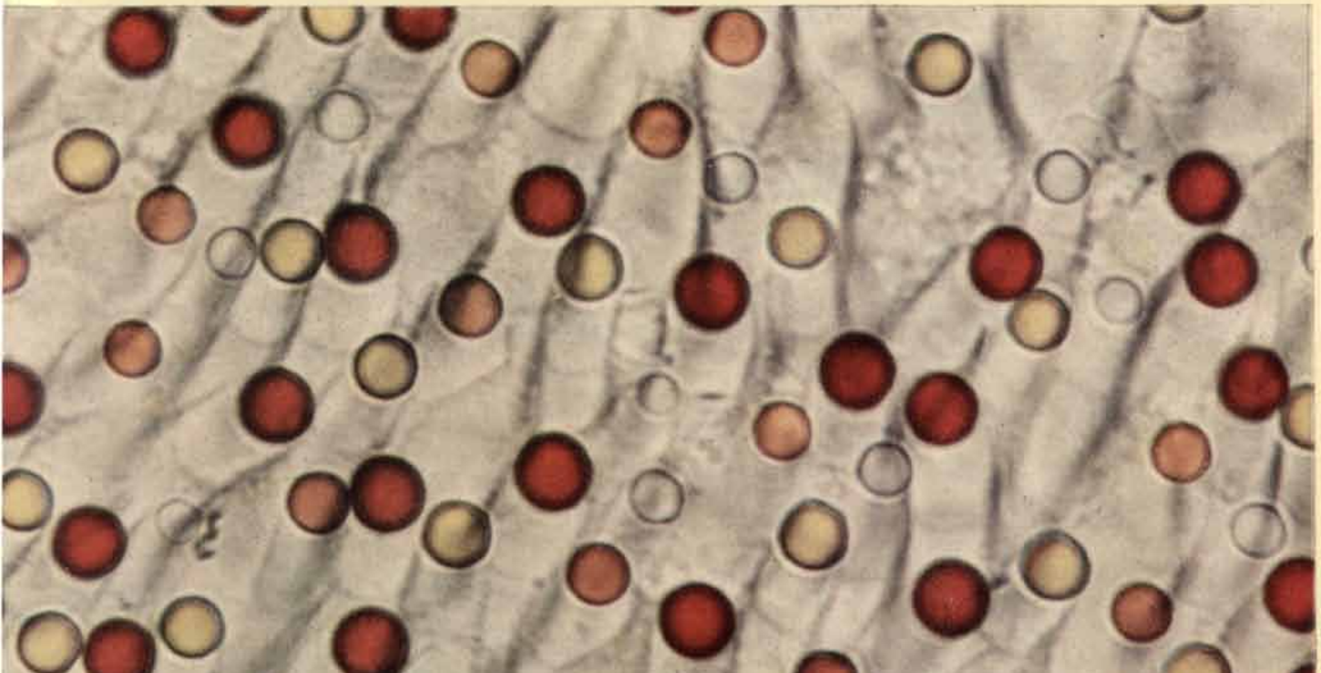
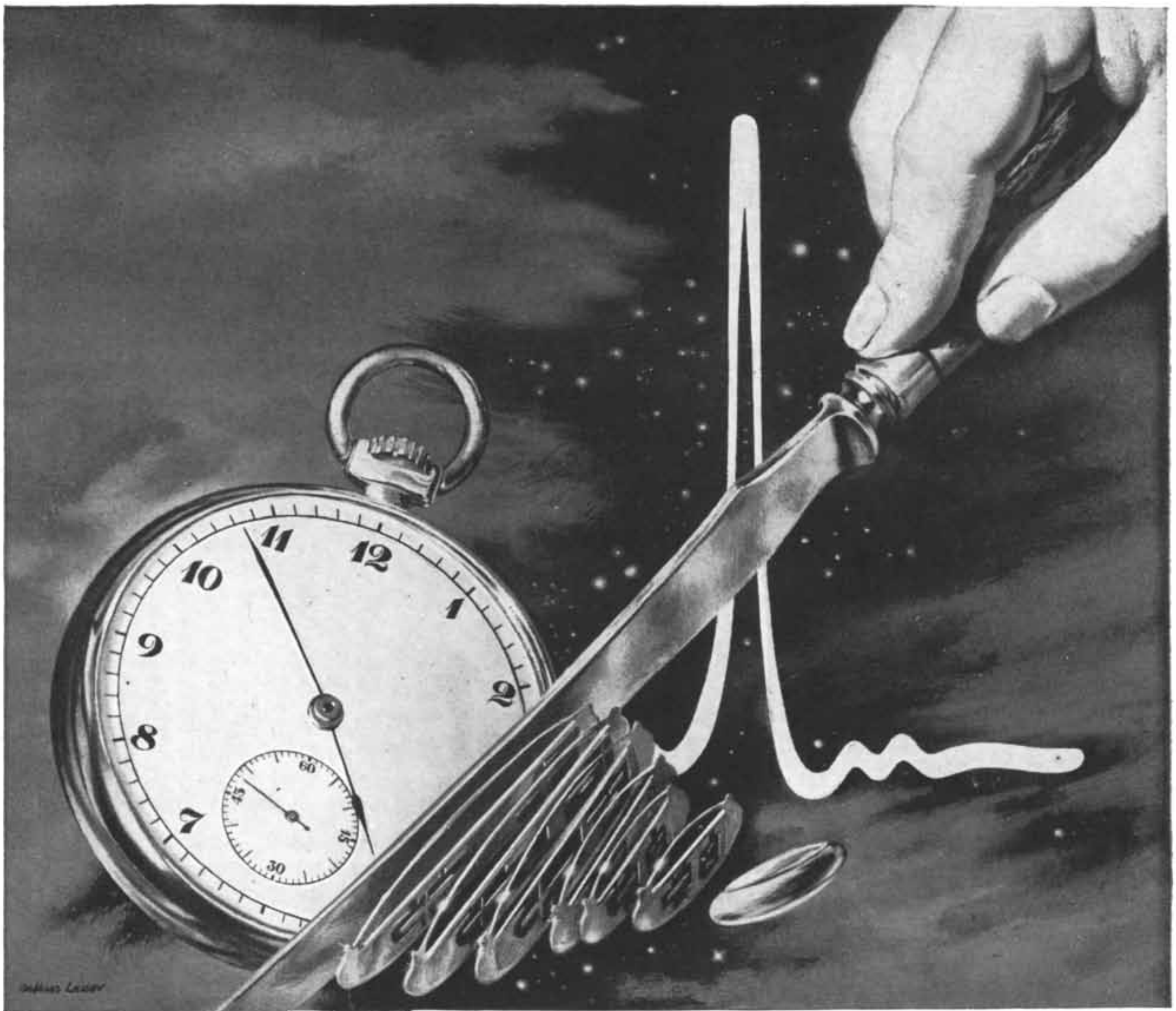
SCIENTIFIC AMERICAN



RETINAL COLOR FILTERS

FIFTY CENTS

August 1950



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* * *

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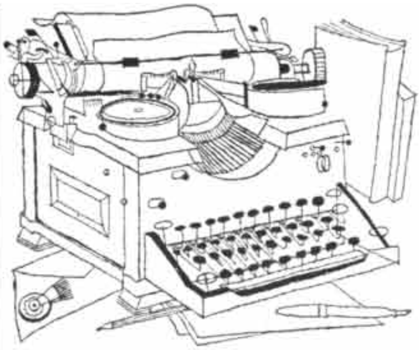

LETTERS

Sirs:

An item in your department "Science and the Citizen" for May greatly alarmed me. It describes a theory of how locusts navigate which has been advanced by the Danish worker T. Weis-Fogh. The item says: "When the insect, flying against a headwind, is blown around from its course, the unequal stimulation by the wind of the hair patches on the two sides of its head enables it to orient itself and reset its course in the original direction."

It is a common fallacy that wind affects a body floating or flying within it. Wind (which is only a mass of air moving over the surface of the earth) affects a body contained within it only in relation to the earth. A body which moves within the air mass cannot feel the direction or speed with which the air mass is carrying it any more than a fish in a fishbowl can feel the speed and direction of the water as the bowl is carried to another room.

Thus the stimulation described by Weis-Fogh is impossible. Perhaps the following experiment will clarify the matter. Stand outside on a windy day holding a gas-filled balloon by a string. Naturally the wind exerts a pressure on the balloon, and the balloon strives to break its anchorage. The wind forces the string to lean in the direction it is moving. The stronger the wind, the greater the tendency of the string to become parallel to the earth. Now release the balloon. Does the string still indicate the force and direction of the wind? No! Once the balloon frees itself, the string adapts itself to the environment, *i.e.*, trails freely behind the balloon. The only air that exerts a force on the balloon is that which flows over it as it rises. This air pressure is called "relative wind" in aerodynamics. There are only two components in the motion of the balloon: its rise and the pressure of the wind.

Now if the locust were flying in a mass of air going west and he wanted to travel north, whence would come the force to stimulate the hairs on the right side of his body more than those on the left? Again the component forces would only be two: the relative wind and the force of the locust's body being propelled through the air mass. In other words, Weis-Fogh is stating that the hairs on the locust flying within a large enclosed package of air would be unequally stimulated by the transportation of that package in a direction other than that being flown by the insect.

HERBERT G. HART

Le Grand, Calif.

Sirs:

The article by Walter H. Bucher entitled "The Crust of the Earth," which appeared in your May issue, brings to mind the theories of the late Dr. John Joly, a celebrated English scientist. In his *Surface History of the Earth* Joly points out that the earth's crust has not only been subjected to compressional stresses during periods of uplift and mountain-building as at present, but also to tensional stresses, with the creation of vast rifts and rift valleys at other times. The great rift valley in central Africa, some 4,000 miles long, is a classical example; the valley of the Rhine is another. Such tensional periods are marked by continental subsidence and the laying down of vast basaltic lava flows such as those of the Deccan plains of India.

Joly claimed that the alternation of subsidence and uplift, of rifting and mountain-building, came about through the cyclical melting and cooling of the basaltic magma underlying the continents, and, of course, the ocean floor. He demonstrated that there was sufficient heat generated by radioactivity in this basaltic stratum to change it from the solid to the liquid state over a period

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of 25 million years or so. At such times the principle of isostasy would have full play, and since basalt increases in volume when liquid, becoming lighter, the continents would sink relative to the oceans. The resulting increase in volume, though moderate, would account for tensional stresses and the crustal rifting. Later a cooling effect took place due to the thinning of the ocean floors and the drifting of the continents over what were before oceanic areas.

If Joly's theories be sound then Bucher's facts concerning isostatically uncompensated areas and the impossibility of continental drift would hold true for this era, but not necessarily for others such as the Oligocene, when rifting was most pronounced and vast continental areas were submerged.

W. F. SUTHERLAND

Toronto, Ont.

Sirs:

The article by Ralph E. Lapp in the June issue of *Scientific American* on the subject of the hydrogen bomb contains some thoughts of considerable merit. However, before any group of city planners or defense authorities take any action in the direction of the "strip city" laid out in a straight narrow line, which he suggests, I wish to point out its one most serious weakness.

The geometric simplicity of construction of a straight line would make a city laid out in that manner second only to the present type of city in vulnerability to most of the modern weapons of attack, which, it should be unnecessary to point out, are aimed with the aid of mathematical computation. One bomber, flying parallel to the longitudinal axis of such a city, could drop a strip of bombs timed to land in a row, any desired distance apart, the length of the city and do virtually as much damage as one much larger bomb placed in the center of a city of the usual outline. In the case of a coastal city or any city within range of the weapons of enemy ships or submarines, the same simplicity of aiming computations would materially assist the enemy in placing any missiles where they would do the most damage.

The idea of dispersion of cities for defense is a sound one; but, against modern long-range weapons and fire-control apparatus there is one cardinal principle which must be considered in the dispersion of cities. That principle is irregularity of arrangement. Any geometric regularity in the arrangement of a decentralized city would detract from the security of that city and, above all, straight lines of any considerable extent should be avoided.

MILTON SHAPIRO

Elizabeth, N. J.

SCIENTIFIC AMERICAN

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST 1900. "The discovery of M. Becquerel, that the radiation given off by certain bodies called radioactive can be deflected by the action of a magnetic field, has brought out a number of new observations in connection with these phenomena. It thus appears that radium gives off two kinds of radiation, one of which may be deflected by the field, while the other is unaffected. It is found that the rays present other differences in character; thus the deflected rays possess a greater penetrating power than the others. The compounds of polonium experimented upon give only the non-deviable rays, as M. Becquerel has already found. There is a marked resemblance to the non-deflected rays of radium, both possessing little penetrating power and being limited in their action by the distance. A series of experiments has been carried out by Mme. Curie to show the differences in the two forms of radiation given off by radium. The non-deviable rays have much less penetrating power than the others, and a study of their comparative penetration shows that their nature is entirely different, thus confirming the results obtained with the magnetic field. It is found that while for the deviable rays the coefficient of absorption decreases or is perhaps constant as the thickness of matter is increased, on the contrary the non-deviable rays are more easily absorbed according to this thickness. This singular law of absorption is contrary to those which are known for all other forms of radiation; it gives the idea of a projectile which loses a part of its *vis viva* in traversing an obstacle."

"The second day of July will long be remembered by aeronauts, for on that day occurred the first ascension of the great airship just completed by Count Zeppelin, the cavalry officer of Wurttemberg. The last rope was cut at three minutes after eight, the sliding weight was quickly regulated, and the airship began to move, trying to rise in a graceful curve, which, however, was interrupted at a height of about 150 feet by what seemed to be a rather strong current of air. After that it was carried along with the wind in the direction of Immenstaad, where it descended to the water at 8:20, having attained a height of something over 1,300 feet and covered a distance of three and a half miles. These results are interesting and important, and, as far as the ascent and descent are concerned, are entirely satisfactory; but it was evident that the amount of energy developed by the propellers was insufficient. Instead of the promised speed of 32 feet per second, a speed of only 26 feet per second was really obtained."

"A new form of cellulose has been recently discovered which possesses many valuable properties. The chemical designation of this new substance is the soda salt of cellulose, xanthogenic acid. It is often designated by the name xanthate of cellulose, or viscose. The discovery is due to the researches of Messrs. Cross, Revan and Beadle, and the fundamental action is that of the alkali upon cellulose. The substance somewhat resembles glue in appearance. It is remarkable for its viscosity, whence its name. The property of viscose which makes it of especial value is that at the end of a certain time, often but a few hours, it forms an insoluble gelatinous mass which becomes comparatively hard and washes perfectly. It may be molded into different forms or spread in a thin layer upon wood, paper, fabrics, etc."

"The streets of our great cities are not kept as clean as they should be, and probably they will not be kept scrupulously clean until automobiles have entirely replaced horse-drawn vehicles. At the present time a large number of women sweep through the streets with their skirts and bring with them, wherever they go, the abominable filth which they have taken up, which is by courtesy called 'dust.' The management of a long gown is a difficult matter, and the habit has arisen of seizing the upper part of the skirt and holding it in a bunch. This practice can be commended neither from a physiological nor from an artistic point of view. Fortunately the short skirt is coming into fashion, and the medical journals especially commend the sensible walking gown which is now being quite generally adopted. These skirts will prevent the importation into private houses of pathogenic microbes."

AUGUST 1850. "The celebrated Liebig is about to visit the United States for the purpose of lecturing on chemistry."

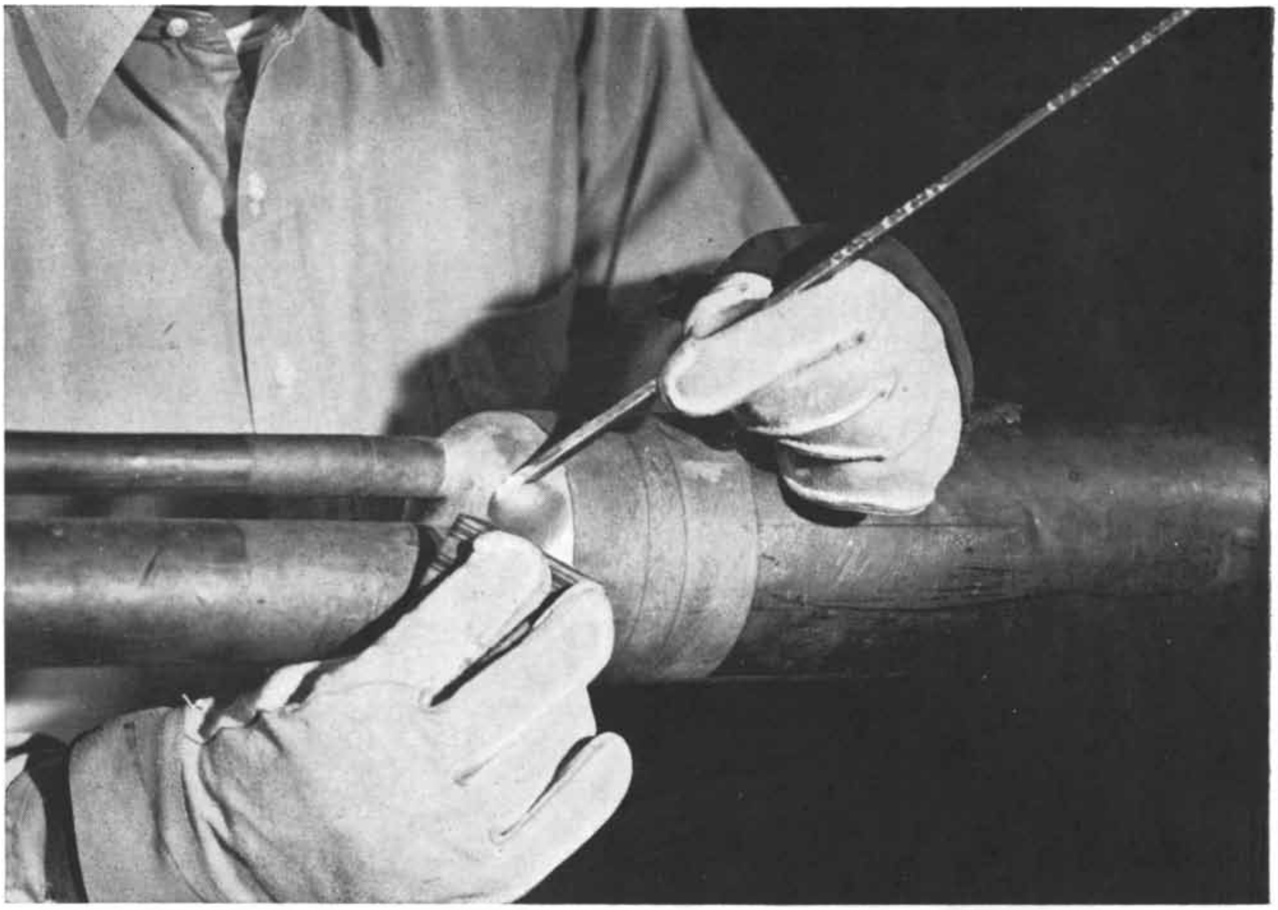
"The Messrs. Fizeau and Gounelle, of Paris, have recently been making experiments by a new method to determine the velocity of the propagation of electricity. Their experiments were made upon the wires of the electric telegraph from Paris to Rouen and from Paris to Amiens. The former are 175 and the latter 195 miles in length. The following were their results. In an iron wire sixteen hundredths of an inch in diameter, electricity is propagated with a velocity of 62,159 miles per second. In a copper wire one tenth of an inch in diameter, the velocity was 111,886 miles per second."

"The next meeting of the American Association for the Advancement of Science will be held in New Haven, Conn., commencing on Monday, August 19th, and will continue through the week."

"The men of forty-five years of age, now living in our city, have seen the first successful steamboat which navigated our waters, and the young man of twenty-one, he who has just arrived at the age of manly responsibility, is a contemporary of the first locomotive. What revolutions these two inventions have produced—steam navigation and railway locomotion—and what a gorgeous panorama passes before our vision as we trace the progress of other inventions. In 1809 there was only one steamboat in the whole world; now, who could count their number? In 1830 there were only thirty miles of locomotive railway in the world; now there are no less than 18,000 miles. What with the steamboat, the railroad and the telegraph, the ends of the earth are brought together, and civilization is now fast finding its way into the most darkened corners of the earth. And shall it ever be that we shall see the atmosphere as safely navigated as we now see the ocean?"

"The appearance of Saturn is unparalleled in the solar system. He is a spheroid 1,000 times larger than the earth. His ring rotates from east to west about the planet in ten hours and a half. Hence a point on its surface moves at the rate of 100 miles per minute, 58 times swifter than the earth's equator. According to Bessel, its mass is equal to the 18th part of that of the planet. Each side has alternately 15 years of sunshine and 15 of darkness."

"A sea-cow has been caught near Jupiter Creek, in Florida, which weighs 1,500 pounds. Barnum, it is said, has bought it."



He seals out trouble...

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To make cable joints tight and strong, splicers formerly used lots of solder. Then, Bell Telephone Laboratories developed a new technique for making *better* joints with much less solder. This saves one million pounds of solder a year — helps keep the price of your telephone service low.

Two kinds of solder are now used. One makes the splice strong; the other seals it. First, the splicer builds up a joint with a solder of lead and tin, which flows easily under his wiping cloth. To seal the joint, he applies a light coating of low-melting-point solder, composed of lead, tin and bismuth. On contact with the still hot joint, it flows into and seals every pore.

Cable-sealing solder is only one of 30 low-melting-point alloys which Bell metallurgists have developed for special uses — in fuse wires, for example, and in the solder connecting hair-like wires to piezoelectric crystals for electric wave filters.

Continuing research with a substance seemingly as commonplace as solder demonstrates again how Bell scientists help keep your telephone service the world's best.

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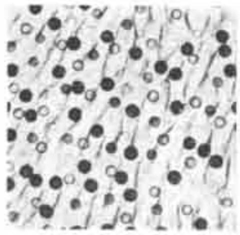

THE COVER

The photomicrograph on the cover shows the retina of a turtle known as Troost's terrapin. Suspended in the retina, which is magnified some 1,800 diameters, are tiny red, yellow, orange and colorless globules of oil. Each of these globules lies in a light-sensitive receptor cell of the retina. The globules appear to act as color filters that provide the turtle with color vision. This retinal feature is peculiar to certain turtles and certain birds such as chickens and pigeons. There are no color filters in the retina of man. The mechanisms that are responsible for human color vision are not yet fully understood (*see page 32*). The photomicrograph was made by Paul K. Brown in the Biological Laboratories of Harvard University.

THE ILLUSTRATIONS

Cover by Paul K. Brown

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34	Courtesy George Wald
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What GENERAL ELECTRIC People Are Saying

H. N. HACKETT

Apparatus Department

MERCURY POWER CYCLE: [In a typical mercury-unit power plant] heat from the burning fuel is absorbed by liquid mercury within the tubes of the mercury boiler to form mercury vapor, which passes from the boiler to the mercury turbine, where it releases a portion of its energy to produce electric power. The vapor from the turbine is exhausted to the vacuum shell of the mercury condenser boiler. There it condenses and releases its heat of vaporization to water within the tubes. The liquid mercury is returned from the sump, or hot well, to the boiler by a mercury feed pump or by gravity, as the case may be.

The feed water that absorbs heat from the condensing mercury vapor is boiled into steam at any desired pressure. This steam is then superheated in tubes located in gas passages of the mercury boiler. This superheated steam is then available for driving a steam turbine or may be put to other desired uses.

. . . The steam thus produced by the binary cycle is only slightly less in amount than it would be if the equivalent fuel were burned directly in a steam boiler. . . .

The mercury-steam cycle as we know it today is one of the most efficient power cycles in commercial use. Mercury-unit power plants of relatively small capacity compare favorably in efficiency to the largest steam units now being built.

Plant Engineers Club,
Cambridge, Mass.
April 20, 1950

★

L. P. HART, JR.

Apparatus Department

TRANSFORMER GASKETS: There is a large class of electrical apparatus that is filled with insulating liquids. The liquids provide a means of cooling and insulating such devices as power transformers, distribution transformers, and voltage regulators. Construction of this equipment involves the use of tanks, covers, radiators, and bushings. The joining of these components is accomplished in most cases by the use of a gasket. The gasket must be made of a relatively soft, resilient, deformable material that will function as a sealing means between two surfaces. Ideally it should prevent entrance of moisture into the unit and completely retain the insulating liquid.

One of the earliest materials used as a transformer gasket was felt . . . A better sealing mechanism was that provided by the use of glue-bonded composition cork. This was considerably less pervious to oil and moisture . . . Subsequently there was developed a composition of cork and Neoprene, which was much less pervious to liquids and moisture . . .

The study of the gasketing problem . . . led to the conclusion that a rubber-like material showed the best possibilities. A thorough survey of such materials showed that nitrile rubber was the most promising type of compound for such gasket applications. An active development program in conjunction with several rubber companies produced compounds which met the following requirements: (1) resistance to attack by hot oil; (2) freedom from contaminating effect on the electrical properties of insulating liquids; (3) excellent compression-set characteristics; (4) satisfactory aging characteristics; (5) low moisture vapor permeability; (6) low cost.

The application of nitrile rubber gaskets to transformers and other liquid-filled electrical apparatus has resulted in the following advantages: (1) the virtual elimination of gasket leakage . . . (2) a permanency of seal which was hitherto unknown . . . (3) a reduction in assembly time . . . (4) a lowering of cost.

"G.E. Review"
June, 1950

W. C. WHITE

Research Laboratory

CYBERNETICS: Scientists and engineers have worked for many years on labor-saving devices. This is now largely a matter of accomplishment. The next step is what may be termed "routine saving." This is doing things electrically that require the use of the human senses, such as hearing, seeing, speaking, and smelling, and also need a muscular response but not the thinking part of the brain.

Electronics, of course, is the main tool in this trend. For example, a person can watch a production line of manufactured objects pass by and note whether a certain part has been included or properly located. To do this requires looking at the object and, when a certain difference in appearance is noted, to operate a lever or respond in some other way. After a time, this is easy to accomplish while thinking of something else. Also this is a job easy to accomplish by means of electronics, because a phototube may be substituted for the eye so that a beam in question is missing or improperly placed. When the phototube is thus actuated, electrical relays plus solenoids or motors can follow up with the desired action.

This idea is old, but it has recently been dignified by the name of "cybernetics," by Professor Weiner of M.I.T., who has written the book *Cybernetics*. The possible impact of this science on our future lives can literally be called stupendous. As regards changes in the daily routine of most of us, it will probably be more of a factor than the atomic bomb and nucleonics.

Institute of Radio Engineers,
New York City,
February 1, 1950

You can put your confidence in—

GENERAL ELECTRIC

SCIENTIFIC AMERICAN

Established 1845

CONTENTS FOR AUGUST 1950 **VOL. 183, NO. 2**

ARTICLES

DEPARTMENTS

Hay Fever Sufferers! "Summer Cold" Victims!

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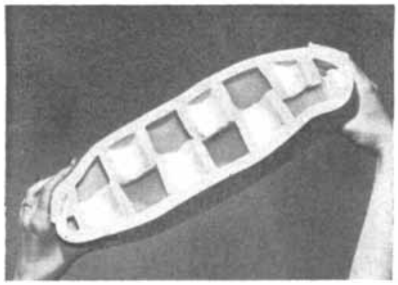

3. No other pillow has patented "staggered core" construction, cradles your head in the most restful position. Millions of microscopic air cells actually "breathe" inside your PLAYTEX Pillow—give cool, "air-conditioned" sleeping comfort!

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CHOOSE YOUR FAVORITE PILLOW HEIGHT!

Regular Height, white, pink, or blue extra-fine Sanforized cotton cover, nylon double-stitched for longer, stronger wear . . **$8.95**

Extra-Plump, white, pink, or blue extra-fine Sanforized cotton cover, nylon double-stitched for longer, stronger wear . . **$9.95**

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SCIENTIFIC AMERICAN

AUGUST 1950 VOL. 183, NO. 2

The Food Problem

The hunger of two thirds of the people is a serious economic and political threat to the rest. A summary of the problem and an approach that may alleviate it

by Lord John Boyd-Orr

THE FOOD PROBLEM confronts the world with two dangers. One is the political danger of hunger. A lifetime of malnutrition and actual hunger is the lot of at least two thirds of mankind. Hungry people who believe that an abundant supply of food is possible will overthrow any government that does not make it available. The upsurge in Asia, the most important political event in the world today, is fundamentally a revolt against hunger and poverty.

Side by side with the political menace of hunger there exists in the now small world an economic danger, arising from diametrically opposite causes. This economic difficulty is due to the ease with which food production can be increased with the help of modern technology. Certain countries, the U. S. and Canada in particular, are embarrassed by surpluses of food. To prevent a slump in agriculture, the U. S. Government has taken billions of dollars worth of food out of the world market and is now embarked upon a program of restricting production. Communists are hopeful that the capitalist system will break down because it cannot be adjusted to carry the great wealth produced by modern technology.

In a well-ordered world the danger of revolt against hunger and the threat of food surpluses would cancel each other out. The necessary adjustment could well begin with a world food policy based upon human needs. It will not be easy, but the effort must begin soon.

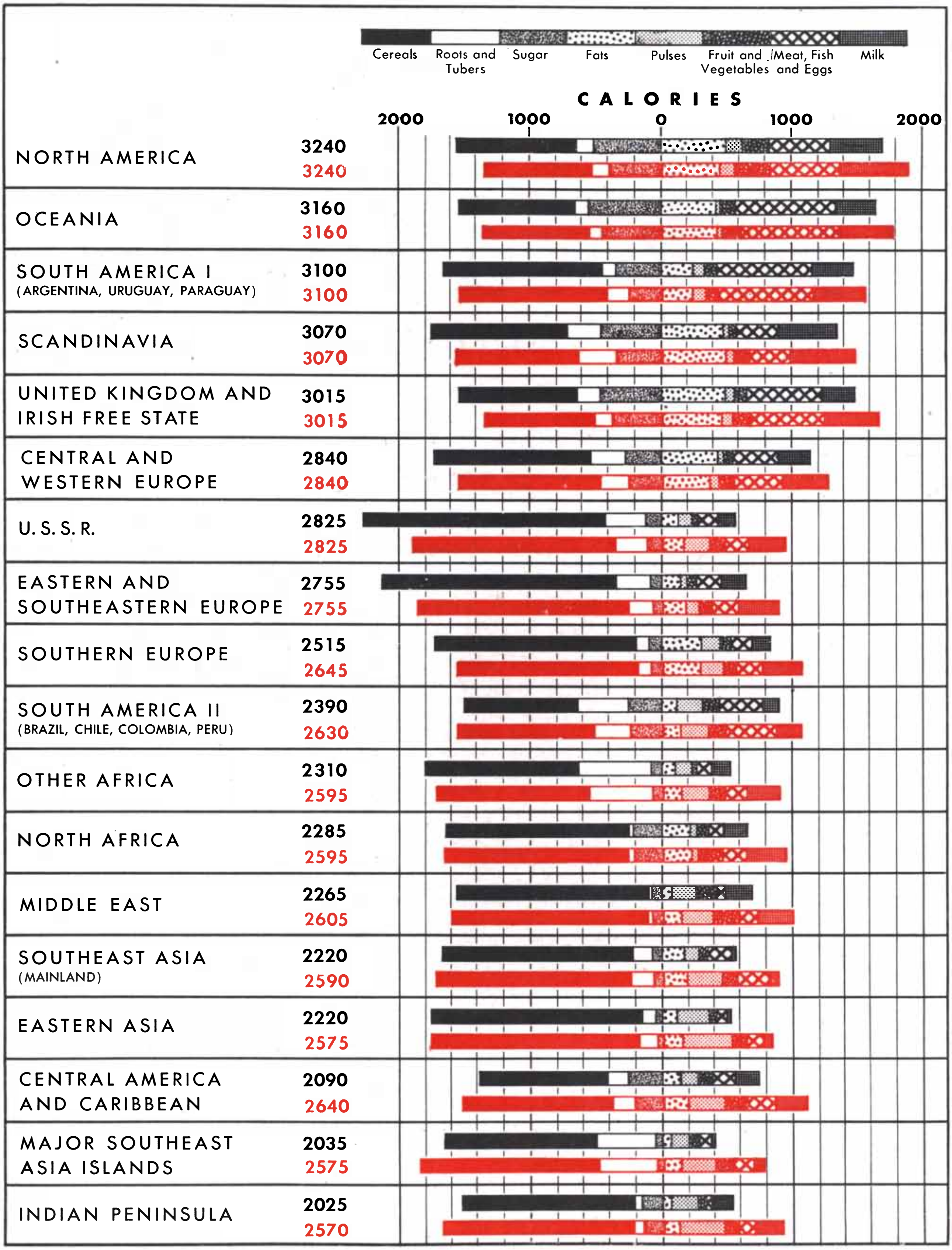
THE GRAVITY of the food problem is such that some observers have arrived at the hopeless conclusion that the 19th-century English economist Thomas Malthus was right, *i.e.*, that population tends to increase faster than the supply of food, and that part of the population inevitably has less food than it needs. Certainly the population of the world is increasing at an accelerating rate. At the beginning of the 19th century it was estimated at a little over 900 million. At the outbreak of World War II it had reached about 2,000 million. It is now about 2,250 million and is increasing at the rate of more than one per cent or about 22 million a year. At this rate the world population will reach between 3,000 and 4,000 million during the lifetime of our children.

If the kind of effort being made by the World Health Organization succeeds in eliminating preventable diseases, the rate of increase in population will be much greater than one per cent. The life expectancy at birth of half the population of the world is only 30 to 40 years, compared with 65 to 70 years in countries where modern preventive medicine has been applied. Thus the first efforts to relieve destitution in the overpopulated countries raise the prospect of a calamitous "explosion of population," unless measures are carried out concurrently to provide food and the other primary necessities of life for the increased numbers.

The anticipated increase in population must be considered in the light of pressure of population on the land. In the 19th century the most rapid increase in population was in Europe. Despite the emigration of millions to America and Australasia the population increased by more than 100 per cent, compared with a little more than 60 per cent in Asia. Cheap food from the virgin soils of the Western and Southern Hemispheres, however, successfully met this increase in demand. For a time Europe enjoyed the illusion that there was no end to the new arable land. But the last new land which could be easily brought under the plow was broken during World War I. Though some old pastures were plowed up during World War II, practically no land which had not been previously cultivated was added to the arable land of the world. We have exploited the last of the world's virgin soil. Today the very serious evil of erosion, dramatized by Fairfield Osborn in his book *Our Plundered Planet,* confronts us with the prospect of an absolute decline in arable land.

A rapidly rising tide of world population on a diminishing acreage of arable land—this is the food problem. Some believe that the only solution is birth control. Birth-control propaganda might help, but it will not act quickly enough to equate population and food supply in our day. Speaking for the neo-Malthusians, William Vogt suggests in his book *Road to Survival* that the road to survival for some of us lies in stopping preventive medicine, assistance in food and efforts to increase food production in the overpopulated regions until disease and hunger have reduced their populations to the numbers the land will support.

