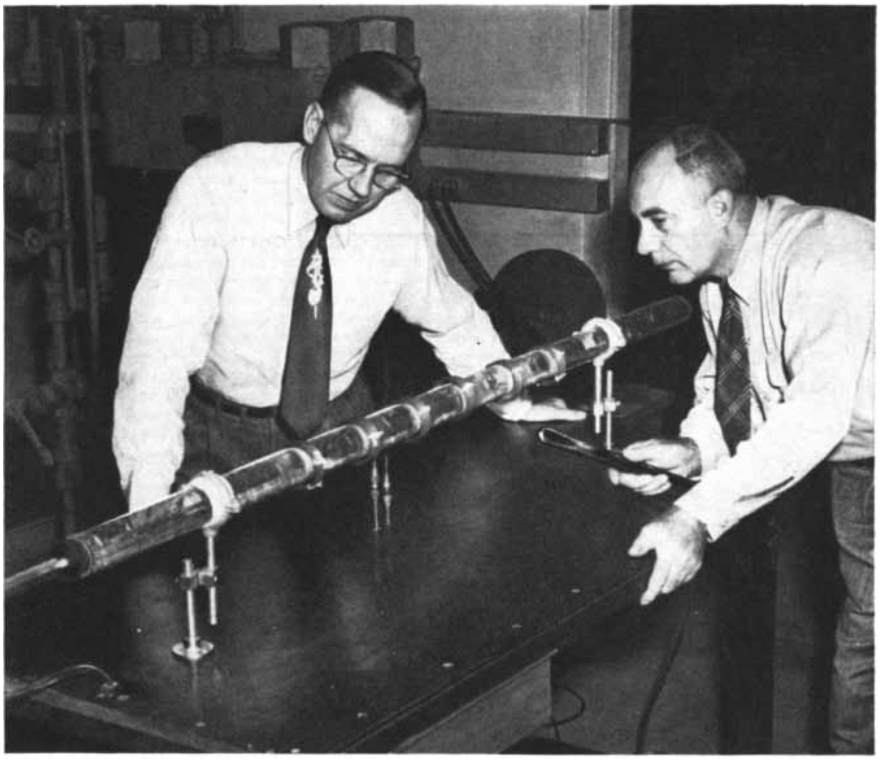


50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1904: "The efforts being unremittingly put forth in telegraphy to expedite the immense and constantly increasing mass of traffic between the great central points over fewer wires and with the aid of fewer assistants, have achieved results worthy of consideration through the final perfection of the tuning fork system of Prof. Mercadier. At the sending station, and by means of a series of tuning forks, a variety of perfect musical tones are generated. The vibrations corresponding to these tones are transferred electrically to the conductor; every vibration transmits a short electrical impulse or current to the conductor. The current waves formed by other and differently tuned forks may pass over the same wire at the same time; they work their way side by side, and independently of each other. At the receiving station each wave current finds its way to its correspondingly tuned receiver; leaving those not tuned in harmony with it quite undisturbed. These receivers are called monotelephones. They possess the characteristic of giving expression to the alternating currents passing through them, only insofar as they reproduce the tone peculiar to their membrane. Accordingly, when several of these differently tuned transmitters and receivers are cut into a circuit, each telephone will reproduce essentially only the tones emanating from its correspondingly attuned companion at the other end."

"In order to explain the production of helium from radium on strictly chemical lines, it has been suggested that radium is not a true element, but is in reality an unstable compound of helium with some known or unknown element, and that this compound is steadily breaking up with the liberation of helium. It must be borne in mind, however, that this postulated compound is very unique in character, for it is necessary to suppose that, unlike any other molecular compound, it breaks up with the expulsion velocity, and that the energy liberated during these changes is about one million times greater than the energy lib-



Zone Refining apparatus, showing tube and induction-heating coils. For transistors—tiny electronic amplifiers—germanium is made extremely pure. Then special impurities are added in controlled amounts for best transistor performance.

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To make the most of their revolutionary invention, the transistor, Bell Laboratories scientists needed ultra-pure germanium.

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It has only *one part in ten billion* of impurities harmful to transistor performance. That's about the same as a pinch of salt in 35 freight cars of sugar.

Yet the new process, Zone Refining, is simple in principle. An ingot of germanium is drawn through a series of induction-heating coils that melt narrow zones of the substance. Since impurities are more soluble in the liquid than in the solid form of a metal, the molten zones collect impurities. They are swept along by the successive melts to the end of the ingot, which is finally cut off.

Zone Refining is also being applied to the ultra-purification of other materials useful to telephony. This single achievement of research at Bell Telephone Laboratories clears the way for many advances in America's telephone system.

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erated in the most violent chemical reaction. In addition, it is necessary to suppose that the process by which helium is liberated is unaffected by wide changes of temperatures—a result never before observed in any chemical reaction. On the disintegration theory put forward last year by Messrs. Rutherford and Soddy, the helium and the radioactive products appear as a consequence of the disintegration of the radium atoms. Taking into account the novel character of the changes occurring in radium, and the enormous emission of energy, it appears more reasonable to suppose that these appear as the result of changes of quite a new character in matter—a breaking up of the chemical atom rather than of the chemical molecule."

"Recently, in these columns, we were deploring the number of fatalities that occur in transportation on our railroads; but now it seems that the risk of travel on railroads is insignificant compared with that to which those who use the modern elevator are exposed—at least in New York City. For according to a statement of Coroner Jackson, no less than 30 persons have lost their lives in elevator accidents in that city since the opening of the present year; and, of course, a still larger number of people have received injuries more or less serious."

SCIENTIFIC AMERICAN

OCTOBER, 1854: "Some have supposed heat to be a subtle substance pervading all space, and in the discussions of the application of heat to hot air which have appeared in some journals, the authors have dealt with heat as a grocer does with cheese—cut it up into slices. The great difference between the two is that the grocer's slices were veritable, tangible realities, while the slices of hot air were merely hieroglyphics, as substantial food for the mind as air is for the body. By some recent experiments of Regnault, in Paris, the old hypothesis of heat being a fluid seems to be settled in the negative, and the phenomenon of heat, like sound, is attributed to a vibratory motion in bodies. In a recent lecture, he stated that if hot air in a vessel like a glass globe be allowed to expand into another empty vessel kept in a water bath at the same temperature, there would be neither an

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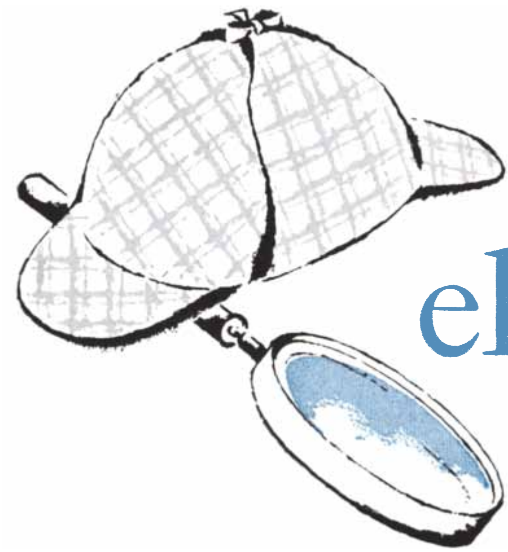

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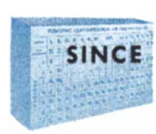

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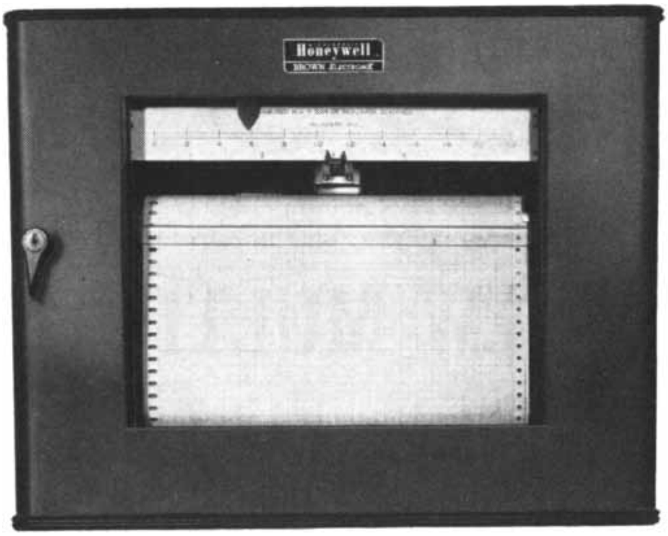
"Our country, and especially the city of New York, is now clothed in mourning, caused by one of the saddest events that has transpired for a great number of years. The steamship *Arctic*, one of the staunchest of the Collins Line, while running at the rate of thirteen knots per hour, was struck by the French propeller *Vesta*, during a dense fog, on September 27th, at noon, near Cape Race, and sank in a few hours afterward, carrying down to a watery grave a large majority of the passengers, of whom there were no less than two hundred and fifty. From all the accounts which have been received respecting the lamentable occurrence, it appears that both the *Arctic* and the *Vesta* were running at full speed, using neither bell nor whistle; and we have been informed that it is the practice of steamers and sailing vessels to rush on their ocean course during fogs at sea without employing any alarm to warn other vessels which might be in the same track. The reasons given for pursuing this nautical policy, are, first, that with regard to large steamships like the *Arctic*, it is safest to run at the highest speed, even if there should be a collision, as their great momentum must be in their favor; second, that the ocean highway is so broad that the chances of collisions are no more than one to a thousand against such a possibility. The fate of the *Arctic* shows that the first reason for high speed in a fog was a selfish and false business maxim; and the second, in our opinion, is just as untrustworthy."

"At the annual meeting of the British Association for the Advancement of Science Prof. Owen, the celebrated naturalist, delivered a lecture with diagrams, on man-like apes, and described a new species recently discovered on the western coast of Africa, named the Gorilla species, the adults of which attain the height of five feet five inches, and are three feet broad across the chest. The strength of this man-ape is enormous; his jaw is said to be as powerful as that of a lion, and his canine teeth are equally formidable."



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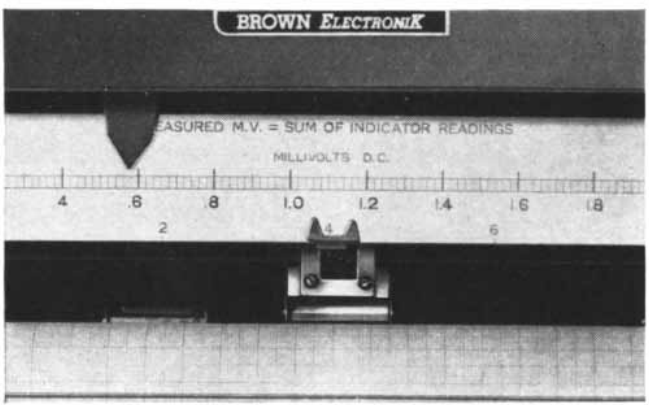


Closeup of indicating scale. Upper pointer shows millivolts within the span; lower pointer indicates millivolts to be added. Total reading: 4.58 mv.

DESIGNED especially for recording variables which change over a wide range, this new *ElectroniK* instrument records on a chart effectively *55 inches in width.* It has five equal measuring spans. Whenever the variable being measured reaches either the upper or lower limit of one of these ranges, the instrument automatically steps to the adjoining range and continues recording.

Two indicating pointers show the range in use and the value within the range. Connected to each pointer is a pen; one draws a purple record showing the range, the other draws a red record of the variable itself. To get the complete reading, you simply add both pen or pointer indications.

The complete range is 10.2 millivolts, in five 2-millivolt steps with an extra 0.2 millivolts on the high end of each span to provide an overlap that facilitates measurements near the change-over point. Pen speed of 4½ seconds full scale affords rapid response to quickly changing variables.

You'll find this new instrument particularly valuable in strain gage measurements and in dozens of other uses where high resolution aids interpretation of data. Your nearby Honeywell sales engineer will be glad to discuss your specific application . . . and he's as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division,* Wayne and Windrim Avenues, Philadelphia 44, Pa.

● **REFERENCE DATA: Write for Data Sheet No. 10.0-18, "Extended Range Recorder."**

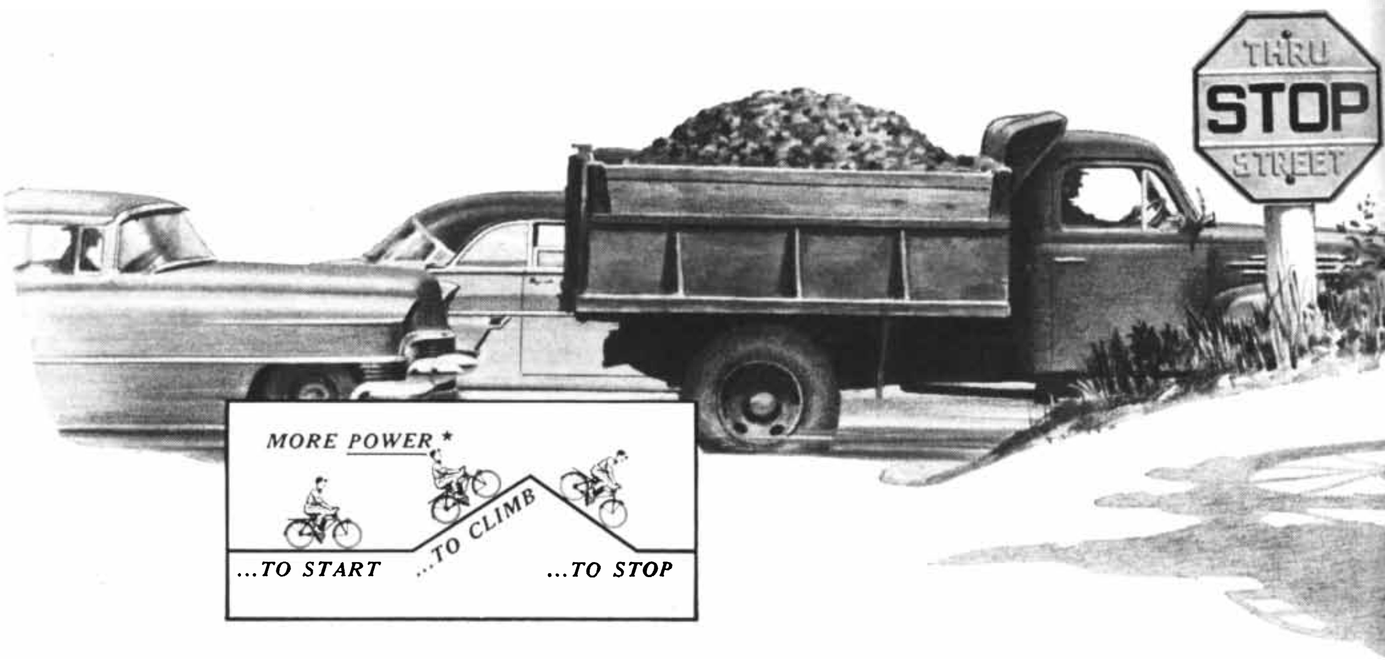
MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS

First in Controls

See what **Bendix** has built
for your kids!

A WONDERFUL NEW MULTI SPEED POWER* BRAKE FOR BIKES....

(something every Dad should know about!)



The main reason you should know about this new Bendix brake for bikes is because it's safer than the one your boy or girl has now . . . it will stop them quicker with 32% less effort. This gives your 68-pounder just as much braking power as the 100-pound lad with an ordinary coaster brake.

He also pedals easier because it has two gears. For starting up or going uphill, he flicks a trigger control alongside his handle grip to put him in "low." Another flick, when under way, and he's in "high."

But remember he brakes with his *foot!* Unlike imported hand-control brakes, our internal-expanding automotive type brake doesn't try to change his habits and confuse him. He still brakes the way he's *used* to braking—only it's a lot safer and easier.

How to Order It

Fourteen leading makes of American bicyles are now equipped with the new Bendix* MultiSpeed Power Brake. Whatever bike you buy, be sure that it is equipped with this great new safety feature.

World's Foremost Producer of Brakes

Bendix and braking are almost synonymous; we've built millions of complete braking systems, brake components, linings and power brakes for cars, trucks, airplanes and bicycles over a 40-year period.

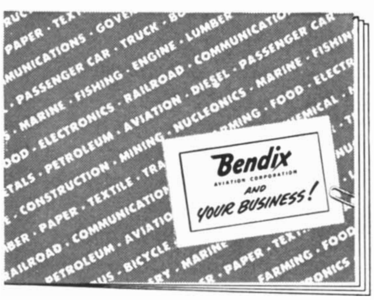
But it's only one field of Bendix endeavors.

Bendix Aviation Corporation is primarily a manufacturing organization, strong on research and engineering, which produces about a thousand products and basic components for a score or more of industrial and nuclear fields, as well as end products for you as a consumer . . . television, power brakes you can put on your present car, new-lined brake shoes, carburetors, electric fuel pumps, a fine barometer for your home,

car radios, marine ship-to-shore radio, and automatic pilots for boats.

Diverse

If you get the idea that Bendix policy is planned diversity, you are right. Its chief advantage to you and your business is the many ways Bendix can help you lower costs, improve efficiency and up production through the use of new products or recent research developments.



You'll find a list of our principal divisions and products at the right. But for the complete story of Bendix write for the new digest, "Bendix and Your Business," on your company letterhead direct to:

BENDIX AVIATION CORPORATION
Fisher Building • Detroit 2, Michigan

THE NAME **Bendix*** AVIATION CORPORATION MILLIONS TRUST

PRINCIPAL DIVISIONS AND BASIC PRODUCTS

ECLIPSE MACHINE, ELMIRA, N. Y.
bicycle coaster brakes, Stromberg carburetors, electric fuel pumps, starter drives.

SCINTILLA, SIDNEY, N. Y.
aviation ignition systems; industrial engine magnetos; diesel fuel injection; electrical connectors; ignition analyzers.

ZENITH CARBURETOR, DETROIT, MICH.
automotive, marine and small engine carburetors.

BENDIX-SKINNER, DETROIT, MICH.
micronic filters.

PACIFIC, NORTH HOLLYWOOD, CALIF.
telemetering equipment; hydraulic and electric actuators; depth recorders; boat steerers.

BENDIX FRIEZ, TOWSON, MD.
meteorological instruments, precision instruments and recorders.

BENDIX PRODUCTS, SOUTH BEND, IND.
automotive brakes, carburetors, power steering; aviation brakes, landing gear, fuel metering.

ECLIPSE-PIONEER, TETERBORO, N. J.
aviation instruments and components; foundry.

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radar; auto, railroad, mobile and aviation radio; television.

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automatic viscosity regulators, nuclear products.

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digital computers.

HAMILTON, HAMILTON, OHIO
jet engine controls and aircraft pumps.

LAKESHORE, ST. JOSEPH, MICH.
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UTICA, UTICA, N. Y.
aviation components.

MONTROSE, SOUTH MONTROSE, PA.
aviation components.

PIONEER-CENTRAL, DAVENPORT, IOWA
aviation instruments and components.

YORK, YORK, PA.
electronic devices; test equipment.

BENDIX-ECLIPSE OF CANADA, LTD.
Windsor, Ont.

BENDIX INTERNATIONAL
New York City

*REG. U. S. PAT. OFF.

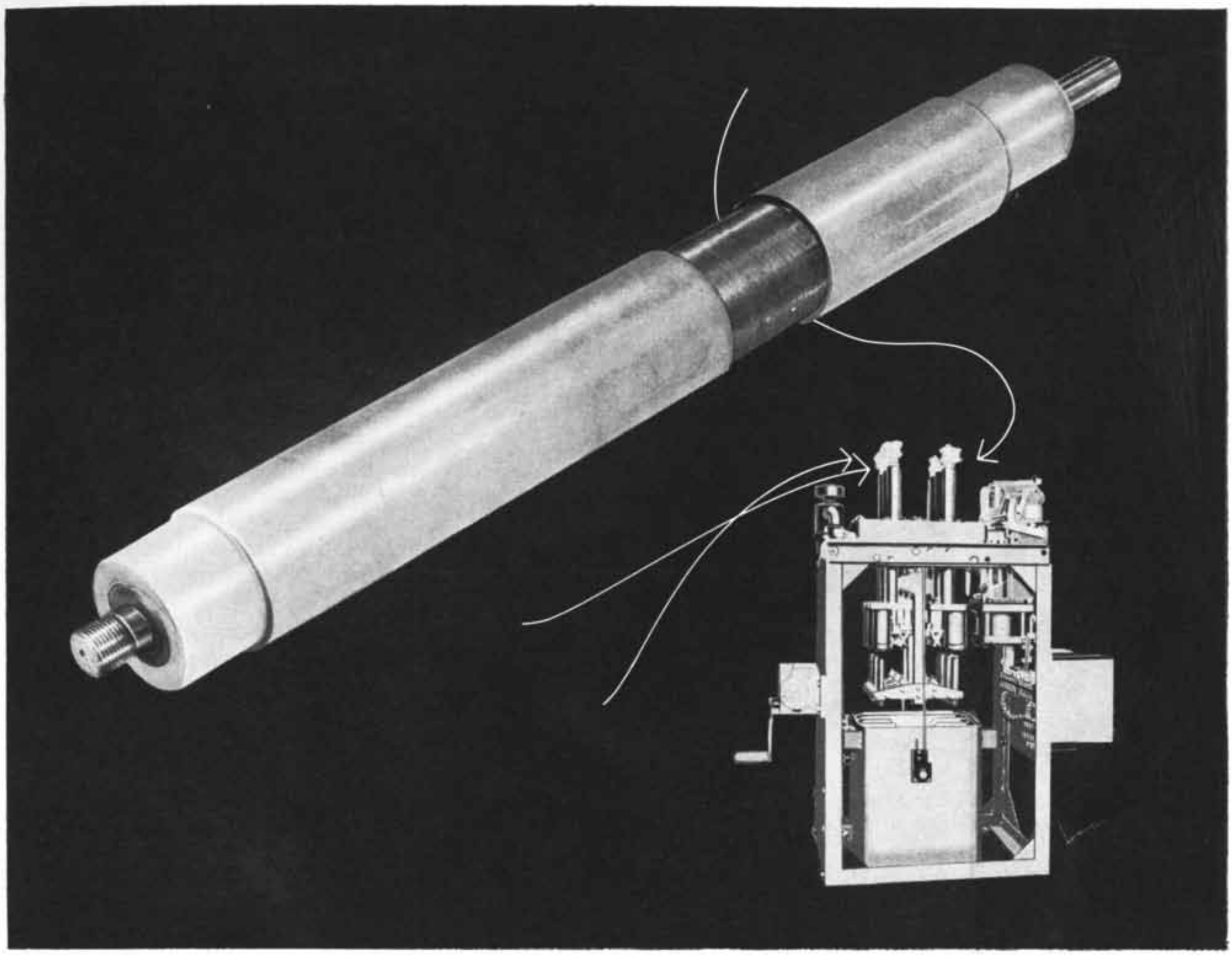
THE AUTHORS

GEORGE KATONA ("Economic Psychology"), professor of economics and psychology at the University of Michigan, was born in Budapest and educated in Germany, where he obtained a Ph.D. in psychology at the University of Göttingen in 1921 and studied under Gestalt psychologist Max Wertheimer. He was for a time associate editor of the *Deutscher Volkswirt*, a leading political-economic weekly. In the 1930s he came to the U. S. and worked as a business economist in Wall Street and as a psychologist with Wertheimer at the New School for Social Research. He did experimental studies on the psychology of learning and published them in the book *Organizing and Memorizing*. During World War II he turned his attention to the psychology of a war economy. For the past eight years he has directed the Economic Behavior Program at the University of Michigan.

RALPH L. MILLER and JAMES R. GILL ("Uranium from Coal") are on the staff of the U. S. Geological Survey. Miller took his Ph.D. in geology at Columbia University in 1937. He joined the Geological Survey staff in Utah full time in 1942 and is now chief of the Survey's Fuels Branch. His original interest in coal goes back to his early years in his native Pennsylvania. Gill went into geology after several years as an aerial photographer in World War II, during which he received the Air Medal and two Oak Leaf Clusters.

WOLFGANG PANOFSKY ("The Linear Accelerator") is professor of physics at Stanford University. He was born in Berlin, the son of art historian Erwin Panofsky, who later came to the Institute for Advanced Study at Princeton. After graduating from Princeton University in 1938, young Panofsky went to the California Institute of Technology, where he took a Ph.D. in physics and stayed to direct a project for the Office of Scientific Research and Development. From 1945 to 1951 he taught physics at the University of California, and since then he has been at Stanford. He is director of Stanford's High-Energy Physics Laboratory.

F. H. C. CRICK ("The Structure of the Hereditary Material") is a British biologist who was originally trained as a



physicist. After war years spent designing mines for the British Admiralty, he decided to go into molecular biology. He obtained a Medical Research Council studentship, entered the Strangeways Laboratory in Cambridge, worked on the viscosity of the cytoplasm of chick fibroblasts and "read everything I could lay my hands on." He then joined a molecular biology unit sponsored by the Medical Research Council, where he was able to concentrate on molecular structure. During the past year he has worked on X-ray diffraction of crystals of the protein ribonuclease at the Polytechnic Institute of Brooklyn.

JEROME S. PRENER and DON B. SULLENGER ("Phosphors") are phosphor chemists in the General Electric Company Research Laboratory. Prener, a graduate of Brooklyn College in 1944, worked as a research chemist in the atomic energy project from 1944 to 1946, then as a graduate student at the Polytechnic Institute of Brooklyn did research on phosphors under contract with the Navy. He joined General Electric in 1949. Sullenger, who graduated from the University of Colorado in 1950, tested petroleum and did hospital laboratory work for the U. S. Army during the Korean War. He is entering the Cornell University graduate school to work toward a doctorate in chemistry.

MITCHELL WILSON ("Priestley") has worked in nuclear physics and also has published three novels. His *American Science and Invention: A Pictorial History* will be published by Simon & Schuster next month. For the July issue of SCIENTIFIC AMERICAN he wrote a biographical sketch of Joseph Henry.

HANS KALMUS ("The Sun Navigation of Animals") is a lecturer at University College, London. His most recent appearance in these pages ("More on the Language of the Bees") was in the issue of July, 1953.

CURT STERN ("The Biology of the Negro") is professor of zoology at the University of California at Berkeley. Born in Hamburg, Germany, he took his Ph.D. at the University of Berlin in 1923, then spent 10 years in research at the Kaiser Wilhelm Institute. He came to the U. S. in 1933. For 14 years he was a member of the Department of Zoology at the University of Rochester. He went to the University of California in 1947. Stern was the author of an article on "Man's Genetic Future" in the February, 1952, issue of this magazine.

CORNING GLASS BULLETIN

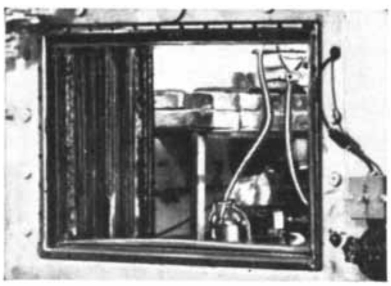
FOR PEOPLE WHO MAKE THINGS

Gamma guardians for protection and perception. Gamma rays are one of the dangers you encounter in taming atomic energy. Those who delve into molecular manifestations often face the double problem of how to *see* what they're doing while keeping out of reach of lethal radiations. Happily, glass can extricate you from both horns of this dilemma.

Our Harrodsburg plant recently cast and assembled what're undoubtedly the heaviest glass windows in the world, designed for the protection of employees working on an atomic power development program. Some of these windows are 5½ x 8 feet in area and weigh 12 tons.

Glasses for such windows come in three different densities—one has a density of 3.3, which has very high light transmission and doesn't brown when gamma rays hit it; the second a density of 6.2—about the densest glass ever made; almost as dense as steel and six times heavier than water. And the third has a density of 2.7 to match that of concrete.

By using those remarkable remote-control manipulators you've seen pictures of, scientists are able to perform their experiments by looking through these windows without fear of radiation injury.



▶ Maybe you're not in the market for a 12-ton, gamma-absorbent window, but if you have any kind of problem calling for the selective absorption and/or transmission of *rays* —cosmic, atomic, X-, ultraviolet, visible, infrared, micro-, radio, what have you, we might be able to help you find a solution. Leastwise, we'd be delighted to hear from you as a starter.

Laboratory ⇄ ?

Some years ago an enterprising designer came into possession of a simple piece of PYREX brand laboratory ware—a standard flask. With a certain ingenuity and imagination, and the aid of some material to wind around the neck, he transformed this laboratory flask into a beautiful (and salable) coffee carafe.

Since that time, other equally sales-minded designers have designed everything from flower vases to sugar bowls from laboratory glassware. The sales appeal of such items is built in with clean simple lines, heat resistance, functional design and the glistening attractiveness of glass.

Thus, such as humble laboratory flasks travel the oft-unyielding distance from lab to home on the wings of men's creative imagination.

The reverse happened to a bowl we make for manufacturers of kitchen blenders. This time the creative wings carried our product from home kitchen to laboratory. It came about when some fellows in a laboratory hit upon the idea of adapting these kitchen blender bowls to laboratory blending purposes. Simple, huh?

▶ The starting point for other potentially rewarding ventures could well lie hidden among the more than 40,000 standard items on the Corning product shelves. Could be you're next in line to put the magic of imagination to work projecting one of these into a new area of utility. The first step on this "maybe road" to fame and fortune is simple: Just drop us a note requesting same and we'll let loose a deluge of data on standard items.

How to engineer a platypus. A happy combination of purposeful practicality is the furry platypus with its webbed feet, beaver's tail, and duck's bill.

A lot of our customers, to their continuing delight and profit (we hope), have discovered that glass is sort of platypus-like in that it, too, can be made to combine many useful characteristics.

Take, for example, PYREX brand pipe. Here you see a man using a piece of it to drive one-inch nails in a pine plank. This is essentially an extra-curricular activity for glass pipe, which is more at home conveying metal-eating acids around chemical plants, but it's a way of showing just how tough glass can be when it's *made* that way.

All of which may serve to illustrate for you how we can arrange the optical, chemical, thermal, mechanical, and electrical properties of glass in different combinations to match a considerable variety of end-use requirements. In fact, we've worked up some 50,000 different formulas for glass in our years of helping customers solve specific design and processing problems.

▶ If platypus-like glass is a novel idea to you, if you've never given glass a second thought as a highly adaptable design and construction material, we suggest your reading a pocket-size volume entitled "Glass and You." It tells in a few words and many pictures how glass contributes to profit and pleasure and we'd be delighted to send you a copy. Or, if you're more concerned with putting glass to work for you than in learning what it's doing for others, there's a slightly more technical bulletin called, "Glass—its increasing importance in product design." We'll be glad to send you either—or both.

In all fairness to you—and to glass, too, we must admit that this is not the whole story. Fact is, experience indicates that it's *customer* ideas and problems that really bring out the best in glass. So, even if what's on your mind seems unrelated to any item this page discusses, glass may still be its fulfillment. We'd like to hear from you.

Corning means research in Glass

CORNING GLASS WORKS 30-10 Crystal St., Corning, N.Y.

THE COVER

The painting on the cover depicts a honeybee and a compass on a landing platform—both symbolic elements to illustrate the discovery of the remarkable ability of bees and other animals to orient themselves by means of a built-in natural compass (*see page 74*). This bee, *Apis mellifera*, was captured by the artist at Montauk Point, Long Island. Its orange pouches are pollen baskets. The compass is from the French city of Lyons. It is of the floating-dial type—that is, its whole dial is attached to a North-seeking magnet. Here the pointer, or gnomon, of the dial indicates late afternoon.

THE ILLUSTRATIONS

Cover painting by Stanley Meltzoff

Page	Source
31-35	Bernarda Bryson
36	Ralph L. Miller and James R. Gill
37-39	Emil Lowenstein
40	Bunji Tagawa
41	Radiation Laboratory, University of California (*top*); Stanford University
42	Stanford University
43-44	Bunji Tagawa
54-55	Sara Love
56	Paul Weller
57	H. R. Wilson (*left*); R. E. Franklin (*right*)
58-60	Sara Love
62	Bunji Tagawa
63-64	Paul Weller
65	Bunji Tagawa
66	General Electric Research Laboratory (*top*); Bunji Tagawa (*bottom*)
68	New York Public Library
69	Priestley-Forsyth Memorial Library
70	New York Public Library
74-78	Bunji Tagawa
80	*Journal of Heredity*
82-84	Sara Love
87	Robert Emmett Ginna
96-99	Roger Hayward

Some typical parts produced from *HAYNES alloys*

A TECHNICAL REPORT from Du Pont

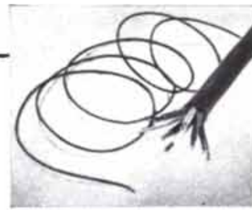
Properties and uses of Du Pont "Alathon" polyethylene resin

Design engineers and manufacturers in many fields use "Alathon" polyethylene resin. It is easy to mold and lightweight (sp. gr. 0.92). Thin sections are flexible yet strong. Thick sections of "Alathon" have a considerable degree of rigidity. "Alathon" retains its strength and flexibility at low temperatures.

This engineering material has superior electrical properties. The low power loss and dielectric constant of "Alathon" polyethylene resin are unchanged over a wide range of frequencies and temperatures. "Alathon" has remarkable resistance to most corrosives. It needs no plasticizer ... is tasteless, odorless and non-toxic.

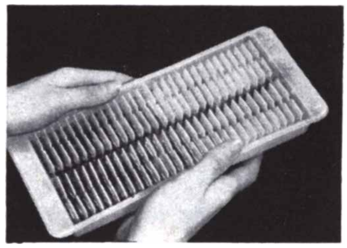
The applications pictured here are typical of the many forms in which molded "Alathon" is used today. Listed on the opposite page are the properties which have made these established applications so successful.

Be sure to evaluate "Alathon" in terms of your particular product-design problems. Mail the coupon for additional information on the properties, applications and processing of this unique engineering material — Du Pont "Alathon."

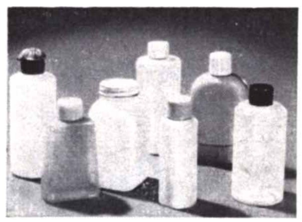


Wire and cable insulation of "Alathon" has low power loss. Its dielectric constant (2.3) remains unchanged over a wide range of frequencies.

Chemical pipe of "Alathon" is easily installed, long-lasting, and affords protection against freezing. "Alathon" does not contaminate fluid stream.



Ice tray of "Alathon" stays flexible at temperatures well below the brittleness points of other materials. It's comfortable to handle and odorless.



Squeeze bottles made of Du Pont "Alathon" are unbreakable and light in weight. They're pleasant to handle, convenient to use, add sales appeal to the product.

Flashlight case of "Alathon" is dent-proof, break-proof, corrosion-resistant. Dielectric strength of "Alathon" means production savings because of fewer parts.

Drum of "Alathon" resists practically all chemicals. It's lightweight yet strong, molded in many convenient shapes and sizes for easy handling.

ZYTEL†	ALATHON*	LUCITE*	TEFLON*
Nylon Resin	Polyethylene Resin	Acrylic Resin	Tetrafluoroethylene Resin
Tough	Excellent Dielectric Properties	Clear, Transparent	Heat-Resistant
Abrasion-Resistant	Tough and Flexible	Outdoor Durability	Chemically Inert
Strong in Thin Sections	Tasteless, Odorless, Non-Toxic	Excellent Range of Colors	Superior Dielectric Properties
Form Stability	Excellent Water Resistance	Ability to Pipe Light	Non-Sticky Characteristics

†"ZYTEL" is the new trade-mark for Du Pont nylon resin
*Registered trade-marks of E. I. du Pont de Nemours & Co. (Inc.)

DU PONT
REG. U. S. PAT. OFF.

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

TYPICAL PROPERTIES OF DU PONT "ALATHON"

MECHANICAL

Tensile strength, —70°F.	4,700	LB./SQ. IN.	D638-49T
73°F.	1,800	LB./SQ. IN.	D638-49T
170°F.	850	LB./SQ. IN.	D638-49T
Elongation, —70°F.	65	%	D638-49T
73°F.	> 100	%	D638-49T
170°F.	> 100	%	D638-49T
Modulus of elasticity, 77°F.	19,000	LB./SQ. IN.	D638-49T
Shear strength	2,700	LB./SQ. IN.	D732-46
Impact strength, Izod, —40°F.	0.8	FT. LB./IN.	D256-47T
Stiffness, 73°F.	27,000	LB./SQ. IN.	D747-48T
Compressive stress at 1% deformation	280	LB./SQ. IN.	D695-49T
Hardness, Rockwell	D48	(1)	D676-49T

THERMAL

Flow temperature	225	°F.	D569-48
Coefficient of linear thermal expansion per °F.	9×10^{-5}		D696-44
Thermal conductivity	2.3	B.T.U./hr. sq. ft./°F./in.	(2)
Spe			
Specific heat	0.55		
Deformation under load 122°F., 100 lb./sq. in.	0.6	%	D621-48T
Heat-distortion temperature, 66 lb./sq. in.	122	°F.	D648-45T

ELECTRICAL

Dielectric strength, short-time	460	V/MIL	D149-44
step-by-step	420	V/MIL	D149-44
Volume resistivity	> 10^{15}	OHM-CM	D257-49T
Dielectric constant, 60 cycles	2.3		D150-47T
10^3 cycles	2.3		D150-47T
10^6 cycles	2.3		D150-47T
10^8 cycles	2.3		D150-47T
Power factor, 60 cycles	< 0.0005		D150-47T
10^3 cycles	< 0.0005		D150-47T
10^6 cycles	< 0.0005		D150-47T
10^8 cycles	< 0.0005		D150-47T

OPTICAL

Index of refraction	1.51	n_D	D542-42

MISCELLANEOUS

Water absorption	0.014	%	D570-42
Flammability	1.1	IN./MIN	D568-43
Specific gravity	0.92	IN./MIN	D792-48T
Mold shrinkage	0.02-0.05	IN./IN.	
Compression ratio	2.1-3.6		
Resistance to weathering	excellent	(3)	
Basic color	white translucent		
Resistant to:	alkalies, oxygenated solvents, water, acids		
Not resistant to:	chlorinated solvents, aliphatic and aromatic hydrocarbons		

(1) Hardness of "Alathon" determined by Shore Durometer.
(2) Thermal conductivity measured by Cenco-Fitch apparatus.
(3) The outdoor durability of black-pigmented "Alathon" is excellent.
Note: This table shows the property data for Du Pont "Alathon" 10.

