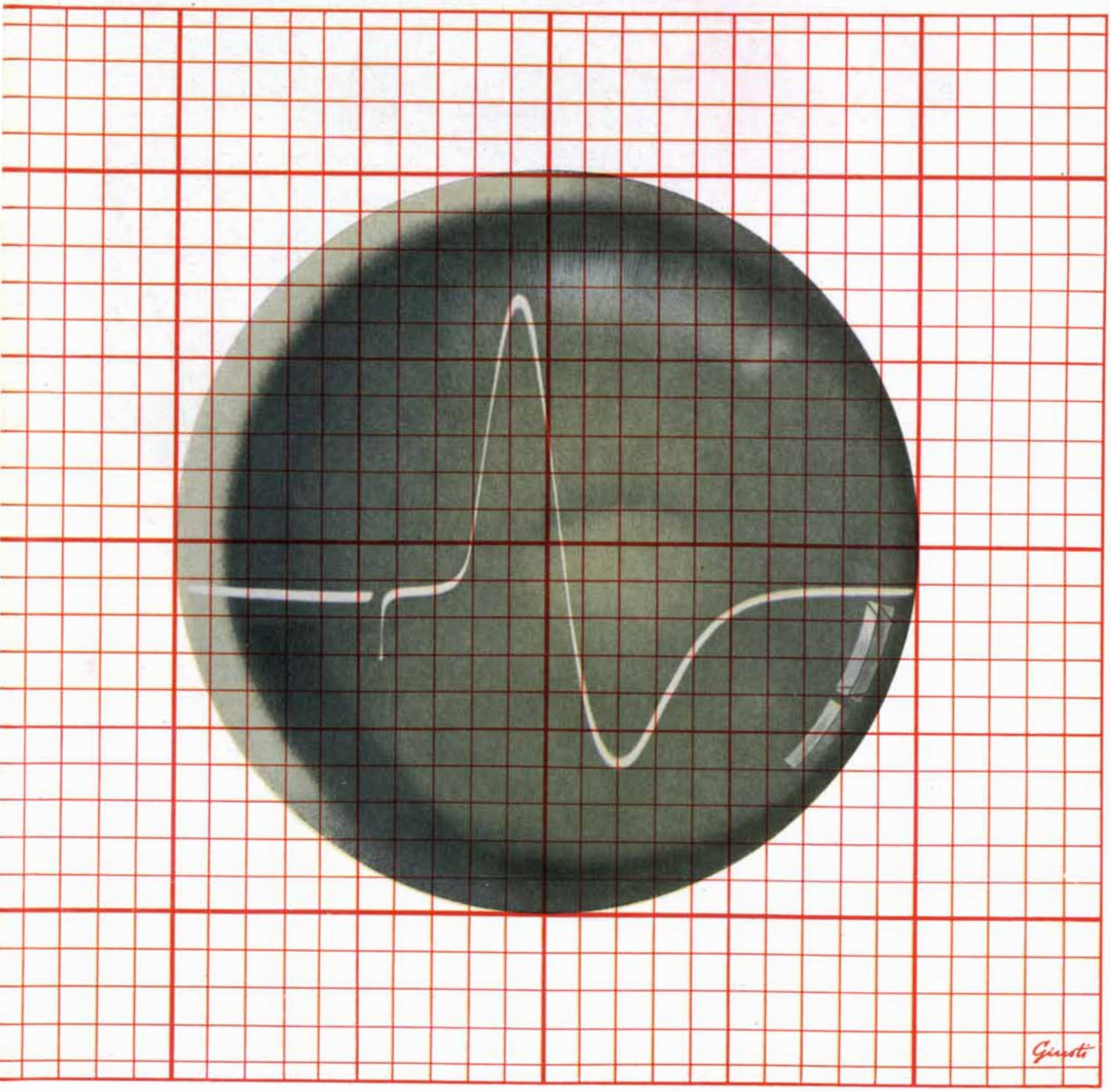
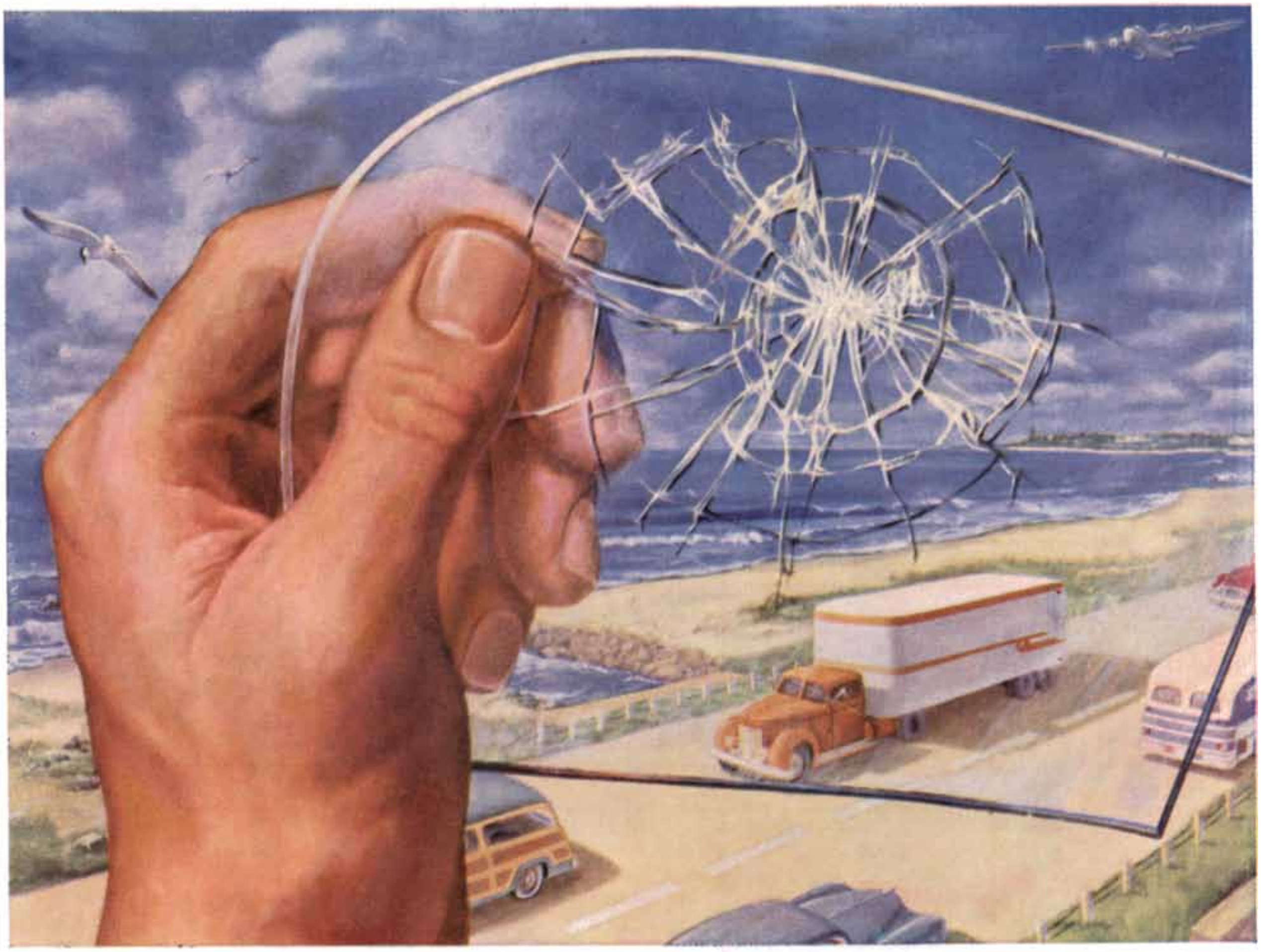
SCIENTIFIC AMERICAN



NERVE IMPULSE

FIFTY CENTS

November 1952



Clipping the wings of flying glass

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Birds flying in the airways . . . pounding waves at sea . . . emergencies on the highway or railroad—these are among the many things that can cause broken windshields and windows while you are traveling.

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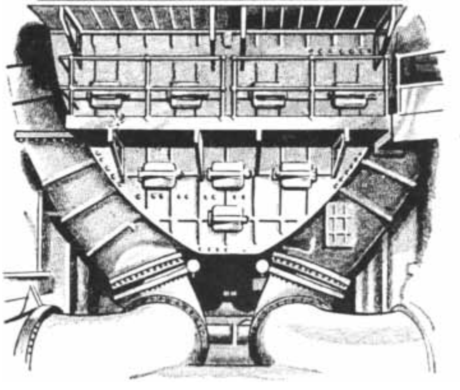
BUSINESS IN MOTION

To our Colleagues in American Business . . .

Everyone who has to deal with water and steam is concerned with the reduction of corrosion. Power plants, for example, spend large sums annually to treat boiler feed water, and condenser operation is watched carefully. Because of this, the Revere Research Department over a long period of years has studied intensively the causes of corrosion, and how corrosion can be reduced, as it usually can.

Recently the Revere Research Department was asked to investigate the failure of Admiralty metal tubes after some five years of use in a condenser. The user felt such tubes should last longer under average conditions. Samples from failed tubes were sent to the laboratory, and subjected to physical, metallurgical, chemical and microscopic tests. It was found that the outer surfaces were pitted, thinned, grooved and cracked. In some places corrosion had completely destroyed the tube wall. Inside, there was but little pitting of the underlying metal. Thus, it was evident that the destructive process took place on the outside, or steam side of the tube.



The chemical analysis of the outside scale was evidence that the excessive corrosion was due to carbon dioxide and other non-condensable gases carried along with the steam. It is not unusual to have these and other corrodents present in damaging amounts in the air-ejector system, whereas they are not injurious elsewhere.

Photomicrographs were then taken of sections through the cracks. It was found that the cracks originated in corrosion pits on the outside of the tube, and progressed inward. In doing so they broke across the grains of the metal rather than following the grain boundaries. This transgranular pattern showed that the pits created stress-concentration points of weakness. Other characteristics of the microstructure confirmed that failure was due to a combination of corrosion and fatigue. The conclusion was, of course, that not only were there corrodents in the steam, but that in addition the tubes were subject to vibration.

Given these facts, the remedies were not difficult. The copper-base tube alloy that generally possesses the greatest resistance to the non-condensable gases responsible for such corrosion is 5% aluminum bronze. This is somewhat more expensive per pound than Admiralty metal, but in this case when balanced against the expected extension of life, the ultimate cost became favorable. It was also recommended that steps be taken to reduce tube vibration materially by installing a baffle in the steam inlet. Finally, it was pointed out that many operators find it good practice to discharge the after-condenser drain to the sewer, instead of returning it to the system, thus substantially reducing the amount of carbon dioxide, ammonia and other corrodents in the system.

This report provides a typical example of the thoroughness with which the Revere Research Department attacks the problems that are brought to it. If you have questions concerning the selection, fabrication, or service of Revere Metals, get in touch with the nearest Revere Sales Office, through which the experience of our Technical Advisors, and if necessary, of Research, can be made available to you. And do not forget that other suppliers to industries of all kinds also operate laboratories upon whose knowledge you can call. It will pay you to do so.

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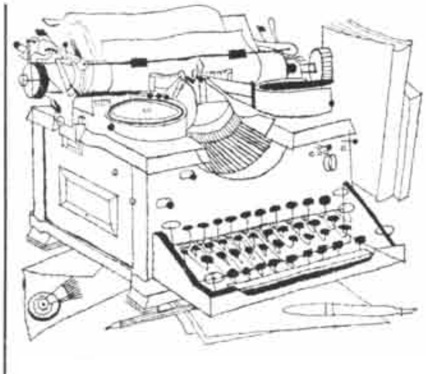

LETTERS

Sirs:

Congratulations on your September issue devoted to automatic control. The process of scientific research itself is analyzable in terms of feedback loops. Perhaps feedback engineering will feed back a stimulus to other research? This seems especially likely once we are aware of the topological "structure" inherent in the development of science.

Ernest Grunwald and I have injected this idea into our chapter on the strategy of elucidating reaction mechanisms, to appear in the forthcoming Volume III of *Technique of Organic Chemistry*. We find several distinct stages in the complete evolution of a reaction mechanism: study of the reagents and products, kinetic analysis and study of the transition state. The stages are not distinct in time, however, because the later ones stimulate further experiments belonging to the earlier stages, which in turn lead to further development of the later stages. This is undoubtedly a feedback network, a feature that decreases the predictability of the final state, but increases the fun in getting there. As yet there does not appear to be even *one* such network in which all circulation has ceased.

JOHN E. LEFFLER

Department of Chemistry
The Florida State University
Tallahassee, Fla.

Sirs:

As one actively interested in automatic control, I am deriving pleasure and benefit from your September issue. It is a pity that I have to disagree with some of your definitions, admittedly the most difficult and controversial part of all science.

I will not be finical enough to find fault with the *feedback* definition, although information or energy may be returned to the input of the same stage as well as to an earlier stage.

But how about *hunting*? If it really is a characteristic of all feedback systems, why attempt to eliminate it? That sounds like the logician's paradox: "All philosophic statements are lies, including this one. True or false?" Call hunting a tendency of all feedback systems and we'll let it go at that.

Now to *information*. We consider information a reduction of freedom of choice, hence it corresponds to negative entropy.

Finally *noise*. This term stems from acoustical engineering, prior to radio. It means a disturbing or interfering sound (or energy, signal or message in the derived sense). The most important type of noise is of a random character, like hissing steam.

I hope these minor adjustments will help some of your fans who may be bewildered enough by the novelty of automatic control, even without logical pitfalls.

WALTER J. ALBERSHEIM

Bell Telephone Laboratories
Deal, N. J.

Sirs:

I compliment you on the general excellence of *Scientific American* during the past few years but hope that you will not publish numbers, like that for September, so fatly concentrating upon a tedious technology.

The diversity of subjects within each issue has been enjoyable, and each article has usually been broad. I hope that you will continue your refreshing and stimulating diversity of good articles.

This country has enough fat, technical engineering journals bulging with manufacturers' advertisements and technical

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articles written in appropriate jargons. Please don't permit *Scientific American* to become one of these, or the world will be the poorer.

The troubles with your September number were that the articles were all in one field; the treatments technical rather than scientific; the articles redundant; the level of complexity high enough to bore a general reader (my wife, for instance, who reads all other issues avidly) yet not advanced enough for even a half-specialist (me, for instance, in charge of the world's biggest collection of large digital machines: ENIAC, EDVAC, ORDVAC, Bell Relay Calculator). Frankly, I found little in many of the articles that was new to me.

You write editorially on page 43, "Automatic control will further liberate man from the routine tasks of mere survival. It can only give him more time for the creative enjoyment of life and for the exploration of the universe." Excellent—the creative enjoyment of life and the exploration of the universe! Please permit your magazine to help its readers to enjoy life by assisting them in exploring the universe. Please don't let your magazine degenerate into merely one more journal in which to find expositions of tedious technologies. Please!

THEODORE E. STERNE

Bel Air, Md.

Sirs:

I am perturbed by the bland assumption of your authors that the human organism is going to be able to assimilate the complexities of life under automatic control. I think a review of the record will show that as man employs more and more automatic control his own homeostasis becomes more and more disorganized. In other words, as we strive to attain perfection to the point of eliminating "noise," our humoral machines seem to absorb this noise.

There is no question that there is an absolute increase in the diseases that may be blamed on stress. If we progress logarithmically in becoming automatized, we may expect to have the incidence of hypertension, angina, peptic ulcer, colitis, etc., to increase likewise. How are we going to prevent it? The answer is to apply the methods of automatic control to our own physiology as it progressively breaks down.

Let us make a device that will measure blood pressure continuously and strap it to the patient's arm. Let it incorporate a transmitting unit so that impulses can be received and recorded at a central location. Let us also make a device for recording skin temperature, respiration, gastric acidity, electrocardiogram and electroencephalogram.

As we select our crew and have a well-integrated plant in operation we will

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sooner or later see evidence of human breakdown. If the labor market is limited we may decide to set feedback mechanisms into operation. Blood-pressure-lowering or -raising drugs, sedatives, stimulants, cardiac tonics, cardiac depressants, cerebral stimulants and sedatives, diuretics, laxatives, etc., can be injected automatically through jet hypodermics with little sensation as they are needed.

It would be important to have all of the controls on our men completely automatic. (Watch Jones' electroencephalograph; he just left here to talk to Smith. See those wide fluctuations. When the time-amplitude integrals reach a certain value his prefrontal lobes will be depressed and his overt mental activity reduced for as long as necessary.) It would not do to have a physician or plant manager at the controls. (Jones is the slowest vice-president I have. Zip! There, that's better.)

As men develop their environment to the point of needing automatic control they will be in the category of refineries. They won't work without it. As their dependency increases the natural functions involved will increase until we find pulsing devices for respiration, heartbeat and motor activity. It will eventually mean that men will have to ride in little scooters, and be properly plugged back in, every time they leave them. (We lost Jones yesterday; he plugged urination into respiration.)

I can foresee buttons for "general plant morale," "automatic polling" by recording skin temperatures when Eisenhower is mentioned over the loudspeaker, "sensual depression," *ad infinitum.* (I think Miss Brown will have to be moved to a female division, she produces too much noise in the men in Division A.)

Seriously, I want to ask the editors where the stopping point is. If we can't make gasoline without automatic control, how long will it be before we can't make food? I think we will finally realize that in copying our physiology we will find that cost and efficiency are not the determinants for automatic control, and that there are many physiologic functions that are not automatically controlled simply because the organism doesn't absolutely need it that way.

PAUL REASER, M. D.

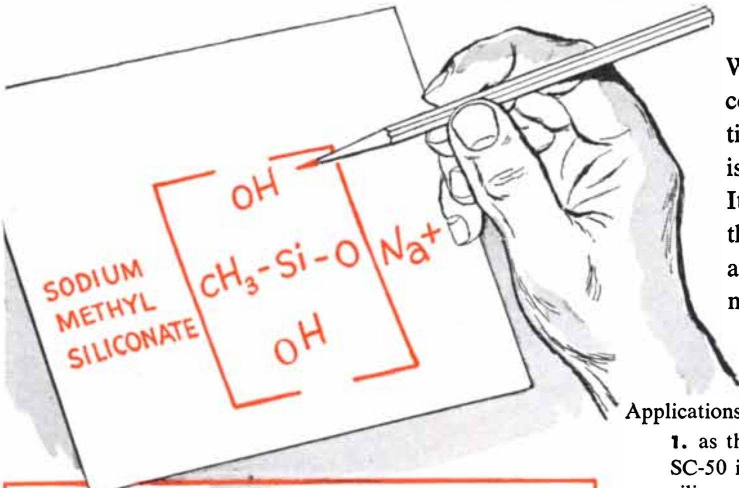
Longview, Texas

Sirs:

Your issue on automatic control is a vivid portrayal of a materialistic culture in which bright young men study engineering instead of philosophy. Only two authors (the first and last) weigh the tremendous problems that will follow the advances described by the other six. Each of these two speaks with the circumspection of one who elects to

WANTED!

Applications for General Electric's
NEW WATER SOLUBLE SILICONE, SC-50



Where can *you* use a new General Electric silicone with these unusual and original properties? SC-50, a reactive chemical intermediate, is a water solution of sodium methyl siliconate. It offers new possibilities for manufacturers in the field of silicone water repellents. It may be applied from water solution; it is nonflammable; and it may be cured without heat.

POSSIBLE USES

Applications for SC-50 might include its use—

1. as the active agent in masonry water-repellent formulations. SC-50 is more effective on gypsum and limestone than previous silicone water repellents.
2. in integral mixes of cement paint, gypsum, and concrete.
3. as an additive to water-base paints to improve washability.
4. to make water-repellent aerogels.
5. as a water repellent for textile and paper products.

REACTIVITY

In addition to its water-repellent properties, SC-50 has marked possibilities as a chemical intermediate. With salts of other metals such as calcium and lead, it forms relatively insoluble, easily hydrolyzed salts, e.g., calcium methyl siliconate. Quaternary ammonium salts react similarly, giving quaternary ammonium methyl siliconates with a variety of solubility and hydrolytic characteristics. With aluminum salts it forms neutral solutions which are stable at use dilutions and which are effective water repellents. Experimentally, it has been used to make copper methyl siliconate to impart water and mildew resistance to textiles.

COMPOSITION AND PROPERTIES OF SC-50

Total solids	31.2 ±2.8%
Total base (titrated as Na_2O)	9.5 ±0.5%
Total silicone (as $CH_3SiO_{1.5}$)	20.0 ±0.5%
Specific gravity	1.23—1.25
pH	about 13
Color	Gardner 3 max.
Solubility	Miscible in all proportions with water, methanol, ethanol, aqueous formaldehyde. Slightly miscible with n-propanol, i-propanol, acetone, dioxane, higher alcohols, ketones and ethers.
Solvent	Water

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drift with the current rather than inquire too critically as to its direction. Less inhibited philosophers—say Bertrand Russell, Karl Menninger, Julian Huxley, Henry Thoreau and Philip Wylie—have been genuinely worried that so much genius is directed at producing more and better gadgets rather than improving the aims, morals and happiness of man himself, a field commonly left to opportunists and superstition-mongers. Is it not cause for alarm that Nobelists in peace—unlike those in physics or medicine—have often been conspicuous only by their absence? Or that such a basic human urge as pride of achievement (the family piano) is steadily giving ground to pride of ownership (the family television)?

Many psychiatrists blame the machine age for the growing neuroticism in America. City people, though often possessed of greater wealth, feel less secure than country folk; the agrarian worker, assured at least of a continuing roof over his head, faces the natural hazards of health and weather with a confidence the industrial worker cannot muster toward sophisticated economic aggression and an uncontrolled economic cycle. The subsistence homestead, which effectively cushioned the occasional shocks of living, is gone, and no really effective substitute has been devised. Children, no longer a family asset but rather a tremendous liability, tend to become unwanted children, who eventually take their revenge on society in ways well known to psychologists. Is this progress?

The idea that the machine creates more jobs than it destroys—while perhaps true in certain very special cases—is in the broad view ludicrous as it offers the curious spectacle of man working himself to death as he becomes cleverer. It would be encouraging to see less extenuation of the evils of industrialization and more thought poured into the basic problem of how to maintain a healthy exchange economy when large numbers of people, unendowed by nature or training with the ability to build enormously productive machines, are faced with the necessity of "trading" with a very small group of people who are so endowed—that is, how to maintain trade when the greater part of the people have nothing to exchange. Lord Keynes remarked that it seemed "an extraordinary imbecility that a wonderful outburst of productivity should be the prelude of impoverishment and depression." It is similarly shocking to note that so much effort is being poured into devising new machines when it is evident that we are already lagging behind on the problem of learning to live with those we already have.

ROBE B. CARSON

Miami, Fla.