THERE IS ANOTHER view of the world food problem which conflicts with this gloomy outlook on the future. Many observers believe that with modern agricultural and engineering technology the only practical limit to food production is the amount of capital and



DIETARY PATTERNS of the various regions of the world have been plotted by the United Nations Food and Agriculture Organization. To the left of the vertical line marked 0 calories are foods rich in carbohydrate; to the right, foods rich in protein. The black numbers in the column at left center give the average calories per person per day for each region. The red numbers and bars give the nutritional and dietary targets of FAO.

labor devoted to it. Land damaged by soil erosion can be, and indeed is being, reconditioned not only in the U. S. but in North Africa and Asia Minor, where once-fertile land is now desert. It is now difficult and costly to break in new land, as the British East African groundnut scheme has shown, but it is being done. Frequently it will involve the application of other than strictly agricultural sciences. The elimination of the tsetse fly on the African veld, for example, offers the prospect of opening up a vast new area of grazing land on a continent which is not only an agricultural frontier but also is not even fully explored.

It is claimed that the land presently under cultivation could support twice the present world population if it were made to yield to the full capacity possible by modern technology. The most frequently cited example of overpopulation is India, with "its three mouths to two rice bowls" and its population increase of four million a year. Yet the task of doubling the food output of India has now been thoroughly investigated; the means are at hand, and the engineering program to this end is already underway. At present the Indian yield per acre of rice and wheat is little more than a third of that in Japan. This is because the land is starved for humus, fertilizers and water. The humus and fertilizers can be provided, and plenty of water falls on the land. India is lacking only in storage and irrigation facilities to use the rainfall to the best advantage. This can be remedied. The new government of India has embarked on a great plan of agricultural development which will go hand in hand with the complementary industrial program. If the industrial program could be carried to completion in time, the food supply of India could be doubled in 10 or 15 years.

In countries with the necessary technical knowledge and industrial equipment, food output can increase much faster than in the undeveloped countries. During the war, when there was a market for all that could be produced, the U. S. increased its agricultural production by 35 per cent with 25 per cent less labor, despite soil erosion. In the United Kingdom food production increased by 30 per cent during the war, and the present program aims at a 50 per cent increase by 1952. Better conservation of pastures, by grass-drying and silage, is relieving the island of its dependence upon imported livestock-feed, purchased abroad at the rate of eight million tons per year in prewar days. In the past, except during wars, the food production of industrialized countries has been limited not by the capacity of the land but by the buying power of the world market.

But what of the Malthusian axiom that population must increase in geometrical progression? If that held true, the food problem, of course, would be ultimately insoluble; there would not be standing room on the surface of the earth. History shows no such long-term process. The population of Europe, after its explosive growth of the 19th century, entered a new phase in this century. With the rise in the standard of living and education, the birth rate fell to such an extent that some governments, alarmed at the resulting decline in population, offered grants to induce women to have children. The probability is that the same course of events will ensue in the poverty-stricken countries where populations are now increasing at an accelerating rate. In the long run the rise in the standard of living and education all over the world should be followed by a decline in the birth rate to the replacement level corresponding to the reduced death rate.

So much for the conflicting views on whether old mother earth can produce sufficient food for her children. The view of the author is that if she fails and the gloomy predictions of famine by Aldous Huxley and others are fulfilled, the disaster will not be due to her niggardliness. It will be due rather to the failure of governments to adjust international politics and economics to permit her to give of her almost inexhaustible potential abundance.

LET US EXAMINE first the political threat of hunger, since it is the most urgent. The estimate that two thirds of mankind suffers chronic malnutrition dates from before World War II. The acute postwar food shortage has been relieved by the increased production of grains, rice, sugar and potatoes from the prewar level of 502 million to 547 million tons (in terms of wheat equivalent). These gains are offset somewhat by the failure of the production of high-protein animal products to recover to prewar levels. But meanwhile the world population has increased by about 200 million. Hence though the production of carbohydrate-rich food has increased, the supply per person is still about three per cent below prewar. Correspondingly the supply of animal products is nearly 10 per cent below the inadequate prewar level. As a result the aggregate calorie supply is about seven per cent less, or about 2,200 against 2,390.

The shortage is the more severe in many regions because the distribution of available supplies is uneven. In the U. S., where before the war the average intake of the more expensive protein foods was already high, the consumption of these foods has now increased 20 to 30 per cent. The reverse is true for most of the food-deficit countries, where both total calorie and protein intake have declined. Indeed, less protein has been available to more than 80 per cent of the world's population since the war. The deterioration of supply has been most severely felt in Asia, the region of greatest prewar need. In this period daily calorie intake per person declined in India from 1,968 to 1,621, in Burma from 2,080 to 1,937 and in Japan from 2,175 to 1,834. The calorie requirement for these warm countries is estimated at about 2,600 per head. In the U. S. the present average consumption is about 3,200.

It was hunger following the bad harvests of 1788 that led to the excesses of the French Revolution of 1789. In the European revolutionary movement of the 1840s—the "hungry forties"—the mobs in the industrial towns of England chanted "bread or blood." Today the hunger and poverty of two thirds of the world's people, who comprehend that their lot can be improved, is a more potent cause of the spread of Communism than fifth-column movements in the U. S. and Western Europe.

Yet in the midst of this dire need there remains the economic threat of the food surpluses generated by the progressive technologies of a few fortunate nations. The abundant food output of the U. S. already imposes a heavy burden upon its economy and now has begun to undermine its prosperity. Up to January 31, 1950, the U. S. Treasury had paid out $2,470 million for taking surplus food off the market. In inevitable accord with this policy, production is now being restricted. The 1950 wheat acreage has been reduced nearly 10 million acres below 1949. A further 10-million-acre reduction planned for 1951 would bring total U. S. wheat acreage down to a little more than 60 million. Since U. S. farmers in previous prosperous years bought industrial goods to the value of $9,000 million per year, reduction in their purchasing power will inevitably lead to urban unemployment. This in turn leads to a reduction in the market for more expensive foods. The consumption of these has, in fact, already declined by five to 10 per cent from the postwar peak, increasing the unmarketable surpluses.

THE ONLY way to avoid the catastrophe inherent in this vicious cycle is to adjust international finance and economics to permit the distribution and consumption of the abundance that modern technology can create. The best starting point for action toward this grand objective would be a world food policy based upon human needs. Under such a policy, directed at the abolition of famine and chronic hunger, the world would have no unmarketable surpluses for many years to come.

Taking account of the anticipated increase in the world population, it is estimated that food production would have to be doubled in the next 25 years in order to provide enough for all. Such a goal presents no insuperable difficulties. The doubling of world food production,

	CHINA 15 PER CENT INCREASE IN POPULATION BY 1960	INDIA 25 PER CENT INCREASE IN POPULATION BY 1960	SOUTHEASTERN EUROPE 10.4 PER CENT INCREASE IN POPULATION BY 1960	SOUTH AMERICA 48.6 PER CENT INCREASE IN POPULATION BY 1960
CEREALS (WHOLE GRAIN)	15	39	−3	70
ROOTS AND TUBERS (FRESH)	66	103	26	22
SUGAR	15	25	10	49
FATS AND OILS	58	113	31	65
PULSES, NUTS AND COCOA	59	84	93	70
FRUITS AND VEGETABLES	327	330	78	73
MEAT, FISH AND EGGS	45	305	11	59
MILK (FLUID EQUIVALENT)	5,650	60	77	184

FOOD NEEDS of four regions are given in percentages of their present consumption of various foods. These percentages are required to meet FAO goals by 1960. The percentages are given at the end of horizontal bars.

with a guaranteed market for all that could be produced, would bring prosperity and stability to agriculture all over the world. It would demand vast quantities of industrial products for water storage and irrigation schemes, for reclamation of land destroyed by soil erosion, for fertilizers and equipment, for means of transport and for consumer goods to supply the increased purchasing power of the vast market of food producers. It would thus bring about business prosperity with full employment in an expanding world economy.

A world food plan on these lines would of course call for the creation of enormous credits. There is ample precedent for international financing on this scale. In the 19th century Britain granted credits and made loans to countries in every continent, including the U. S., with no political strings attached. These credits were repaid through the creation of new wealth. Without doubt another such investment would again be repaid in the future.

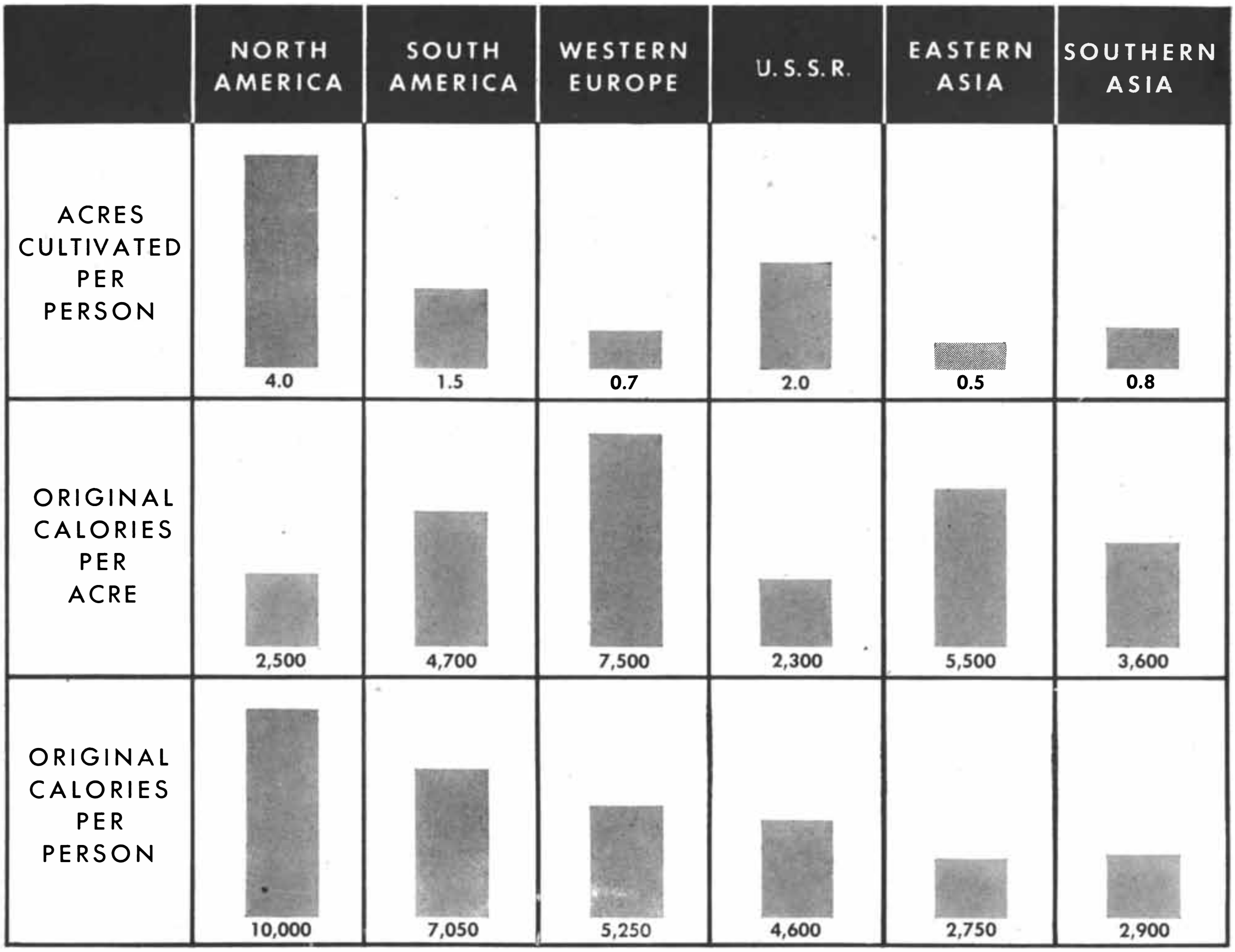
It was to this end that the United Nations' specialized agencies were organized. The Food and Agriculture Organization, the Economic and Social Council and the World Bank for Reconstruction and Development were set up to enable nations to cooperate in the development of the resources of the earth for the benefit of all mankind.

But we must contend with the immediate crisis created by the existence of hunger side by side with food surpluses. In 1946 the author, then Director General of FAO, submitted to the governments of the world a proposal for a World Food Board. This agency was designed to provide the financial and other technical arrangements necessary to convert human need into effective demand in the markets of the world. It was to have the power and the funds for positive action.

If it were at work today, the World Food Board would be engaged in operations similar to those conducted by the agricultural commodity agencies of the U. S. Thus it would be responsible for maintenance of stable world prices and would be empowered and financed to buy and sell food on the world markets. Its determination of price levels, however, would involve international rather than national or sectional interests. As a result of its investigations, the Board would calculate prices to call forth the production of food in volume sufficient to meet world demand. Since it would be buying at lower and selling at higher prices, successful management would make it possible to conduct these operations on a revolving fund of reasonable size.

Moreover, the Board would now as a principal function be finding use for the food surpluses of the U. S. and the few other nations that are burdened with them. With the collaboration of the appropriate UN agencies, it would arrange for the financing necessary to dispose of these surpluses on special terms to the peoples whose need for them is most urgent. In addition the Board would have famine reserves on hand adequate for any emergency that might arise through failure of crops in any part of the world. Finally such an agency would inevitably be playing a major role in advancing international effort to double the world's food production.

At the first FAO conference the U. S.



FOOD PRODUCTION of six regions is compared. The U. S. leads in acres cultivated per person and calories per person per day, but it lags in calories per acre per day. Land use of most other regions is more efficient.

approved of the World Food Board proposal, and its delegation moved to set up the preparatory commission to get it going. But when the commission met two months later the U. S. had changed its mind. The World Food Board proposal continued to hold the support of the majority of national delegations, particularly those of France and India, which did everything possible to get it carried through. The best that could be done, however, was to establish a council which has neither the funds nor the authority to get action taken.

TODAY the U. S., by Marshall Plan aid to Europe and the offer of technical assistance and financial aid to other countries, is trying to do by itself what the UN agencies were created to do. It is doubtful whether it will succeed. To make it work, the U. S. Government would have to expand its program to the $50,000 million scale projected by Senator Brien McMahon. This would impose an intolerable burden upon the U. S. taxpayer. The world cannot be made richer by making the U. S. poorer. Further, the unparalleled generosity of the U. S. can be, and is already being, misrepresented as an attempt to impose American economic imperialism on the world.

To be realistic in advancing the proposal for a World Food Board again in 1950, one must meet a serious political question. Would the U.S.S.R. cooperate? In 1946 the late Fiorello La Guardia, with whom the author was working in the closest contact, reported that he had discussed the proposal with Joseph Stalin and other responsible Soviet leaders. He quoted them as saying that it was the one UN project in which they would participate, once they were convinced that the U. S. and Britain would do likewise and that it would not be dominated in the interests of the U. S. Relations have since worsened, and it is now very doubtful whether the Russians would join. But they should be given a chance. If they refused, the selfish objectives of their national policy would be exposed to world opinion.

Even without the U.S.S.R., the cooperation of the other nations would go far toward removing international trade and financial restrictions. By consolidating the economic position of these nations, such action might prove more important in a continuing cold war than an advantage in the arms race. Further, it would fire the imagination of the peoples presently in revolt and create a new world spirit of hope and a willingness to work together.

The two evils of the glut of food in the U. S. and hunger in widespread areas in the rest of the world cannot be eliminated by U. S. charity. The food problem is international. It can be met only by an international effort. Conducted through the technical agencies of the UN, the world food program would be placed upon a business footing and bring as much benefit to the U. S. as to other countries. Only by multilateral action can the UN redeem the forgotten pledge of the Atlantic Charter to achieve "freedom from want among the people of all lands."

Lord John Boyd-Orr, winner of the Nobel Peace Prize in 1949, is former Director-General of the United Nations Food and Agriculture Organization.

Power from the Sun

While man steadily consumes his limited store of fossil fuels, a bounteous supply of energy is showered upon him by the sun. What are the fundamental means of tapping it?

by Eugene Ayres

WE are engaged today in an intensive search for anything that can be burned. Just a century ago wood was our principal fuel, and the art of the woodcutter embodied all the necessary technology of fuel procurement. Today with our fossil fuels we are dependent upon a host of technologists in almost every branch of pure and applied science—physics, chemistry, metallurgy, geology, geophysics and all the various kinds of engineering. We have finally reached a furious tempo of effort to find and produce and destroy. The climax of this effort will certainly be reached within the lifetime of some of our children.

The use of energy is habit-forming. We cannot now conceive of a satisfactory way of life without abundant and economical power and heat. So while we continue to find and produce materials that can be burned, we are beginning a new search—a search for the elements that can support a nuclear chain reaction. This search too will promptly reach a climax if and when technology has shown that it is practicable to develop industrial nuclear power.

While these two enterprises are being prosecuted to their inevitable ends, we have showered upon us an essentially perpetual supply of energy from the sun. How abundant is this energy?

Let us imagine that we can take from the earth at once all the coal, lignite, peat, tar sands, crude petroleum, natural gas and oil shale that we are ever likely to produce in the future (according to the more optimistic forecasts) and that we have cut up all of our timber into cordwood. Suppose we have segregated all of the uranium and thorium that we are likely to produce in the future (based on recent estimates by Lawrence R. Hafstad of the Atomic Energy Commission) and that we have it all purified and prepared for nuclear fission. We distribute this total amount of energy-producing material over the surface of the earth, and then suddenly we extinguish the sun. We ignite our fuel in such fashion as to give us energy at the rate at which we are accustomed to receive it from the sun. In about three days our entire supply of combustible fuel would be gone. Then we would get the nuclear reactions underway. This would last us less than an hour—provided we had been able to develop the "breeder" reactor, which produces fissionable material while consuming it. Otherwise the nuclear reactions would last only a few seconds. At the end of a few days the earth with its load of ashes and radioactive wastes would begin its descent toward absolute zero. This gives a rough idea of what it would mean to try to compete with the sun.

Fortunately we have, and we will continue to have, plenty of the beneficent solar energy which provides, directly or indirectly, all of the warmth and beauty of the earth. We shall here examine the possibilities of using this form of energy for industrial power.

THERE are two particularly interesting things about the sun. One is the high order of magnitude of the amount of energy it generates. The other is the low order of magnitude of the rate of the nuclear reactions that are believed to be responsible for this energy. Both are quite beyond our terrestrial experience and hence are difficult to comprehend. But in order to understand some of the problems involved in the terrestrial conversion of solar energy to power it is useful to consider the way in which this energy is believed to come into being.

The source of the sun's energy lies deep within its interior. There every second some four million tons of matter are converted into energy, largely by the transmutation of hydrogen to helium with the emission of gamma rays. This transmutation, first proposed by the Cornell University physicist Hans A. Bethe, involves a multistage nuclear reaction which is catalyzed by carbon. It is incredibly slow. Bethe tells us: "Only one per cent of the hydrogen in the sun is transformed into helium in a billion years." Yet the sun radiates energy at the staggering rate of 4×10^{27} or four billion billion billion horsepower hours per annum.

Much of the heat and light of the sun is due not to degraded or stepped-down gamma radiation, but rather to the collision of the material particles involved in the hydrogen-helium cycle. But why does the sun radiate almost none of the original gamma rays? The only difference between the gamma rays generated in the sun and the light that reaches the earth is frequency, or number of oscillations per second. Both are small parts of the great electromagnetic spectrum which passes up from radio waves to infrared to visible light to ultraviolet to X-rays to gamma rays, in order of increasing frequency. The earth receives a little of all of these radiations. But nearly half of the sun's radiation as we know it is in the visible spectrum, and most of the rest is short-wave infrared. There is less than four per cent of ultraviolet.

It is fortunate for us that the sun can act as a step-down frequency converter, for even a moderate amount of gamma radiation would destroy life instead of fostering it. In spite of the vaporous character of the sun it is opaque to all radiation. Bethe tells us that the rays formed in the center of the sun take such tortuous and interrupted journey that they may be on their way for 10,000 years before reaching the surface of the sun. By that time they have been almost entirely degraded to lower frequencies. And any frequencies higher than light tend to be intercepted by atoms in the sun's corona and by the molecules of our atmosphere.

There has been much discussion of the prospect of developing industrial power from the nuclear fission of uranium. This problem is enormously more complicated than the utilization of solar energy. The two projects are alike in that in both cases radiations from nuclear reactions must be converted into some form of useful work. But whereas the solar radiations have been made harmless by natural forces, the artificially induced radiation retains all of its virgin malignity. Whereas the generation of solar energy presents no problems for us, the generation of nuclear energy from uranium is beset with dozens of very serious problems. Whereas solar energy is essentially perpetual, the supplies of uranium are definitely limited. A technology for the utilization of solar energy will become obsolete only by virtue of the substitution of an improved technology for the same purpose. It seems that the sun must be our primary source of energy for the future.

THERE are two conceivable ways of utilizing solar radiation: 1) by taking advantage of its wave aspect; 2) by the use of its particle aspect. The first is perhaps unlikely, while the second is known to be effective.

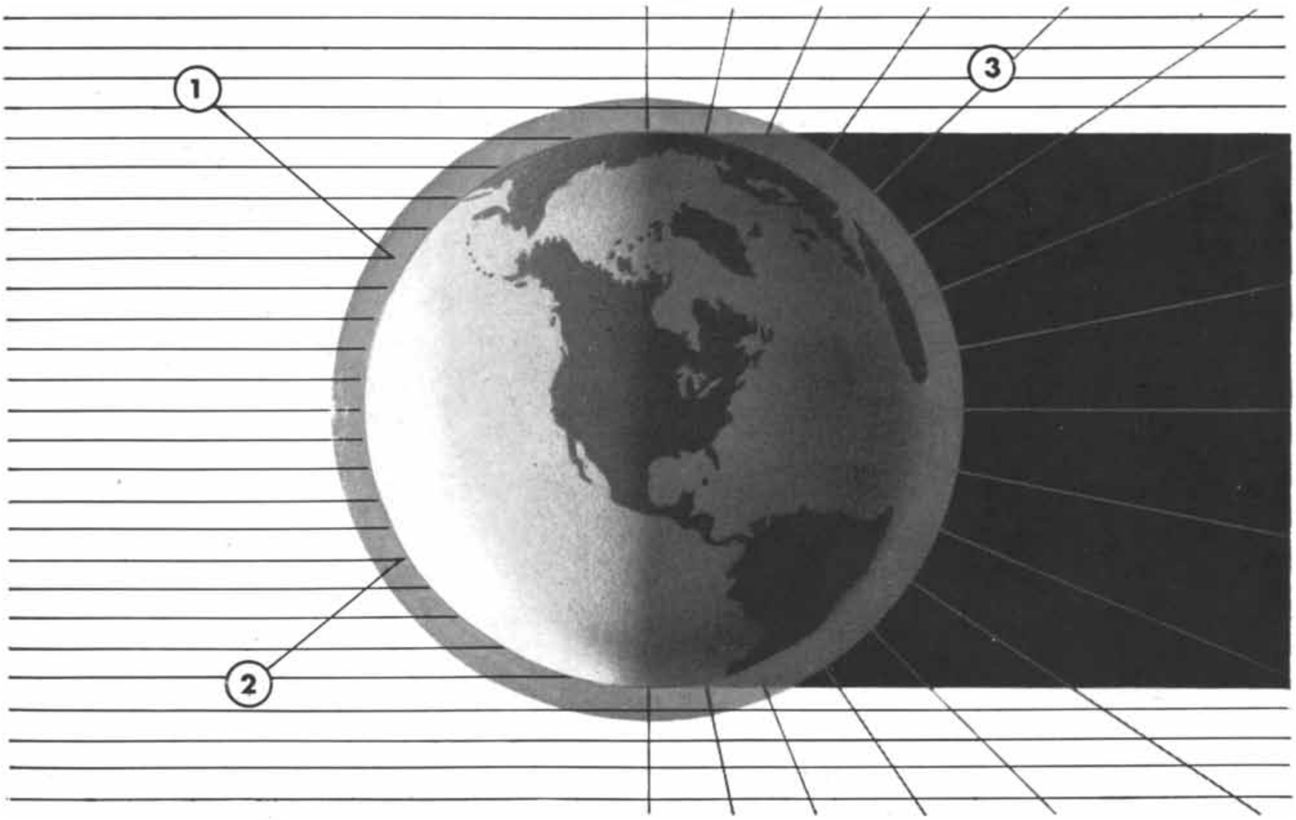
The problem of converting solar radiation to electric power is one of the most fascinating and fundamental of all problems for the physical chemist and the electrical engineer. The great German physicist Max Planck tells about problems that in the cold light of reason turn out to be void of meaning. He calls them "phantom problems." One of his examples is the controversy between the corpuscular and wave theories of light: whether light is in reality made up of particles, occupying a certain position in space at a certain time; or waves, filling all of infinite space. The phantom nature of this problem is now generally accepted by physicists. But while philosophically sound, this dismissal of the problem leaves the engineer with nothing substantial to bite upon. For the practical purposes of invention, the engineer must create in his mind some sort of analogy; and if this analogy is not too faulty, he can do certain useful things with it.

First let us try to forget the particles and think only of the wave characteristics of solar energy. Radio waves, heat, light and X-rays differ widely in frequency and hence in wavelength, but they all satisfy electromagnetic criteria. It is therefore natural to wonder whether we could not contrive to do some of the things with light, for example, that we do with certain radio waves. In this age of radio we are all aware that we are using man-made electromagnetic radiation; that these waves radiate from electrical circuits in which flow rapidly alternating currents. We are aware that this radiation, after traversing space, induces similar alternating currents in other circuits at the receiving end, and that communication is thereby achieved. We understand that the frequencies used in radio range from, say, 20,000 to some millions of cycles per second. We have been told of the recently devised equipment developing considerable power at frequencies as high as 30 billion cycles per second, or a wavelength of one centimeter. Such small waves may readily be concentrated in beams for communication or radar purposes.

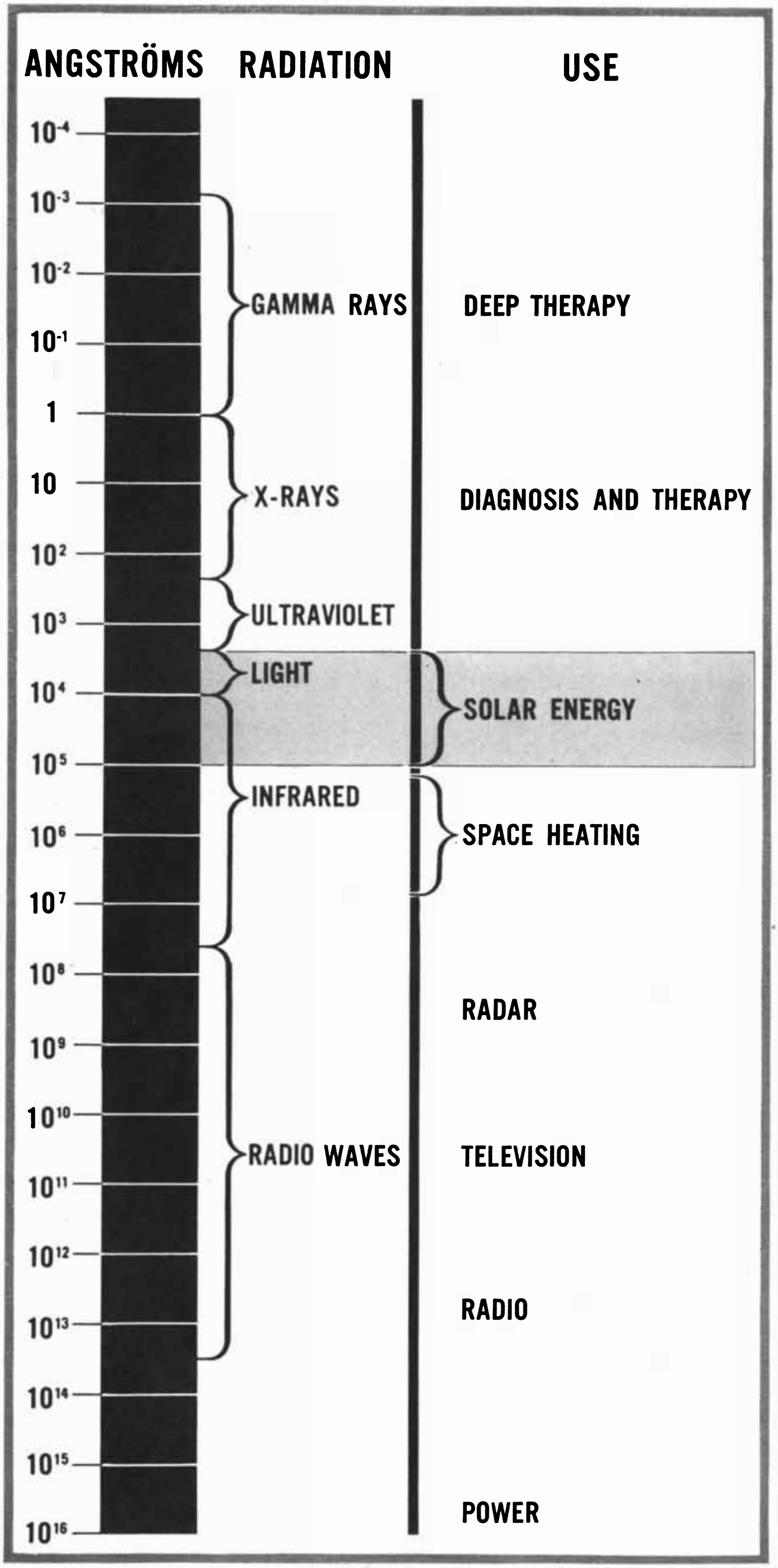
Now such frequencies approach those of the longer heat waves, which start at about 50 times the frequencies employed for radar and end where light begins. Since we already have electrical circuits capable of dealing with electromagnetic radiation approaching the frequency of heat waves, it might seem but a step to the use of equivalent circuits and techniques in our attempts to utilize directly the radiation from the sun.

But in the attempt to handle higher and higher frequencies with man-made equipment, we meet with some apparently insurmountable difficulties. Electrical circuits and the thermionic tubes used in such equipment must have reasonably large dimensions if appreciable power is involved. But certain constituents of the equipment must be small or the circuits cannot be made to respond to the high frequencies. Thus as we approach the higher frequencies the physical size of the apparatus becomes vanishingly small to conform with the wavelength of the radiation, while the power-handling capabilities of the equipment decrease correspondingly.

Thus we see that while the handling of radiation of one-centimeter wavelength is practicable in circuits fabricated by man, the handling of heat



HALF OF THE EARTH intercepts a tiny fraction of all solar energy. About half of the energy intercepted is reflected by the earth's atmosphere (1). Some that reaches the earth's surface is also reflected, notably by vegetation (2). The energy absorbed during the day is balanced by that which radiates away at night (3).



THE SOLAR ENERGY which can be utilized for power is concentrated in a relatively narrow band of the electromagnetic spectrum. In this chart the wavelength of electromagnetic radiation is given in Angström units.

radiation on the order of .02 to .00007 centimeters involves physical dimensions approaching the molecular. In nature, heat and light radiations generated by molecular and atomic phenomena apparently require molecular or atomic mechanisms for their absorption and utilization.

THESE facts bring out another and equally important difference between man-made radio waves and those of heat and light. Our radio waves, even of the shortest wavelength, are produced by a single generator or at most relatively few generators or oscillators operating synchronously so that their outputs combine to excite a single radiating system or antenna with a single oscillating current. In this way we can radiate from a single source a relatively large amount of power. On the other hand, light is produced within single atoms by the spontaneous change in energy state of electrons from a higher to a lower level. The difference in these energy states of the electron within the atom is emitted as electromagnetic radiation. The frequency is determined by the change in energy within the configuration of the particular atom involved. The total energy emitted from a given light source may be large indeed, since countless billions of radiating atoms may be involved, but this energy may be scattered over a wide band of frequencies. Moreover, even if each atom emitted the same frequency, the generators are not triggered simultaneously but at random. The resultant radiation is not synchronized. Each atomic source is independent of every other source, and hence the phase of each wave is random with respect to that of every other wave. Instead of marching in regimented order, the waves move like a disorganized mob.

As early as 1924 the gap between the then-known radio frequencies and heat radiation was filled by the experiments of Ernest F. Nichols of the Case School of Applied Science. He used the earliest and simplest form of radio-wave generation. A high voltage was impressed across the ends of a tube loosely filled with metallic filings. At the points of contact between each pair of metallic particles a spark occurred. This excited electrical-current oscillations in the pairs. Because the dimensions of the radiators were very small, the electromagnetic radiation from each of the numerous individual dipole antennas was of correspondingly short wavelength. Since each pair of filings radiated independently of every other pair there was no uniformity in either the frequency or the phase of the radiated pulses. Replace the numerous metallic particles by an infinitely greater multitude of atomic mechanisms generating waves of light, and the analogy is excellent.

Nichols was able to demonstrate that

the wavelength of the radiation spanned the gap in the electromagnetic spectrum between the thermal waves from the radiator in your living room and the wireless waves that are received by your radio. But there has been no indication that the one can be converted to the other. It does not appear likely that the step from radiant energy to power can be made without an intermediate step involving the molecular or atomic intervention of matter.

All that can be done in this area at present is to define some of the problems. If some genius can find a way to make use of the oscillatory properties of the natural electromagnetic radiations, the discovery might be of far greater importance than the development of nuclear physics. Some work is being done now on the direct conversion to electric power of the gamma radiation from nuclear reactions—a variation of the general problem outlined in the foregoing paragraphs.

LET US now try to forget the wave characteristics of solar energy and think of it as a shower of tiny particles: photons or quanta. This will lead us to a discussion of four possible means of obtaining power from the sun: 1) photosynthesis, the process by which plants utilize light to build their substance; 2) other photochemical reactions; 3) photoelectric phenomena; 4) devices for the development of heat from solar energy.

The energy of each photon or quantum is proportional to the frequency of the radiation. According to this conception, a receiver or absorber of such radiation must be capable of responding to energy levels commensurate with the energy contained in a single photon. The receipt of such energy is manifested as the summation of all the countless individual photons. This is the way light is utilized in nature and the basis of all successful attempts, so far, to develop artificial methods of utilization.

The sun of course radiates impartially in all directions. Only a tiny fraction of this radiation impinges upon the planets of the solar system. The vast remainder flows out into interstellar space. About two billionths of the sun's radiation is intercepted by the earth, but about half of it is radiated back into space by our atmosphere. We receive at the earth's surface about 10^{18} horsepower hours per annum. For purposes of comparison, the total energy represented by our present use of fuels and water power is only about .003 per cent of this or 3×10^{13} horsepower hours per annum.

Now let us consider what happens to the sunlight and the sun heat that reach the earth. Because of the earth's rotation we have alternate periods of night and day. Hence we have alternate periods in which the net flow of energy is toward and away from given points on the earth. If we regard the earth as a whole we have a steady condition in which the outflow and inflow are almost equal. The outflow is very slightly higher because of the generation of heat in the interior of the earth.