E. I. du Pont de Nemours & Co. (Inc.), Polychemicals Department,
Room 3610 Du Pont Building, Wilmington 98, Delaware

Please send me more information on Du Pont "Alathon" polyethylene resin: Uses ☐; Processing Techniques ☐; Properties ☐. I am also interested in receiving more information on: "Zytel" nylon resin ☐; "Teflon" tetrafluoroethylene resin ☐; "Lucite" acrylic resin ☐.

Name ________________
Title ________________
Firm Name ________________
Street Address ________________
City ________________
State ________________
Type of Business ________________

High-Purity Fused Alumina Grains... What Can They Do For You?

FUSED alumina, with its inherent properties of hardness, chemical stability and high density, is one of the most widely used electrochemically refined materials. It is produced in many forms. One of these, Norton 38 ALUNDUM* grain has proved successful for many applications demanding high purity. Electrically fused from Bayer-processed alumina, this white grain is shown by typical chemical analysis to be 99.49% pure Al_2O_3. It is insoluble in common solvents and extremely resistant to reduction. It is an amphoteric refractory and has high dielectric strength. Other characteristics include:

Melting point — about 3600°F.
Specific gravity — 3.94
Crystal structure — hexagonal system (rhombohedral division)
Hardness — 9.0 Mohs' scale
Index of refraction — 1.76 mean

Typical uses of 38 ALUNDUM grain are: pure oxides and sintered refractories, refractory cements, catalyst supports, heat exchange pebbles, wear-resistant parts, laboratory ware.

Other types of Norton fused alumina with unique combinations of properties which make them highly suitable for special requirements include:

38500 and 38900 AWIF ALUNDUM Grains

In these further refinements of 38 ALUNDUM grain, the terminal designations 500 and 900 indicate particle sizes. In the 38500 grain, average and maximum particle sizes are 19.5 microns and 50 microns, respectively; in the 38900 grain average and maximum particle sizes are 7.5 microns and 30 microns, respectively. Particle sizes are consistently very uniform. AWIF signifies "acid-washed and iron-free."

Although these grains have the same physical properties as 38 ALUNDUM grain, their special processing to remove objectionable elements results in unusually high purity. A typical chemical analysis reveals:

Al_2O_3 — 99.86% • Fe_2O_3 —.01 to .05%
SiO_2—.01 to .05% • Na_2O—.01 to .08%
C — <.01% • pH — >4.1

Very good electrical resistance, high heat conductivity and inertness are further advantages of 38500 and 38900 ALUNDUM grains for applications in both the electrical and chemical fields. In addition to their use in electronic tubes, as illustrated, other possible uses include the manufacture of ceramic pieces, particularly electronic components where the inherent qualities of this extremely pure grain are of great value.

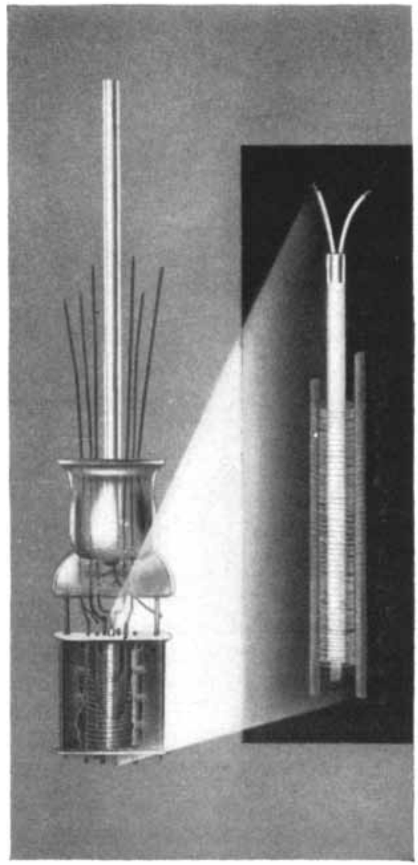
Other Norton Electrochemically Refined Materials

We made ALUNDUM grains the subject of this message. But we could just as well have chosen any of the long list of well known Norton electric furnace materials — CRYSTOLON* silicon carbide, MAGNORITE* magnesium oxide, NORBIDE* boron carbide, FUSED STABILIZED ZIRCONIA, and many others, including a number still undergoing research and development.

These high-melting materials which have varied applications in many fields, are also the basic ingredients of the famous Norton Refractory ℞'s — refractories *engineered and prescribed* for the widest range of uses.

For Your Own Applications or Developments

Norton Company not only supplies these materials in their crude form, but has extensive facilities for processing and fabricating — and is ready to work with you in engineering materials to your particular requirements. A new booklet "Norton Refractory Grain — Electrochemically Refined" contains detailed information on these interesting materials. NORTON COMPANY, 549 New Bond Street, Worcester 6, Mass.



IN ELECTRONIC TUBES Norton 38500 or 38900 ALUNDUM fused alumina grain is used to coat heater filament tubes (shown enlarged). The grain is put in suspension and the filament is drag coated, spray coated or electrically deposited (cataphoresis).

NORTON
REFRACTORIES
Engineered... ℞... Prescribed

Making better products... to make other products better

*Trade-Marks Reg. U. S. Pat. Off. and Foreign Countries

SCIENTIFIC AMERICAN

Established 1845

CONTENTS FOR OCTOBER, 1954 VOL. 191, NO. 4

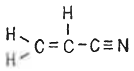
ARTICLES

DEPARTMENTS

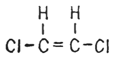
Monomers from Monsanto

New Resins, New Adhesives, New Coatings

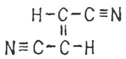
ACRYLONITRILE



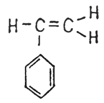
1, 2-DICHLOROETHYLENE



FUMARONITRILE



STYRENE



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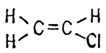

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SCIENTIFIC AMERICAN

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Economic Psychology

Recent investigations of the human element in Economic Man may help to explain why the behavior of businessmen and consumers departs so often and so radically from the textbook predictions

by George Katona

In 1923, the year of the great inflation in Germany, when the price of a loaf of bread rose to 214,000 million marks and one could make a living by buying cigarettes in a retail store in the morning and selling them in the evening, I was a young psychologist engaged in experiments on visual perception at a university. Like many of my colleagues, I had to leave my work and get a job in a bank, where we were paid daily at noon so that we could spend the money right away. I also began to read economics to try to find out what was going on.

I read that inflation is the result of an increase in the money supply—of more purchasing power competing for the available goods. Observing that hardly anybody had ready cash, and finding out from statistical tables that the German note circulation was exceedingly small when expressed in real purchasing power, I wondered. Then I discovered in the literature a second vicious character, called "velocity of circulation," which joined forces with the major culprit, the "quantity of money." But naming the phenomenon did not seem to explain it. I pondered whether the explanation should not have been looked for in the psychological factors that induced the German people to get rid of their money as fast as they received it, rather than in the high rate of turnover itself.

During the mild inflation in the U. S. that followed the outbreak of the Korean War in 1950, I was again impressed by the disagreement between actual events and what I had read in economic textbooks. Prices rose rapidly before there was any appreciable increase in Government spending or money supply. But when, in the spring of 1951, rearmament expenditures really got under way, prices stopped rising. U. S. families ceased their rush buying and began to hold on to their money.

The price of a loaf of bread

It seemed that here again, as in Germany in 1923, the answer must lie in psychology; the people's economic behavior appeared to be governed more by their expectation of what was going to happen than by the situation of the moment. And so in 1950-1951 at the Survey Research Center of the University of Michigan we undertook to examine the developments with a new approach, that of economic psychology. There were available then, as there had not been in 1923, conceptual tools and measuring sticks, such as sample interviewing, for investigating changes in mass behavior.

Let us consider first the theoretical background of economic psychology. In traditional economics the term "economic behavior" has been used in three different ways. In one sense it has purported to explain the behavior of businessmen and consumers in terms of a norm: how rational men should seek a maximization of profits or of utility, on the assumption that they have full knowledge of and control over all means of achieving the postulated economic end. In a second sense economic behavior has been used to mean the behavior of prices, of incomes and of the economy of a nation. Economists with this outlook have been concerned with

The saturation concept yields dire predictions for the future

the relationships that exist between changes in supply, prices, incomes, consumption, saving and investment.

These two approaches have been of great value. But they disregard the fact that it is human beings who supply the goods, make prices, strive for incomes, spend, save and invest money. They leave out of the equation human needs and desires, hopes and fears, opinions, prejudices and misinformation.

Traditional economics has, to be sure, done some exploration of economic behavior in the third sense of the term—the behavior of businessmen and consumers as people. It has made case studies of business behavior, statistical studies of business cycles and theoretical studies of mass behavior. But the information obtained was of a general nature. It was known, for instance, how national income changed from one year to the next, but it was not known how many families had an increase and how many a decrease in income, what kinds of families these were or how they reacted to their income development. Nor were there any data on changes in attitudes and expectations, the frequency of such changes or their causes and effects.

In recent years the development of the sample interview survey has made it possible to investigate these matters. Economic psychology maintains that businessmen and consumers are not marionettes pushed around by the law of supply and demand; they have some discretion and latitude, within limits. We shall illustrate both the latitude of the actors on the economic scene and its limits with reference to consumer behavior. We select the consumer because the influence of his psychology on employment and business conditions has not been generally recognized.

In our studies of consumer behavior we distinguish five sets of variables. First there are the *enabling conditions* that set the limits to the consumer's discretion: his income, assets and access to credit. Second, his economic behavior is influenced by *precipitating circumstances:* an increase or decrease in purchasing power, a change in family status, the birth of a child, a move to a new house or locality, the wearing out or breakdown of possessions, and so on. Third, there is the important factor of *habit:* the set patterns of behavior that operate, for instance, in such matters as the purchase of groceries. Fourth, we have to take into account *contractual obligations:* for example, rent, repayment of debt, life insurance premiums, taxes, dues and the like. Previous actions, such as the purchase of an automobile on installments, make both for contractual obligations (repayment of debt) and for consequent actions (purchase of gasoline). Finally, we must deal with the consumer's *psychological state.* Whether a rise in income, a transfer to a new locality, the breakdown of an old refrigerator or any other event will result in important changes in spending depends on the prevailing motives and attitude. If the attitude is conducive to spending, one kind of decision will be made; if it is not, another decision.

How does all this affect the economy as a whole? Can the actions of individuals, influenced by these variables, produce a general economic trend? Sometimes it has been assumed that the attitudes of different people, their optimism and pessimism, for instance, should cancel out. Our studies, however, show that trends do appear. As a result of group identification and mass communication, similar changes in attitudes often occur among very many people at about the same time. This proposition serves as the starting point for quantitative studies of the origin of changes in attitudes and their influence on economic fluctuations.

The power of consumers to influence economic fluctuations will not be the same in different economies. In a subsistence economy, in which the entire income of most consumers is devoted to the acquisition of minimum necessities, the consumer and his attitudes may perhaps be disregarded. But today in the U. S. we find substantial discretionary income in the possession of broad groups of people, and also widespread ownership of liquid assets and easy access to credit. Moreover, the things that people consider necessities now include numerous durable goods (automobiles, television sets) the purchase of which can be postponed or advanced. Therefore economic psychology is particularly important in this country at this time.

The sample interview survey offers a bridge between individual attitudes and aggregate behavior, as measured by national statistics on income, spending, saving and so on. Individuals are interviewed, and for each individual respondent who falls in the sample three kinds of measures are obtained: (1) demographic data, such as occupation, education, age, marital status and the like; (2) economic data, such as income, expenditures, assets and debts; (3) psychological data, such as motives, expectations and intentions. From representative samples it is possible to determine the frequency of each type of measure at successive time points; for instance, we may find that one year 25 per cent and the next year 30 per cent of U. S. families had annual incomes over $5,000; or that one year 20 per cent expected their incomes to go up and the next year 30 per cent. We can also measure functional relations between different variables. We may find, for instance, that of those who say they feel better off, 50 per cent buy durable goods in a given year, while of those who say they feel worse off, only 25 per cent buy such goods. By repeating such measurements under different circumstances the sample interview survey may serve to test hypotheses.

What insights were obtained from such surveys in 1950-1951? They disclosed dramatic shifts in attitudes which were connected with the shifting fortunes of the Korean War. When military reversals came in the summer of 1950 and again a few months later after the intervention of the Chinese Communists, many people feared that World War III was imminent. Fear of war evoked not-too-distant memories of shortages of goods and of rapid and substantial price increases. The buying sprees of consumers in 1950 occurred in two waves, coinciding with the two periods of adverse military news.

Early in 1951 the situation changed completely. When the military front in Korea was stabilized, the expectation of World War III gave way to the notion that we were living in a period of cold war. Acute fear gave way to uneasy anxiety. The expectation of shortages disappeared; people learned that the U. S. economy could supply both butter and guns (for a cold war). By the summer of 1951 many experts spoke of a

A colloquy on Economic Man; left to right, Smith, Malthus, Ricardo, Bentham, Mill, Fourier, Saint-Simon, Comte, Marx, Proudhon buying lull and attributed it to saturation due to previous extensive purchases. But it appeared to us who studied people's opinions and feelings that this was not an adequate description of the developments. "Lull," says Webster, means "temporary cessation," but there was nothing temporary in people's attitudes. We found that in many cases money was not lacking, and on the whole needs and desires for new and better things were expressed as frequently as before. But "this is not a good time to buy" was a frequent comment. The business outlook did not appear favorable; people complained of high taxes and high prices. Many decided to postpone the purchase of automobiles, television sets and furniture. The prevailing attitudes resulted in a low rate of spending and a correspondingly high rate of saving during 1951 and most of 1952. It is not money in the possession of consumers that moves goods off the shelves; it is people who decide to spend their money. In order to predict the trend of consumers' spending, it is necessary to obtain data both on the resources of consumers and on the motives that tend to encourage or discourage the spending of money.

What generalizations can we draw from the recent research in economic psychology?

The economic theory of Lord Keynes, which has dominated the thinking of economists in recent decades, put great stress on the effects of changes in income on spending and saving. We have found that in a period of good business, those who suffer declines in income reduce their rate of saving so as to maintain their accustomed standard of living, as the Keynes theory predicts, provided they expect the decline to be temporary and have liquid assets. On the other hand, with an increase in income, spending often rises faster than the income if the economic trend is upward. That is to say, an increase in income often leads people to reduce saving, contrary to the Keynes theory. If an economist were asked which of three groups borrows most—people with rising income, stable income or declining income—he would probably answer: those with declining income. Actually in the years 1947-1950 the answer was: people with rising income. People with declining income were next and those with stable income borrowed least. People's readiness to step up their level of living in response to their feeling that their situation has improved contributes to the dynamic nature of American society. Similar investigations carried out in Great Britain at the same time yielded different results, more in accord with traditional assumptions about saving and spending.

Another traditional assumption is that if people expect prices to go up, and have money, they will hasten to buy; if they expect prices to go down, they will postpone buying. But our surveys showed that this is not always true. Often the expectation of price increases does not stimulate buying. One typical attitude was expressed by the wife of a mechanic in an interview at a time of rising prices. "In a few months," she said, "we'll have to pay still more for meat and milk; we'll have less to spend on other things." Her family had been planning to buy a new car, but they postponed this purchase. Furthermore, the rise in prices that has already taken place may be resented and evoke buyers' resistance. For example, there is this typical comment of a teacher in 1951: "I just don't pay these prices, they are too high. Prices will go up still more. Nobody will be able to buy anything." To be sure, as we have seen, expectations of war, shortages and very large price increases may result in different behavior.

The effect of price reductions varies. If people believe them to be the beginning of a downward trend, buying may freeze up. If they feel that they are being offered a bargain which will last only a short time, they hurry to buy.

The condition most conducive to spending appears to be price stability. If prices have been stable and people have become accustomed to consider them "right" and expect them to remain stable, they are likely to buy. Thus it appears that the common business policy of maintaining stable prices with occasional sales or discounts is based on a correct understanding of consumer psychology.

Finally, consumers' spending is influenced by the general economic outlook as well as by their personal circumstances and the immediate price picture. Even though a family head does not expect a cut in his own income, if he fears a general recession he may say no to the family demand that he trade in the old television set for a new one with a 21-inch screen. It appears that many people feel vaguely that their own income is an

Hoarding is not always predictable

insensitive indicator; that sooner or later economic trends prevailing in the country will affect them personally. Group influences, experiences shared with neighbors and friends, also shape people's attitudes. Most U. S. families have an abundance of unsatisfied needs. (The rich are no exception.) Under what conditions are needs most likely to be transformed into effective demand? When people are confident about the future of the economy. They are most likely to postpone such satisfactions when they feel uneasy about the future course of the economy.

The notion of "saturation" of the market is based on old-fashioned psychological assumptions which in turn rest on the analogy of biological drives: for example, if an animal is hungry, it is motivated to search for food; after it has eaten, the motive disappears or becomes weak. The saturation concept has resulted in dire predictions about the future of the U. S. economy. Some people point to the large proportion of U. S. families that already possesses major goods, such as refrigerators (over 80 per cent) or automobiles (about 70 per cent), and they argue that in the future sales will be limited largely to replacement needs.

But social motives are different from biological ones. Levels of aspiration—in sports, for school grades, for position, for income and for goods—most commonly rise with achievement. A beginner in golf, for instance, may strive hard to achieve a score of 100; when he has achieved his goal, he invariably raises his sights. We give up aspirations when we have failed, not when we have succeeded.

In the economic field, a family that has saved enough to buy a home usually sets out on a new objective, such as college education for the children; fulfillment of one aim leads to striving for another. Indeed, in a recent survey it was found that this applied to goods already owned; families with a refrigerator in good operating condition often were preparing to buy a larger one, or one with shelves on the door and a better freezing compartment.

We translate our needs into demand when we are optimistic, confident and secure. We are "saturated," on the other hand, when we are pessimistic, insecure and especially when our past endeavors have been unsuccessful.

America is prosperous. Prosperity means that many more people than ever before own houses, automobiles, refrigerators, TV sets and the like. Is prosperity its own gravedigger; must a few years of high rates of purchasing inevitably be followed by saturation and slump? The answer is no: it is not automatic or inevitable that prosperity be followed by depression or that cyclical movements occur. This, of course, does not mean that we already know how to avoid depressions. But an understanding of what motivates people, and of how motives change, should contribute to this goal.

Increase in spending may exceed increase in income

The few generalizations derived from recent surveys of consumer attitudes and expenditures represent a promising beginning. As yet we know far too little about the origin of mass attitudes, their spread among people and the effects of different attitudes on action. But what we do know is that economic psychology may usefully supplement the theoretical and statistical approach of traditional economics. It contributes to the understanding and prediction of economic fluctuations, and thereby promises to provide policy makers with better tools which they may use to combat the recurrence of periodic depressions and inflations. It should also contribute toward the attainment of the ultimate goal of the behavioral sciences—the development of a theory of social action.

URANIUM FROM COAL

The Bad Lands of the Dakotas have never been good for much except as a hideout for outlaws and warring Indians. Now the high buttes are found to bear surprising amounts of uranium

by Ralph L. Miller and James R. Gill

North of the Black Hills in the Dakotas is a desolate region furrowed here and there with "badlands"—mazes of gullies and small canyons. Except in particularly wet years the countryside is largely barren of vegetation. Most of the landscape is nearly flat, but its general monotony is broken in places by buttes standing 300 to 600 feet above the plain. They range in size from small knobs to mesas several miles long and a mile wide. The more prominent ones bear colorful names such as Slim Buttes, Table Mountain, Medicine Pole Hills, Cave Hills, Bullion Butte and Sentinel Butte. These buttes have recently become invested with a new interest, for it has been discovered that they bear a great deal of uranium, not richly concentrated but in amounts that make the area a significant reserve for future development.

The uranium lies in beds of lignite, a carbonaceous material sometimes called "brown coal." The curious relationship between uranium and coal has been known since 1875, when E. L. Berthoud noted that carbonaceous material had a high affinity for uranium. Recent laboratory experiments have shown that peat, lignite and subbituminous coal can extract more than 98 per cent of the uranium in a liquid solution of uranium sulfate. Other organic materials such as wood and tricalcium phosphate also can extract substantial percentages of uranium from solution. In the field, geologists have observed that nearly all the uranium deposits in the Colorado Plateau, the chief source of that vital mineral in the U. S., contain a great deal of organic material in the form of fossil wood and other plant debris.

LIGNITE BED which contains uranium ore is the dark stratum in the photograph. Its base is in line with the man's arm. "Hot" lignite beds are always just below the butte's cap rock.

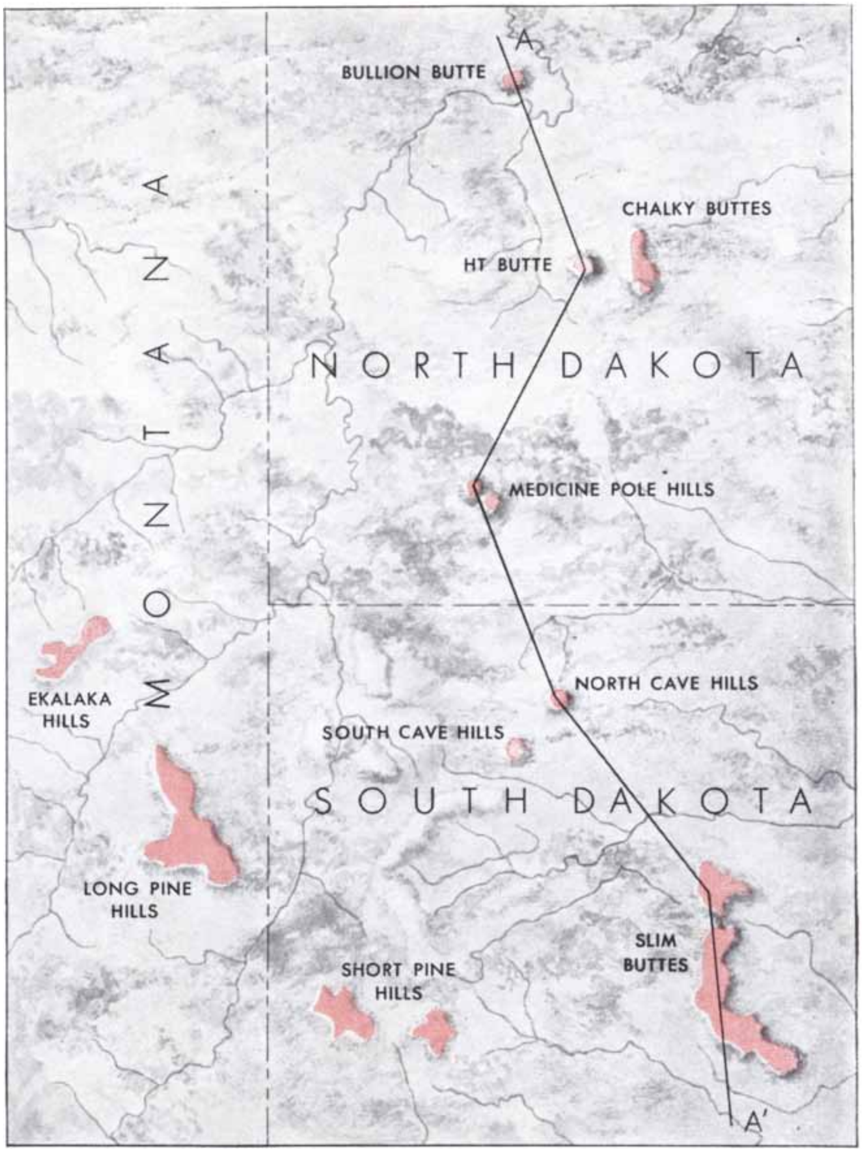
When the intensive reconnaissance for uranium began in the U. S. toward the end of World War II, it seemed logical to check coal, lignite and other carbon-rich beds with Geiger counters. In 1948 D. G. Wyant and E. P. Beroni of the U. S. Geological Survey, working on behalf of the Atomic Energy Commission, discovered promising levels of radioactivity in various beds of lignite in northwestern South Dakota, southwestern North Dakota and eastern Montana. They recommended exploration of this material, and analyses of many samples showed that the lignite did indeed contain uranium. These detailed studies are still in progress and provide the basis for this account. The principal contributors have been H. L. Bauer, Jr., N. M. Denson, G. O. Bachman, H. D. Zeller, J. R. Gill, G. W. Moore and J. M. Schopf, all of the Geological Survey. The investigations are being conducted for the Atomic Energy Commission.

The region in which the uranium-bearing lignites were found has had a long and complex geologic history. Upon a basement consisting of very old igneous and metamorphic rocks inland seas and rivers deposited many different sedimentary formations during the long Paleozoic and Mesozoic eras. About 60 million years ago, when the continent had been uplifted sufficiently to put an end to the seas' flooding of large areas in the interior, the northern Great Plains became a region of vast swamps in which plant life flourished, died and accumulated to form peat beds. These swamps were buried from time to time by sands and clays washed in by rivers from the Rocky Mountains region. As the peat beds were buried deeper and deeper, they were slowly transformed into lignite, but the transformation in this region did not go far enough to produce bituminous or anthracite coal.

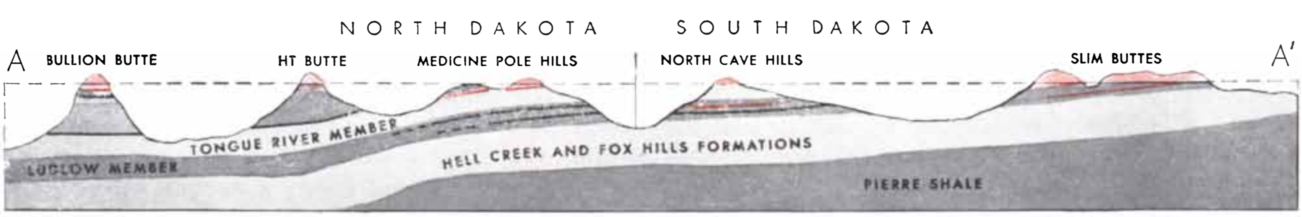
Eventually these strata, which geologists call the Fort Union formation, were rather abruptly tilted northward by a general uplift and warping of the earth's crust. The surface was then beveled nearly flat again by stream erosion. Now came a new series of deposits, this time consisting of sand with considerable amounts of very fine volcanic ash, probably from volcanoes to the west. These younger deposits were laid across the tilted and eroded edges of the older sediments. Later stream erosion stripped away almost all of the sand-ash mantle. The only remnants of it now left are the buttes, which, with their sheer sides and caps of hard rock, stand like the pebble-capped little mounds of earth you see on bare ground after a hard rain.

This, then, is a capsule history of the way in which the buttes were formed; the history is written in their strata, which include beds of lignite as much as 20 feet thick [*see diagram below*]. Exploring these lignites as potential ores of uranium was quite a new experience and a new kind of economic geology, even for experienced coal geologists. Uranium-bearing coal looks no different from ordinary coal except in rare instances when associated minerals discolor interfaces in the layers. To find out whether a lignite bed contains uranium, and how much, one must scan it with a radiation-measuring instrument, such as the Geiger or the scintillation counter, and then analyze any radioactive samples by extremely sensitive chemical assays. Many radiation measurements and chemical analyses for uranium have been made of samples from Dakota lignites to determine the amount of uranium in various beds and parts of the same bed.

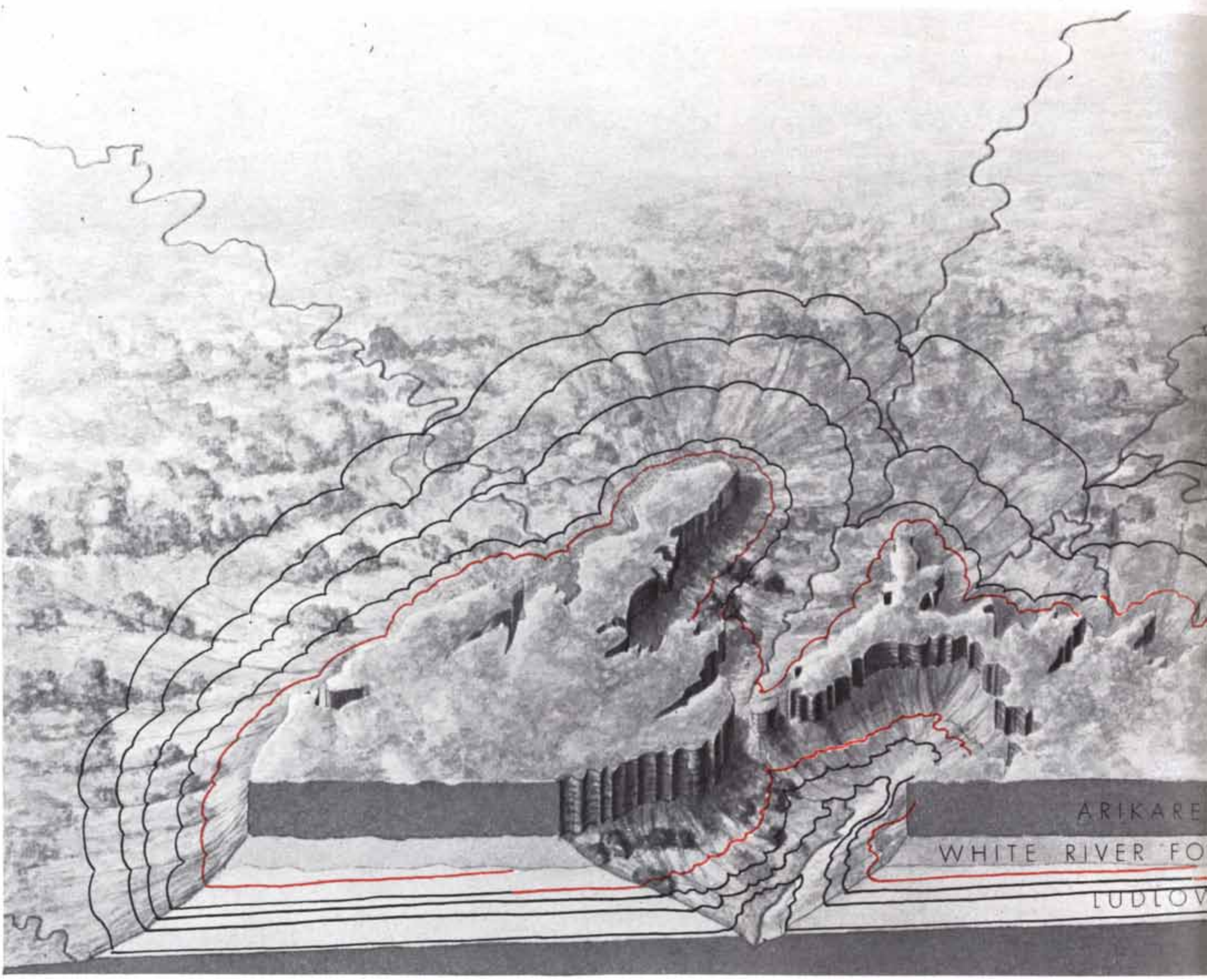
How did the uranium get into the lignite in the first place? One theory is that it was present in solution in the water of the original swamps, having been carried there by streams from distant areas. If there were significant quan-



ORE-BEARING BUTTES, capped by radioactive volcanic rock, are designated by red on this map of the Bad Lands. The line A-A′ marks the profile shown in cross section below.



CROSS SECTION through the Dakotas shows the relation between cap rock and lignite beds. The "hot" beds appear as red lines beneath the cap rock. Black lines mark nonradioactive beds. Fort Union formation includes Tongue River and Ludlow members.

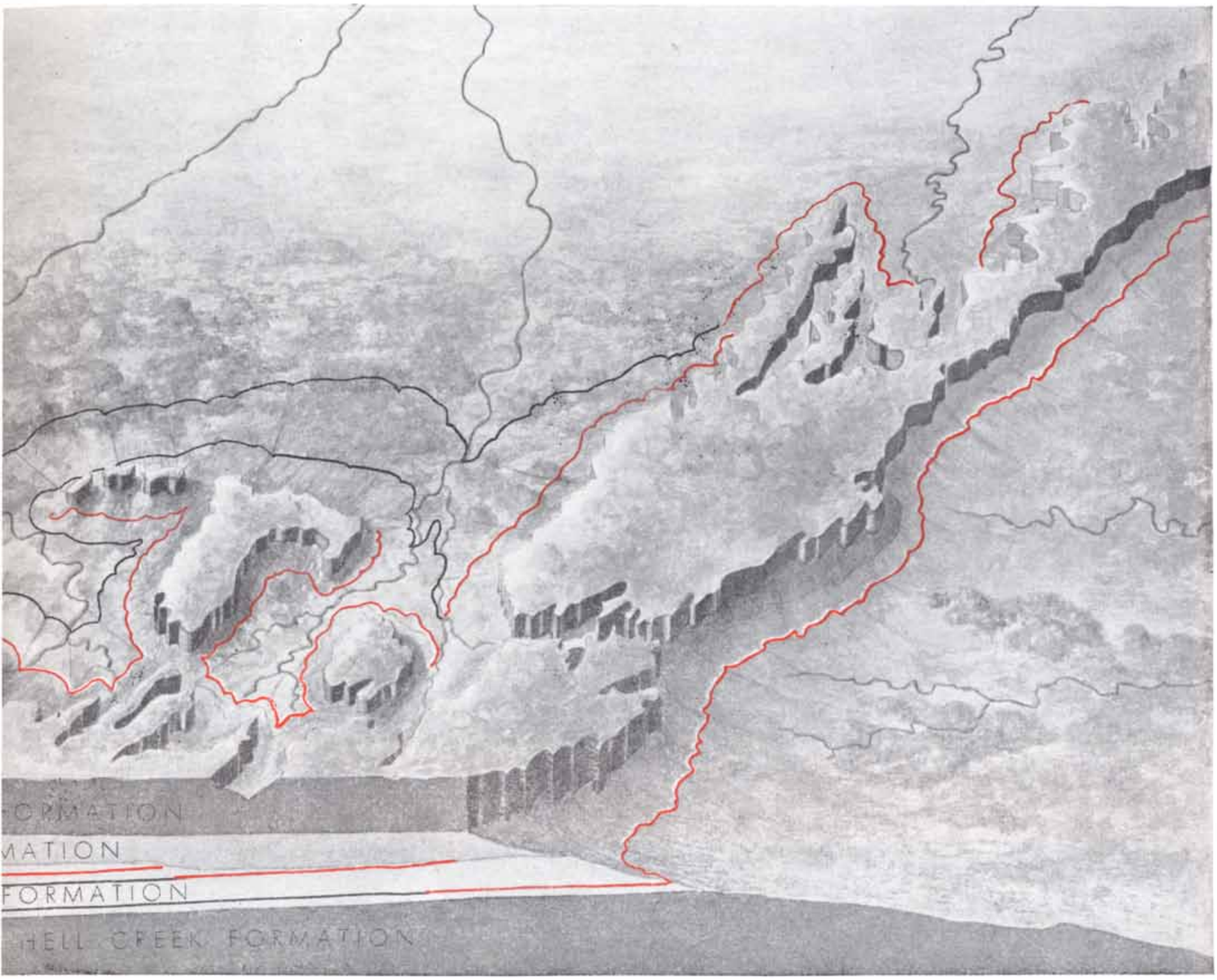


SLIM BUTTES, South Dakota, is shown by this block diagram. The cliff-forming cap rock of the buttes is composed of the volcanic sandstones of the Arikaree and White River formations. The older coal-bearing Ludlow and Hell Creek formations lie beneath. The

tities of uranium in the swamp water, it is logical to believe that the uranium would be abstracted from solution by the woody material, just as happens in the laboratory when wood is immersed in a uranium solution. This theory, however, seems to leave several questions unanswered. Denson, Bachman and Zeller of the Geological Survey have suggested what seems to be a much more likely explanation. They noticed that of the different lignite beds in a butte only the highest one contained a significant percentage of uranium [*see diagram on pages 38-39*], and, furthermore, uranium tended to be more abundant at the top of the bed than farther down. This indicated strongly that the uranium had trickled down from above. Tests with counters showed that the volcanic rocks overlying the lignite were indeed radioactive. (The sand and volcanic ash deposits are called the White River and Arikaree formations.) Apparently ground water dissolved uranium in these beds and washed it down into the highest lignite bed. Every time rain fell, some of it percolated through pores and cracks in the uranium-bearing volcanic ash and carried uranium down in solution to the lignite. Because of the affinity of uranium for carbonaceous material, the lignite extracted the uranium from the solution. One confirmation of this theory is the fact that water in springs around the margins of the buttes is radioactive, showing clearly that uranium is still being dissolved from the volcanic rocks.

It now becomes apparent why uranium-bearing lignites have been found only near and beneath the buttes of the region. In the intervening broad lowlands, erosion has removed all the volcanic cap rock and also the highest lignite beds, which would have captured most of the uranium. Only in the vicinity of the buttes are these highest lignite beds still preserved.

This hypothesis of the origin of the uranium-bearing lignites in the Dakota region has prompted geologists of the Geological Survey to explore for uranium-bearing coals and carbonaceous shales in other regions where beds of this type are known to be in proximity to beds containing volcanic ash. A number of other deposits have been found in



red lines represent lignite beds containing unusual and significant amounts of uranium. Black lines designate lignite beds essentially barren of uranium. These beds appear as outcroppings about the middle and lower slopes. The distance across the base is 26 miles.

areas where this favorable set of geologic conditions exists. The theory gives geologists a guide for exploration which is an improvement over mere random sampling of carbonaceous deposits.

The process described is certainly not the only mechanism by which uranium deposits have been formed, even in carbonaceous beds. Each new deposit found has to be interpreted in the light of the geologic history of the region in which it lies, and each one presents its own peculiarities and its own problems of origin.