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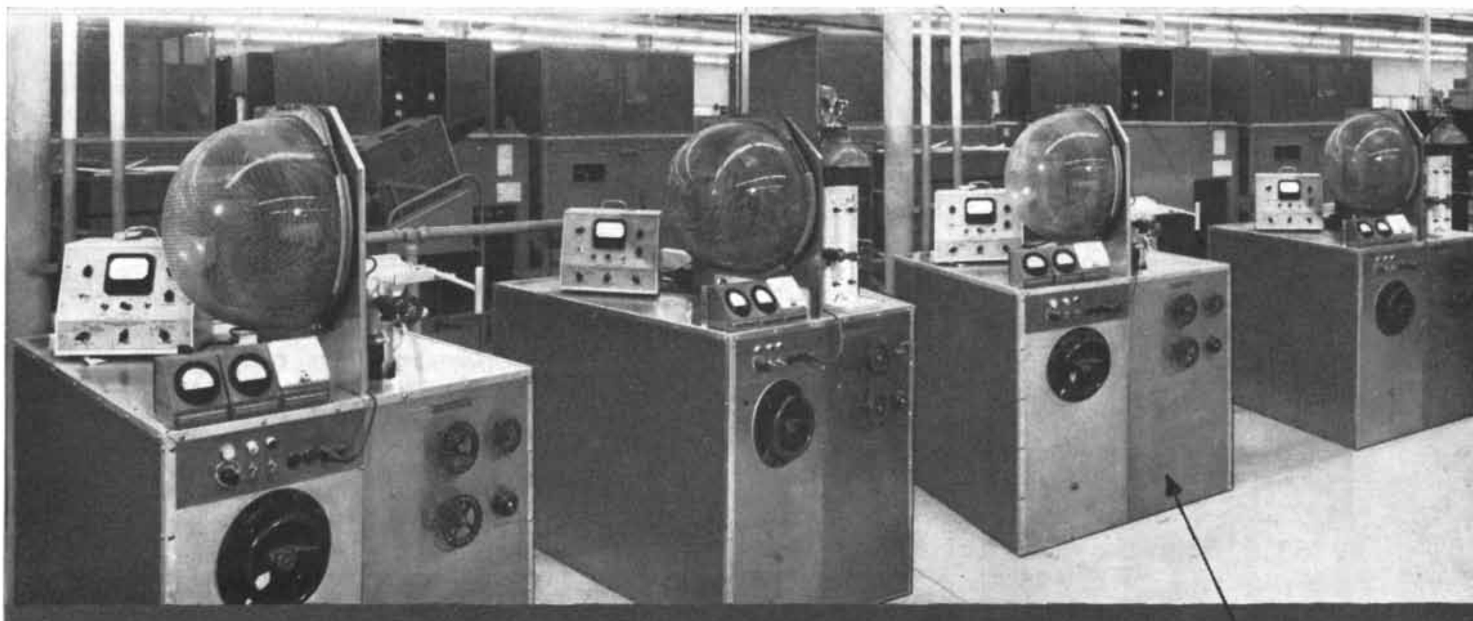

Diffusion Pumps to produce high vacuum at rates up to 50 litres per second from 10^{-8}mm to 10^{-6}mm range against forepressure as high as .300 mm.

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50 AND 100 YEARS AGO

NOVEMBER, 1902: "Word has just been received from Paris that Henri Fournier has once more accomplished the feat of breaking the world's automobile record for the mile and the kilometer. His speed of 75.9 miles per hour is scarcely exceeded by the new Twentieth Century Limited when spurting to make up lost time between New York and Chicago. At the present rate of increase it will be a very short time before the automobile capable of developing a speed of one hundred miles an hour will be an actual fact."

"At the recent opening of the Copenhagen Exhibition a letter was made public from Thomas A. Edison on the future of electric traction. Mr. Edison, asked as to his opinions concerning electric traction and aerial navigation, replied: 'I believe that within thirty years nearly all railways will discard steam locomotives and adopt electric motors, and that the electric automobile will displace the horse almost entirely. In the present state of science, there are no known facts by which one could predict any commercial future for aerial navigation.'"

"The much-talked-of, much-obstructed and long-delayed Anglo-Pacific cable has at last been actually opened for the transmission of messages. Congratulations were exchanged on October 31 between Canada and Australia over the new line."

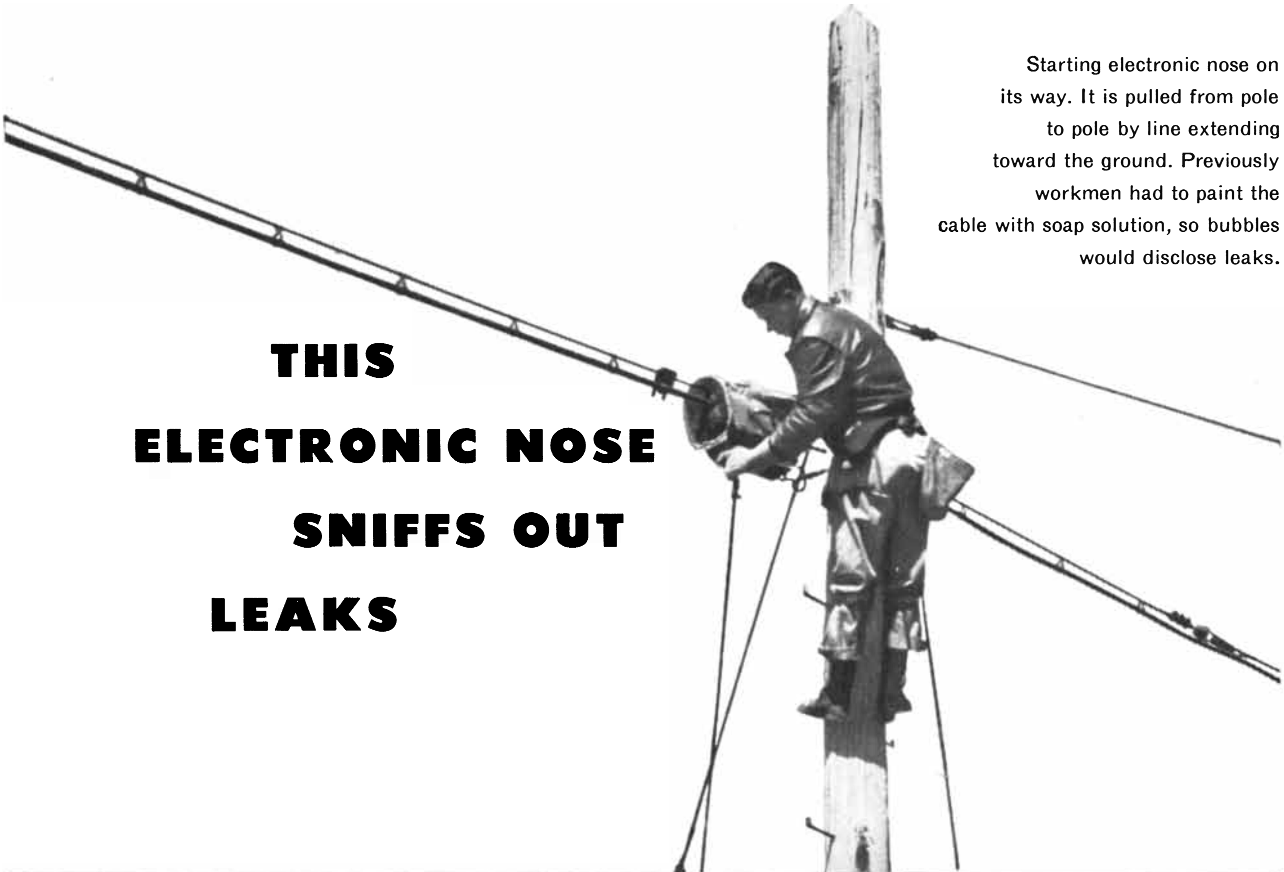
"Mr. Peary has devoted practically the whole of the last twelve years to Arctic work. He announces that he has now retired from Arctic exploration and will hereafter devote his energies to his profession, civil engineering. The results of his long labors in the Far North are most important. He has proved Greenland an island and mapped its northern coastline; he has defined and mapped the islands to the north of Greenland known as the Greenland Archipelago; he has shown that an ice-covered Arctic ocean probably extends from the Greenland Archipelago to the North Pole; he has accurately defined the lands opposite the northwestern coast of Greenland, Grant Land, Grinnell Land, and Ellesmere Land; he has reached the most northerly known land in the world; he has gained the most northerly point yet reached on the Western Hemisphere, 84 degrees 17 minutes; he has studied the Eskimo as only one can who has lived with them for years; he has added much to our knowledge of Arctic fauna and flora; of the musk ox, the Arctic hare, and the deer."

"What is popularly known as the 'flying machine' is literally a machine, without gas to support it, in no way resembling a balloon, and which its inventor has called the aërodrome (signifying 'air runner'). The aërodrome is, then, the name given to this apparatus by Mr. Langley to indicate the principle of its action. A balloon floats because it is lighter than the air; the aërodrome is hundreds of times heavier than the air. The weighty machine owes its support to another principle—that like a skater on thin ice. The balloon in a calm remains indefinitely suspended over one spot. This machine, built almost entirely of steel, is far heavier in relation to the air than a ship of solid lead would be in relation to the water, and could not remain in the air if still. It is not generally known that several of Langley's machines have actually flown considerable distances. The first successful flight was made on May 6, 1896, at a private trial at which Dr. Alexander Graham Bell was the only witness."

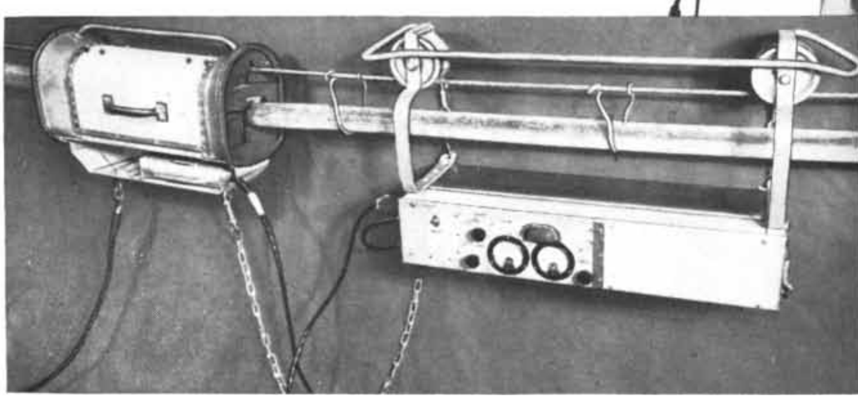
"Professor Charles Frederick Holder, reporting on the abilities of various fish to make vocal sounds, writes: 'One of the most remarkable sound producers I have ever heard is a Haemulon in the Gulf of Mexico. When I took one of these fishes from the water it began to grunt: "Oink-oink-oink"; now with one prolonged "o-i-n-k," then strung along rapidly, as though to intensify its agony; all the while it rolled its large eyes at me in a comical manner. No one in listening to such a remarkable outcry from a fish could refrain from wondering whether it had any significance; in other words, the impression was created that it was barely possible that the sounds were repeated in the water, and that they represented a very primitive attempt at vocal communication among fishes.'"

NOVEMBER, 1852: "Among the articles to be taken on the Japanese Expedition are the following: A locomotive and ten miles of railroad iron; a telegraphic apparatus with wire sufficient to lead from the Emperor's palace to one of the principal towns; an

THIS ELECTRONIC NOSE SNIFFS OUT LEAKS



Starting electronic nose on its way. It is pulled from pole to pole by line extending toward the ground. Previously workmen had to paint the cable with soap solution, so bubbles would disclose leaks.



For test, the cable is cleared of protective nitrogen or air, and filled with Freon gas. Case at left collects escaping gas which operates Freon-sensitive detector underneath. At points where Freon escapes through sheath cracks, the box at right—a combined control unit and power supply—rings a bell. Workmen mark the point of leak for later repair.

After years of buffeting by the wind, even tough telephone cable sometimes shows its age. Here and there the lead sheath may crack from fatigue or wear through at support points. Before moisture can enter to damage vital insulation, leaks must be located and sealed.

To speed detection, Bell Laboratories scientists constructed an electronic nose which *sniffs* out the leaks. Using an electrically operated element developed by the General Electric Company, the device detects leaks of as little as 1/100 cubic foot per day. Sheath inspection can be stepped up to 120 feet per minute.

Thus Bell scientists add findings in other fields to their own original research in ways to make your telephone system serve you better. On the other hand their discoveries are often used by other industries. Sharing of scientific information adds greatly to the over-all scientific and technological strength of America.

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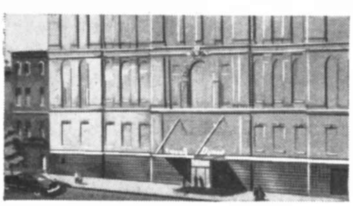
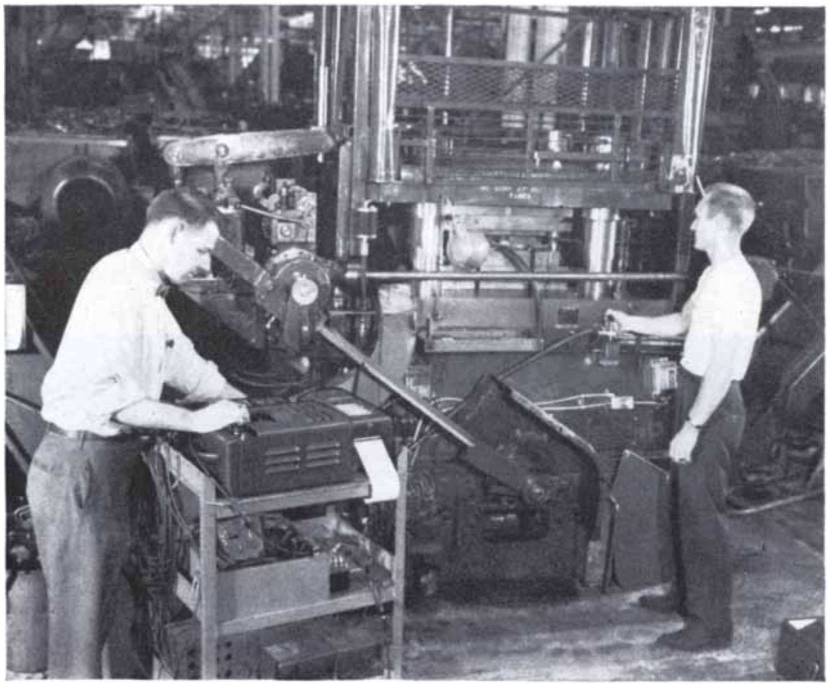
Improving telephone service for America provides careers for creative men in scientific and technical fields apparatus for taking daguerreotypes; a magnificent barge for the Emperor, and some fifty boxes of domestic goods of all kinds and descriptions."

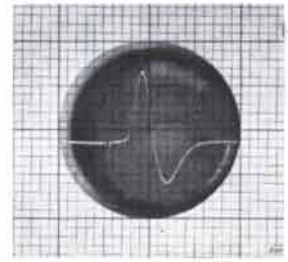
"Dr. Schofield asserts that 1,000 pounds of opium are sold by retail in New York weekly. This amounts to 52,000 pounds per annum, and does not embrace the quantities that may be purchased wholesale by some of those who daily use it. Dr. Schofield states that 'its use is fearfully on the increase in New York and it is constantly receiving recruits from the alcoholic ranks as a cheap means of producing intoxication. Opium inebriation is productive of the greatest evils; it is a fearful species of drunkenness. It drowns care for a while, and is therefore very seductive in its influence, but it bringeth forth tears, disease, and death. It is regretted that its use should be on the increase among us; something should at once be done to meet and arrest the evil.' "

"It has always appeared to us that in many parts of our country the rich beds of iron, coal, and lime, lying so near to one another, afforded advantages for the manufacture of iron of as good a quality, and at as little cost, as it can be made in any country in the world. One of the most important iron makers of Great Britain, while on a visit to this country a few years ago, made it a special part of his business to travel extensively and examine the different ironworks in several states. The conclusion at which he arrived was that we were perfectly blind to our own interests in the mode of conducting the making of iron, and that it could be made as cheap, if not cheaper, in various places in America than in England, if the business was well managed."

"Photography is still but little practiced in America. The difference between it and the daguerreotype consists simply in the former embracing sun-drawn pictures on paper, while the latter relates to sun-drawn pictures on metal plates. Let us explain how photographs are taken: Treated paper is placed in the *camera obscura* like a daguerreotype plate. The time required to take an impression is from one up to thirty minutes, as experience determines, which time depends on the character of the light and the object, the picture of which is to be taken. The best light to work with for obtaining good pictures on the prepared paper is under a clear sky, when the sun is shining, and when the light falls chiefly on the darker shades of the object, or scene, leaving such as are of light color under the influence of diffused light only. It requires practice to judge by the eye how to manage the time in the camera, according to the kind of light, and the object or objects to be represented."







THE COVER

The picture on the cover shows the cathode-ray tube of an oscilloscope, the sensitive electronic instrument that is used to study the tiny electric currents associated with the impulse that travels along a nerve (*see page* 55). On the face of the tube is a luminous line that traces the shape of an "action potential" traveling along the nerve of a frog. To observe this potential the nerve is dissected from the frog and mounted on two pairs of electrodes. One pair of electrodes stimulates the nerve, causing the small break in the left side of the oscilloscope trace. The tall peak in the trace represents the action potential passing the first electrode of the second pair. The valley in the trace represents the reversal of the potential as it passes the second electrode.

THE ILLUSTRATIONS

Cover by George Giusti

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21	Sara Love
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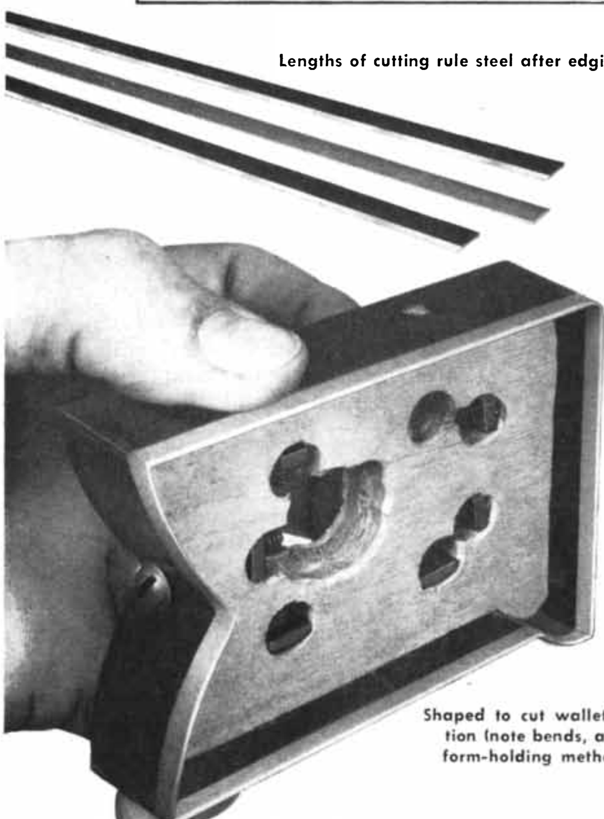
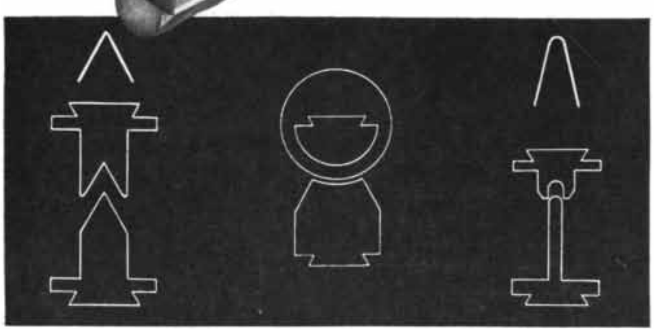
about scoring and cutting rule steel



Lengths of cutting rule steel after edging

Shaped to cut wallet section (note bends, and form-holding method)



Some examples of the many shapes of bends needed

Scoring and cutting rule steel is a cold-rolled specialty steel for use in preparing dies for cutting paper, leather, rubber and other materials.

It is a pre-tempered product manufactured by skilled workmen, using precision rolling and hardening equipment, to close limits for chemistry, grain size and hardness. This product must also be capable of meeting intricate bend requirements in the hardened and tempered condition.

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SCIENTIFIC AMERICAN

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A PSYCHOLOGIST EXAMINES 64 EMINENT SCIENTISTS

The present shortage of qualified scientific workers raises the question of how they are made. Some interesting answers are given by the techniques of modern psychological testing

by Anne Roe

WHAT elements enter into the making of a scientist? Are there special qualities of personality, mind, intelligence, background or upbringing that mark a person for this calling? Besides the natural interest in these questions, they have a practical importance, because the recruitment of qualified young people into science is a growing problem in our society. Where and how shall we find them?

During the past five years I have been making a study of the attributes of a group of scientists and the reasons why they chose this field of work. The most eminent scientists in the U. S. were selected as subjects, since they are most likely to exemplify the special qualities, if any, that are associated with success in research science. They were selected by panels of experts in each field of science. The study finally settled on a group of 64 eminent men who agreed to participate—20 biologists, 22 physicists and 22 social scientists (psychologists and anthropologists). A high percentage of them are members of the National Academy of Sciences or the American Philosophical Society or both, and among them they have received a staggering number of honorary degrees, prizes and other awards.

Each of the 64 individuals was then examined exhaustively by long personal interviews and tests: his life history, family background, professional and recreational interests, intelligence, achievements, personality, ways of thinking—any information that might have a bearing on the subject's choice of his vocation and his success in it. Each was given an intelligence test and was examined by two of the modern techniques for the study of personality: the Rorschach and the Thematic Apperception Test (TAT). The Rorschach, popularly known as the inkblot test, gives information about such things as the way the subject deals with problems, his manner of approach to them, the extent and efficiency of his use of rational controls, his inner preoccupations, his responsiveness to outside stimuli. The TAT gives information about attitudes toward family and society and self, about expectations and needs and desires, and something about the development of these.

My study was financed during the first four years by grants from the National Institute of Mental Health and is being continued this year under a Guggenheim Fellowship. It has developed

	AGE AT TIME OF STUDY		AVERAGE AGE AT TIME OF RECEIVING COLLEGE DEGREES	
FIELD	Average	Range	B. A.	Ph. D., Sc. D., M. D.
Biologists	51.2	38-58	21.8	26.0
Physical scientists	44.7	31-56	20.9	24.6
Social scientists	47.7	35-60	21.8	26.8

AVERAGE AGE of the subjects at the time of the study and at the time they received their degrees is given in this table. The upper age limit was set at 60; the lower limit was determined by the eminence of the subjects.

THE THEMATIC APPERCEPTION TEST

One of the projective psychological tests used by the author in her interviews with the 64 scientists is the Thematic Apperception Test, commonly called the TAT. In this test the subject is given a set of large cards, one blank and 19 bearing pictures. One of the pictures is shown above. The subject is asked to write a story about each of the cards; the stories are then studied by a trained interpreter as a method of revealing some of the subject's drives, emotions, sentiments, complexes and conflicts of personality.

The test was devised by Henry A. Murray of Harvard University, who observes about it: "The TAT will be found useful in any comprehensive study of personality, and in the interpretation of behavior disorders, psychosomatic illnesses, neuroses and psychoses. The fact that stories collected in this way often reveal significant components of personality is dependent on the prevalence of two psychological tendencies: the tendency of people to interpret an ambiguous human situation in conformity with their past experiences and present wants, and the tendency of those who write stories likewise to draw on the fund of their experiences and express their sentiments and needs, whether conscious or unconscious. The subject's interest, together with his need for approval, can be so involved in the task that he forgets his sensitive self and the necessity of defending it against the probings of the examiner, and, before he knows it, he has said things about an invented character that apply to himself, things which he would have been reluctant to confess in response to a direct question."