In the simple case of the moon, 90 per cent of the solar energy received during the day is absorbed, the other 10 per cent is reflected and all of the absorbed energy is radiated away during the night. The case of the earth is more complex not only because of our atmosphere but because of the peculiar effects of our vegetation and our hydrosphere, or the water surface of the earth. The moon has no atmosphere, vegetation or hydrosphere. The effect of vegetation is peculiar because while it utilizes a little of the light falling upon it to form food and combustible material it rejects most of it at once. The world's annual growth of land vegetation utilizes about 6×10^{13} horsepower hours per annum of solar energy—less than a thousandth of the incident sunshine. But about 30 per cent, or 3×10^{17} horsepower hours per annum, of the energy that reaches the earth from the sun is reflected back into space without waiting for night to fall. Most of the reflection of sunshine during the day is from vegetation which rejects a thousand quanta of light for every quantum that it usefully employs. Vegetation is essential to life because it provides not only the food we eat but also the oxygen we breathe. We must forgive its extravagance. Furthermore, we can get along very well without this 30 per cent.

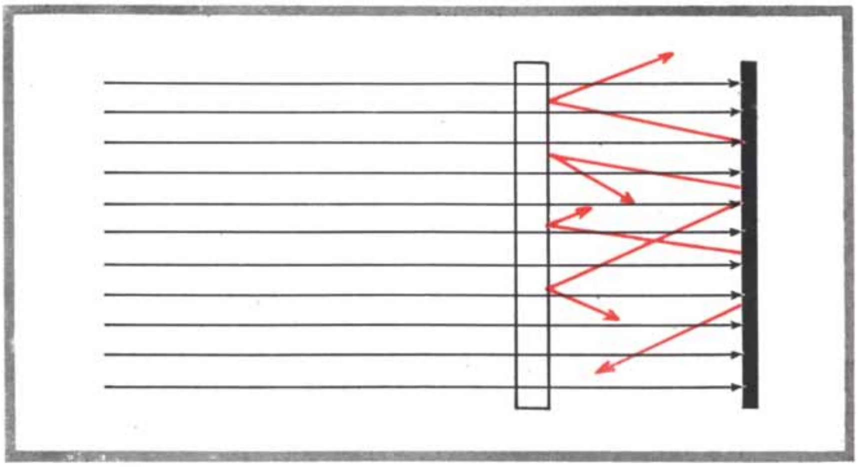
What happens to the other 70 per cent of the solar energy that is absorbed during the daylight hours? About 15 per cent of it is absorbed by bare earth. The other 85 per cent goes to evaporate water from the hydrosphere, and to raise the temperature of the surface water and promote the growth of marine vegetation. The energy expended for evaporation cannot be recovered as power because it is balanced by nocturnal radiation away from the earth by the atmosphere, with the resulting condensation of water vapor to rain or snow. But the energy required to raise the water vapor away from the earth is partly recoverable in the form of the water power of our streams. As a practical matter about .001 per cent of the sunshine absorbed by the earth can and probably will be recovered as hydroelectric power. This is about 10 times more than we are recovering now.

AT THE PRESENT time about 14 per cent of our annual crop of land vegetation is being used for food (53 per cent), fuel (25 per cent) and such miscellaneous items as lumber, paper pulp and chemicals (22 per cent). The unused 86 per cent returns to the earth where it maintains an essential biological balance. It is conceivable that the fuel use of vegetation, now about 10^{12} horsepower hours per annum, can be somewhat increased in the future without endangering our supply of food. But the increase could not be very great, and we cannot count on it. In fact, the concern for dependable supplies of food has inspired research in a number of countries on the industrialization of photosynthesis as applied to marine algae.

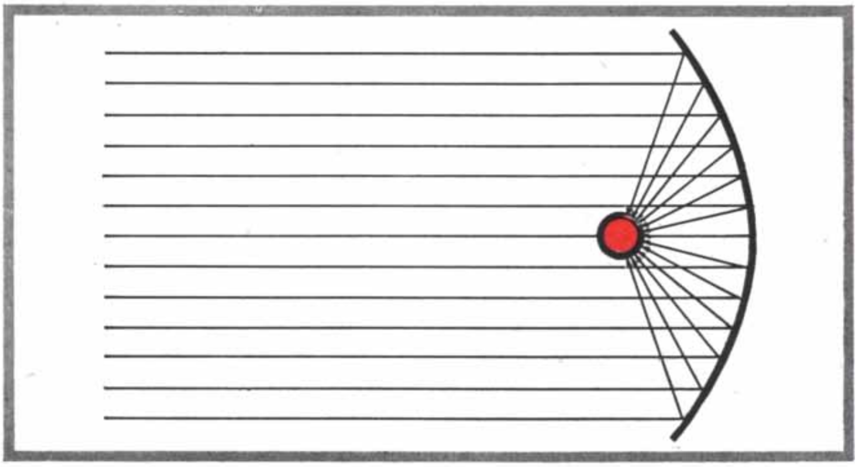
Special emphasis has been placed on studies of the single-celled alga *Chlorella pyrenoidosa,* which multiplies at a rate that appears now to be limited by the concentration of carbon dioxide in the water. The natural source of carbon dioxide is, of course, the .03 per cent ordinarily present in the air. The production of such algae in tanks of water about six inches deep is said to be capable of absorbing up to two per cent of the total solar energy falling upon a given area as compared with less than .1 per cent for average agriculture. The yield has been as high as 15 dry tons per acre per annum, about five times the yield of the *best* land growth, and some investigators believe this yield can be trebled. The process can be made wholly continuous. The rate of flow of growing algae would be adjusted automatically to conform with the sunlight and to maintain optimum conditions for growth.

This work is being carried out in Japan and Israel with the practical hope of improving the food supply. The interest of the many laboratories in this country has been somewhat academic because at the moment we have in this country a more than adequate food supply. Although the protein and fat content of Chlorella can be manipulated, there is no assurance that the alga can be made into food. R. L. Meier of the University of Chicago has made the interesting suggestion that the algae be fermented to alcohol to provide motor fuel at around 40 cents per gallon, or that it be carbonized to form coke. He proposes that, since the concentration of carbon dioxide is a limiting factor to the rate of algae production, the carbon dioxide from the fermentation be used to speed up the photosynthesis still further. If alcohol could be made in this way for 40 cents per gallon, gasoline itself could be made from algae at about 23 cents per gallon by employing the well-known Fischer-Tropsch process.

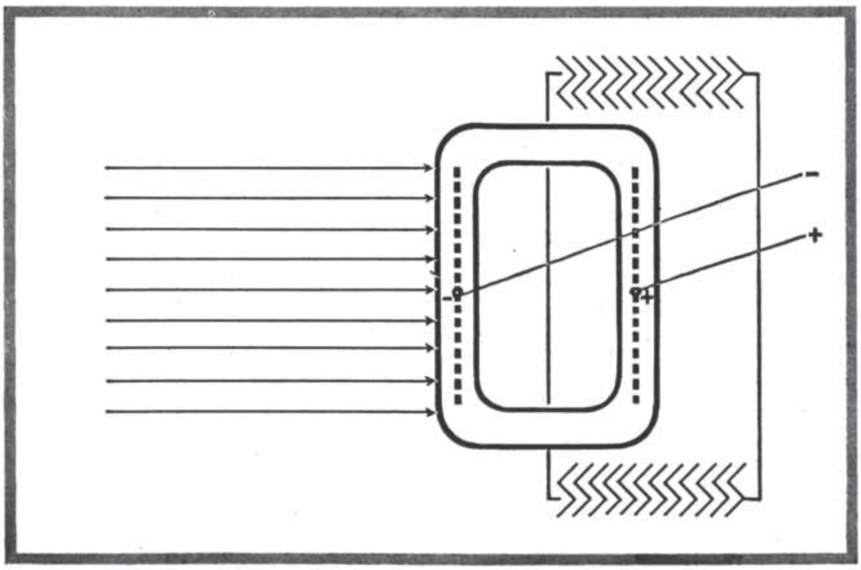
At the present time we are consuming in our internal-combustion engines about a billion barrels of motor fuel per annum. To make this volume of motor fuel by the application of the Fischer-Tropsch process to Chlorella would require an area of about 35,000 square miles—an area nearly as large as the state of Louisiana. This is assuming that a predicted yield of 35 dry tons per acre per annum can be realized. Such an operation would be located preferentially on level land in a southern climate where a river would



FLAT-PLATE COLLECTOR is based on the fact that glass is opaque to the long-wave infrared (*red lines*) that is radiated by a good absorber of solar energy. Glass and the absorber can thus be used to trap the energy.



PARABOLIC REFLECTOR is another means of collecting solar energy. Here infrared is focused to produce a small region of high temperature. This may be removed by various means or used directly to melt various substances.



IRON-THIONINE CELL is based on the light-sensitive oxidation-reduction equilibrium between the two substances. When half the cell is exposed to light and the other half kept in the dark, current may be removed directly.

ensure an ample supply of fresh water. Our scientists will probably come up with something much better than this, but here is one possible solution to the motor-fuel problem for the distant future. Admittedly by that time we may not want motor fuel as we know it today.

There are many fascinating possibilities in this field of industrialized photosynthesis. Although we cannot discuss all of these possibilities, we might point out in summary that technology appears already to have shown the way to at least a 20-fold increase in the efficiency of utilization of sunlight through the agency of chlorophyll. A substantial part of this improvement comes from the smaller proportion of solar energy reflected back into space by marine vegetation. In the summer sun a stagnant pool becomes much warmer than a tree.

THE exact mechanism of photosynthesis is not yet understood. The basic reaction of plant growth may be illustrated by the simple union of carbon dioxide with water to produce carbohydrates and oxygen. This requires the input of 112,000 calories per gram atom—a gram multiplied by the atomic weight—of oxygen. It is assumed that the reaction is accomplished by the stepwise utilization of light. Red light, for example, has an energy intensity corresponding to about 44,000 calories per gram atom. If the efficiency of the operation were perfect this would mean that about 2.5 quanta of red light would be required per atom of oxygen. Extensive studies of Chlorella at the Marine Biological Laboratory in Woods Hole, Mass., indicate a quantum requirement averaging a little below four.

The remarkably efficient job done by chlorophyll for plant growth has been just about equaled with some synthetic dyes and inorganic chemicals. Photosynthesis is of course a species of photochemical reaction. Many photochemical reactions are chain reactions which give up energy. The results are out of all proportion to the energy applied. But for photochemical reactions which absorb energy in the inanimate world efficiencies have usually been quite low. There have been some recent exceptions.

Lawrence J. Heidt and Maynard E. Smith of the Massachusetts Institute of Technology have done some interesting work on the photochemical decomposition of water in the presence of ceric perchlorate and perchloric acid. Under optimum conditions the amounts of cerous and ceric compounds remain unchanged, and hydrogen and oxygen are evolved. The solutions were irradiated with ultraviolet. The yield per quantum was not quite as high as that of photosynthesis but of the same order of magnitude. Further research may point the way to the development of practical methods of generating hydrogen from water by solar irradiation. If the over-all efficiencies can be made high enough, this kind of process will be of fundamental importance.

The interesting work of Eugene I. Rabinowitch, now of the University of Illinois, on the photochemical system involving thionine and iron indicates a quantum yield about as high as that of chlorophyll. The oxidation-reduction equilibrium between iron and thionine is highly sensitive to light. A potential difference can be maintained between illuminated and dark cells containing these substances, and it is conceivable that a direct conversion of sunlight to electric current might be arranged by this means.

Such photogalvanic cells have a low over-all efficiency, but research on liquid and solid cells is proceeding and may turn out important power developments in the course of time. Because of the engineering simplicity of the direct conversion of sunlight to electric power, the photogalvanic cell would not need to be as efficient as photosynthesis, but to compete with nature we shall have to find ways of multiplying its efficiency by a factor of at least 10.

THE simplest utilization of quantum energy is in the development of heat. Ordinary window glass happens to have the property of transmitting nearly all of solar radiation. A little is reflected and a little is absorbed, but about 90 per cent of both light and infrared pass through. On the other hand, window glass has also the property of being almost opaque to the long-wave infrared which is reradiated by a good absorber of solar energy. Glass can therefore be used to make a flat-plate collector of solar energy. The glass and the absorber are arranged in such a way that light and infrared can be absorbed but their energy not permitted to radiate away.

Glass can be used also to construct mirrors for the concentration of light by reflection. Here the surface is coated to reflect all except the small amount of radiation that is absorbed. A large amount of excellent work has been done to evaluate the possibilities of both flat-plate collectors and parabolic mirrors, where glass is used respectively for transmission and for reflection. In appraising this work H. C. Hottel of the Massachusetts Institute of Technology has given a figure of about 50 horsepower per acre as the amount that might reasonably be salvaged in the form of power from the solar energy that reaches an acre of the earth's surface in Arizona on an average annual basis. This would mean about 440,000 horsepower hours per annum per acre. Our 35 dry tons of Chlorella would give about 216,000 horsepower hours per annum per acre if the Chlorella were used directly as fuel, and only about 60,000 horsepower hours per annum if the fuel were used to generate power.

So the simple conversion of solar energy to heat and the use of the heat to operate an engine would seem to be about seven times as efficient as the most optimistic agricultural proposal, and photosynthesis is well out ahead of any substitute plan for the harvesting of quanta through chemical intervention. To produce by optical means all the heat and power now consumed in the U. S. would require an area of about 50,000 square miles—about two fifths of the state of New Mexico. The installation would preferably be in arid country that has a maximum amount of sunshine.

Some useful things are already being accomplished with solar-energy collectors. Interesting experimental houses have been built which utilize solar energy for space heating. The solar heating of domestic water supplies in our southern states has become a general practice. The equipment is usually crude but it is effective for the purpose. One large water heating system in Switzerland is said to have obtained 36 per cent of the theoretical maximum of heat inflow during July, with monthly averages of around 10 per cent for March and August. This is excellent.

UNDER optimum conditions it is possible to obtain from solar energy without optical concentration temperatures well above the boiling point of water. Most of the power-generating proposals, however, have called for the use of reflectors of various kinds.

The Power Institute of the Academy of Sciences in the U.S.S.R. is said to have a group devoted to the development of means for the utilization of solar energy. The mirrors proposed by this group are roughly of paraboloidal shape made up of sections of flat glass. The first mirror was 33 feet in diameter. Later mirrors were planned to be many times as large. The solar installations were to be in Central Asia where the highest power requirements coincide with the sunny season of the year. Such installations were expected to provide steam at all temperatures and pressures required in industry. The subjunctive mood is used here because there has been no description of the final working out of the plan.

It is reported that in Stalingrad in 1941 a solar installation was used to demonstrate the feasibility of melting iron. Felix Trombe of France believes that solar energy, which can be concentrated about 50,000 times with optical systems, is even more adapted to high-temperature processes than to industrial power levels. He notes that "to melt a kilogram of iron one needs much fewer calories than to heat and vaporize one liter of water." Trombe has found it convenient to melt a number of highly refractory materials by optical means.

One application of the high-temperature technique is in the use of thermocouples to develop electric power without the intervention of the steam cycle. The thermocouple is essentially an electric circuit made up of two dissimilar metals. When one junction of the two metals is heated more than the other, an electric current flows through the circuit. It has been found, however, that the thermoelectric power of metal couples does not increase without limit as the temperature increases. Hottel has reported a "five per cent useful conversion of heat to electrical power" by the use of what appeared at that time to be the best materials. This represents real progress, and research has been continuing.

About a quarter of the electric power we use is for lighting. Engineers of the Westinghouse Electric Corporation have predicted the use in the future of phosphor powders as components of paint and wallpaper. Phosphors are substances that have the power of absorbing radiant energy and radiating it after various lengths of time. They might thus be used to absorb some light during the day and radiate it at night. Because phosphors are used to coat the phosphorescent faces of television tubes, the advent of television has led to renewed interest in the development of phosphors. In view of the interesting new information being accumulated, the Westinghouse prediction does not now seem impossible. Here is a quantum phenomenon that need not be efficient to be useful because it involves the use of a little of the light that otherwise would be wasted. Clear daylight varies from about 2,400 foot-candles in winter to about 8,000 foot-candles in summer. A room is well lighted at night with little more than 100 foot-candles. In other words, we need at night only a few per cent of the illumination intensity of the day, and we do not commonly need even this except for a few hours.

THE future will probably see some of these things come to pass. Even the clumsy application of the primitive scientific knowledge that we have at this time could ensure a plentiful supply of energy—at a price. With the fuller understanding of the fundamentals of radiation that is sure to come later on, the price will shrink. The sun will again be recognized as the most important of all natural physical phenomena—the same sun that was worshipped as a deity and valued for its comfort and healing by all ancient peoples.

Eugene Ayres is director of the chemistry division of the Gulf Research and Development Company.

THE PARALYTIC PLAGUE

The virus that causes the symptoms of poliomyelitis has a subtle relationship with man. Not all of its hosts are sick, which explains some curious aspects of its behavior

by David Bodian

IT WAS the winter of 1948 and 1949 along the northwest shore of Hudson's Bay, only a few hundred miles south of the Arctic Circle. The average temperature was 32 degrees below zero. The Eskimos of the small and scattered communities of this remote region could have imagined almost any calamity but the one that overtook them: a pestilence that struck down young and old with crippling or mortal strokes. History being what it is, no one can affirm or deny that the contagion had ever visited these people before. It is certain that none among them remembered it.

The disease that visited the Eskimos of Hudson's Bay is familiar to us as infantile paralysis, or poliomyelitis, a recurrent and increasingly serious problem of public health. In the U. S. and Europe poliomyelitis characteristically occurs in summer epidemics among younger age groups. How could this be the paralytic plague of the Eskimos, which occurred in the dead of the subarctic winter and which indiscriminately paralyzed or killed people in every age group including the oldest? If it was, it was especially noteworthy that the fatality rate among those affected by the disease was about 5 to 10 times that of similar epidemics in the U. S.

What was the meaning of the Eskimo epidemic? The fact that it was indeed poliomyelitis has served to bring a number of enigmas into sharper focus—enigmas which must be solved before the disease can be controlled. But before we can consider the meaning of the Eskimo epidemic we must outline what we know of poliomyelitis.

In poliomyelitis, as in most infectious diseases, the relationship between the parasitic organism and its host is so complex that the problems of the disease must be studied by many disciplines of medicine, biology and chemistry. The parasitic organism of poliomyelitis is known to be a virus, but it has curiously received less attention than the host. The reason is that the direct study of the virus has been prevented by our inability to purify it. But although the chemical nature of the virus is unknown, except as implied by similarities in its behavior to other viruses studied more successfully, it has been extensively investigated in human and experimental hosts and their environment.

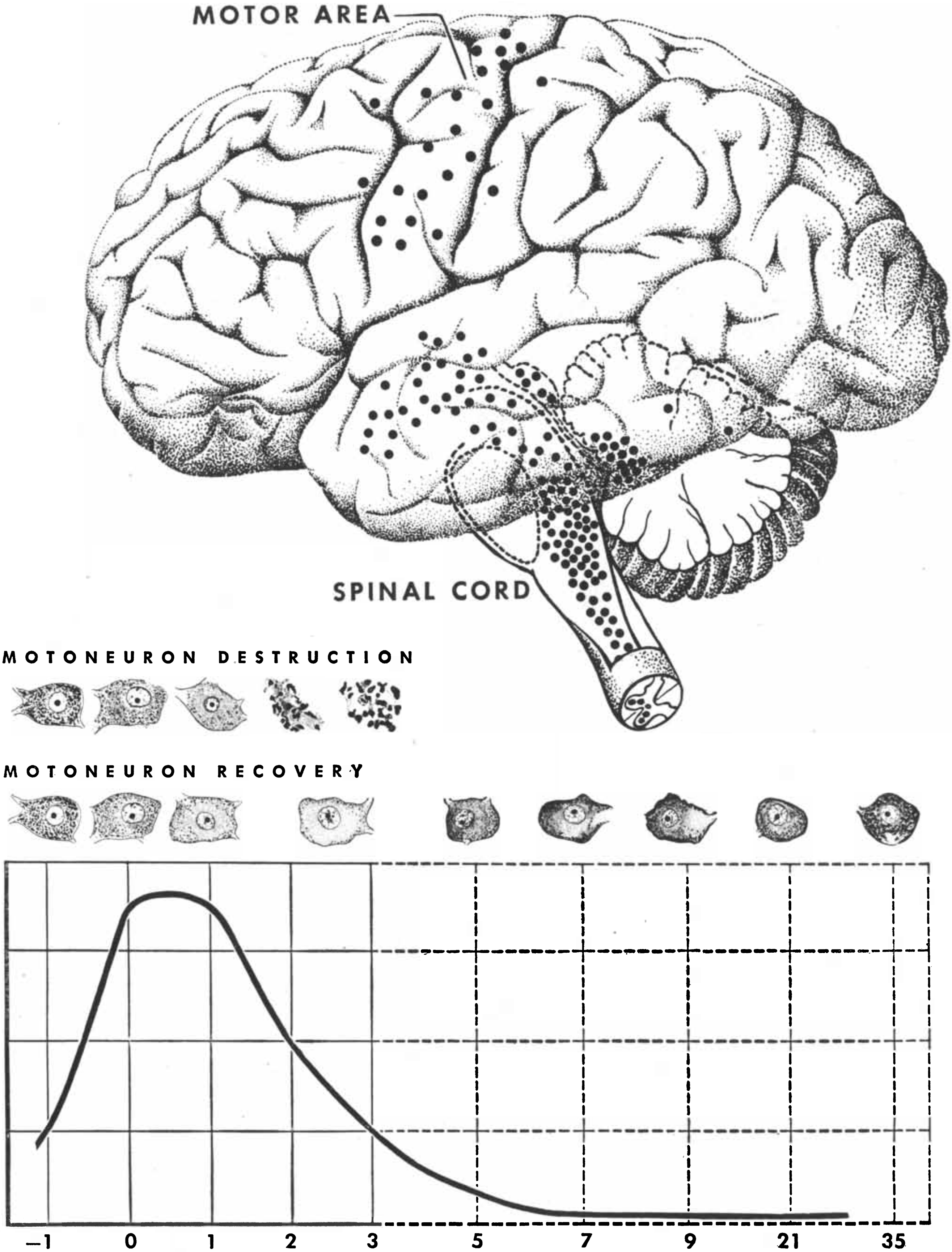
THE VIRUS of poliomyelitis is distributed all over the world. So far as we know its only natural host is man. The virus can readily be recovered from the brain and spinal cord of someone who has died during the acute paralytic form of the disease. It can also be recovered from the throat and bowel excretions of sick people and of many others who become infected during an epidemic but who show no outward signs of the disease. It is therefore no surprise that the virus has been found frequently in sewage and occasionally in houseflies. But there is no evidence that the virus multiplies in the housefly. There is no evidence that under natural conditions it multiplies anywhere but in the central nervous system and alimentary tract of its human host.

Nor does the discovery of the virus in sewage indicate that the infection is transmitted, like typhoid fever or dysentery, by contaminated water, milk or other foods. There is indeed considerable evidence against this possibility. Near the turn of the century the Swedish investigator Ivar Wickman, who made the first thorough study of poliomyelitis, showed that the occurrence of the disease could be explained only by the assumption that the infection is spread from person to person. He also concluded, and the conclusion has been amply confirmed since his time, that infected but apparently healthy people were involved in the spread of the disease.

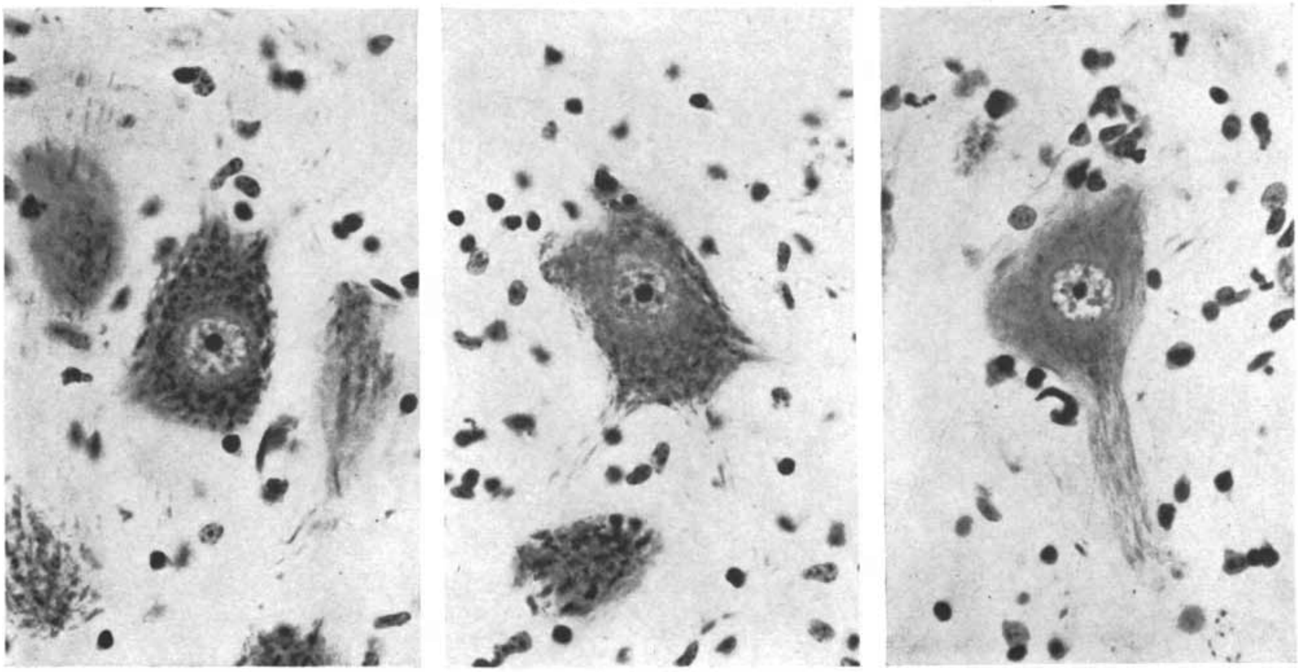
The difficulties of investigating poliomyelitis today are due largely to the fact that the virus can be identified only by its ability to produce in the nervous system of monkeys a disease that is almost identical to the human disease. When experiments require monkeys instead of mice or even test tubes, the cost and the sheer labor of research are immensely increased. Although one of the three known types of poliomyelitis virus can produce a paralytic disease in mice and cotton rats, the identity of even this type must occasionally be checked by introducing it into the brains of monkeys.

When material suspected of harboring the virus is inoculated into the brains of monkeys, the presence of the virus is revealed by a disease which follows after one or two weeks. The disease is characterized primarily by a paralysis of the monkey's muscles which strikes rapidly after a day or so of fever and muscular stiffness, and which usually progresses for a day or two until one or more of the monkey's limbs may be almost or completely powerless. But although this set of symptoms is typical of poliomyelitis, it is still necessary to confirm the diagnosis by laboratory tests. These include the identification of characteristic microscopic changes in the brain and spinal cord and, in monkeys which recover, the demonstration in the blood serum of antibodies which specifically combat the virus.

The identification of the virus is unusually important in the diagnosis of poliomyelitis. There are many other viruses of similar size that cause a disease of the nervous tissues, and some of them produce symptoms that closely resemble those observed in mild or nonparalytic poliomyelitis cases. In 1924 only three neurotropic viruses, *i.e.*, those which have an affinity for nervous tissues, had been identified in man; now we know of some 20, and scarcely a year passes without the identification of another. Many more viruses of this type are known to infect animals other than man. Whether some of the newly identified viruses have only recently acquired the ability to infect man, or whether they have long had this ability, it is impossible to say. Surely our increased knowledge, our improved techniques and our new laboratories have made it easier to identify viruses. Oddly the fact that poliomyelitis often leaves its victims severely paralyzed but alive did not make it particularly easy to identify the disease in earlier times. The first cases that were described clearly occurred in England in 1835, and the first epidemic that was well reported took place in Sweden in 1887. Yet it is more than likely that poliomyelitis occurred in antiquity. The ancient and modern view of disease are



MOTOR NERVE CELLS, or motoneurons, suffer most from the invasion of the poliomyelitis virus. The drawing at the top shows the general distribution of lesions in the brain and brainstem. The vertical coordinate of the chart is the concentration of virus in the spinal cord. The horizontal coordinate is days after first symptoms.



INFECTION of the motor nerve cells of a rhesus monkey is shown at three stages. The first photomicrograph shows a normal cell. The second shows a cell in an early stage of infection. The principal change is in the diminution of Nissl bodies, tiny granules outside the nucleus. The third shows further changes in Nissl bodies.

so different that even diseases with stigmata that seem obvious to us today are difficult to identify in historic writings.

Since viruses live only in cells, the cells of the living host are the only test tube in which the behavior of the poliomyelitis virus can be observed. The study of the virus is thus largely the study of changes in the host which act as indicators of virus activity of one kind or another. Obviously the changes in a living host are much more complex than those in a test tube containing bacteria multiplying in nutrient broth. The living system especially tends to react strongly against a foreign process within it and to re-establish its normal condition. Nervous tissue is notably complex, so the interaction of neurotropic viruses and their host tissues is unique.

THE INTERACTIONS of virus and host tissues can be divided for convenience into two stages which sometimes occur in order but which usually go on simultaneously. The first stage involves the multiplication of the virus and its effects on the host. The second stage occurs when these infectivity effects are countered by the defensive mechanisms of the host, which usually lead to recovery and convalescence.

The infectivity effects of the virus of poliomyelitis are astonishingly selective, since they affect to any appreciable extent only the nerve cells of the brain and spinal cord and certain cells of the alimentary tract. The particular cells of the alimentary tract in which the virus multiplies have not yet been identified because, unlike the infected nerve cells, they do not show obvious signs of the disease. Even within the nervous system of the host the virus multiplies only in the cells of certain regions. This selectivity reveals a delicate balance between the virus's requirements for growth and the host cells' capacity to satisfy them.

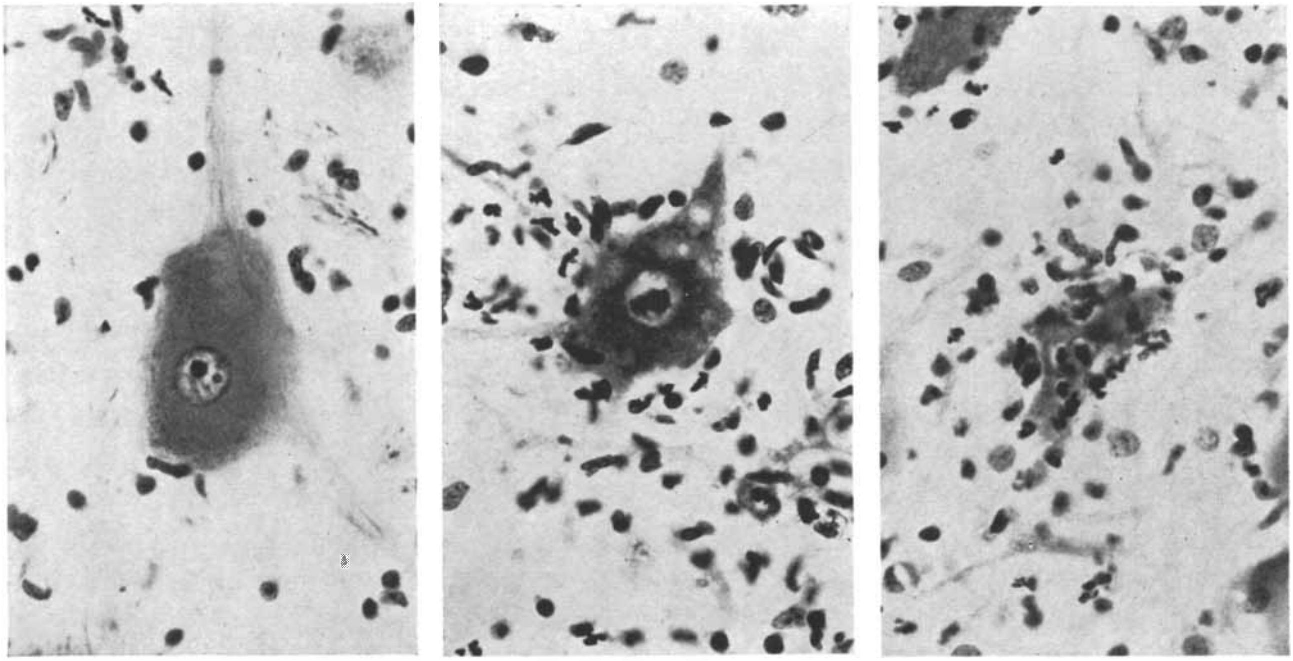
Although they are not exclusively infected by the virus, the motor cells of the brain and spinal cord suffer most from the infection. Many of them, especially those in the spinal cord, are destroyed. It is this destruction of nerve cells, which are irreplaceable because they cannot reproduce themselves, that causes the tragic paralysis of poliomyelitis. Other motor cells may be damaged during the acute stage of the disease to the extent that muscles they control are temporarily paralyzed. When these cells recover, however, the muscles also regain their power of voluntary contraction.

The initial step of the pathological process in nervous tissue is an increase in the amount of virus. In experimental animals this increase occurs in a typical growth curve for the first day or two. A rapid decline in the virus concentration follows, and after one to two weeks virus can no longer be found in the previously infected nervous tissue. One might expect that the decline is due to the exhaustion of the medium in which the virus grows. This is belied, however, by the fact that many nerve cells are little affected during the course of the disease. The decline is due rather to defensive reactions in the tissues which are still imperfectly understood.

The growth of the virus is paralleled by a sequence of dramatic microscopic changes in the infected nerve cells. At first the Nissl bodies, which are small granules outside the nucleus of the cell, diminish in size. Since the Nissl bodies contain nucleoprotein, which is also the fundamental constituent of the chromosomes in the nucleus, these early changes appear especially significant. In many cells the changes go no further than the Nissl bodies, and if the nucleus is not greatly affected, the cell will recover. In other cells, however, the changes progress to the point where the cell dies. It is then absorbed or its remains are ingested by scavenging white blood cells.

ALL these infectivity effects are followed by the second stage: the defensive mechanisms. The changes in the nerve cells, and perhaps the multiplication of the virus itself, cause another series of changes of equal and even greater magnitude due to the inflammatory reaction which follows all infections. The reaction consists of an outpouring of millions of white cells from the blood vessels in the infected regions. These cells, and other cells derived from them, take part not only in the removal of dead nerve cells but also in chemical responses such as the production of antibodies.

So the multiplication of the poliomyelitis virus in nerve cells sets off a train of interrelated events, all of them varying in intensity among various people. The pathological changes in the tissues result not only in such symptoms as paralysis; they also bring about the production of antibodies which enter



DESTRUCTION of the motor nerve cells of a rhesus monkey is also shown at three stages. The first photomicrograph shows a cell in which the Nissl bodies have disappeared. The second shows a cell which has disintegrated and which has begun to be removed by white blood cells. The third shows late stage of absorption.

specifically into immune reactions with the virus. These immune reactions occur whether the original infection was clinically severe or "silent."

The immune reactions are called forth when the virus multiplies in the tissues that are susceptible to it, or when it is introduced as a vaccine into tissues that are not. The reactions are apparent in several measurable ways. One is that an infected host, whether man or experimental animal, is protected against subsequent infection. Another is that an adequately vaccinated host is similarly protected. The degree of protection is related to the concentration of antibodies in the blood serum, and this may be measured in experimental animals by inoculating them with a series of increasingly large doses of virus.