In comparison with other sources of uranium that are being mined or developed today, the Dakota lignites are very low-grade. No efficient or inexpensive means of extracting the uranium from them has yet been found. Nevertheless, the tonnages of uranium in the lignites are large, and thus form a reserve of considerable strategic value, particularly if the U. S. were to be cut off from foreign sources of supply in a time of national emergency. For these reasons it has seemed important to the Atomic Energy Commission and to the Geological Survey to learn as much as possible about the potential of uranium from coal. Thousands of outcrops of coal beds have been examined by Survey geologists, and many of them have been sampled. In addition, diamond-drill holes have been put down at strategic locations by the Geological Survey and the Bureau of Mines to probe the ore possibilities in beds below the surface.

The photograph on page 36 shows a "hot" lignite bed in one of the buttes. The base of the lignite is in line with the man's arm, and the top of the bed is about three feet below the edge of the meadow.

Mining of these deposits for uranium is not likely in the near future, in view of their low grade. It seems, however, that increasing demands for uranium, coupled with development of new inexpensive metallurgical techniques for recovering the uranium, will eventually result in their exploitation. That day may be accelerated if industries decide to utilize the lignites in large quantities for fuel and recover the uranium from the otherwise worthless ash as a by-product.

The Linear Accelerator

The early idea of accelerating particles in straight lines instead of circles has made a strong comeback. Linear machines generate electron or proton beams of respectable velocity and sharp focus

by Wolfgang Panofsky

A quarter of a century ago physicists started a "race" toward more and more energetic machines for the acceleration of atomic particles. The evolution of particle accelerators has now reached a stage where specialization of the machines for the specific purposes for which they are to be used has become as important as brute energy. The linear accelerator, which is the subject of this article, falls in the category of a specialized tool.

The idea of linear acceleration actually is older than the cyclotron or the present more potent successors of the cyclotron. Indeed, the linear accelerator was once believed to be the most promising candidate to win the energy race [see "The Bevatron," by Lloyd Smith; SCIENTIFIC AMERICAN, February, 1951]. It is still the "favorite" to attain the highest energy in the acceleration of electrons, but at the present time it is not a leading contender for the maximum acceleration of protons; in that field circular machines have taken the lead as a result of improvements in their design and certain practical difficulties of the linear accelerator. The main attractions of the linear machine now, however, are not its peak energy possibilities but other qualities which we shall examine.

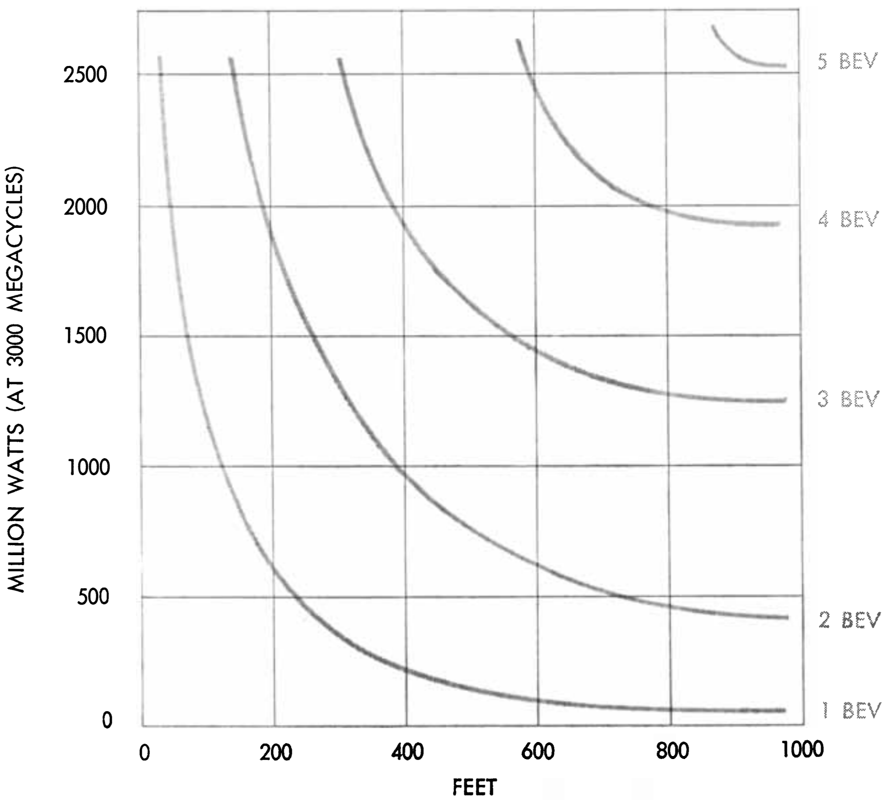
The linear accelerator, as its name implies, accelerates particles in a straight line; this distinguishes it from all other present accelerators, which drive the particles around a circular track. Like the other machines, the linear one speeds up the particles by means of a series of boosting kicks, or, in another version, by means of a continuously accelerating electrical wave.

The first of these two forms is known as the "drift-tube" accelerator. The particles travel through a long series of pipes, and at each gap between one pipe and the next they are given a boost by a voltage applied in the right direction at precisely the right time. The energy and timing of the alternating voltage are provided by radio waves from powerful transmitters.

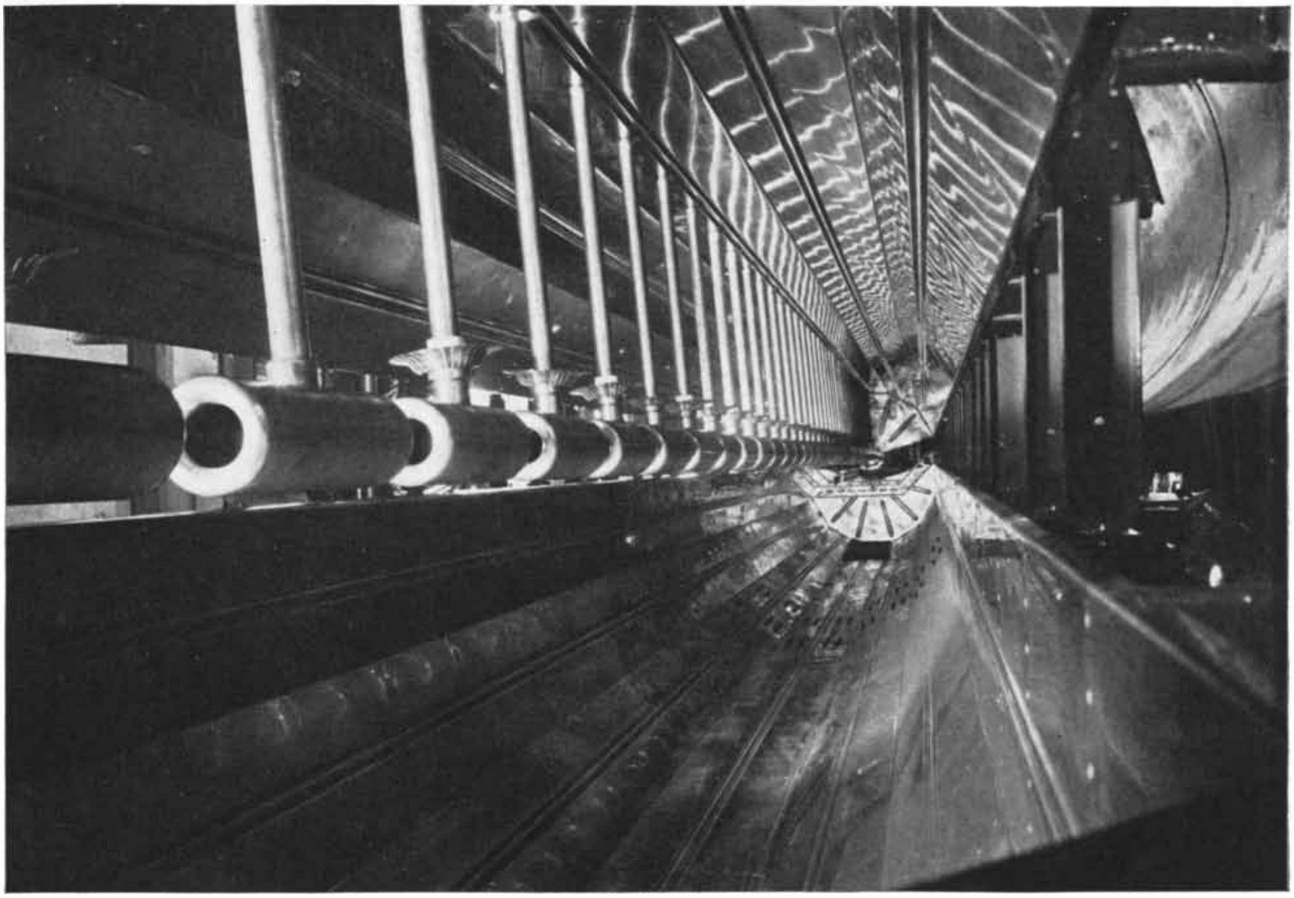
The second form of the linear machine is called a "traveling-wave" accelerator. Here the long pipe is continuous. An electric field generates an electromagnetic wave in it, and the wave, controlled in speed to stay with the particle, carries it along to steadily higher velocities. The effect is analogous to a water wave carrying a surfboard rider.

The idea of a linear accelerator was suggested as early as 1924 by Gustaf Ising in Sweden. Ernest O. Lawrence and David H. Sloan at the University of California were the first to build one. They used radio-frequency power. Because of the limitations of radio generators of that time they could not accelerate particles to very high velocities.

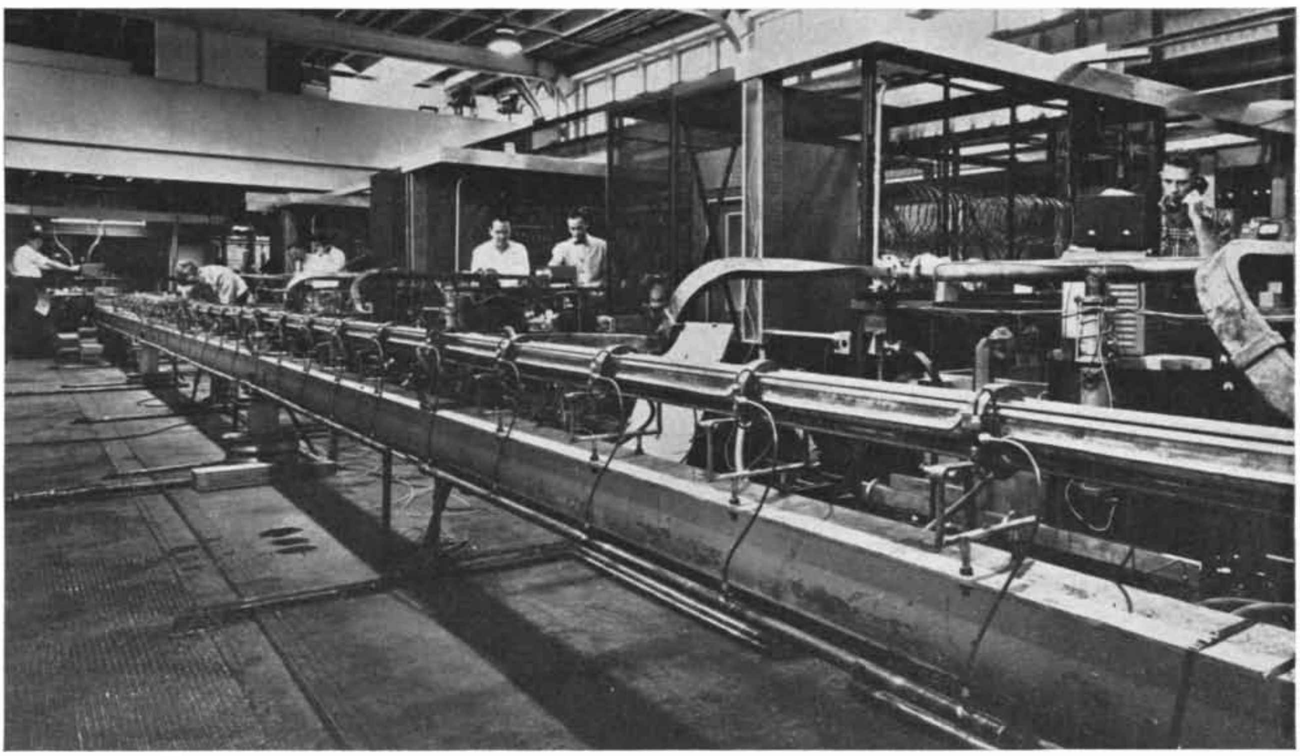
The late W. W. Hansen of Stanford University became interested in such a machine and realized that success would depend on obtaining large amounts of



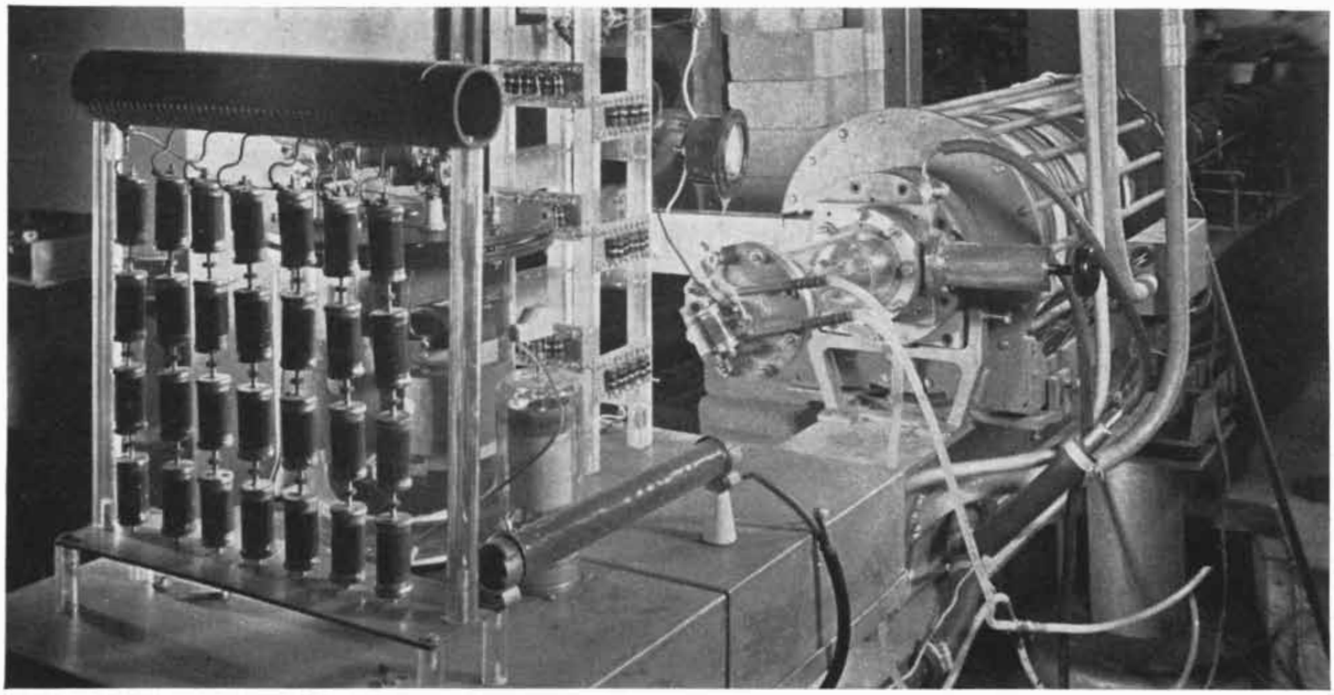
ENERGIES attainable from the linear electron accelerator operating at 3,000 megacycles are plotted in billions of electron volts. Length can be traded for power on equal terms.



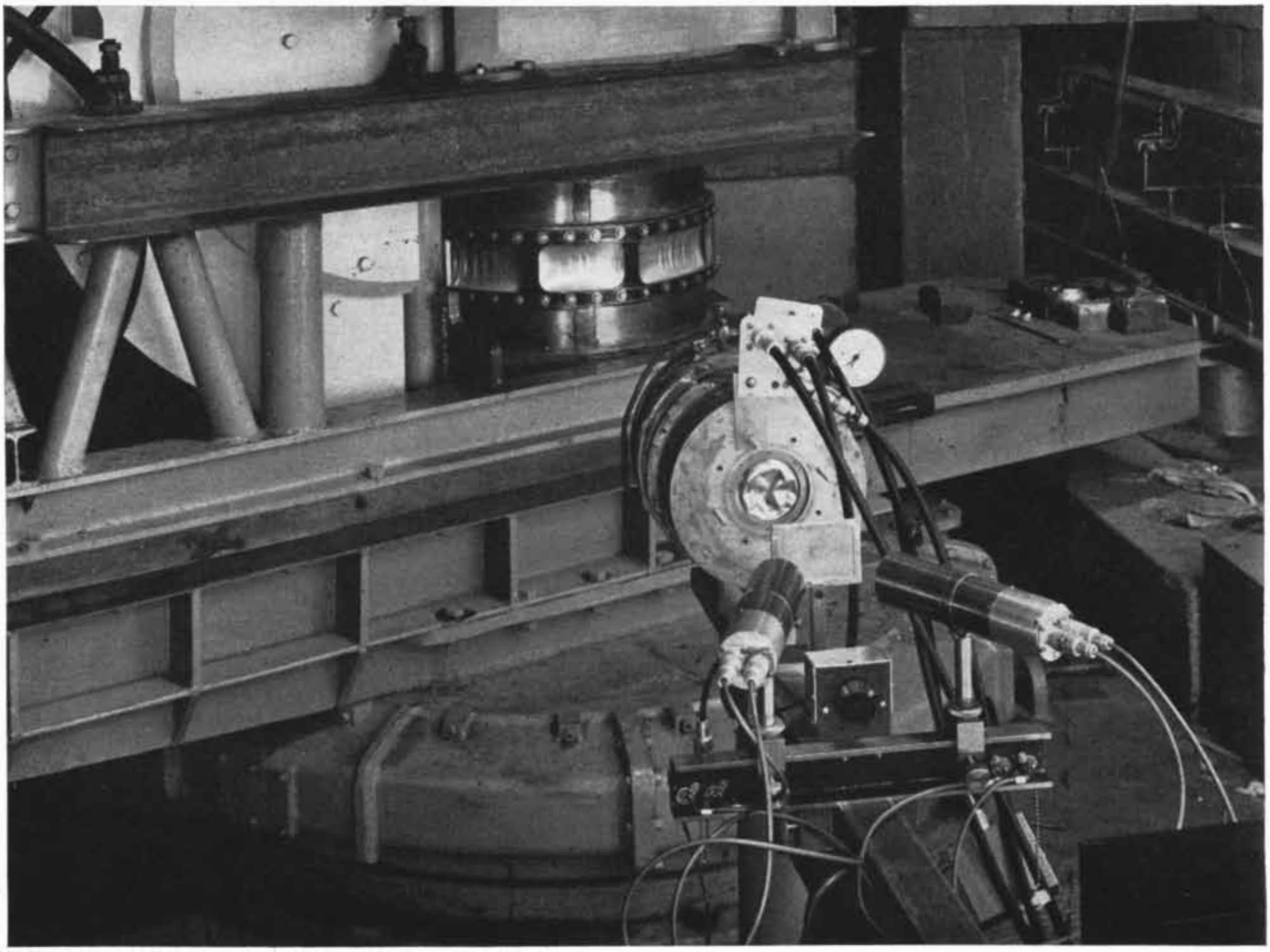
BERKELEY ACCELERATOR of the internal drift-tube type is shown with the resonator cavity open. Supports locate the drift tubes precisely in the proton path. Protons spend one whole cycle traveling through each tube. They develop energy up to 32 Mev.



STANFORD ACCELERATOR of the traveling-wave type attains energies of 600 Mev. Each feed point every 10 feet delivers 20 million watts of power from a klystron generator. The present total length is 220 feet. The usual shielding is absent in this picture.



SOURCE of electrons for the Stanford 600-Mev linear accelerator is a hot filament housed at the beginning of the traveling-wave tube (*right*). As the electrons are evaporated off the filament, they are given an initial velocity of 80 kilovolts by a pulser (*left*).



TARGET installation at Stanford has the beam enter a scattering chamber (*bottom*) where it is scattered at various angles. Electrons are drawn by the semicircular magnet to a shielded counter (*above*). The latter can be turned on its rotating gun mount.

radio-frequency power and on generating high voltages at the minimum expense of power. The latter is necessary because a linear accelerator must apply power at many different gaps instead of at only one, as in the cyclotron. Hansen therefore looked for a more efficient means of generating high radio-frequency voltages, and he hit upon the cavity resonator, which was translated into the klystron tube [see "The Klystron," by Edward L. Ginzton; Scientific American, March].

Hansen had set out to find the means of realizing a practical linear machine for accelerating electrons; his work actually led to the development of powerful radio-frequency generators and to microwave radar and radio. After the war these developments in turn led, by feedback, to the realization of linear accelerators not only for electrons but also for protons and heavier particles. Luis W. Alvarez of the University of California and others reopened the possibilities of this type of machine.

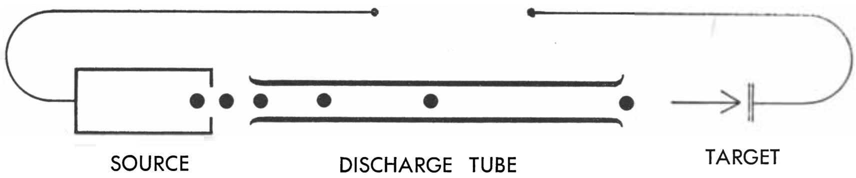
Some experiments in physical research are done best by a circular accelerator, others by a linear machine. In gauging the suitability of a machine for a given task, the nuclear physicist must consider a number of factors: the kind of particle to be accelerated, the maximum velocity to which the machine can accelerate them, how large a current (*i.e.*, the number of accelerated particles per second) it can deliver, how well it can focus the beam on the target, how sharp an energy spectrum it can provide, and so on. And of course there is the factor of cost, not only the initial cost of building the machine but also the costs of operating and maintaining it.

Let us see how the linear accelerator compares with the circular types in these respects. If electrons are the particles to be accelerated, the linear accelerator can reach higher energies and deliver larger currents than any other machine. It can also train a beam on the target more easily. On the debit side of the ledger are the facts that its energy spectrum is generally less sharp and that its power requirements restrict its operating time to shorter pulses and create engineering problems which have not yet been solved as satisfactorily as those of the circular machines. As a consequence a linear accelerator at present is less reliable and costs more to maintain. When it comes to accelerating protons, the linear accelerator in principle can reach any desired level of energy; however, the once-held idea that linear machines in the high-energy range would be less costly to build has proved wrong, partly because innovations such as the strong-focusing principle have reduced the cost of the circular types [see "A 100-Billion Volt Accelerator," by Ernest D. Courant; Scientific American, May, 1953].

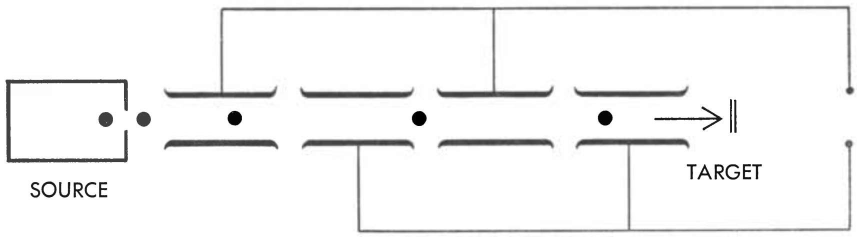
Nonetheless for certain uses the linear accelerator offers such marked advantages—particularly the ease with which it delivers a well-collimated beam of accurately regulated energy on the target—that it is sometimes the best choice. For example, the British Atomic Energy Research Establishment, after considering whether to build a three-billion-electron-volt circular accelerator or a 600-million-electron-volt linear accelerator for protons, recently decided in favor of the linear machine.

The illustrations accompanying this article show some of the principles and components of the various types of linear accelerators. In the first machine, as suggested by Ising and worked out by Sloan and Lawrence, an electric generator discharged positively charged particles into a series of drift tubes [*see second drawing above*]. As a positively charged particle leaves the source, tube 1 is negative, tube 2 is positive, tube 3 is negative, and so forth. By the time the particle reaches the end of tube 1, the voltage has reversed, so that tube 1 is positive and tube 2 negative. Thus the particle continues to be accelerated. This process continues through the length of the machine. The lengths of the tubes have to be tailored so that the particle spends exactly one half cycle in each drift-tube space. This essentially is the machine which, before the war, accelerated mercury ions to two million electron volts (2 Mev).

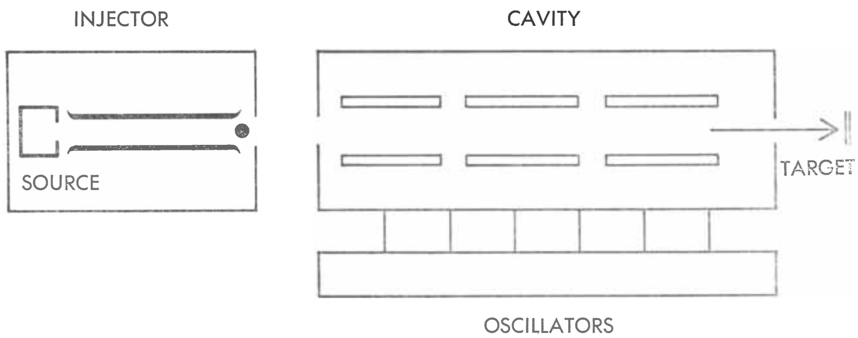
The limiting factor on a structure of this kind is the power source. Particles of interest to nuclear physicists travel with a large fraction of the speed of light;



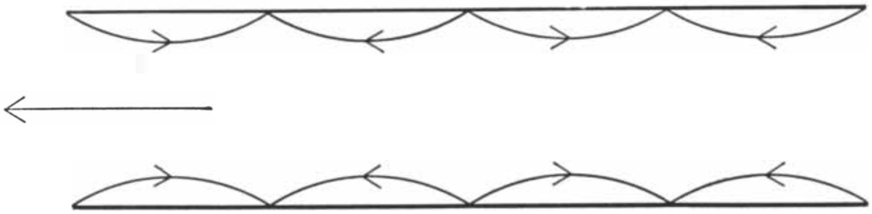
STATIC ACCELERATOR is simplest design. The particles are generated by an electron or ion source. A high static voltage accelerates the particles down a discharge tube.



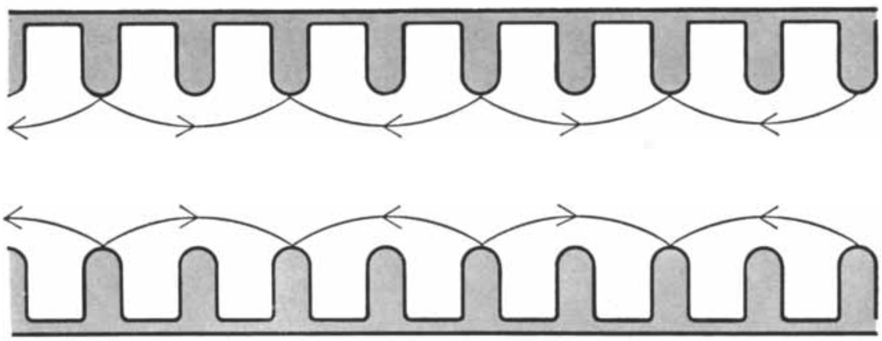
DRIFT-TUBE ACCELERATOR of an externally fed type accelerates particles down a series of tubes by alternating voltage so that successive tubes are of right charge as particle passes.



CAVITY ACCELERATOR employs drift tubes, but radio-frequency oscillators apply alternating voltage along cavity. Timing is such that particles meet accelerating field in each gap.



UNIFORM WAVE GUIDE is diagrammed showing the generated electromagnetic field with components parallel to the tube axis. In this tube the field travels faster than light.



LOADED WAVE GUIDE, of corrugated type, works by placing load on the wave. This slows the wave to the speed of the particles, which, for electrons, approaches the speed of light.

hence the voltage on the electrodes has to be alternated very rapidly. This requires a large current flow through the wires, which in turn results in large power losses. And the high-frequency power is expensive to generate.

Hansen's cavity resonator reduced the power losses by distributing the currents over the large conducting surfaces of the cavity instead of concentrating them in wires where much of the energy was lost as heat. The lower drawing on the preceding page, illustrating the operation of the proton linear accelerator at Berkeley, shows how a cavity-controlled system works. Power is fed to the cavity from banks of high-powered radio transmitters. The cavity transforms this radio energy into an alternating electric field which makes currents rush back and forth across the gaps between the ends of the drift tubes in the series. At any instant the direction of the accelerating force is the same in all the gaps. If the structure is designed so that a group of particles takes the time of one full cycle of the alternating voltage to travel through each drift tube, then the particles will always find themselves in an accelerating field when they cross a gap.

Although a structure of this design is much more efficient than the first one, it still requires very high power. In order to hold down the average power consumption to a reasonable level, the power must be applied in very short pulses. The 32-Mev proton linear accelerator at Berkeley requires 2.2 million watts of radio-frequency power (near the ultrahigh-frequency television band). It is powered by eight individual transmitters. This machine has been in continuous operation for several years and has been a very valuable tool in physics. A 70-Mev machine of similar design is nearly completed at the University of Minnesota, and similar principles will be used in the 600-Mev machine at Harwell, England.

The traveling-wave type of linear accelerator is particularly applicable to electrons. The wave travels in a cylindrical pipe with conducting walls, known as a waveguide. Of the various kinds of traveling waves used, a particularly interesting type is the so-called TM wave, in which the electric field always has a component parallel to the axis of the cylinder [*see upper drawing above*]. Imagine now that this whole field structure travels along the axis. If any particles happened to be moving with the same speed, they would be accelerated. For theoretical reasons which we need not go into here, electromagnetic waves cannot be slowed down to the maximum speed at which particles can travel in a simple, uniform pipe. To slow them down we must use some sort of interruption; the most popular method is to introduce disks of conducting material at regular intervals along the pipe, forming what is known as a "corrugated" waveguide [*lower drawing above*]. The disk spacing, disk thickness, disk aperture and pipe radius all have to be chosen to give minimum power loss at the needed wave velocity. The structure has to be fabricated with high precision (sometimes within a tolerance of .0002 of an inch), for the wave speed is very sensitive to small variations in the dimensions. The general dimensions of the tube also depend on the kind of particles to be accelerated; a proton machine must be much larger than one for electrons.

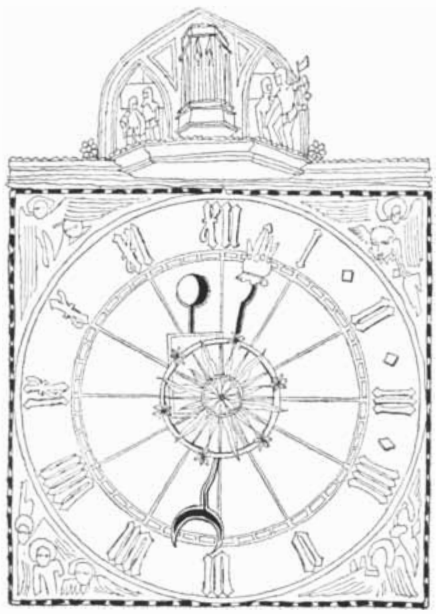
The corrugated-guide linear accelerator has been advanced furthest at Stanford University. Two machines are operating: one, 10 feet in length, attains 38 Mev; the other has reached 600 Mev and is expected to go higher. In the latter machine the accelerating tube itself is dwarfed by its auxiliary equipment, its shielding and the facilities for performing experiments on target material [*see lower photograph on page 41*]. This emphasizes the point that the economics of high-energy machine physics often depends only in small part on the design of the accelerating device.

The 600-Mev machine pictured is designed for a total power input of 400 million watts (roughly 20 million watts for each 10-foot section). Such power, at a frequency of 3,000 megacycles, is not available from commercial sources at this time. It is generated at Stanford by a set of klystron amplifiers driven from a common high-frequency source.

The British have been notably successful in commercial development of this type of accelerator for uses that do not require such high power. They have built research machines yielding four Mev and 15 Mev, and several firms are producing machines of four Mev energy for cancer therapy and radiography.

Essentially there are two ways to go to high energy in a linear accelerator: build a bigger machine or put in more power. The choice between these is fundamentally an economic question: whether the extra construction or the extra power will be more costly. It appears in retrospect that the Stanford machine might have been slightly more economical if we had made the tube longer and needed less power. The designer of a linear accelerator has to estimate how much a megawatt of power is going to cost him and what the cost per foot of machine would be; an optimum for a given output energy can then be calculated.

This article has given only a general outline of technical features of linear accelerators and has not attempted to discuss their applications in detail. It is clear, however, that these machines should be valuable tools in the struggle to understand high-energy phenomena.



Atomic Energy Act of 1954

A new regime in atomic energy began last month when Congress passed and President Eisenhower signed a general revision of the Atomic Energy Act which ended the Government's strict monopoly of the field. Adopted by a 59 to 17 vote in the Senate and by voice vote in the House, the Act embodies many compromises and controversial sections which most Congressmen had not had time to study and which some predicted would be reopened at the next session.

Among the main new provisions of the Act are the following:

The Federal government will continue to own all energy-yielding nuclear materials (redefined to include fusion elements as well as fissionables), but the Atomic Energy Commission is now directed to license private individuals and groups to own and operate reactors or other atomic facilities for uses other than military. The Government will buy all nuclear material produced as a by-product at standard, "fair" prices.

Inventors of new processes or devices in atomic energy may obtain private patents upon them, except when the invention is developed under an AEC contract. Within the next five years the Commission may require the patentee of any invention of "primary importance" to license it to others, provided that the licensee's activities will be of primary importance in effecting the purposes of the Act.

The AEC is prohibited from selling electric power except as a by-product of its research, development or weapon-production activities. Any power it sells must be offered first to public bodies and cooperatives or to private utilities serving high-cost-power areas. Private applicants for power-reactor licenses will be given preference if they are to serve high-cost areas.

The Act states that each member of the AEC has "equal responsibility and authority in all decisions and actions of the Commission," but the chairman is its "official spokesman" and responsible for executing its decisions.

A special division of the AEC is to be charged with the "development and application of civilian uses of atomic energy."

The Commission is prohibited from making cost-plus contracts or from agreeing to pay directly the Federal income taxes of any contractor.

In the area of cooperation with foreign nations, the AEC may make agreements with individual countries, regional defense organizations or groups of nations to pool information on the tactical use of atomic weapons and work in the nonmilitary development of atomic energy. Such agreements must be approved by the President and the Joint Congressional Committee. They must include guarantees that the cooperating parties will maintain specified security standards, will not use any special material received to make weapons and will not transmit material or restricted data to third parties.

Shortly after signing the new Act President Eisenhower announced an informal agreement with Great Britain, France, Canada, Australia and South Africa to pool fissionable material and technical information in a program to "foster the growth and spread of the new atomic technology for peaceful use." He said that discussions would soon begin with Belgium for construction of a power reactor in that country. "Negotations with other friendly nations will swiftly follow," said the President, adding his hope that "no nation will long stand aloof from the work of this agency."

The atomic power agency is to be independent of the United Nations, at least at the beginning. If and when the U.S.S.R. joins the pool, it may be placed under the UN.

As part of its contribution to the cooperative enterprise, the U.S. will open a school of reactor technology for the training of engineers from participating countries.

Radiation Effects

That nuclear radiations have important effects on structural materials has been emphasized in several reports by the Atomic Energy Commission. A declassified account of some of these effects was published last month in *Materials and Methods* by D. O. Leeser of the Reactor Engineering Division at the Argonne National Laboratory.

Neutrons, Leeser explains, are the chief culprits; they cause changes in properties by knocking crystal-lattice atoms out of place. The degree of change depends on the speed of the neutrons and on the temperature. Most materials have a saturation point of radiation damage, beyond which additional radiation has little effect.

The chief result of irradiating metals such as steels, nickel alloys and certain others is to make them more brittle. Their tensile strength increases while their resistance to impact decreases. There is little change in physical dimensions, density or fatigue strength. Electrical resistance increases slightly.

Radiation shrinks rubber and decreases the electrical resistance of insulators. Intense irradiation destroys plastics; some swell, some shrink, some crumble. It damages lubricating oils, changing their viscosity and eventually breaking them down into gases and liquids or gels.

Augean Stable, Atomic Style

In 1952 an accident caused overheating and a partial breakdown of the Chalk River nuclear reactor in Canada. The result was a 12-months repair job which made the labors of Hercules look like child's play. The story of the big decontamination project was recently told in *Chemical Engineering Progress* by F. W. Gilbert, a Chalk River engineer.

The precipitating circumstance was an uncontrolled "power surge." (One story goes that someone pulled out the control rods when he should have pushed them in.) It attacked the protective aluminum sheathing around some of the uranium fuel rods and melted the uranium. Before the reactor was brought under control, the surge had damaged the reactor vessel beyond repair, con-

taminated all auxiliary equipment and the building itself with radioactivity and flooded the basement with "hot" water of 10,000 curies—equal to the radioactivity of 10,000 grams of radium.

The engineers set out to clean up the mess, because to build a completely new reactor would have cost several times as much in time and money. First they drained the radioactive water by building a special pipeline to distant ground where it was allowed to seep into the earth. Then they built a ventilating system to pump out the contaminated air around the reactor vessel. Wearing protective clothing and masks, they next disassembled the reactor vessel for rebuilding. Finally they set to work to decontaminate the whole plant and its equipment; this they did by scrubbing, rinsing, sand-blasting or covering the radioactive surfaces. To detect any hot spots they may have missed, they exposed photographic film in a pinhole camera in darkness; radiation from the spots showed up on the film.

The accident taught some valuable lessons about how to build a reactor, says Gilbert. For instance, a drainage system for removing radioactive water quickly in an emergency can avert much of the contamination. The replaced reactor has been designed for easier cleaning in the future. All surfaces likely to be contaminated, even stainless steel, are painted or otherwise sealed. Rubber tile covers the concrete floor.

Gilbert suggests that all parts of a reactor be made removable for replacement or cleaning.