The picture, copyrighted in 1943 by the President and Fellows of Harvard College, is reproduced by permission of the Harvard University Press.

a great deal of material, much of which has been published in technical detail in special journals. In this brief article it is possible only to recapitulate the high points.

THERE IS no such thing, of course, as a "typical" scientist. Eminent scientists differ greatly as individuals, and there are well-marked group differences between the biologists and the physicists, and between the natural scientists and the social scientists. Certain common patterns do appear, however, in the group as a whole, and the most convenient way to summarize these generalizations is to try to draw a picture of what might be called the "average" eminent scientist.

He was the first-born child of a middle-class family, the son of a professional man. He is likely to have been a sickly child or to have lost a parent at an early age. He has a very high I.Q. and in boyhood began to do a great deal of reading. He tended to feel lonely and "different" and to be shy and aloof from his classmates. He had only a moderate interest in girls and did not begin dating them until college. He married late (at 27), has two children and finds security in family life; his marriage is more stable than the average. Not until his junior or senior year in college did he decide on his vocation as a scientist. What decided him (almost invariably) was a college project in which he had occasion to do some independent research—to find out things for himself. Once he discovered the pleasures of this kind of work, he never turned back. He is completely satisfied with his chosen vocation. (Only one of the 64 eminent scientists—a Nobel prize winner—says he would have preferred to do something else: he wanted to be a farmer, but could not make a living at it.) He works hard and devotedly in his laboratory, often seven days a week. He says his work is his life, and he has few recreations, those being restricted to fishing, sailing, walking or some other individualistic activity. The movies bore him. He avoids social affairs and political activity, and religion plays no part in his life or thinking. Better than any other interest or activity, scientific research seems to meet the inner need of his nature.

This generalized picture represents only majority traits; there are, of course, many exceptions to it, not only in individual cases but by groups; the social scientists, for instance, tend to be by no means shy but highly gregarious and social. Let us now consider the differences between groups. I have separated the physicists into the theorists (12) and the experimentalists (10), because these two groups differ sharply. The biologists (physiologists, botanists, geneticists, biochemists and so on) are sufficiently alike to be grouped together, and so are the social scientists.

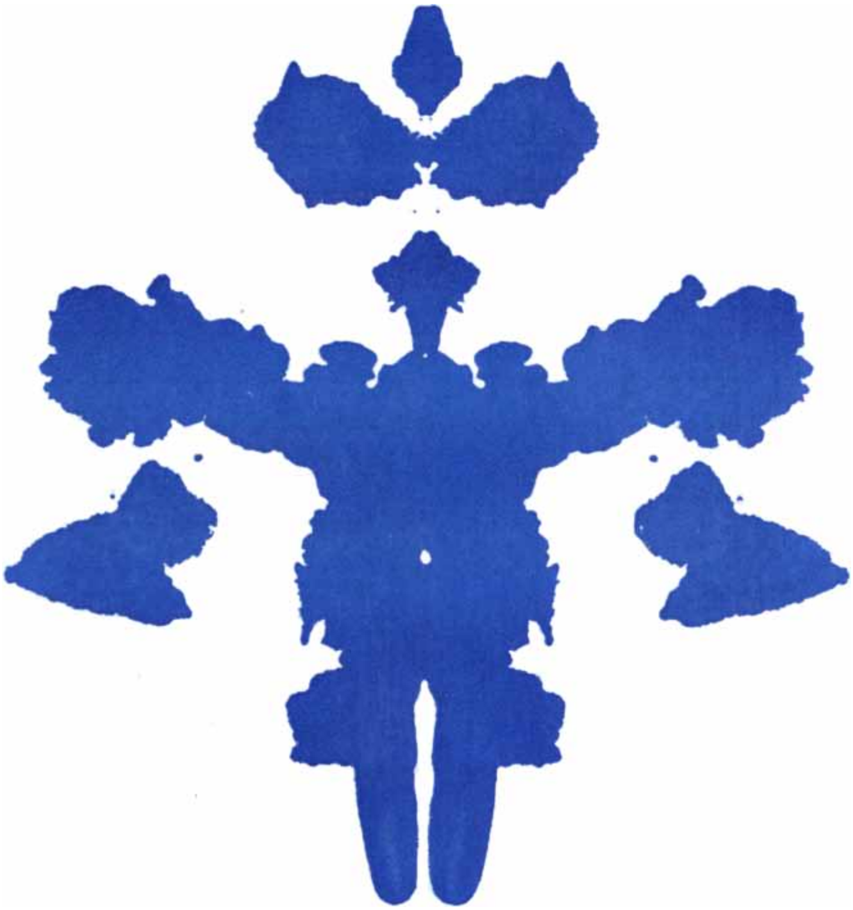
NO STANDARDIZED intelligence test was sufficiently difficult for these eminent scientists; hence a special test was constructed by the Educational Testing Service. To provide ratings on particular intellectual factors, the test was divided into three parts: verbal (79 items), spatial (24 items) and mathematical (39). (The mathematical test used was not difficult enough for the physicists, and several of them did not take it.)

While the group as a whole is characterized by very high average intelligence, as would be expected, the range is wide (*see table on page 24*). Among the biologists, the geneticists and biochemists do relatively better on the nonverbal tests than on the verbal, and the other biologists tend to do relatively better on the verbal. Among the physicists there is some tendency for theorists to do relatively better on the verbal and for the experimentalists to do relatively better on the spatial test. Among the social scientists the experimental psychologists do relatively better on the spatial or mathematical than on the verbal test, and the reverse is true of the other psychologists and the anthropologists.

On the TAT the social scientists tended to give much longer stories than the other groups did—verbal fluency is characteristic of them. The biologists were inclined to be much more factual, less interested in feelings and, in general, unwilling to commit themselves. This was true to a lesser extent of the physical scientists. The biologists and physical scientists manifested a quite remarkable independence of parental relations and were without guilt feelings about it, while the social scientists showed many dependent attitudes, much rebelliousness and considerable helplessness, along with intense concern over interpersonal relations generally. The biologists were the least aggressive (but rather stubborn) and the social scientists the most aggressive. The most striking thing about the TAT results for the total group, however, is the rarity of any indication of the drive for achievement that all of these subjects have actually shown in their lives.

On the Rorschach the social scientists show themselves to be enormously productive and intensely concerned with human beings; the biologists are deeply concerned with form, and rely strongly upon a non-emotional approach to problems; the physicists show a good deal of free anxiety and concern with space and inanimate motion. Again the social scientists, particularly the anthropologists, are the most freely aggressive.

Early in the course of the work it became apparent that there were some differences in habits of thinking, and a special inquiry was instituted along these lines. The data are unsatisfactory from many standpoints—there are no objective tests for such material, and I had to ask many leading questions in order to convey any idea of what I was after. Nevertheless rather definite and meaningful patterns did appear. The biologists and the experimental physicists tend strongly to dependence upon visual imagery in their thinking—images of concrete objects or elaborate diagrams or the like. The theoretical physicists and social scientists tend to verbalization in their thinking—a kind of talking to themselves. All groups report a considerable amount of imageless thinking, particularly at crucial points. Men whose fathers followed talkative occupations (law, ministry, teaching) are more likely to think in words.



RORSCHACH TEST, in which the subject describes the pictures he is able to perceive in a standard set of inkblots, also was used in the study.

THE LIFE histories of these 64 men show some general similarities, and there are patterns characterizing some of the subgroups. Geographical factors seem not to be particularly significant, except that only a few came from the South. The economic level was varied, ranging from very poor to well-to-do; among the anthropologists and the theoretical physicists a somewhat higher percentage came from well-to-do homes.

In several respects the scientists' backgrounds differ very much from the population at large. There are no Catholics among this group of eminent scientists; five come from Jewish homes and the rest had Protestant backgrounds. Only three of the 64 now have a serious interest in any church; only a few even maintain church memberships.

Another striking fact is that 53 per cent of the scientists were the sons of professional men; not one was the son of an unskilled laborer and only two were sons of skilled workmen. Why do more than half of our leading scientists come from the families of professional men? It seems to me most probable, from more knowledge of the family situations of these men than I can summarize here, that the operative factor is the value placed by these families and their associates on learning—learning for its own sake. Most of the scientists developed intellectual interests at an early age.

Another remarkable finding is how many of them were their parents' first children. This proportion is higher than chance expectancy in all of the subgroups. Thirty-nine were first born; of the rest five were eldest sons and two

	Biologists	Experimental physicists	Theoretical physicists	Psychologists	Anthropologists	TOTALS
PROFESSIONS	**9**	**5**	**10**	**7**	**3**	**34**
Research Science	0	1	0	0	0	1
Physician	0	2	1	2	0	5
Lawyer	0	0	1	1	3	5
Engineer	0	0	3	2	0	5
Clergyman	2	0	1	0	0	3
Editor	2	0	0	0	0	2
College teacher	4	0	3	2	0	9
School teacher	0	2	0	0	0	2
School superintendent	1	0	0	0	0	1
Pharmacist	0	0	1	0	0	1
BUSINESS	**8**	**1**	**2**	**4**	**5**	**20**
Own business	4	0	2	2	4	12
Clerk, agent, salesman	4	1	0	2	1	8
FARMER	**2**	**4**	**0**	**2**	**0**	**8**
SKILLED LABOR	**1**	**0**	**0**	**1**	**0**	**2**
TOTALS	**20**	**10**	**12**	**14**	**8**	**64**
PER CENT PROFESSIONAL	**45**	**50**	**84**	**50**	**38**	**53**

OCCUPATIONS OF THE FATHERS of the 64 eminent scientists showed a strong bias in favor of the professions. This was especially true of the 12 theoretical physicists, 10 of whose fathers had been professionals. The anthropologists were an exception: five out of eight came from business backgrounds. Four of the 10 experimental physicists were the sons of farmers. None of the scientists were the sons of unskilled laborers.

	Number	VERBAL TEST		SPATIAL TEST		MATHEMATICAL TEST	
		Average	Range	Average	Range	Average	Range
Biologists	19	56.6	28-73	9.4	3-20	16.8	6-27
Experimental physicists	7	46.6	8-71	11.7	3-22		
Theoretical physicists	11	64.2	52-75	13.8	5-19		
Psychologists	14	57.7	23-73	11.3	5-19	15.6	8-27
Anthropologists	8	61.1	43-72	8.2	3-15	9.2	4-13
TOTAL	**59**	**57.7**	**8-75**	**10.9**	**3-22**	**15.9**	**4-27**
APPROXIMATE IQ EQUIVALENTS		**163**	**121-177**	**140**	**123-164**	**160**	**128-194**

INTELLIGENCE TEST RESULTS revealed minor variations among the specialties of the scientists. The theoretical physicists did best in the verbal test; the experimental physicists rated lowest. Both theoretical and experimental physicists did not take the mathematical test because it was not sufficiently difficult. Two anthropologists who took the verbal test did not take the other tests on the ground that they could not do them.

who were second born were effectively the eldest because of the early death of the first child. For most of the others there is a considerable difference in age between the subject and the next older brother (averaging five years). It seems probable that all this may point to the most important single factor in the making of a scientist—the need and ability to develop personal independence to a high degree. The independence factor is emphasized by many other findings: the subjects' preference for teachers who let them alone, their attitudes toward religion, their attitudes toward personal relations, their satisfaction in a career in which, for the most part, they follow their own interests without direction or interference. It is possible that oldest sons in our culture have a greater amount of independence or more indulgence in the pursuit of their own interests than other children have. On the other hand, there is some psychological evidence that first-born tend to be more dependent, on the average, than other children, and a good case could be made out for a hypothesis that reaction to this over-dependence produced the scientists' strong drive to independence.

The early extracurricular interests of these men were varied, but here, too, there are some general patterns. More of the physicists than of the other groups showed early interests directly related to their later occupations, but this seems quite clearly to be due to the common small-boy preoccupation in this country with physical gadgets—radio, Meccano sets and so on. The theoretical physicists were omnivorous readers, the experimentalists much less so. Among the social scientists many went through a stage of considering or even working toward a literary career. Half of the biologists showed some early interest in natural history, but for only five was it of an intense and serious sort, involving keeping field records of birds and flowers, and so on. Many of the biologists did not know during childhood of the possibility of a career in biology. This was even more true of the psychologists and anthropologists, since there are almost no boyhood activities related to professional social science.

IT IS of considerable interest that over half of these men did not decide upon their vocations until they were juniors or seniors in college. More important, perhaps, than when they decided, is why they decided. It certainly was not just a matter of always following an early bent. From fiddling with gadgets to becoming a physicist may be no great leap, but the attractions of theoretical physics are not so obvious or well known, nor are those of the social sciences or advanced biology. In the stories of the social scientists and of the biologists it becomes clear that the most important factor in the final decision to become a scientist is the discovery of the joys of research. In physics the discovery may come so gradually as not to be noticed as such, but in the other sciences it often came as a revelation of unique moment, and many of these men know just when and how they found it out. A couple of quotations will illustrate this:

"I had no course in biology until my senior year in college. It was a small college and the teacher was about the first on the faculty with a Ph.D. It was about my first contact with the idea that not everything was known, my first contact with research. In that course I think my final decision was really taken. It was mainly that I wanted to do something in the way of research though I didn't know just what, but working out something new."

"One of the professors took a group of us and thought if we wanted to learn about things, the way to do it was to do research. My senior year I carried through some research. That really sent me, that was the thing that trapped me. After that there was no getting out."

That research experience is so often decisive is a fact of very considerable importance for educational practice. The discovery of the possibility of finding things out for oneself usually came through experience in school with a teacher who put the students pretty much on their own.

There are other things in the general process of growing up that may have influenced the choice of career in subtle ways. One fourth of the biologists lost a parent by death or divorce at an early age. This may have tended to shove them to greater independence. Among the theoretical physicists there was a high incidence of serious illness or physical handicaps during childhood, which certainly contributed to the feelings of isolation characteristic of them. Among the social scientists there is an unusually intense concern with personal relationships, which often goes back to family conflicts during childhood. A relatively large proportion of them seem to have come from homes in which the mother was dominant and the father inadequate in some way. The divorce rate among the social scientists in this study was remarkably high—41 per cent.

Whereas the characteristic pattern among the biologists and physicists is that of the shy, lonely, over-intellectualized boy, among the social scientists the characteristic picture is very different. They got into social activity and intensive and extensive dating at an early age. They were often presidents of their classes, editors of yearbooks and literary magazines, frequently big shots in college. This contrast between the natural and social scientists was still evident after they grew up. It is true only in general, of course; even among the theoretical physicists there are some ardent party-goers.

The one thing that all of these 64 scientists have in common is their driving absorption in their work. They have worked long hours for many years, frequently with no vacations to speak of, because they would rather be doing their work than anything else.

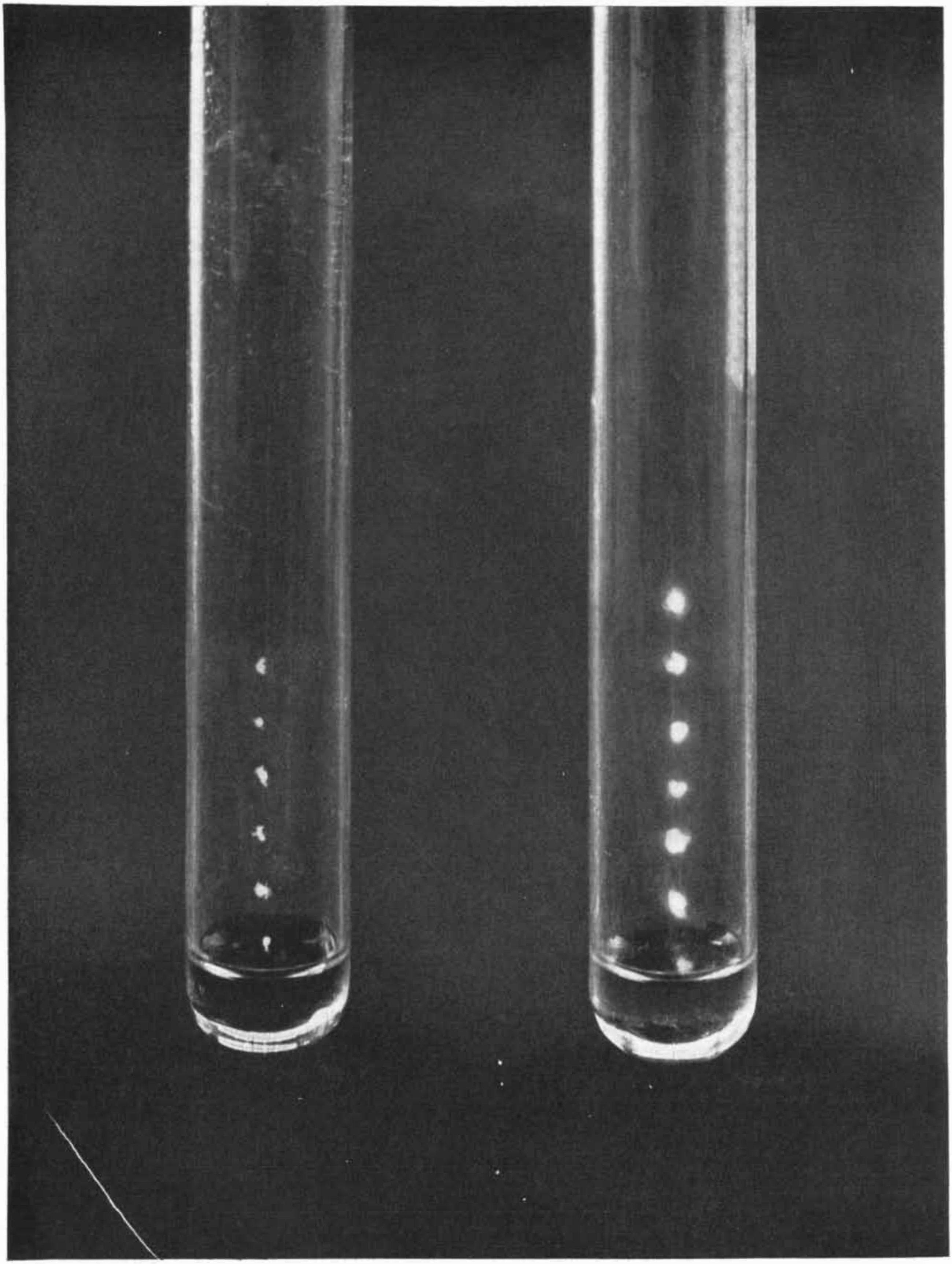
Anne Roe is a clinical psychologist and the wife of the eminent paleontologist George Gaylord Simpson.

FIELD	Visual	Verbal	Imageless	TOTALS
Biologists	10	4	3	17
Physicists	10	4	4	18
Psychologists and anthropologists	2	11	6	19
TOTALS	22	19	13	54

IMAGERY OF THE SCIENTISTS was correlated with specialty. The natural scientists were strong in visual imagery; the social scientists, in verbal.

PROFESSION OF FATHER	Visual	Verbal	Imageless	TOTALS
Verbal	5	10	3	18
Non-verbal	8	2	2	12
TOTALS	13	12	5	30

IMAGERY OF THE FATHER'S PROFESSION was strongly influential. The numbers on the right side of this table refer to the imagery of the sons.



TEST TUBES contain small pieces of monkey tissue growing in a culture medium. The test tube at the left contains tissue that has just been implanted. The bits of tissue in the test tube at the right are fuzzy because they have had time to grow many tiny strands. When polio virus is placed in tube, these cells deteriorate.

A New Era in Polio Research

Until recently the virus that causes the disease was grown by the expensive and inconvenient procedure of inoculating monkeys with it. Now it can be cultivated in the test tube

by Joseph L. Melnick

THE discovery of a way to grow poliomyelitis virus in tissue culture—made three years ago by John F. Enders, Thomas H. Weller and Frederick C. Robbins at the Children's Hospital in Boston—has given a tremendous impetus to the study of this disease. It means the end of the "monkey era" in poliomyelitis research and opens the way to a much wider attack on the problem. Now that experimental work in poliomyelitis is no longer dependent mainly on the infection of monkeys, many more investigators can work on the problem and new kinds of experiments can be undertaken. Advances are already being made on many fronts.

Before considering these advances and the prospects for the control of poliomyelitis let us see how the new technique has changed the laboratory picture. The chief obstacle to experimental investigation of the disease has been that it attacks only man and the other primates (although rare strains of the virus can infect certain rodents). To detect the presence of the virus in tissue specimens and to grow it for laboratory purposes, experimenters have had to use monkeys as experimental animals. The monkeys had to be trapped in Asia or Africa and transported to this country. The supply was irregular, and research sometimes was held up for weeks awaiting a new shipment. Furthermore, a poliomyelitis laboratory had to be equipped with fairly extensive quarters, and needed a sizable staff, to care for the large numbers of monkeys. Much of its time was consumed in dealing with the monkeys' special nutritional needs and their susceptibility to such diseases as tuberculosis, dysentery, and parasitic infections—diseases acquired in nature before the animals entered the laboratory. And at best the monkey assay method was cumbersome and slow. For example, when monkeys were inoculated with a specimen suspected of containing poliomyelitis virus, they had to be closely watched and their temperatures taken each day for a period of four weeks. If and when the signs of the disease developed, the animal was sacrificed and the diagnosis of poliomyelitis was confirmed by microscopic examination of its spinal cord.

In short, monkeys are in every way an exceedingly expensive laboratory animal. Not many institutions had the money or equipment to handle poliomyelitis research, and relatively few investigators could work in this field.

The tissue-culture method has changed things. The monkeys have been replaced by test tubes in which the virus is grown in cultures of tissues. We now have a relatively simple and rapid test for detecting the presence of poliomyelitis virus or its antibodies.

The new method stems directly from the discovery that poliomyelitis virus may grow in cultures of human tissues other than those of the brain and spinal cord. Together with other evidence, this suggests that in the body also, poliomyelitis virus can grow in other than nervous-system cells. If this concept is true, it is indeed fortunate, for such cells presumably are not damaged. Actually there is often no sign of disease, and yet the body gains an enduring immunity. Such multiplication of virus without producing disease means that the body, when it meets the virus again at some future date, is able to thwart its attack, and prevent the virus from moving to the nervous system—for it is only in this latter tissue that the damaging lesion is produced. This concept of virus growing in cells outside the nervous system and conferring an immunity to subsequent paralytic infection is opening up new channels for investigation, from which may come a means of preventing the disease.

The materials used in the new culture technique are certain monkey or human tissues, the latter being available after some types of surgical operations. They are cut into tiny fragments about 1/25-inch square. When such a piece is bathed in a suitable nutrient medium, long strands of cells grow out from it within a few days and continue to grow for several weeks. If virus is added to the test tube, the strands of cells are broken up and destroyed, usually within a few days. That these destructive changes are specifically associated with the growth of virus is shown in two ways. The first is that they fail to occur in uninoculated tubes. The second is that the addition to the culture tube of serum containing specific antibodies for poliomyelitis virus prevents this destruction of cells. From this may come a laboratory diagnostic test for poliomyelitis infection in man. The method is already useful for the classification of poliomyelitis viruses and for the quantitative measurement of antibodies to each type.

A huge program of research at several universities, in which vast numbers of monkeys were used and more than $1 million was spent, has established that three different species or types of poliomyelitis virus exist in nature. Each of the three can cause the human disease. It has been found in monkeys that infection with one type confers little or no immunity against the other two. This may explain why paralytic poliomyelitis is sometimes contracted more than once by the same person.