The immune reactions are obviously an important clue to previous infection, silent or otherwise. In the U. S. people of older age groups are not only less susceptible to poliomyelitis than those of younger age groups; they are also more likely to have antibodies in their blood serum. The evidence has grown to the point that the presence of poliomyelitis antibodies is a certain mark of previous poliomyelitis infection, and of some degree of immunity to the disease.

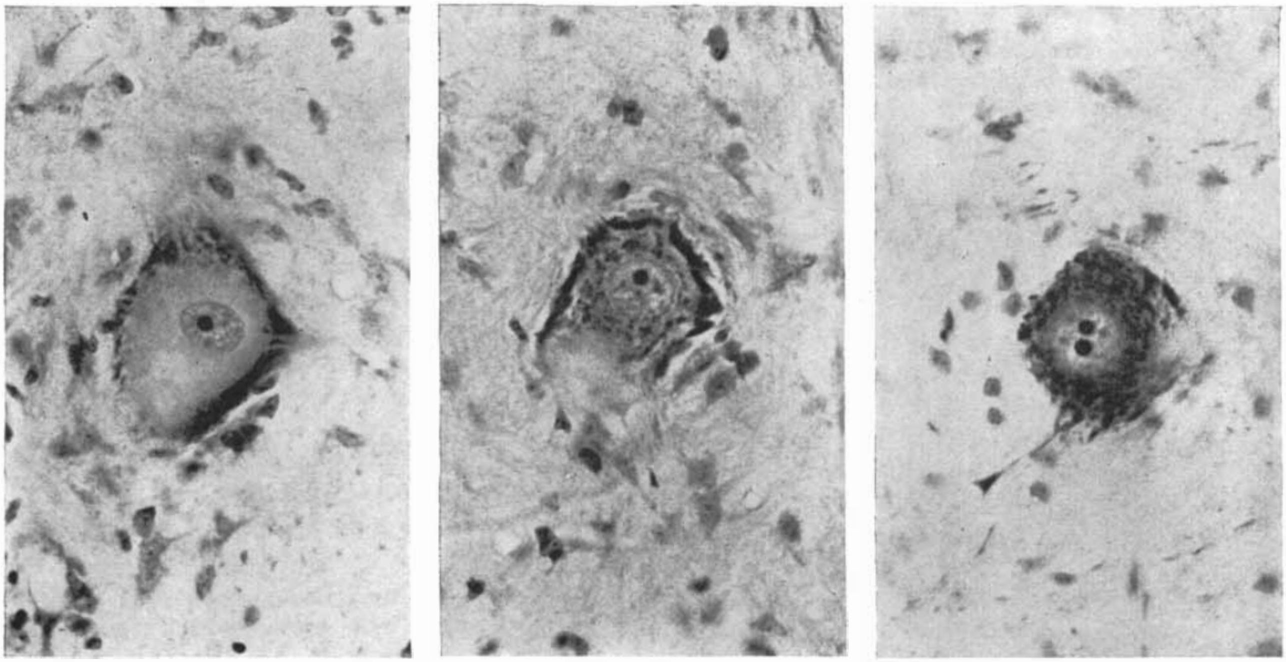
The immune reactions are also valuable in the identification of neurotropic viruses. Since the reactions are related to the molecular nature of the viruses, they are our most subtle tool for distinguishing one virus from another. They even enable us to distinguish differences between subgroups of each virus, where such subgroups exist. It was thought at one time that viruses such as that of poliomyelitis could not produce antibodies at all, since one infection did not always protect the host against a second. It is now clear that this is not due to the poor immunizing power of the poliomyelitis virus, but to the three distinct types of the virus. Clinically and pathologically the three types produce the same disease, but they do not confer effective protection against one another. Such heterogeneity is also characteristic of the viruses of encephalitis and influenza.

The consequences of the heterogeneity of poliomyelitis viruses are far-reaching. If we are to know whether a population possesses any degree of immunity, it is necessary to examine the serum antibodies of individuals in all age groups against all three known virus types. And if we are ever to employ protective vaccination against poliomyelitis it will be necessary to include in the vaccine all its viruses.

This brings us back to the paralytic plague that visited the Hudson's Bay Eskimos. We can now view their calamity and our problem in a larger context. We might first ask why such a high proportion of the Eskimo population became sick as compared with the proportion in our own epidemics. One might assume that contact was more favorable among the Eskimos because of their intimate way of life, their gregariousness and their ignorance of modern hygiene. Yet we know that in our own epidemics many people harbor the virus in their alimentary tracts without any sign of illness. So actual infection is much more common in our epidemics than is apparent from the number of individuals who are sick. It seems likely that at least one factor determining the relatively large number of severe cases among the Eskimos was their low level of immunity. Unfortunately we have no information about the poliomyelitis antibodies in this group of Eskimos, but their previous experience with the poliomyelitis virus must have been quite limited because of their isolation.

IT is now clear from the evidence of the antibodies in their blood serum that most people in the U. S. have had contact with the poliomyelitis virus by the time they reach their teens. This confirms earlier studies in the epidemiology of poliomyelitis, which showed that the decreasing risk of paralytic attack with increasing age must in large part be due to the acquisition of immunity by means of silent infection or infections early in life. In adults there is evidence of a general distribution of antibodies against all three known types of poliomyelitis virus in the blood serum. The presence of these antibodies in people who have had no obvious infection indicates the extraordinary prevalence of the poliomyelitis virus in the U. S. Although the antibodies resulting from silent infection will not always protect against infection later in life, there is little doubt that they have increased the total immunity of our population.

If we were to assume that half the Eskimo population had become sick with poliomyelitis because it had had little or no previous contact with the disease,



RECOVERY of the motor nerve cells of a rhesus monkey is shown at three stages. The first photomicrograph shows an early stage in the recovery of a cell. The second shows the reappearance of Nissl bodies. The third shows almost complete recovery except for an "inclusion body" which remains within the nucleus of the cell.

we could conclude that our own low rate of sickness was due to the fact that our silent infections are spread out over years rather than concentrated in epidemics. Unfortunately such conclusions must be tentative. Our statistics on the incidence of poliomyelitis in various regions are not accurate enough. It is also possible that the specific immunity produced by previous contact with the virus cannot completely explain differences in the sickness rate. There may be, for example, genetic differences in susceptibility to paralysis by the virus. On a larger scale this genetic difference would amount to a racial difference.

By the same reasoning we have followed in comparing the sickness rates of the Eskimos and of the U. S., we can conclude that the mortality rates are determined by the same factors of previous immunization and innate resistance. Variations in the so-called "virulence" of different strains of the virus—that is, their ability to invade host tissues and to produce pathological effects—may also play a role in the severity of the disease. For example, different viruses of a single type may produce in monkeys symptoms of greatly different degrees of severity. It is of course conceivable that "mild" viruses may be able to proliferate in the alimentary tract, spread from person to person, produce immunity, and produce little apparent infection. Our information as to whether this occurs in a given population by chance, or whether it occurs only in populations with some previous immunity, is very meager. These aspects of poliomyelitis are only beginning to be investigated. The fact that viruses obtained from fatal cases in our own population, as well as from those in the Eskimo epidemic, may produce a relatively mild disease in monkeys also suggests that the virulence of various viruses cannot alone explain differences of severity and mortality in the human population.

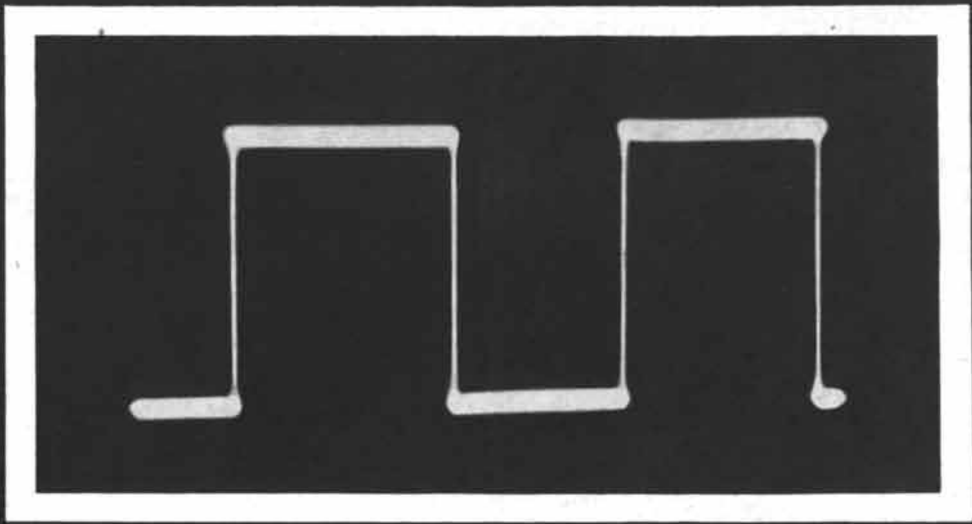
One of the most unusual features of the Eskimo epidemic was the even distribution of paralytic cases and deaths among people of all age groups. This phenomenon also suggests the absence of immunity among the Eskimos, and indicates the significance of previous infections in the low rate of poliomyelitis in our own older age groups. There had been similar evidence in the fact that older people in isolated rural populations are more susceptible to the disease than those in urban populations. The Eskimo outbreak, however, is unique in demonstrating that aging alone plays no role in resistance, and that early contact with the virus is probably the basis of the relatively great immunity of our adult population to paralytic and fatal poliomyelitis infections.

It is of great interest that John R. Paul of Yale University has recently shown that antibodies against the Lansing type of poliomyelitis virus were few or absent in almost all people below the age of 20 in an isolated Eskimo group in northern Alaska. Almost all of these Eskimos older than 20, however, did possess serum antibodies. The fact that their last recorded cases of poliomyelitis had occurred just 20 years previously indicates in striking fashion the relation between the occurrence of disease and the development of antibodies, as well as the importance of surveys of serum antibodies in revealing the immune status of populations.

I think we may be justified in holding the secure belief that a paralytic plague of the scope and severity of the Eskimo outbreak could not possibly occur in our own population, granting the correctness of our information and its interpretation by most immunologists and epidemiologists. In view of our inability to prevent poliomyelitis because of the role of apparently healthy persons in spreading the disease, our present problem is to protect the susceptible portion of our population, largely children. Since it has been shown that monkeys can be successfully vaccinated with virus rendered noninfective by treatment with formaldehyde, appropriate methods of vaccinating humans are now being actively investigated.

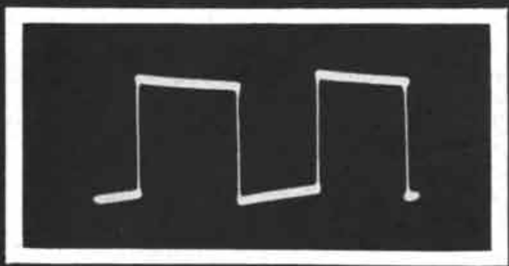
It is of course always possible that a drug such as penicillin will be found that can arrest the course of the disease in its early stages. But successful vaccination offers the greater promise both of preventing paralytic attacks and of supplementing the immunity already being produced by a natural process—the widespread occurrence of silent infections. Vaccination is indeed our principal hope for the complete control of the paralytic plague.

David Bodian is associate professor of epidemiology at Johns Hopkins University.

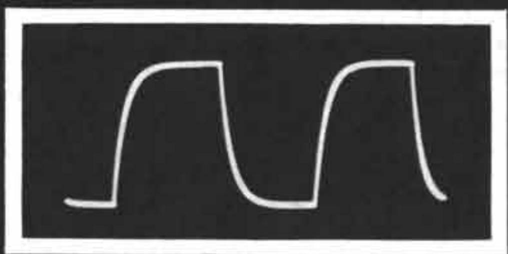


A perfect square wave, photographed by engineers of Allen B. DuMont Laboratories, Inc., at the output of a high-frequency amplifier. This is the result of repeated adjustment and readjustment of a compensated attenuator and peaking coils.

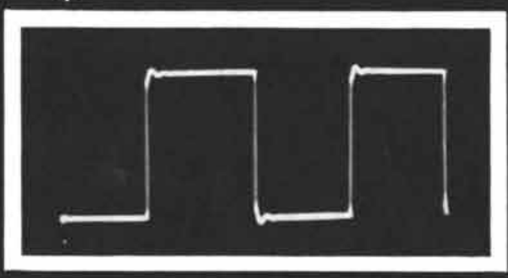
Improper adjustment results in poor low-frequency response. Note tilt in top and bottom flats. Percentage of tilt is a measure of low-frequency response and low-frequency phase shift.



Effect of "under peaking" of high-frequency compensating inductances. Note that rise time of square wave has been distorted so that the leading edge is rounded instead of sharp.



"Over peaking" with extremely fast rise. This produces "ringing" in the leading edge of the square wave.



PHOTOGRAPHY

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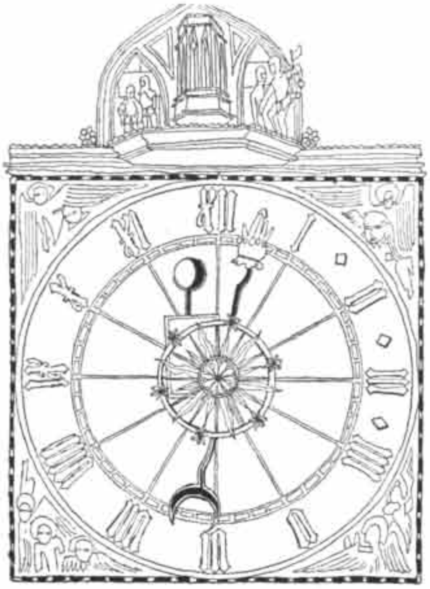
TRADE-MARK

SCIENCE AND



The Curious Pike Affair

TO officials and workers in the atomic energy project, and to many scientists outside it, Sumner T. Pike has been known as one of the ablest and most likable members of the Atomic Energy Commission. One of the five original members appointed to the Commission in 1946, he is the only Commissioner still remaining in the project. He has been noted among his fellow Commissioners for his enthusiasm for the great possibilities in atomic energy, his quick grasp of the problems and his political independence (he is a Maine Republican).

It therefore came as a considerable surprise when Pike's renomination by President Truman for a new term on the Commission was disapproved by a majority of the Senate members of the Joint Congressional Committee on Atomic Energy. While the Committee members unanimously endorsed the reappointments of Commissioner Henry D. Smyth for a one-year term, of Thomas Murray for two years and of Gordon Dean for three years, four Republican Senators and Edwin C. Johnson, Democrat of Colorado, joined to register a 5-to-4 vote against approval of Pike's reappointment for a four-year term.

Although Pike's reappointment was eventually confirmed by a 55-to-24 vote on the Senate floor, the curiously reticent opposition that had been registered against him left some disquieting questions. His opponents had offered only vague objections; the closest to a concrete criticism was Republican Senator Bourke B. Hickenlooper's assertion that Pike had opposed development of the hydrogen bomb. Pike, in reply, indicated that in a pre-decision memorandum to President Truman he had raised some questions about the hydrogen bomb proposal, among them the fact that such a development could have no constructive uses, such as nuclear fission had; but Commissioner Smyth testified before the Joint Committee that after the President's order to proceed with the hydrogen bomb, Pike, as acting chairman of the Commission, took vigorous steps to carry out the order and push the H-bomb program.

What, then, were the unspoken reasons for the fight against Pike, and what effects may they have on the Commission's work? Washington speculated that Pike's support of ex-Chairman David E. Lilienthal in the abortive Hickenlooper investigation last year, his clash with Hickenlooper during the same investigation over the construction of a gas pipeline to Oak Ridge and his reported unreceptiveness to patronage demands from Republicans may have played a part in the opposition. The two Colorado Senators, Johnson and Eugene D. Millikin, also disclosed that they were dissatisfied with the AEC's progress in developing Colorado's low-grade uranium ores. But those interested in the atomic energy enterprise thought a deeper issue might be involved. Like Lilienthal, Pike has been a vigorous advocate of the development of the constructive aspects of atomic energy; he has been particularly keen on pushing the reactor program to develop applications of atomic energy for industrial power. Observers familiar with the underlying conflict that has existed between certain Congressmen and the AEC during the period of civilian control believe that the attack upon Pike may well have been prompted by those in Congress who regard the AEC as strictly a weaponeering agency and who are suspicious of any projects for nonmilitary (and nonsecret) uses of the atom.

At all events, the attack on Pike ended any possibility that he might be named permanent chairman of the Commission. The day after Pike's confirmation President Truman appointed as chairman Gordon Dean, who had just completed his first year in the AEC. A 44-year-old lawyer, Dean had been assistant dean of the Duke University Law School, chief of the appellate section in the criminal division of the Justice Department, a law partner of Senator Brien McMahon, an assistant to Associate Justice Robert H. Jackson during the Nuremberg war crimes trials and professor of law at the University of Southern California.

Atomic Free Enterprise

WHEN David E. Lilienthal announced his resignation as chairman of the Atomic Energy Commission

THE CITIZEN

last November, he said one of his chief reasons was in order to have "greater latitude . . . to engage in public discussion and public affairs." Now, in two highly publicized articles in *Collier's*, he has proposed a major change in the nation's atomic energy program: he urges that we "develop the atom as we normally would any new industrial knowledge: through private industry and competition."

Lilienthal argues that government ownership of all atomic industry, as required under the Atomic Energy Act of 1946, is stifling the peacetime uses of atomic energy. "The time for the first industrial applications of atomic knowledge is overdue. . . . The government has today an ironclad, airtight and all-embracing legalized monopoly of this vast enterprise. . . . There is no private investment, no risk of loss nor chance of profit by any private individual or corporation. . . . No private individual or institution that Government Monopoly has not expressly admitted to the necessarily narrow circle of its 'contractors' can work on or experiment with atomic industrial materials."

Lilienthal repeats a suggestion, already made by Charles A. Thomas of the Monsanto Chemical Company, that private concerns be allowed to build power-breeder reactors, which would simultaneously produce fissionable material and electric power. He says that if the necessary technical information were released private industry would also be interested in building reactors for research and for the commercial production of radioactive isotopes.

"The [Atomic Energy] act's process of 'declassifying' information . . . has proved hopelessly academic and unworkable. It resembles nothing so much as trying to cut down the redwood tree of secrecy with a penknife: the tree grows faster than the whittler can cut. . . . Only *one* corporation in the country is making or is permitted to know how to make by the method now in use the basic atomic material known as uranium 235. Only *one* industrial concern in the country is making, and only two know how to make, the basic atomic end product, plutonium. . . . The Russians have made and tested an atomic bomb. We must assume that they had at their disposal adequate technical information [and] men able to translate such information into industrial operations. . . . I believe in secrecy about atomic weapons, and particularly the status of their development. Our Army, Navy, and Air Forces manage to protect secrets about their weapons and equipment without going to the extreme of establishing Government Monopoly of the entire industry that produces those secret weapons. . . . The present scope of Government Monopoly and Secrecy *hurts us more than it helps us*. . . . Only industry—as proprietor and manager and investor—can do the actual job of developing industry."

Meanwhile, a Senate subcommittee approved an appropriation of $947,970,000 for the Atomic Energy Commission, and President Truman asked for an additional $260 million for development of the hydrogen bomb. The H-bomb appropriation will be used to build plants at secret new sites unconnected with the present installations at Oak Ridge, Hanford and Los Alamos.

Bromide Poisoning

THE use of bromides as sedatives was so widespread 25 years ago that a platitude tending to put a listener to sleep became colloquially known as a "bromide." Since 1927 it has been known that excessive dosing with bromides produces severe toxic effects, including chronic depression, gastro-intestinal disturbances, hallucinations. But bromide poisoning is still common, according to a study by Herbert A. Perkins published in *Archives of Internal Medicine*.

Perkins points out that at last report five per cent of the admissions to mental institutions in the U. S. were due to bromide intoxication. In a study of 27 cases observed over 17 years at the Boston City Hospital he finds that "bromidism is most frequently a result of taking medicine prescribed by a physician. All too frequently additional amounts of bromide are further given in an effort to rid the patients of symptoms caused by the bromides."

An additional problem is "the unfortunate habit of self-medication with Bromo-Seltzer at the corner drugstore. . . . There can be little doubt that it is habit-forming. One of our patients could give no better reason for the ingestion of massive amounts of Bromo-Seltzer than that she liked the taste."

The poisoning takes effect through the replacement of the chloride ion in the body by bromide. The antidote is therefore sodium chloride, given in dosages as high as the patient can tolerate, until bromide toxicity is eliminated by replacement with chloride. This takes between four and 40 days. The trouble is that "the average physician is not sufficiently aware of this condition to make the diagnosis promptly." Four of the patients in Perkins' series who were suffering from bromide poisoning when admitted were given more sodium bromide as a sedative before their condition was recognized.

Perkins concludes: "1) The possibility of bromide toxicity is not considered with sufficient frequency in the evaluation of mental and neurologic problems. 2) Physicians are initially responsible for approximately 50 per cent of cases of excess bromide ingestion. Prescriptions for bromides should be non-refillable. The practice of self-medication with Bromo-Seltzer should be condemned, particularly in view of its habit-forming properties." Similar recommendations were made at the recent convention of the American Medical Association in San Francisco by Theodore Cornbleet of the University of Illinois.

Gravitational Lens

AS predicted in Albert Einstein's general theory of relativity, light rays are bent when they pass close to very large bodies of matter. A newly discovered object in the sky—a round, bright halo with a fuzzy center—may prove to be a hitherto unknown phenomenon: an entire galaxy acting as a "gravitational lens" on the light of a second galaxy behind it.

The object was discovered in the constellation Serpens by Arthur Hoag of Harvard College Observatory, using a 26-inch Schmidt camera with 75-minute exposure. Hoag described it to the American Astronomical Society meeting at Indiana University. The object is of the 17th magnitude and has an almost perfect halo 17 seconds of arc in radius. It might be taken for a planetary nebula—a hot blue star surrounded by a huge shell of luminous gas. However, its center is red, not blue. Its spectrum does not show the bright emission lines characteristic of planetary nebulas. And it is located 54 degrees above the plane of the Milky Way where most planetaries are situated. Hoag therefore suggested that the central red object is a spheroidal galaxy, and the halo around it the bent light of a second galaxy directly behind it in the line of sight from the Earth. This would explain its position in the sky, the red color of the center and the continuous spectrum of the halo. If he is correct, the nearer galaxy of the two is 10 million light-years away, and has a mass of more than 100 billion suns.

Anti-Histamine Settlement

FIVE manufacturers of anti-histamines have agreed not to claim that their products will "cure, prevent, abort, eliminate, stop, or shorten the duration of the common cold." The companies had been accused last March by the Federal Trade Commission of using "false and misleading" advertising, after several investigators had been unable to confirm the curative or preventive properties of anti-histamines. The agreement came after three months of hearings in Washington. Said the Commission, "Unjustified claims for anti-histamines in reference to the common cold will stop immediately." Said Kenneth C. Royall, the former Secretary of War who is attorney for the

Anahist Company, "The stipulation permits the company to represent the efficacy of Anahist substantially as it has . . . in the past." The concerns involved, in addition to the Anahist Company, were Bristol-Myers Company, makers of Resistab, Whitehall Pharmacal Company (Kriptin), Union Pharmaceutical Company, Inc. (Inhiston), and the Grove Laboratories, Inc. (Antamine).

Blue Monday

ALTHOUGH every employer is concerned with employee morale, so far no one has been able to measure it. Such functions of morale as rate of labor turnover, productivity, number of absences, are all influenced by many other factors. Now two sociologists at England's University of Birmingham, W. Baldamus and Hilde Behrend, think they have found the answer. In a report in *Nature* they reason thus: "Owing to cumulative fatigue, the number of absentees in a factory should be expected to increase from Monday to Friday; if in reality the opposite happens, factors other than fatigue or working conditions (which do not change from day to day) must be involved, notably morale. People with a low morale . . . will particularly dislike the return to work on the Monday."

Applying this test to a British factory, Baldamus and Behrend found absenteeism consistently highest on Mondays, and steadily declining from Monday to Friday. "Morale is lowest on Mondays; as the week goes on, workers get more and more used to the daily grind of factory routine, and . . . attendance improves as pay-day and the week-end approach."

This explanation was confirmed by the figures for workers who might be expected to have higher morale. The downward curve from Monday to Friday was less steep for employees of over three years than for those of less than three years; while foundry workers had 57 per cent more absences on Mondays than on Fridays, skilled toolroom workers had about the same on both days. Women teachers at a girls' grammar school, where voluntary absenteeism was known to be "insignificant," actually showed fewer absences on Mondays than on Fridays.

On comparing men and women in the same factory the two investigators made a surprising finding. Although it had been claimed, from over-all absence and turnover statistics, that women factory workers have a lower morale than men, the downward slope of the absence curve was less marked for women than for men, least of all for married women. Their tentative explanation: "Women do not mind so much going back to the factory on Monday, since the week-end does not bring them true leisure but involves work as hard as in the factory."

EYE AND CAMERA

The classical comparison of the two devices is still fruitful. Today it has gone beyond their optics into their basic physics and chemistry

by George Wald

Of all the instruments made by man, none resembles a part of his body more than a camera does the eye. Yet this is not by design. A camera is no more a copy of an eye than the wing of a bird is a copy of that of an insect. Each is the product of an independent evolution; and if this has brought the camera and the eye together, it is not because one has mimicked the other, but because both have had to meet the same problems, and frequently have done so in much the same way. This is the type of phenomenon that biologists call convergent evolution, yet peculiar in that the one evolution is organic, the other technological.

Over the centuries much has been learned about vision from the camera, but little about photography from the eye. The camera made its first appearance not as an instrument for making pictures but as the *camera obscura* or dark chamber, a device that attempted no more than to project an inverted image upon a screen. Long after the optics of the camera obscura was well understood, the workings of the eye remained mysterious.

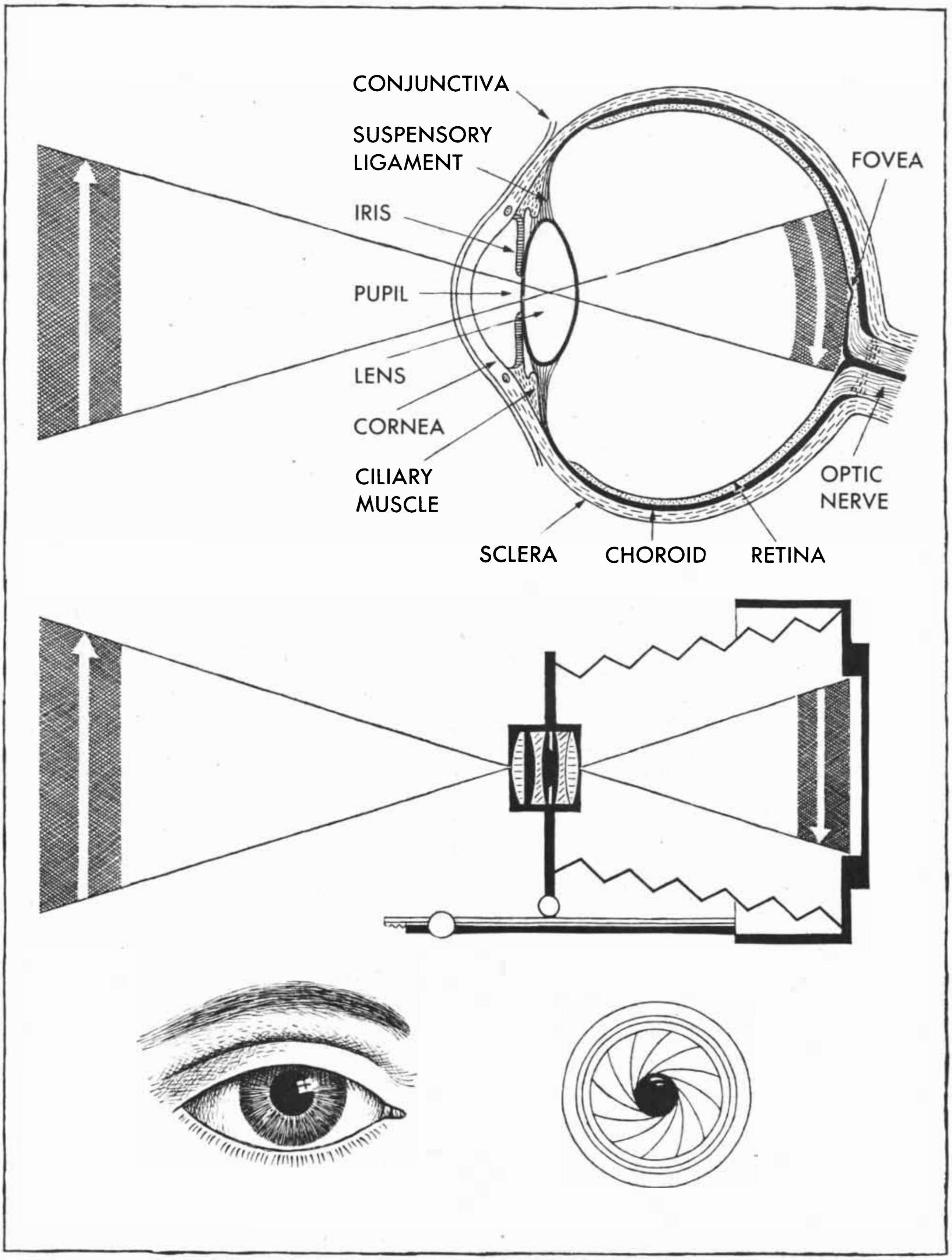
In part this was because men found it difficult to think in simple terms about the eye. It is possible for contempt to breed familiarity, but awe does not help one to understand anything. Men have often approached light and the eye in a spirit close to awe, probably because they were always aware that vision provides their closest link with the external world. Stubborn misconceptions held back their understanding of the eye for many centuries. Two notions were particularly troublesome. One was that radiation shines out of the eye; the other, that an inverted image on the retina is somehow incompatible with seeing right side up.

I am sure that many people are still not clear on either matter. I note, for example, that the X-ray vision of the comic-strip hero Superman, while regarded with skepticism by many adults, is not rejected on the ground that there are no X-rays about us with which to see. Clearly Superman's eyes supply the X-rays, and by directing them here and there he not only can see through opaque objects, but can on occasion shatter a brick wall or melt gold. As for the inverted image on the retina, most people who learn of it concede that it presents a problem, but comfort themselves with the thought that the brain somehow compensates for it. But of course there is no problem, and hence no compensation. We learn early in infancy to associate certain spatial relations in the outside world with certain patterns of nervous activity stimulated through the eyes. The spatial arrangements of the nervous activity itself are altogether irrelevant.

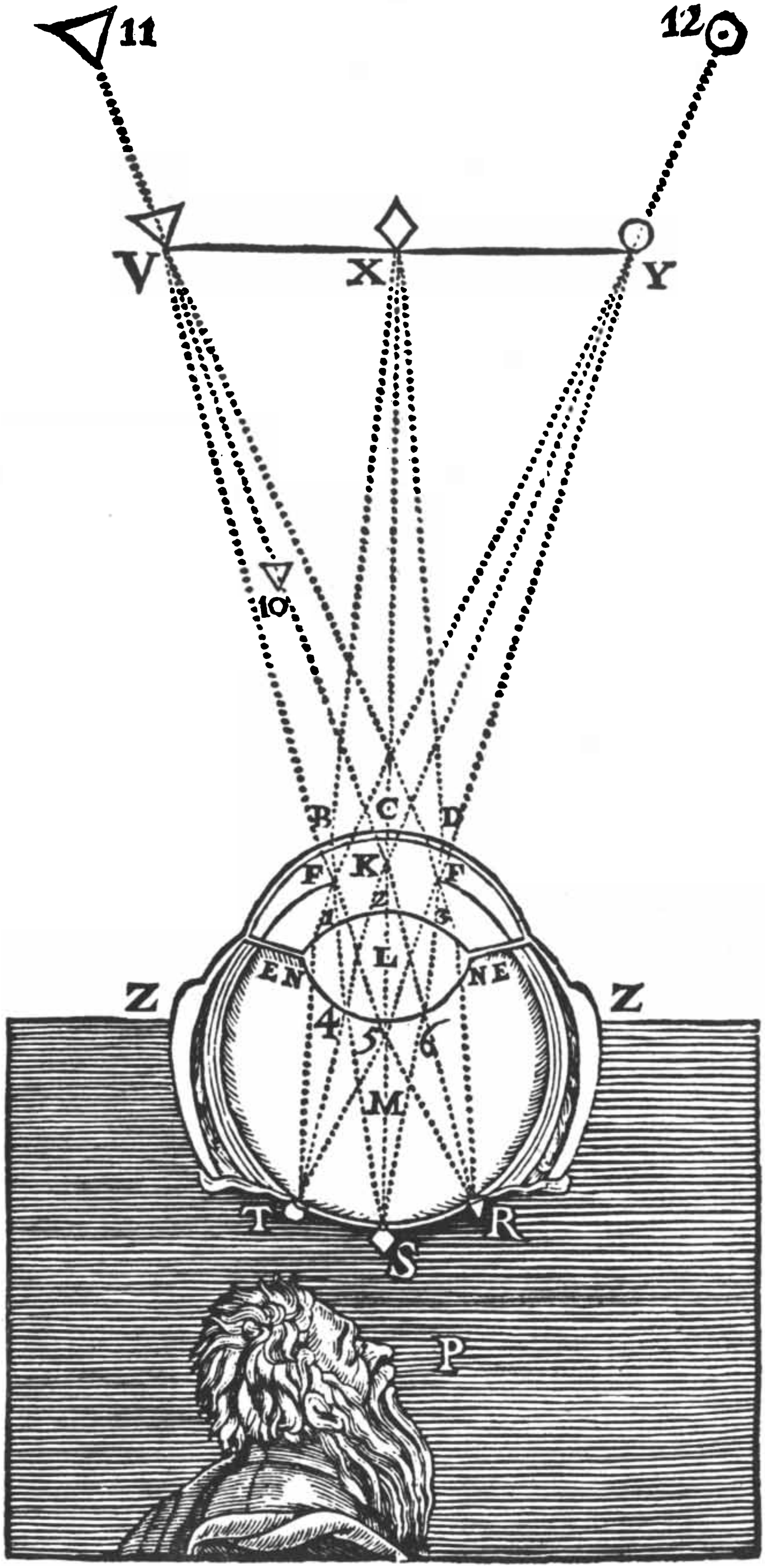
It was not until the 17th century that the gross optics of image formation in the eye was clearly expressed. This was accomplished by Johannes Kepler in 1611, and again by René Descartes in 1664. By the end of the century the first treatise on optics in English, written by William Molyneux of Dublin, contained several clear and simple diagrams comparing the projection of a real inverted image in a "pinhole" camera, in a camera obscura equipped with a lens and in an eye.

Today every schoolboy knows that the eye is like a camera. In both instruments a lens projects an inverted image of the surroundings upon a light-sensitive surface: the film in the camera and the retina in the eye. In both the opening of the lens is regulated by an iris. In both the inside of the chamber is lined with a coating of black material which absorbs stray light that would otherwise be reflected back and forth and obscure the image. Almost every schoolboy also knows a difference between the camera and the eye. A camera is focused by moving the lens toward or away from the film; in the eye the distance between the lens and the retina is fixed, and focusing is accomplished by changing the thickness of the lens.