Artificial Rice

One of the most effective steps toward solving the world's food problem would be to find a cheaper and more nutritious replacement for rice. A synthetic rice which may meet these requirements has now been developed in India.

Describing the product in *Nature*, the Indian researchers point out that more than half the world's population live chiefly on rice. Having grown used to the neutrally flavored, easily cooked and digested grain, rice eaters will not readily switch to other cereals. Attempts to encourage wheat and corn consumption in India have failed.

The basic recipe for the synthetic rice is a mixture of flours made from tapioca root and peanuts. These are kneaded into a dough, extruded into long strings, then cut into rice-sized bits. A good deal of additional treatment is necessary to make this stuff really resemble rice. This includes boiling in water and adding small amounts of karaya gum, alkali-digested corncob, stearic acid and alkali bisulfite to the dough. Finally, the cut up "grains" are sprayed with a casein solution to make them water-resistant enough to wash.

The product, say the scientists, looks like slightly under-milled rice and tastes much like certain brands of rice sold in India. Animal experiments show that it is about twice as nutritious as natural rice. A given parcel of land will yield three to four times as much tapioca and peanuts as rice, and with less attention. The cost of the product is estimated at about $100 per ton, making it "distinctly cheaper" than rice. The synthetic food was developed at the Central Food Technological Research Institute in Mysore. V. Subrahmanyan, D. S. Bhatia, M. Swaminathan and G. S. Bains reported the work.

Protein Factory

A new experimental technique for studying how cells manufacture proteins has been announced in *Nature* by British investigators. E. F. Gale and Joan P. Folkes of the Medical Research Council Unit at the University of Cambridge have discovered that broken cells of the bacterium *Staphylococcus aureus* can synthesize protein from amino acids.

Gale and Folkes break up the bacterial cells with ultrasonic vibrations and then feed selected amino acids to the debris. Although the ruptured cells cannot breathe or reproduce, they do form protein from the assortment of amino acids. They fail, however, if their nucleic acids are dissolved away (*see F. H. C. Crick's article on page 54*).

Thus far the British investigators have studied the synthesis of three specific protein enzymes. They begin with a preparation from which nucleic acids have been removed, then observe the effects of introducing measured quantities of the acids or their constituent purines and pyrimidines. Apparently the broken cells can make their own nucleic acid from the constituents and then use this acid to manufacture protein.

Gale and Folkes suggest that the nucleic acid DNA or a combination of DNA and certain proteins acts as an organizing structure or template which first forms the nucleic acid RNA. This acid in turn, either alone or in collaboration with DNA, organizes the synthesis of protein.

Protective Chemical

The human organism has several well-known specific defenses against infection, notably the white blood cells and antibodies against specific germs. But it also has a general kind of immunity which has long mystified bacteriologists. Now a group of biochemists working under Louis Pillemer at Western Reserve University report in *Science* that they have identified a protein which seems to have the general ability to fight various infections. They have named the substance "properdin," after the Latin *perdere*—to destroy.

The protein is a globulin with a molecular weight some eight times that of gamma globulin. Blood serum from which properdin has been removed (by treatment with a yeast preparation called zymosan) shows no ability to kill bacteria or inactivate viruses, as normal serum can. When properdin is restored, the serum recovers this ability.

Properdin acts in conjunction with certain other blood constituents, known as "complement," and with magnesium ions. Both of these factors must be present to make properdin effective. Complement is known to be necessary for antibodies to work.

Pillemer and his colleagues have assayed the blood of various mammals for properdin. Rats are richest in the substance; guinea pigs are poorest; human beings fall in the middle of the range. Pillemer recalls that rats are known for their high resistance to infection and guinea pigs for their extreme susceptibility to it.

The Western Reserve group has shown that irradiation destroys properdin in rats, which may account for the vulnerability to infection that has generally been found to follow exposure to radiation. They were able to give irradiated rats partial protection against infection by injecting properdin from cow serum.

Roy G. Biv

People who remember their high-school physics will recognize this odd name as the mnemonic device for listing the "spectral colors"—red, orange, yellow, green, blue, indigo and violet. (Today indigo is out of style, so Mr. Biv becomes the less euphonious Mr. Bv.) Verne F. Ray, an anthropologist at the University of Washington who has been looking into the matter of color perception, now reports that this division of the color spectrum is quite arbitrary and has little relation to the color shadings that people actually see.

Ray has studied color perception among a hundred Indian tribes. No two of these, he reports in the *Transactions of the New York Academy of Sciences*,

divide the spectrum in the same way. Some distinguish only three colors in their language; others, as many as eight. The Santiam Indians recognize two different colors in the band conventionally called yellow. A wavelength which in one system lies on the dividing line between two colors may fall in the middle of a band in another system.

The differences in dividing the scale reflect no psychological or physiological variations among peoples, so far as Ray can tell. He concludes that there is no "natural" division of the spectrum. Human beings can differentiate a great many more color shadings than the textbooks list.

Tunable Tubes

Two new kinds of microwave vacuum tubes, which can be tuned electrically over thousands of megacycles, have recently been announced. Until now, except over narrow ranges of frequency, microwave oscillators have had to be tuned mechanically by varying the size of a resonant cavity. Electrical tuning is much faster, can be remotely controlled and will add substantially to the versatility of microwave circuits.

One of the tubes is called the "strophotron," from a Greek word meaning "turn to and fro." The electron beam follows a zigzag course between two negatively charged reflector electrodes as it moves from the cathode to a collector plate. The frequency of the zigzagging is the frequency of the energy given out, and it can be controlled by adjusting the voltage on the electrodes. The strophotron was invented by Hannes Alfvén and Dag Romell, of the Royal Institute of Technology in Stockholm.

The second device is known as the "backward wave oscillator." It is an outgrowth of the traveling-wave tube described by J. R. Pierce in his article on "Microwaves" in SCIENTIFIC AMERICAN of August, 1952. As a wave travels down this type of tube, it sends certain components back in the direction from which it came. R. Kompfner and N. T. Williams of the Bell Telephone Laboratories have found that the backward component can be made to set the tube into oscillation. The frequency of the oscillation depends on the speed of the electron beam that carries the wave, and this in turn depends on the voltage applied to accelerate the electrons. Thus by varying the voltage the tube can be tuned to different frequencies. Kompfner and Williams have swept an experimental model continuously from 6 to 7.5 millimeters—a frequency range of 10,000 megacycles.

The Structure of the Hereditary Material

An account of the investigations which have led to the formulation of an understandable structure for DNA. The chemical reactions of this material within the nucleus govern the process of reproduction

by F. H. C. Crick

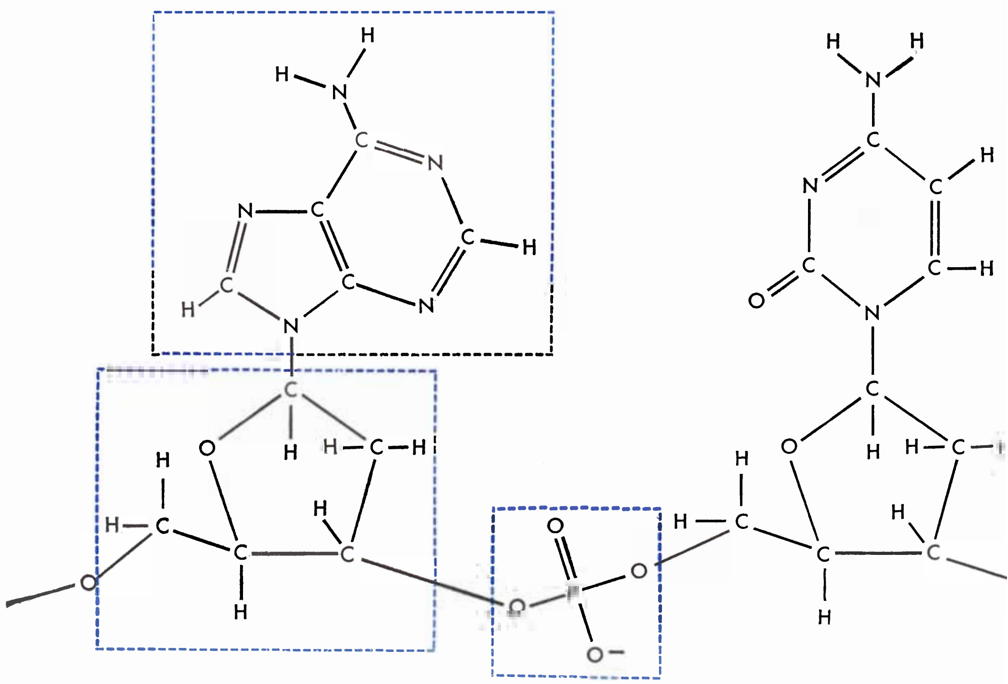
Viewed under a microscope, the process of mitosis, by which one cell divides and becomes two, is one of the most fascinating spectacles in the whole of biology. No one who watches the event unfold in speeded-up motion pictures can fail to be excited and awed. As a demonstration of the powers of dynamic organization possessed by living matter, the act of division is impressive enough, but even more stirring is the appearance of two identical sets of chromosomes where only one existed before. Here lies biology's greatest challenge: How are these fundamental bodies duplicated? Unhappily the copying process is beyond the resolving power of microscopes, but much is being learned about it in other ways.

One approach is the study of the nature and behavior of whole living cells; another is the investigation of substances extracted from them. This article will discuss only the second approach, but both are indispensable if we are ever to solve the problem; indeed some of the most exciting results are being obtained by what might loosely be described as a combination of the two methods.

Chromosomes consist mainly of three kinds of chemical: protein, desoxyribonucleic acid (DNA) and ribonucleic acid (RNA). (Since RNA is only a minor component, we shall not consider it in detail here.) The nucleic acids and the proteins have several features in common. They are all giant molecules, and each type has the general structure of a main backbone with side groups attached. The proteins have about 20 different kinds of side groups; the nucleic acids usually only four (and of a different type). The smallness of these numbers itself is striking, for there is no obvious chemical reason why many more types of side groups should not occur. Another interesting feature is that no protein or nucleic acid occurs in more than one optical form; there is never an optical isomer, or mirror-image molecule. This shows that the shape of the molecules must be important.

These generalizations (with minor exceptions) hold over the entire range of living organisms, from viruses and bacteria to plants and animals. The impression is inescapable that we are dealing with a very basic aspect of living matter, and one having far more simplicity than we would have dared to hope. It encourages us to look for simple explanations for the formation of these giant molecules.

The most important role of proteins is that of the enzymes—the machine tools of the living cell. An enzyme is specific,



FRAGMENT OF CHAIN of desoxyribonucleic acid shows the three basic units that make up the molecule. Repeated over and over in a long chain, they make it 1,000 times as long often highly specific, for the reaction which it catalyzes. Moreover, chemical and X-ray studies suggest that the structure of each enzyme is itself rigidly determined. The side groups of a given enzyme are probably arranged in a fixed order along the polypeptide backbone. If we could discover how a cell produces the appropriate enzymes, in particular how it assembles the side groups of each enzyme in the correct order, we should have gone a long way toward explaining the simpler forms of life in terms of physics and chemistry.

We believe that this order is controlled by the chromosomes. In recent years suspicion has been growing that the key to the specificity of the chromosomes lies not in their protein but in their DNA. DNA is found in all chromosomes —and only in the chromosomes (with minor exceptions). The amount of DNA per chromosome set is in many cases a fixed quantity for a given species. The sperm, having half the chromosomes of the normal cell, has about half the amount of DNA, and tetraploid cells in the liver, having twice the normal chromosome complement, seem to have twice the amount of DNA. This constancy of the amount of DNA is what one might expect if it is truly the material that determines the hereditary pattern.

Then there is suggestive evidence in two cases that DNA alone, free of protein, may be able to carry genetic information. The first of these is the discovery that the "transforming principles" of bacteria, which can produce an inherited change when added to the cell, appear to consist only of DNA. The second is the fact that during the infection of a bacterium by a bacteriophage the DNA of the phage penetrates into the bacterial cell while most of the protein, perhaps all of it, is left outside.

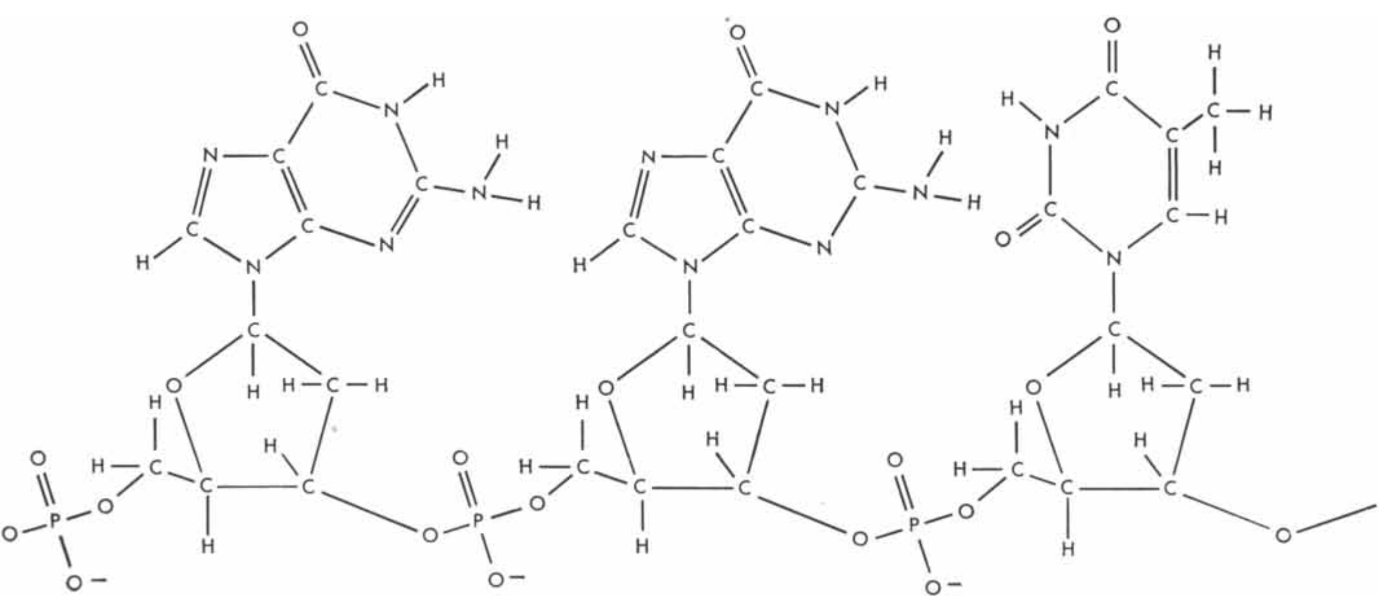
The Chemical Formula

DNA can be extracted from cells by mild chemical methods, and much experimental work has been carried out to discover its chemical nature. This work has been conspicuously successful. It is now known that DNA consists of a very long chain made up of alternate sugar and phosphate groups [*see diagram below*]. The sugar is always the same sugar, known as desoxyribose. And it is always joined onto the phosphate in the same way, so that the long chain is perfectly regular, repeating the same phosphate-sugar sequence over and over again.

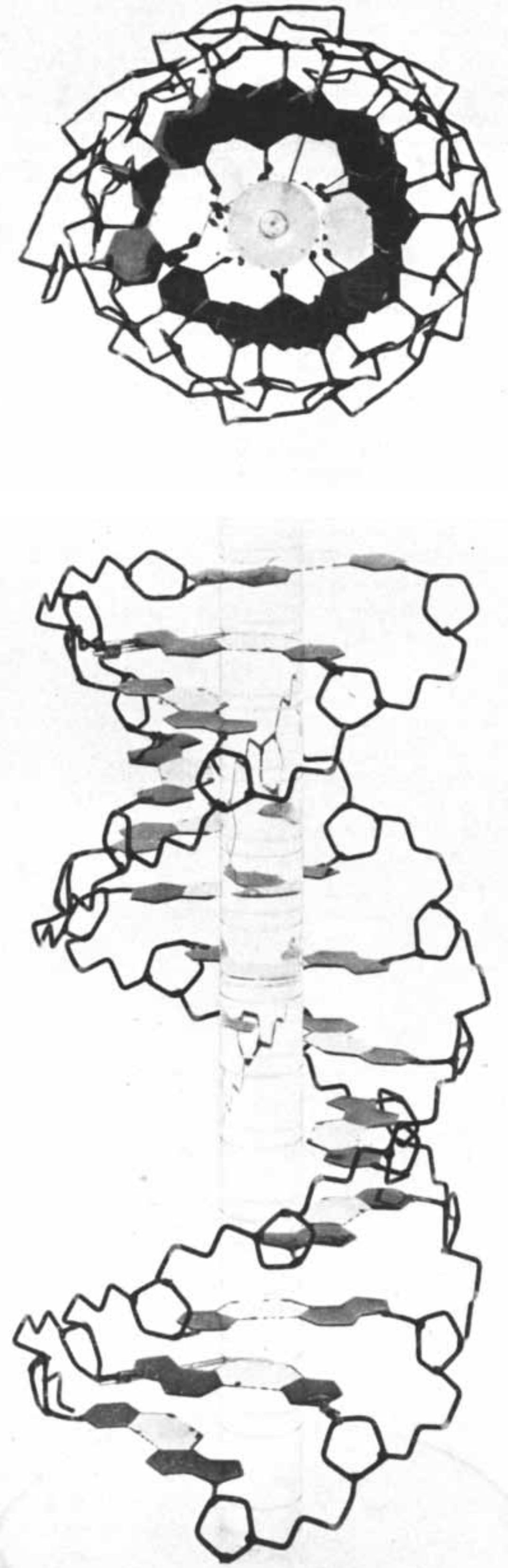
But while the phosphate-sugar chain is perfectly regular, the molecule as a whole is not, because each sugar has a "base" attached to it and the base is not always the same. Four different types of base are commonly found: two of them are purines, called adenine and guanine, and two are pyrimidines, known as thymine and cytosine. So far as is known the order in which they follow one another along the chain is irregular, and probably varies from one piece of DNA to another. In fact, we suspect that the order of the bases is what confers specificity on a given DNA. Because the sequence of the bases is not known, one can only say that the *general* formula for DNA is established. Nevertheless this formula should be reckoned one of the major achievements of biochemistry, and it is the foundation for all the ideas described in the rest of this article.

At one time it was thought that the four bases occurred in equal amounts, but in recent years this idea has been shown to be incorrect. E. Chargaff and his colleagues at Columbia University, A. E. Mirsky and his group at the Rockefeller Institute for Medical Research and G. R. Wyatt of Canada have accurately measured the amounts of the bases in many instances and have shown that the relative amounts appear to be fixed for any given species, irrespective of the individual or the organ from which the DNA was taken. The proportions usually differ for DNA from different species, but species related to one another may not differ very much.

Although we know from the chemical formula of DNA that it is a chain, this does not in itself tell us the shape of the molecule, for the chain, having many single bonds around which it may rotate, might coil up in all sorts of shapes. However, we know from physical-chemical measurements and electron-microscope pictures that the molecule usually is long, thin and fairly straight,



as it is thick. The backbone is made up of pentose sugar molecules (marked by the middle colored square), linked by phosphate groups (bottom square). The bases (top square), adenine, cytosine, guanine and thymine protrude off each sugar in irregular order.



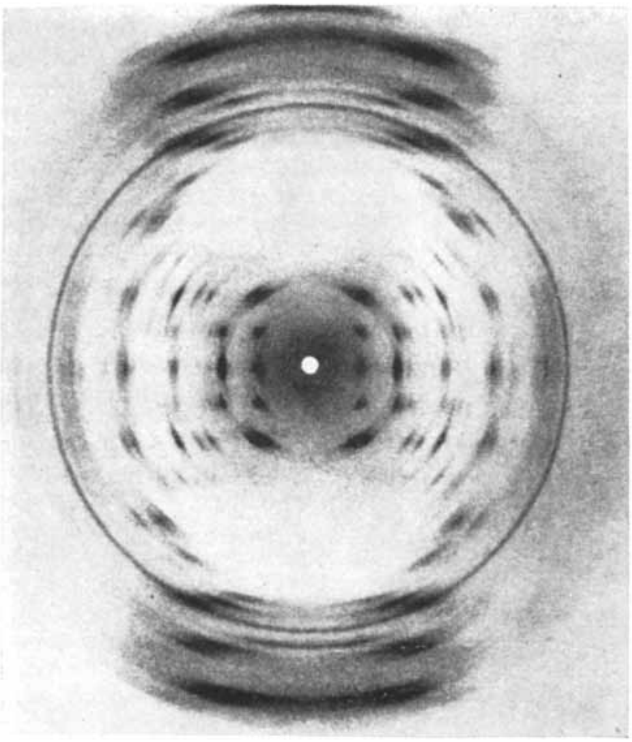
STRUCTURAL MODEL shows a pair of DNA chains wound as a helix about the fiber axis. The pentose sugars can be plainly seen. From every one on each chain protrudes a base, linked to an opposing one at the same level by a hydrogen bond. These base-to-base links act as horizontal supports, holding the chains together. Upper photograph is a top view.

rather like a stiff bit of cord. It is only about 20 Angstroms thick (one Angstrom = one 100-millionth of a centimeter). This is very small indeed, in fact not much more than a dozen atoms thick. The length of the DNA seems to depend somewhat on the method of preparation. A good sample may reach a length of 30,000 Angstroms, so that the structure is more than 1,000 times as long as it is thick. The length inside the cell may be much greater than this, because there is always the chance that the extraction process may break it up somewhat.

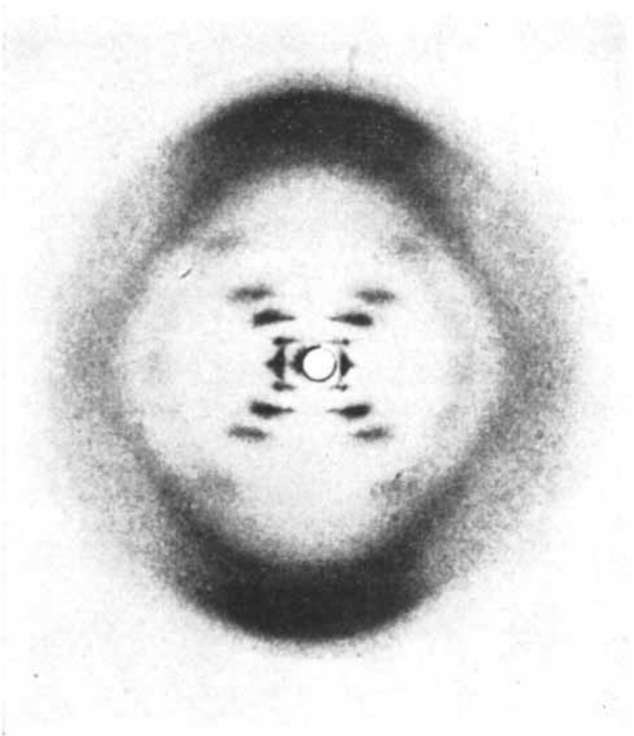
Pictures of the Molecule

None of these methods tells us anything about the detailed arrangement in space of the atoms inside the molecule. For this it is necessary to use X-ray diffraction. The average distance between bonded atoms in an organic molecule is about 1½ Angstroms; between unbonded atoms, three to four Angstroms. X-rays have a small enough wavelength (1½ Angstroms) to resolve the atoms, but unfortunately an X-ray diffraction photograph is not a picture in the ordinary sense of the word. We cannot focus X-rays as we can ordinary light; hence a picture can be obtained only by roundabout methods. Moreover, it can show clearly only the periodic, or regularly repeated, parts of the structure.

With patience and skill several English workers have obtained good diffraction pictures of DNA extracted from cells and drawn into long fibers. The first studies, even before details emerged, produced two surprises. First, they revealed that the DNA structure could take two forms. In relatively low humidity, when the water content of the fibers was about 40 per cent, the DNA molecules gave a crystalline pattern, showing that they were aligned regularly in all three dimensions. When the humidity was raised and the fibers took up more water, they increased in length by about 30 per cent and the pattern tended to become "paracrystalline," which means that the molecules were packed side by side in a less regular manner, as if the long molecules could slide over one another somewhat. The second surprising result was that DNA from different species appeared to give identical X-ray patterns, despite the fact that the amounts of the four bases present varied. This was particularly odd because of the existence of the crystalline form just mentioned. How could the structure appear so regular when the bases varied? It seemed that the



STRUCTURE A is the crystalline form of DNA found at relatively low humidity. This X-ray photograph is by H. R. Wilson.



STRUCTURE B is the paracrystalline form of DNA. The molecules are less regularly arranged. Picture is by R. E. Franklin.

broad arrangement of the molecule must be independent of the exact sequence of the bases, and it was therefore thought that the bases play no part in holding the structure together. As we shall see, this turned out to be wrong.

The early X-ray pictures showed a third intriguing fact: namely, that the repeats in the crystallographic pattern came at much longer intervals than the chemical repeat units in the molecule. The distance from one phosphate to the next cannot be more than about seven Angstroms, yet the crystallographic repeat came at intervals of 28 Angstroms in the crystalline form and 34 Angstroms in the paracrystalline form; that is, the chemical unit repeated several times before the structure repeated crystallographically.

J. D. Watson and I, working in the Medical Research Council Unit in the Cavendish Laboratory at Cambridge, were convinced that we could get somewhere near the DNA structure by building scale models based on the X-ray patterns obtained by M. H. F. Wilkins, Rosalind Franklin and their co-workers at Kings' College, London. A great deal is known about the exact distances between bonded atoms in molecules, about the angles between the bonds and about the size of atoms—the so-called van der Waals' distance between adjacent non-bonded atoms. This information is easy to embody in scale models. The problem is rather like a three-dimensional jig saw puzzle with curious pieces joined together by rotatable joints (single bonds between atoms).

The Helix

To get anywhere at all we had to make some assumptions. The most important one had to do with the fact that the crystallographic repeat did not coincide with the repetition of chemical units in the chain but came at much longer intervals. A possible explanation was that all the links in the chain were the same but the X-rays were seeing every tenth link, say, from the same angle and the others from different angles. What sort of chain might produce this pattern? The answer was easy: the chain might be coiled in a helix. (A helix is often loosely called a spiral; the distinction is that a helix winds not around a cone but around a cylinder, as a winding staircase usually does.) The distance between crystallographic repeats would then correspond to the distance in the chain between one turn of the helix and the next.

We had some difficulty at first because we ignored the bases and tried to work only with the phosphate-sugar backbone. Eventually we realized that we had to take the bases into account, and this led us quickly to a structure which we now believe to be correct in its broad outlines.

This particular model contains a pair of DNA chains wound around a common axis. The two chains are linked together by their bases. A base on one chain is joined by very weak bonds to a base at the same level on the other chain, and all the bases are paired off in this way right along the structure. In the diagram opposite, the two ribbons represent the phosphate-sugar chains, and the pairs of bases holding them together are symbolized as horizontal rods. Paradoxically, in order to make the structure as symmetrical as possible we had to have the two chains run in opposite directions; that is, the sequence of the atoms goes one way in one chain and the opposite way in the other. Thus the figure looks exactly the same whichever end is turned up.

Now we found that we could not arrange the bases any way we pleased; the four bases would fit into the structure only in certain pairs. In any pair there must always be one big one (purine) and one little one (pyrimidine). A pair of pyrimidines is too short to bridge the gap between the two chains, and a pair of purines is too big to fit into the space.

At this point we made an additional assumption. The bases can theoretically exist in a number of forms depending upon where the hydrogen atoms are attached. We assumed that for each base one form was much more probable than all the others. The hydrogen atoms can be thought of as little knobs attached to the bases, and the way the bases fit together depends crucially upon where these knobs are. With this assumption the only possible pairs that will fit in are: adenine with thymine and guanine with cytosine.

The way these pairs are formed is shown in the diagrams on page 60. The dotted lines show the hydrogen bonds, which hold the two bases of a pair together. They are very weak bonds; their energy is not many times greater than the energy of thermal vibration at room temperature. (Hydrogen bonds are the main forces holding different water molecules together, and it is because of them that water is a liquid at room temperatures and not a gas.)

Adenine must always be paired with thymine, and guanine with cytosine; it is impossible to fit the bases together in any other combination in our model. (This pairing is likely to be so fundamental for biology that I cannot help wondering whether some day an enthusiastic scientist will christen his newborn twins Adenine and Thymine!) The model places no restriction, however, on the sequence of pairs along the structure. Any specified pair can follow any other. This is because a pair of bases is flat, and since in this model they are stacked roughly like a pile of coins, it does not matter which pair goes above which.

It is important to realize that the specific pairing of the bases is the direct result of the assumption that both phosphate-sugar chains are helical. This regularity implies that the distance from a sugar group on one chain to that on the other at the same level is always the same, no matter where one is along the chain. It follows that the bases linked to the sugars always have the same amount of space in which to fit. It is the regularity of the phosphate-sugar chains, therefore, that is at the root of the specific pairing.

The Picture Clears

At the moment of writing, detailed interpretation of the X-ray photographs by Wilkins' group at Kings' College has not been completed, and until this has been done no structure can be considered proved. Nevertheless there are certain features of the model which are so strongly supported by the experimental evidence that it is very likely they will be embodied in the final correct structure. For instance, measurements of the density and water content of the DNA fibers, taken with evidence showing that the fibers can be extended in length, strongly suggest that there are two chains in the structural unit of DNA. Again, recent X-ray pictures have shown clearly a most striking general pattern which we can now recognize as the characteristic signature of a helical structure. In particular there are a large number of places where the diffracted intensity is zero or very small, and these occur exactly where one expects from a helix of this sort. Another feature one would expect is that the X-ray intensities should approach cylindrical symmetry, and it is now known that they do this. Recently Wilkins and his co-workers have given a brilliant analysis of the details of the X-ray pattern of the crystalline form, and have shown that they are consistent with a structure of this type, though in the crystalline form the bases are tilted away from the fiber axis instead of perpendicular, as in our model. Our construction was based on the paracrystalline form.

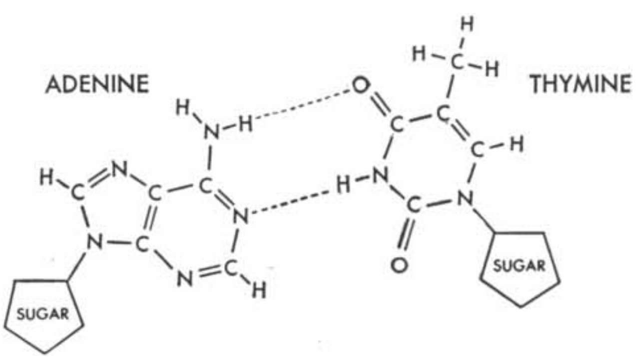
Many of the physical and chemical properties of DNA can now be understood in terms of this model. For example, the comparative stiffness of the structure explains rather naturally why DNA keeps a long, fiber-like shape in solution. The hydrogen bonds of the bases account for the behavior of DNA in response to changes in *p*H. Most striking of all is the fact that in every kind of DNA so far examined—and over 40 have been analyzed—the amount of adenine is about equal to the amount of thymine and the guanine equal to the cytosine, while the cross-ratios (between, say, adenine and guanine) can vary considerably from species to species. This remarkable fact, first pointed out by Chargaff, is exactly what one would expect according to our model, which requires that every adenine be paired with a thymine and every guanine with a cytosine.

It may legitimately be asked whether the artificially prepared fibers of extracted DNA, on which our model is based, are really representative of intact DNA in the cell. There is every indication that they are. It is difficult to see how the very characteristic features of the model could be produced as artefacts by the extraction process. Moreover, Wilkins has shown that intact biological material, such as sperm heads and bacteriophage, gives X-ray patterns very similar to those of the extracted fibers.

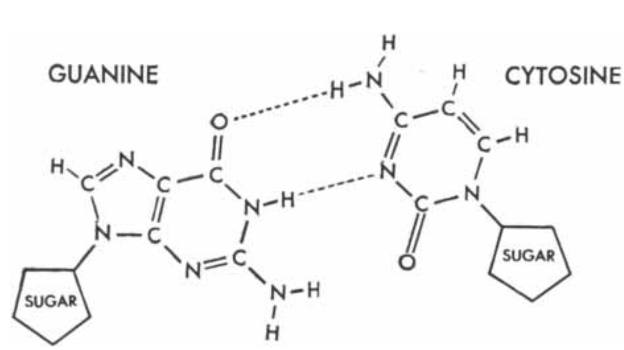
The present position, therefore, is that in all likelihood this statement about DNA can safely be made: its structure consists of two helical chains wound around a common axis and held together by hydrogen bonds between specific pairs of bases.

The Mold

Now the exciting thing about a model of this type is that it immediately suggests how the DNA might produce an exact copy of itself. The model consists of two parts, each of which is the complement of the other. Thus either chain may act as a sort of mold on which a complementary chain can be synthe-



ONE LINKAGE of base to base across the pair of DNA chains is between adenine and thymine. For the structure proposed, the link of a large base with a small one is required to fit chains together.



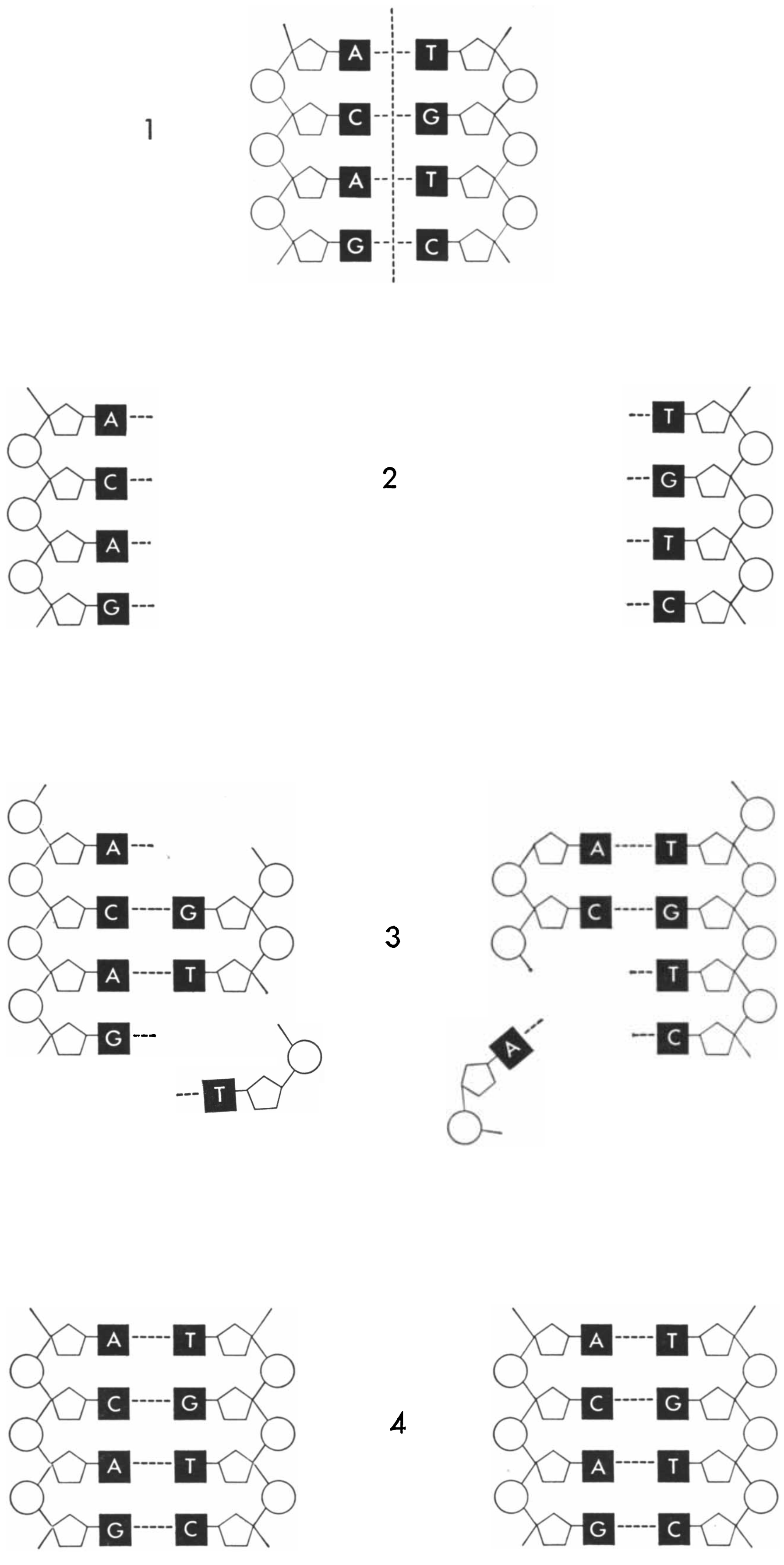
ANOTHER LINKAGE is comprised of guanine with cytosine. Assuming the existence of hydrogen bonds between the bases, these two pairings, and only these, will explain the actual configuration.

sized. The two chains of a DNA, let us say, unwind and separate. Each begins to build a new complement onto itself. When the process is completed, there are two pairs of chains where we had only one. Moreover, because of the specific pairing of the bases the sequence of the pairs of bases will have been duplicated exactly; in other words, the mold has not only assembled the building blocks but has put them together in just the right order.

Let us imagine that we have a single helical chain of DNA, and that floating around it inside the cell is a supply of precursors of the four sorts of building blocks needed to make a new chain. Unfortunately we do not know the makeup of these precursor units; they may be, but probably are not, nucleotides, consisting of one phosphate, one sugar and one base. In any case, from time to time a loose unit will attach itself by its base to one of the bases of the single DNA chain. Another loose unit may attach itself to an adjoining base on the chain. Now if one or both of the two newly attached units is not the correct mate for the one it has joined on the chain, the two newcomers will be unable to link together, because they are not the right distance apart. One or both will soon drift away, to be replaced by other units. When, however, two adjacent newcomers are the correct partners for their opposite numbers on the chain, they will be in just the right position to be linked together and begin to form a new chain. Thus only the unit with the proper base will gain a permanent hold at any given position, and eventually the right partners will fill in the vacancies all along the forming chain. While this is going on, the other single chain of the original pair also will be forming a new chain complementary to itself.