In order to gain a better understanding of poliomyelitis epidemics, it is necessary to know just which types are prevalent during a single outbreak, and the tissue-culture method is ideally suited for such work. For example, in

Easton, Pa., during the summer of 1950 tissue-culture analysis showed that all three virus types were present in poliomyelitis patients sent to the hospital, but Type 1 accounted for most of the cases. Whether all three types occur in every epidemic, with one type in ascendancy, is a question for future investigation to answer. At least it shows that as far as the poliomyelitis family of viruses is concerned, "birds of a feather flock together."

In addition to the three types of poliomyelitis virus, three other viruses were isolated in tissue culture in Easton. They were found in patients diagnosed as having mild poliomyelitis. They did not belong to the poliomyelitis virus family, for none of the three poliomyelitis antisera neutralized their capacity to destroy cells in tissue culture. Further study has shown that two of the agents can be grouped with the poliomyelitis fellow-travelers—the Coxsackie or C viruses. The remaining agent is as yet unidentified. The following summer there were isolated three similar viruses with the capacity to produce cellular damage in monkey-tissue cultures, but not, as far as could be determined, with the capacity to cause disease in monkeys or other laboratory animals. Thus a whole new field is opening up in which heretofore unrecognized human viruses may be detected by the tissue-culture method.

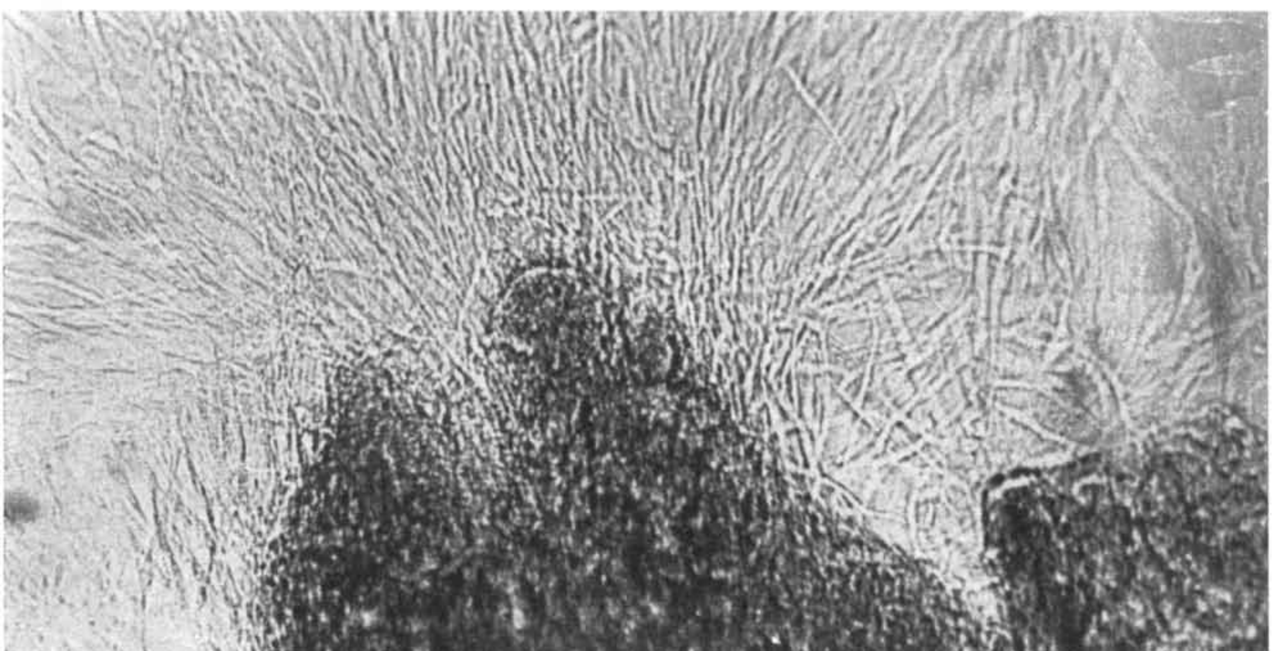
For many infectious diseases the presence of specific antibodies is generally believed to mean that the individual is immune to that disease. If this assumption is correct for poliomyelitis, tissue culture may provide a simple tool to tell who is immune to poliomyelitis and who is not. This may have great practical significance. By sampling the population periodically to determine the prevalence of antibodies to the three poliomyelitis viruses, health officers may be able to predict the occurrence of epidemics.

Recent studies carried out in the Yale Poliomyelitis Laboratory illustrate the kind of information that can now be obtained. Antibody tests have shown that children in Cairo, Egypt, who live under conditions of sanitation far more primitive than ours, acquire poliomyelitis antibodies much more rapidly than do children in U. S. cities. More than half of the children of Cairo are already infected and presumably rendered immune by the age of two. This much "immunity" is usually not reached in U. S. cities until the age of 10 or so. Because exposure to virus is frequent in Egypt, the level of infection, with resultant immunity, in the Cairo population is high. Thus there are few cases beyond infancy, and large epidemics have never been reported. To learn more about how poliomyelitis strikes in the U. S., the city of Winston-Salem, N. C., was selected for study during the 1948 epidemic of the disease in North Carolina. The virus strains isolated from paralyzed patients were found to belong to Type 1. During the summer this type also infected about 25 per cent of those children who were devoid of antibodies at the start of the outbreak without giving them symptoms of the disease. Type 2 also was prevalent in Winston-Salem, infecting 17 per cent of the apparently well children. There was no evidence that Type 3 virus was active during the summer of 1948, although the antibody measurements showed that Type 3 had been present in Winston-Salem in earlier years.

The new test-tube method for identifying poliomyelitis viruses and measuring antibodies is not yet available to practicing physicians and health officers. At this writing its use is confined to research laboratories, but it is our hope that in the near future the test will become a practical tool and available on a large scale.

Immunity to poliomyelitis cannot be left to chance, and two approaches to possible immunity and control of epidemics are currently being made. One is based upon the fact that the virus can be grown in cultures of non-nervous tissue, and the other relies on the use of a human blood fraction called gamma globulin, obtained from large pools of human plasma and rich in antibodies to all three poliomyelitis viruses (as well as to other infectious agents).

When some viruses are cultivated in a medium different from the one to which they are accustomed in nature, they sometimes change in their ability to cause the kinds of diseases they once produced. The new virus is still a living agent and causes infection, but this infection does no damage to tissue. And it will produce antibodies which render



UNINFECTED TISSUE is shown in this photomicrograph of a test tube culture. From the surface of the tissue grow fine strands of cells. Tissue protected by antibodies has the same appearance in the presence of virus.

the subject resistant to subsequent infections by a wild, disease-producing related virus. In this way such diseases as smallpox and yellow fever have been conquered and it appears that rabies will be next on that list. Even though we do not yet possess any attenuated strains of poliomyelitis virus which can be considered safe for human trial, there is good evidence that the viruses being propagated generation after generation in tissue culture already differ from the viruses grown in the spinal cord of laboratory animals. Some of the cultivated strains confer immunity in monkeys even after their capacity to produce paralysis in laboratory animals has almost disappeared.

As it may be a long time before investigators find strains of live virus which can be safely administered to children, work is going forward with vaccines containing killed virus. Monkey spinal cords could never have been entirely safe for this purpose, even if adequate supplies had been available, because the inoculation of nervous-tissue material all too often produces allergic encephalitis, a very serious disease. Test tube-grown viruses which are killed before being incorporated into the vaccine obviate this danger.

Killed viruses have been shown to be effective in producing immunity in animals. Virus particles have an exquisite architecture, characteristic of large nucleoprotein molecules. If this architecture is altered by chemical or physical means, certain properties of the virus are also altered. Several investigators are studying the most effective ways to destroy only that part of the virus responsible for the production of disease. As the rest of the particle, now harmless, would be similar in architecture to a virulent virus, it might be expected to stimulate the production of antibodies and thus confer immunity on a susceptible individual.

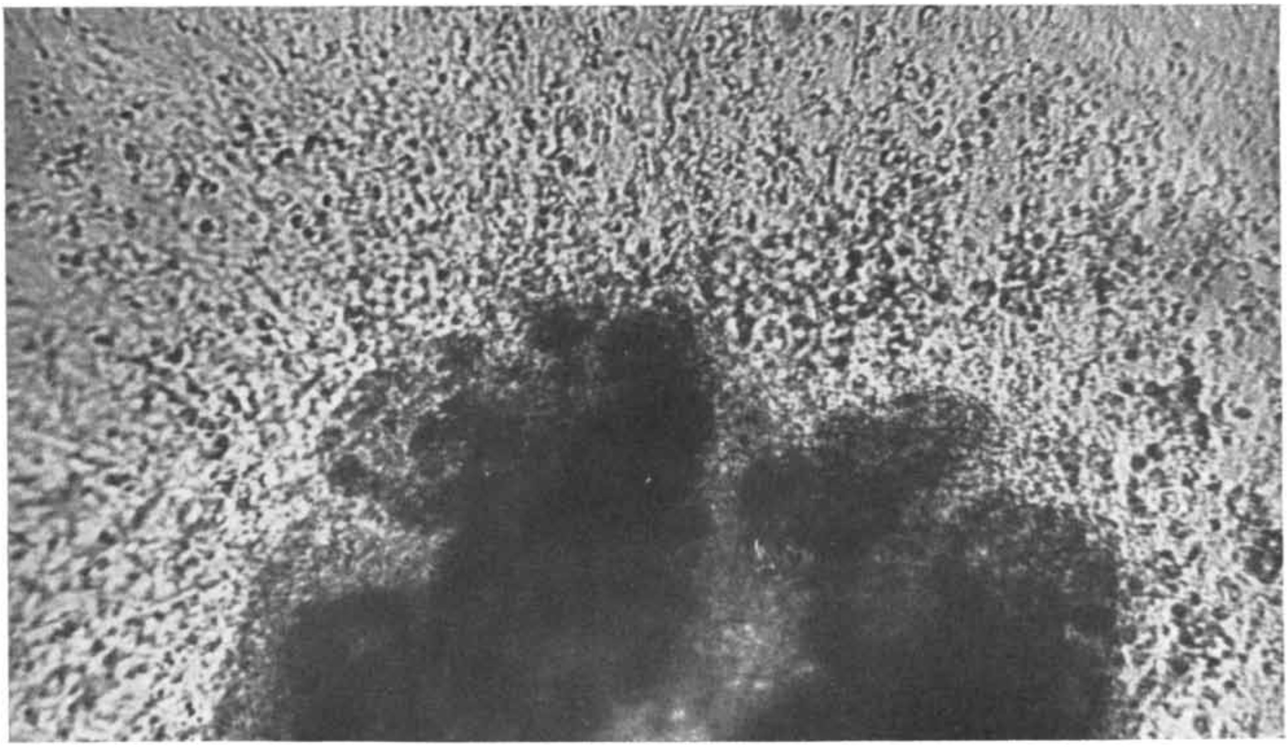
The other approach to immunity, involving the use of gamma globulin, was tested in the field last summer under the direction of William McD. Hammon of the University of Pittsburgh. The results are not yet published at this writing. In the laboratory, gamma globulin protects animals if injected before the virus has begun to multiply in the brain or spinal cord. People are naturally infected at different times during an epidemic, and it was therefore hoped that injections of gamma globulin in thousands of children in an epidemic area might reach some early enough to furnish a supply of poliomyelitis antibodies at a crucial period. The effect of the injected gamma globulin is temporary, and its duration would depend on the amount injected. There is a possibility that some children may achieve a more lasting protection by contracting a low-grade or silent infection of poliomyelitis while they are still protected by gamma globulin antibodies; such a child would then produce his own antibodies, which would remain for years, if not for life. But obviously acquisition of immunity in this way depends on chance.

It is not yet known whether gamma globulin will be effective, and physicians should refrain from injecting it until they know whether and how it should be used. It would be unfortunate if the stocks of human gamma globulin were depleted for no good purpose, leaving it in short supply for use in susceptible persons exposed to measles and infectious hepatitis, two diseases in which it has proved its value.

Tissue-culture methods have provided virologists with a simple *in vitro* method for testing a multitude of chemical and antibiotic agents for their effect on the multiplication of viruses in living cells. Some workers in the poliomyelitis field have already found that certain antimetabolites suppress the growth of the virus in tissue culture. These organic chemicals are structural analogues of compounds found within normal cells, and for this reason they interfere with the normal pathways of metabolism. It is thought that if these pathways can be temporarily blocked, the parasitic virus within the cell may find itself in an environment unfavorable for its propagation.

Altogether the arrival of the tissue-culture technique has greatly encouraged investigators of poliomyelitis. The day when the disease will be brought under control now seems closer.

Joseph L. Melnick is associate professor of microbiology at the Yale University School of Medicine.



INFECTED TISSUE has strands that are in the process of being broken up and destroyed. This effect occurs a few days after the virus is placed in the culture. The uninfected strands are capable of growth for weeks.

Photographic Development

Although picture-making today is a highly refined art, chemists still do not fully understand the basic process whereby an image is formed and developed in an emulsion

by T. H. James

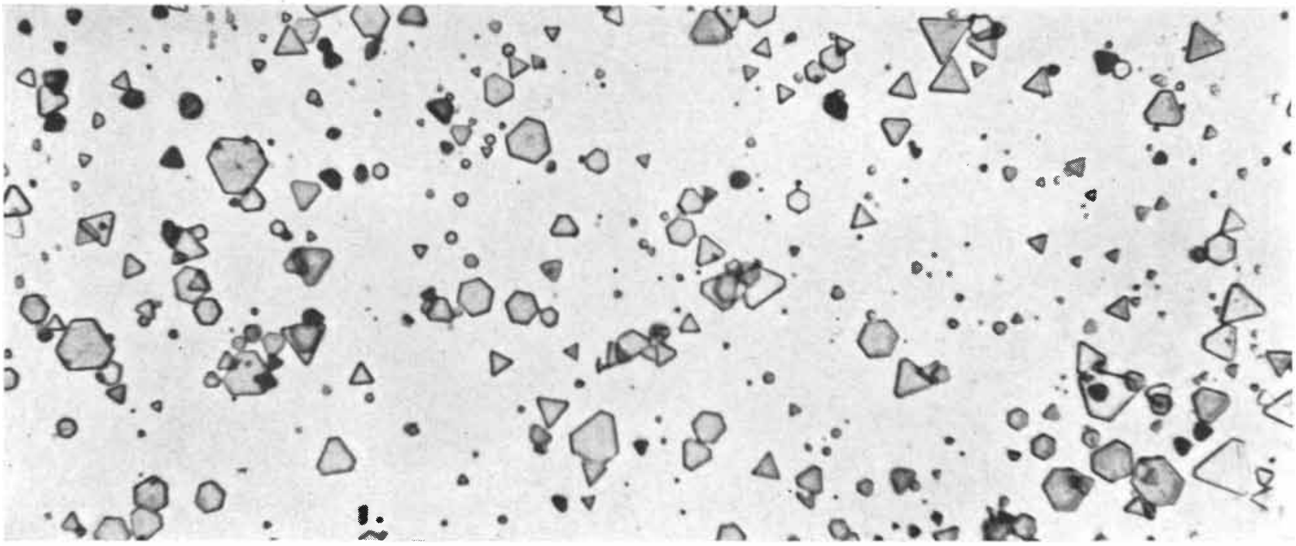
PHOTOGRAPHY is more than 100 years old, but its chemistry is still something of a mystery. Although photographic materials have been refined to a high degree of technical efficiency, we do not yet understand the basic process—exactly what happens in an emulsion when a picture is made and developed. Many people have worked on the problem, and some of their theories and researches will be outlined in this article.

The development of photography has been a triumph of empiricism—which is often a polite word for accident. Its origin goes back to 1727, when a German chemist, J. H. Schulze, noticed that silver nitrate mixed with chalk darkened when it was exposed to light. Using stencils laid on a background of this sensitive material, Schulze made fugitive copies of letters, but he did not know how to "fix" the darkened letters and apparently had no thought of using his discovery as a means of making pictures. It was not until 75 years later that an Englishman, Thomas Wedgwood, took the next step of combining light-sensitive silver nitrate with a light-focusing lens to make an image. He reported in 1802 that he had photographed some profiles by this means. But the discovery of a process for fixing the image had to wait for another 37 years.

It was the French painter Louis Daguerre who made this discovery. He was working with a chemist named J. Nicéphore Niepce, who had fixed some crude images on an asphaltum coating by dissolving away the unexposed part of the coating. Daguerre experimented with silver plates fumed with iodine. By long exposures of such plates in the camera he was able to obtain faint but unsatisfactory images. One day he happened to place an exposed plate in a dark cupboard. When he later removed it, he found a beautiful, strong image upon the plate. Investigation showed that the cupboard had contained some spilled mercury, and the mercury had "developed" the image. Daguerre had discovered the phenomenon of "development."

Daguerre's method required relatively long exposures and development with mercury fumes. A simpler and more effective method was soon discovered by the Englishman William Henry Fox Talbot, working without knowledge of Daguerre's experiments. He took pictures on paper impregnated with silver chloride and developed them in a solution of gallic acid and silver nitrate. An exposure of about three minutes was sufficient to obtain a good photograph. Whereas Daguerre's process yielded a direct reproduction of the image, *i.e.*, a "positive," Fox Talbot's gave a "negative," reversing the light and dark parts of the picture. Fox Talbot made positive prints simply by waxing or oiling the paper to render it transparent and transferring the image, reversed, to a second piece of sensitive paper beneath the negative. To make the picture permanent he dissolved the undeveloped silver chloride in a strong solution of sodium chloride.

Thus Fox Talbot was the inventor of the modern negative-positive method of photography. Subsequent improvements in the photographic materials reduced the required exposure time from three minutes to a small fraction of a second.



GRAINS of a photographic emulsion are tiny crystals of silver salts suspended in gelatin. The grains of a high-speed negative emulsion are about .001 millimeter across; those of a low-speed positive emulsion, .0001 mm.

And the fixer used today is sodium thiosulfate ("hypo") instead of sodium chloride.

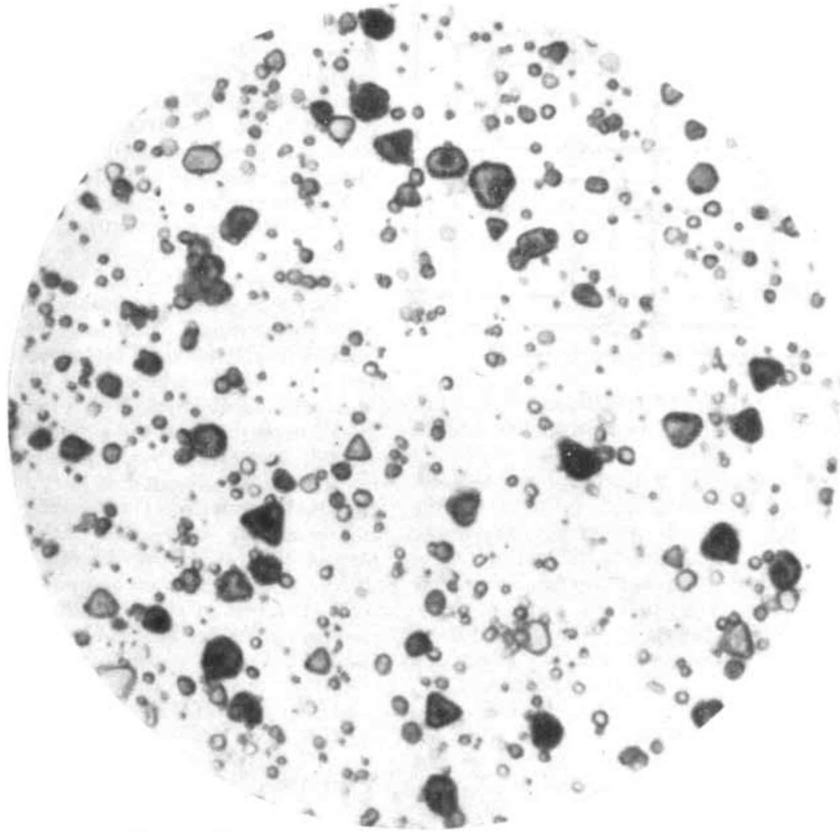
IN THE modern photographic film the light-sensitive layer, or emulsion, consists essentially of very small crystals of a silver salt, chiefly silver bromide, embedded in a layer of gelatin. In the more sensitive emulsions the crystals also contain small amounts of silver iodide and certain important impurities—silver sulfide, sometimes metallic silver and gold, and organic dyes which sensitize film to light of the longer wavelengths.

The silver bromide crystal is made up of an array of positive silver ions and negative bromide ions arranged in the same pattern as are the sodium and chloride ions of common table salt, *i.e.*, positive ions alternating with negative. Most of the crystals in an emulsion, called "grains," are visible through a high-powered microscope. They vary in shape and size (*see page 30*).

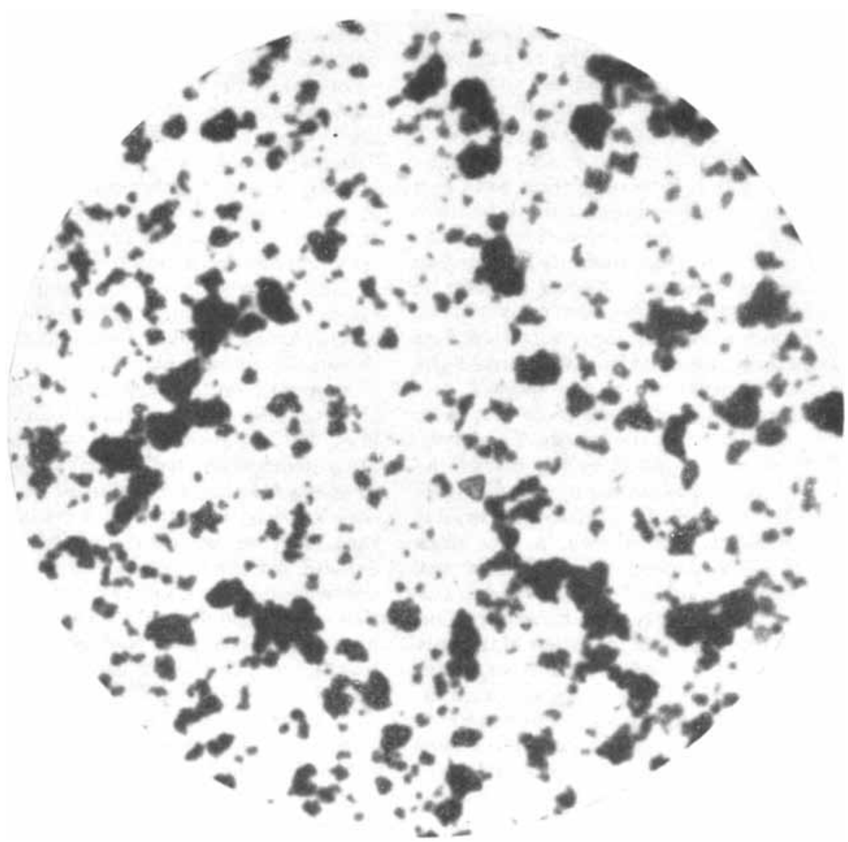
When a photographic film is exposed, a subtle alteration takes place. No visible change in the film can be detected, but it contains a "latent image." The image appears when the film is placed in the developing solution, where some of the silver bromide grains are converted to particles of silver. The important fact is that the number of grains converted into silver on any particular area of the film depends on the amount of light that has struck that area. Areas of the film which have received little or no light, corresponding to dark areas of the object photographed, yield comparatively few developed silver grains; areas which have received relatively large amounts of light, corresponding to the bright areas of the object, yield a high percentage of developed grains. The bromide ions are dissolved away in the developer solution, and the fixed silver grains form the image.