The usual fate of such comparisons is that on closer examination they are exposed as trivial. In this case, however, just the opposite has occurred. The more we have come to know about the mechanism of vision, the more pointed and fruitful has become its comparison with photography. By now it is clear that the relationship between the eye and the camera goes far beyond simple optics, and has come to involve much of the



OPTICAL SIMILARITIES of eye and camera are apparent in their cross sections. Both utilize a lens to focus an inverted image on a light-sensitive surface. Both possess an iris to adjust to various intensities of light. The single lens of the eye, however, cannot bring light of all colors to a focus at the same point. The compound lens of the camera is better corrected for color because it is composed of two kinds of glass.



FORMATION OF AN IMAGE on the retina of the human eye was diagrammed by René Descartes in 1664. This diagram is from Descartes' *Dioptrics.*

essential physics and chemistry of both devices.

Bright and Dim Light

A photographer making an exposure in dim light opens the iris of his camera. The pupil of the eye also opens in dim light, to an extent governed by the activity of the retina. Both adjustments have the obvious effect of admitting more light through the lens. This is accomplished at some cost to the quality of the image, for the open lens usually defines the image less sharply, and has less depth of focus.

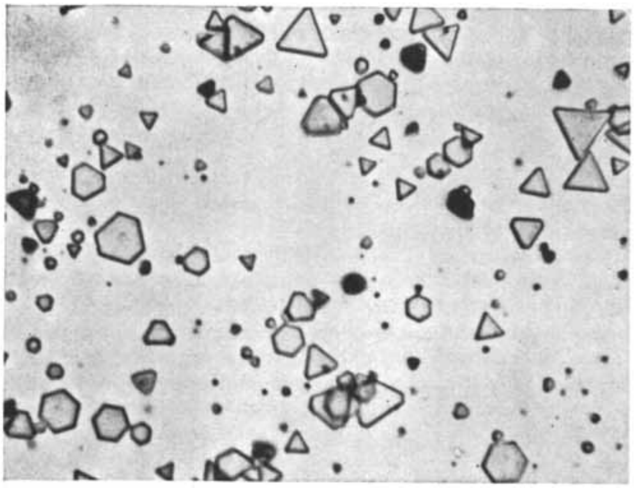
When further pressed for light, the photographer changes to a more sensitive film. This ordinarily involves a further loss in the sharpness of the picture. With any single type of emulsion the more sensitive film is coarser in grain, and thus the image cast upon it is resolved less accurately.

The retina of the eye is grainy just as is photographic film. In film the grain is composed of crystals of silver bromide embedded in gelatin. In the retina it is made up of the receptor cells, lying side by side to form a mosaic of light-sensitive elements.

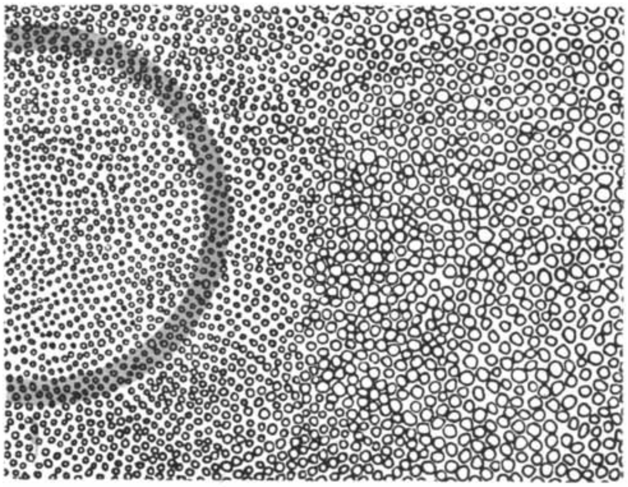
There are two kinds of receptors in the retinas of man and most vertebrates: rods and cones. Each is composed of an inner segment much like an ordinary nerve cell, and a rod- or cone-shaped outer segment, the special portion of the cell that is sensitive to light. The cones are the organs of vision in bright light, and also of color vision. The rods provide a special apparatus for vision in dim light, and their excitation yields only neutral gray sensations. This is why at night all cats are gray.

The change from cone to rod vision, like that from slow to fast film, involves a change from a fine- to a coarse-grained mosaic. It is not that the cones are smaller than the rods, but that the cones act individually while the rods act in large clumps. Each cone is usually connected with the brain by a single fiber of the optic nerve. In contrast large clusters of rods are connected by single optic nerve fibers. The capacity of rods for image vision is correspondingly coarse. It is not only true that at night all cats are gray, but it is difficult to be sure that they are cats.

Vision in very dim light, such as starlight or most moonlight, involves only the rods. The relatively insensitive cones are not stimulated at all. At moderately low intensities of light, about 1,000 times greater than the lowest intensity to which the eye responds, the cones begin to function. Their entrance is marked by dilute sensations of color. Over an intermediate range of intensities rods and cones function together, but as the brightness increases, the cones come to dominate vision. We do not know that



GRAIN of the photographic emulsion, magnified 2,500 times, is made up of silver-bromide crystals in gelatin.



"GRAIN" of the human retina is made up of cones and rods (*dots at far right*). Semicircle indicates fovea.

the rods actually stop functioning at even the highest intensities, but in bright light their relative contribution to vision falls to so low a level as to be almost negligible.

To this general transfer of vision from rods to cones certain cold-blooded animals add a special anatomical device. The light-sensitive outer segments of the rods and cones are carried at the ends of fine stalks called myoids, which can shorten and lengthen. In dim light the rod myoids contract while the cone myoids relax. The entire field of rods is thus pulled forward toward the light, while the cones are pushed into the background. In bright light the reverse occurs: the cones are pulled forward and the rods pushed back. One could scarcely imagine a closer approach to the change from fast to slow film in a camera.

The rods and cones share with the grains of the photographic plate another deeply significant property. It has long been known that in a film exposed to light each grain of silver bromide given enough developer blackens either completely or not at all, and that a grain is made susceptible to development by the absorption of one or at most a few quanta of light. It appears to be equally true that a cone or rod is excited by light to yield either its maximal response or none at all. This is certainly true of the nerve fibers to which the rods and cones are connected, and we now know that to produce this effect in a rod—and possibly also in a cone—only one quantum of light need be absorbed.

It is a basic tenet of photochemistry that one quantum of light is absorbed by, and in general can activate, only one molecule or atom. We must attempt to understand how such a small beginning can bring about such a large result as the development of a photographic grain or the discharge of a retinal receptor. In the photographic process the answer to this question seems to be that the absorption of a quantum of light causes the oxidation of a silver ion to an atom of metallic silver, which then serves as a catalytic center for the development of the entire grain. It is possible that a similar mechanism operates in a rod or a cone. The absorption of a quantum of light by a light-sensitive molecule in either structure might convert it into a biological catalyst, or an enzyme, which could then promote the further reactions that discharge the receptor cell. One wonders whether such a mechanism could possibly be rapid enough. A rod or a cone responds to light within a small fraction of a second; the mechanism would therefore have to complete its work within this small interval.

One of the strangest characteristics of the eye in dim light follows from some of these various phenomena. In focusing the eye is guided by its evaluation of the sharpness of the image on the retina. As the image deteriorates with the opening of the pupil in dim light, and as the retinal capacity to resolve the image falls with the shift from cones to rods, the ability to focus declines also. In very dim light the eye virtually ceases to adjust its focus at all. It has come to resemble a very cheap camera, a fixed-focus instrument.

In all that concerns its function, therefore, the eye is one device in bright light and another in dim. At low intensities all its resources are concentrated upon sensitivity, at whatever sacrifice of form; it is predominantly an instrument for seeing light, not pattern. In bright light all this changes. By narrowing the pupil, shifting from rods to cones, and other stratagems still to be described, the eye sacrifices light in order to achieve the utmost in pattern vision.

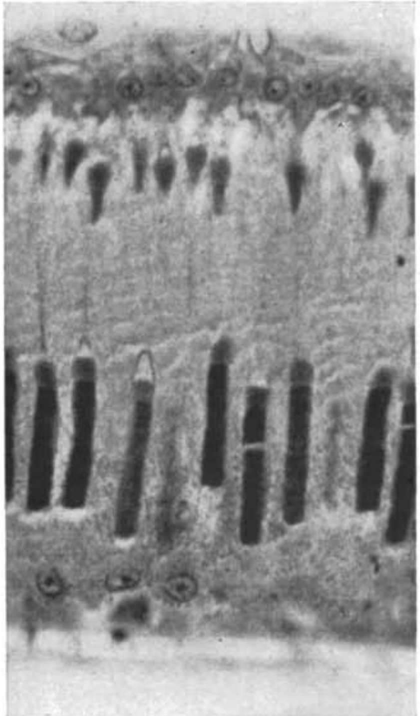
Images

In the course of evolution animals have used almost every known device for forming or evaluating an image. There is one notable exception: no animal has yet developed an eye based upon the use of a concave mirror. An eye made like a pinhole camera, however, is found in Nautilus, a cephalopod mollusk related to the octopus and squid. The compound eye of insects and crabs forms an image which is an upright patchwork of responses of individual "eyes" or ommatidia, each of which records only a spot of light or shade. The eye of the tiny arthropod Copilia possesses a large and beautiful lens but only one light receptor attached to a thin strand of muscle. It is said that the muscle moves the receptor rapidly back and forth in the focal plane of the lens, scanning the image in much the same way as it is scanned by the light-sensitive tube of a television camera.

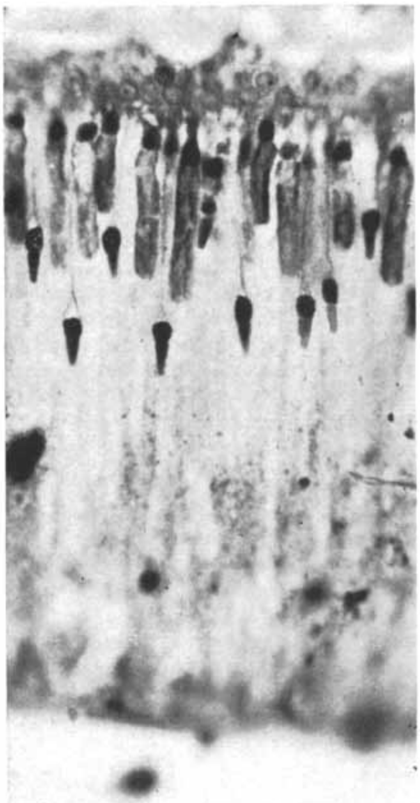
Each of these eyes, like the lens eye of vertebrates, represents some close compromise of advantages and limitations. The pinhole eye is in focus at all distances, yet to form clear images it must use a small hole admitting very little light. The compound eye works well at distances of a few millimeters, yet it is relatively coarse in pattern resolution. The vertebrate eye is a long-range, high-acuity instrument useless in the short distances at which the insect eye resolves the greatest detail.

These properties of the vertebrate eye are of course shared by the camera. The use of a lens to project an image, however, has created for both devices a special group of problems. All simple lenses are subject to serious errors in image formation: the lens aberrations.

Spherical aberration is found in all lenses bounded by spherical surfaces. The marginal portions of the lens bring rays of light to a shorter focus than the central region. The image of a point in space is therefore not a point, but a little "blur circle." The cost of a camera is largely determined by the extent to



CONES of the catfish *Ameiurus* are pulled toward the surface of the retina (*top*) in bright light. The rods remain in a layer below the surface.



RODS advance and cones retreat in dim light. This retinal feature is not possessed by mammals. It is peculiar to some of the cold-blooded animals.

which this aberration is corrected by modifying the lens.

The human eye is astonishingly well corrected—often slightly overcorrected—for spherical aberration. This is accomplished in two ways. The cornea, which is the principal refracting surface of the eye, has a flatter curvature at its margin than at its center. This compensates in part for the tendency of a spherical surface to refract light more strongly at its margin. More important still, the lens is denser and hence refracts light more strongly at its core than in its outer layers.

A second major lens error, however, remains almost uncorrected in the human eye. This is chromatic aberration, or color error. All single lenses made of one material refract rays of short wavelength more strongly than those of longer wavelength, and so bring blue light to a shorter focus than red. The result is that the image of a point of white light is not a white point, but a blur circle fringed with color. Since this seriously disturbs the image, even the lenses of inexpensive cameras are corrected for chromatic aberration.

It has been known since the time of Isaac Newton, however, that the human eye has a large chromatic aberration. Its lens system seems to be entirely uncorrected for this defect. Indeed, living organisms are probably unable to manufacture two transparent materials of such widely different refraction and dispersion as the crown and flint glasses from which color-corrected lenses are constructed.

The large color error of the human eye could make serious difficulties for image vision. Actually the error is moderate between the red end of the spectrum and the blue-green, but it increases rapidly at shorter wavelengths: the blue, violet and ultraviolet. These latter parts of the spectrum present the most serious problem. It is a problem for both the eye and the camera, but one for which the eye must find a special solution.

The first device that opposes the color error of the human eye is the yellow lens. The human lens is not only a lens but a color filter. It passes what we ordinarily consider to be the visible spectrum, but sharply cuts off the far edge of the violet, in the region of wavelength 400 millimicrons. It is this action of the lens, and not any intrinsic lack of sensitivity of the rods and cones, that keeps us from seeing in the near ultraviolet. Indeed, persons who have lost their lenses in the operation for cataract and have had them replaced by clear glass lenses, have excellent vision in the ultraviolet. They are able to read an optician's chart from top to bottom in ultraviolet light which leaves ordinary people in complete darkness.

The lens therefore solves the problem of the near ultraviolet, the region of the spectrum in which the color error is greatest, simply by eliminating the region from human vision. This boon is distributed over one's lifetime, for the lens becomes a deeper yellow and makes more of the ordinary violet and blue invisible as one grows older. I have heard it said that for this reason aging artists tend to use less blue and violet in their paintings.

The lens filters out the ultraviolet for the eye as a whole. The remaining devices which counteract chromatic aberration are concentrated upon vision in bright light, upon cone vision. This is good economy, for the rods provide such a coarse-grained receptive surface that they would be unable in any case to evaluate a sharp image on the retina.

As one goes from dim to bright light, from rod to cone vision, the sensitivity of the eye shifts toward the red end of the spectrum. This phenomenon was described in 1825 by the Czech physiologist Johannes Purkinje. He had noticed that with the first light of dawn blue objects tend to look relatively bright compared with red, but that they come to look relatively dim as the morning advances. The basis of this change is a large difference in spectral sensitivity between rods and cones. Rods have their maximal sensitivity in the blue-green at about 500 millimicrons; the entire spectral sensitivity of the cones is transposed toward the red, the maximum lying in the yellow-green at about 562 millimicrons. The point of this difference for our present argument is that as one goes from dim light, in which pattern vision is poor in any case, to bright light, in which it becomes acute, the sensitivity of the eye moves away from the region of the spectrum in which the chromatic aberration is large toward the part of the spectrum in which it is least.

The color correction of the eye is completed by a third dispensation. Toward the center of the human retina there is a small, shallow depression called the fovea, which contains only cones. While the retina as a whole sweeps through a visual angle of some 240 degrees, the fovea subtends an angle of only about 1.7 degrees. The fovea is considerably smaller than the head of a pin, yet with this tiny patch of retina the eye accomplishes all its most detailed vision.

The fovea also includes the fixation point of the eye. To look directly at something is to turn one's eye so that its image falls upon the fovea. Beyond the boundary of the fovea rods appear, and they become more and more numerous as the distance from the fovea increases. The apparatus for vision in bright light is thus concentrated toward the center of the retina, that for dim light toward its periphery. In very dim light, too dim to excite the cones, the fovea is blind. One can see objects then only by looking at them slightly askance to catch their images on areas rich in rods.

In man, apes and monkeys, alone of all known mammals, the fovea and the region of retina just around it is colored yellow. This area is called the yellow patch, or *macula lutea.* Its pigmentation lies as a yellow screen over the light receptors of the central retina, subtending a visual angle some five to 10 degrees in diameter.

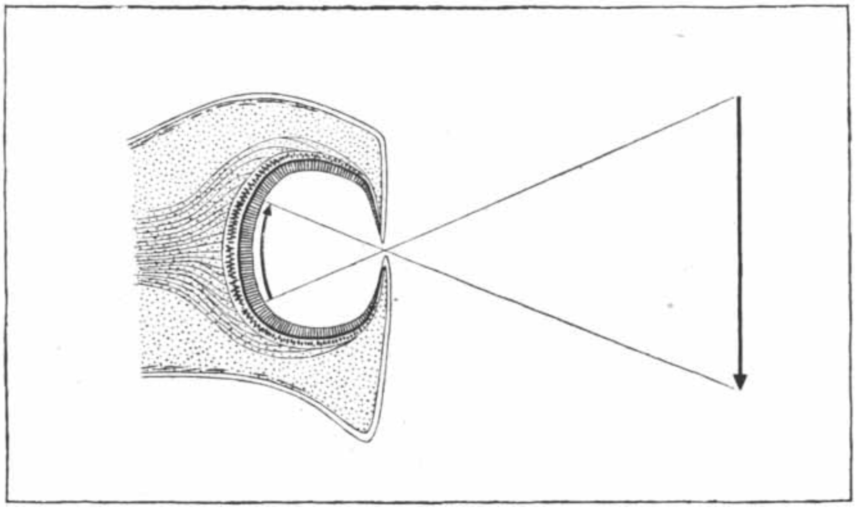
Several years ago in our laboratory at Harvard University we measured the color transmission of this pigment in the living human eye by comparing the spectral sensitivities of cones in the yellow patch with those in a colorless peripheral area. The yellow pigment was also extracted from a small number of human maculae, and was found to be xanthophyll, a carotenoid pigment that occurs also in all green leaves. This pigment in the yellow patch takes up the absorption of light in the violet and blue regions of the spectrum just where absorption by the lens falls to very low values. In this way the yellow patch removes for the central retina the remaining regions of the spectrum for which the color error is high.

So the human eye, unable to correct its color error otherwise, throws away those portions of the spectrum that would make the most trouble. The yellow lens removes the near ultraviolet for the eye as a whole, the macular pigment eliminates most of the violet and blue for the central retina, and the shift from rods to cones displaces vision in bright light bodily toward the red. By these three devices the apparatus of most acute vision avoids the entire range of the spectrum in which the chromatic aberration is large.

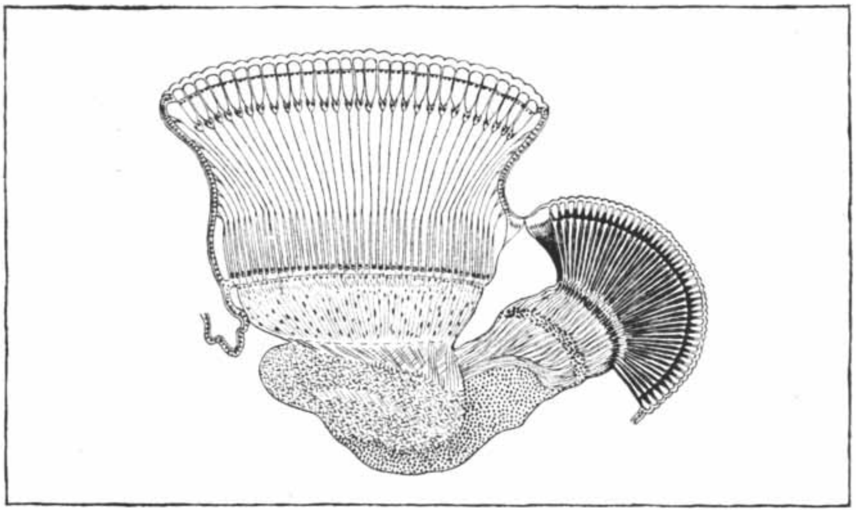
Photography with Living Eyes

In 1876 Franz Boll of the University of Rome discovered in the rods of the frog retina a brilliant red pigment. This bleached in the light and was resynthesized in the dark, and so fulfilled the elementary requirements of a visual pigment. He called this substance visual red; later it was renamed visual purple or rhodopsin. This pigment marks the point of attack by light on the rods: the absorption of light by rhodopsin initiates the train of reactions that end in rod vision.

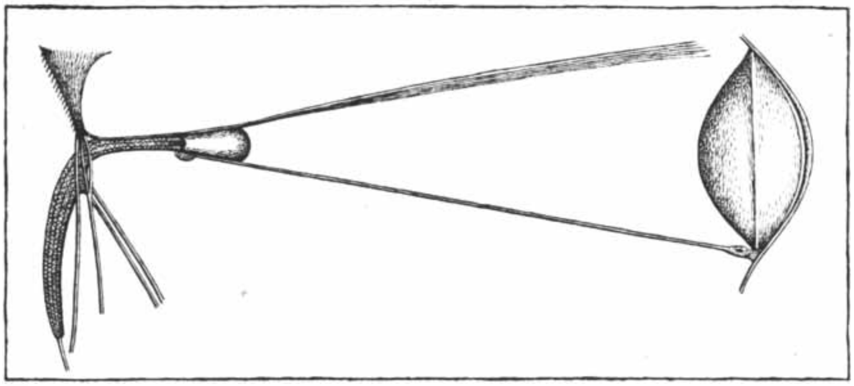
Boll had scarcely announced his discovery when Willy Kühne, professor of physiology at Heidelberg, took up the study of rhodopsin, and in one extraordinary year learned almost everything about it that was known until recently. In his first paper on retinal chemistry Kühne said: "Bound together with the pigment epithelium, the retina behaves not merely like a photographic plate, but like an entire photographic workshop, in which the workman continually renews



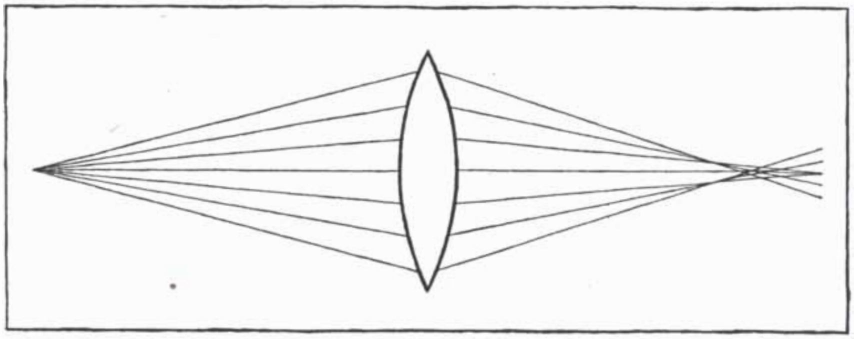
PINHOLE-CAMERA EYE is found in Nautilus, the spiral-shelled mollusk which is related to the octopus and the squid. This eye has the advantage of being in focus at all distances from the object that is viewed. It has the serious disadvantage, however, of admitting very little light to the retina.



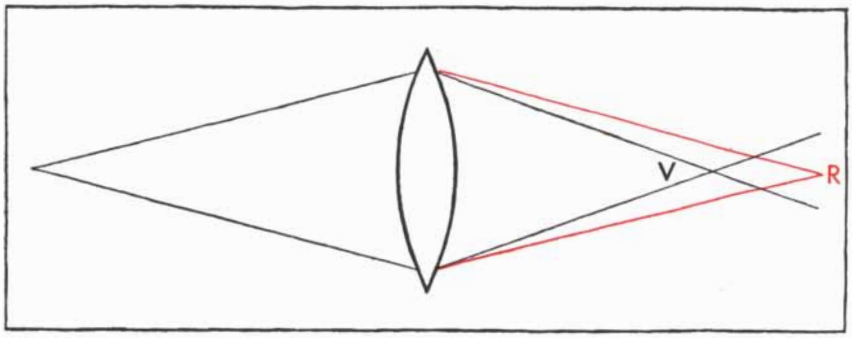
COMPOUND EYE is found in insects. Each element contributes only a small patch of light or shade to make up the whole mosaic image. This double compound eye is found in the mayfly *Chloeon.* The segment at the top provides detailed vision; the segment at the right, coarse, wide-angled vision.



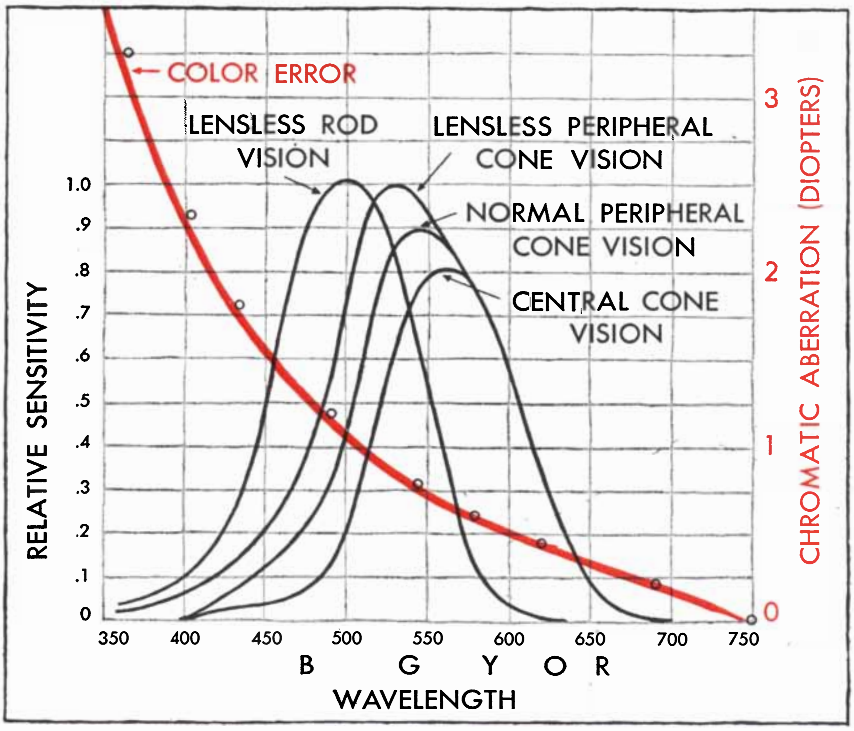
SCANNING EYE is found in the arthropod Copilia. It possesses a large lens (*right*) but only one receptor element (*left*). Attached to the receptor are the optic nerve and a strand of muscle. The latter is reported to move the receptor back and forth so that it scans the image formed by the lens.



SPHERICAL ABERRATION occurs when light is refracted by a lens with spherical surfaces. The light which passes through the edge of the lens is brought to a shorter focus than that which passes through the center. The result of this is that the image of a point is not a point but a "blur circle."



CHROMATIC ABERRATION occurs when light of various colors is refracted by a lens made of one material. The light of shorter wavelength is refracted more than that of longer wavelength, *i.e.*, violet is brought to a shorter focus than red. The image of a white point is a colored blur circle.



CHROMATIC ABERRATION of the human eye is corrected by various stratagems which withdraw the cones from the region of maximum aberration, *i.e.*, the shorter wavelengths. The horizontal coordinate of this diagram is wavelength in millimicrons; the colors are indicated by initial letters.

the plate by laying on new light-sensitive material, while simultaneously erasing the old image."

Kühne saw at once that with this pigment which was bleached by light it might be possible to take a picture with the living eye. He set about devising methods for carrying out such a process, and succeeded after many discouraging failures. He called the process optography and its products optograms.

One of Kühne's early optograms was made as follows. An albino rabbit was fastened with its head facing a barred window. From this position the rabbit could see only a gray and clouded sky. The animal's head was covered for several minutes with a cloth to adapt its eyes to the dark, that is to let rhodopsin accumulate in its rods. Then the animal was exposed for three minutes to the light. It was immediately decapitated, the eye removed and cut open along the equator, and the rear half of the eyeball containing the retina laid in a solution of alum for fixation. The next day Kühne saw, printed upon the retina in bleached and unaltered rhodopsin, a picture of the window with the clear pattern of its bars.

I remember reading as a boy a detective story in which at one point the detective enters a dimly lighted room, on the floor of which a corpse is lying. Working carefully in the semidarkness, the detective raises one eyelid of the victim and snaps a picture of the open eye. Upon developing this in his darkroom he finds that he has an optogram of the last scene viewed by the victim, including of course an excellent likeness of the murderer. So far as I know Kühne's optograms mark the closest approach to fulfilling this legend.

The legend itself has nonetheless flourished for more than 60 years, and all of my readers have probably seen or heard some version of it. It began with Kühne's first intimation that the eye resembles a photographic workshop, even before he had succeeded in producing his first primitive optogram, and it spread rapidly over the entire world. In the paper that announces his first success in optography, Kühne refers to this story with some bitterness. He says: "I disregard all the journalistic potentialities of this subject, and willingly surrender it in advance to all the claims of fancy-free coroners on both sides of the ocean, for it certainly is not pleasant to deal with a serious problem in such company. Much that I could say about this had better be suppressed, and turned rather to the hope that no one will expect from me any corroboration of announcements that have not been authorized with my name."

Despite these admirable sentiments we find Kühne shortly afterward engaged in a curious adventure. In the nearby town of Bruchsal on November 16, 1880, a young man was beheaded by guillotine. Kühne had made arrangements to receive the corpse. He had prepared a dimly lighted room screened with red and yellow glass to keep any rhodopsin left in the eyes from bleaching further. Ten minutes after the knife had fallen he obtained the whole retina from the left eye, and had the satisfaction of seeing and showing to several colleagues a sharply demarcated optogram printed upon its surface. Kühne's drawing of it is reproduced at the bottom of the next page. To my knowledge it is the only human optogram on record.

Kühne went to great pains to determine what this optogram represented. He says: "A search for the object which served as source for this optogram remained fruitless, in spite of a thorough inventory of all the surroundings and reports from many witnesses. The delinquent had spent the night awake by the light of a tallow candle; he had slept from four to five o'clock in the morning; and had read and written, first by candlelight until dawn, then by feeble daylight until eight o'clock. When he emerged in the open, the sun came out for an instant, according to a reliable observer, and the sky became somewhat brighter during the seven minutes prior to the bandaging of his eyes and his execution, which followed immediately. The delinquent, however, raised his eyes only rarely."

Color

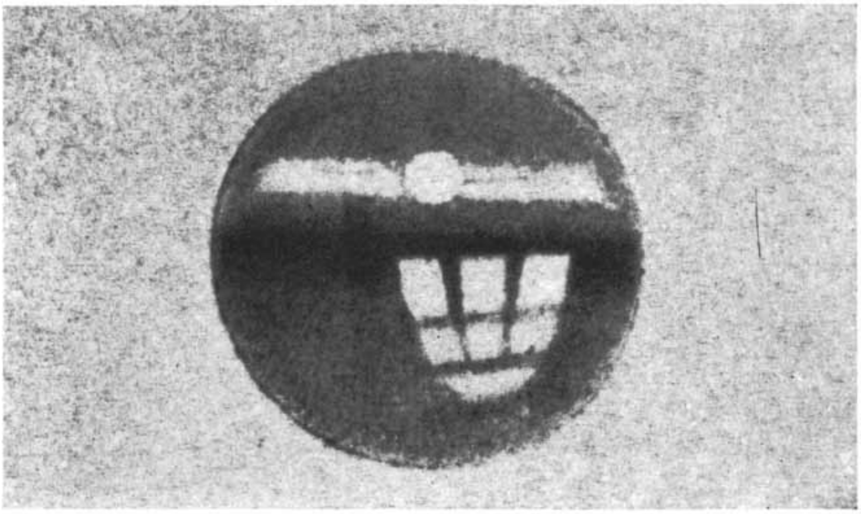
One of the triumphs of modern photography is its success in recording color. For this it is necessary not only to graft some system of color differentiation and rendition upon the photographic process; the finished product must then fulfill the very exacting requirement that it excite the same sensations of color in the human eye as did the original subject of the picture.

How the human eye resolves colors is not known. Normal human color vision seems to be compounded of three kinds of responses; we therefore speak of it as trichromatic or three-color vision. The three kinds of response call for at least three kinds of cone differing from one another in their sensitivity to the various regions of the spectrum. We can only guess at what regulates these differences. The simplest assumption is that the human cones contain three different light-sensitive pigments, but this is still a matter of surmise.

There exist retinas, however, in which one can approach the problem of color vision more directly. The eyes of certain turtles and of certain birds such as chickens and pigeons contain a great predominance of cones. Since cones are the organs of vision in bright light as well as of color vision, these animals necessarily function only at high light intensities. They are permanently night-blind, due to a poverty or complete absence of rods. It is for this reason that chickens must roost at sundown.

In the cones of these animals we find a system of brilliantly colored oil globules, one in each cone. The globule is situated at the joint between the inner and outer segments of the cone, so that light must pass through it just before entering the light-sensitive element. The globules therefore lie in the cones in the position of little individual color filters.

One has only to remove the retina from a chicken or a turtle and spread it on the stage of a microscope to see that the globules are of three colors: red, orange and greenish yellow. It was suggested many years ago that they provide the basis of color differentiation in the animals that possess them.



RETINAL PHOTOGRAPH, or an optogram, was drawn in 1878 by the German investigator Willy Kühne. He had exposed the eye of a living rabbit to a barred window, killed the rabbit, removed its retina and fixed it in alum.

In a paper published in 1907 the German ophthalmologist Siegfried Garten remarked that he was led by such retinal color filters to invent a system of color photography based upon the same principle. This might have been the first instance in which an eye had directly inspired a development in photography. Unfortunately, however, in 1906 the French chemist Louis Lumière, apparently without benefit of chicken retinas, had brought out his autochrome process for color photography based upon exactly this principle.

To make his autochrome plates Lumière used suspensions of starch grains from rice, which he dyed red, green and blue. These were mixed in roughly equal proportions, and the mixture was strewn over the surface of an ordinary photographic plate. The granules were then squashed flat and the interstices were filled with particles of carbon. Each dyed granule served as a color filter for the patch of silver-bromide emulsion that lay just under it.

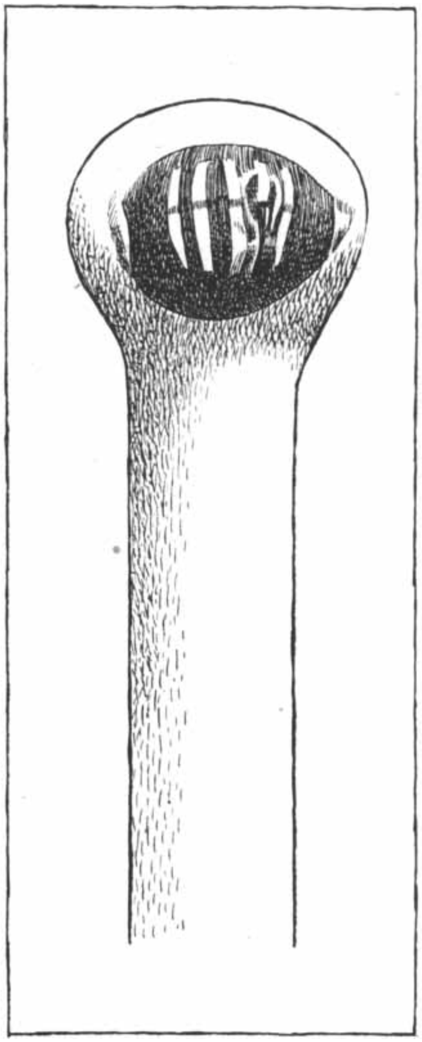
Just as the autochrome plate can accomplish color photography with a single light-sensitive substance, so the cones of the chicken retina should require no more than one light-sensitive pigment. We extracted such a pigment from the chicken retina in 1937. It is violet in color, and has therefore been named iodopsin from *ion,* the Greek word for violet. All three pigments of the colored oil globules have also been isolated and crystallized. Like the pigment of the human macula, they are all carotenoids: a greenish-yellow carotene; the golden mixture of xanthophylls found in chicken egg yolk; and red astaxanthin, the pigment of the boiled lobster.