At the moment this idea must be regarded simply as a working hypothesis. Not only is there little direct evidence for it, but there are a number of obvious difficulties. For example, certain organisms contain small amounts of a fifth base, 5-methyl cytosine. So far as the model is concerned, 5-methyl cytosine fits just as well as cytosine and it may turn out that it does not matter to the organism which is used, but this has yet to be shown.

A more fundamental difficulty is to explain how the two chains of DNA are unwound in the first place. There would have to be a lot of untwisting, for the total length of all the DNA in a single chromosome is something like four centimeters (400 million Angstroms). This



REPLICATION mechanism by which DNA might duplicate itself is shown in diagram. A helix of two DNA chains unwinds and separates (1). Two complementary chains of DNA (2) within the cell begin to attach DNA precursor units floating loosely (3). When the proper bases are joined, two new helixes will build up (4). Letters represent the bases.

means that there must be more than 10 million turns in all, though the DNA may not be all in one piece.

The duplicating process can be made to appear more plausible by assuming that the synthesis of the two new chains begins as soon as the two original chains start to unwind, so that only a short stretch of the chain is ever really single. In fact, we may postulate that it is the growth of the two new chains that unwinds the original pair. This is likely in terms of energy because, for every hydrogen bond that has to be broken, two new ones will be forming. Moreover, plausibility is added to the idea by the fact that the paired chain forms a rather stiff structure, so that the growing chain would tend to unwind the old pair.

The difficulty of untwisting the two chains is a topological one, and is due to the fact that they are intertwined. There would be no difficulty in "unwinding" a single helical chain, because there are so many single bonds in the chain about which rotation is possible. If in the twin structure one chain should break, the other one could easily spin around. This might relieve accumulated strain, and then the two ends of the broken chain, still being in close proximity, might be joined together again. There is even some evidence suggesting that in the process of extraction the chains of DNA may be broken in quite a number of places and that the structure nevertheless holds together by means of the hydrogen bonding, because there is never a break in both chains at the same level. Nevertheless, in spite of these tentative suggestions, the difficulty of untwisting remains a formidable one.

A Code for Heredity?

There remains the fundamental puzzle as to how DNA exerts its hereditary influence. A genetic material must carry out two jobs: duplicate itself and control the development of the rest of the cell in a specific way. We have seen how it might do the first of these, but the structure gives no obvious clue concerning how it may carry out the second. We suspect that the sequence of the bases acts as a kind of genetic code. Such an arrangement can carry an enormous amount of information. If we imagine that the pairs of bases correspond to the dots and dashes of the Morse code, there is enough DNA in a single cell of the human body to encode about 1,000 large textbooks. What we want to know, however, is just how this is done in terms of atoms and molecules. In particular, what precisely is it a code for? As we have seen, the three key components of living matter—protein, RNA and DNA—are probably all based on the same general plan. Their backbones are regular, and the variety comes from the sequence of the side groups. It is therefore very natural to suggest that the sequence of the bases of the DNA is in some way a code for the sequence of the amino acids in the polypeptide chains of the proteins which the cell must produce. The physicist George Gamow has recently suggested in a rather abstract way how this information might be transmitted, but there are some difficulties with the actual scheme he has proposed, and so far he has not shown how the idea can be translated into precise molecular configurations.

What then, one may reasonably ask, are the virtues of the proposed model, if any? The prime virtue is that the configuration suggested is not vague but can be described in terms acceptable to a chemist. The pairing of the bases can be described rather exactly. The precise positions of the atoms of the backbone is less certain, but they can be fixed within limits, and detailed studies of the X-ray data, now in progress at Kings' College, may narrow these limits considerably. Then the structure brings together two striking pieces of evidence which at first sight seem to be unrelated—the analytical data, showing the one-to-one ratios for adenine-thymine and guanine-cytosine, and the helical nature of the X-ray pattern. These can now be seen to be two facets of the same thing. Finally, is it not perhaps a remarkable coincidence, to say the least, to find in this key material a structure of exactly the type one would need to carry out a specific replication process; namely, one showing both variety and complementarity?

The model is also attractive in its simplicity. While it is obvious that whole chromosomes have a fairly complicated structure, it is not unreasonable to hope that the molecular basis underlying them may be rather simple. If this is so, it may not prove too difficult to devise experiments to unravel it. It would, of course, help enormously if biochemists could discover the immediate precursors of DNA. If we knew the monomers from which nature makes DNA, RNA and protein, we might be able to carry out very spectacular experiments in the test tube. Be that as it may, we now have for the first time a well-defined model for DNA and for a possible replication process, and this in itself should make it easier to devise crucial experiments.

PHOSPHORS

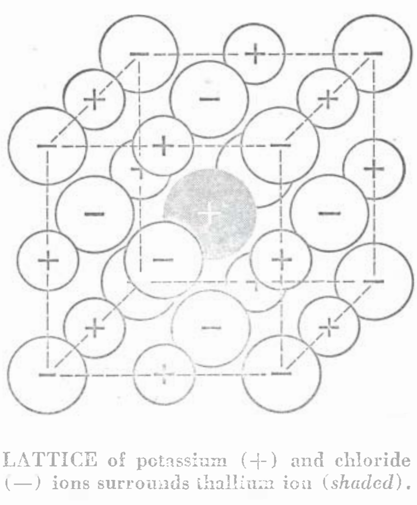
Most absorb energy at invisible wavelengths and emit it as visible light. Recent work on the physics of luminescence is making possible the design of phosphors for specific purposes

by J. S. Prener and D. B. Sullenger

These blazes . . . giving more light than heat . . .
Hamlet, Act I, Scene 3

Although Polonius in this remark to his daughter Ophelia had another subject in mind, he might have been speaking of luminescence, for luminescence is certainly an emission more of light than of heat. This production of "cold light" has long been a source of amazement. In early times men regarded luminescent animals and minerals as possessing magical qualities. In 1603 a Bologna shoemaker, who apparently practiced alchemy on the side, heated together a mixture of charcoal and barites and accidentally produced the first recorded synthetic phosphor. Instead of the philosophers' stone, he obtained a material which glowed in the dark after exposure to sunlight.

We employ today a multitude of organic and inorganic phosphors—in fluorescent lighting, in television, in radar, in paints and inks, in instruments for detecting various radiations. The fluorescent lamp, first exhibited to the U. S. public at the 1939 New York World's Fair, now challenges the incandescent lamp in popularity. The exploitation of the properties of phosphors has removed them from the realm of the laboratory curiosity. Some phosphors are now being produced in tonnage quantities, though most of their uses require only gram amounts in each device. The total annual world production of phosphors is estimated to be more than one million pounds.



LATTICE of potassium (+) and chloride (—) ions surrounds thallium ion (*shaded*).

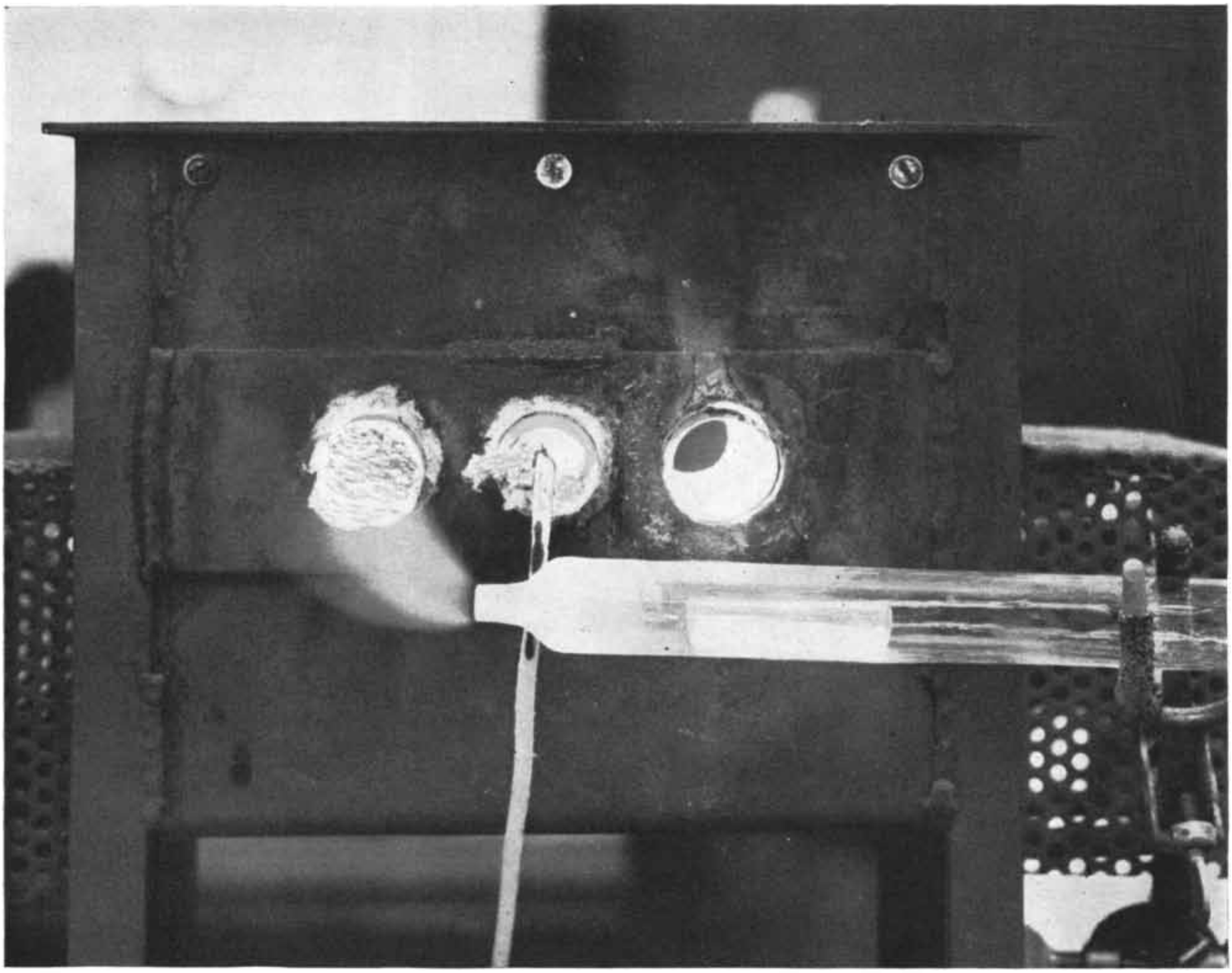
The word "phosphor" comes from a Greek word meaning light-carrier. From the same word we get the name of the element phosphorus, which, upon exposure to natural weathering, emits light. This has been shown to be due to the chemical release of energy by oxidation of the element. Photoluminescent phosphors are substances which absorb electromagnetic energy, usually ultraviolet light, and then re-emit this energy in the form of visible light. The absorption of energy by the phosphor is called "excitation" of the phosphor, and the release of the energy is called fluorescence. The difference in the wavelength of the absorbed and emitted light is an important property of phosphors, because the material as a consequence does not reabsorb much of the light it emits.

The photoluminescent phosphors are not easy to prepare, for their composition must be rigidly controlled. Because of this, and because of the desirability of having exact knowledge as to their physico-chemical properties, much research has centered upon them in the past two decades.

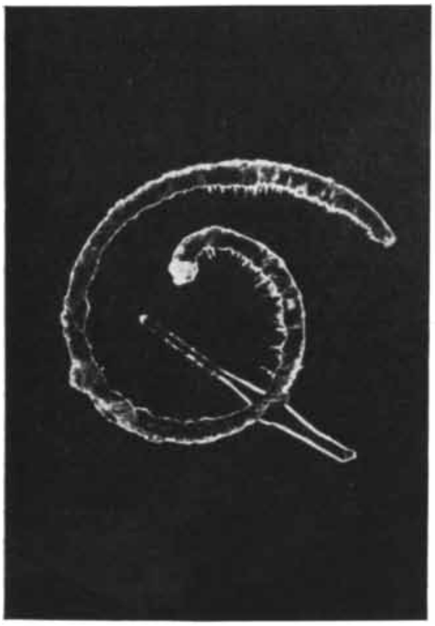
In the fluorescent lamp the phosphor is coated on the inside of the glass tube, and the exciting ultraviolet light comes from a mercury glow discharge. There are many natural phosphors; typical ones are the minerals willemite (zinc orthosilicate), wurtzite (zinc sulfide) and fluorite (calcium fluoride). The phosphor chemist has been able to synthesize, under carefully controlled conditions, much more efficient phosphors than those found in nature. The property of fluorescence is known to be due to the presence of small amounts of impurities, called activators, in the compound. The specific properties of a phosphor (*e.g.*, the color of the light it emits, the wavelength of light it must absorb to be excited to fluorescence, the brightness of the emitted light, the duration of phosphorescence, or afterglow) depend primarily on the chemical nature of the material and the activator it contains. In the zinc orthosilicate phosphor (green fluorescence) the activator is manganese; in zinc sulfide (blue fluorescence) it is silver; in calcium fluochlorophosphate (white fluorescence) it is antimony and manganese. The needed impurities amount to less than 1 per cent.

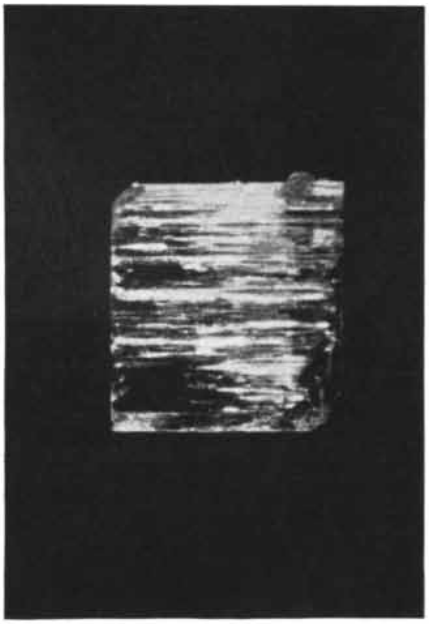
Let us see how a chemist prepares a typical phosphor: manganese-activated zinc orthosilicate. He takes very pure zinc oxide and silicon dioxide, adds .1 per cent manganese in the form of a salt such as manganese sulfate, mixes these ingredients together and heats them to 1,100 degrees centigrade. At this temperature the zinc oxide and silicon dioxide react to form zinc orthosilicate (Zn_2SiO_4) and the manganese atoms diffuse into the crystals. Many other phosphors are made as polycrystalline powders by similar solid-state diffusion methods. Some phosphors can also be prepared as single crystals and as transparent thin films about one micron thick.

A great deal of research and development has gone into the improvement of old phosphors, synthesis of new ones

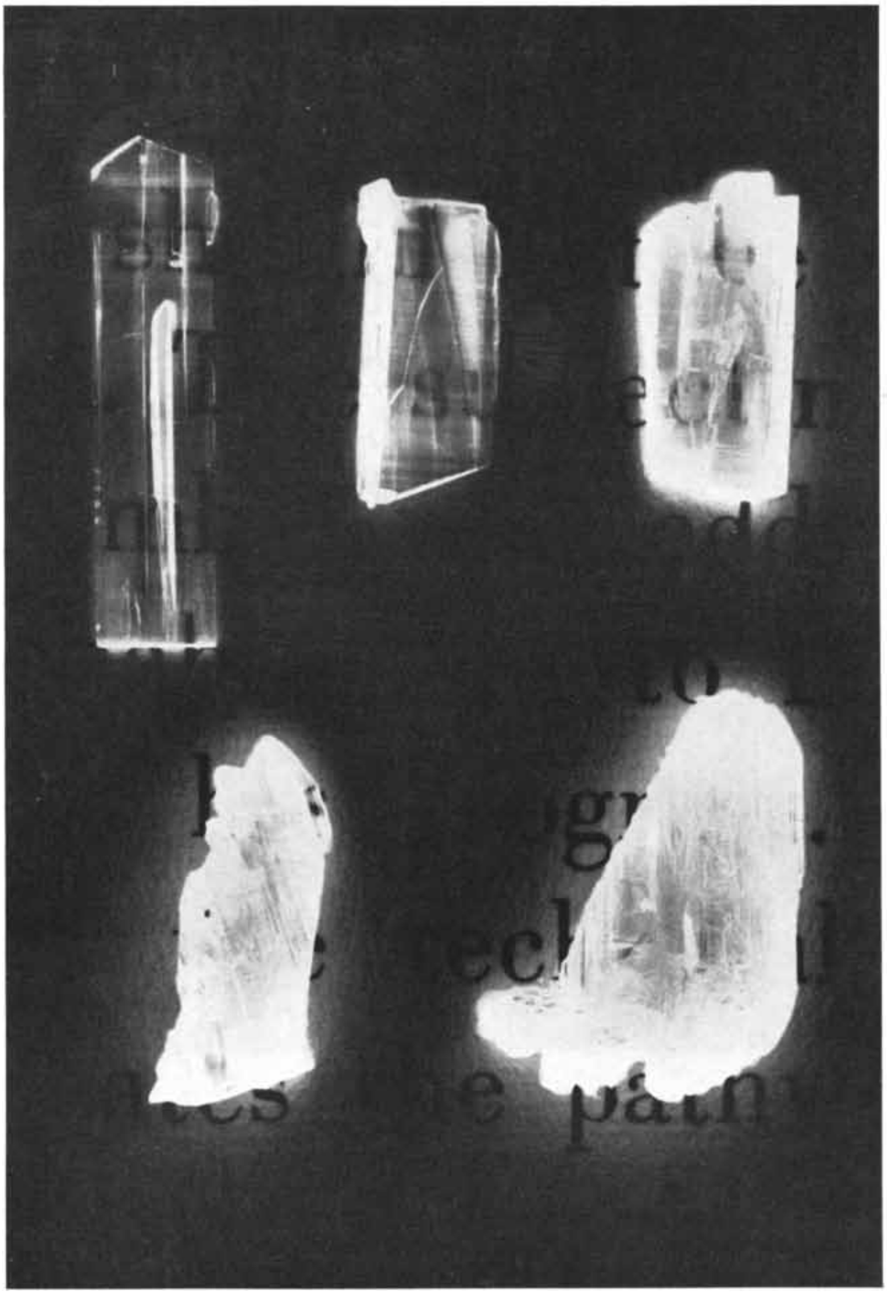


PREPARATION of experimental zinc sulfide phosphor in the General Electric Research Laboratory is accomplished by mixing powdered ingredients in a quartz boat and firing them in an electric furnace at 1,000 degrees in atmosphere of hydrogen sulfide.





SINGLE CRYSTALS are shown photographed by an external light. At left is a spiral form of zinc sulfide; center is cadmium sulfide; at right, potassium chloride activated with manganese. They are not in scale; the first two are five millimeters wide; the third, 20.



PHOSPHORESCENCE of six pure crystals of zinc sulfide is evident in this photograph taken by light emitted from them during excitation from an ultraviolet light source.

and attempts to understand the physics of fluorescence. Most of the development of new phosphors and the improvement of old ones has proceeded along purely empirical lines. Recently, however, detailed studies of the physics of luminescence have enabled us to understand the phenomenon well enough to begin designing phosphors for specific applications from theoretical considerations. For instance, on the basis of studies of one simple phosphor (thallium-activated potassium chloride) it was predicted that use of mercury as the impurity in a material such as the mineral harmotome, a silicate of aluminum, barium and potassium, would yield a phosphor capable of absorbing light at 2,537 Angstroms and emitting blue light. Such a phosphor has already been prepared. As more complicated phosphors are treated theoretically, no doubt more such analogous cases will arise.

In predicting the luminescent properties of a phosphor, the theory of luminescence starts with the properties of the ions that make up the material and the known forces of interaction between them. The only phosphors studied theoretically so far have been those that are the simplest to treat mathematically. The first was the one mentioned above—thallium-activated potassium chloride.

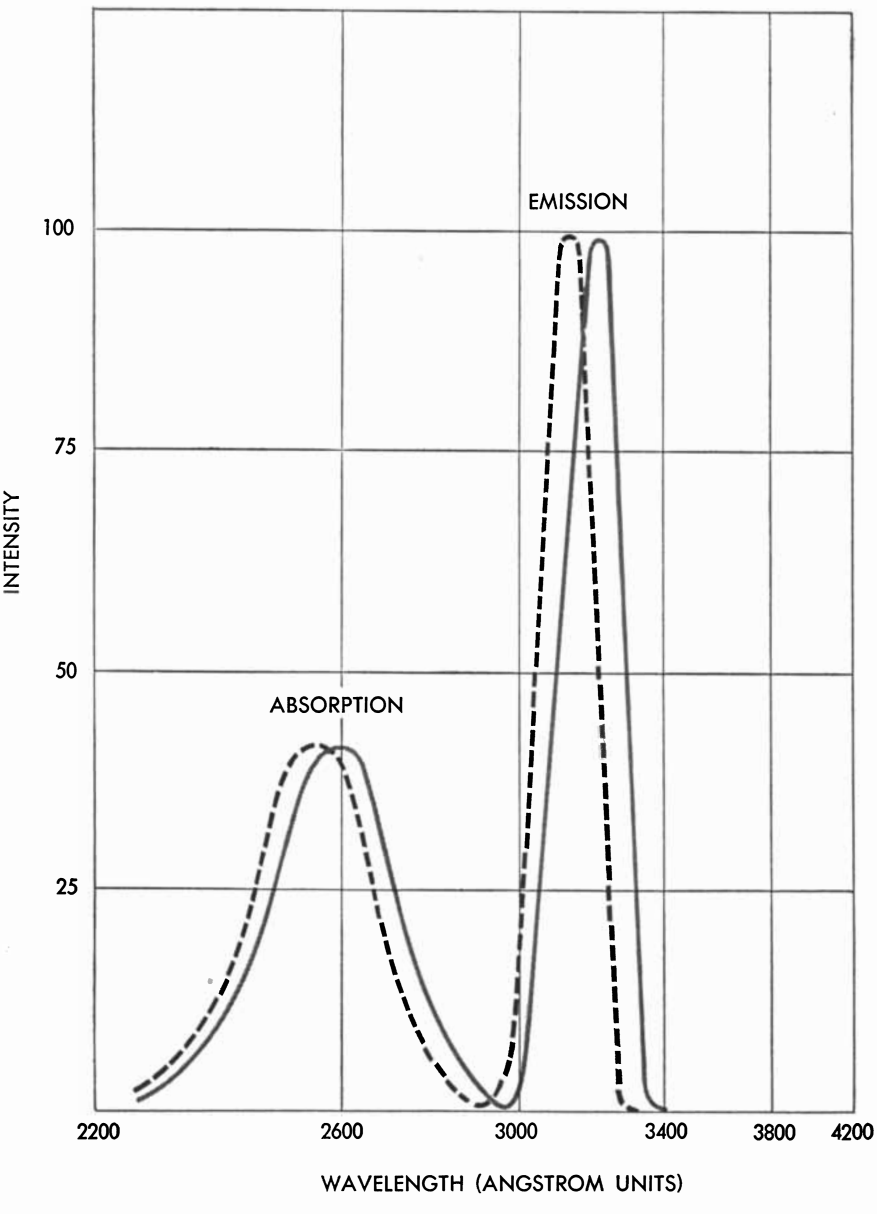
This phosphor consists of potassium chloride with monovalent thallium ions randomly distributed in the crystal, replacing about .1 per cent of the potassium ions. Let us look at one little region of the crystal in the vicinity of a typical thallium ion [*see diagram on page 62*]. The thallium ion is closely surrounded by six chloride ions, and farther away are other chloride and potassium ions. The whole crystal can, of course, be built up by a repetition of this fundamental building block in three dimensions, except that a potassium ion usually sits where the thallium ion is in this diagram.

What holds the crystal together? We first recognize that potassium chloride, being an ionic solid, is built up of positively charged potassium ions and negatively charged chloride ions, which are attracted to one another by virtue of the electrostatic forces between charged particles. When two ions get too close together, however, the overlap of the electron clouds surrounding their nuclei results in repulsion. This force is not due entirely to the electrostatic repulsion between the negatively charged electrons; it can be understood in detail only on the basis of quantum mechanics. At all events, the equilibrium distance between ions in a crystal is regulated by a balance of the attractive and repulsive forces. It takes energy to pull the six chloride ions farther than this distance from the thallium ion or to push them closer to it. Of course the ions in the lattice are not stationary; they vibrate around their equilibrium position.

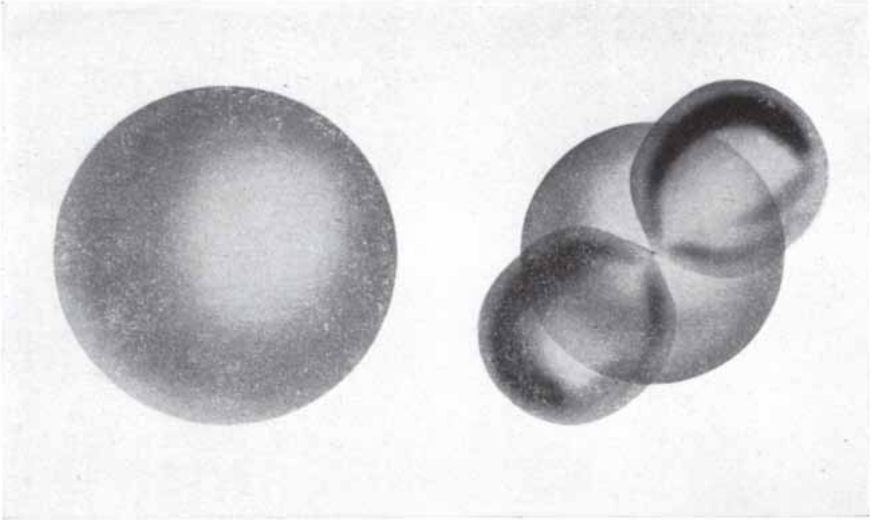
The thallium ion and its six surrounding chloride ions are called the activator system. When the six chlorides are at any given distance from the thallium, we have what is called a "configuration" of the system; the lowest-energy configuration is the one at the equilibrium distance, and those corresponding to higher energies are said to have positive configuration coordinates. The configuration coordinate is the distance between the thallium ion and the surrounding chloride ions. We can show the energy of the activator system graphically as a function of the configuration coordinate if we can calculate in detail what energy is required to move the six chloride ions from their equilibrium position to some new position. This energy can be calculated by the methods of quantum mechanics. It depends on the specific distribution of the electrons around the thallium ion and around the chloride ions, for the repulsive forces are particularly sensitive to these distributions. We would like to re-emphasize that the activator system takes up these various configurations because of the thermal vibrations of the chloride ions around their equilibrium positions.

Now let us see what happens when we shine ultraviolet light on this thallium-activated phosphor. It can absorb only a certain range of wavelengths. Each thallium ion will absorb a photon of this ultraviolet radiation. This absorption will increase the energy of the system by a certain amount depending upon the wavelength of the radiation. In the higher energy state the electrons are rearranged in a different way around the nucleus of the thallium ion. This distribution can again be calculated by the methods of quantum mechanics. Because of the new distribution, the repulsive forces between the thallium ion and the six surrounding chloride ions are less than they were in the unexcited thallium ion. Hence the equilibrium position of the chloride ions is different: they are closer to the thallium ion than in the ground state. The difference in the shapes of the electron distributions in the unexcited and excited states of the thallium ion is shown schematically in the model on the next page.

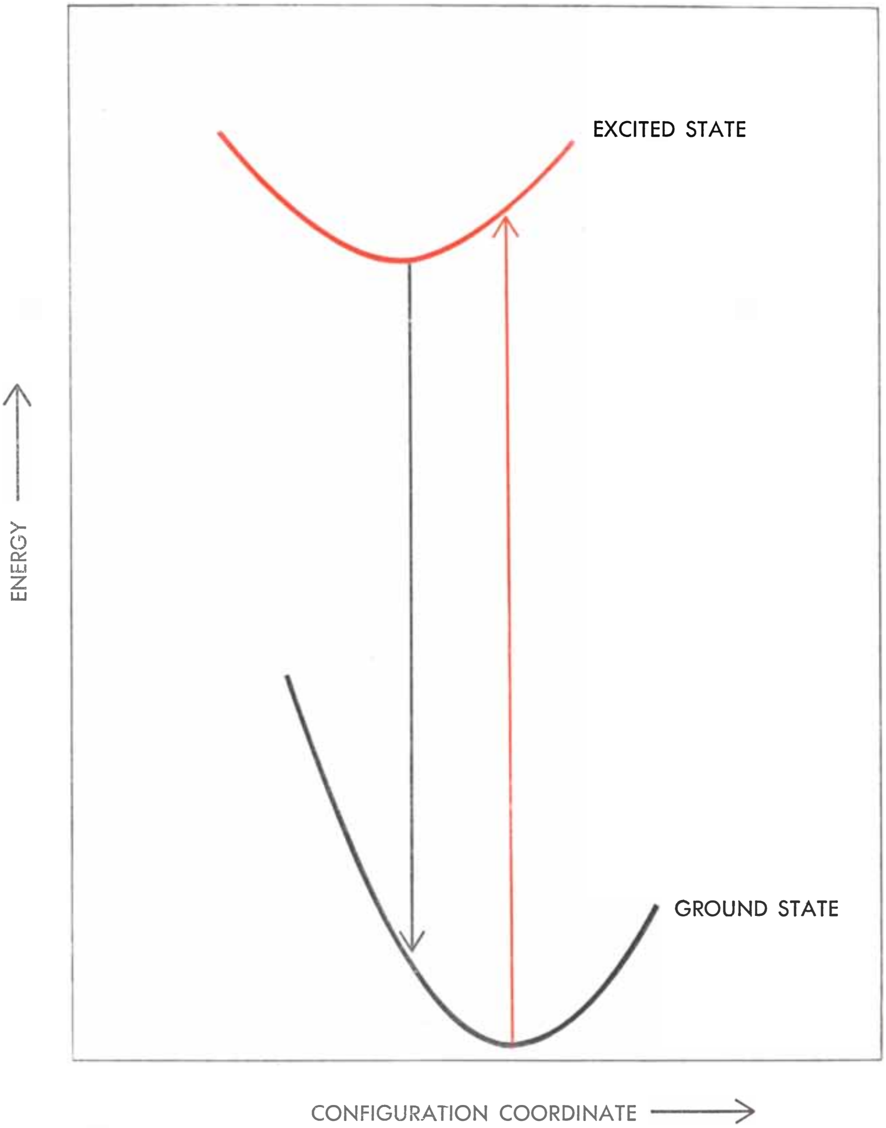
From curves representing the energy configurations in the two states we can derive theoretically the absorption and emission spectra of the phosphor [*see chart on next page*]. The peak of the absorption spectrum will correspond to the energy difference shown by the arrow at the right on the chart, and the peak of the emission spectrum to the arrow on



ABSORPTION AND EMISSION curve theoretically calculated (*solid line*) for thallium activated potassium chloride agrees well with the experimental one (*broken line*). The peak of absorption of light comes at shorter wavelength than peak of emission.



ELECTRON CLOUD of a thallium ion differs in the unexcited state (*left*) from that in excited state (*right*). The model shows difference in electron distributions around nucleus.



ACTIVATOR SYSTEM of the thallium ion is shown by the graph. As it absorbs one photon of ultraviolet light, its energy is raised by the amount of the photon's 5.48 electron volts from the ground state (*lower curve*) to the excited state (*higher curve*). The system comes to equilibrium. Then ion emits one photon of light, returning to the ground state.

the left. The difference in length of the two arrows indicates that the peaks in the absorption spectrum and in the emission spectrum come at different wavelengths. It is this property that makes the phosphor transparent to its own emission, as we have mentioned. The exact shape of the absorption and emission spectra can be calculated from a knowledge of the relative probability of various configurations. The curves of these theoretical spectra come very close to those based on actual observation [*chart on page 65*].

We can sum up the absorption and emission processes in a phosphor briefly as follows: The most probable configuration of the activator system is the one of lowest energy. When we shine ultraviolet light on the phosphor, the thallium ion absorbs a photon of ultraviolet light and is excited to a higher energy state. The energy rise is represented by the length of the arrow at the right in the chart. The activator system adjusts itself to a new equilibrium position, corresponding to the upper end of the arrow at the left in the chart. The difference in energy between this level and that of the tip of the arrow at the right appears as heat, which is dissipated in the crystal. The excited thallium ion now emits a photon of visible light which appears as luminescence, and the energy of this photon is equal to the length of the arrow at the left. The activator system now readjusts itself to its equilibrium configuration in the unexcited state, and again the difference in energy appears as heat. Now the thallium ion is ready to absorb another photon of ultraviolet light and begin a new cycle. It takes about a millionth of a second to complete one cycle.

Although this theory is only in its infancy, it has been applied quite successfully to a simple phosphor, predicting most of the important luminescent properties. The configuration coordinate model recently has been sustained independently by studies of the effects of pressure on the emission and absorption spectra. Furthermore, as we have noted, the theory has already yielded one new synthetic phosphor, and more complicated ones are under investigation.

The approach offers considerable hope of creating phosphors which will greatly improve the performance of devices utilizing luminescence and open up many new, large-scale applications. Fully as important as the applications is our increased understanding of the nature and properties of the solid state.

Priestley

Clergyman and experimenter, he isolated oxygen and other gases. Although he was one of the first scientists of his day, he was forced to choose exile in America because of his political views

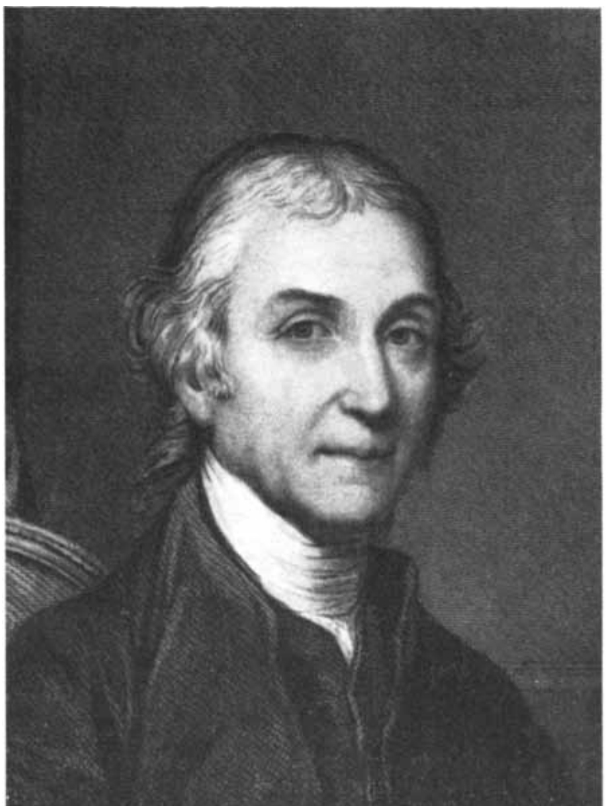
by Mitchell Wilson

On Monday morning, June 9, 1794, the Philadelphia newspaper the *American Daily Advertiser* greeted the arrival of a refugee from England:

"It must afford the most sincere gratification to every well-wisher to the rights of man, that the United States of America, the land of freedom and independence, has become the asylum of the greatest characters of the present age, who have been persecuted in Europe, merely because they have defended the rights of the enslaved nations.

"The name of Joseph Priestley will be long remembered among all enlightened people; and there is no doubt that England will one day regret her ungrateful treatment of this venerable and illustrious man . . ."

The illustrious chemist's flight across the Atlantic to the New World came at the end of a career of embroilment not only in science but also in the social turmoil of his uneasy time. Thirty years earlier Priestley, as a young clergyman, had come to a London teeming with fops, highwaymen, industrious apprentices and geniuses. He was then 30 years old, slender, with delicate, almost feminine features. For an ordained minister he dressed with somewhat worldly elegance. He had gaiety, a quiet wit, and enjoyed his growing reputation as a writer on religious matters. He had a genteel poverty that he took for granted; he also had an incorruptible moral courage.

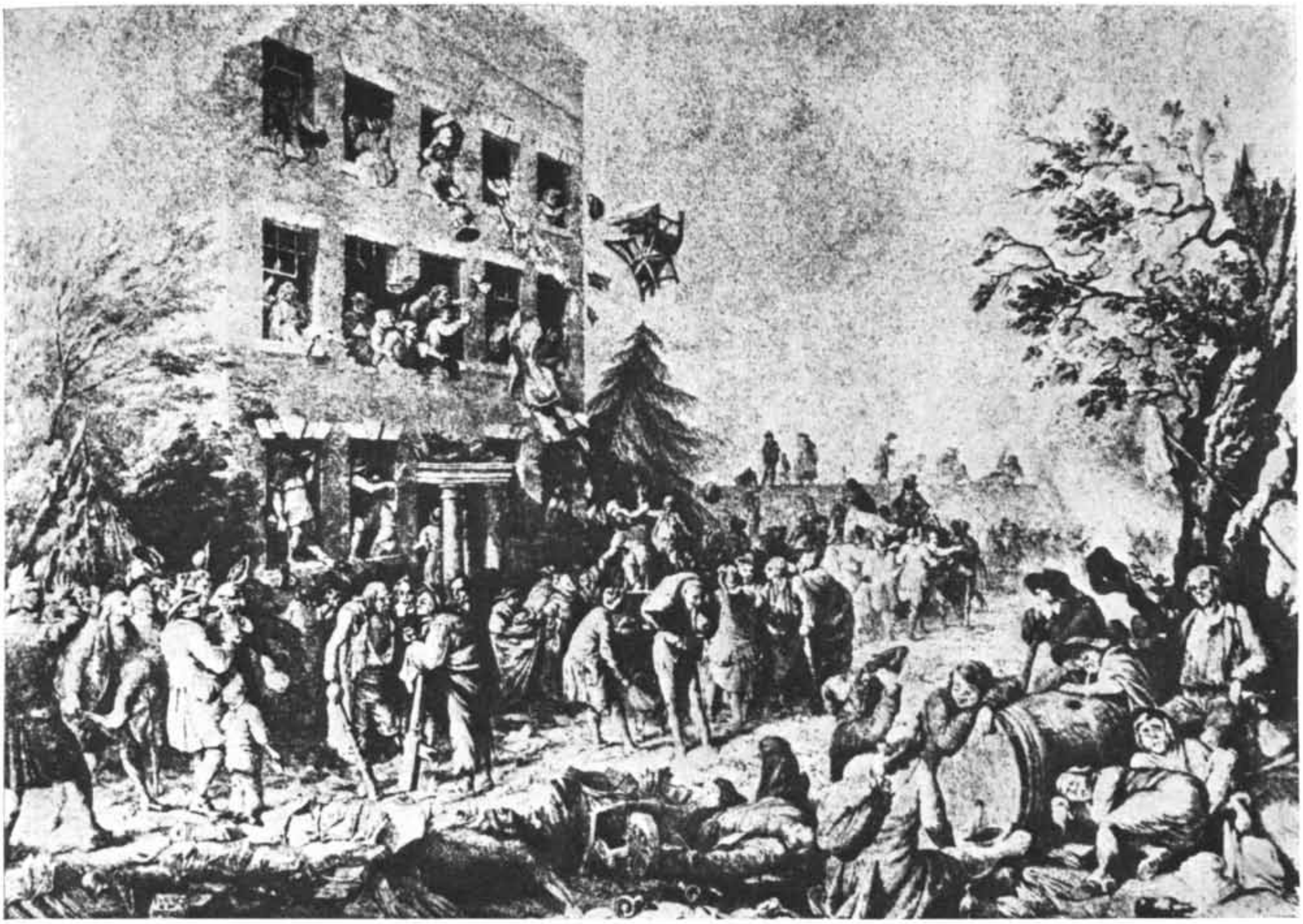


PORTRAIT of Priestley was engraved at the height of his eminence. He fancied rather elegant attire for a minister.