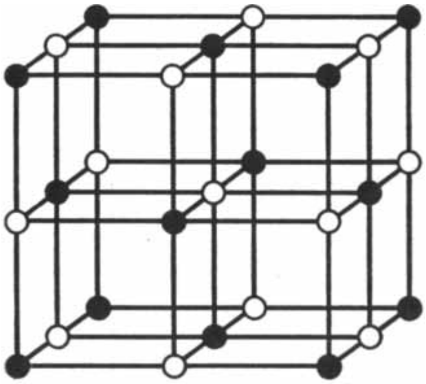
What has the light done to the silver bromide to bring about this result? We have reason to suspect, from various kinds of indirect evidence, that the brief exposure to light produces tiny, undetectable amounts of atomic silver in the emulsion, but this does not explain how the light triggers the much more extensive conversion to silver that occurs when the image is developed. We know that the formation of a few silver atoms during exposure is sufficient to make a grain developable into a silver particle containing as many as 100 billion silver atoms. We have here a process of tremendous amplification! It is this fact that makes possible the making of a picture in a fraction of a second, in contrast to the six hours Wedgwood needed to photograph his profiles.

THE FIRST substantial theory about how the latent image is formed was proposed by S. E. Sheppard, A. P. H.



DEVELOPMENT of a typical photographic emulsion is shown in these two photomicrographs. The illustration above shows the silver bromide grains of the emulsion before exposure. The illustration below shows the same grains after exposure and development. The grains are enlarged 2,500 diameters.





CRYSTAL of silver bromide is a lattice of silver and bromine atoms.

Trivelli and R. P. Loveland of the Kodak Research Laboratories in 1925. On the basis of several experimental discoveries, they suggested that in the preparation of a photographic emulsion submicroscopic specks of silver sulfide are formed in the silver bromide grain. They called these "sensitivity specks," and they postulated that when the grain is exposed to light, the silver atoms so created are concentrated at these specks. The grain becomes developable when one of the specks reaches a certain critical size. Development starts at the speck. Sheppard and his associates did not explain, however, just how the sensitivity speck acted to concentrate the silver.

The next important step was made by J. H. Webb, also of the Kodak Laboratories, in 1936. Reasoning from the fact that the electrical conductivity of a silver-salt crystal increases markedly when it is exposed to light, he suggested that electrons are liberated within the crystal and wander through it until they enter the region of a sensitivity speck. There they are trapped and are no longer free to move. This suggestion went part of the way toward explaining how silver might be concentrated at the speck. To convert silver bromide to silver two things are needed: a silver ion and an electron—the combination makes a silver atom. Webb's idea suggested how electrons, liberated by the action of light, could concentrate at the specks.

It remained only to explain how silver ions collected at the specks. This explanation was supplied by the English investigators Ronald Gurney and N. F. Mott in 1938. In a silver-salt crystal, experiments had shown, a few silver ions are not locked in place but are free to move around and conduct electric current; it was believed that such ions occupied "interstitial" positions in the crystal lattice. Gurney and Mott suggested that the negatively charged sensitivity speck with its trapped electrons attracts the positively charged interstitial silver ions. These ions move up to the speck and are neutralized by the electrons to form silver atoms.

Thus a reasonable theory about how the latent image is formed was put together. The action of light on the silver bromide crystal liberates electrons, which are trapped at sensitivity specks on the crystal. They combine there with silver ions to make atoms of silver, which in turn become the nuclei of the image.

This theory has suggested many new experiments which have substantially increased our knowledge. But it has also run afoul of some puzzling facts which it fails to explain. For instance, it has been shown that a latent image can be formed *inside* the rigid lattice of silver bromide crystals, whereas the Gurney-Mott mechanism suggests that the silver nuclei must grow on the surface of the crystals. Moreover, there are now sensitive emulsions prepared in such a way that they cannot have any sulfide sensitivity centers. Again, there is the question of the fate of the bromine atom which is formed when a quantum of light removes an electron from a bromide ion in the first stage of latent image formation. Bromine reacts readily with silver; why, therefore, does it not destroy the latent image? The Gurney-Mott theory has little to say on this point.

LET US shift now to the problem of how a picture is developed. The early workers in photography were content for the most part to accept development for what it could do and not worry too much about why it took place. The first theory of any importance was proposed in 1893 by one of the great chemists of the 19th century, Wilhelm Ostwald. He suggested that the silver bromide went into solution in the developer, and the silver ions from it were immediately converted to silver atoms. Since the solubility of silver in water is extremely small, the resulting solution of silver was highly supersaturated. Wherever latent image nuclei were present, silver condensed out upon them, and they grew in size in much the same way as sugar crystals grow in a supersaturated solution of sugar. But within the past decade Ostwald's theory has been shown to be untenable.

Sheppard long ago suggested a theory of development along entirely different lines. He had observed that sodium sulfite in solution reacted with silver nitrate in solution to form metallic silver. The reaction was slow. Its rate increased as time went on, however, and it became evident that some product of the reaction was acting to accelerate the process; that is, some product was acting as a catalyst. Sheppard soon showed that this product was the silver itself. When he added very finely divided metallic silver to a freshly mixed solution of sodium sulfite and silver nitrate, the reaction proceeded much more rapidly than it would have in the absence of the silver.

Sodium sulfite will not develop a picture. But Sheppard, arguing from this analogy and certain other known facts, suggested that a developing agent is adsorbed by the silver bromide grains in an emulsion and combines with silver ions on the surfaces of the grains to form a complex analogous to that formed between the silver ions and the sulfite ions. This complex would eventually decompose into metallic silver. While ordinarily the reaction is slow, in the presence of metallic silver the decomposition takes place much more rapidly. Hence grains which have been exposed to light and therefore contain nuclei of silver react much more rapidly with the developing agent than do unexposed grains.

It must be borne in mind that development is a matter of preferential rates. Even an unexposed grain of silver salt will be converted to silver if the developer acts on it long enough, but an exposed grain is converted from 10 to 100 times faster. In practice we stop the development process at the point where a strong image has been formed and before any significant amount of unexposed silver bromide has broken down.

Sheppard's theory has received experimental support from several sources. The writer and W. Vanselow have demonstrated by indirect methods that some developers are adsorbed strongly by the silver bromide in an emulsion, and others are adsorbed by the silver itself as well as by silver bromide.

The reaction that develops the grain occurs at the interface between silver and silver bromide. Adsorption of the developing agent by the silver bromide facilitates the reaction. Adsorption by the silver, when it occurs, may serve the same end. As the reaction proceeds, more and more silver is formed, and development spreads as the boundary between the silver bromide and the newly formed silver spreads. Microscopic studies of developing grains have shown that the rate of development increases with the increasing area of that boundary.

SEVERAL other theories about the process of development have been suggested within the past decade. While they have not been able to account satisfactorily for some of the experimental findings, it is possible that one or more of these suggested mechanisms does operate under some conditions.

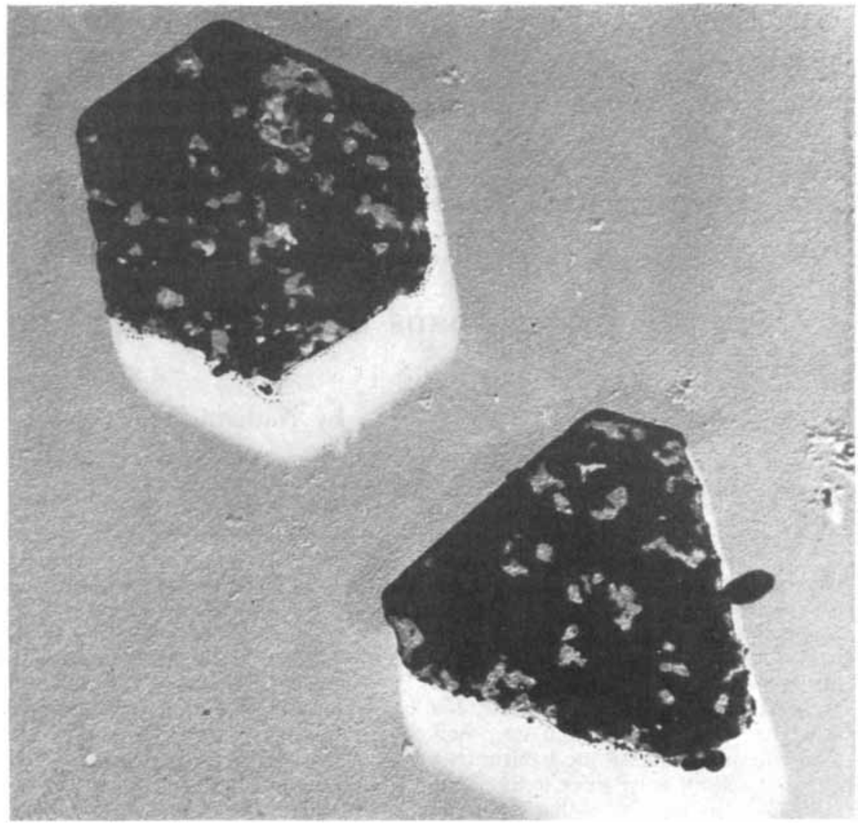
It is well known that if two strips of a nonreacting metal are placed in a solution of a silver salt, and an electric current of sufficient voltage is passed between the two electrodes, silver will be deposited upon the negative electrode. In this process electrons supplied by the source of current combine with the silver ions at the electrode and form silver atoms. Now if a strip of the same metal is placed in a solution of a developing agent, electrons will pass from some of the ions or molecules of developing agent to the metal, leaving behind a corresponding number of ions or molecules which are deficient in electrons and hence are in an "oxidized" state. The developing agent is acting here as a source of electrons. The British investigator H. Baines has shown experimentally that a developing agent *can* supply electrons to a silver electrode and that these electrons can reduce silver bromide. It may be that the silver atoms of the latent image accept electrons from the developing agent and transmit them to the silver ions of the silver bromide. Several writers have suggested detailed mechanisms based on this simple idea. Gurney and Mott used it to extend their mechanism of latent-image formation to cover development. They suggested that in development the negative charge which the latent-image nucleus acquires from the developer attracts interstitial silver ions to that nucleus. The silver ions then combine with the electrons to form silver atoms.

When developed photographic grains were examined for the first time under the high magnification of an electron microscope, a surprising discovery was made. The grains had hair-like threads or filaments protruding from them. How were they formed? It is now believed that they are built up by crystal growth. Many crystals are known to grow in long, needle-like chains, and experiments proved that silver crystals can grow in this shape (*bottom right*).

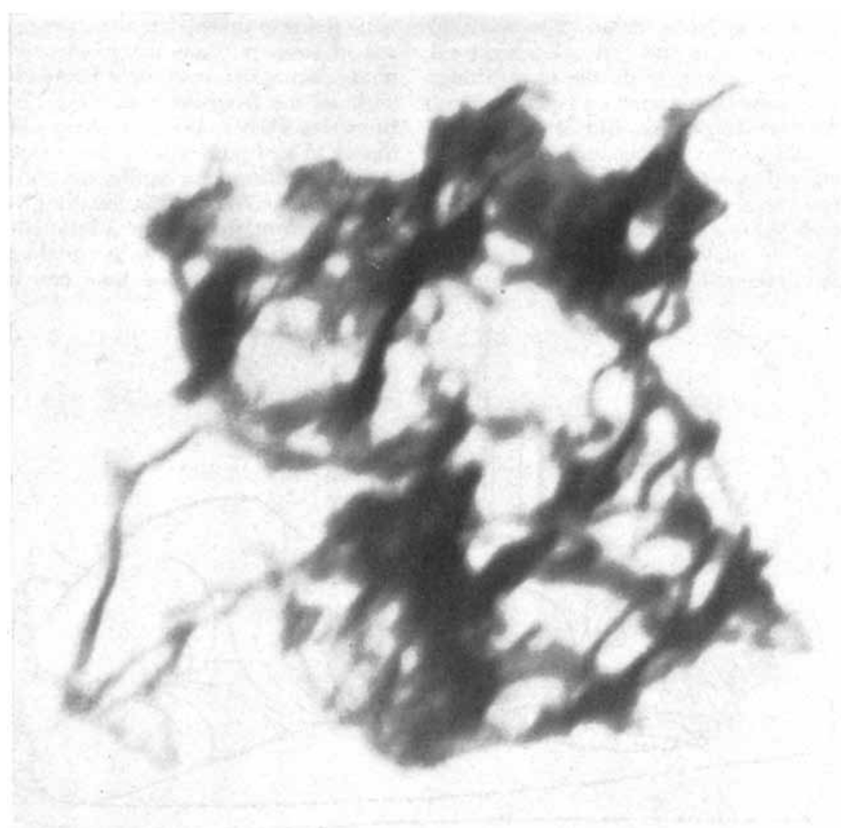
It is easy to see how the silver atoms produced during development could migrate out to form filaments. Atoms newly formed on a solid surface do not immediately assume the properties of a solid but have a surprising mobility; they act in many ways like a two-dimensional gas. For example, E. N. da C. Andrade of University College, London, prepared some very thin continuous films of silver on glass by condensation of silver vapor. After a few hours' storage at 250 degrees Centigrade, the films had broken up, and the silver now appeared in a number of crystals, well separated from one another. To accomplish this crystallization, the silver atoms had migrated over distances easily seen through the microscope, and this migration had occurred at a temperature 700 degrees below the melting point of silver! It is not at all unlikely that at room temperature silver atoms can travel far enough to form the development filaments.

There are still many unsolved problems in the theory of the photographic process, and it has not yet had any satisfactory quantitative analysis. But progress has been made.

T. H. James is a chemist in the Research Laboratories of the Eastman Kodak Company.



UNDEVELOPED GRAINS are shown by electron micrograph. The grains have the same characteristic crystal shape as those shown on pages 30 and 31.



DEVELOPED GRAIN is revealed by electron micrograph to be a twisted filament of metallic silver. The width of the grain is about .000025 inch.

SLEEP

The diurnal rhythm of man's life is significantly reflected in his physiology. To the physiologist the question of why we sleep is perhaps less interesting than why we stay awake

by Nathaniel Kleitman

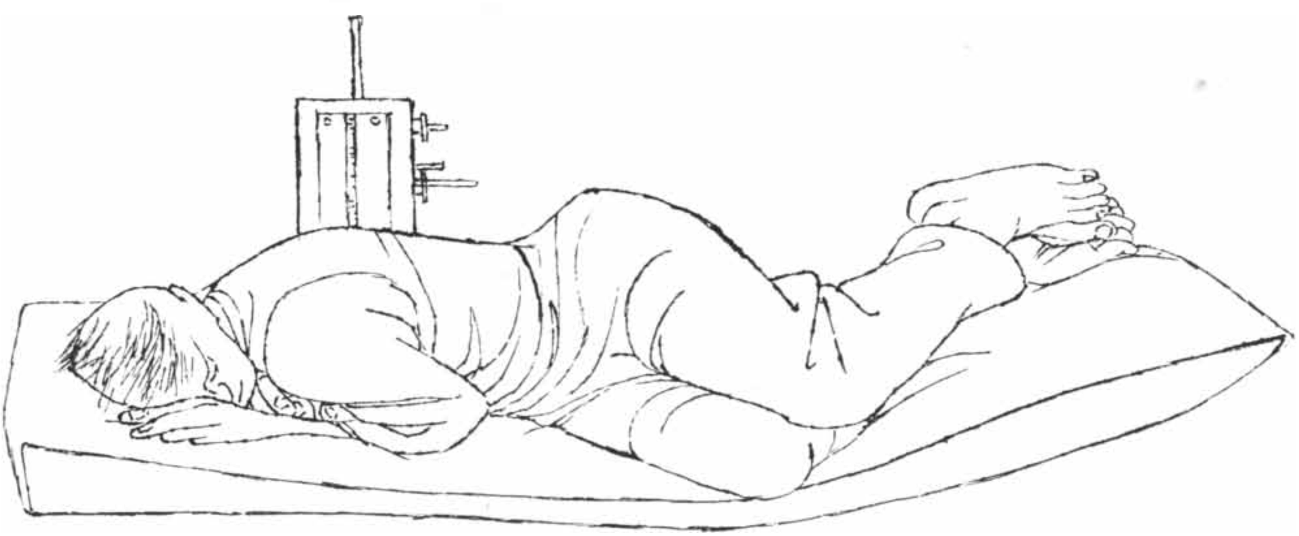
WHY sleep? Must we waste one third of our life in sleep? What makes us sleep? Will a pill some day enable us to do without it? Such questions evidence a fundamental misconception of the nature of the alternation of sleep and wakefulness that characterizes our existence. They put the emphasis in the wrong place, for it is doubtful that we shall ever find a specific physiological mechanism that puts us to sleep; much more to the point is to find out what it is that keeps us awake.

If we turn the usual question around and ask, "Why wake up?" anyone can give a ready, and essentially correct, answer: to go to school or to work, to eat or drink, to take care of one's natural wants—in short, to do the many things that even kings and millionaires must do for themselves. But it is not the whole answer. In modern civilized society these necessary chores do not take more than seven or eight hours per day, and yet we remain awake twice that long—to play, read, attend shows, listen to the radio or watch television, visit with family and friends, contemplate the wonders of nature, meditate and ask questions.

This supplementary wakefulness of choice is the result of anatomical development and physiological maturation of the highest organ of our nervous system—the cerebral cortex. A newborn infant—for practical purposes an animal without a cortex—remains awake only for short periods, adding up altogether to about eight hours out of each 24. But the influences to which it is subjected—largely social—soon condition it to a daily rhythm which Arnold Gesell, the famed investigator of child development, has called acculturation. The baby tends to consolidate the short periods of sleep into one continuous sleep phase during the quiet night hours (but with all too frequent departures, alas, from this ideal!). Daytime sleep is reduced to two naps after a few months and to one afternoon nap by the end of the first year. The nap is usually given up at kindergarten age or a little later. The wakefulness phase is gradually lengthened, and by the time one becomes an adult, he spends twice as much time awake as asleep, instead of the other way around.

We can see the connection between the cerebral cortex and sleep in a laboratory animal such as the dog, which has a sleep-wakefulness pattern similar to our own. When an adult dog is surgically deprived of its cerebral cortex, it reverts to its puppyhood state. It loses its regular daily pattern of sleep and awakens only from time to time when it is hungry. Almost immediately after it is fed, it stops activity and soon falls asleep. A decorticated dog is blind to specific objects, has forgotten everything it knew and is practically unable to learn or profit from experience. Except while it is being fed (the food must be put into its mouth), its emotional expressions are those of displeasure.

In nature's own laboratory human infants occasionally are born without a cerebral cortex and survive for a year or two. Like decorticated dogs, such infants awake from time to time and they can nurse, but they do not develop a diurnal sleep-wakefulness pattern. They



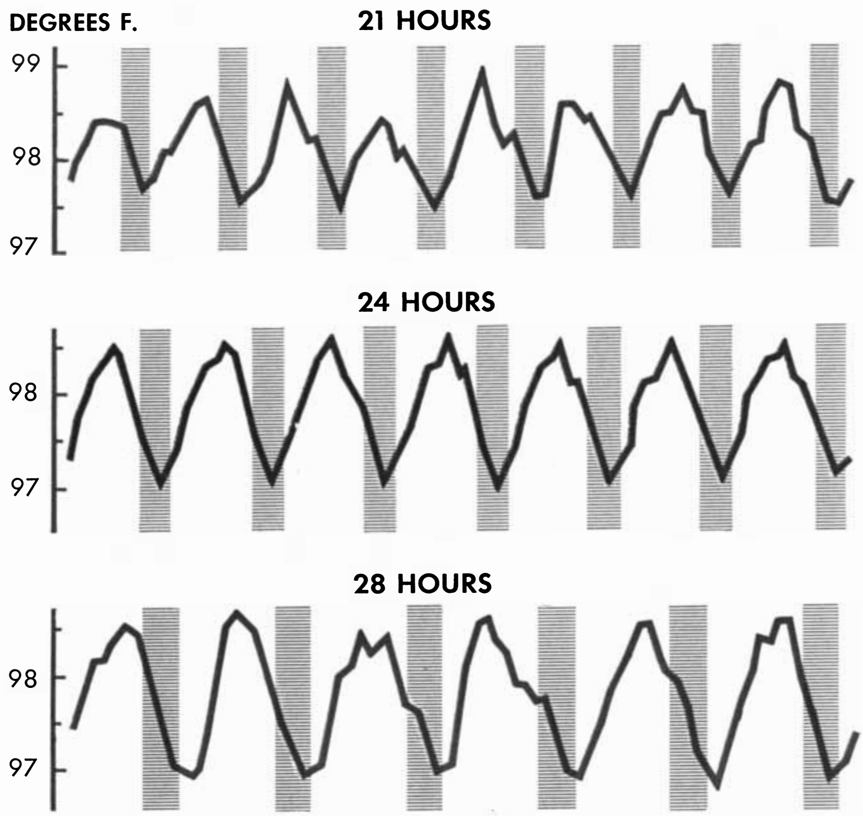
SLEEPERS WERE STUDIED in the author's laboratory at the University of Chicago. In the background is part of a photoelectric-cell device that was used to record the twistings and turnings of the subject.

fail to learn to recognize those who take care of them, and their emotional expressions resemble those of decorticated dogs.

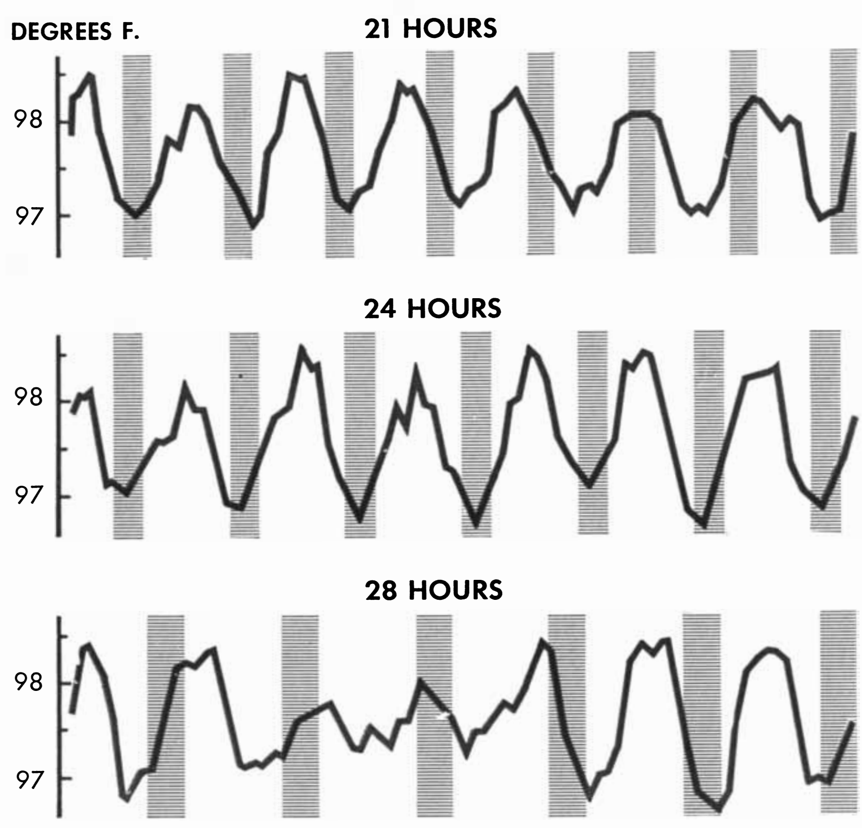
Thus it is clear that the cerebral cortex is needed for wakefulness of choice and for adaptation of the sleep-wakefulness pattern to the cycle of night and day. On the other hand, the primitive, unlearned wakefulness of necessity depends on lower parts of the nervous system. If we remove an animal's entire cerebrum, we get a "preparation" which never wakes up. The animal, however, cannot be said to be asleep, for sleep as we know it is a *temporary* suspension of the waking state and clearly involves reversibility, or the capacity to be awakened. A decerebrated cat or dog can never be roused, though it may be kept alive for several days by keeping it warm and ministering to other needs. Again, an injury to the hypothalamus (a region in the brain stem), whether by disease or artificial destruction, produces "sleeping sickness"—another case of permanent inability to maintain the waking state.