Controversy thrives on ignorance, and we have had many years of disputation regarding the number of kinds of cone concerned in human color vision. Many investigators prefer three, some four, and at least one of my English colleagues seven. I myself incline toward three. It is a good number, and sufficient unto the day.

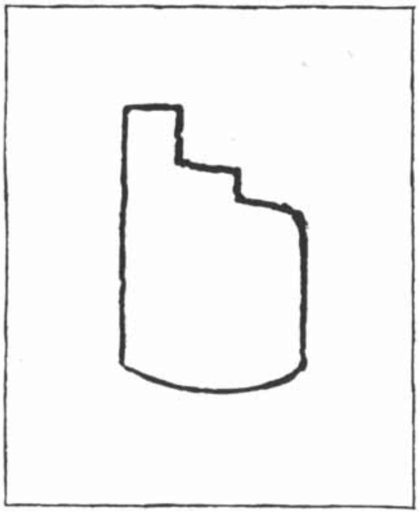
The appearance of three colors of oil globule in the cones of birds and turtles might be thought to provide strong support for trichromatic theories of color vision. The trouble is that these retinas do in fact contain a fourth class of globule which is colorless. Colorless globules have all the effect of a fourth color; there is no doubt that if we include them, bird and turtle retinas possess the basis for four-color vision.

Latent Images

Recent experiments have exposed a wholly unexpected parallel between vision and photography. Many years ago Kühne showed that rhodopsin can be extracted from the retinal rods into clear water solution. When such solutions are



FROG OPTOGRAM showing a barred pattern was made by the German ophthalmologist Siegfried Garten. The retina is mounted on a rod.



HUMAN OPTOGRAM was drawn by Kühne after he had removed the retina of a beheaded criminal. Kühne could not determine what it showed.

exposed to light, the rhodopsin bleaches just as it does in the retina.

It has been known for some time that the bleaching of rhodopsin in solution is not entirely accomplished by light. It is started by light, but then goes on in the dark for as long as an hour at room temperature. Bleaching is therefore a composite process. It is ushered in by a light reaction that converts rhodopsin to a highly unstable product; this then decomposes by ordinary chemical reactions—"dark" reactions in the sense that they do not require light.

Since great interest attaches to the initial unstable product of the light reaction, many attempts were made in our laboratory and at other laboratories to seize upon this substance and learn its properties. It has such a fleeting existence, however, that for some time nothing satisfactory was achieved.

In 1941, however, two English workers, E. E. Broda and C. F. Goodeve, succeeded in isolating the light reaction by irradiating rhodopsin solutions at about −73 degrees Celsius, roughly the temperature of dry ice. In such extreme cold, light reactions are unhindered, but ordinary dark processes cannot occur. Broda and Goodeve found that an exhaustive exposure of rhodopsin to light under these conditions produced only a very small change in its color, so small that though it could be measured one might not have been certain merely by looking at these solutions that any change had occurred at all. Yet the light reaction had been completed, and when such solutions were allowed to warm up to room temperature they bleached *in the dark*. We have recently repeated such experiments in our laboratory. With some differences which need not be discussed, the results were qualitatively as the English workers had described them.

These observations led us to re-examine certain early experiments of Kühne's. Kühne had found that if the retina of a frog or rabbit was thoroughly dried over sulfuric acid, it could be exposed even to brilliant sunlight for long periods without bleaching. Kühne concluded that dry rhodopsin is not affected by light, and this has been the common understanding of workers in the field of vision ever since.

It occurred to us, however, that dry rhodopsin, like extremely cold rhodopsin, might undergo the light reaction, though with such small change in color as to have escaped notice. To test this possibility we prepared films of rhodopsin in gelatin, which could be dried thoroughly and were of a quality that permitted making accurate measurements of their color transmission throughout the spectrum.

We found that when dry gelatin films of rhodopsin are exposed to light, the same change occurs as in very cold rhodopsin. The color is altered, but so slightly as easily to escape visual observation. In any case the change cannot be described as bleaching; if anything the color is a little intensified. Yet the light reaction is complete; if such exposed films are merely wetted with water, they bleach in the dark.

We have therefore two procedures—cooling to very low temperatures and removal of water—that clearly separate the light from the dark reactions in the bleaching of rhodopsin. Which of these reactions is responsible for stimulating rod vision? One cannot yet be certain, yet the response of the rods to light occurs so rapidly that only the light reaction seems fast enough to account for it.

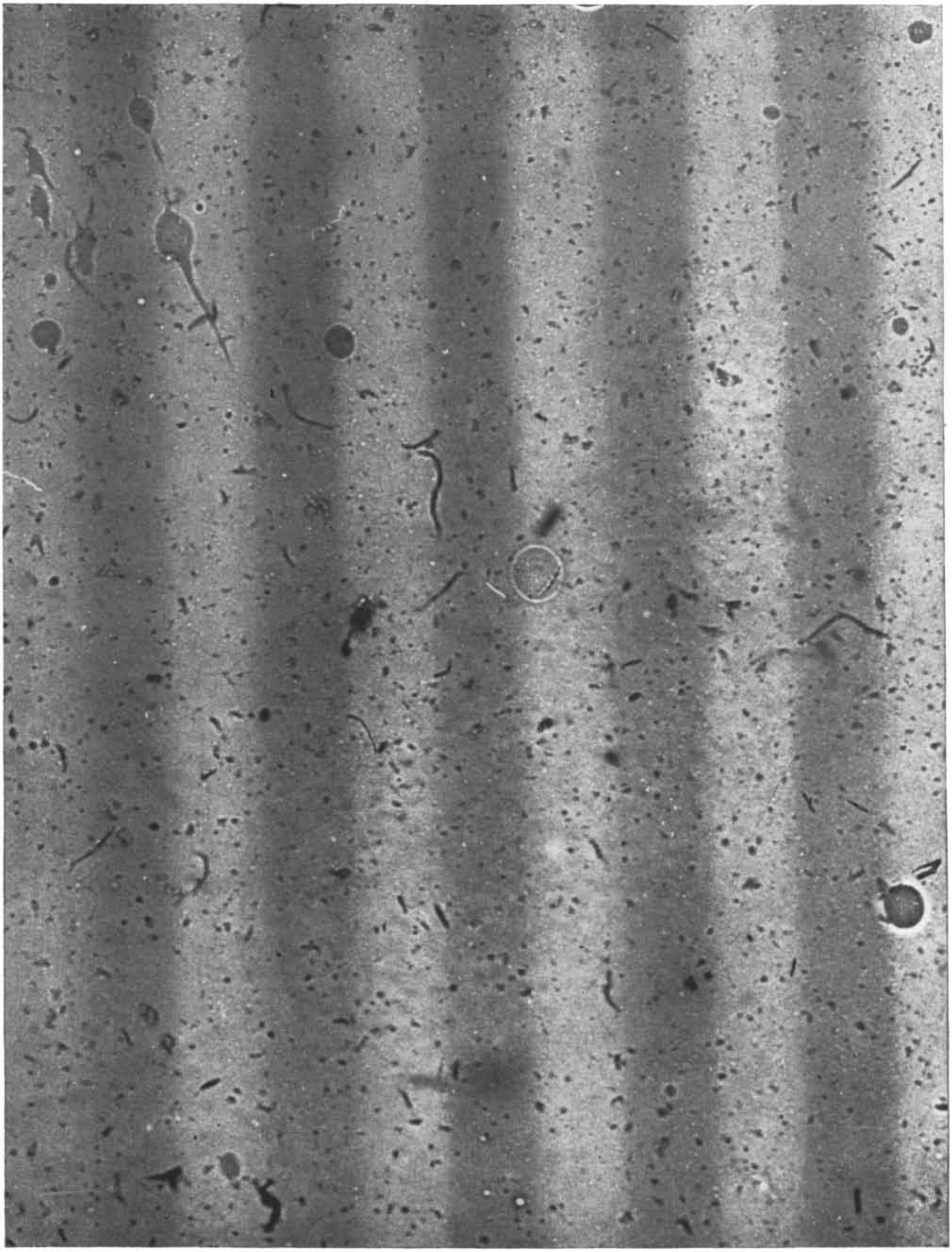
What has been said, however, has a further consequence that brings it into direct relation with photography. Everyone knows that the photographic process also is divided into light and dark components. The result of exposing a film to light is usually invisible, a so-called "latent image." It is what later occurs in the darkroom, the dark reaction of development, that brings out the picture.

This now appears to be exactly what happens in vision. Here as in photography light produces an almost invisible result, a latent image, and this indeed is probably the process upon which retinal excitation depends. The visible loss of rhodopsin's color, its bleaching, is the result of subsequent dark reactions, of "development."

One can scarcely have notions like this without wanting to make a picture with a rhodopsin film; and we have been tempted into making one very crude rhodopsin photograph. Its subject is not exciting—only a row of black and white stripes—but we show it at the right for what interest it may have as the first such photograph. What is important is that it was made in typically photographic stages. The dry rhodopsin film was first exposed to light, producing a latent image. It was then developed in the dark by wetting. It then had to be fixed; and, though better ways are known, we fixed this photograph simply by redrying it. Since irradiated rhodopsin bleaches rather than blackens on development, the immediate result is a positive.

Photography with rhodopsin is only in its first crude stages, perhaps at the level that photography with silver bromide reached almost a century ago. I doubt that it has a future as a practical process. For us its primary interest is to pose certain problems in visual chemistry in a provocative form. It does, however, also add another chapter to the mingled histories of eye and camera.

George Wald is professor of biology at Harvard University.



RHODOPSIN PHOTOGRAPH was made by the author and his associates Paul K. Brown and Oscar Starobin. Rhodopsin, the light-sensitive red pigment of rod vision, had been extracted from cattle retinas, mixed with gelatin and spread on celluloid. This was then dried and exposed to a pattern made up of black and white stripes. When the film was wetted in the dark with hydroxylamine, the rhodopsin bleached in the same pattern.

EXPLORING THE OCEAN FLOOR

One of the last frontiers of the earth's solid surface has been made more accessible by new instruments built in Sweden and carried around the world by the *Albatross*

by Hans Pettersson

IN THE COURSE of this century geographers have realized their most ambitious dreams. The North and South Poles have been attained. The desert highlands of Central Asia and the jungles of Africa and South America have been penetrated. The icecaps of Greenland and Antarctica have been traversed. What remains for the future explorer? My answer to the question is: the enormous expanse of the deep ocean floor, so far merely touched by instruments of little efficiency. There, hidden under 12,000 to 36,000 feet of water, lies a unique archive of past events.

For millions of years minute particles have settled like snow on the original rocky bottom of the oceans. The particles have covered the bottom with a carpet of sediments, ranging in hue from the deep chocolate of the "red" clay to the light color of the calcareous ooze which bears the countless shells of small organisms that have drifted down from the sunlit surface waters. In this carpet, the thickness of which increases with incredible slowness, is the evidence of great catastrophes that have altered the face of the earth. Climatic catastrophes, which piled thousands of feet of ice on the higher latitudes of the continents, also covered the oceans with icebergs and ice fields at lower latitudes and chilled the surface waters even down to the Equator. Volcanic catastrophes cast rains of ash over the sea, inserting the bookmarks of Vulcan, god of the nether fires, into the sedimentary records of his colleague Neptune. Tectonic catastrophes raised or lowered the ocean bottom hundreds and even thousands of feet, spreading huge "tidal" waves which destroyed plant and animal life on the coastal plains. The records of the deep which unlike the eroded continental records of the rocks contain no missing volumes nor torn pages, can give us new and startling insights into such happenings of the past.

Until recently the records of the deep were effectively sealed. The ordinary core sampler, a steel tube that is pressed into the ocean bottom to bring up a thin cross section of it, rarely sampled layers deeper than three feet, and the samples were often deformed by the walls of the tube. But during World War II, Swedish oceanographers, who were unable to go to sea, devoted their efforts to improving the tools required for the study of the

CRUISE OF THE "ALBATROSS" began and ended at Göteborg in Sweden. It took 15 months and traversed a course of 44,000 miles. The difficulty of handling the long core samplers made it desirable to seek regions of deep ocean. In 1942 B. Kullenberg and I constructed at the Oceanographic Institute in Göteborg a vacuum core sampler that obtained from the bottom of the deep Gullmar Fjord an undeformed sediment core 45 feet long. Three years later Kullenberg used his piston core sampler to secure a core 65 feet long. In the case of both of these instruments it is the tremendous pressure of the water at great depths that forces the sediment column up into the coring tube.

During the same period W. Weibull of the Bofors Armament Works developed a method of measuring the thickness of deep-ocean sediments by exploding specially built depth charges many thousands of feet below the surface of the sea. The sound of such an explosion is reflected not only from the bottom but also from the "bottom beneath the bottom," *i.e.*, the boundaries of layers deep in the sediment. The echoes are received on shipboard by hydrophones and preserved for study with an oscillograph or a wire recorder. In the spring of 1946 the Swedish government ship *Skagerack* carried these new tools to the western Mediterranean on a test cruise which proved that they were efficient at depths greater than those near the coast of Sweden.

WE had already begun to plan an oceanographic cruise around the world. The Royal Society of Göteborg, with the assistance of private donors, financed the cruise; the Broström Shipping Combine of Göteborg lent us its fine new training ship *Albatross*. The ship was fitted out with air-conditioned cabins and laboratories for work in the tropics. It was also provided with a special electric winch for lowering and raising the core samplers, which weighed as much as a ton and a half, at the end of a 26,000-foot steel cable. The *Albatross* carried a scientific crew of 10 and occasionally 12, assisted by 12 apprentices under the ship's normal complement of officers and engineers. The expedition left Göteborg on July 4, 1947, and it returned more than a year later on October 3, 1948.

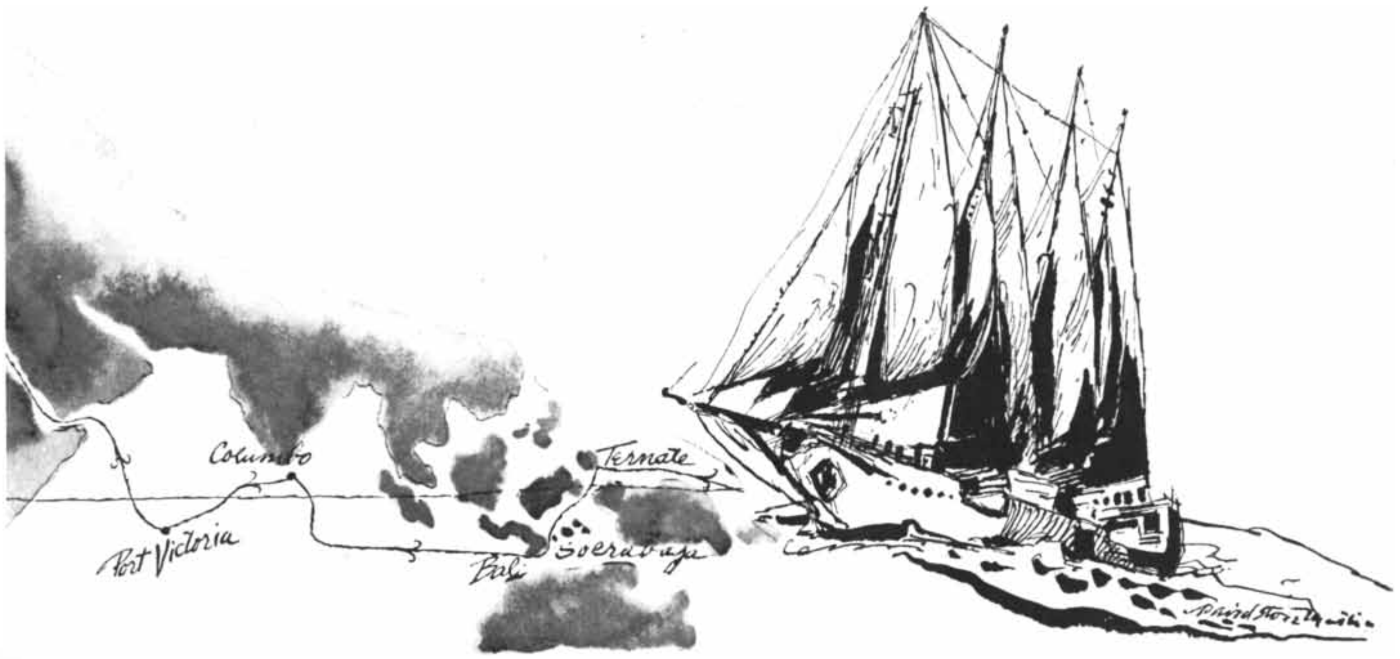
We brought back in the cold-storage room of the *Albatross* some 200 deep-ocean sediment cores obtained with the piston core sampler. Their total length was more than a mile. We had also the records of 400 depth charges indicating the thickness of the sediment carpet, several thousand water samples (some of large volume for the measurement of the uranium and radium content of sea water) and tens of thousands of temperature measurements down to great depths. Our echograms, drawn by an ultrasonic depth recorder, had delineated with unprecedented detail the profile of the bottom for 17,000 miles of our course. We had made measurements of the optical properties of sea water, revealing the concentration of clouds of particles at certain depths; and we had recorded the various spectral regions, including the ultraviolet, of submarine daylight down to more than 600 feet.

All this wealth of new material is now being analyzed at scientific institutions in Sweden and other countries by specialists in sediments, chemistry, spectrography, X-ray analysis, radioactivity, marine biology and so on. The detailed results are being published volume by volume in the *Report of the Swedish Deep-Sea Expedition* over a period of perhaps five years; some of the investigations may take even longer to complete. But our novel methods have now been thoroughly tested, and it is possible to describe some general results of their application on the cruise of the *Albatross*.

THE CONSIDERABLE weight of the core samplers made it desirable for our expedition to do much of its work under conditions of fair weather and relatively calm water. Our course was therefore laid in or near the doldrums, with repeated crossings of the Equatorial Countercurrent and its adjacent regions of ascending water rich in nutrient salts.

Our ultrasonic depth recorder, designed expressly for the cruise, drew a surprisingly uneven profile of the bottom, even when it was at great depth. Often the bottom rose or fell 300 to 600 feet in abrupt steps a mile or more across. Perfectly smooth stretches were the exception rather than the rule. To our cost such a stretch frequently proved to be a hard formation, presumably a lava bed of geologically recent origin, covered only by a thin veneer of sediment. Against these unexpected obstacles our precious long core samplers were sometimes bent or broken. The sediments of the Pacific and Indian Oceans, which often bore particles of volcanic material, also testified to the importance of volcanism in submarine geology. Some of our cores from the Mediterranean were marked with coarse-grained layers consisting largely of volcanic ash that had settled on the bottom after great volcanic explosions. These layers are an unrivaled record of the irregular volcanic activity of the past.

In regions of strong volcanic activity



the fairest weather and calmest water. The course was accordingly laid for the most part in the equatorial doldrums. The *Albatross* itself, which is sketched at the right, is the training ship of a Göteborg shipping firm.

the layers of ash in various cores may be compared to date sediments and to establish their rates of deposition. Another method of geochronology makes use of the microscopic fossils that are found in sediment cores. These fossils are the remnants of tiny calcareous or siliceous organisms that live near the surface (plankton) or on the bottom (benthonic animals). Fred B. Phleger, Jr., of the U. S., and W. Schott of Germany have been able to show that the calcareous shells of certain heat-loving Foraminifera are concentrated in core levels corresponding to the warm interglacial periods of the Pleistocene Epoch. The shells are nearly absent, on the other hand, from levels corresponding to the cool glacial periods. In this way the time scale of submarine geology is linked to that of glacial geology. Phleger has analyzed the Foraminifera in one of our longest cores, taken from the bottom of the Caribbean, to show how the temperature of the ocean surface must have varied as the glaciers contributed more or less melting ice to it at higher latitudes.

Still another geochronological method is based on the proportion of radioactive elements to the products of their decay. The uranium 238 in sea water breaks down into uranium 234, which in turn breaks down into thorium 230, often called ionium. The ionium then breaks down into radium 226. The ionium, however, is precipitated to the bottom together with iron. There its decay into radium proceeds. The proportion of ionium to radium remains constant, but the amount of radium falls off regularly with the increasing depth and age of the sediment. Since half of the ionium is known to decay in 83,000 years, it is possible to use it as a kind of hourglass to approximate the ages of the upper layers of the sediment. Applying this method to cores from sediments in the central Pacific, I have been able to determine their rate of growth for the past 250,000 years. In 1,000 years it is less than .05 inch! This would imply that our 50-foot core taken from that region reaches back in time some millions of years. The red clay of the Atlantic generally shows a deposition rate 10 to 20 times higher.

THERE has been a great deal of interest in the surprisingly high content of nickel found in our central Pacific red-clay cores by H. Rotschi of France. Nickel is very scarce in sea water; there is only about one part of nickel in 10 billion parts of water. In a central Pacific red-clay core the proportion is 300 to 700 parts of nickel to a million, a concentration very much greater. The concentration is about eight times the average nickel content of the Atlantic red clay, a ratio which inversely approaches its sedimentation rate with respect to similar material in the Pacific. Perhaps even more interesting are the five distinct maxima of nickel content at different levels in a single central Pacific core, where the concentration jumps two and almost three times its average value.

It has been suggested that the high nickel content of these slowly deposited sediments is derived from volcanic lava, or basalt, emitted over the deep ocean floor. Recently, however, S. Landergren of the Geological Survey in Stockholm made a spectrographic analysis of basalt and found it to contain only modest amounts of nickel. It is tempting to assume quite a different origin for the abyssal nickel: meteoric dust. This extraterrestrial material settles from the billions of meteors that enter the earth's atmosphere daily and usually burn to dust high in the stratosphere. It is known to have a very high nickel content averaging about two per cent. The maxima of nickel content found at certain levels of our cores might then be due to very heavy showers of meteors in the remote past. The principal difficulty of this explanation is that it requires a rate of accretion of meteoric dust several hundred times greater than that which astronomers, who base their estimates on visual and telescopic counts of meteors, are presently prepared to admit.

Weibull's depth-charge method of measuring the thickness of the sediment carpet has given us a maximum value for the thickness of the red clay in the eastern Atlantic between Madeira and the submarine Mid-Atlantic Ridge. There the deepest reflecting layer was found to be about 13,000 feet below the bottom. If we assume that the present rate of sedimentation in the region has remained unchanged for an enormous stretch of time, the sediment carpet has been laid down over a period of at least 500 million years. And if we allow for the compaction of the deeper strata of the carpet, its age is considerably greater. We found no comparable depths of sediment in the equatorial Pacific and Indian Oceans; there the deepest reflecting layers were not more than 1,000 feet below the bottom. Possibly this striking difference is the result of a slower rate of sedimentation. It may also be due to layers of lava in the sediment that prevent the penetration of sound waves to deeper layers.

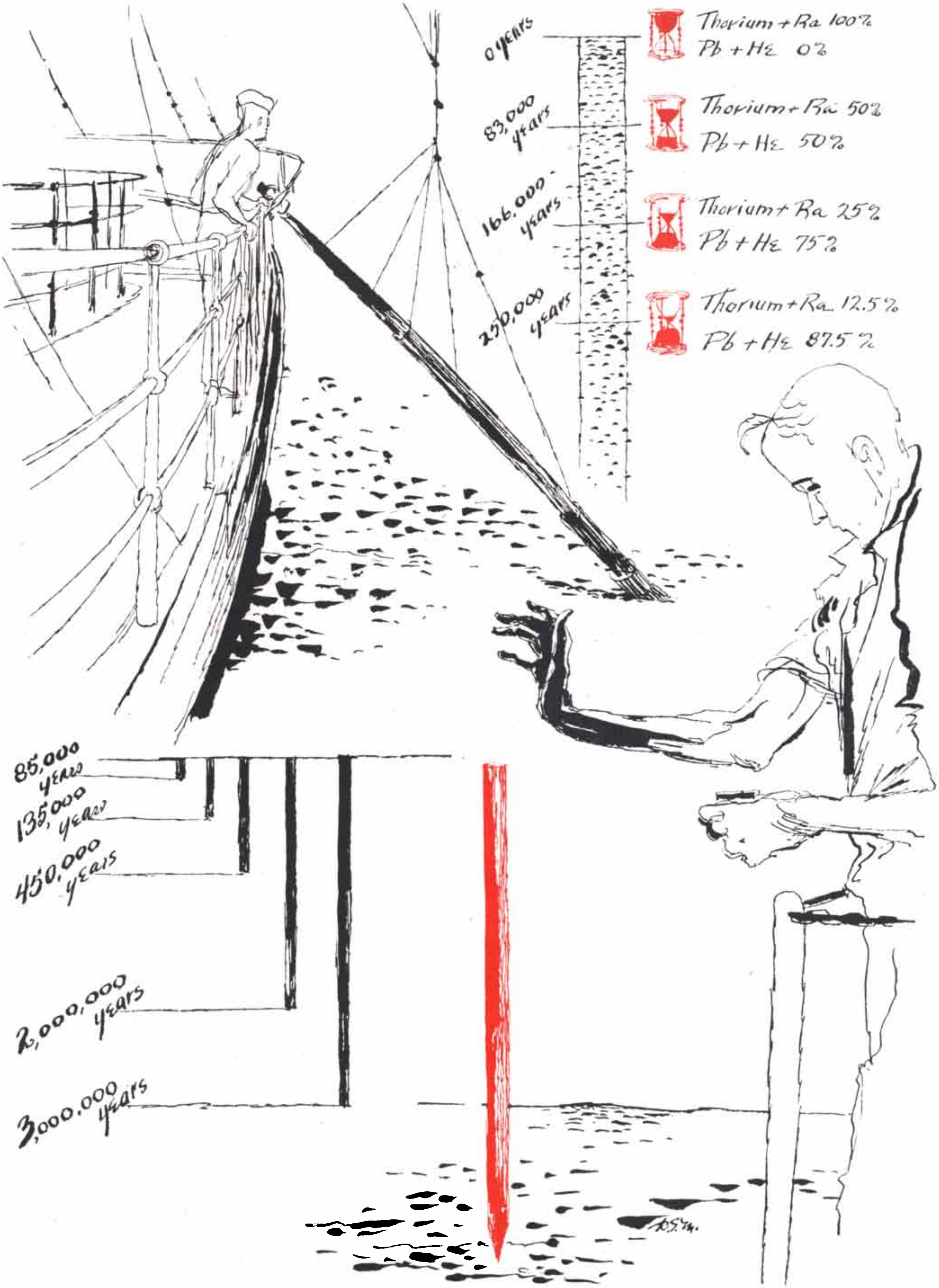
ALL these results of the Swedish Deep-Sea Expedition can only hint at the extraordinary fruitfulness of investigating the deep ocean floor. It is my hope and belief that this abyssal region in the basement of the earth's crust will be the subject of coordinated scientific efforts on an international scale. The U. S. should occupy a key position in such efforts: it is situated between the two largest and deepest oceans; it has men of outstanding genius in oceanography, geophysics, geology and marine biology; it has greater resources for the support of scientific work than other countries. Considering these favorable circumstances, it is surprising how few and far between have been U. S. efforts to explore the depths of the ocean since the turn of the century, when that great pioneer Alexander Agassiz made his famous cruises of the Pacific and Caribbean in his ship named, like ours, the *Albatross*. It is true that in recent years, largely because of the farsighted policy of the U. S. Office of Naval Research, deep-sea research of a very high quality has been conducted from the Oceanographic Institution at Woods Hole, Mass. But the small size of the Woods Hole oceanographic vessel *Atlantis* has inevitably limited its activities to the northwest Atlantic.

Save for the few cruises of the ill-fated nonmagnetic ship *Carnegie*, the vast expanse of the Pacific, the greatest abyssal area of our planet, is virtually untouched by deep-ocean exploration. There are fascinating problems of geophysics and geology in its equatorial regions, particularly those traversed by our *Albatross* between Tahiti and the Hawaiian Islands.

Is it too optimistic to hope that some of the many benefactors of science in the U. S. will give the same support to deep-ocean research as did the few citizens of Göteborg who financed the expedition of the *Albatross*? A specially built and equipped ship of the same size, about 1,500 tons, could add immensely to our knowledge of the deep Pacific. If such a ship were given to the nation together with the means of keeping it active for eight to 10 months of the year, universities and other research institutions on the Pacific coast and all over the U. S. could collaborate on the problems of the deep ocean. Such a ship moreover could teach the methods of deep-ocean research to new generations of specialists, the lack of which is perhaps the greatest obstacle to the advance of the science of the sea.

Hans Pettersson is director of the Oceanographic Institute at Göteborg in Sweden.

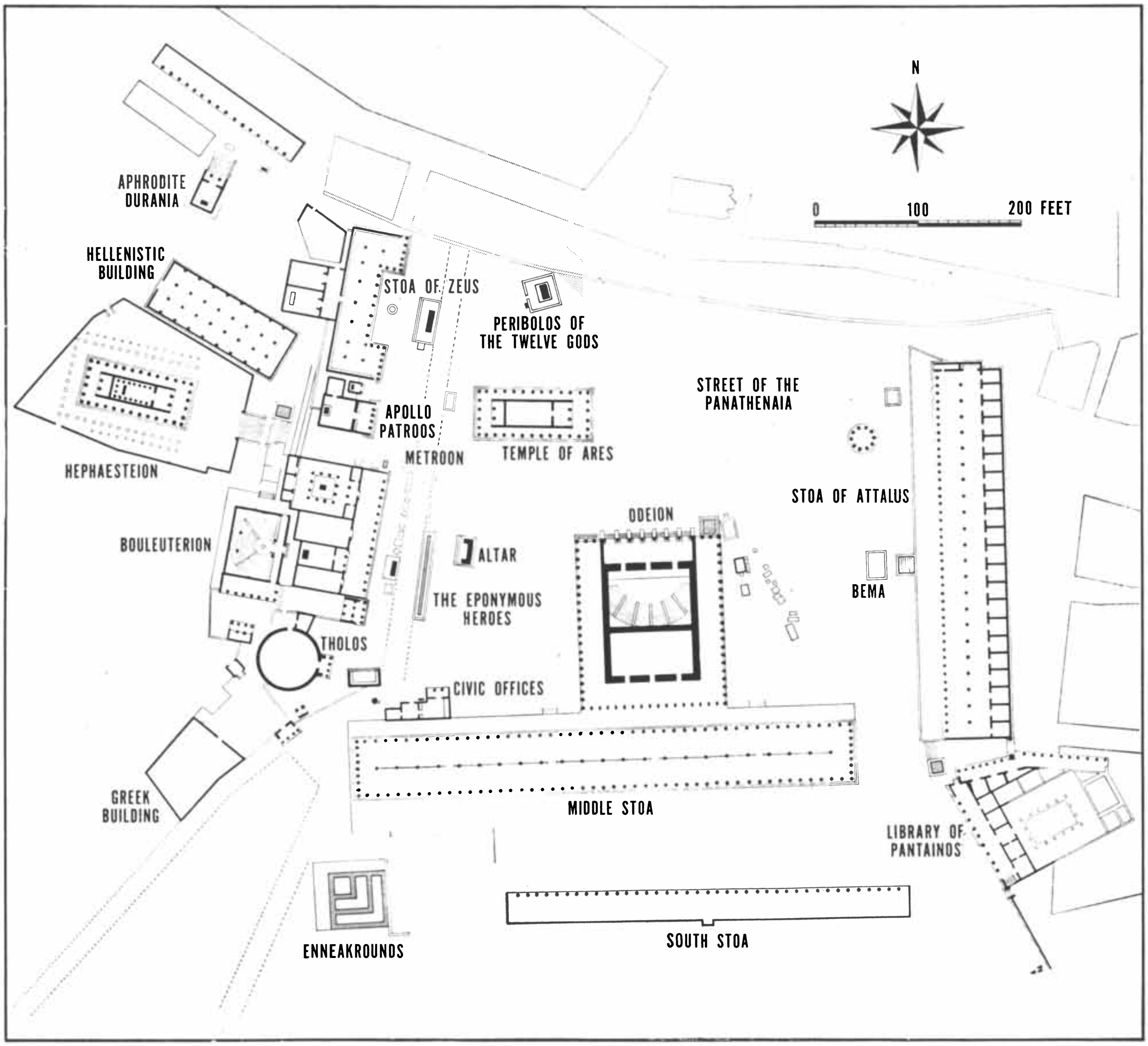
SOME TECHNIQUES used by the Swedish oceanographers are illustrated on the opposite page. At the upper left a core sampler is lowered. At the lower left is a comparison of the depth of core samples taken from the Atlantic red clay during the past 75 years. In 1873 the depth of the core was two feet; in 1925 it was three feet; in 1936, 10 feet; in 1942, 45 feet; and in 1945, 65 feet. At the upper left is diagrammed a method of determining the age of core levels by the proportion of radioactive elements and their breakdown products. At the lower left a special depth charge is dropped from the *Albatross*.


0 years
83,000 years
166,000 years
250,000 years
Thorium + Ra 100%
Pb + He 0%
Thorium + Ra 50%
Pb + He 50%
Thorium + Ra 25%
Pb + He 75%
Thorium + Ra 12.5%
Pb + He 87.5%
85,000 years
135,000 years
450,000 years
2,000,000 years
3,000,000 years

THE AGORA

It was the great public square of ancient Athens. In recent years it has been extensively excavated to reveal its plan and its relation to the good life of the Greek city-states

by Homer A. Thompson



RESTORATION of the Agora shows it as it appeared at the height of its development in the second century A.D. The north side of the square, beyond the bounds of the present excavations, was also closed by buildings.

AMONG the most striking achievements of man are the literature, the visual arts, the philosophy and the political science of ancient Greece. It is even more striking that in the Greek city-states these and other aspects of the good life flourished together. Such a rich flowering must have been due in large part to the nature of community life in the city-state. In recent years students of ancient Greece have thus been inclined to deprecate narrow specialization; they have endeavored to relate the various specialties to one another and to the life of the time. For such an approach a knowledge of ancient city planning is basic.

The testimony of ancient authors and the exploration of the few Greek townsites that have been adequately examined make it abundantly clear that community life in the comparatively small city-state was much more concentrated than in our sprawling urban communities. Civic life was centered in a public square, the agora, which is best paralleled by the Forum of Rome or the Piazza San Marco of Venice. The agora (literally "gathering place") served at once as a civic center, as a market place, as a setting for the outdoor religious and festive gatherings in which Mediterranean people have always delighted, and as the scene of much of the social and intellectual intercourse of the citizens. The agorae of several Greek cities have long been known, especially those of the cities of Asia Minor such as Miletus, Priene and Magnesia. We are now in the fortunate position of having a detailed knowledge over a very long span of time of the Agora of Athens, most distinguished of all the ancient Greek city-states.