He had come to London to meet the famous philosopher from the American Colonies, Benjamin Franklin, who was at the height of his fame as a scientist. Franklin's experiments with lightning had made him an almost Mephistophelean figure to his European contemporaries. People believed that he was capable of producing a thunderbolt at will, and the very benignity of his bearing made him the more terrible. Although he had been sent to London to plead the cause of the colonies, Franklin found it diplomatic to live the life of a visiting scientist rather than that of a political emissary.

Priestley was a theological polemicist on behalf of what was then considered radical doctrine: Unitarianism. The son of a weaver in the small town of Leeds, he had been orphaned and had been adopted by an aunt, a strong-minded woman of independent temper. She had raised him in an atmosphere of free religious discussion. Because his health was fragile, he had had little formal schooling but had taught himself French, Latin, algebra and geometry. His aunt's influence had turned him to the ministry; he taught at an academy, married a sympathetic, intelligent woman when he was 28 and became a popular writer on theological subjects. No one was less suited to the name of traitor and anti-Christ that was to be fastened on him.

Priestley's visits to Franklin's salon in London, which occurred shortly after his marriage, resulted in a new turn of his career. Up to that time he had taken only an educator's interest in science. Casually he suggested to Franklin that someone ought to write a popular book on electricity; Franklin urged him to do so. From this came Priestley's brilliant work *The History and Present State of Electricity*, which he finished within a year. In writing it he was led to investigate for himself certain disputed points of electrical theory. As it happened, he had a natural flair for research and made some original discoveries, one of which



SACKING of Priestley's home in Birmingham in 1791 is recorded in a contemporary print. The citizens were incensed by Priestley's attending a dinner celebrating Bastille Day. This was taken as proof of his radical views. He and his family narrowly escaped hanging.

was the fact that carbon is an excellent conductor of electricity.

The book was so successful that a year after its appearance Priestley was elected to the Royal Society.

This taste of science was all that was needed to start him on a new life, but it was an accident that led him to chemistry. In Leeds he lived next to the public brewhouse of Jakes and Nell. The odoriferous product of fermentation permeated his house and became the object of his first researches.

Chemistry was still dominated by the ideas of alchemy. Matter was supposed to be made up of a *prima materia* modified by four elements—earth, fire, air and water. By Priestley's day these original Aristotelian elements had been elaborated into various kinds and orders. Earth was differentiated into three varieties—mercurial, vitreous and combustible. There were, in addition to the elements, four spirits—sulfur, mercury, arsenic and sal ammoniac. There were also six bodies—gold, silver, copper, lead, tin and iron. And the "soul" of all matter was phlogiston; by virtue of it, combustible bodies burned.

Priestley set out to make one of the varieties into which air had been divided —"fixed air" (actually carbonic acid). It was commonly thought that sea scurvy was due to an insufficient supply of "fixed air" in the human system. Priestley worked out a method of producing this gas from chalk and sulfuric acid, and he charged water with it by leading the gas through a flexible tube containing traps for impurities. Thus he invented soda water. Priestley explained his method to Lord Sandwich, the First Lord of the Admiralty, and after an investigating commission had given its approval, two shops were set up with his apparatus to supply the Navy. The Royal Society was so impressed with Priestley's achievement that it awarded him the Copley medal, its highest honor in chemistry. The product also won commercial recognition. A Mr. Bewley bottled and sold the preparation under the following formula:

"To prepare Mr. Bewley's julep dissolve three drachms of fossil alkali in each quart of water, and throw in streams of fixed air till the alkaline taste be destroyed. This julep should not be prepared in too large quantities, and should be kept in bottles very closely corked and sealed. Four ounces of it may be taken at a time, drinking a draught of lemonade or water acidulated with vinegar or weak spirit of vitriol, by which means the fixed air will be extricated in the stomach."

Priestley's next scientific project was less happy. The Royal Navy had yielded to the plea of astronomers to send a vessel to observe a lunar eclipse in the South Pacific; the Navy had been looking for an excuse to dispatch an innocent-looking expedition to these waters, and so it outfitted a collier under the command of Captain James Cook, allowed the periwigged scientists to go aboard, and sent it off with sealed orders to Cook to afford the astronomers every opportunity to make observations and then proceed on his true mission: to chart and claim the land mass in the South Pacific known as Terra Incognita Australis. Priestley, eager to go along, was commissioned chaplain to the crew. But at the last moment he was barred from the voyage because his radical theological writings had earned him enemies who charged that he would subvert the men on the expedition.

Priestley resumed his experiments in gas chemistry ("pneumatic chemistry"), which he was to report eventually in his classic *Experiments and Observations on Different Kinds of Air.* His apparatus had the elegance of true simplicity. His method was to place the reaction material in a glass flask partly filled with mercury. He would invert the flask in a trough filled with mercury so that each vessel became a sort of Torricellian barometer. If the chemical reaction generated gas, the additional pressure would push down the mercury level within the flask. On the other hand, if the reaction absorbed one of the gases in the enclosed atmosphere, the mercury level would rise. Thus the change in gas volume was easy to measure. To heat substances in the flask Priestley used the rays of the sun focused by a lens.

Priestley's first discovery was his greatest: the production and isolation of oxygen. He heated what was then called *mercurious calcinatus* (mercuric oxide) and found that the salt gave off four to five times its own volume of gas. When he fed a sample of this gas into an enclosed flask in which a candle was burning, the candle "burned in this air with a remarkably vigorous flame. . . . I had got nothing like this remarkable appearance from any [other] kind of air. . . . the candle burned with splendor . . . and a piece of red-hot wood *sparkled* in it . . . and consumed very fast . . ."

Later Priestley learned that mice lived much longer in his new gas than in an equal volume of ordinary air. In a closed container a burning candle or a live animal somehow "injured" the air so that the flame or the animal soon expired. Priestley realized that he had discovered a way to "restore" the vital element lost from the air. He next found out how nature maintained this element in air. He wrote:

"I have been so happy as by accident to have hit upon a method of restoring air which has been injured by the burning of candles, and to have discovered at least one of the restoratives which Nature employs for this purpose. It is *vegetation.*

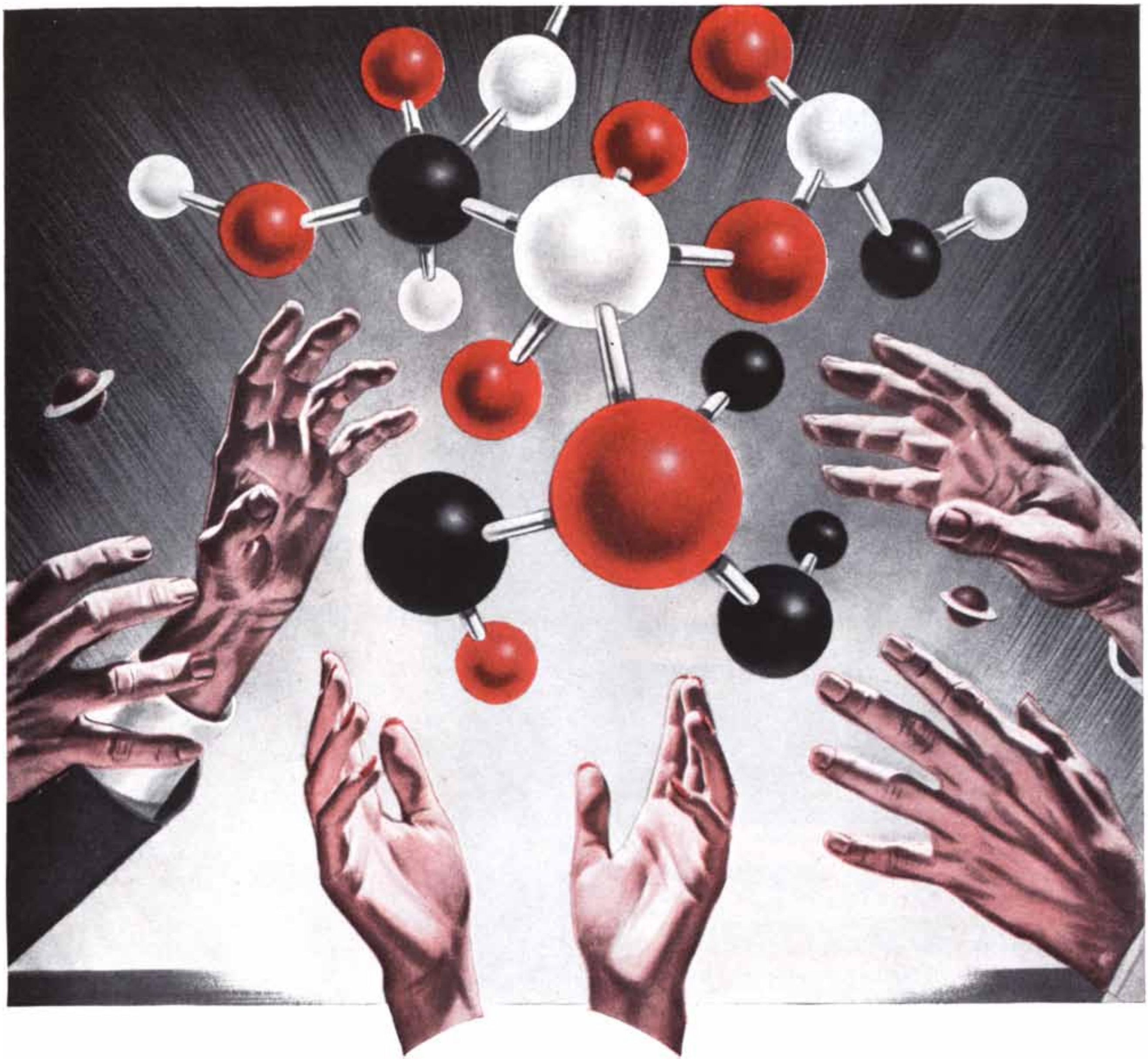
"On the 17th of August, 1771, I put a sprig of mint into a quantity of air in which a wax candle had burned out, and found that on the 27th of the same month, another candle burned perfectly well in it. This experiment I repeated without the least variation in the event, not less than eight or 10 times in the remainder of the summer . . ."

Priestley elaborated the experiment to remove as many extraneous details as possible in order to arrive at the simplest general statement. He demonstrated that the remarkable ability to restore air was not peculiar to mint, for spinach, "sprigs of balm" and the weed called groundsel had the same effect. He concluded: "Plants, instead of affecting the air in the same manner with animal respiration, reverse the effects of breathing and tend to keep the atmosphere sweet and wholesome when it is become noxious in consequence of animals either living and breathing, or dying and putrefying in it."

Priestley, who was so radical in his theological and political beliefs, was extremely conservative as a scientific theorist. He unquestionably accepted and clung to the theory of phlogiston, one of the last remnants of alchemy, and his prestige kept it alive far longer than it deserved. Hardly understanding what he was doing, Priestley isolated for the first time not only oxygen and carbon dioxide but also ammonia ("alkaline air"), nitrogen, nitric oxide, carbon monoxide, sulfur dioxide ("vitriolic acid air") and other substances.

Now recognized as a man of genius in science, Priestley was invited to join the famous Lunar Society in Birmingham, whose members and guests included some leading scientists of the day—the astronomer Sir William Herschel, the

CARTOON of the times lampooned "Doctor Phlogiston," calling him a politician.



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engineer John Smeaton, the botanist Erasmus Darwin, the inventor James Watt. The dozen or so members met at one another's homes each month on the Monday nearest to the full moon. Meetings began with dinner about two o'clock in the afternoon and went on until eight in the evening, when the brilliant moon gave light by which to walk home. Soon after Priestley joined, a member wrote to a friend:

"We have long talked of phlogiston without knowing what we talked about: but now that Dr. Priestley hath brought the matter to light we can pour that element out of one vessel into another; can tell how much of it by accurate measurement is necessary to reduce a calx into contact with any visible thing. In short, this goddess of levity can be measured and weighed like other matter. For the rest, I refer you to the doctor himself."

Priestley spent the next 10 years or so in Birmingham, happily busy not only in chemistry but also writing on education and ethics. Though an undeviating monarchist, he publicly expressed sympathy with the objectives of the American colonists during the Revolutionary War. Priestley might have escaped punishment for this, as many Englishmen did, had he not also come out boldly for the separation of Church and State in England and supported the cause of the French Revolution.

His biographer T. E. Thorpe has remarked that, "great as Priestley's merit is as an experimentarian philosopher, his greater claim on our regard and esteem rests upon his struggles and his sufferings in the cause of civil, political and religious liberty."

On Bastille Day in 1791 Priestley joined a small group of his friends in a quiet celebration of the event in Birmingham. For five days before the celebration a group of hotheads and bigots had distributed pamphlets and broadsides accusing those who planned to attend the dinner of treason, and threatening Priestley and his family with hanging. Ignoring the threats, Priestley and his friends had their dinner at noon in a private dining room without interference, but in the evening trouble began. A hysterical mob put the two dissident churches in Birmingham to the torch and set out to burn down Priestley's house and lynch him and his family. A female neighbor of Priestley gave this description of what happened when news of the mob's approach arrived and her father went out to try to halt it:

"Arriving at Dr. Priestley's gate before the mob, he stationed himself withinside until the mob came up, and then addressed them, endeavoring to induce them, by fair words and money, to desist and return home. They seemed inclined to listen, till one more loud than the rest, and who had the appearance of a ringleader cried out, 'Don't take a sixpence of his money: in the riots of '80 in London a man was hanged for only taking sixpence!' and began to fling stones. My father, then finding it rashness to brave two or three thousand men, turned his horse and rode . . . off."

While Priestley and his family took refuge with friends, the howling crowd looted his house, scattered his papers, battered down the walls and made a bonfire of the debris. Several hours later the mob went in pursuit of Priestley. He and his family escaped in a coach with only a few minutes to spare. They reached London after a week of roundabout traveling.

In London many people were shocked at the news, but many more felt that where there was smoke there must be fire: the Priestleys must be disloyal. A servant of a family living on the same street asked for her release because she dreaded being so near the infamous Dr. Priestley. Members of the Royal Society began to cut Priestley dead. His sons could not be placed anywhere, and the young men sailed to America. England was entering that 30-year period of repression which was to send shiploads of political nonconformists to Botany Bay or to the gallows.

After two years in London Priestley, realizing that he would never be able to live and work in peace in England, decided to follow his sons to Pennsylvania. In the new nation he became a welcome visitor of George Washington in retirement. He preached to a congregation that included President John Adams, and became a close friend of Thomas Jefferson. However, he refused a professorship and later the presidency of the University of Pennsylvania, preferring to live quietly. His favorite son died, and shortly afterward his wife, who had never recovered from the shock of the Birmingham riots.

But Priestley's American exile was not entirely passive. He demonstrated and explained his marvelous experimental techniques to James Woodhouse, John Maclean and Robert O'Hare, the pioneer U. S. chemists who began the process of forging that science which, more than any other, was to lead the way in exploring and exploiting the wealth of the American frontier.

THE SUN NAVIGATION OF ANIMALS

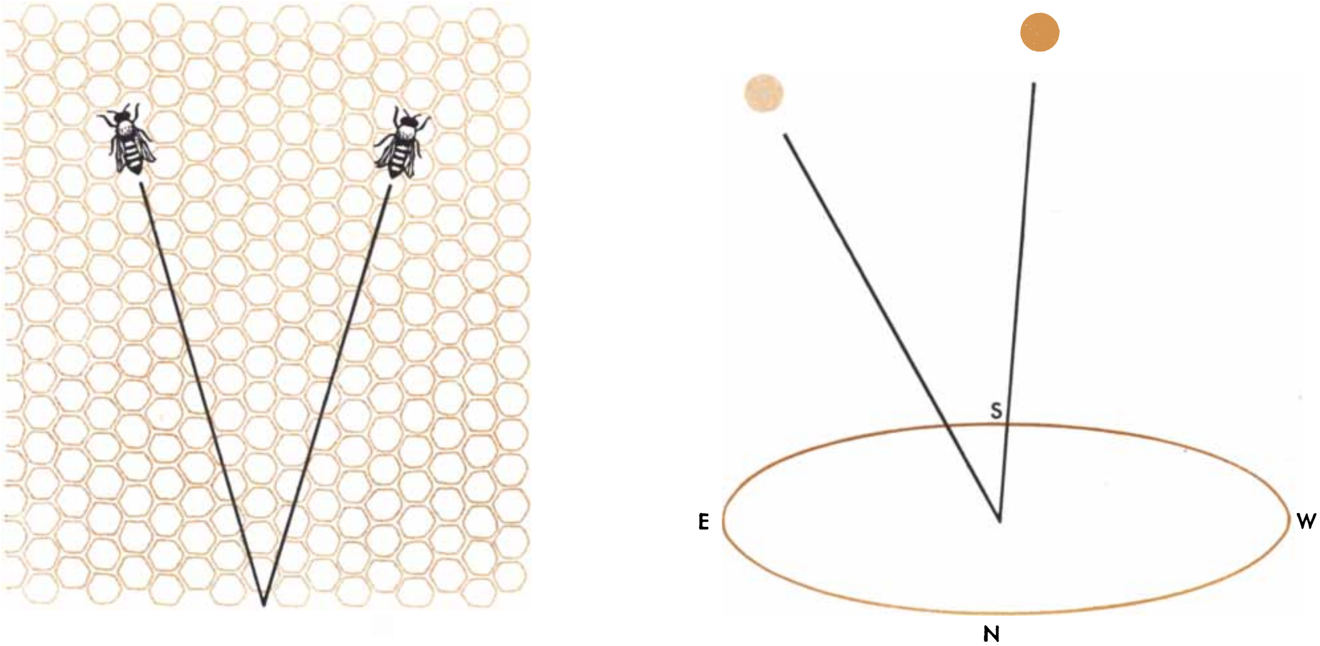
Observation of such diverse creatures as bees, birds and a tiny crustacean indicates that they possess a common faculty to use the sun as a compass and a clock to guide their travels.

by Hans Kalmus

Homo sapiens has two general methods of navigation: he can guide himself by landmarks or steer a course in a specified direction (using a magnetic compass, the stars or some other indicator). Curiously, man has always been considerably mystified as to how the lower animals navigate. Presumably they too, or at least some of them, use the same two methods, but this is not easy to prove. That many animals can recognize landmarks has been definitely established. But as to whether animals possess a sense of direction, and just how it may operate, there has been much dispute. Attempting to account for the accurate navigation of birds, experimenters have tested various wild hypotheses—such as that birds have a magnetic sense or can perceive the Coriolis force due to the rotation of the earth—invariably with devastating consequences for the hypothesis. If animals have a built-in "compass," it is extremely subtle.

This article will describe certain remarkable experiments of the past two years which show that such diverse creatures as birds, bees, ants and crustaceans do possess a direction-finding mechanism. They can navigate by the sun and, in some cases, even by the moon!

Let us take first the bees, whose navigational powers are best known, thanks to the remarkably ingenious Austrian investigator Karl von Frisch. Bees remember the direction of a food site from the hive and can communicate this direction to their fellow bees by a dance on the comb in the hive ["The Language of the Bees," by August Krogh; Scientific American, August, 1948]. They locate the direction by its angle with respect to the position of the sun. Now von Frisch has demonstrated that in doing so the bees "take the hour of the day into account." In one experiment he placed a syrup dish about 200 yards west of a beehive. After the bees had fed at it for several sunny days in

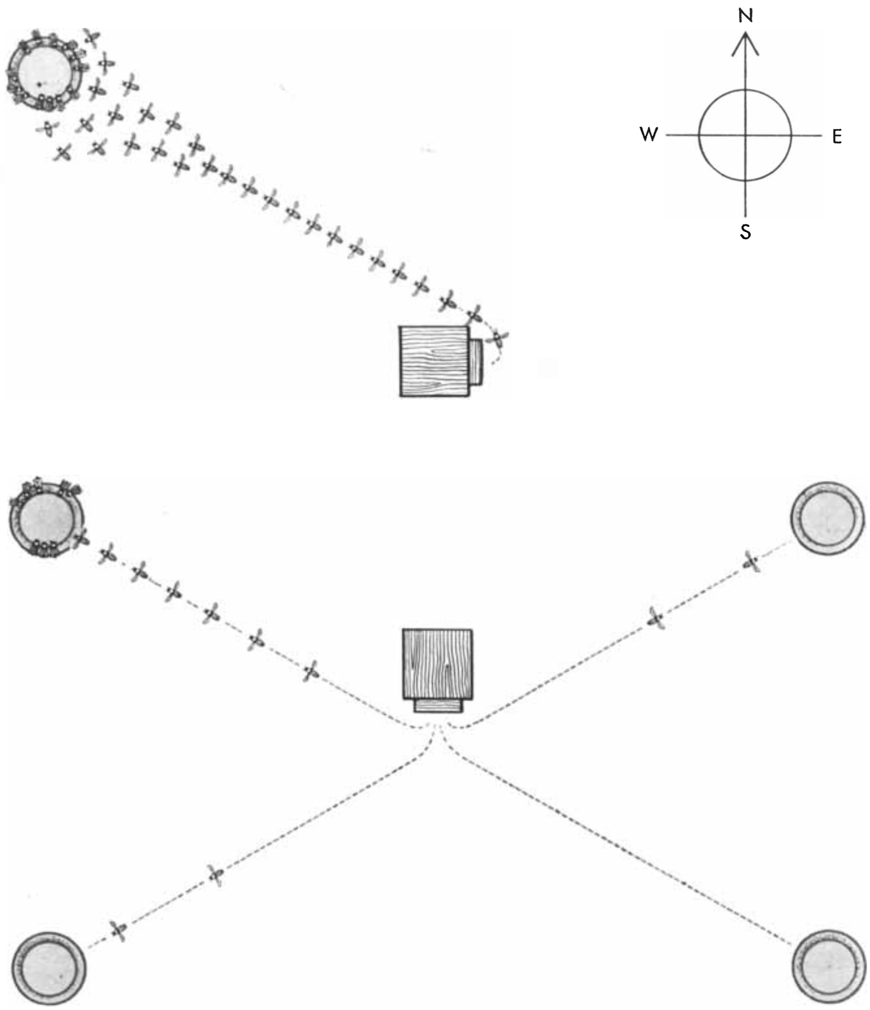


WORKER'S DANCE on face of hive shifts in direction by angle of 33 degrees as sun moves almost the same number of degrees across the sky. Deviation of dance from sun's azimuth, which tells direction of food source to other bees in hive, is thus held constant.

succession, he abruptly moved the hive one night to a new neighborhood, and this time he placed four identical syrup dishes at the same distance in four different directions—north, east, south and west. The next morning 20 out of 29 foragers from the hive visited the dish to the west; only seven were found at the other three dishes. The remarkable feature was that the bees still went to the dish in the West although the sun was in a different position; when they had last fed, the preceding afternoon, the sun stood in the West, and now it was in the East.

That the bees were taking the movement of the sun into account was further demonstrated by their dances. The angle the bees took in their dance on the vertical comb in each case precisely showed the angle of deviation of the food site from the azimuth of the sun. On one occasion a pupil of von Frisch, watching a bee during an unusually long dance of 84 minutes, observed that the main axis of the dance gradually shifted counterclockwise; at the end of the 84 minutes, during which the sun's azimuth had swung around 34 degrees, the dance axis had shifted almost exactly the same amount—33 degrees.

By other experiments von Frisch excluded the possibility that the bees were guided by nonsolar clues, such as the direction in which the hive entrance faced. Finally, if any further proof were needed it was furnished by the fact that on two heavily clouded days, when the bees could see neither the sun nor the polarization of the light in the sky, they lost their sense of direction and visited dishes at all points of the compass indiscriminately.



CONTROL EXPERIMENT confirmed role of sun in bees' navigation. At top, bees are trained to go to feeding station toward northwest. Below, with hive moved to distant site and with direction of hive entrance changed, bees still make for feeding dish to northwest.

To investigate the navigation of birds, Gustav Kramer of Germany did experiments similar to those of von Frisch on bees. Working with starlings, he set up in their cage a ring of 12 feeding stations spaced at equal 30-degree intervals around the circle. Then he trained the starlings to look for their food in a station in a particular direction. The surroundings were screened from the birds so that they could see only the sky overhead. The birds soon learned to search for the food in the right direction at any time of day. They succeeded only on sunny days, however; when the sky was overcast they hunted at random.

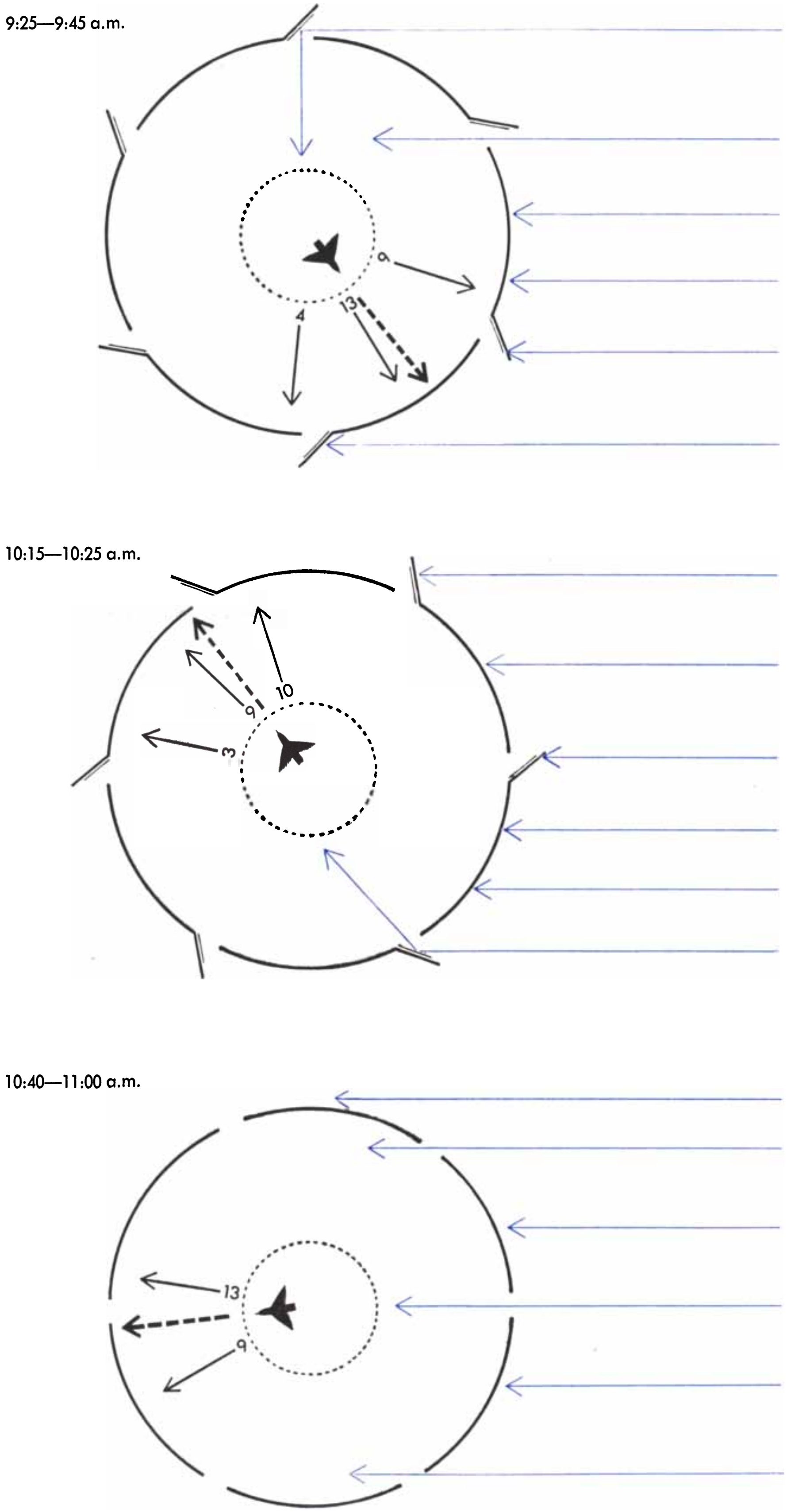
Even more interesting were experiments in which captive starlings demonstrated their homing sense of direction. In an outdoor aviary near Wilhelmshaven, Kramer had a group of young starlings which were thought to have come from the East Baltic area. When the migrating season began in the fall, he observed that they showed a distinct tendency to fly eastward in the aviary, as if they wished to head for home and knew the direction. The birds faced east even when they were put in a small round cage only two feet in diameter. Just to make sure that the starlings had no magnetic sense, he placed around the cage a great mass of iron which completely altered the direction of a compass needle; it affected the birds' flight not at all.

In the most remarkable experiment of all, Kramer used a covered hexagonal pavilion with a window in each of the six sides. When he attached a large mirror to each window so that the sunlight entering the cage was deflected by 90 degrees, the birds' predominant direction of flight also shifted by 90 degrees, and in the same direction. When the skies were overcast, the starlings lost their sense of direction entirely. This phenomenon has occasionally been observed during birds' free migrations.

Kramer was even able to train starlings to use a bright lamp, which they apparently accepted as a substitute for the sun, to guide their sense of direction. He also undertook to test an observation of the English investigator G. V. T. Matthews, who has claimed that birds are able to guide themselves by the sun's height in the sky at any season, in spite of the seasonal variations. Kramer was not able to confirm this.

We shall pass over the ants simply with mention of the fact that there is a species of Australian termite (*Hamitermes meridionalis*) which is called the compass termite, because it builds its boardlike mounds to face precisely North and South. Presumably temperature considerations are responsible for this practice, but no one knows how the insects orient the structures so exactly.

The most intriguing exhibit in the



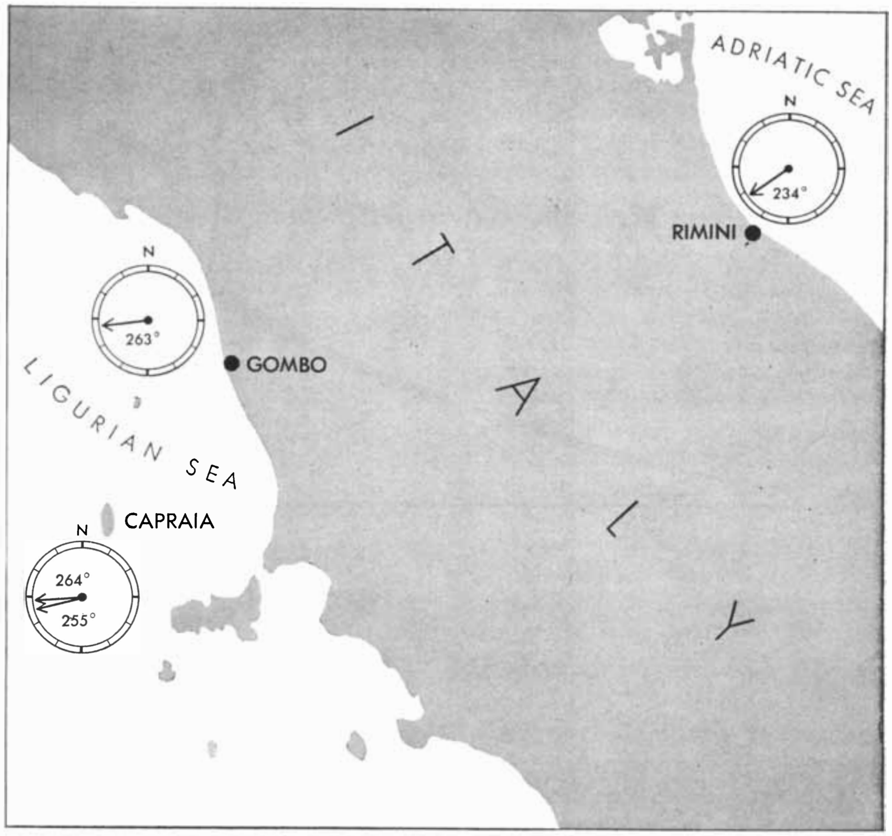
NAVIGATION OF BIRDS was shown by this experiment to be dependent on sun. Mirrors in windows of building were used to deflect sunlight (colored arrows). Direction of starlings' flight was deflected as light was deflected. Numbers indicate frequency of flight in each direction indicated by a black arrow; a broken arrow indicates the mean direction in each case.

whole gallery of navigating animals is *Talitrus saltator*, a little shrimplike crustacean which lives in the millions along the sandy shores of Europe. A person strolling along the shore can see them scurry toward the water when his approach disturbs them. The creatures dwell in the intertidal zone along the sea, moving toward less moist ground when it becomes too wet, and toward the water when the terrain is too dry.

Recently two Italian scientists, L. Pardi and F. Papi, have investigated the sense of direction of these animals. When Talitrus were taken away from the shore and released inland, they headed straight for the coast from which they had come. Pardi and Papi placed a number of the animals inside a circle rimmed with sticky material; most of them were later found trapped on the side of the circle toward the sea. Within a glass dome, similarly, most of the Talitrus clustered on the side toward the water from which they had been taken. The investigators noticed that they tended to move toward the sun before they headed in the sea direction.

By systematic experiments Pardi and Papi excluded the possibility that the sight of the sea or the sight of shore objects or the slope of the terrain was the clue that guided Talitrus. Indeed, even when they took the animals to the coast on the opposite side of the Italian peninsula, the crustaceans still moved toward the coast from which they had come, away from the nearby water. Their instinct said that their home lay to the east or the west, as the case might be, and they migrated inexorably in that direction. This was true whether Talitrus were taken from the Adriatic Coast, the Tyrrhenian Coast or an island in the North Sea. In some manner a "compass" within them was set in a certain direction, and they almost invariably followed it. The experimenters have not yet been able to determine whether this setting is inherited or acquired early in life; there may be a clue in the fact that after two days in captivity the animals begin to lose their sureness of direction.

It was not difficult to prove that the animals were guided by the sun and that the "compass" compensated for the movement of the sun across the sky as the day went on. A mirror experiment which changed the direction of the sun, as in the case of Kramer's starlings, also diverted Talitrus from the true line to the shore. The crustaceans responded to the polarized pattern of the sun's light in the sky as well as to direct sunlight: when a polarizing screen was placed over them, the direction of their move-



NAVIGATION OF CRUSTACEAN, ***Talitrus saltator,*** **shows dependence upon sunlight. These tiny shrimplike creatures swarm on beaches and are commonly observed to hop toward the water. When moved from east coast to west coast of Italy, however, they persist in hopping in accustomed easterly direction, even though this takes them away from water.**

ment could be altered by rotating the screen. When the sky was heavily overcast, the animals were disoriented. Pardi and Papi found that some daily and seasonal factors slightly modified Talitrus' orientation; they hope that these clues may lead to enlightenment on the mechanism by which animals use the sun for navigation.

The experiments so far reported may seem incredible enough, but Pardi and Papi went on to discover an even more astounding surprise. They decided to investigate the orientation of the crustaceans at night. In a dark room or on a moonless night in the open, Talitrus generally had no particular sense of direction, though occasionally they did seem to find guidance in the direction of the coastal winds. But when the moon shone, the animals showed a marked recovery of their orientation. They responded to mirror deflections of the moon's direction just as to deflections of the sun. What was more, they apparently took into account the movement of the moon, although the moon's travels across our sky are far more complicated than those of the sun! If Pardi's and Papi's experiments and interpretations are confirmed, here is the first convincing demonstration of the use of the moon for navigation by an animal other than man.

All these findings compel us to conclude that the sense of geographical direction, guided primarily by the sun, is more fundamental and "primitive" than man has supposed. It is well known, as a matter of fact, that very primitive peoples have an uncannily accurate directional sense. Probably in their case, and certainly in the cases of the animals discussed in this article, navigation by the sun, with compensation for its daily movements, is not a conscious or abstract mental operation. It must depend basically on the combination of two faculties: namely, the perception and accurate memory of angles and a reference system which shifts with the daily movements of the sun—a "time sense." In anthropomorphic language, a compass and a clock are needed for sun navigation. Both are controlled by the sun itself. Both faculties are also of wide occurrence in the animal kingdom and, indeed, among plants.

Whether these faculties are hereditary or acquired, and how many animals possess them, is as yet anybody's guess. The whole subject remains a fascinating invitation to further research.

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ADAM AND EVE in the Garden of Eden were painted by an unknown artist about 1710 on a door panel of an apothecary in Calw, Germany. Contemplating the races, this pious artist or his patron deduced that the original parents of mankind must have been of different hues. Thus he placed in Paradise two progenitors of the most colorful dissimilarity to explain the persisting diversity.