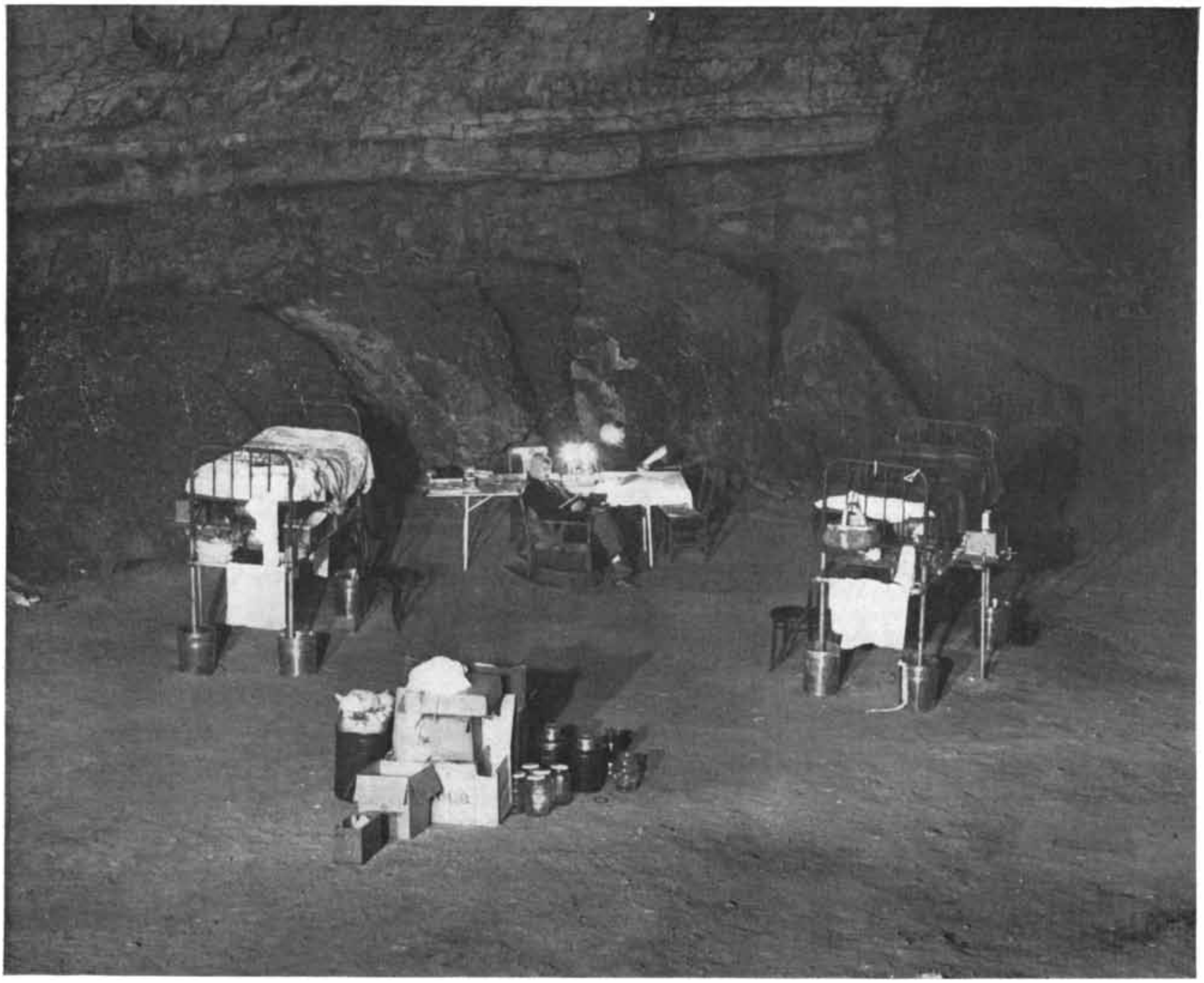
WHAT is the physiological mechanism for waking up—the "alarm clock" of the organism? Certainly it does not lie in the cerebral cortex alone. The Belgian neurophysiologist Frédéric Bremer showed this by investigating the activity of "decatted" brains (instead of debrained cats). He found that brain waves (electroencephalograms) from a cat's cerebral cortex showed patterns characteristic both of sleep and of wakefulness as long as the cortex was connected with the subcortical regions of the nervous system, but when these connections were cut, the only pattern from the cortex was that of sleep.

The inescapable conclusion is that sustained wakefulness of any kind is impossible without the active participation of a subcortical center. This "wakefulness center" not only radiates impulses upward to the cerebral cortex and downward to the rest of the central nervous system but is itself capable of being aroused and kept active by excitations from either or both of those directions. Conduction of nerve impulses is not one-way but recurrent over feedback circuits. Sleep is a peaceful resting state, although the body's "household activities," such as circulation, respiration, digestion, metabolism, excretion and so on, go on unabated. When a stimulus is strong enough to irritate the wakefulness center, it disrupts the vegetative state of the organism and ushers in animalistic activities required to cope with the situation. In the absence of a cerebral cortex this primitive wakefulness of necessity is sustained only long enough to satisfy the internal needs or remove the external annoyances. As already mentioned, in a young animal or infant the interruption of sleep leads to



BODY TEMPERATURE of two subjects was measured during the normal and two abnormal cycles of sleep. In these two charts the blue lines indicate the variation in body temperature. The vertical bands denote sleep periods. The chart above shows that the temperature cycle of one subject changed readily to conform to the abnormal sleep cycles. The chart below indicates that the temperature cycle of the other subject changed little.





MAMMOTH CAVE EXPERIMENT enabled the author and Bruce Richardson to change their sleep cycles in surroundings constant in temperature and darkness and free from disturbances of the normal cycle of life.

expressions of displeasure. The peaceful state has been disturbed and must be restored as promptly as possible.

The cerebral cortex can prolong the waking state, but not beyond certain limits. Sixteen hours of wakefulness in 24 is probably near the physiological limit of tolerance over the long run for most of us. But the proportion, not the duration, of sleeping time is what counts. Our pattern of 16 hours of wakefulness followed by eight hours of sleep is dictated by the earth's 24-hour period of rotation rather than by physiological needs; a person can adjust himself to a routine of staying up 18 hours and sleeping nine, or being awake 12 hours and sleeping six.

Many sleep theorists, it seems, disregard this obvious explanation of our sleep pattern. They figure that we must sleep eight hours because it takes that long to restore some depleted substance in the body or to get rid of some accumulated poison. If this body-chemistry theory were correct, we should expect people to be most alert and efficient on waking up in the morning, but in fact their scores on mental and physical tests are no higher, and sometimes even slightly lower, in the morning than just before going to bed. This does not mean that no benefits accrue from sleep, as one can quickly discover by going without sleep for any length of time.

EXPERIMENTAL sleep deprivation has been a favorite method of attacking the sleep problem. When an individual is kept awake for 60 to 90 hours—four to six times the usual daily span of wakefulness—the most prominent effect is extreme muscular fatigue and lassitude. The subject of the experiment wants nothing more than to lie down and close his eyes. Yet that is exactly what the watcher must not permit him to do. Keeping a person awake involves making him move about, keep his eyes open and use some of his muscles at all times, even if no more than to talk or sing. As soon as he relaxes his muscles, he promptly falls asleep. Among the effects of prolonged wakefulness are irritability and mental disorganization, leading to daydreaming and automatic behavior, occasionally bordering on temporary insanity.

One striking aspect of the effects is that they fluctuate in a daily cycle; the subject reaches his lowest ebb during the early hours of the morning, roughly from 2 to 6 a.m. Quite by accident we discovered that the daily ups and downs in the ability to remain awake ran parallel to fluctuations in the body temperature.

Temperature affects life processes in many ways. Most protoplasmic activities, being chemical in nature, are speeded up by a rise in temperature and slowed down by its fall. Our bodies have a thermostatic mechanism which keeps the internal temperature fairly constant, but it can and does fluctuate normally within a range of one or two degrees; the neat and precise marking of 98.6 degrees Fahrenheit as the "normal" tem-

EXPERIMENTERS RESPONDED DIFFERENTLY to the changes in cycle. Richardson (*left*) could adjust to them; Kleitman (*right*) could not.

perature on the ordinary clinical thermometer is rather meaningless. Our temperature regularly goes up and down each day on a fairly smooth, wave-like curve, with a peak or plateau in the middle of the waking period and a minimum at night during sleep. This diurnal temperature variation is not present at birth. It is acquired by each of us in the process of acculturation during the first year of life and thereafter is reinforced by our daily cycle of activities.

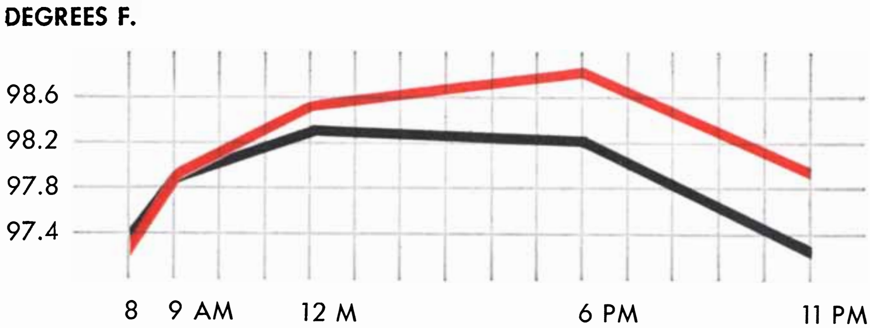
Our body temperature is about the same just before we go to bed at night as when we rise in the morning, which explains why there is no difference in efficiency of performance. During prolonged deprivation of sleep, a subject's alertness in each 24 hours waxes and wanes with the rise and fall of the temperature curve, his greatest sleepiness coinciding with the temperature trough in the wee morning hours.

To use a crude analogy, water in its liquid state may be likened to wakefulness, and, when frozen, to sleep. These two states of water can be distinguished from each other by direct inspection, as can frank sleep from wakefulness. But by feeling the water or ice with the hand, or, still better, by using a thermometer to determine its temperature, one can detect considerable gradations of cold in ice and of warmth in water. The freezing point and thawing point are identical and correspond to the drowsiness level of body temperature. The greater the agitation of the molecules, the higher the temperature of the water, which now represents increasing alertness with a rise of body temperature. The boiling of water at a certain temperature may be compared to the hyperactivity of a maniac. Quite a number of everyday expressions pertaining to human behavior are couched in temperature terms: cold reception, warm greeting, feverish activity, boiling mad and so on.

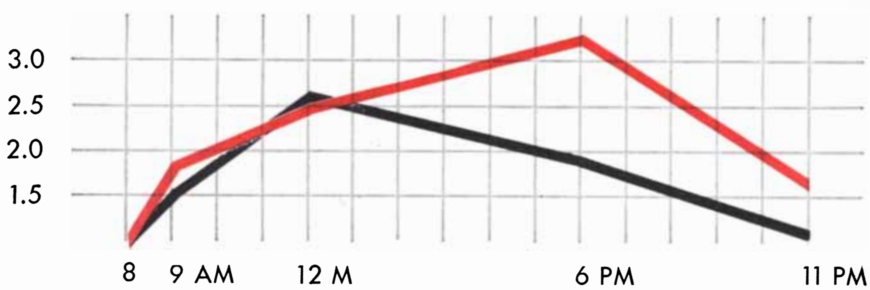
INDEED, the temperamental make-up of the individual (note that temperature and temperament have a common etymological derivation) seems to influence his ability to adjust himself to the community pattern of living. The social anthropologist W. H. Sheldon, who has exhaustively studied the relation of temperament to physical constitution, reported that the athletic, or "somatotonic," type is a "voluntary early riser." "Somatotonics feel good in the morning. They love to jump out of bed, take a shower, make a lot of noise and greet the sun." Sheldon also found that for "cerebrotonics," or thin people, "the process of getting up in the morning is often an extremely painful business." They "often become most alert and do their best work in the evening of the day. They are usually wide awake at bedtime, and they are often worthless in the early part of the morning."

Without passing on the validity of Sheldon's classification of temperaments, we can say that what distinguishes these two extremes of personality is the degree of ability or willingness to conform to the social pattern of living, which is, simply stated: first work, then leisure. By convention the usual hours of work are roughly between 9 a.m. and 5 p.m., and the evening hours are free. Thus the time of arising in the morning is in most cases community-fixed, whereas retiring for the night is a matter of personal choice. Going to bed early permits one to get enough rest—hence the dictum "early to bed, early to rise, etc." Late to bed and late to rise would be just as satisfactory physiologically, but is harder to manage in practice. The conformists who adjust themselves most easily to the group routine are the early birds who *spontaneously* wake up rather early in the morning and get sleepy at a fixed early hour in the evening. These individuals do their best creative work in the morning, and they characteristically reach their body temperature peak shortly before or after noon. The "night owls"—Sheldon's cerebrotonics—seldom get enough sleep and depend upon alarm clocks or other artificial promptings to wake them in the morning. They do not reach their temperature maximum until late in the afternoon or evening, and that is the part of their waking period when they are most alert. Night-owl types sometimes deliberately choose occupations that involve night work and permit them to sleep late in the morning. Naturally there are many gradations between these extreme types. The majority of the population apparently approaches the up-bright-and-early conformist type.

Can one, by changing his routine of living, switch from a morning to an evening alertness? Yes, under duress, but usually the shift is temporary. An evening-type housewife may conform as long as her children are little and have to be seen off to school early in the morning, but after her children are



TWO TEMPERAMENTAL TYPES are reflected by the difference in the physiological cycles of two subjects. The chart above shows the daily variations in their temperature, averaged for 20 days. The temperature of one subject (*black line*) was highest at noon; the temperature of the other (*red line*) reached its peak late in the afternoon. The chart below shows the daily variations in "steadiness" for the same two subjects, also averaged for 20 days. The steadiness was measured by having the subject try to place a stylus in a small hole without touching its sides; when the stylus touched the sides of the hole, an electric circuit was closed. The numbers at the left in the bottom chart are units of an arbitrary scale. Here again one subject made his best steadiness score at noon; the other, late in the afternoon.



grown she will revert to the evening type. Of course it is relatively easy to shift the peak of body temperature and alertness to conform with a change in sunrise. Ship travelers crossing the Atlantic eastward find themselves getting up later and going to bed later from day to day as they pass to new time zones. When a traveler crosses the Atlantic by plane overnight, adjustment to the sudden five-hour shift in time is harder, but it takes only a day or two for his diurnal body-temperature curve to swing to the new time schedule.

WHAT is the mechanism by which this rhythm is established and maintained? It cannot lie solely in the nervous system, for the fluctuations of body temperature are far too small to influence markedly the rate at which the nervous system performs. The fluctuations arise mainly from variations in muscular activity. The body muscles and the cerebral cortex act as a mutual feedback circuit, for the muscles are not only doers but feelers. Muscle sense, truly a sixth sense, signals to the brain information about the position and activity of the body. Messages concerning the tonus of the muscles, which are under tension even when they merely maintain the body's posture, heighten the brain's level of activity and lead to a greater discharge from the cortex to the muscles. This in turn stimulates the muscles further. As muscle tonus rises, so does body temperature. Sooner or later, however, muscular fatigue stops this *crescendo*. The muscles begin to relax, and the cycle turns downward, bringing a *diminuendo* in cortical activity, alertness and body temperature. In fact, at any time of the day muscular relaxation, intentional or accidental, will cause a fall in body temperature and make it hard to stay awake.

In going to bed at night we lie down on a soft couch to relax our muscles, but this does not necessarily shut off stimulation. Any sort of emotional excitement, worry, anxiety or just thinking serves to keep the muscles tense. Under these conditions "trying" to go to sleep only makes matters worse. To fall asleep we must relax the muscles by laying aside disturbing thoughts. For this there are many familiar and tested devices: taking a hot bath, prolonged grooming (by women), reading indifferent material, reciting familiar prayers, counting imaginary sheep and (for children) the reassurance of being tucked in and kissed goodnight by a kindly parent or nurse.

What makes the conformist wake up every morning at precisely the same time and become sleepy at his customary bedtime? To put it another way: What regulates his diurnal rhythm of muscle tonus? It is tempting to suspect the pituitary gland, which is conveniently located close to the hypothalamus and is known to control several other daily rhythms in vertebrates. For example, the University of Wyoming zoologists H. Rahn and F. Rosendale found that removal of this gland from the *Anolis* lizard, which is usually bright green at night and dark brown in the daytime, makes the animal permanently green. The pituitary, often called the master gland of the body, influences the activity of nearly all the other endocrine glands, among them the adrenal cortex. There is some evidence of a diurnal variation in the functioning of the adrenal cortex. Our rhythm of wakefulness and sleep is started by conditioning of the nervous system, but it may end up as an endocrine rhythm, which both fortifies and is fortified by the nervous rhythm.

It is interesting to note that the seasonal disappearance of the cycle of darkness and light in the Arctic has little or no effect upon this rhythm. In civilized communities of northern Norway, where for weeks the sun does not set in summer nor rise in winter, the sleep-wakefulness pattern of the population remains unchanged. The only variation is that people tend to go to bed an hour later in summer than in winter and manage to get through the day on an hour's less sleep.

THE round-the-clock needs of society of course require that many people follow an unconventional routine, working in the hours when most of us sleep. The number of night workers is not small: it includes myriads of people in transportation, communications, police and fire protection, hospitals, public utilities, industry and the military services. Some individuals prefer to work at night, but for most people this separation from the community pattern of living is unacceptable as a regular thing. As a result, it has become common practice to rotate workers between day and night shifts. Such a scheme will work well, however, only if a worker changes shifts no oftener than every four or six weeks, as it sometimes takes a week or so to swing into a new diurnal rhythm. It is essential to give him time to adjust to the new routine, for not only will he be more alert on the job, but the reversal of his body temperature rhythm will make it easier for him to sleep during the daytime.

Nathaniel Kleitman is professor of physiology at the University of Chicago.

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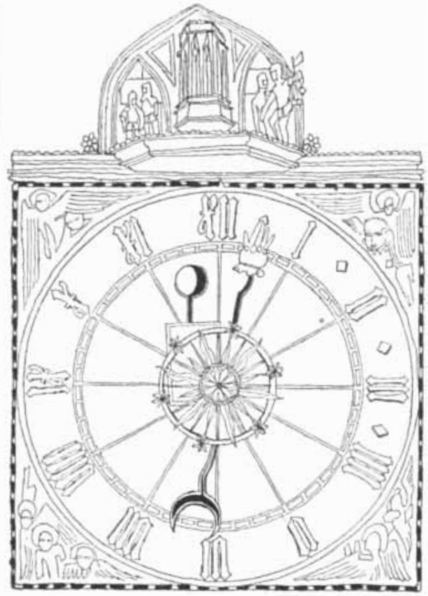

Insufficient Funds

MORE than half of the hospital beds in the U. S. are occupied by mental patients. Yet the nation spends only about $5 per hospitalized patient for research in mental health, as against nearly $100 per patient in poliomyelitis. In the fiscal year 1951 the Federal government provided $1.5 million for mental health research while it was spending $30 million on the study of hoof-and-mouth disease. Indignantly recapitulating these figures, the Yale University psychiatrist Lawrence S. Kubie exclaimed in a recent issue of *Science*: "Research in psychiatry is starving to death."

Kubie documented his thesis by comparing the research facilities available in psychiatric and medical units in hospitals. In one case the medical service had two-and-a-half times as many scientists and one-and-a-half times as many technicians per bed as a comparable psychiatric service, and allocated twice as much of its total budget to research. In another comparison the medical group had four times as many scientists and 13 times as many technicians per bed and spent 15 times as large a proportion of its budget for research.

Psychiatric research should receive much more money than other services instead of much less, said Kubie. He explained that a full research investigation of a single case could usefully occupy 15 to 20 psychiatrists, clinical psychologists and psychiatric social workers for at least a year. They would make simultaneous observations, take and analyze continuous recordings of the patient's conversation, observe him around the clock and investigate members of his family group and his home situation.

To reinforce his point that research is neglected, Kubie asserts that not one of the important discoveries in psychiatry during the past 50 years was made in the U. S.

Infant Training

THE idea that breast-fed babies grow up better adjusted than bottle babies, or that severe toilet training makes a child neurotic, gets no support from objective study of the matter. So reports William H. Sewell, professor of rural sociology at the University of Wisconsin, who examined 162 Wisconsin farm children to seek evidence on such questions.

Sewell's subjects were a group of children between five and six years old from similar family backgrounds. Information on their infant training was obtained through interviews with their mothers, and estimates of their personality adjustment came from a battery of psychological tests and from talks with their mothers and teachers.

The chief training practices with which Sewell concerned himself were: bottle *v.* breast feeding; schedule *v.* demand feeding; abrupt *v.* gradual weaning; early *v.* late bowel and bladder training; punishment *v.* no punishment for toilet accidents; sleeping with mother *v.* sleeping alone during the first year of life. He reports in *The American Journal of Sociology* that he could find no correlation between the way children had been reared and their general personality adjustment. There were a few specific correlations, some of them surprising, between certain practices and later behavior: children fed on demand had less feeling of belonging than those fed on schedule; those weaned gradually rated high in social standards and the feeling of belonging; late toilet training made for better tempers and less nail biting, but poorer school relations; lack of punishment for toilet accidents resulted in better social standards, school relations and social adjustment; sleeping with mother led to poorer self-adjustment and family relations and to more disturbed sleep. When Sewell rated each child's total training pattern, giving one point for each supposedly favorable training practice, he found no significant personality difference between children with high indices and those with low indices.

These results, Sewell concludes, "cast serious doubts on the validity of the psychoanalytic claims regarding the importance of the infant disciplines and on the efficacy of prescriptions based on them." Possibly, he concedes, "the crucial matter may be not the practices themselves but the whole personal-social situation in which they find their expression, including the attitudes and behavior of the mother." He suggests that this question needs further investigation.

I.Q. Order of the Professions

THE physical sciences attract the largest percentage of the best brains among college graduates in the U. S., according to a survey by the Commission on Human Resources and Advanced Training.

The Commission reviewed the scores made on the Army General Classification Test by graduates in 20 fields of specialization. On the basis of the median scores of those with bachelor's degrees in the various fields, the specialties ranked in the following order: physical sciences (except chemistry), chemistry, engineering, law, English, foreign languages, psychology, economics, geology and the earth sciences, biological sciences, fine arts, nursing, history, agriculture, business and commerce, humanities (except English and the foreign languages), social sciences (except history and economics), education, home economics, physical education. In graduate school the specialties lined up in approximately the same order, except that agriculture moved up to sixth place.