The exploration of the Athenian Agora was begun by the Greek Archaeological Society almost 100 years ago, and it was continued intermittently by the Society and by the German Archaeological Institute. After World War I the project was taken up by the American School of Classical Studies in Athens, which has served since 1881 as a base of operations for U. S. classical scholars working in Greece. This new archaeological excavation of the Agora was begun in 1931, and it was pushed vigorously in regular annual campaigns through 1940. For five years the work was interrupted by the war, but now it continues.

THE ANCIENT Agora lies at the northwest foot of the famed Acropolis and near the center of modern Athens. This latter fact necessitated the purchase and demolition of some 360 houses that had sheltered 5,000 people in an area of 25 acres. A formidable mass of accumulated material—10 feet on the average and 40 feet at the deepest—has had to be removed to reveal the levels of classical times. This thick blanket consists in part of the debris from the repeated destruction of buildings at the site; in larger measure it is made up of silt and gravel carried down from the neighboring slopes by winter rains.

The primary objective of the excavations has already been achieved. The scheme of the ancient square has been exposed and its history unraveled over the period from the time of Solon in the early sixth century B.C., when the area came into use as a public place, down to 267 A.D., when this part of Athens was sacked by the Heruli, a band of barbarians from the region of the Black Sea. Men have lived in the area, however, over a much greater span: from the Neolithic Period of about 3000 B.C. down to the present day, and much evidence has been gathered by the excavators on the private life of this entire 5,000 years.

The development of the square was gradual and deliberately controlled. When a new building was to be added, careful thought was given not only to its design but also to its relationship with older neighbors. The judgment of the Athenians was not always impeccable, but they maintained a remarkably high standard of planning. By the second century A.D. the Agora had reached its fullest development, and Athens, a city of not more than 200,000, possessed a public square which in spaciousness, convenience and richness of architecture is seldom surpassed by modern cities.

The four sides of the square were closed by public buildings, all of which presented deep colonnaded porches to an open area. At any season of the year and any hour of the day thousands of citizens might choose between sun and shade, breeze and shelter—an ideal arrangement for the Mediterranean climate. The east, south and west sides have now been laid bare; the north side is outside the area of the present excavations.

On the west side of the square stood the administrative buildings: the Bouleuterion or council house, the Metroon or state archives and the Tholos, a small round structure that served as a clubhouse for the councilors and as a bureau of weights and measures, many of which have been found in its vicinity. Farther north rose a small temple of Apollo; at the extreme north was the Stoa of Zeus, a small but attractive public colonnade which is known to have been a favorite haunt of Socrates and his pupils.

The east side of the square was closed in the second century B.C. by the large Stoa of Attalus. To the south stood the Middle Stoa, an enormous market hall divided longitudinally by a screen wall so that the building faced both northward toward the main square and southward toward a narrow lesser square which would seem to have been intended for practical market purposes. Conveniently placed at the west end of this market area was a large fountain house, the Enneakrounos or Nine-Spouter; its east end was closed by a public library which also housed a sculptor's studio.

In the early period the central area of the main square, some six acres in extent, had been kept open to accommodate large gatherings of the citizens for political and judicial purposes and for dramatic performances. It was also designed to permit a clear view of the Panathenaic Procession that made its way diagonally through the square toward the Acropolis bearing offerings and a new dress to the patron goddess Athena on her birthday. Gradually through the centuries the square came to be forested with statues, altars and monuments; in the first century B.C. it was more violently encroached upon by the intrusion of two large buildings, the Temple of Ares and the Odeion or concert hall.

Of the many sanctuaries and temples that bordered on or stood close about the Agora one of the most interesting is the Temple of Hephaestus which overlooked the square from the west. Hephaestus was the patron god of the metalworkers, the ruins of whose workshops have been found on the slopes of the temple hill. Here Hephaestus was associated with Athena, patron goddess of such crafts as pottery-making; this whole region of the city took the name Kerameikos from the potteries. This fine marble temple rose in the middle of the fifth century B.C., at a time when Athenian metalworking and pottery-making flourished and accounted for a large proportion of the national income.

This is the larger aspect of the Agora. We can only summarize the many individual finds that have come from the excavations: an extraordinarily rich series of ancient pottery, many fine pieces of sculpture, 100,000 coins, 6,000 documents inscribed on marble that have added greatly to our knowledge of Athenian history, and abundant other evidence of the private, industrial and artistic activity that went on around the public square. The investigation of three buildings, however, will illustrate the present work in the Agora.

AS A FIRST example let us take the gable sculpture of the Temple of Hephaestus. This is the best preserved and, next to the Parthenon, the most familiar of all Greek temples. Yet it has also been one of the most enigmatic, particularly in the matter of the sculpture that once filled the triangular fields or pediments of its two gables. Two hundred years ago the English architect James Stuart inferred the existence of such sculpture from cuttings in the gables; 50 years ago the German scholar Bruno Sauer worked out an elaborate though implausible restoration of the two groups based on the cuttings, especially those that served as beds of individual statues on the floors of the gables.

The current excavations around the slopes and the foot of the temple hill have brought to light several pieces of marble sculpture which invite attribution to the gables because of their size and period and their superb quality. The pieces are a standing figure of the goddess Athena, readily recognizable from the Gorgon's head on her breastplate; a youthful standing male figure and a reclining male figure; a horse's hoof and the draped foot of a woman. All are approximately three quarters life-size. A direct check on the original location of the pieces was possible only in the case of the woman's foot, which alone retains its plinth or low base. A systematic examination of the gable floors soon revealed a cutting in the west gable into which the foot clicked with reassuring precision.

This success encouraged the investigation of the other pieces. All of them had been found to the east of the building, which suggested that they came from the east gable. The attitude of the reclining male figure appears to fit the extreme left angle of the triangular space. A hole in the broken underside of the torso indicated that the statue had been made out of two pieces of marble. The floor of the left side of the gable is cut to fit a statue made of two blocks, a coincidence which may be taken as confirmation that the torso once rested in the gable.

The standing male figure and the Athena are too tall to have come from anywhere but near the middle of the gable. To the left and right of a rectangular bed in the middle, in fact, are beds of the appropriate size and shape. The evidence for the location of the horse's hoof is indirect but cogent. In either wing of the gable is a series of three related beds which when studied in comparison with the better preserved sculptures of the Temple of Zeus at Olympia are seen to have supported a chariot, a charioteer and a four-horse team. The angle and weathering of our small fragment identify it as the right forefoot of the outermost horse in the left wing.

The rectangular shape of the bed in the middle of the gable at once suggests a throne. This possibility is supported by the fact that the head of a figure seated on the throne and facing to the right would be directly beneath the peak of the gable. In order to fill the space in the middle of the gable this figure must have been of larger scale than its neighbors and thus, according to the Greek artistic convention, of greater dignity. In Athens, where Athena was the patron goddess, no other divinity in her immediate company would have been accorded this honor except her father Zeus, the principal god of Olympus.

As for our standing male figure, the fact that he is identical in scale with Athena suggests that he too is divine; his vigorous, youthful form would be most appropriate to Heracles, the Greek

TEMPLE OF HEPHAESTUS, best preserved and, next to the Parthenon, best known of the ancient Greek temples, stands above the excavated Agora. In the foreground are the ruins of the administrative buildings.

equivalent of the Roman Hercules. The identification is strengthened by the close similarity between the newly found statue and a figure of Heracles at his labors in the carved metopes or panels on a frieze of the temple immediately beneath the gable. In the gable Heracles and Athena, each with a chariot, are shown arriving in the presence of Zeus. Our sculpture thus deals with one of the favorite themes of Greek art: the deification of the hero. Having completed his appointed labors as illustrated in the frieze below, Heracles ascends to the home of the gods to receive the hand of Hebe, symbol of eternal youth. Between Heracles and his team of horses are cuttings in the gable which would fit a tree and an entwined serpent, suggesting the famed story of the golden apples of the Hesperides. Heracles was very likely shown as he presented one of the exotic fruits to Zeus.

From a well immediately to the east of the temple has been recovered a battered but lovely marble group representing one girl raised on the back of another. The group is appropriate in scale and composition to have served as the ornament at the peak of the east ridge of the building. The figures possibly represent two of the Hesperides, the fair sisters who were placed by Hera to guard the apple tree but who stealthily assisted Heracles to acquire the forbidden fruit. This entire façade glorifying a favorite Athenian hero looked down throughout antiquity on the Agora and formed one of its noblest ornaments.

ANOTHER BUILDING that has been investigated since the war is the Odeion or concert hall in the very middle of the square. Although the building is mentioned by only two ancient authors (Pausanias and Philostratus) and very little of it has survived, its plan and its history can be reconstructed in fair detail from its remains. Enough of the foundation blocks were found to establish the plan; the design of the superstructure may be won back from a few scattered marbles with the help of other buildings of similar type. The history of the Odeion is documented by the levels at which its various remains have been found, by its architectural style, by its roof tiles stamped with the date of manufacture and by literary references to it.

The Odeion proves to have been a curiously dual-purpose building. Its central core was a square auditorium with a seating capacity of about 1,000, a long narrow stage, a dressing room and a lobby. It is particularly noteworthy that, although the auditorium is 80 feet across, there is no trace of an interior support for the roof. The building was certainly roofed, presumably with wooden trusses, the charred remains of which have been found among its debris. Around three sides of the central core ran a raised balcony or loggia from which hundreds of citizens might look down on processions, ceremonies or meetings in the square.

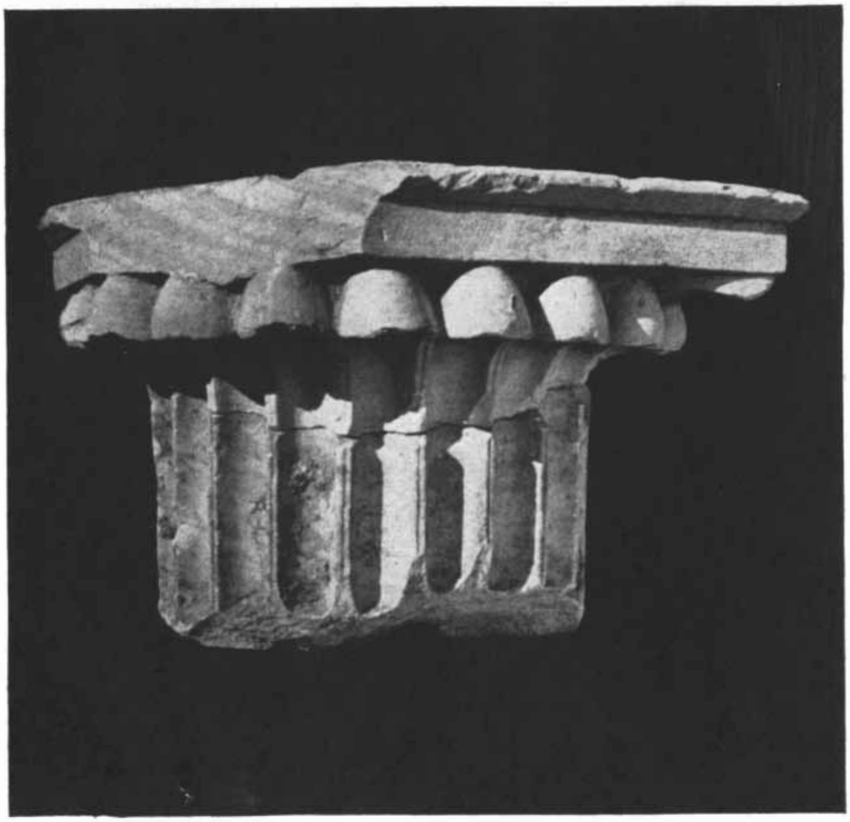
The Odeion bore the name of Agrippa, minister of the Roman emperor Augus-

Some 360 houses and 10 feet of debris were removed to reveal these ruins.

STOA OF ATTALUS is still partly standing. Shown here are the doors to four of the 21 shops on its ground floor. In the background is the Acropolis.

ODEION, here shown under excavation, had an auditorium with a seating capacity of 1,000. In the foreground is the semicircular floor of the orchestra.

MARBLE CAPITAL from the rear of the Odeion rested atop a column 65 feet above the ground. The capital weighs about two and a half tons.



PERGAMENE CAPITAL is from the Stoa of Eumenes, Attalus' predecessor as king of Pergamum. It is being copied in restoration of Stoa of Attalus.

tus, and it was presumably built by him when he served in the eastern Mediterranean about 15 B.C. It was the most modern and most convenient concert hall in the city, and it remained so until its roof collapsed about 150 A.D. When the Odeion was rebuilt the auditorium was cut in half to make the roof safer, and the old dressing room was turned into an open porch. From that time until it was burned by the barbarians in 267 A.D. the building served as a university lecture hall. After a period of desolation lasting more than a century a great building containing many lecture rooms was erected above the ruins of the Odeion. It was employed as one of the principal university buildings of the city until the schools of Athens were closed by the order of Emperor Justinian in 529 A.D.

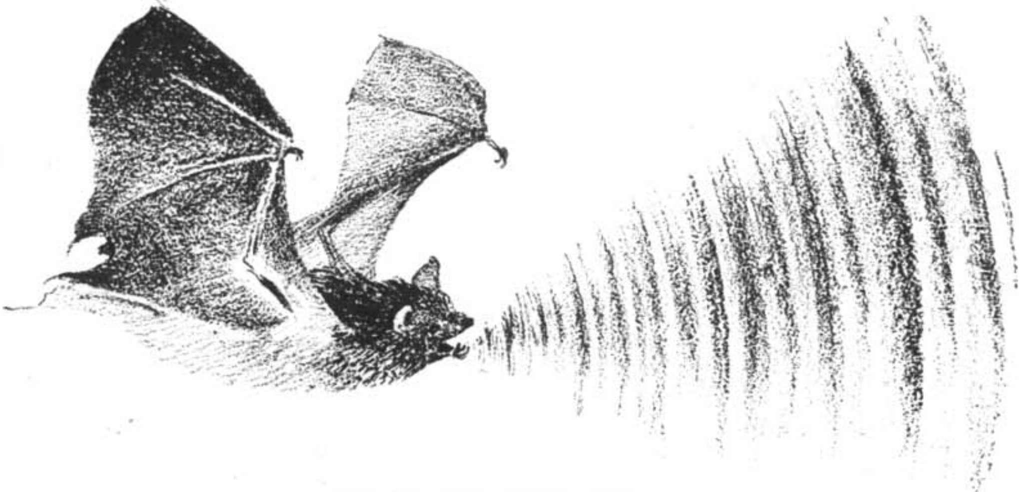
A THIRD BUILDING that has recently been studied is the great market hall, the Stoa of Attalus, which closed the east side of the square from the time of its erection in the middle of the second century B.C. until it too was burned by the barbarians in 267 A.D. The Stoa, like the Odeion, was a gift to the city from a foreign admirer: Attalus II, ruler of the small but energetic kingdom of Pergamum in northwestern Asia Minor. As a young man Attalus had studied philosophy in Athens; after ascending the throne he made this gesture as a distinguished alumnus.

The building was large, measuring some 380 by 65 feet. Its plan was simple but admirably suited to its purpose. A row of 21 shops each looked out through a large door on a broad colonnade; a second story of the same general plan could be reached by an outside stairway at either end. A terrace some 20 feet wide ran the full length of the building.

The Stoa is comparatively well preserved because of the fact that it was incorporated into a new wall of fortifications hastily thrown up after the barbarian sack of 267 A.D. For this reason the Stoa has been chosen for reconstruction as a museum to house the finds from the Agora excavations. The two stories of the great building should provide adequate space for storage, workrooms and the display of the ancient objects in close relation to their original context. The preparatory work of clearing the site and of making a thorough archaeological survey began in April, 1949, and it is now practically complete. A start has already been made on the carving of the new marble members, a task in which the skilled craftsmen of modern Athens will compete with their talented ancestors.

Homer A. Thompson is Field Director of the Agora Excavations.

FOUR FRAGMENTS from the east gable of the Temple of Hephaestus represent Heracles (*upper left*), Athena (*upper right*), a horse's hoof (*lower left*) and two girls. The fragments are not reproduced in the same scale.



FLYING BAT emits ultrasonic cries of remarkable intensity. A few inches in front of its mouth an ultrasonic pulse may reach a level of 113 decibels.

The Navigation of Bats

How do the tiny winged mammals so skillfully avoid obstacles in the dark? Some say that they possess radar, and this is surprisingly close to the truth

by Donald R. Griffin

ALMOST everyone has at least a casual acquaintance with bats; those "winged mice" which fly about in the dusk or darkness and occasionally enter the attics of houses. To some they are terrifying creatures alleged to entangle themselves in women's hair. In folklore and artistic symbolism they are manifestations of the supernatural—images of evil spirits in our culture but symbols of good luck in the Chinese. To the naturalist they are bizarre and obscure animals of which more than 1,000 species have been described. In recent years, however, bats have come to be mentioned in a quite different context, often in the same breath with the elaborate developments of modern electronics. Thus I have heard in widely scattered places—in a subway, in a schoolroom, in a bar—the bald statement "bats have radar." This startling idea seems well on its way to become common knowledge, although strictly speaking it is quite untrue. Yet there is no doubt that a bat can fly through the total darkness of a cave, locating and dodging obstacles in its path. Sometimes hundreds of individual bats fly through the same passageways at the same time, all dodging the jutting rocks as well as one another. If they possess neither magic nor radar, how do they do it?

Bats' eyes are not the means by which they guide their flight in the dark. Biologists have known since the late 18th century that bats retained their skill even when blinded. Lazaro Spallanzani of Italy was the first man to experiment with the power of bats to avoid obstacles; before 1800 he and Louis Jurine of Switzerland had discovered that if bats' *ears* were covered, they became helpless and collided even with large and conspicuous obstacles. But a bat's flight is silent, or very nearly so; and it was difficult to imagine how the ears could help to locate threads stretched across a room or the branches of trees in a forest. As one critic wrote sarcastically in 1809, "Since bats see with their ears, do they hear with their eyes?" Not until 1920 was a plausible explanation suggested by the English physiologist H. Hartridge, who watched bats flying through darkened rooms and advanced the theory that they might be orienting themselves by means of ultrasonic sounds too high in frequency for human ears to hear.

IN 1938 I had the opportunity to bring some live bats to the laboratory of G. W. Pierce of the Harvard University Department of Physics. Pierce had developed an apparatus that detected ultrasonic sounds, and it was at once apparent that the bats made sounds which we could not hear but which were readily detected by the Pierce apparatus. The frequency of the sounds was roughly 50,000 cycles per second, whereas human ears can hear sounds only within a range of about 20 to 20,000 cycles. Young children can hear high frequencies more easily than adults; and smaller mammals such as cats, guinea pigs and rats can hear frequencies up to 30,000 cycles or perhaps even higher. The little brown bats (*Myotis l. lucifugus*) that we used in these experiments are much smaller than housemice, and my colleague Robert Galambos has shown by experiments that the inner ear of these bats is sensitive to frequencies as high as 100,000 cycles. Galambos and I worked together from 1939 to 1941 analyzing in some detail the obstacle-avoidance techniques of bats, and we confirmed Hartridge's theory in every respect.

We tested the skill of the bats by making them fly through a room divided across the middle by a row of wires hanging vertically from the ceiling and spaced a foot apart. The bodies of the bats almost never collided with a wire 3/16 of an inch in diameter, though occasionally their wingtips brushed against the wire in passing. In 90 per cent of the passages the bats did not touch such heavy wires at all. Smaller wires were more difficult for the bats to detect; their score with wires 1/20 of an inch in diameter was only 70 per cent. With wires three one-thousandths of an inch thick they did no better than chance alone would allow. Stopping the ears or covering the mouth of a bat also reduces its score to the chance level.

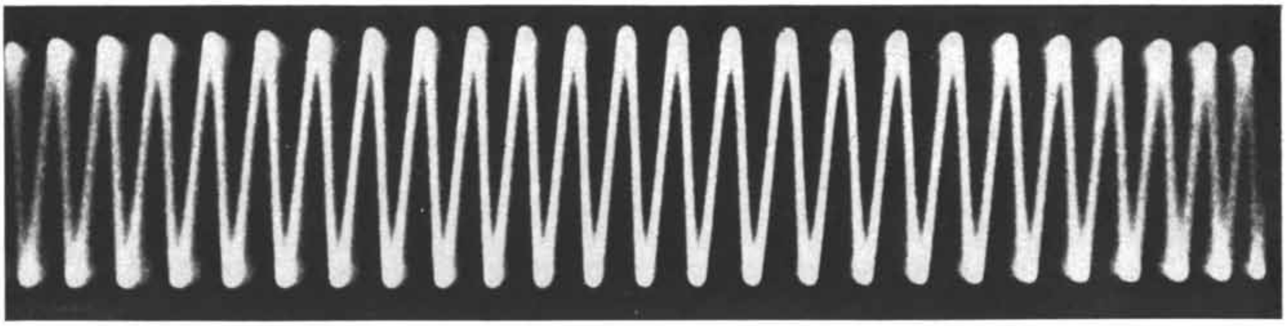
OTHER experiments showed that the bats needed both ears for normal obstacle avoidance. With one ear covered they could detect the walls but avoided wires only a little better than with both ears stopped. Locating the source of a sound requires two ears in men and other animals which have been tested, so it seems natural that a bat would detect the position of an obstacle by localizing the source of the echo in the same way. The reason both ears are required for auditory localization is that sound waves coming from the side reveal their origin by reaching the two ears at different times, at different intensities or in different phase relations. Bats emit their ultrasonic cries in rapid succession as they approach difficult obstacles such as wires, sometimes giving as many as 30 to 50 cries per second. When the obstacles are numerous and complicated the rate of the emission is increased; when the path is clear the rate is lower.

We were surprised to find on close study that the ultrasonic sounds were faintly audible to us; they were always accompanied by a click that could be heard in a quiet room if the bat was held within a few inches of one's ear. When the cries were emitted in rapid succession the clicks fused into a sound best described as a buzz. The bats also gave occasional loud and clearly audible cries, but these were not at all related to obstacle detection and came usually when a bat was struggling to escape from an experimenter's hands. At times bats seem to emit their ultrasonic cries with a louder audible component which can be heard at several feet. These bats are usually in poor physical condition or not completely awakened from the torpor of hibernation; it might be said that they are "not in good voice." During the same wartime years as our experiments, the Dutch zoologist Sven Dijkgraaf also turned his attention to bats while he was living under the hardships of the Nazi occupation. Working alone with no special instruments and without knowing of our studies, Dijkgraaf noticed the relationship between these faintly audible clicks and buzzing sounds and the avoidance of obstacles. Relying on his own ears and careful observation of a few individual bats, he discovered virtually all the facts I have described above. He naturally thought in terms of faint audible clicks, however, rather than ultrasonic sounds. Like so many scientific findings, this elucidation of the bat's method of obstacle avoidance was thus achieved almost simultaneously in widely separated parts of the world.

SINCE the war I have made more refined measurements of the properties of bats' ultrasonic sounds and have photographed their wave-form as seen on the cathode-ray oscilloscope. These photographs show that a typical ultrasonic cry lasts only for a very short interval of time—about one five-hundredth of a second. An audible sound of this extreme brevity is heard as a sharp click. The cathode-ray oscilloscope also revealed other unsuspected details. Each cry contains about 100 individual waves of sound; but instead of being evenly spaced across the oscilloscope screen, the waves are always crowded together at the beginning of the pulse and farther apart at the end, showing that the frequency drops during its fleeting lifetime. The first few waves may have a frequency of 100,000 cycles or even higher, while at the end of a pulse the frequency may have dropped to 40,000 cycles or even lower. In other words each pulse, though it contains only about 100 waves, is frequency-modulated. The frequency always seems to drop at least an octave from the beginning to the end of the pulse.

To understand what use this frequency modulation may have, let us consider how much space each pulse occupies as

WIRES strung from top to bottom of a room were largely avoided by bats. The heavier the wires, the more successfully the bats avoided them. The apparatus that detected their ultrasonic cries is depicted at lower right.

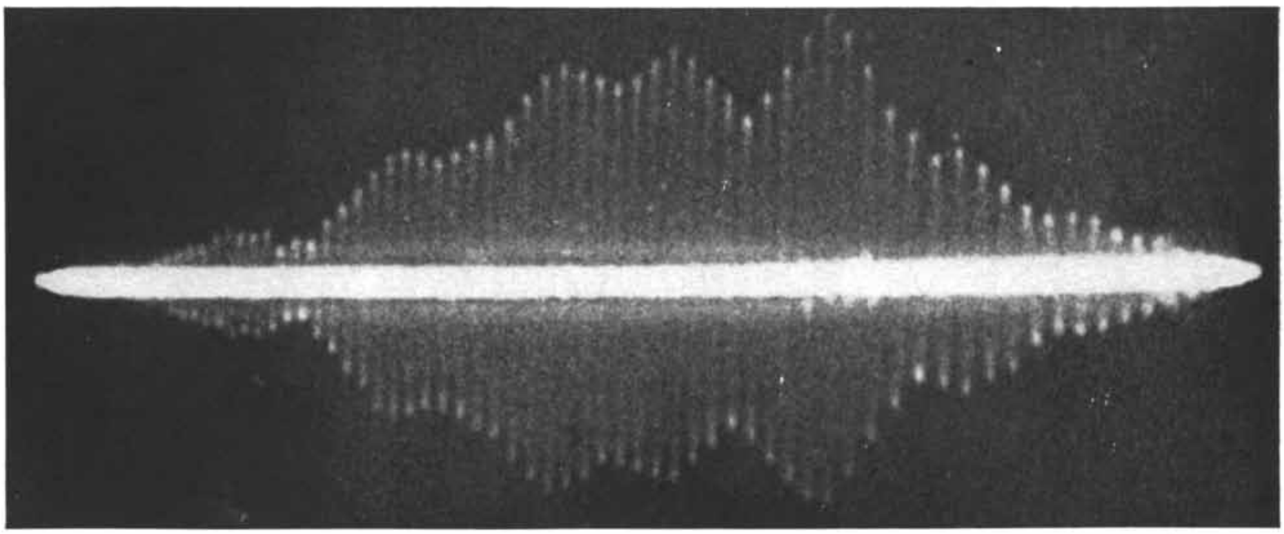


AUDIBLE sound frequency of 20,000 cycles per second is shown on the face of a cathode-ray oscilloscope. This is roughly the upper limit of human hearing. The wave is reproduced on same scale as the ultrasonic pulse below.

it spreads out ahead of the flying bat at the characteristic speed of sound: 1,130 feet per second. It is most convenient to express this velocity of sound in terms of the distance traversed in a thousandth of a second, or one millisecond, since the duration of the bat's pulses is measured in such microscopic intervals of time. In one millisecond sound travels 1.13 feet; and since the duration of the pulse is about two milliseconds the first waves are roughly two feet ahead of the bat's nose when the last waves leave its mouth. If there is a solid object three feet away, the first waves of the echo will return to the bat's ears after about six milliseconds (we may neglect the motion of the bat since it is very slow compared with the velocity of sound). But suppose the object is closer, perhaps only nine or 10 inches ahead. Bats often fly this close to an obstacle and then turn aside, and other observations show that they can use their pulses of ultrasonic sound to detect objects as close as six inches. Under these conditions an echo will return to the bat's ears before the pulse can even finish leaving its mouth. Since the emitted pulse must sound far louder to the bat than the echo from a small object, how does the animal distinguish the faint echo from the emitted pulse? I cannot give a positive answer, but it would seem easier for a bat to distinguish between echo and original pulse if the two differed in frequency, as in fact they do. For it is the high-frequency beginning of the echo that overlaps the low-frequency end of the emitted pulse.

Another important consideration is the surprisingly high intensity of these ultrasonic pulses or clicks. A few inches in front of the animal's mouth the intensity, in terms of sound pressure, may be 10 times as great as the noise of a subway train passing the station platform. This is about 100 dynes per square centimeter, or 113 decibels on the conventional scale of sound intensity. Sounds as intense as these must be very loud to the bat's ears, yet the bat must be extremely sensitive to these same frequencies in order to pick up the faint echoes from small objects. This problem may be simplified by a mechanism in the middle ear which serves to reduce the sensitivity of the receiving mechanism. This consists of a set of muscles which vary the tension of the ligaments connecting the ossicles of the middle ear, those tiny bones which conduct the mechanical energy of sound waves from the eardrum to the sensitive cochlea where it can stimulate nerve fibers. The contraction of these muscles is known to reduce the sensitivity of the ears of men and experimental animals such as guinea pigs. The muscles presumably have a similar function in the bat, perhaps contracting with the emission of each ultrasonic pulse to protect the delicate ear from the blast of emitted sound. Significantly these muscles are enormously large in bats, considering the small size of the animals. One, the *tensor tympani,* is about the same actual size in a bat as in a cat, which weighs more than 100 times as much. Perhaps these highly developed muscles serve as the protective devices I have suggested; perhaps they do not.

HAVING considered some of the adaptations of structure and function which enable bats to locate objects at a distance, we can return to the statement "bats have radar." Now we can appreciate both its truth and its error. Sound waves are used rather than radio waves; but there are startling similarities between the bat's method and radar, not only in basic principles but even in some of the less obvious details. An even closer



ULTRASONIC pulse of the bat begins at 80,000 cycles and ends at 40,000. The purpose of this frequency modulation is possibly to enable the bat to hear during the last part of the pulse an echo from the first part.

analogy is sonar, the apparatus that locates objects beneath the surface of the ocean by generating sounds which echo from the bottom, from submarines or even from fish. All three devices have much in common. Each employs bursts of energy which are projected outward in order to detect distant objects by means of echoes. In all three systems short wavelengths, *i.e.*, high frequencies, are advantageous because they permit the detection of smaller objects. The principle involved here is the same one that sets a lower limit to the size of objects visible through a microscope by ordinary light, although still smaller objects may be photographed by the shorter waves of ultraviolet radiation. If the object is much shorter than the length of the impinging waves, the waves flow past without appreciable reflection or scattering. The wavelengths employed by the three systems are all roughly the same: 1.5 to 3 centimeters for modern airborne radar systems, 10 centimeters or less for sonar, and about .6 centimeter for the bat's ultrasonic sounds. The bats use the shortest wavelengths of the three, but they are concerned with the smallest obstacles.

Radar and sonar engineers have found it advisable to suppress the sensitivity of the receiving device while the original signal is being emitted; otherwise a receiver sensitive enough to detect the faint echoes would be overloaded and perhaps damaged by the intense emission. As we have seen there is also an effective suppressing mechanism in the bat's ear. A further similarity is that all three systems find it advantageous in many cases to concentrate the emitted energy in two ways. The energy is concentrated in time by employing brief pulses rather than continuous emission, and it is concentrated in direction by focusing it in a beam. Pulsing has the obvious advantage of providing silent periods for listening to echoes, but there is also another merit to pulsed emission. The ease of detection of an echo is determined by the instantaneous intensity, so that a given average power output achieves better results if projected in brief pulses of high intensity rather than in weaker signals of longer duration. Parabolic radar antennae are familiar sights on ships and at our larger airports, and in view of other similarities between bats and radar it was no surprise to find that the bats' ultrasonic pulses are concentrated in the forward direction.

ANOTHER phenomenon related to the bat's system of obstacle detection is the use of sound by totally blind people, who are sometimes extraordinarily skillful in finding their way about. Most persons who have been sightless for several years but are otherwise in good health have this ability to some extent, but even those in whom it is best developed may not realize that their skill is based on hearing. Often they may sincerely believe that they feel objects with their foreheads or faces in time to stop before colliding with them. Yet recent experiments have shown that blind people lose most if not all of this ability when their ears are tightly stopped. They seem to have developed a method of orientation resembling the bat's but employing audible sounds. At an Army hospital for the convalescence and rehabilitation of blinded veterans it was found helpful to supply the men with metal plates on the heels of their shoes; the sharp clicks of the metal against floors or sidewalks helped the men avoid obstacles.

Almost everyone has experienced one kind of auditory orientation, namely the differing sounds of footsteps in different rooms. In a large empty room the footsteps are answered by reverberant echoes, and in the dark one can readily tell a room with hard, bare walls from one containing curtains, rugs or other sound-absorbing materials. The forlorn atmosphere of an empty house results partly from the unusually loud echoes from bare walls and floor. It is important in this connection that most auditory orientation by blind people is at such close range that the echoes overlap in time the sounds a person makes in moving about. Partly because of the short distances to important obstacles and partly because the sounds employed have much longer durations than the bats' ultrasonic clicks, the blind have much the same problem as bats which must detect obstacles only a few inches away. In both cases emitted sound and echo may not be heard separately; rather the echo changes the quality of the original sound. In an empty house we hear not temporally distinct echoes but a difference in the quality of our own voices or footsteps. In a similar fashion the bat probably detects obstacles at close range by hearing an altered quality in the sound of its own ultrasonic clicks.

Had biologists understood a few decades earlier the methods by which bats orient themselves, might not the invention of radar and sonar have come sooner? Or might we not already be in a position to perfect acoustic means for self-guidance by the blind? A prominent zoologist has broadcast the mistaken belief that our studies of bats aided the wartime development of radar; actually, our findings were not published until 1940, when radar was already in military use. Yet, granted that in this case the engineers anticipated the biologists, one may speculate whether this sequence is inevitable.

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BOOKS

On the relation of science and poetry, and why they should now be reconciled

by James R. Newman

SCIENCE AND ENGLISH POETRY, by Douglas Bush. Oxford University Press ($3.50).

THE scholarly works of the U. S. have occasionally been criticized in Britain on the basis that after long and sedulous devotion we have at last succeeded in emulating German scholarship in its most dismal aspects. If the charge is true, it is wholly inapplicable to this book by Douglas Bush. Dr. Bush's account of the effects of science upon English poetry is neither formidable, humorless nor turgid; it is witty, human, urbane, carrying its learning easily and not like a head cold. Studies of the relationship between science and poetry are not rare: I. A. Richards in his well-known *Science and Poetry* provided an interesting and useful psychological critique; Marjorie Hope Nicholson and F. E. L. Priestley have written on the changes in the poetic concept of nature brought about by the discoveries of Newton; other examples could easily be added. This survey, however, seems the most balanced and satisfying of the historical sketches yet to have appeared. One might complain of its undue brevity on certain points, of its failure to explain adequately the effect on poetry of economic circumstance and the Industrial Revolution; of the author's tendency, though he warns of it in advance, to leap like a circus rider from horse to horse. But the subject is as untidy as it is large, and the defects of Bush's treatment are relatively minor blemishes on a first-rate accomplishment.

The apparent conflict between science and poetry which forms the main theme of Bush's book is easily described. It is a conflict that appeared very early in the history of thought, when philosophers, scientific thinkers and poets began to sharpen their debates over man's place in the world. The issue assumed many forms: permanence *v.* flux, reality *v.* appearance, skepticism *v.* faith, transience *v.* immortality, God *v.* man as the measure of all things. It was personified by Plato, who, as Bush says, reconciled some of these opposites in a "comprehensive orthodoxy that was ethical, metaphysical and religious"; and by Democritus, who saw the world composed only of atoms and the void. In these antitheses may be found "the essence of all subsequent conflicts."