The Biology of the Negro

In America the continuing amalgamation of Africans, Caucasians and Indians is forming a people of mixed genetic character. Centuries hence students may ask, "What became of the Negro?"

by Curt Stern

The history of many species of life on this earth is a long story of diverging from a common descent into separate lines, then remixing, new separations, remixing again and so on. Such is the evolutionary history of those divisions of mankind vaguely called races, tribes or ethnic groups. The races of man have been subject to the opposing processes of separation and amalgamation. We are witnessing in North America in this millennium one of the instances of the intermingling of two human groups. Within the same country live white and Negro races which, though segregated in certain ways and in certain places, have a great deal in common. The Negro in America is no foreigner, either geographically or culturally. How far is the amalgamation of these groups likely to go? What is the probable genetic future of the whole population of the U. S.?

The drama of racial relations in our nation stems largely from the conspicuous differentness of the Negro from his neighbors in the color of his skin. We must consider how deep-seated, or superficial, the biological differences between these groups may be.

The American Negro is a new group of mankind which came into existence only 300 years ago. He is the product of the mingling of three main races—African, Caucasian and American Indian. None of these races, of course, was ever "pure." The Indians were a population of diverse tribes, and the Caucasians came from different breeds in northern, central, southern and western Europe. It appears that the Africans themselves were the most diverse group of all. Imported from almost every part of Africa and from way stations such as the West Indies, the Negro slaves brought to America were of many types, some of them hybridized with Caucasians.

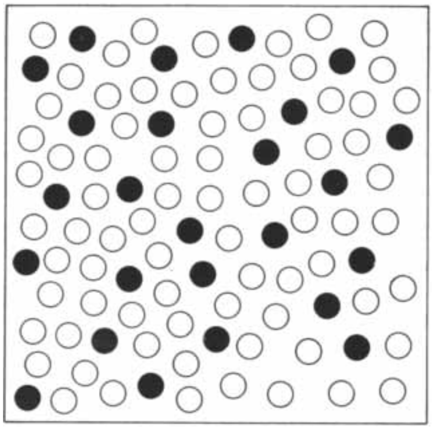
Since the Negro's arrival in North America there has been a great deal of miscegenation—just how much was long a matter of conjecture. Some 25 years ago the anthropologist Melville J. Herskovits, of Northwestern University, made the first reasonably large-scale survey, interviewing a sample of more than 1,500 U. S. Negroes. Of these, 78 per cent claimed some Caucasian or Indian ancestry; only 22 per cent considered their background exclusively African. To be sure, these figures are not to be taken too literally. For one thing, the respondents may have exaggerated the amount of Indian parentage; it was surprising to learn that 27 per cent of them claimed forebears among the small Indian population. For another, the figures give a misleading impression of the extent of the contribution of Caucasian genes to the Negro population. Assume that four Negro children share the same grandparents and that three of these were Africans and one a Caucasian. Then all four grandchildren rightly claim some white ancestry, although the actual Caucasian contribution would be only one quarter.

Today, a generation after Herskovits' study, it is likely that more than 78 per cent of U. S. Negroes would testify that they had mixed ancestry; indeed, a small recent sampling confirmed this expectation. Probably by 1980 there will hardly be a single Negro in the U. S. who can claim a purely African descent.

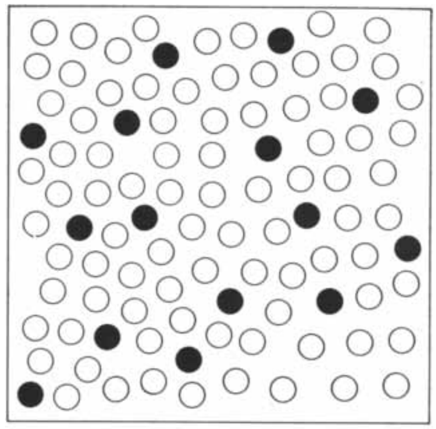
Can we measure the contributions of the various ancestries to the present Negro stock by genetic yardsticks? One might suppose that from comparative studies of skin color, nose width, hair form and other measurable traits a human geneticist could deduce that x per cent of the American Negro's makeup came from his African ancestry, y per cent from Caucasian forebears and z per cent from Indians. Unfortunately the workings of heredity are not as simple as this. Often a hybrid exhibits a trait like that of one parent instead of somewhere between both, so that the mixing is hidden; for example, the hair of the first generation offspring of a union between a Negro and an Indian is straight like that of the latter, and the hair of a Negro-white hybrid often is nearly as woolly as that of the African. Then too, in later generations the interplay of the different genes in development obscures any quantitative relation among the original contributions.

One excellent, simple guide to racial heredity is offered, however, by the blood groups [*see* "Rh and the Races of Man," by William C. Boyd; Scientific American, November, 1951]. Knowledge of the blood-group makeup of a population furnishes knowledge of its corresponding genic makeup. Usually the differences are only differences in relative frequencies; for instance, Africans have more blood of the O type than Caucasians, while there are more persons with blood of the A, B and AB types among the latter. The blood makeup of the American Negroes is intermediate between the African and Caucasian, and from the observed frequencies it is a matter of simple arithmetic to calculate that about two thirds of the genetic building material of the U. S. Negro comes from Africa and about one third from Europe.

An important question remains. Are the genes evenly mixed in this fashion through the whole Negro population, or are there large numbers of people with nearly 100 per cent African genes and other large numbers whose Caucasian fraction is higher than one third? A casual observer might be inclined to answer without hesitation that the latter



CAUCASIAN people sampled in the U. S. possess more type A blood than do Negroes. Twenty-five per cent have this type.



AFRICAN people sampled show 15 per cent have type A blood. (The black circles indicate per cent.) Genes determine blood type.

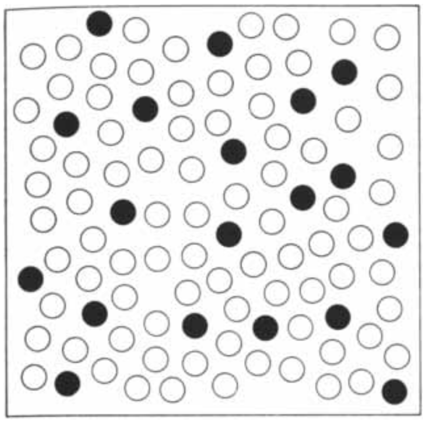
is the case; he would classify the dark, thick-lipped Negroes as unmixed descendants of Africans and the light, thin-lipped ones as hybrid. But such reasoning neglects the simple fact, discovered by Gregor Mendel, that the second-generation offspring of a cross between white and colored peas have either white or colored flowers, giving no indication of their mixed ancestry. Similarly the appearance of a human being may be deceptive. The shuffling of the cards—as the recombination of genes in the course of reproduction has been called—sometimes produces hybrid traits and at other times pure traits in different offspring of the same hybrid parents.

There are, however, ways to approach this problem. One can measure the degree of association of different racial traits. The traits are more or less independent of one another; for example, there are many Negroes with dark skin and thin lips, and many others with light skin and thick lips. If a large proportion of the Negro population has no Caucasian ancestry, then we should expect that a correspondingly large proportion should have both dark skin and thick lips. The matter has been investigated, and it has been found that the combination of dark skin and thick lips is indeed more frequent than would be expected according to chance—but it is not much more frequent. This indicates that the mixture of genes has percolated fairly generally through the Negro population.

Another approach is geographical: Do groups of Negroes in different parts of the country differ in genetic makeup? The answer again is no: the average pigmentation of Negroes in various sections—Mississippi, West Virginia, Kentucky, New York—is about the same, and so is the range of variability in these sections. This test also, therefore, seems to indicate that the Negro population is fairly homogeneous.

Trying a third approach, Herskovits obtained somewhat different results. He questioned students of Howard University regarding their ancestry, and divided them into four classes: (1) strictly African, (2) more African than Caucasian, (3) more Caucasian than African, and (4) about half African and half Caucasian. Now no such division would have been possible if all or most American Negroes were alike in their degree of white admixture. Perhaps the extent of this differentiation may be questioned on the ground that the individuals may not really have known their background but inferred it from their appearance. In any case, the study was made about a generation ago, and the present generation of Negroes undoubtedly has reached a greater degree of homogeneity.

A fourth approach to the question as to the homogeneity of the Negro population lies in a study of its mating practices; *i.e.*, with respect to skin color does like marry like, or unlike, or without discrimination? Here the evidence is conflicting. Some observations indicate that Negro men tend to marry women lighter than themselves. (The studies are silent on the marriage prospects of dark women!) Other studies seem to show a tendency for Negroes to choose mates of about their own hue. Not only is this evidence inconclusive but we must take into account that legal marriages are not the only means of disseminating genes. The extent of illegitimacy is considerable and is presumably very much less assortative than official unions. On the whole it seems reasonable to assume that the degree of marriage of like by like is quite insufficient to slow down appreciably the approach to



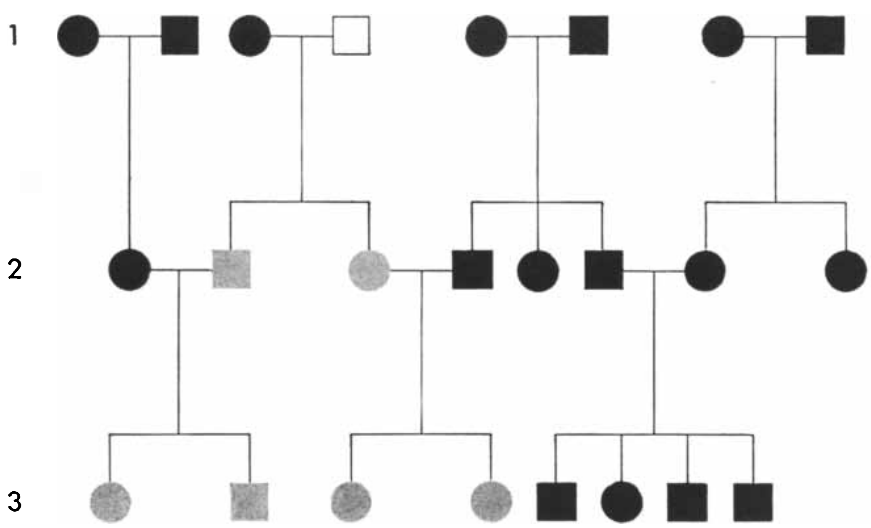
AMERICAN NEGROES sampled proved to have 19 per cent type A genes, indicating ⅓ Caucasian and ⅔ African ancestry.

genetic homogeneity of the U. S. Negro.

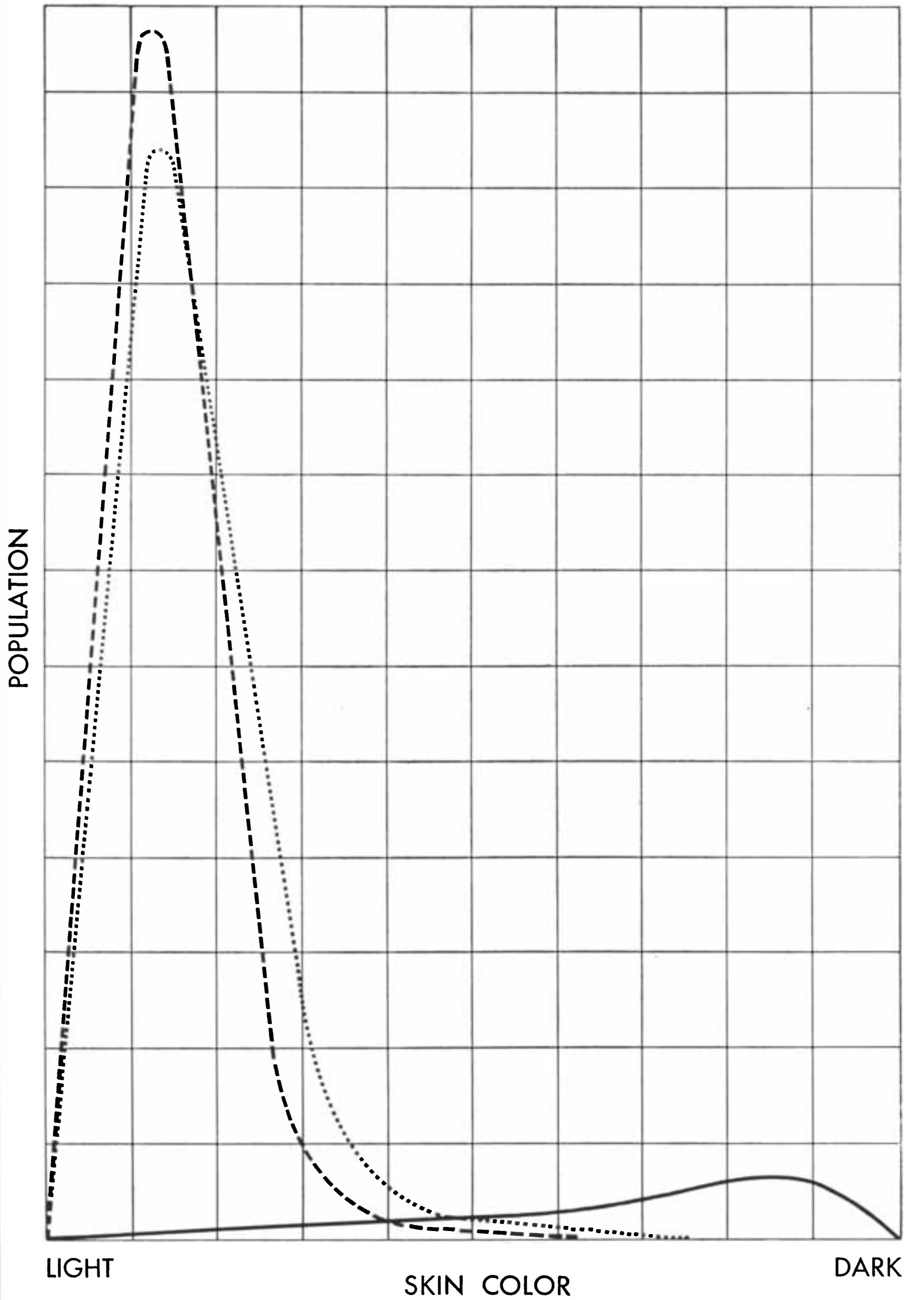
Homogeneity of course is not the same as uniformity. Homogeneity means that any sample of the Negro population will resemble closely in its total genic content, one might say in its corporate holdings, any other sample: two thirds of the genes for all traits come from African sources and one third from Caucasians. This setup results in anything but uniformity. It produces the whole range of skin color from white to deep black, the whole range of lip dimensions from thin to thick, the whole range of all other traits in which the component races differed. Any combination of the different traits may be expected.

Has this new group, the American Negro, synthesized any peculiar features of its own? There used to be a belief that the mulatto was sterile, or at least of low fertility, by analogy with the mule, a hybrid of the horse and donkey. How times have changed! There is no longer doubt about the basic fertility of the Negro-white hybrid. It is true that the growth of the Negro population in the U. S. (from about 750,000 in 1790 to about 15 million in 1951) has been less rapid than that of whites; they have fallen from over 19 per cent to less than 11 per cent of the total population. But a good part of the relative increase of the whites was due to large-scale immigration and to the high fertility of the immigrants. The birth rates among Negroes probably have been higher than among whites during most of the history of the U. S., but that edge has been more than counteracted by the Negroes' very high mortality rates, especially among infants. In recent decades their balance of births and deaths has approached that of the rest of the population, and the Negro increase has kept in remarkable step with that of the whites. At present it is safe to say that the Negro will not die out, as predicted with assurance as recently as the 1920s, or soon replace the whites, as announced just as boldly some time earlier. The ratio of the two groups probably will not change much in the coming decades. Beyond that immediate future, however, prediction becomes very difficult.

For the long run, there seem to be no inherent biological weaknesses in the Negro which place him at a disadvantage. Socio-economic factors are largely responsible for his higher infant mortality, venereal disease rate and alcoholic psychoses. It is quite possible that the Negro has a hereditary predisposition to tuberculosis, but on the other hand he seems to enjoy more immunity than



PEDIGREE of generations descended from seven "unmixed" African ancestors (*dark forms*) and one "unmixed" Caucasian (*white form*) shows the percentage of descendants with mixed ancestry (*light gray forms*). Fifty per cent of the third generation are mixed.



SKIN COLOR distributions in the U. S. are plotted as curves. The dashed curve shows distribution of color shadings among whites. The solid curve shows the color among Negroes. Complete amalgamation would produce a shift toward the dark as shown by dotted curve.

whites to some types of cancer, particularly cancer of the skin.

Last but not least we must consider intelligence. A generation ago most students of race were inclined to credit the Caucasian with a higher intellectual endowment than the Negro. Opinion has changed greatly. While there remains a group of believers in the mental inferiority of the Negro, the majority today holds this proposition to be unproved. All tests of intelligence involve so much culturally loaded material that they lose most of their meaning in comparisons of different groups' native endowment. The one truly significant fact that has emerged from these tests is the showing that the range of measured "intelligence" is as wide among Negroes as among whites. Many Negro children score 140 or higher in the Stanford-Binet tests; one Negro girl scored 200! That Negroes as a group have had a lower mean score than whites in several samplings is undoubtedly due largely to socio-economic and cultural disadvantages.

Those who point to the lack of many high accomplishments by the Negroes of Africa might ponder Lord Raglan's recent words:

"It has been said against the African Negroes that they never produced a scientist; but what kind of a scientist would he be who had no weights and measures, no clock or calendar, and no means of recording his observations and experiments? And if it be asked why the Negroes did not invent these things, the answer is that neither did any European people, and for the same reason—namely, that the rare and perhaps unique conditions which made their invention possible were absent."

Let me add one more point to the discussion of the mental attributes of U. S. Negroes. Whenever outstanding minds among them have risen to high recognition, people have tended to attribute their achievements to the white part of their genetic makeup, as judged by lightness of skin or some other such external sign. The fact is that external features are poor indicators of the total genic content. An intellectually outstanding very light Negro may or may not have obtained many of the genes influencing intellectual responses from his African ancestors; conversely, the very dark little girl who scored an I.Q. of 200 may or may not have contained many Caucasian genes.

The biological future of the U. S. Negro of course will depend primarily on sociological developments. Large-scale fusion of the Negro and white populations will probably not occur for a long time, and complete separation is impossible even at present. This impossibility has two different aspects. On the one hand miscegenation continues, both legitimately and illegitimately. On the other hand, many of the Caucasian-appearing hybrids "pass" into the white group; in time this will drain the U. S. Negro population of some of its Caucasian-derived genes and may leave it on the whole a bit more African-appearing than before. Whether this will be balanced or more than balanced by the continued influx of Caucasian genes is a difficult question.

Looking into the centuries ahead, it seems likely that the flow of African genes into the numerically dominant white population will increase. These African genes will become so dispersed in the dominant group that only slight changes in its appearance will be apparent. The average of skin color will shift slightly toward a light brunette. When complete fusion has occurred, there will probably be no more than a few thousand black people in each generation in the entire country, and these are likely to have straight hair, narrow noses and thin lips. I suppose that if some person now living could return at that distant time, he would ask in wonder: "What became of the Negro?"

BOOKS

A sweeping history of China's science and its intellectual relations with the Western World

by James R. Newman

SCIENCE AND CIVILISATION IN CHINA, by Joseph Needham. Cambridge University Press ($10.00).

What exactly were the Chinese contributions, ancient and modern, to science and technology? How is it that the Chinese, though singularly weak in theory and systematization, nevertheless made discoveries and inventions often far in advance of Europe? What features of Chinese civilization were responsible for the fact that Chinese "backwardness in scientific theory coexisted with the growth of an organic philosophy of nature . . . closely resembling that which modern science has been forced to adopt after three centuries of mechanical materialism?"

These are among the questions Joseph Needham discusses in the book before me, the first of seven projected volumes, all of which are already completed in manuscript. Needham characterizes his seven volumes as no more than a "reconnaissance." His bibliography shows that there is a vast "ocean" of literature on Asiatic science. But the material has never before been digested into the compass of a single work; a work, moreover, addressed not to Sinologists but to "all educated people" interested in scientific thought and technology. Needham's survey therefore promises to be a landmark of intellectual history.

"It is well to observe the force and consequences of discoveries," wrote Francis Bacon. "These are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure; namely printing, gunpowder and the magnet." In Bacon's time little reliable knowledge about China was available in Europe. That these discoveries, which "changed the whole face and state of things throughout the world," were of Chinese origin was scarcely appreciated, nor did Europeans recognize how many other techniques which they considered the product of their own civilization had been adopted from China. The learned were dimly aware of that vast and ancient society, "at least as intricate and rich as their own," and even the vulgar had long been nourished on marvelous tales of Cathay. But dependable facts about the country and its people were hard to come by.

In the 17th century a stream of information about China began to flow into the West. Much of it came from the Jesuits, whose missionaries, led by the remarkable and brilliant Italian, Matteo Ricci, had established themselves in Peking. Ricci, named Li Ma-Tou by the Chinese, was an extraordinary linguist as well as a gifted scientist and mathematician. Together with some learned converts he translated Western scientific books—among them, Euclid, Ptolemy, Clavius—into Chinese and aroused wide interest at the Imperial Court in all aspects of science and technology. The Jesuits taught Chinese scholars about the ways and thought of the West and in turn learned about Chinese history and culture. The liaison was admirable, but unfortunately the Jesuits often accepted legend for fact and relayed much misinformation to Europe, some of which still lives on.

In the 18th century a romanticized picture of Chinese civilization was frequently held up as a model for Europe. To this day a tendency "to ascribe too much to East Asian origins" persists among some persons, while at the same time there is a countercurrent of "reluctance to allow that any discovery or invention of importance could have taken place outside of Europe." Needham gives illustrations of these extremes: the producer of a documentary film who consulted Needham thought that the Chinese had invented the potter's wheel (it was known in Sumeria 1,500 years earlier); on the other hand, the author of a recent book on the history of technology gives the Chinese no credit for such achievements as the first knowledge of magnetic polarity, the discovery of gunpowder and the earliest manufacture of cast iron.

Admittedly the task of writing a history of Chinese science is formidable. The language is a dragon that swallows Westerners without a trace. The history of China is inordinately complex, even for veteran Sinologists. Few of the Chinese source materials have been translated into European languages. English histories of China are to be judged, one gathers, only on the pejorative scale: some are worse than others. The best history of China in any Western language is said to be a German work, O. Franke's *The History of the Chinese Empires*, but it is in five volumes and difficult to read.

It is clear, then, that a scholar who undertakes a comprehensive survey of Chinese science must possess extraordinary equipment. Needham is such a one. He is a biochemist distinguished for his original researches and writings; he has an excellent grasp of the history of science and its connection with social history; he has traveled extensively in China and has a good working knowledge of the language; he is a bear for work and a veteran in handling masses of detail without losing perspective or a sense of humor. Further, Needham loves the Chinese people, and his feeling—not sentimental but based on understanding and respect—pervades his book. The work has been pursued, he tells us, as a contribution to international understanding, in the spirit of the great 17th-century English scholar Lancelot Andrewes, of whom a biographer said that "many conceive that he might well have been . . . Interpreter-General [of] the Confusion of Tongues."

Needham furnishes the reader with a 14-page "Note on the Chinese Language" which is a model of lucidity. It explains the fundamentals of the symbolic characters, the development of script, the various methods devised to systematize a language immensely rich in characters yet remarkably poor in sounds. This poverty of sounds has had some bearing, Needham believes, on the difficulties of the Chinese in forming a terminology for science. And in inventing new characters for scientific terms they were at a great disadvantage in not having old roots to draw upon, as the West Europeans had in Greek, Latin and Arabic.

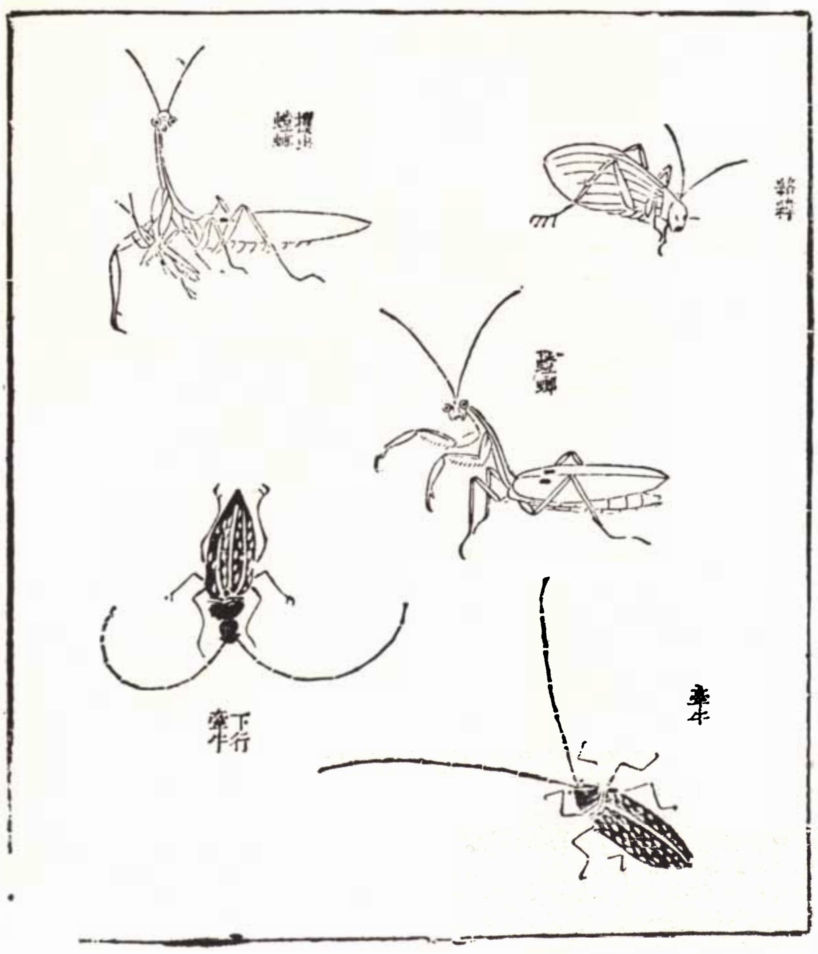
Needham gives a brief history of China, with emphasis on events, movements and periods of special significance in the history of science. It is surprising to learn that history in China cannot be pushed back beyond 1500 B.C. The earliest records of ancient China are the now famous "dragon bones" found by farmers tilling their fields near Anyang in the latter part of the 19th century. The bones were sold to drug stores to be used as medicine, but by 1900 Chinese scholars realized that these fragments of the shoulder blades of mammals or the carapaces of turtles, which had been used for a method of divination known as scapulimancy, were inscribed with ancient writing.

Once the Chinese civilization got under way, it rapidly surpassed all other parts of the world in many important branches of technology, including the manufacture and working of iron, ceramics and textile techniques. Geography, mineralogy and botany flourished in China even in the most distracted times. Entomological control of plant pests is described in a second-century book on plants and trees; the wheelbarrow was a Chinese invention, as were the crossbow, the iron-chain suspension bridge, the kite, canal-lock gates, piston bellows, the stern-post rudder, metallurgical blowing engines, efficient harnesses for draught animals. Incredible armies of labor were drafted to build reservoirs and canals. In the construction of a grand canal section between the Yangtze and the Hangchow in about the sixth century, some five million workers toiled under a guard of 50,000 police. "Every fifth family was required to contribute one person to participate in the supply and preparation of food. Those who could not or would not fulfill the demands made on them were 'punished by flogging and neck weights'; some had to sell their children. Over two million men were said to have been 'lost'." The Chinese word leaves it uncertain how many of those "lost" ran away and how many died. "This was the way things went throughout Chinese history," Needham remarks. Possessing no machinery, the Chinese could only build on the principle of "a million men with teaspoons."

The canal so dearly bought made a splendid spectacle—40 paces wide, roads along both banks planted with elms and willows, "imperial resting pavilions" at frequent intervals.

The invention of printing may be dated about the sixth century. A small printed notice, "Beware of the dog," survives from 594; the earliest block printing known is that of a Buddhist charm of 770 A.D. What printing meant in the development of Chinese culture, on the humanistic as well as the scientific side, is easily imagined. The Confucian classics, cut on wood blocks and printed in a set of 130 volumes, were widely distributed throughout the country. There were printed books of poetry, on alchemy, on law and mathematics, on botany, pharmacy, chemistry, cartography, military science, political theory and agriculture. The "Dream Pool Essays" of Shen Kua, published in 1086, was a great miscellany containing scientific observations in many fields; it was one of the first books to describe the magnetic compass. The book appeared during the Sung dynasty (950-1250), which Needham characterizes as the major focal point of Chinese scientific and technological history. It was a period that produced notable practical inventions, writings in every known branch of science and scholarship, and huge chronological and geographical encyclopedias.

A most interesting feature of Chinese intellectual history is the gargantuan scale of some of the scholarly works. It is as if an enormous country had to have enormous books—they dwarf even the incontinent monuments of German research. The most spectacular example is the 15th-century *Yung-Lo Ta Tien*, an encyclopedia which attained 11,095 volumes. More than 2,000 scholars were employed in writing it. They shortened the labor by incorporating whole books already published, so that the encyclopedia took only four years to complete. Understandably reluctant to undertake the printing of so immense a work, the Emperor ordered only three copies to be made, with melancholy



Drawings of insects in a Chinese woodcut of the Ming period consequences: the main collection perished in the destruction of the Yuan Ming Yuan palace during the Boxer Rebellion of 1901.

The noted modern scholar Hu Shih has drawn a striking contrast between Europe and China in the period of the rise of Western science: "Four years before Ku Yen-Wu [the philologist] was born, Galileo had invented his telescope and was using it to revolutionize the science of astronomy, and Kepler was publishing his studies of Mars and his new laws of the movements of the planets. When Ku Yen-Wu worked on his philological material and reconstructed his archaic pronunciations, Harvey had published his great work on the circulation of the blood, and Galileo his two great works on astronomy and the new science. Eleven years before Yen Jo-Chhü began his critical study of the *Book of History*, Torricelli had completed his great experiment on the pressure of air. Shortly after, Boyle announced the results of his experiments in chemistry, and formulated the law that bears his name. The year before Ku Yen-Wu completed his epoch-making *Five Books* on philological studies, Newton had worked out his calculus and his analysis of white light. In 1680 Ku wrote his preface to the final texts of his philological works; in 1687, Newton published his *Principia*."

Thus while the Chinese were examining themselves, probing minutely into the roots of their culture, writing books about their predecessors' books, the West worked with "stars, balls, levers, inclined planes and chemical substances" creating, instead of "more book-learning, a new world." But this does not mean, says Needham, that the Chinese were incapable of practicing logical systematization or other scientific processes; their scholarship entailed systematic use of the inductive method. It was merely that the subjects which drew their energy and to which they applied the rigorous canons of analysis were of a different kind. Why the Chinese came to prefer poetry to algebra, or the study of words, plants, maps and chronicles to the study of planetary motions, ballistics, combustion and igneous rocks, is to be the subject of one of the later volumes of Needham's work.

The last, and in many respects the most interesting, section of his first volume deals with the travel of ideas and techniques between China and Europe. Needham briefly examines parallelisms of scientific ideas and the possible mutual influences.

In metaphysics, philosophy and religion the parallelisms are obvious and not particularly surprising. On the other hand, it is astonishing to learn that Zeno, the Greek spinner of paradoxes, had a Chinese contemporary, Hu Shih, who posed apparently similar paradoxes; or that reports like Aristotle's on the growth and contraction of sea urchins with the waxing and waning of the moon also appear in an ancient Taoist book, the *Kuan Tzu*, said to have been composed soon after Aristotle's time. One can safely rule out the possibility that Zeno's ingenious fables were carried from West to East by gossips; as for the references to the sea urchin, it is far more likely that they rested on independent observations by Greek and Chinese fishermen than that the "rapid transfer of the idea took place over thousands of miles among peoples who had never even seen the sea." Exchanges certainly took place, but the foregoing are not of this class.

The earliest knowledge the peoples of the Mediterranean basin had of China concerned silk, the silk trade and the routes of this traffic. One of the most ancient trade routes was the Old Silk Road, which linked China and Central Asia "by means of a series of oases formed by the melting snows of the Nan Shan or Chhilien mountains as the waters ran down to lose themselves in the Sands of the Gobi." The opening of this road dates around the first century. The travelers along this and later highways included Roman-Syrian merchants, Nestorian missionaries, Parthian foot soldiers, Mongolian cavalry, Arab adventurers and a curious motley of wandering jugglers, acrobats, conjurers, leeches, mechanicians and star clerks. Besides silk the main commodities transported were iron, skins, wool and linen textiles, cinnamon bark, rhubarb and glass—the last-named being one of the few Mediterranean exports for which there was a market throughout Asia. The commodities were relatively few (and the balance of trade seriously adverse to the West) but the ideas that seeped through were much more numerous and of vastly greater importance. One of the most interesting examples of cultural diffusion is the ancient representation of the "flying gallop" of the horse: all four legs extended and all off the ground. Except when a horse is jumping, this position does not occur in nature, yet it was widely pictured so in both Chinese and Mediterranean art. It occurs first about 1000 B.C. in Greece and Phoenicia; it then travels east and is found in Sassanid, Persia, Bactria and China in the second century; in the 18th century it turns up

in European art as an import from China; it later adorns every English racing print and imposes its authority as a faithful representation of a horse's gallop until modern slow-motion cinematography demonstrates its inaccuracy.

I can offer only a few more glimpses of the wealth of engrossing detail in Needham's account. The orange, the peach and the pear came from China and its borderlands. From China, too, came new tools and foods, helicopter tops, the sailing carriage, porcelain, the rose, the peony, the azalea, the camellia and of course the chrysanthemum. The Chinese ambassadors who introduced these treasures to the West did not go back empty-handed. They took back the chive, the coriander, the cucumber, the fig, the pomegranate, the walnut, the "blood-sweating horses of Ferghana," astronomical and mathematical knowledge, the art of trepanning, chaulmoogra oil for leprosy, marvelous clockworks, tools, new fabrics and asbestos. The Mongols, surprisingly, accelerated this traffic. By uniting under one political authority the lands from Shanhaikuan to Budapest and from Canton to Baghdad, Genghis Khan's nomadic horsemen made travel easier. The road from Tana (at the mouth of the Don) to Cathay "is perfectly safe whether by day or by night," says a merchant handbook of the 14th century. When Marco Polo returned from the East bringing his servant, Peter the Tartar, Italian ladies began to clamor for Mongol and Chinese slaves. Between 1366 and 1397, for instance, 259 Tartars, mostly young women, were sold in the slave markets of Florence. It is most probable, Needham remarks, that the oriental girls "contributed some useful genes to the European population." On the other hand, Western technicians were much sought by the Mongol Khans. One who went to China in the 13th century was a Parisian goldsmith, William Bouther; his work may account for the fleur-de-lys motifs on the robes of Buddhist statues.

In his introductory volume Needham's discussion of China's independent innovations and of its cross-fertilization with Europe is necessarily brief, but he will return to these matters in more detail later. This book lays the foundations of a magnificent survey—a triumph of thought and of research. It is a book which, in Robert Hooke's words, will "lay open to us an Empire of Learning, hitherto only fabulously described," and "admit us to converse with the best and greatest of that Empire, that either are, or ever have been." Needham has an admirable style, and the publishers have given his book a handsome dress—fine maps and plates, a stunning frontispiece and a beautiful decorative cover portraying the Taoist genii, of whom Kou Hsüan Shuai, assistant Secretary of State in the Ministry of Thunder, is the most impressive bureaucrat I have ever seen.

Short Reviews

CHINA IN THE SIXTEENTH CENTURY: THE JOURNALS OF MATTHEW RICCI, 1583-1610, translated by Louis J. Gallagher. Random House ($7.50). Matthew Ricci, alluded to in the review of Needham's book above, was an exceptionally gifted Jesuit missionary who almost singlehanded built a bridge between Europe and China. Born in Italy in 1552, Ricci studied law, philosophy, theology and mathematics and in 1583 established a mission in China. He devoted himself to spreading knowledge of European culture—especially science—among educated Chinese and to bringing to Europeans information about the history and culture of China. Ricci was a brilliant linguist and had a sympathetic understanding of China and her people. When in 1601 he was able to proceed to Peking, he "assimilated himself and his Jesuit colleagues to the manners and customs of Confucian scholarly society" and succeeded in gaining the hospitality of the Imperial Court. With the help of Chinese collaborators he translated numerous important Western scientific books, and by his world map, calendar reforms and other scholarly labors made major contributions to the development of Chinese thought. Ricci's journals, now presented in English for the first time, describe the extent of the Chinese empire, its agricultural products and mechanical arts, Chinese science, humanistic pursuits and educational practices, the administration of the Commonwealth, the customs, dress, rites, superstitions and "peculiarities" of the people. His book makes engrossing reading of the widest possible interest.

SCIENCE AND THE COMMON UNDERSTANDING, by J. Robert Oppenheimer. Simon and Schuster ($2.75). This volume consists of the 1953 Reith Lectures delivered by Oppenheimer over the BBC from London. Their main thesis is that the ideas of modern science, in particular atomic physics, "provide us with valid and relevant and greatly needed analogies to human problems lying outside the present domain of science or its present borderlands." An example of such an analogy is the principle of complementarity. In atomic physics the principle epitomizes the fact that there are two ways of describing a system, two sets of defining concepts which cannot be applied at once, and which might indeed be regarded as antithetical. Yet it turns out that both sets of concepts are valuable; when properly used in concert they deepen rather than obfuscate our understanding. The same principle, says Oppenheimer, is valid in many other departments of life: "We can neither think, nor in any true sense live, without reference to these antinomic modes." Such an approach, in Oppenheimer's view, will help in meeting the tormenting problems and paradoxes of freedom and restraint, means and ends, transience and permanence, community and individual. When these lectures were given in Britain, critics felt they did not fulfill the purposes of the Reith program, namely, to put leaders of thought in communication with a wide audience. Nonetheless his book reflects the sensitivity and restlessness of an admirably uncomplacent spirit, and even the hard passages are illuminated by poetic insight into the nature of science and its relation to common understanding.