Considering only the very superior intellects (the top fifth of all graduate students), the physical sciences again get the lion's share. One out of every three physicists is of this caliber, compared with one of four in the arts and humanities and only one of 36 in physical education. On the other hand, of the lowest fifth of the graduate students nearly half are in education. This fact is attributed to the "low salaries and low prestige accorded to the nation's schoolteachers."

The report observes that while the fields reputed to demand the most abstract and rigorous thinking attract a higher average grade of students, every field receives some mediocre people and some of the very brightest.

100 Billion Volts?

PHYSICISTS at the Brookhaven National Laboratory have developed a new synchrotron technique which they believe may make possible the acceleration of particles to energies as high as 100 billion volts. Their method involves an improved means of controlling the path of particles as they are accelerated in the circular synchrotron. It will be described in a forthcoming paper in *The Physical Review* by Ernest D. Courant,

M. Stanley Livingston and Hartland S. Snyder. The article, called "The Strong-Focusing Synchrotron," will present plans for a 30-billion-volt machine.

What the Brookhaven workers propose is to change the nature of the magnetic field that guides particles around the synchrotron. Instead of making the magnetic field uniform around the whole track, they plan to split the field into many short sections of alternately converging and diverging force, whose net effect is strongly convergent. With this system of "magnetic lenses" they believe they will be able to keep particles within a pipe only one inch by two inches in cross section, whereas Brookhaven's cosmotron, the most powerful present accelerator, requires a pipe six inches high by 27 inches wide. The sharper beam will also greatly decrease the size of the magnet. The magnet of the three-billion-volt cosmotron weighs 2,200 tons; only half as large a magnet will be needed, the Brookhaven men estimate, for the new 30-billion-volt machine they propose. The circular track, however, will have to be 10 times as long as the 190-foot doughnut of the cosmotron. The machine also will need 72 oscillators to kick the particles along instead of only one. Its designers estimate that a 30-billion-volt model could be built for about twice the $8 million cost of the cosmotron.

Jumbo

FROM Stanford University comes word of a new vacuum tube that looks like a fire hydrant, consumes energy at the rate of 100 million watts and puts out as much power (in short bursts) as the entire supply of the city of San Francisco. The monster is a klystron, an ultra-high-frequency oscillator. Stanford plans to use 20 such tubes to speed the electrons in a billion-volt linear accelerator it is building.

The new klystron, with 400,000 volts applied at its cathode, puts out millionth-of-a-second pulses of energy at more than 15 million watts—some 10 times as much as the output of any other tube. The Stanford engineers believe that the power potential of a tube of this type is "practically unlimited."

Breeder Reactor

THE first description of the experimental breeder reactor of the Atomic Energy Commission at Arco, Idaho, was made public last month by W. H. Zinn, director of the Argonne National Laboratory.

The reactor's core of fissionable material is no larger than a football. It is surrounded by a blanket of U-238 which, by capturing excess neutrons from the core, is converted to fissionable plutonium. The chain-reacting core has no moderator; it operates with fast neu-

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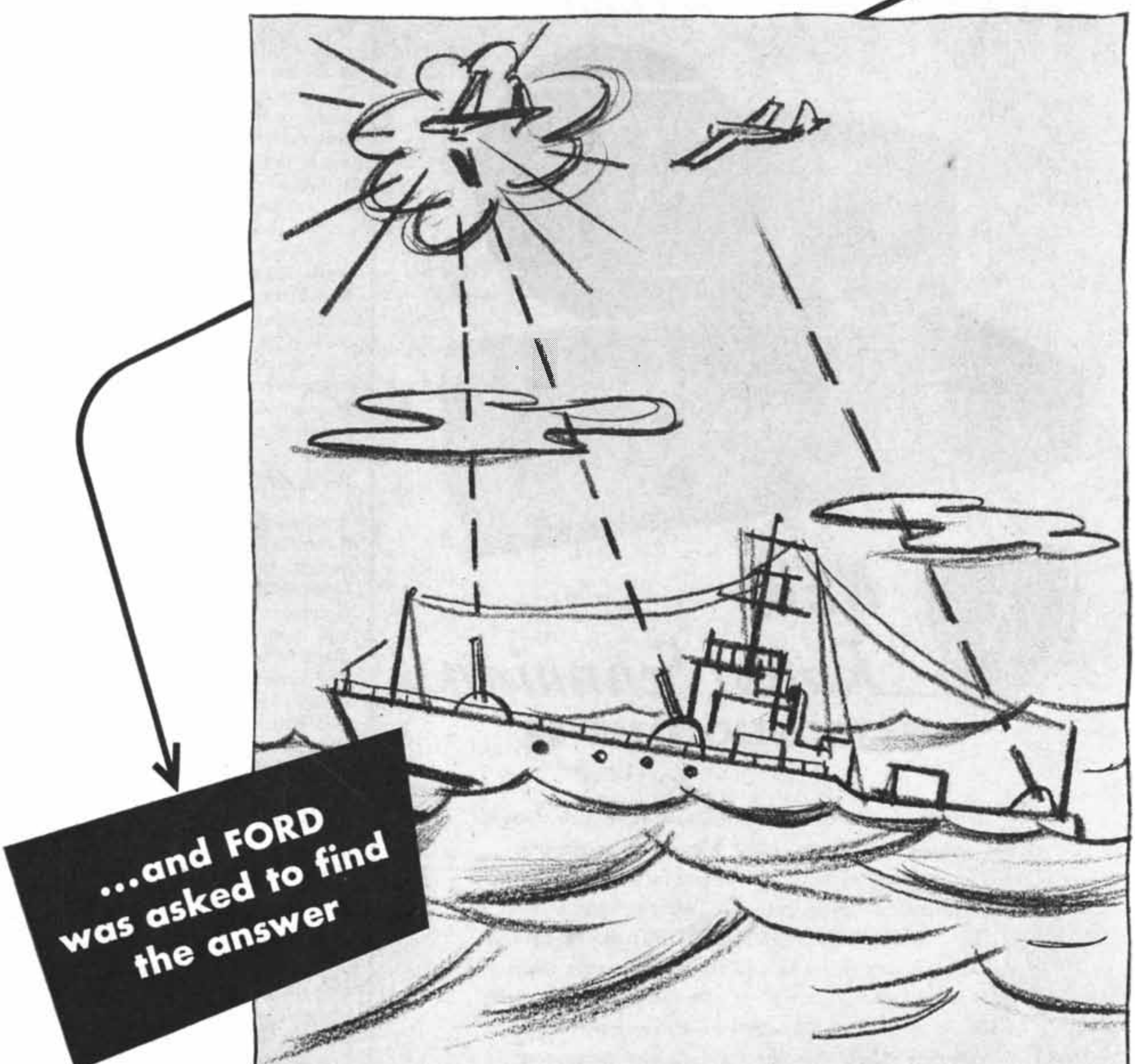

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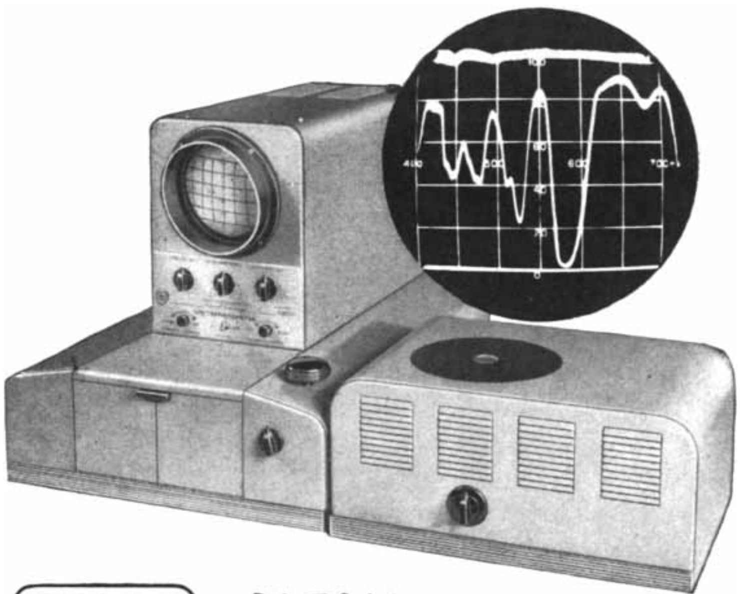


trons. Heat is taken from the core by a coolant consisting of an alloy of sodium and potassium which is liquid at room temperature. Because this alloy ignites on contact with air and explodes if mixed with water, it must be handled very carefully. The coolant flows through the blanket and then through the core. It leaves the core at a temperature of 660 degrees, flows to a heat exchanger and is pumped to a storage tank from which it returns to the reactor. The pump is electromagnetic and has no moving parts, packing gland or seal. From this system, which is enclosed in a concrete shield because of its high radioactivity, a second circuit of sodium-potassium coolant carries the heat to a steam generator. The steam runs a turbogenerator.

The capacity of the unit is 250 kilowatts. Zinn computes that this represents four kilowatts per cubic inch of reactor core—a far higher power output in proportion to space than in conventional combustion chambers. The neutron flux in the core is the highest of any known reactor: 650 million million fast neutrons per square inch per second.

New AEC Contractor

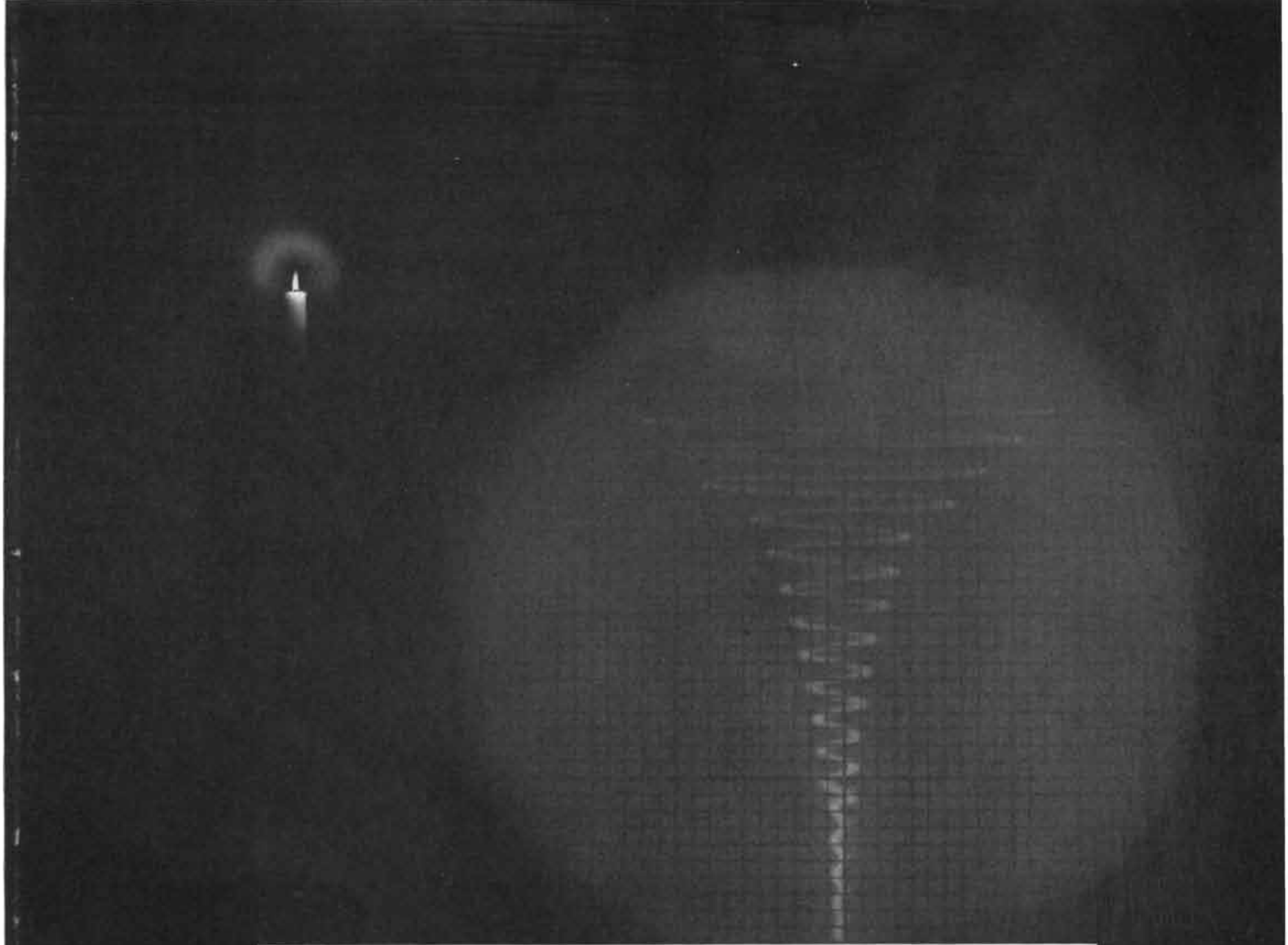
IN line with its policy of bringing additional U. S. industries into the atomic energy program, the Atomic Energy Commission has announced that the Goodyear Tire and Rubber Company will operate the uranium separation plant to be built in Pike County, Ohio. The Union Carbide and Carbon Corporation, which operates the Oak Ridge and Paducah plants, will assist Goodyear in setting up the new facility and in training key personnel.

Building Proteins

BIOCHEMISTS have supposed that the body builds proteins by combining amino acids, the so-called "building blocks" into which a protein molecule breaks down. Researchers at Washington University in St. Louis now find that this may not be the case. The plant physiologist Barry Commoner reported recently to the American Institute of Biological Sciences that the tobacco mosaic virus, a large protein molecule, reproduces itself with nitrogen atoms obtained directly from the simple inorganic compound ammonia. He said: "The studies show that the living cell must possess hitherto unsuspected machinery" that puts together "the enormous and elaborate virus molecule in one blow instead of by hitching up previously assembled amino acid sub-units."

Chemists in Atlantic City

AT its 122nd national meeting last month the American Chemical Society heard more than 1,000 papers in 19 specialized sections. The Society's



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chief concern, however, was the increasing shortage of chemists. Its Committee on Manpower reported that the number of students receiving bachelor's degrees in chemistry next year will drop to 5,300 —less than half the 1949-50 peak, and many of the new graduates are slated for military service. Ralph A. Connor, chairman of the Committee, urged industry and the armed services to make the most intelligent and economical use of technical personnel. Local chapters of the Society were asked to make efforts to recruit more high school students into chemistry.

The technical sessions featured a number of large symposia on such topics as nuclear and paramagnetic resonance, very fast reactions, methods of screening large numbers of compounds for tumor-inhibiting properties, new weed killers, chemistry of fluorine compounds and catalysis in petroleum chemistry.

Waclaw Szybalski and Vernon Bryson, of the Cold Spring Harbor biological laboratories, reported that in laboratory experiments tuberculosis bacilli developed resistance to the new drug isoniazid 1,000 times faster than they did to streptomycin. Szybalski suggested that both drugs should be used together to wipe out the bacteria and prevent resistant strains from developing.

Astronomers in Rome

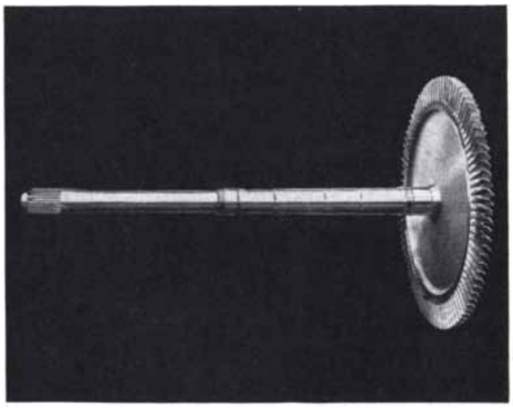
THE International Astronomical Union held its eighth general assembly in Rome last month, with 35 countries represented.

Harlow Shapley of Harvard University reported that the Milky Way may be larger than has been supposed. Observers have found a sparse "corona" of stars extending out to 25,000 light-years beyond the previously seen limits of the galaxy. The corona does not rotate with the inner disk, but it is nevertheless a part of our galaxy. It extends the total diameter of the Milky Way disk to about 150,000 light-years.

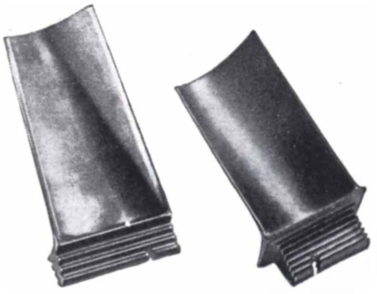
The first radio stars to be seen with a telescope were reported by Walter Baade, chief observer on Palomar Mountain. He said the 200-inch telescope had photographed two of the most important radio stars, one in the constellation Cygnus and the other in Cassiopeia. Some 100 sources of radio radiation have been detected in the sky; until Baade's observation it was not known whether such radiation comes from stars or clouds of interstellar material.

Soviet astronomers at the congress declared that their country is free of flying saucers. Boris Kukarkin called them "optical illusions" and products of "pure war psychosis."

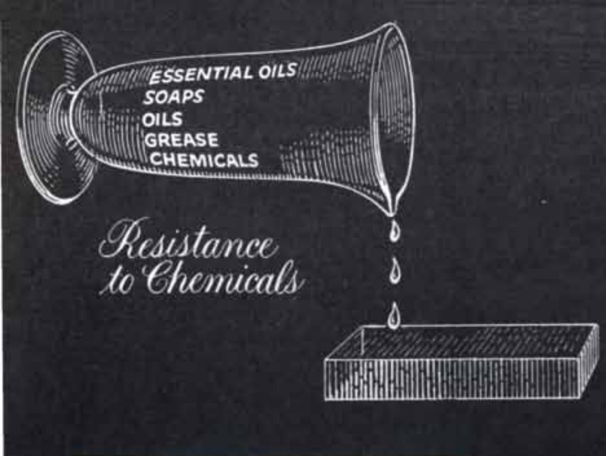
The congress considered a proposal from the International Bureau of Weights and Measures to change the standard of time. The present astronomical check period is the mean solar day.

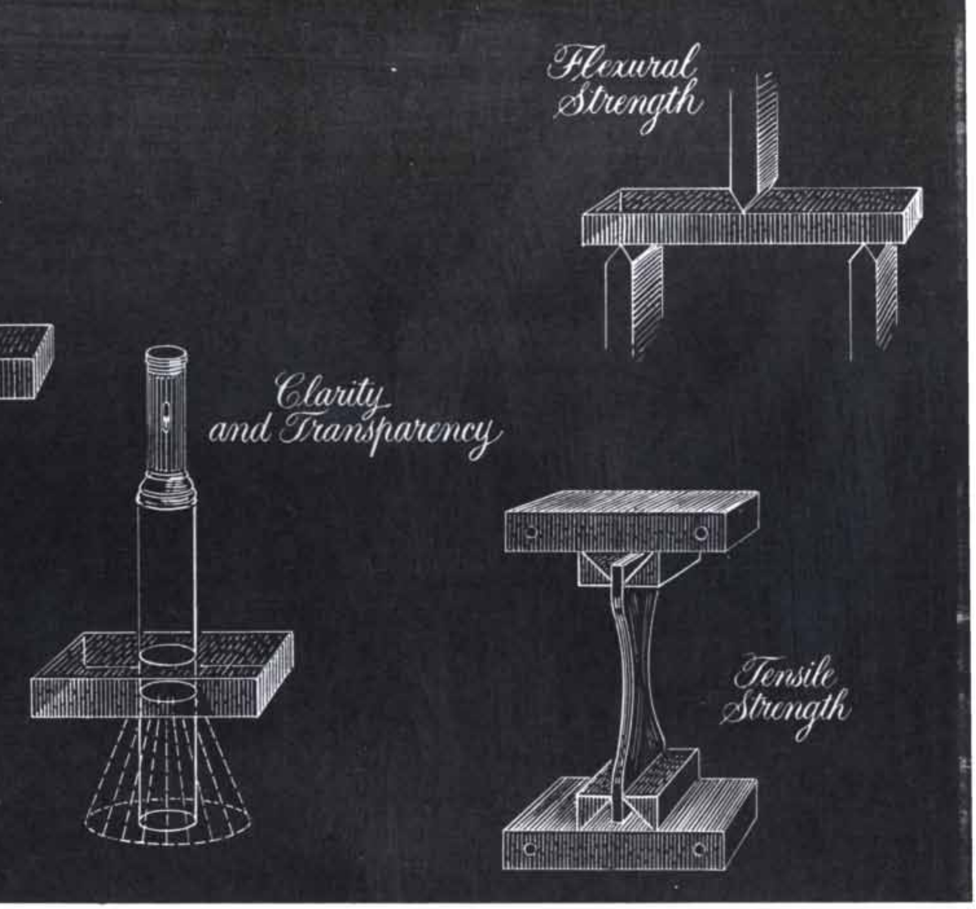


Turbine Wheel for Jet Engine.



Buckets for Turbine Wheel.



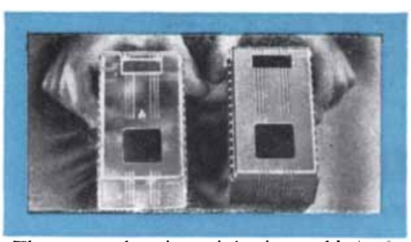


The Hannifin "Air Warden" filter-regulator-lubricator for air-driven equipment has bowls of tough, transparent BAKELITE C-11 plastic. One holds water with impurities collected from the air. The other, lubricating oil for atomizing into air stream. They withstand temperatures up to 125°F., air pressure of 150 psi.

Molded by E. Mills Corp., Chicago, Ill., for Hannifin Corp., Chicago, Ill.

These sturdy, colorful dishes molded of BAKELITE C-11 plastics are light in weight, low in cost. They resist breakage, staining, attack by foods, soaps and detergents, heat and cold.

Made by Gits Molding Corporation, Chicago, Illinois.



Thermostat housings, injection-molded of BAKELITE C-11 plastic, have good detail, impact strength, smooth finish. Easily spray-coated with metallic paint. Easy moldability reduces production cost and mold maintenance.

Made by Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

This transparent protective cover used on levels made by the Empire Level Mfg. Co. is BAKELITE C-11 plastic. It provides a neat, attractive appearance, high mechanical strength, less chance of breakage if dropped.

Made by National Lock Co., Rockford, Ill., for Empire Level Mfg. Co., Milwaukee, Wis.

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In addition to the applications illustrated, C-11 materials are employed for high-quality drafting instruments requiring dimensional stability. Other uses include containers and closures for the packaging of products made with essential oils mixed with non-volatile diluents.

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This standard is unsatisfactory because of a gradual slowing up of the earth's rate of rotation (about one hundredth of a second per century) and because of periodic unexplained and unpredictable variations. The astronomers recommended that the sidereal year be adopted as the standard. This is the time of one complete rotation of the earth about the sun as measured with respect to the fixed stars.

The British astronomer R. A. Lyttleton outlined a new theory about double stars. He said they begin as widely separated pairs of small stars, pick up interstellar hydrogen in their passage through space, draw closer together as they become heavier, and eventually merge into a single star. Lyttleton's view opposes an older theory by James Jeans, who thought that binaries resulted from the rupture of a single star.