The poet has one vision of truth and the scientist another; it would not be correct to say that either vision is complete, or that the two are incompatible. Nor can it be asserted that the poet is always on the side of Plato and the scientist on the side of Democritus; there have been poets as skeptical as Protagoras and scientists as intoxicated by faith as Saint Francis. Yet it is easy to understand that the basis for conflict exists in at least one very important area. Poetry affirms an interest in the "worth and dignity of life and man"; science, on the other hand, claims less concern with these values. In a universe indifferent to life like our own, science makes its way by an analogous indifference. That art is imitation of nature is a more difficult thesis to defend than that science is imitation of nature's most significant attribute, inflexible impartiality. Surely no better method has been devised for gaining the knowledge to extend man's control over nature.

Spenser

It must be recognized, nonetheless, that the method is blind as well as brilliant, and that science, for all the vast benefits it has conferred, often gives power without wisdom. Bush writes: "It is a commonplace that the effect of science has been to dislodge man from his supposedly central position in a divine order, to reduce him to a dubiously relevant—though unique—accident in an infinite universe and an infinite biological process, and, in recent times, to make him also a victim both of the mechanical forces that he has created and of the blind forces within himself that he has not created."

These results have inevitably had tremendous repercussions in poetry. The poet is not only "a man among men, a citizen among citizens," sharing with other men the impact of science on society; his particular creed as an artist, his belief in the uniqueness of man is continually being challenged by the progress of science, or at least so it has appeared to him. The story Bush tells is largely concerned with the poet's periodic revolts, his attempts to survive with his art in a bloodless but bitter struggle for existence.

The poets were slow in responding to the scientific discoveries of the Renaissance. Sir John Davies, for example, could dispose of Copernicus:

Only the earth doth stand for ever still:
Her rocks remove not, nor her mountains meet,
(Although some wits enriched with learning's skill
Say heaven stands firm, and that the earth doth fleet
And swiftly turneth underneath their feet). . . .

Spenser's *The Faerie Queene* (1596) explicitly recognizes science; but in his two *Cantos of Mutability* (1609) one may find the characteristic medieval attitude toward the painful problem of impermanence and change underscored by the advances of astronomy, namely, that "there is no answer to the riddle except in heaven." Shakespeare was indifferent to science as such. Yet by 1600, the time of *Hamlet,* there had been an upsurge of skepticism among those in the forefront of thought, a restlessness and a persistent tendency to question earlier orthodoxies. A good deal of faith in the inherent virtues of man and the divine order of the world remained, but the stage was well set for the profound upheaval of ideas to follow.

John Donne was perhaps the first of the poets to show a knowledge of Copernicus, Kepler and Galileo. He never went so far as to doubt the Christian faith, and he was essentially antiscientific. But he was deeply shaken by the new philosophy which replaced the old orderly world with one which was:

. . . all in pieces, all coherence gone,
All just supply, and all relation.

In the 17th century there were some literary men like Sir Thomas Browne, Henry Vaughan and Thomas Hobbes who were able to reconcile the old and new by marrying science to mystical religion.

The English civil war and the Puritan regime, however, made this more difficult by conditioning men to look with suspicion on anything that "savored of 'enthusiasm' in religion or poetry." A fetish was made of "accuracy of language," and Bishop Samuel Parker desired an Act of Parliament "to abridge preachers the use of fulsom and lushious metaphors." The expulsion of the occult and the mystical from the sciences was, as Bush says, a "salutary clearing out of the intellectual lumber-room," but the rapid growth of science and skepticism also meant that poetry and religion were in danger of suffocation. In the revolt against this threat the most notable leader was John Milton, characterized by Bush as the poetic exponent of Christian humanism. As a young man at Cambridge, Milton had shared Francis Bacon's vision of a new era, and he gave practical science an important place in his curriculum. Nevertheless he clung enough to the older religious orthodoxy to make *Paradise Lost* "the last great presentation of the traditional concept of one divine and natural order." Despite the magnificent eloquence he marshaled in defense of this view, the battle was already lost. It was steadily percolating into the minds of thoughtful men that a "new Nature" had been revealed and that insofar as the faith underlying poetry and religion derived validity from the older orthodox picture of the universe, it was no longer tenable. Nothing, as Dryden admitted in his *Essay of Dramatic Poesy,* "spreads more fast than science, when rightly and generally cultivated."

It was Newton whose discoveries were ultimately to cause poetry more anguish than all other scientific advances, with the possible exception of Darwin's, put together. At first, however, it seemed that the triumph of scientific rationalism would permit poetry to compromise with honor. Samuel Johnson may have provided the saving formula in his definition of poetry as "the art of uniting pleasure with truth by calling imagination to the help of reason." The silently harmonious universe of Newton's *Principia* was itself a masterwork of imagination and reason, and while its discoverer had little use for poetry he stoutly affirmed his faith in God. A century later Laplace had so perfected Newton's cosmic clock that God could be discarded as mere excess baggage. When Napoleon asked why God was not mentioned in the *Mécanique Céleste,* Laplace is said to have answered: "I have no need of that hypothesis." But in the science of the 18th century God was still in his heaven and the gratitude of the poets to Newton for having left him there undisturbed, for having allowed poetry to retain its faith in divine wisdom and authority, the purposefulness of the universe and the high place reserved in it for man was pathetic. Pope expressed the almost universal fervor of admiration in his well-worn epitaph:

Nature and Nature's laws lay hid in Night!
God said, Let Newton be! *and all was Light.*

Poetry's response to 18th-century rationalism took a peculiar form. It was "sentimentalism," an invincibly optimistic "belief in a benevolent and beneficent universe inhabited by benevolent and beneficent man." Despite its opponents, who included such formidable literary men as Bernard Mandeville, Jonathan Swift, Bishop Butler and later Dr. Johnson, sentimentalism characterizes the great bulk of 18th-century poetry. The theme of the best of all possible worlds was expressed repeatedly in Pope's facile couplets:

Donne

All nature is but Art, unknown to thee;
All Chance, Direction, which thou canst not see;
All Discord, Harmony not understood;
All partial Evil, Universal Good:
And, spite of Pride, in erring Reason's spite,
One truth is clear, whatever is, is right.

This optimistic faith is more deeply expressed by the poetry of James Thomson. (Pope was too clever, Bush remarks, to be a philosopher.) Thomson portrayed God as unremitting in His watchfulness and solicitude, not merely one who started the machinery and left it to run by itself: he "fills, surrounds, informs, and agitates the whole." And in the writing of Thomson and others we find the language and the images of poetry touched by science. It was a science which lent itself well to the purpose because it had not yet attained the abstruseness of electromagnetic theory, let alone quantum mechanics. There are references to the rainbow "refracted" from a cloud, to Newton's prism, to the "arch-chemic" sun and its "magnetic beam," to the "optic tube" and even to such practical matters as "mechanic arts and trade." In Edward Young's *Night Thoughts* there are remarkable references to the speed of light and to stars so distant that it is doubtful if their beams,

. . . set out with nature's birth,
Are yet arriv'd at this so foreign world.

The 18th century hailed science as a "sister" of religion and poetry; but this artificial and uneasy sibling relationship was not destined to last. The century's greatest writers of poetry and prose were split into opposed camps; for all the poetic tributes science had not reached the poet's deepest beliefs. Except possibly in the poetry of William Collins and Christopher Smart, the admiration for science had failed to elevate the imaginative power from the level of "description and reflection" to that of "myth-making and symbol." There was nevertheless "a movement away from the abstractions of natural theology and neoclassicism toward the individual, direct and emotional apprehension of mystery and divinity in nature," a movement in which sentimentalism, with the aid of a new revolt, would evolve to the higher form of romanticism.

The romantic poets of the 19th century were altogether dissatisfied with these compromises. The domain of poetry which they had inherited was obviously surrounded and threatened by the still-expanding forces of rationalism. Poetry had degenerated into a prosaic vehicle of "rational statement," incapable of carrying "image, symbol and suggestion." The romantic rebels were the heirs of 18th-century sentimentalism in their concern with the heart of man and the unique essence of human life, but there were also marked differences of view. They were unable to embrace the orthodox Christian faith; they did not believe in the universality of virtue; they could not accept the simple creed of a divine order; they resented the role assigned by Dr. Johnson to imagination as the handmaiden of reason. "The great instrument of moral good is the imagination," said Shelley, "and poetry administers to the effect by acting upon the cause." The romantic poets felt that the evil in the world is real, as is the good; and that poetry not only spurns its responsibility but is doomed to extinction if it compromises with the first and neglects the second. Science and the philosophy of rationalism, if not absolute evils, were to be regarded with the condescension that Newton had shown toward poetry; it might be conceded that like carpentry or bookkeeping they had their uses, but they were as irrelevant as carpentry or bookkeeping to an understanding of the world's "fearful symmetry," to endowing men with happiness or advancing the moral good. The true poet's roots must be in nature; in her could be found a wisdom superior to the wisdom of reason or of formal religion. Only by turning to the primitive and the unspoiled could the poet fulfill his creative duties as teacher, interpreter and prophet.

The poetry of Blake, Coleridge and Wordsworth, much as they differed, had

Milton

the common theme of rebellion against a mechanistic universe. They pushed the common search for "unity and spirituality in a mechanized and disintegrated outer and inner world," a unity which "mere reason" could not provide. Wrote Wordsworth of reason:

. . . that false secondary power
By which we multiply distinctions.

In his *Prelude* Wordsworth did record his interest in science while at Cambridge. He also wrote the famous lines on Newton:

The marble index of a mind for ever
Voyaging through strange seas of
Thought, alone.

But Wordsworth's thought, as became a true romantic, was altogether nonscientific. Even his famous preface to the second edition of *Lyrical Ballads* implied only the hope that some day science would put on "a form of flesh and blood" and with the aid of the "divine spirit" of the poet would be humanized and become "a dear and genuine inmate of the household of man."

The poets' sense of alienation from a society brutalized by the Industrial Revolution, a theme expressed in one of Wordsworth's sonnets and recurring most strongly in modern poetry, is less emphasized in the writings of the second generation of romantic poets. Byron, though "incapable of consecutive or consistent thought," was not indifferent to the claims of science, especially astronomy and geology. Keats, who had had scientific training and made use in his verse of images drawn from astronomy, exhibited a good deal of the romantic's prejudice against science without approaching the philosophical depth of Coleridge or Wordsworth. With Lamb he lamented that Newton had destroyed the poetry of the rainbow, and in *Lamia* there are lines referring to "cold philosophy," philosophy which "will clip an Angel's wings." The most important of the trio, Shelley, whom Alfred North Whitehead called "a Newton among poets" had an "ardent, if amateurish interest in science from the tender age at which, according to tradition, he set fire to the butler . . ." *Queen Mab,* and, to a greater extent, *Prometheus Unbound* have their share of scientific imagery and even scientific meaning. Throughout this poetry there is too strong a faith in the essential goodness of "natural man" to permit of the view that science and mechanization had destroyed him beyond redemption.

Bush concludes his book with a penetrating history of the conflict in the remainder of the 19th and the 20th centuries. By this time what remained of romantic optimism appeared to have passed to the scientists, leaving poets to the "contemplation of a great void." It is not easy to summarize the complex creed enunciated in the voluminous writings of Tennyson, who knew more about science and its implications than any other poet of the century and in whose *In Memoriam* many of the leading Victorian advances in science (Lyell's theories of geology, as an example) were brought to expression. While Tennyson saw a world as bleak as Hardy's, he respected the vision of the scientist without renouncing that of the poet. Matthew Arnold and Arthur Clough found it more difficult to resolve the predicament of their religious doubts so optimistically. There weighed upon them, as upon Thomas Hardy, further doubts engendered by Darwin's theory of evolution and rationalistic criticism of traditional religion. A Stoic morality "nourished by humane letters and poetry and a rational religion, with the intellectual sanctions of science" afforded Arnold the solace he had sought through years of despair; while Clough held "work and duty and loyalty to a stern ideal of truth" as the only moral counterweight to man's sense of desolation in the mechanistic universe described in the lines:

And as of old from Sinai's top
God said that God is One,
By Science strict so speaks He now
To tell us, There is None!
Earth goes by chemic forces; Heaven's
A Mécanique Céleste!
And heart and mind of human kind
A watch-work as the rest!

No thoughtful person can fail to admire late Victorian rationalism, based on rigorous faith in scientific law and reflecting the greatest gains yet made in the temper and self-discipline of human thinking. Bush reminds us, however, that Victorian rationalism could be no less dogmatic and much more arid than Fundamentalism, denying values cherished not only by the poet but essential to the maintenance of self-esteem by every man. Nor was it realized at the time that science itself was on the threshold of an internal revolution, in which many of the certainties and dogmas that had wrecked the doctrines of traditional Christianity, reduced the poet to despair and stripped his work of much of its persuasion and authority, were themselves overturned. The upheaval in 20th-century scientific thought cannot of course be considered to have diminished the validity of science. The scientific method remains unchallenged as the best means for man to gain the end he desires, though there may be bitter disagreement as to what this end ought to be. Nevertheless the partial breakdown of some of the most firmly established scientific notions—of continuity and of

Pope

cause and effect—has contributed its share to the modern poet's feeling of bewilderment. The modern poet's sense of skepticism and futility has been aggravated by the discovery of paradoxes and inconsistencies within science as well as by the new demonstrations of scientific power and the apparent inability of men to control what they have created. In these circumstances the poet has again rebelled, feeling himself more than ever estranged from society and unable to find a basis for belief. Yet it is a rebellion without direction or hope. For the modern poet the world is not only a place he never made but a place where there is little room for him. The man among men, the citizen among citizens has been transformed into "a detached, isolated, hostile observer of society." Imitating a world he does not understand, he often writes verse the world does not understand; verse whose texture, like that of the "new Nature," is deliberately discontinuous, random, full of private symbols and obscure associations; verse written only for other poets or perhaps only for the poet himself. Where an attempt is made to communicate more widely, the purpose may be only to express "complete loathing of the human race" (Aldous Huxley, for example, picturing man as "A poor degenerate from the ape") or it may be an indictment of science for having "deprived modern man of his spiritual heritage." There is to be sure a fashionable cult of despair and a great deal of sentimental self-pity; there is also what Bush calls "authentic pessimism."

I left Dr. Bush's study with the feeling that the issue between science and poetry, a branch of the ancient warfare between science and theology, is no longer sharply drawn. The time may be propitious for a mutual revision of this old antagonism. For it is clearer today than it has ever been that, as Bertrand Russell has said, "To be rational or scientific is only one among virtues; no sane man would pretend that it is the whole of virtue." Poetry is concerned with values and ends that are not diminished because they lie outside the domain of science. The poem that expresses man's regard for tolerance or kindness is no less valid in content, no less "truthful" than the Pythagorean theorem or Boyle's law. We may agree that poetry which refuses to acknowledge the "new Nature" and to reject the magical interpretation of nature deserves no serious consideration from thoughtful men. This is not to say that Avogadro's hypothesis is a good subject for a sonnet, or that poetry should specialize in expounding those aspects of experience that can be expressed quantitatively and verified by the methods of science.

It can be shown, I think, that there are several bonds between science and poetry that have been insufficiently stressed by Bush. Science is not concerned with the value and dignity of man and cannot prove that sincerity or self-respect or tolerance are good; it can, however, show how these things are to be defended, encouraged, obtained—if they are desired. Having decided, say, that honesty is a desirable end, it is possible to prove by scientific means that in a society which is well fed, well clothed and well housed there is less crime and dishonesty than in an impoverished society. Moreover, it is important to recognize the extent to which science, no less than poetry, implies certain underlying affirmations of faith: a faith differing from that of poetry in some respects, but identical with it in others. This can be illustrated by two examples. First, mathematical philosophers agree that at bottom every mathematical system is a matter of taste. The choice of its primitive propositions is an act closer to esthetics than to logic. Second, the creative scientist, as Henri Poincaré, among others, has reminded us, is much more than a chronicler of the outside world. His work, to be fruitful, must be nourished by intuition, and instinctively relevant to men's needs and aspirations. These are attributes of true poetry. The creative intellect, in other words, is constructed of essentially the same traits and ingredients for all activities. The "dehumanizing forces" that threaten man will yield neither to science nor poetry alone; they are more likely to yield, if at all, to the joint assault of the wisdom and strength embodied in both. It is an honorable partnership in which both may join without impoverishing either.

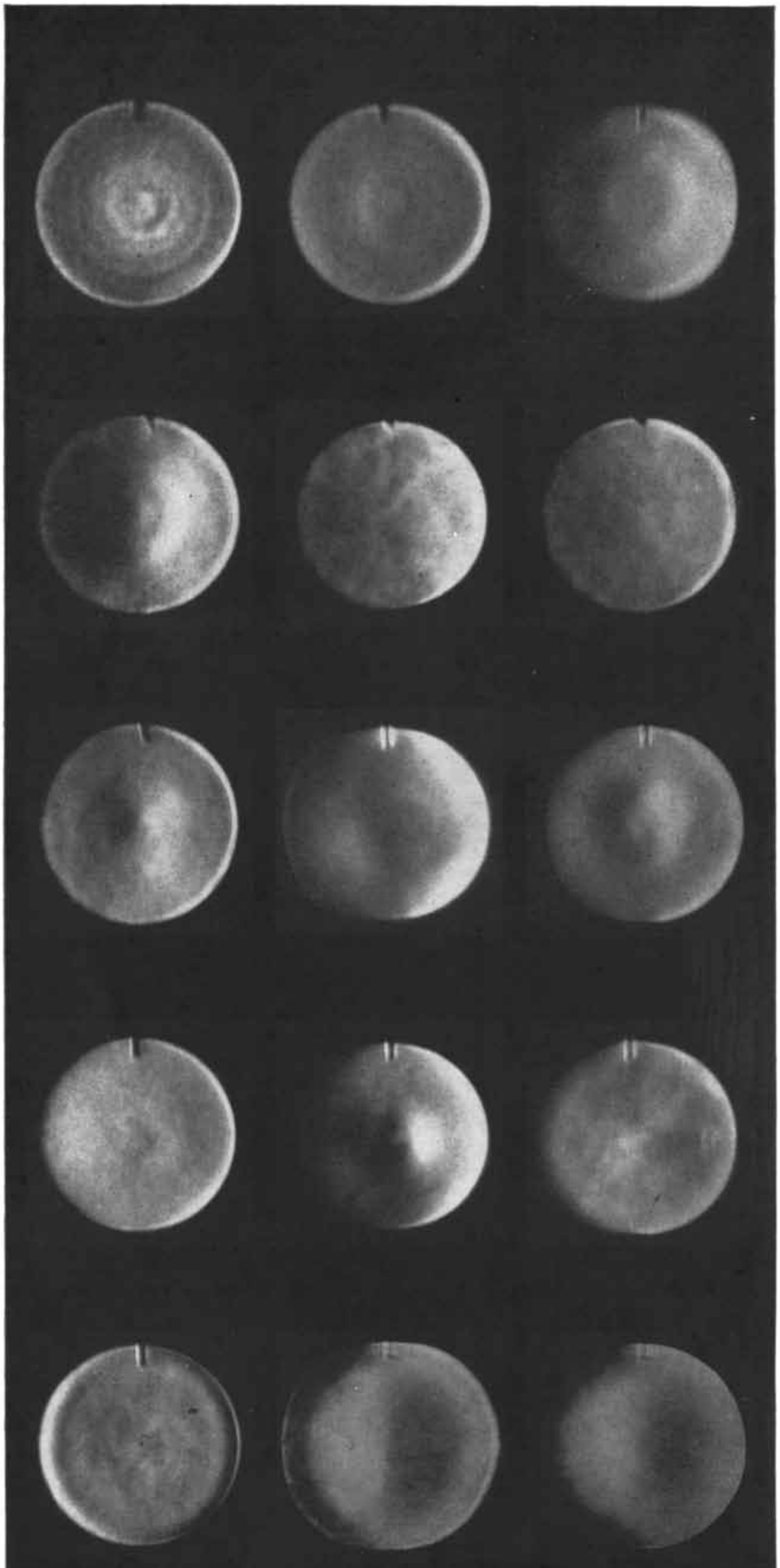
Thomson

SOME EARLY TOOLS OF AMERICAN SCIENCE, by I. Bernard Cohen. Harvard University Press ($4.75). Dr. Cohen offers an agreeable and scholarly account of the beginnings at Harvard of each of the major branches of science. He includes biographical sketches of a number of the earlier Cambridge savants—a pretty undistinguished lot, on the whole, for all the author's valiant attempts to make it appear otherwise—and a most interesting collection of plates illustrating the scientific instruments, mineralogical and biological specimens accumulated at Harvard in the 18th century. Among these were telescopes, microscopes, electrostatic machines, a cometarium and two handsome orreries, a little "thunder house" designed to fall apart when hit by lightning, a dried fish preserved by Professor Peck, a specimen of barite and "a Piece of an Elephant's deffence found at Rome"—the latter two items presented as a token of "fraternal sentiments" by the Committee of Public Safety of the French Republic in the year III.

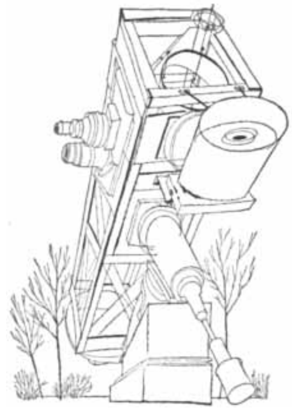
SCIENTIFIC AUTOBIOGRAPHY, by Max Planck. Philosophical Library ($3.75). Autobiographical and other essays by the great German physicist. The brief but revealing personal memoir is no less interesting for its account of Planck's scientific thought than for its frank recital of academic conflicts, scholarly jealousies and other personal details of his long career. One of the best items in the collection, "Phantom Problems in Science," is a lucid discussion of the ancient dichotomy of body and mind. This latter problem is discussed with special reference to the modern theoretical physicist, precariously perched on the top girder of his own edifice, uncertain whether he can safely continue building upward and reluctant to look down below for fear the foundations of the structure may have disappeared.

THE HISTORY OF THE AMERICAN SAILING NAVY, by Howard I. Chapelle. W. W. Norton & Company, Inc. ($12.50). A loving chronicle by a noted naval historian of American sailing men-of-war from the colonial period through the last years of sail, from the "fourth-rate" *Falkland* built for the British Navy at Portsmouth, N. H., in 1690 to the "first-class" corvette *Constellation* built in the Norfolk Navy Yard in 1853-54. Primarily a specialized history of ship design and construction rather than of battles, Navy policies and men, this handsome volume with its plates, elaborate technical appendices, and magnificent collection of ship's plans is the perfect item for your deep-water enthusiast friend—sail, steam, Diesel or armchair.

FINDING THE MISSING LINK, by Robert Broom. Watts and Co., London (6 shillings). One of the world's leading paleontologists gives a brief account of major discoveries in the fascinating search for the link between man and his anthropoid ancestors. Dr. Broom writes about Peking man and the early giants, the famous Taungs skull, his own celebrated finds in the Sterkfontein and Kromdraai quarries and caves, and, with a nice malicious wit, about various academic controversies arising out of these explorations. In his last chapter he explains his finalistic view of evolution: ". . . natural selection certainly eliminates the unfit and establishes the fit but . . . has nothing whatever to do with the creation of the fit"; instead it is guided by a Plan which has had its "ups and downs" but "cannot fail to reach its goal." A highly informative and readable little book.



Focograms that write the biography of a telescope mirror



Conducted by Albert G. Ingalls

THE REASON why an amateur telescope maker is willing to spend many hours polishing a concave mirror, enjoying what must appear to others a tedious task, can now be explained to the non-telescope maker with the aid of the unique series of "focograms" shown at the left. These photographs span the polishing and shaping of a typical mirror from its beginning to its successful completion. They show exactly what a telescope maker sees when he uses the famous Foucault test to ascertain the current shape of his mirror. When explained, they will show that the task is actually a suspenseful adventure.

The Foucault test exaggerates the relief of concave mirrors approximately 100,000 times. Thus irregularities far too small to be otherwise visible or detectable, even by micrometers, stand out so clearly that the worker can decide which areas need more shaping. Focograms are made by placing photographic film where the eye is normally placed in the Foucault test. Since they are not essential, few are made, and then usually only at the end of the work. Thus a record of a common procedure is a most uncommon thing. So far as is known only one amateur telescope maker has ever made focograms throughout all the stages of his first mirror. This amateur is Dr. C. P. Custer, a Stockton, Calif., surgeon, whose focograms are shown on this page.

In the interpretation of all the shapes as they change during polishing, the worker assumes that the mirror is illuminated from the right. The light and dark areas then indicate the shape of the curves. By examining Dr. Custer's focograms and the records he made as he worked, it is possible to follow the trials and tribulations of a mirror maker.

Focogram 1 was made after the mirror, which has a six-inch diameter and a 48-inch focal length, had already been through its preliminary grinding with finer and finer abrasives, had been brought to a spherical curve as nearly as possible by that means, and had been polished for an hour against a pitch lap

THE AMATEUR ASTRONOMER

charged with optician's rouge. In the Foucault test a truly spherical mirror appears shadowless and flat, as in focogram 6. Focogram 1 therefore shows that at the beginning the mirror was not yet spherical. Actually it is everywhere within about 1/50,000 inch of spherical. Its rough, scored appearance is due mainly to the immense magnification of the Foucault test in the one direction of depth.

In focogram 2 most of the circular scorings have been smoothed out. The apparent notch at the top is the hook that holds the mirror in edgewise position in the tests. The narrow cusp of light at the right tells the experienced worker that the mirror has a turned-down edge, a common affliction in which curvature increases rapidly toward the perimeter.

In focogram 3 a raised central area, an "inverted soup plate," has replaced the "saucer" of focogram 2 as a result of the unusually hard pitch used on the lap. Pitch that is too soft usually leads to an excessive deepening of the mirror's central areas, giving a hyperboloidal shape, while pitch that is very hard leads to this oblate spheroidal shape. Long polishing strokes will usually offset the latter, but at first Dr. Custer cautiously experimented only on the slight central depression, hoping to find out how mirror correcting operates. He shaved away a thin layer of the surface of the pitch on the lap opposite the central depression, and found that, after further polishing of the whole mirror, the area rose. It even formed a little peak as shown in focogram 4, giving the mirror the overall appearance of a coolie's hat. Thus he had put into practice for the first time the basic method of correcting a mirror's surface: polishing certain parts more than others. This is accomplished by altering the lap or by changing the pattern of the strokes that push the mirror over the lap in ways that effectively alter it.

THE FACT THAT the Foucault test can measure millionths of an inch, and that precision optics ideally calls for accuracy within two-millionths of an inch, sometimes leads to apprehension concerning the skill needed for such work. However, the glass is removed by such small amounts, each stroke planing off no more than perhaps a hundred-millionth of an inch, that the actual control is not formidable. The difficulties of mirror making are not so much of this tactical kind as they are strategic—the constant planning of the next move in a prolonged campaign. In mirror making as in chess, strategy is happily more interesting than tactics. In mirror correction there are many procedures and an endless variety of strokes. No two mirrors go through the same phases; the sport is infinitely varied.

Dr. Custer next writes, "I now found what my spherical stroke was"—the stroke that would avoid hyperbolas and oblate spheroids and attain the sphere. Each worker and each lap has an individual stroke, discovered by experiment. Written guides teach general principles but cannot impart particulars for each worker. This is why the art appeals to those who enjoy hobbies that cannot be reduced to cut and dried routine. Dr. Custer found that his hard pitch called for very long strokes; it later proved that six-and-one-half-inch strokes would approximately hold a sphere.

These very long strokes reduced the big bulge of focogram 4 to the near sphere of focogram 5; in focogram 6 it became a true sphere, or would have appeared so (except for the turned-down edge) in the visual Foucault test. Focograms tend to exaggerate all evil appearances, perhaps because the film stores light. At this point the sphere could have been converted to the desired paraboloid by deepening the surface toward the center. Unfortunately at this early stage in polishing many pits still remain from grinding. When these pits have been removed by polishing the entire surface to a level below their bottoms, the spherical shape will almost surely have been replaced by some other, since no shape can be held long. The curves drift constantly. The attempts to perfect the shape of the mirror before removing the pits are made to gain practice, learn stratagems, and simply because it is fun.

"Focogram 7 was made," Dr. Custer writes, "after alternating between a sphere and an oblate spheroid. At this point I sent the mirror to the Tinsley Laboratories for an interim check-up." It was returned with the report: excellently spherical except for a turned-down edge and a small central hill.

"When I received the mirror back," Dr. Custer continues, "I poured hot pitch on its back to reattach the handle. Lo and behold! I had a deep hyperbola that persisted indefinitely until I knocked the handle off. Instantly the mirror returned to its original shape. Next time, in attaching the handle, I heated the mirror also and cold-pressed it on the lap overnight. The true figure returned. These procedures occupied a week during which I did quite a little thinking."

WHETHER THE WORKER is a novice or an old hand, he almost inevitably finds himself in perplexing situations that sometimes drive him to wit's end. He may carry these problems

Dr. C. P. Custer's $12\frac{1}{2}$-inch Springfield telescope

around with him for days. An average mirror is good for about five such scrapes. Should the mirror maker happen somehow to proceed to an uneventful finish he should regard himself as unluckily slighted, for he has not yet really lived. While dwelling profoundly on a problem such as Dr. Custer's, one worker was hit by a truck and his arm was broken. Ultimately a solution (or a truck) arrives, sometimes by "trying anything once" but more often by analytic thought.

"In focogram 8, made only three minutes after the mirror was off the lap, I finally had an optical surface," Dr. Custer rejoices. By this he means a surface smooth in texture, unlike the "dog-biscuit" surface in focogram 5 caused by too rapid strokes which heat the glass and expand it unevenly. Nearly an hour later, after some of the heat of friction created even by deliberate strokes had been dissipated, focogram 9 was made. The central area had risen. Change of shape during cooling is an additional phenomenon to complicate mirror making, though the worker learns to predict its amount to some extent. In the later, more crucial stages of his work he prefers to let the mirror cool a full hour before testing, or even work an hour or less at a time and leave the mirror overnight to cool fully.

Focogram 10, made one hour after removing the mirror from the lap, and focogram 11, made two hours after removal, show well the effects of expansion due to the frictional heat even of slow strokes made perhaps once every three seconds. "See how the spherical figure rose during the second hour," Dr. Custer exclaims. The rise, which resembles a goose egg on a bumped head, may have totaled several millionths of an inch. "This convinced me that most of the disturbance of figure was coming from flexure of the glass due to the handle cemented to it with pitch. So I knocked the handle off and have been polishing without a handle ever since, and the figure now becomes permanent after 45 minutes of cooling. No more handles for me! The base of the handle was only four inches in width and the pitch protruded a quarter of an inch beyond its edge." This handle was much too large.

"From here on I got into plenty of trouble from other sources," Dr. Custer remarks. "In hope of attaining a sphere, I tried to eliminate the central hill of focogram 11 by overhung strokes an inch from the edge of the mirror. All of a sudden the hill disappeared and an astonishing depression appeared in its place." Old hands at mirror making, recalling their own similar mistakes, both past and present, will enjoy all these candid confessions. The stroke chosen threw multiplied pressure on one small central area, and excavated rapidly to and below the sphere. It is perhaps best to have made as many of the standard mistakes as possible; this confers the feeling of "belonging."

"I then decided to widen this depression into a paraboloid," says Dr. Custer, "but the deeper hyperboloid developed instead. So with reduced (six-inch) strokes I let the oblate spheroid come back, eliminated this with ¾-inch of side overhang, and took focogram 12, showing I had a sphere." The faint pucker at the right is a dab of dried rouge water.

"Further maneuvers, too varied to describe here, produced the surface shown in focogram 13, a sphere with an outside zone that has fooled all who have seen it. This apparently raised outer zone is actually a depressed zone with a high outer rim. Further maneuvers smoothed the mirror, and 25 strokes were then given to reach the paraboloid. Here I was amazed," Dr. Custer laments, "to find that the mirror had gone 50 per cent deeper than the paraboloid."

Three weary hours of two-thirds strokes repaired the damage. Two rounds of elliptical strokes with lap on top of mirror left the zone barely perceptible, showing that it had consisted mainly of turned-up edge, but also left scratches. Alas, a third round changed the turned-up edge to a turned-down edge. "This disturbed me no end," Dr. Custer sighs. "So I rushed in where angels fear to tread and ground off a zone $3/32$-inch wide with Carborundum." The result is shown in focogram 14. It proved later that only half the width of the turned-down zone had been ground off.

At this point the mirror was again tested by the Tinsley Laboratories, who pronounced the surface a paraboloid with 72 per cent correction and suggested masking off the remaining part of the turned-down zone with a diaphragm. Focogram 15 was therefore made with a diaphragm, and reveals a 5⅝-inch paraboloidal mirror of excellent quality.

WITHOUT waiting to mount his six-inch mirror Dr. Custer tackled a 12½-inch, ground and polished it in 130 days (150 total hours) and mounted it as shown on the opposite page. He buried a pipe 10 feet long, with walls ⅜-inch thick, in five cubic yards of concrete, and filled the pipe with concrete. On this Rock of Gibraltar he placed a Porter-revised Springfield mounting, machined in Stockton by the Carando Machine Shop from castings made by E. S. Ensign of Toledo, Ohio. On the mounting he placed a 10-foot cork-lined tube 15 inches in diameter with a 45-pound counterweight and 150 pounds of lead within its sleeve. Despite this great load he declares that the telescope is "as steady as a rock."

Since the Custer telescope has twice the diameter and twice the length of the Porter design, it has approximately eight times the latter's weight—350 pounds. Theoretically, therefore, its mounting is eight times overloaded. Yet it has proved satisfactory. Several factors account for this. First, there are ball bearings on both axes. On the declination axis there are 205 balls in a race at the edge eight inches in diameter. "Without these," says Dr. Custer, "the tube would be hardly movable by hand, let alone by the vernier adjustment screw. With them, I can move the tube with my little finger." Second, the pier, pedestal, mounting itself, tube and counterweight are all rock-solid. The parts are well designed and accurately assembled without looseness. Third, partly because of this careful assembly the axes remain effectively a full eight inches in diameter. Their connecting casting is rigid. For a less painstaking builder, loading this mounting with a 350-pound telescope would be to push luck to the limit or past it. Dr. Custer's correspondence and his photographs show that he was meticulous with every detail of it.

"I could hang my full weight on the counterweight arm and not bend it a millimeter," Dr. Custer answers to a pointed question. "Its cone is fastened by multiple screws to a curved sheet of boiler iron that covers the entire end of the inside of the tube and is welded to it. Thus the cone is not merely screwed to the thin tube."

The observing chair may be quickly moved up or down the pedestal and reattached at any of the holes in angle irons welded to the pier. Its own seat and back are also adjustable for height and distance from the tube.

The mirror cell has a three-point support and is housed within an outer "basket" having screen-covered ventilating openings, two hasps and two padlocks. Without removing the basket the mirror may be covered when not in use with a cap inserted through a slot in its side and manipulated through one of five large ventilating holes along the tube. The tube is swung to the pier and a flashlight bulb beneath the mirror is plugged into the wiring for the lights that illuminate the setting circles. This prevents dewing. Snap switches for these lights and for the drive motor are placed within quick reach on the south side of the gearbox base for the mounting.

"With this telescope last night," says Dr. Custer, "I showed 17 objects to a group of friends in an hour. It took about one minute to change from one of these objects to the next."

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