HENRI POINCARÉ, by Tobias Dantzig. Charles Scribner's Sons ($3.00). Henri Poincaré (not to be confused with his lesser cousin, the politician Raymond) was a small, frail, stoop-shouldered, near-sighted, absent-minded Frenchman with an execrable handwriting and the keenest mind in Europe. He was witty, an iconoclast and wrote like a dream; his views of space and time anticipated Einstein's Special Theory of Relativity; his essay "On Mathematical Creation" is a classic of psychology; his essays on the philosophy of science, in addition to their dazzling clarity, have the drama and timing of great literature. Poincaré was born in 1854 and died in 1912 after a "successful" operation on the prostate. Into his not-very-long-life span he crammed an astonishingly varied program of research. The one-time premier of France Paul Painlevé, himself a mathematician, eulogized him in these terms: "Poincaré was indeed the living brain of rational science. Mathematics, astronomy, physics, cosmogony, geodesy—he encompassed, he penetrated, he fathomed them. Incomparable inventor, he was not content with following his own aspirations by opening unexpected avenues and discovering unknown lands in the abstract world of mathematics. Wireless telegraphy, radiological phenomena, the birth of the earth—whatever field man's reason had managed to invade, and however subtle,

or however rough was the road, Poincaré, too, would invade it to help the searcher in his pursuit of the precious vein." In this new biography Dantzig explains that he has attempted not a systematic exposition of Poincaré's scientific philosophy but rather variations on themes of Poincaré, interpreting contemporary issues of science "in the light of the teachings of the great thinker." The result is not happy. Dantzig covers Poincaré's life only with a perfunctory sketch and his philosophy with single-paragraph quotations used as chapter-head texts for somewhat misty and overblown essays.

FOUR THOUSAND YEARS UNDER THE SEA, by Philippe Diolé. Julian Messner, Inc. ($4.50). This is a book about marine archaeology, the first of its kind, according to the publisher. Diolé is known for his interesting earlier book, *The Undersea Adventure,* in which he described his submarine promenades in search of zoological knowledge. Here his "skin-diving" has a different purpose: the exploration of the ocean floor to find sunken remains of Roman galleys and Greek sailing vessels and their cargoes. Diolé is an appealing writer and his experiences should make an exciting story. But the diving episodes are hemmed in by long-winded archaeological and historical asides. A photograph of the author wearing a sweater as outer garment under water and another of a Madame Monsenergue examining "enigmatic relics" on the sea bottom with a sketching pad tied to the waist of her very French bathing suit have an appealing *je ne sais quoi* but do not quite suffice to carry the story.

SIR CHRISTOPHER WREN, by John Summerson. The Macmillan Company ($1.75). The celebrated inscription over the north door in St. Paul's *Si monumentum requiris, circumspice* ("If you would see his monument, look around"), does not do Wren full justice. Wren was not only the greatest English classical architect but also made his mark as a geometer, astronomer and physiologist. As an undergraduate at Oxford he helped reform the calendar, invented a pen for writing documents in duplicate, designed a box beehive and made anatomical models. After becoming a fellow of All Souls he worked in mathematics and on astronomical problems connected with the planet Saturn; he tested Cartesian principles of physics; he joined with Robert Boyle in important experiments on the circulation of the blood and on the functions of the spleen;

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A scholarly yet highly readable account of the life and work of "the father of modern chemistry"—the 18th century genius who first broke down air and water into their basic components and compiled the first table of chemical elements. McKee's book is a perceptive recreation of the great scientist's life, written with compassion and understanding. Retail price, $6.00.

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by JOHN RICHARD SAUNDERS

Reading this book is like being taken on a personally conducted tour of that fabulous treasure house, the American Museum of Natural History, in New York City. Along with lucid descriptions and many illustrations of the famous exhibits and Hayden Planetarium, the author gives you the history of man's discovery of the natural sciences and the growth of the Museum over the years. Retail price, $5.00

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he executed beautiful anatomical drawings, studied meteorology and physiological optics, and tinkered with clocks, globes, orreries and "many other artificial, mathematical and magical curiosities." In 1657, when only 25, he was appointed professor of astronomy at Gresham College, London; in 1660, with a dozen others, he organized a "Colledge for the promotion of Physico-Mathematicall Experimental Learning," which before the year was out became the Royal Society. Wren left Gresham in 1661 to take the Savilian chair of astronomy at Oxford. Though he remained a professor for many years, he was drawn more and more into the King's service, becoming his surveyor and principal adviser in the construction of new works. The Great Fire of London afforded him the opportunity to lay out a splendid new city plan; this was not accepted, but he rebuilt some 50 churches which gave the city a character not even the Nazis were able to erase. He lived into his 91st year and then died "very peacefully." This short, readable biography is by a lucid writer and a most knowledgeable critic of architecture.

CONVERSATION WITH THE EARTH, by Hans Cloos. Alfred A. Knopf ($5.75). This is the travel diary of a leading German geologist who died in 1951. It weaves together his experiences, his ethical beliefs and his philosophy of life into a series of remarkable accounts of great mountain ranges, volcanoes, rock formations, rivers, craters, waterfalls and other striking features of the landscape in many parts of the world. Cloos was an unusually penetrating and sensitive observer with amazing descriptive powers. His sympathy for stone was like other men's for birds or flowers. Again and again in his travels the idea came to him that "geology is the music of the earth." The earth's crust was more than a record of the past; it was time and prophecy and change. "Look," he wrote, "the same thing happens to the earth that happens to the hands of a clock, however small, when it is magnified to an adequate degree: each and every part is seen to move. No matter where we look through our magical telescope, everything is crawling or flowing. Grains in the rocks begin to wander like sand in the river; crystals grow, crystals dissolve; fissures open and close like lips that speak; mountains slide across plains like sleds over snow; lands sink and sea bottoms lift up out of the flood." Cloos's extraordinary book is in general densely written and is hard to take in long stretches, but parts of it are poetic and moving.

SPIRIT AND NATURE—PAPERS FROM THE ERANOS YEARBOOKS, edited by Joseph Campbell. Pantheon Books, Inc. ($5.00). In late August of each year since 1933 a group of scholars has been invited to participate in a symposium—the Greek word *eranos* means a meal to which each contributes his share—held at Ascona, Switzerland, in the home of Frau Olga Froebe-Kapteyn. The circumstances of the conference are undeniably auspicious, including luxurious accommodations, meals served on a terrace overlooking Lake Maggiore, and a leisurely two weeks' program of lectures and discussions. The topics chosen for discussion are less auspicious, and in past years have included such themes as "Redemption," "The Symbolism of Rebirth," "The Mysteries," "Man and Ritual," "The Great Mother." Nevertheless, some good talk has been preserved in this book. Among the lectures are C. G. Jung's "The Phenomenology of the Spirit in Fairy Tales," Paul Masson-Oursel's "The Indian Conception of Psychology," Werner Kaegi's "The Transformation of the Spirit in the Renaissance," Erwin Schrödinger's "The Spirit of Science," Friedrich Dessauer's "Galileo and Newton: The Turning Point in Western Thought."

ECONOMIC ACTIVITY ANALYSIS, edited by Oskar Morgenstern. John Wiley Sons, Inc. ($6.75). A collection of studies on the mathematical structure of economics. The topics discussed include models of general economic equilibrium, the input-output system, mathematical concepts for linear economic models, the laws of return. Morgenstern's review article gives an interesting account of the new period of economic analysis ushered in by the theory of games, linear programming, Monte Carlo techniques and high-speed computers. In Morgenstern's opinion these methods will revolutionize the social sciences.

SOME MAIN PROBLEMS OF PHILOSOPHY, by George Edward Moore. The Macmillan Company ($4.50). A collection of lectures on various difficult problems of philosophy—the nature of the external world; the ways of knowing; the meaning of qualities, of beliefs and propositions, of existence, of the term "real," of the notion of infinity—delivered 40 years ago by the famous British philosopher. The problems are still alive and Moore's discussion is still worth reading if you don't mind hard work.

THE AMATEUR SCIENTIST

On the collecting of moths and butterflies and some ingenious and attractive sundials

Conducted by Albert G. Ingalls

At the age of 73, Colonel Otto H. Schroeter of Quaker Hill, Conn., is still chasing butterflies. Except for time out while he studied engineering as a young man in his native Germany, he has been at it more than six decades, including the years when he was employed as construction superintendent in the Panama Canal Zone by the Isthmian Canal Commission.

What fascination keeps a busy construction engineer at the hobby of butterfly-collecting for a lifetime? One explanation is a service that Colonel Schroeter was able to perform several years ago for Carroll M. Williams, the eminent Harvard University zoologist who uses insects to study basic life processes. Williams needed a large insect for investigation of metamorphosis and was stymied for lack of supply until he heard about Schroeter and his collection of giant silkworms.

"Our relationship with Colonel Schroeter," writes Williams, "is certainly an excellent illustration of how the amateur can make a distinct contribution to science and share the satisfactions of scientific investigation. The amateur occupies a very special place in entomology because a high proportion of the so-called 'professionals' begin as amateurs. (Later on, incidentally, the complexities of work in a laboratory and an institution may cause them to wish they had remained amateurs!)

"As far as I can judge, Colonel Schroeter was the first to introduce to this country for scientific study and experimentation a wonderful array of 'wild silkworms.' These creatures live in distant parts of the world such as India, Malaya and the slopes of the Himalayas. Colonel Schroeter developed contacts in all these places and has made available to a number of universities and governmental laboratories, including our own, a rich variety of material.

"Certain species of the silkworms have proved strategic for particular types of scientific studies. For example, we have repeatedly called on Colonel Schroeter for specimens of *Antheraea mylitta*, the so-called giant tussah silkworm of India. This exotic creature is one of the world's largest insects, the full-grown caterpillar weighing about 45 grams. It is easy to see how scientists can use beasts of these proportions to answer chemical and physiological questions which would be quite inaccessible in ordinary insects.

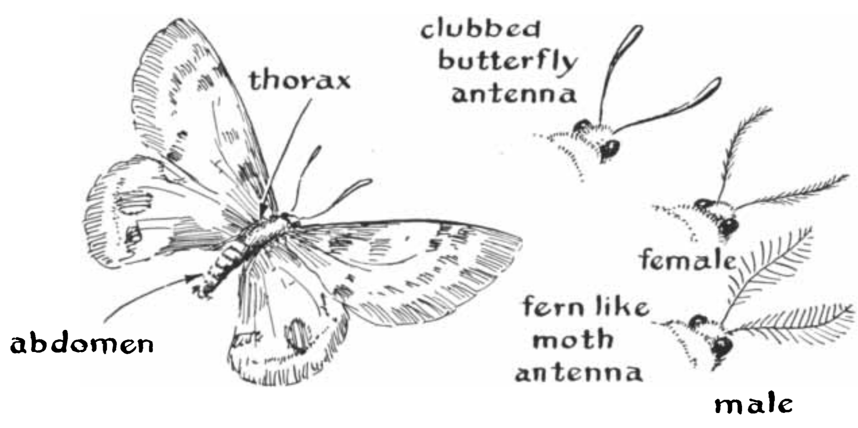
"The Colonel has also made available to us considerable information, derived from his own breeding experiments, concerning the care and feeding of these strange species."

About a year ago many newspapers carried a picture of Schroeter with an 11-inch moth which he had reared from an egg the size of a matchhead. This department sought out the Colonel at his home, and it turned out to be a fascinating visit. Colonel Schroeter explained: "The big fellow is an *Attacus edwardsi*. As you can see, its wings are various shades of brown and yellow and contain transparent windows. Specimens caught in the Philippine Islands have a wing span of 14 inches! Larvae of the Atlas species of this moth feed on ailanthus leaves—you know, the tree that grows in Brooklyn. My scientist friends have not shown much interest in the Atlas caterpillar even though he is far from being a pigmy. He is green, finger-sized and has blue horns on his head. His body looks as if he's frosted with a sugar coating, and natives say that he is delicious.

"I wish you had made your visit a little later in the year. Then I could have shown you a really big moth, *Thysonia aprippina*. It is a native of Brazil. Those I have bred have much larger wing spans than the *Attacus atlas*, which is usually listed as the largest moth in the world. Here is the cocoon of a Thysonia—you can see it is the size of a small sweet potato. You can imagine the proportions of the moth that comes out of it.

"Newspaper reporters make so much fuss over the big fellows that they overlook the really interesting specimens. Take the hybrid luna, for example. Seven years ago an amateur friend of mine in India airmailed to me a dozen cocoons of the Indian moon moth. When the adults emerged some months later, it was evident that they were closely related to the American luna. The two species have about the same shape and size and their wings bear a similar general coloration—a light bluish-green. The wings of the Indian species are distinguished by two patches of red. I decided to try crossing them and finally succeeded last year."

Colonel Schroeter began by acclimatizing the foreign species, which meant breeding several generations of the foreigners here, letting them adapt to local forms of their favorite food plants and to the new environment generally. Then he selected a likely female of the foreign



Antennae readily distinguish moths from butterflies species and mated her with a local male.

He has invented a simple gadget to help assure a successful mating. Most amateurs tack a female to a tree by one of her wings and wait for her to attract a mate. "The chief drawback of this technique," says Schroeter, "is that the female's attraction is not limited to mates of her species. When you pin your specimen to a tree you invite predators—other insects, birds and tree toads—to a free dinner. Too often when you come back you find nothing but a pair of wings. Moreover, when you immobilize a single wing the female is apt to thrash around and injure herself. To overcome this difficulty I made what I call a 'mating panel'—a rectangle of Celotex 18 inches long and a foot wide. A screw eye in the center holds a leash of thread, the other end of which is fastened around the female's thorax. With freedom to crawl around on the surface of the panel, she usually quiets down after a few seconds of fluttering. The panel is then suspended by picture wire from the tip of a branch where it is out of the reach of tree toads and free to swing in the breeze. The movement frightens most birds away.

"Moon moths mate at sundown. The next morning the female is transferred to a large paper bag in which she deposits her eggs in two parallel rows. After the eggs have been laid, the bag is cut into little squares, each holding eggs. These are fastened with bits of Scotch tape to the leaves of food plants and surrounded with a bag to prevent the larvae from escaping when the eggs hatch. If you are lucky, the larvae thrive and metamorphosis gets under way. Sometimes the experiment works, but more often it fails. The eggs may be sterile, disease may strike, the food may not be correct. Murphy's law makes no exception of entomology. If anything can go wrong, it will. The failures, however, can be as interesting as the successes, because they pose problems of finding out what went wrong, where and when. In the case of the moon-luna experiment, nature threw the book at me. But in the end I was rewarded with a beautiful hybrid which bore the characteristics of both parents. Its wing markings fade from bright green into greenish-blue and trail through orange to pink at the wing tips. It is probably the only offspring of this combination in the world."

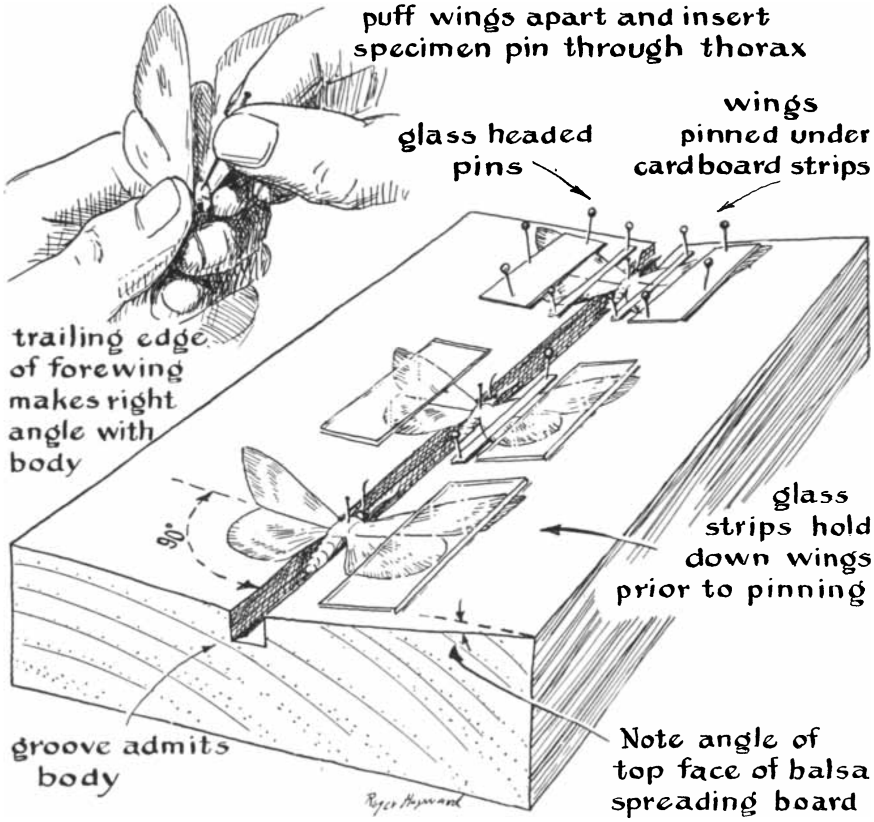
Colonel Schroeter says most lepidoptera mate readily in captivity. Last season he bred more than 5,000 individuals. Eggs come to him from all parts of the world—sometimes in goose quills and other strange containers. Cocoons arrive in balsa boxes from South America and in bamboo cylinders from the Orient. While there is a law against indiscriminate importation of insects into the U. S., the Government has issued to Schroeter a special importing license, subject to strict controls.

"Don't let the import restriction on foreign material keep you out of amateur entomology," he urges. "You can collect domestic species to your heart's content without fear of ever exhausting our known varieties. Reference texts and catalogues list them by the thousands, and scores of new descriptions are added each year.

"You will find caterpillars wherever plants grow. The next time you go for a walk, whether in the park, a meadow or merely in your back yard, take along a paper bag, a piece of string, some note paper and a pencil. When you find a caterpillar, jot down a short description of it—the color, size, markings and such other information as you think will help you recognize the creature when you meet another like it. Make a similar record of the plant on which it was feeding. If you already know the name and nature of the plant, so much the better. Be sure to include the date, approximate time of day and notes on the weather. Then put the bag over the twig or weed on which your specimen is feeding and tie the end closed so it cannot escape. Check up on it a day or so later. You will likely discover that the leaves have been eaten. If so, shift everything to a fresh batch of leaves. You may have to repeat this several times.

"Eventually you will find that your specimen has vanished and a cocoon has taken its place. With luck you may catch the caterpillar in the act of spinning its cocoon. Make full notes of its methods and how long a time it spends in the process. When the cocoon is complete, break off the twig to which it is attached and transfer operations to a small cage, which you can make of window screening. Place the cage outdoors in a location matching as closely as possible that where you found the insect. Some species prefer sunny locations; others do best in shade. After days or weeks—depending upon the species and the season of the year—the adult will emerge, and you will have the thrill of discovering the exotic creature your caterpillar was destined to become."

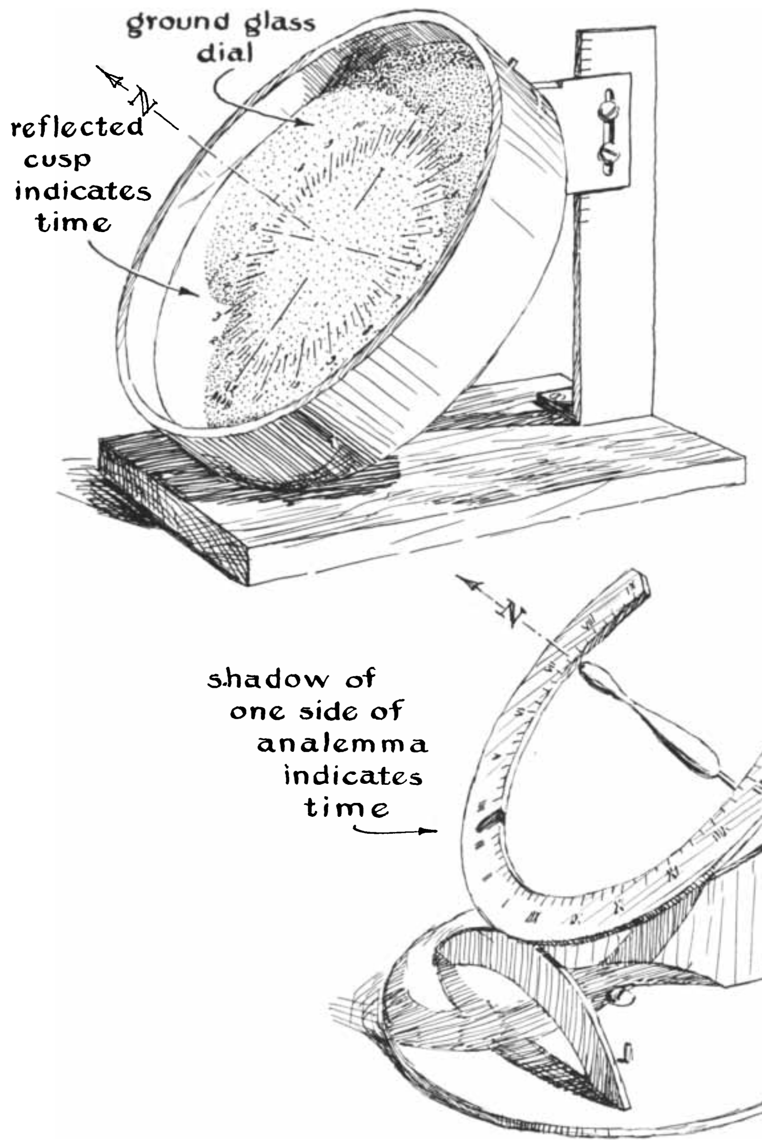
By starting with the caterpillar instead of with the butterfly, Colonel Schroeter explains, you learn to recognize at first hand three of the four stages in the life cycle of your insect—larva, pupa and adult. Your notes now give purpose to your future field trips. You



Steps in the mounting of specimens for display hunt for another caterpillar and cocoon of the same species. With luck you may even come across an adult female in the act of laying her eggs. When they have been mounted and labeled, you have the complete life cycle of the insect and the beginning of a collection of scientific value. Although thousands of adult moths and butterflies have been catalogued, the life cycle of a majority of those in nature still awaits description—an ideal project for the amateur who enjoys original work.

"One attractive feature of amateur entomology," says Schroeter, "is the fact that you never run out of interesting projects for your spare hours. Collecting and breeding are merely two facets of the hobby's many sides. For convenience in study, collections must be mounted and labeled. This can be an absorbing pastime the year around. Only the most perfect specimens are selected for mounting. They are killed and stored against the day when bad weather forces you to remain indoors.

"You first stun the insect by pinching the lower side of the thorax lightly between your thumb and index fingers. The thorax is the part of the body, directly back of the head, to which the wings are attached. Stunning is necessary to prevent the insect from fluttering and damaging itself when you drop it into the killing jar. The jar can be any wide-mouthed container with a tight-fitting cover. A layer of absorbent material, such as plaster of Paris, is placed in the bottom and saturated with a tablespoon of Carbona. Some amateurs prefer poisons such as potassium cyanide, but they are dangerous and unnecessary. The dead specimen is stored in a triangular envelope. The envelopes are numbered to correspond with the entries in your notebook."

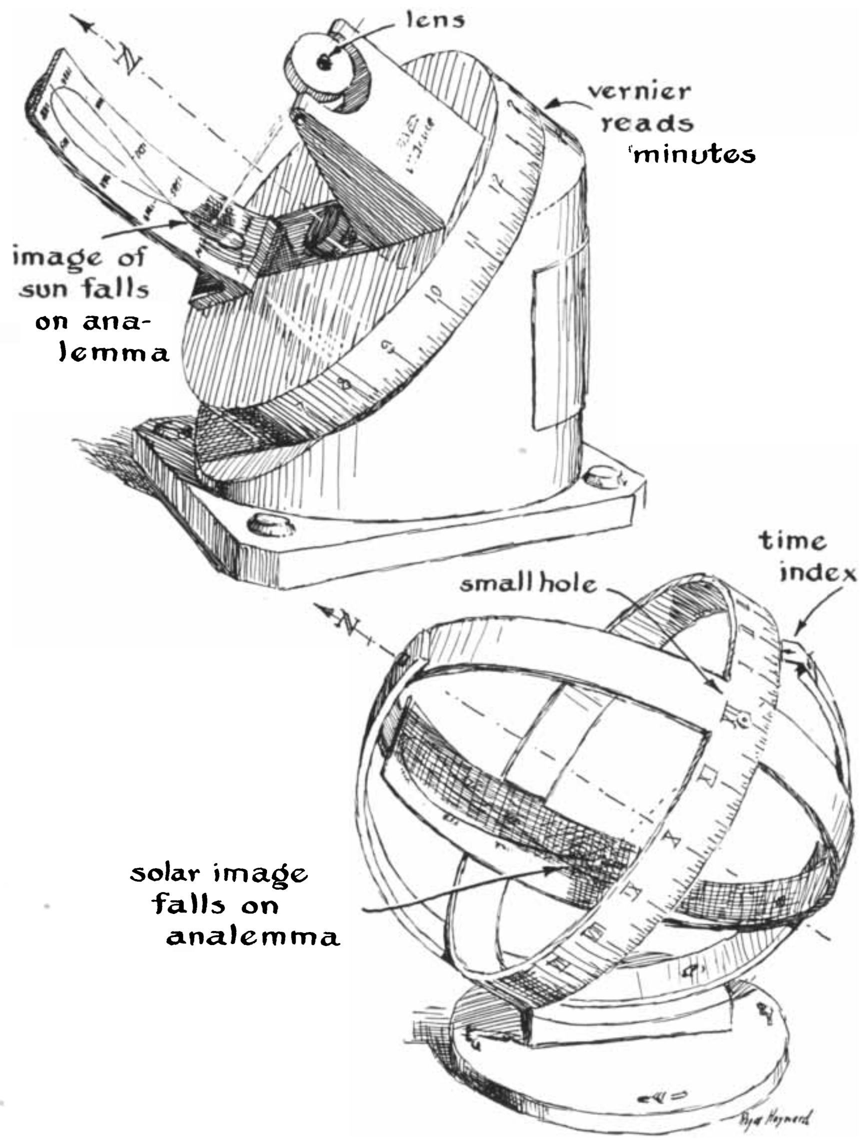


Ingenious sundials from Scotland and France

In about a week the dead insects become hard and brittle. They must be "relaxed" or softened before mounting. You put the dried insects into a jar containing a rubber sponge or other absorbent moistened with water to which a few drops of carbolic acid have been added. The acid prevents the formation of mold or other microorganisms. A couple of blotters placed between the insects and the sponge will prevent them from getting too wet. After two or three days they are ready for mounting.

The sketch on page 97 illustrates the details of the procedure. A convenient outfit for mounting consists of a spreading board, two slender strips of glass, tweezers, scissors, pins and a supply of thin cardboard. A spreading board is easily made from balsa or Celotex, with a groove in the center for the body of the insect. The slight upward slant of the board on each side of the groove makes allowance for the tendency of the wings to droop as they age. Mounting outfits can be bought from a supply house; the Butterfly Art Jewelry, Inc., of 289 East 98th St., Brooklyn, N.Y., for example, lists a kit including spreading board, forceps, pins, a display case and other essentials plus 10 tropical butterflies for practice mounting. Similar materials are available from the Standard Scientific Supply Corp., 36 West 4th Street, New York, N. Y.

To mount the specimen you grasp it by the lower side of the thorax, part the wings by blowing lightly, and thrust a pin through the thorax from the top. The pin should be inserted into the insect just far enough to bring the point of wing attachment level with the surface of the spreading board when the pin has been forced into the bottom of the groove. Then blow the wings apart again and place the specimen on the board,



Solar image on analemma sets these "sun clocks" weighting down the wings with strips of glass. Each glass is lifted in turn just enough to permit pulling the forewings forward by means of a pin inserted behind one of the heavy veins. When the trailing edge of the forewing makes a right angle with the axis of the body, it is pinned down with strips of cardboard as shown. Wider strips of cardboard are then pinned in place of the glass weights. The specimens will be dry enough in about a week for transfer to the display case.

Eggs and pupae are mounted without special preparation. Cement the eggs to paper strips of contrasting color. Pin the pupa as though it were a dried adult. A larva must be degutted and inflated before mounting. After killing, place the larva on a square of blotting paper and, with a fine scalpel, enlarge the anal orifice slightly. Then, beginning at the head, squeeze the viscera out by rolling a pencil down the body. The carcass is restored to normal shape by inflating it with a syringe, which you can make yourself. Heat a section of quarter-inch glass tubing to a dull red and quickly draw one end into a fine nozzle, somewhat thinner than the small end of a medicine dropper. Fit the large end with a rubber bulb. You then inflate the larva by inserting the nozzle into its anal opening and squeezing the bulb sharply. The anal opening is closed with a bit of Scotch tape until the tissues harden.

For convenience in subsequent study, specimens are generally pinned to the bottom of a glass-topped display tray. Many arrange the eggs, larva, pupa and adult of each species as a group. Among the catalogues compiled to aid the beginner in identifying his specimens are *The Butterfly Book* and *The Moth Book*, by W. J. Holland.

Colonel Schroeter recently gave his entire collection of thousands of specimens to the University of Connecticut. J. A. Manter, the University's zoologist, writes: "The Schroeter collection is the most colorful that I have ever seen. Every division of world macrolepidoptera is represented by rare specimens, and it is especially remarkable because of their excellent condition. Such a collection is often spoken of as an 'Oh, my!' one—the reaction it evokes from visitors as the trays are successively pulled into view. Colonel Schroeter's devotion to amateur entomology has resulted in a lasting contribution to science from which future generations of students will derive both knowledge and enjoyment."

The late William Morton Wheeler, the great Harvard entomologist, once summed up the joys of the amateur in these words: "We should realize, like the amateur, that the organic world is also an inexhaustible source of spiritual and esthetic delight. Especially in college we are unfaithful to our trust if we allow biology to become a colorless, aridly scientific discipline devoid of living contact with the humanities. We should all be happier if we were less completely obsessed by problems and somewhat more accessible to the esthetic and emotional appeal of our materials. It is doubtful whether, in the end, the growth of biological science would be appreciably retarded. It quite saddens me to think that when I cross the Styx, I may find myself among so many professional biologists, condemned to keep on trying to solve problems, and that Pluto, or whoever is in charge down there now, may condemn me to sit forever trying to identify specimens from my own diagnoses while amateur entomologists, who have not been damned professors, are permitted to roam at will among the fragrant Elysian meadows netting gorgeous, ghostly butterflies until the end of time."

A sundial, if it is to be accurate, must be designed uniquely for its latitude and longitude. Ready-made sundials are merely attractive bird perches, useless for precise time-telling, because the manufacturers can design only for an average location. Hence anyone who wants a scientific dial must build his own. Sundialing is fascinating fun, and it takes only an hour or two to bone up on the irregularities in the earth's motion—the "equation of time"—that affect a dial. You can get the necessary information from a textbook on elementary astronomy or from *Sundials—How to Know, Use and Make Them*, by R. Newton Mayall and Margaret L. Mayall.

In the September, 1953, issue we published descriptions of several scientific sundials built by readers. Here are some others received since then.

The first [*upper drawing on page 98*] was made by H. M. McNair of Scotland. He says: "My dial has a circular scale with five-minute divisions inked on the upper side of a disk of glass within a ring of polished metal. When the ring is adjusted so that the glass is parallel to the equatorial plane, the sun's reflection from the inside of the ring forms a cusp of light which is visible on the glass because the glass is finely ground on its lower side. This cusp, which indicates the time, travels around the circular scale at a uniform rate for any one day. (The dial will also show the moon's angle.) The equation of time is taken care of by a scale of minutes by which the glass may be slightly rotated and set to a datum mark. The dial has to be adjusted every few days. I adjust the ring parallel to the equatorial plane by supporting it at a notch diametrically opposite the datum mark, on a knife-edge adjustable for height. The height of the knife-edge above the baseboard should equal the cosine of the latitude times the outside diameter of the ring. The lower rim rests on the surface of the baseboard and, after swinging a little, settles to its required position.

"The dial is easily moved and set up. Its one drawback is that for about two days at the equinoxes, when sunlight comes in parallel to the ring, there is no cusp and the timepiece fails."

Jean Haegel, of Paris, has built an equatorial dial [*lower drawing on page 98*] which automatically corrects the irregularities of the earth's motion. On many sundials the irregularities are represented by a curve in the shape of the figure 8, called an analemma. On Haegel's dial the gnomon, the part that indicates the time by casting a shadow, is a spindle in the analemma shape. Haegel writes: "This still makes one approximation necessary: the equation of time has to be made symmetrical with respect to the solstices. But I hasten to say that the small error thus accepted is just about covered by the one weakness of this design: the reading is taken on the edge of the shadow and this edge is not too well defined. One must also remember on which side of the shadow to read the time; a good watch helps!"

Sundialing is so ancient a craft that rarely is a really new principle discovered. Mayall and Mayall, the authors of the sundial book, comment that a dial like Haegel's was made in Europe about 1850 and patented in the U. S. about 1900. Nevertheless the Haegel idea will be new to most amateurs. Haegel himself remarks: "The news that my dial is at least a century old makes me feel better. I felt rather queer before."

In 1925 F. Hope-Jones of England published in the British periodical *Engineering* a description of a mechanical "sun clock" invented by W. E. Cooke of the Sydney Observatory in Australia. The hands of a conventional clock were geared to a large ring with a small hole on its sunward side. An analemma was placed below. To read the time by the hands of the clock you turned the ring until the sunbeam through the hole bisected the curve of the analemma. Russell W. Porter made one of these sun clocks and introduced them to sundialists in this country through SCIENTIFIC AMERICAN (August, 1928, and August, 1935). Porter built 19 sundials and sun clocks; his dooryard was full of them.

As a variation on the original theme Porter mounted one sun clock in a movable, spherical Pyrex flask, omitting the clock hands. Without knowing about the source of this variation, Neal M. Kohler and fellow employees of the Titan Metal Manufacturing Company in Bellefonte, Pa., recently redesigned the flask theme and came out with the sundial illustrated by the upper drawing on page 99. The Titan Company makes brass and bronze products, and its employees know how to make these metals really sing. This is proved by photographs and by the detailed blueprints which are not shown here.

In 1952 Thomas C. Rathbone, a Brooklyn engineer, again without knowing of Porter's series of clocks but working directly from descriptions of Cooke's original sun clock in Australia, designed the rugged and attractive instrument illustrated in the lower drawing on page 99. This one has an hour circle eight inches in diameter. Rathbone has made another which uses three large wagon tires and is capable of telling time within 15 seconds if the graduations for a low sun are adjusted for refraction.

The fact that all these sun clocks have a family resemblance does not prove either telepathy or burglary; it simply suggests that all sundials have ultimately the same designers—the sun and the earth. Form follows function.

For three decades six inches has been the standard size of the amateur telescope maker's first try at building a reflector. Now there is a trend toward beginning at four and a quarter inches, the next smaller size in Pyrex disks. Theoretically a 4¼-inch telescope is only two fifths as big as a six-inch, while its power is two thirds as great. A growing number of advanced amateurs who have built larger instruments are adding a 4¼-inch to their menagerie because the smaller size is more manageable and portable.

A 16-inch telescope is 22 times as heavy, bulky and costly as a six-inch. This may explain why so little came of the hundreds of 16-inch war-surplus Pyrex disks that eager amateurs bought six years ago when a die manufacturer offered them for only $12.50 each (the Corning price for that size is $107.50). Purchased in haste because of the bargain, most of these were repented at leisure when the sobering realities of geometry were thought out. The owners still hold them in hope.

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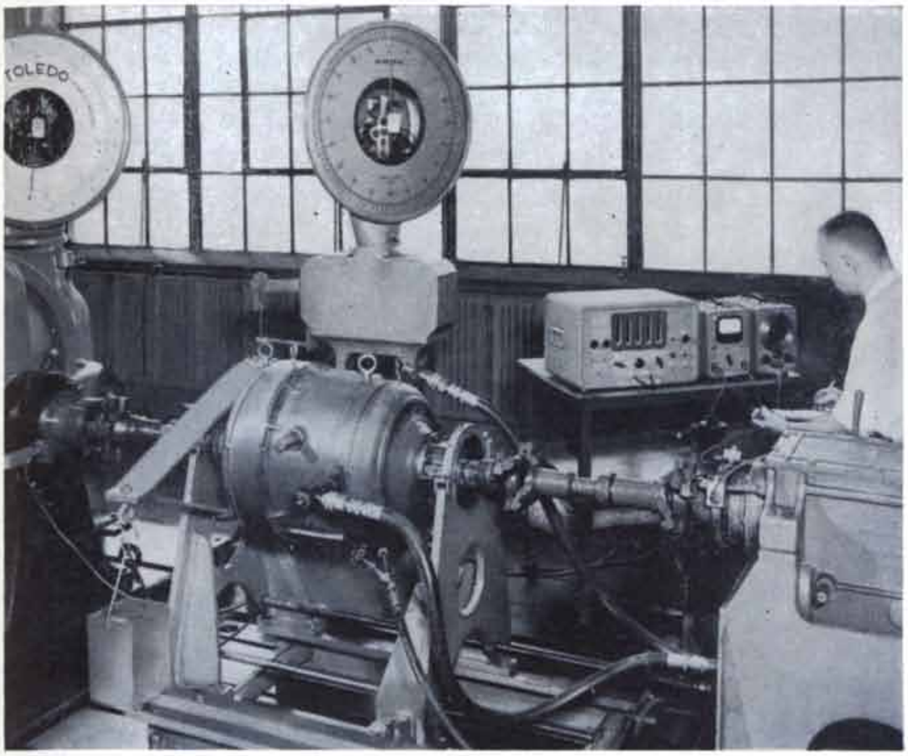

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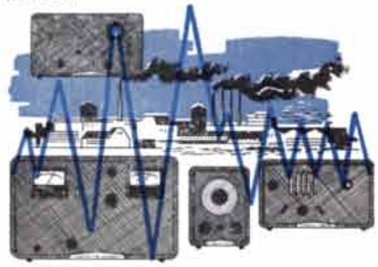

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