World's Oldest Town

WHEN the Israelites leveled the walls of Jericho they were merely adding another layer of rubble to a site whose history goes far, far back of Joshua's time. The British archaeologist Kathleen M. Kenyon has recently uncovered evidence that Jericho is probably the oldest town in the world.

Writing in the British journal *Antiquity,* Dr. Kenyon reports that her group excavated a stone-age town whose inhabitants, though they had not yet learned to make pottery, built mud-brick houses and surrounded their settlement with a substantial stone wall. Dr. Kenyon places the settlement "well back in the fourth millennium, if not earlier." Similarities in technological development suggest that the town may have been roughly contemporaneous with the village at Jarmo, in Iraq, described in last month's SCIENTIFIC AMERICAN ("From Cave to Village," by Robert J. Braidwood).

Good Race Relations

BRAZIL, with a mixed population of European whites, African Negroes, aboriginal Indians and mixtures in between, has long been regarded as an almost ideal example of interracial harmony. Last year UNESCO undertook a broad study of Brazil's race relations "to draw a lesson" for other countries. The results were summarized in the last issue of its journal, *Courier.*

The investigators found that discrimination is not unknown in Brazil, but it is based primarily on economic and educational distinctions. The Negroes descend from a slave class that was not freed until 1888 and are just emerging from the poverty, ignorance and menial occupations of their forefathers. Those who succeed in getting an education find that the opportunity for economic advancement and social acceptance by white society is much greater than in most other countries.

Brazil has no color line but an almost continuous racial spectrum from white to black. Brazilians are intensely conscious of color. They speak of "that dark mulatto" as people in the U. S. might say "that tall, thin fellow." But this intense awareness of pigmentation is not accompanied by a corresponding intensity of prejudice or discrimination. Social intercourse and marriage between close neighbors in the color spectrum is common.

Conflicts and active prejudice have recently cropped up in some of the larger cities, notably Sao Paulo and Rio de Janeiro. These tendencies are being countered, says sociologist Alfred Métraux, "by a strong resistance based on liberal and open-hearted traditions."

The Birds and the Flowers

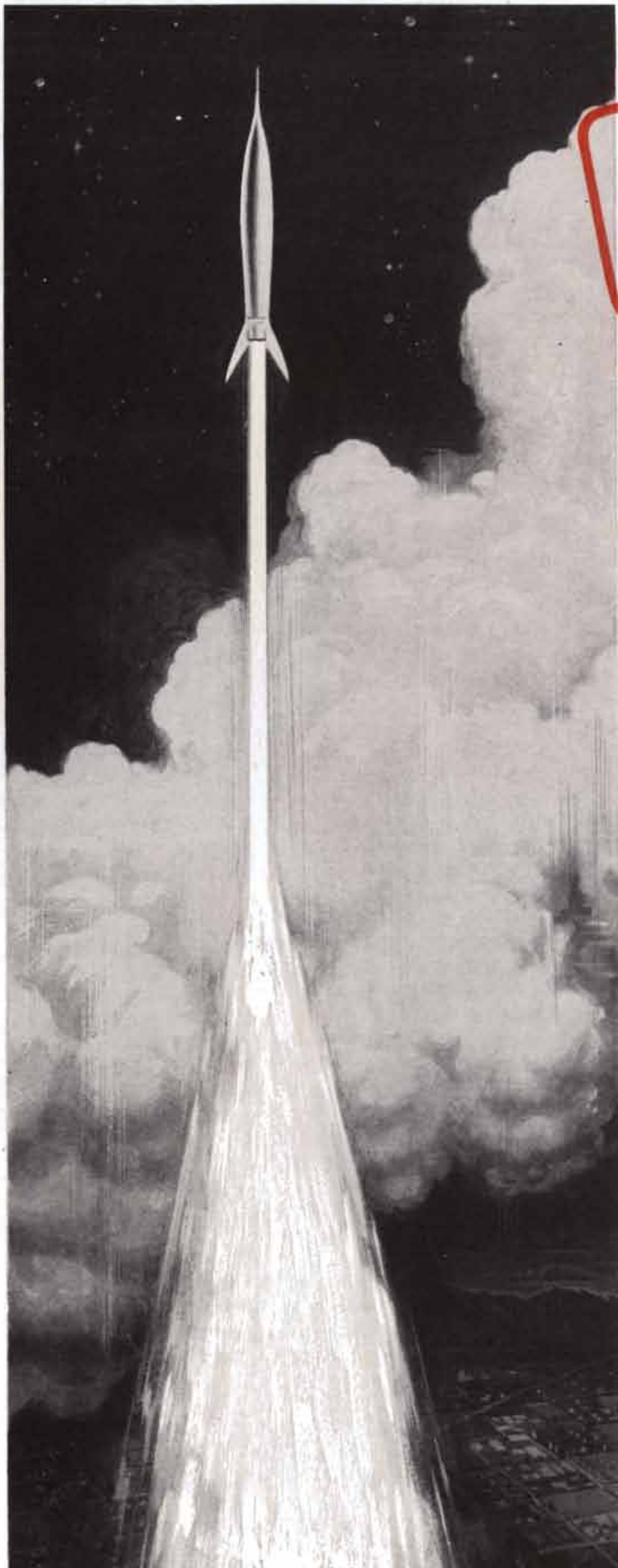
THAT the length of day—photoperiodism—governs flowering and reproduction in plants has been known for some time ("The Control of Flowering," by Aubrey W. Naylor; SCIENTIFIC AMERICAN, May). Biologists have wondered whether photoperiodism also controls the reproductive life of animals. Charles M. Kirkpatrick and A. Carl Leopold of Purdue University concentrated on the bobwhite quail. They are now able to report that the quail is indeed photoperiodic. It is a long-day bird: it matures sexually only when the light period is long and the dark period is short.

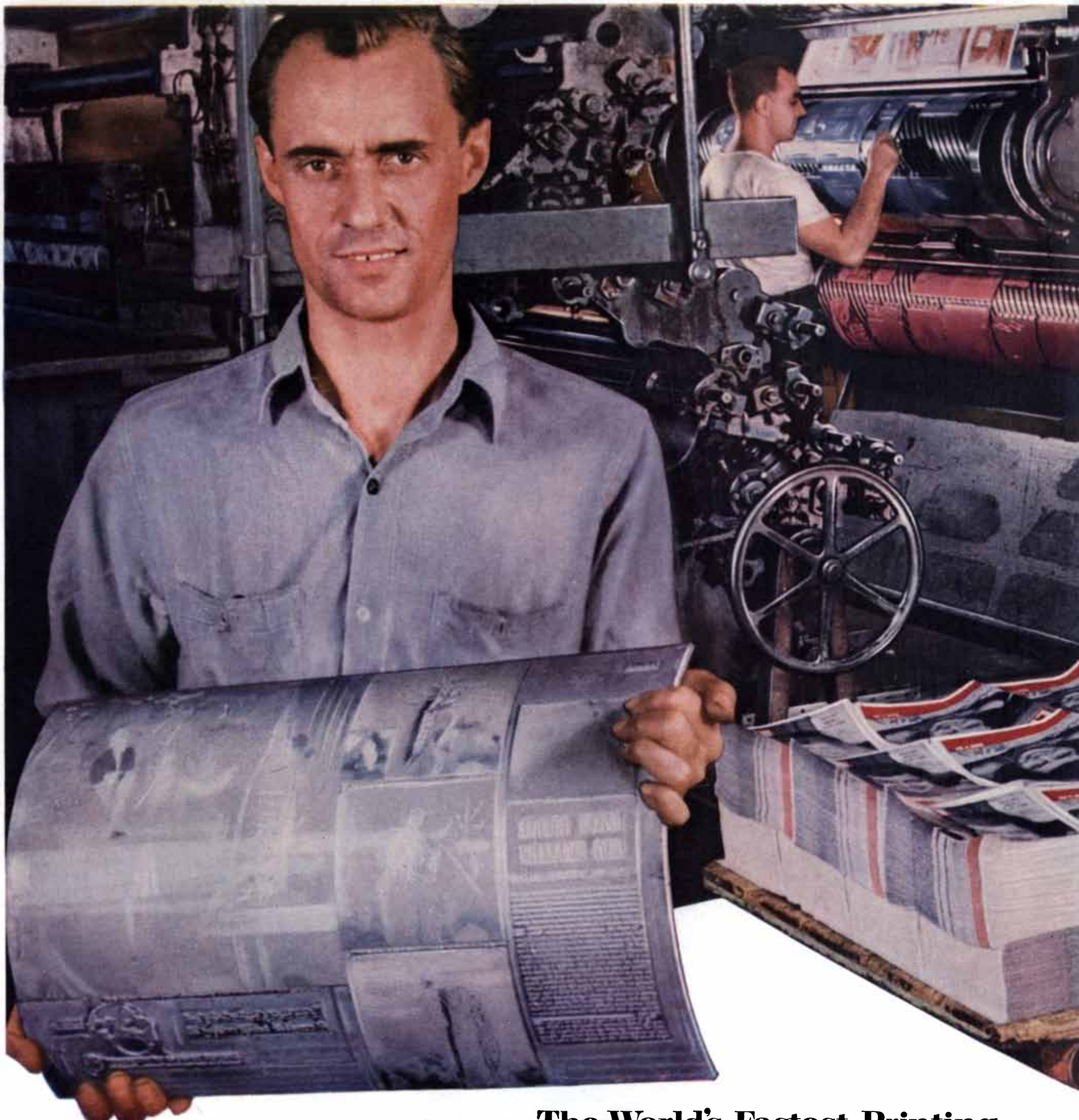
Their research technique was the same as that used in studying plants—interruption of the dark period. Their birds were divided into five groups: one kept on a long day (17 hours), one on a short day (10 hours), the other three on a short day (9 hours) with an hour's interruption of light at different times during the night. After 37 days the birds were examined for sexual development—the females for eggs, the males for spermatozoa. The only birds that had not produced these cells were those kept on a short day with an uninterrupted period of 14 hours of darkness.

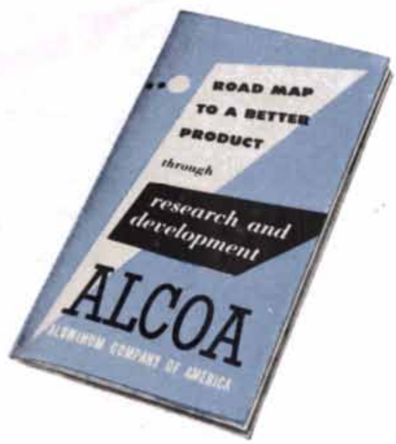
Noble Experiment

INVESTIGATORS at the Stanford University Medical School recently conducted an experiment with three men and a woman as subjects. Every hour for several days they served alcoholic drinks to their subjects. At night, to avoid undue inconvenience, they served triple doses and woke the subjects only twice.

The purpose of this strenuous regime was to determine how much alcohol an average man can metabolize in 24 hours. The best performer, a 39-year-old alcoholic weighing 68.2 kilograms, disposed of the equivalent of 760 milliliters of bottled-in-bond—just about a fifth.







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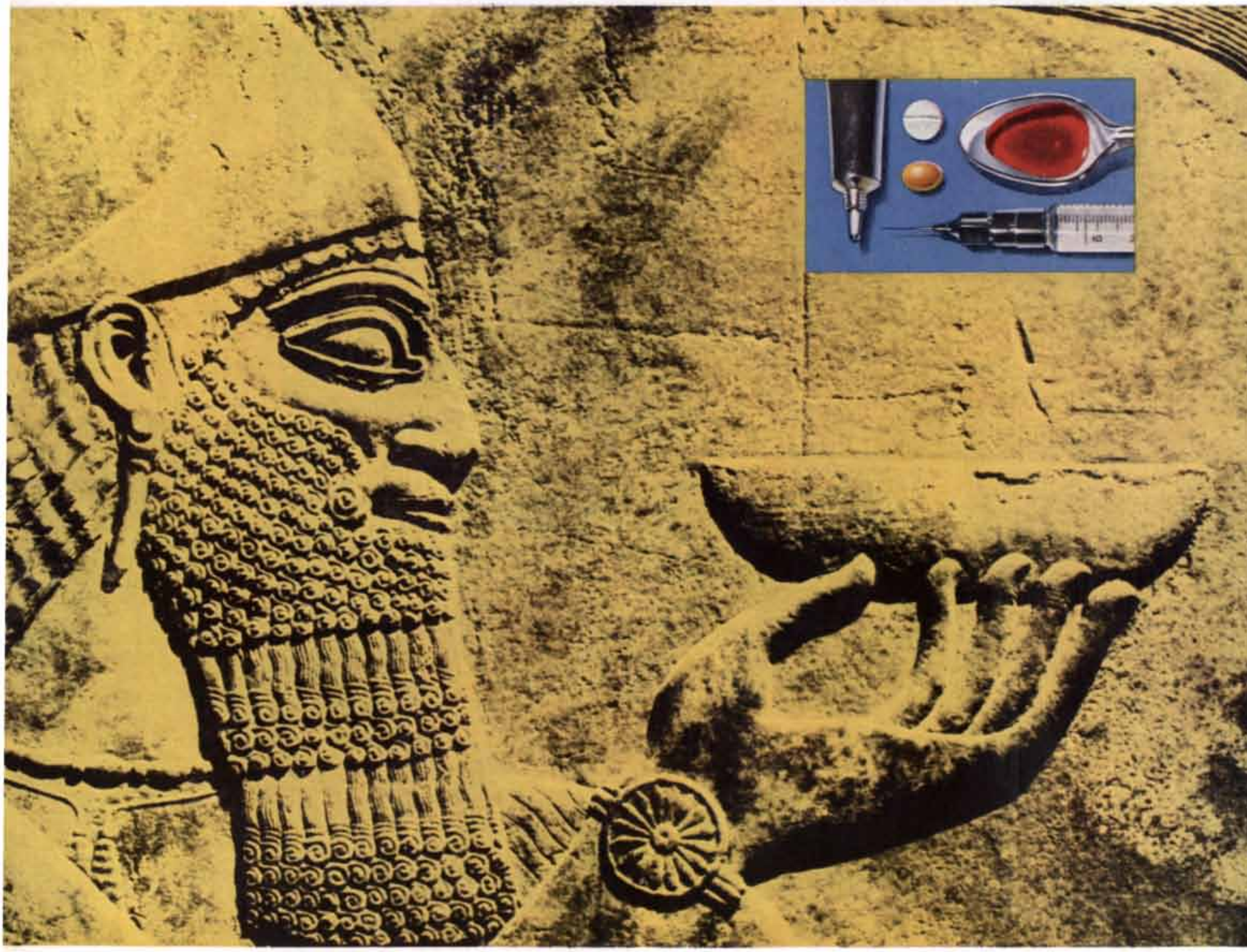


THE NERVE IMPULSE

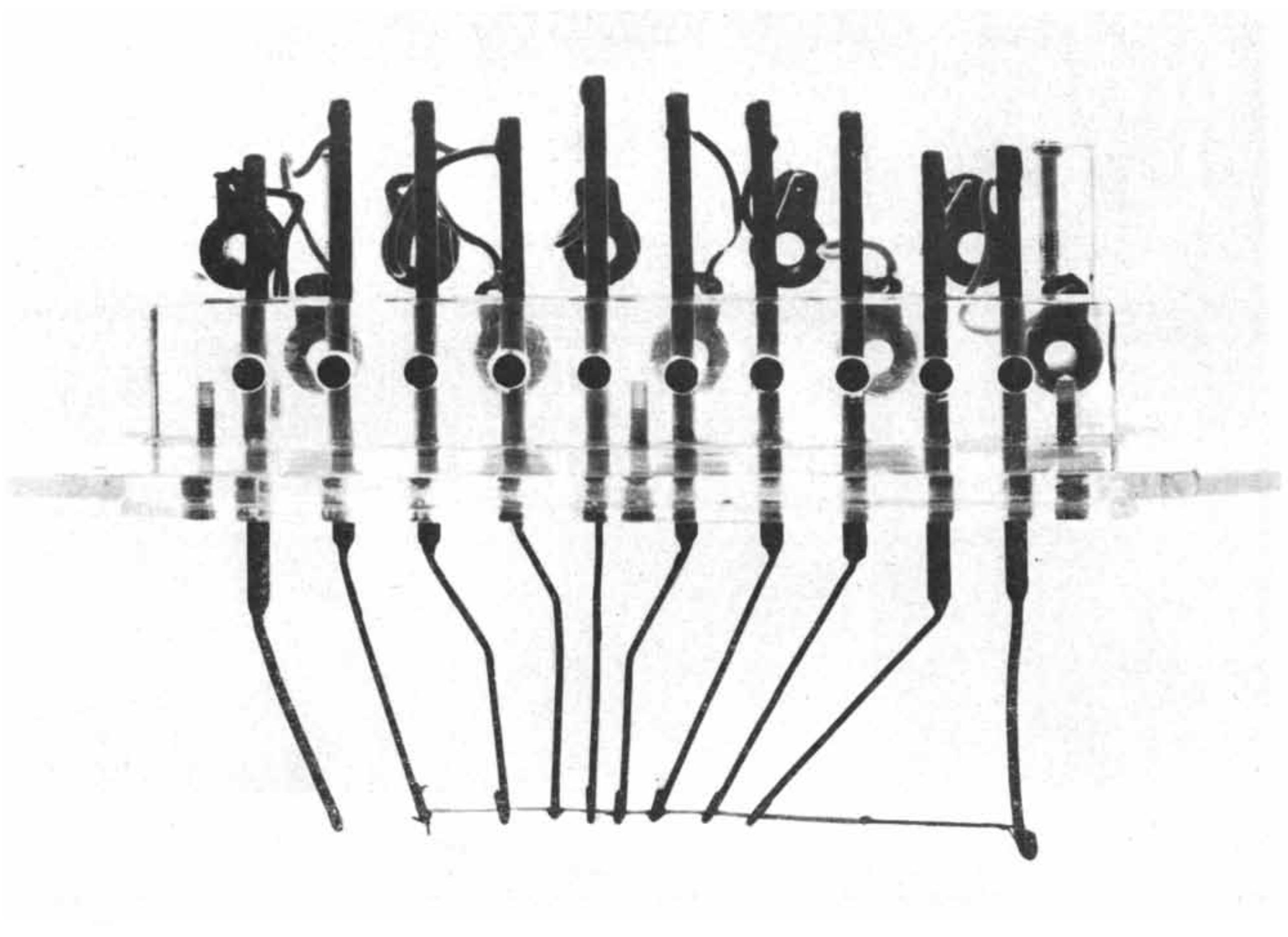
How do living things transmit electrical signals with equipment composed largely of water? Although there is disagreement on some features of the process, much has been learned about it

by Bernhard Katz

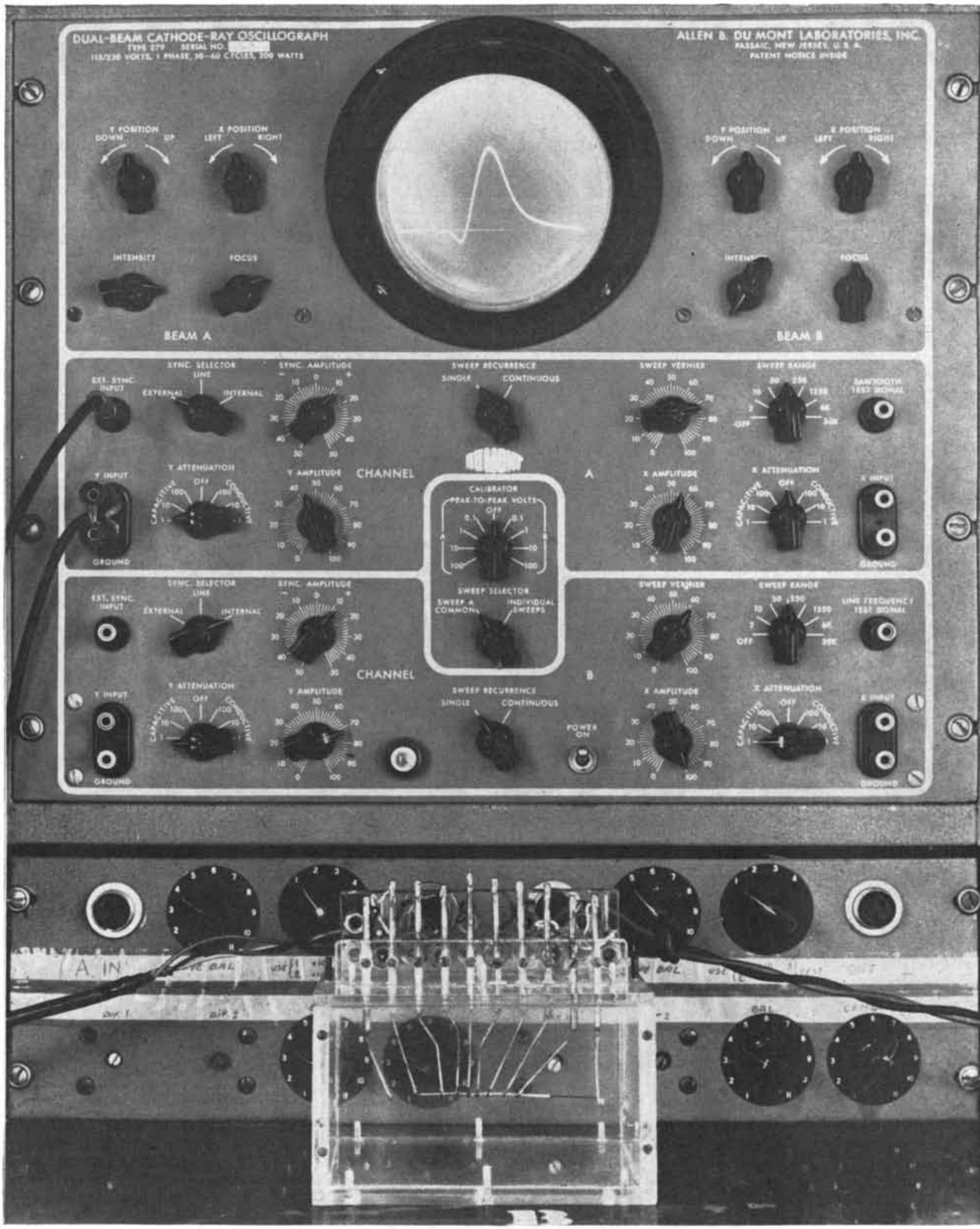
THE LIFE of an organism, like that of organized society, depends upon its system of communication. The remarkable instruments of communication that integrate our civilization—the telephone, telegraph, radio, television—are much less remarkable than the communications system that integrates a human being. Our nervous system has powerful transmitting equipment, sensitive receivers, trunk lines connecting distant points in the body, a central exchange which sorts and coordinates messages. It transmits messages to all parts of the body reliably and rapidly—often in a small fraction of a second. Yet nature has managed to produce this elaborate and efficient signaling system in a most peculiar and implausible way: it is a system built up in minute spaces out of seemingly unsuitable materials (mostly water) and completely devoid of electric wires, radio tubes or the like.

How the human nervous system works is still largely a mystery. But one feature of it is now fairly well understood, and this article will concentrate on that feature. We shall consider how the nerves carry a message—what is commonly known as the "nerve impulse."

The story begins on that September evening in 1786 when Luigi Galvani, professor of anatomy at the University of Bologna, discovered accidentally that a frog's leg touching an iron railing propagated an electric current. The mean-



SCIATIC NERVE of a frog is mounted for the study of its electrical properties. The apparatus consists of 10 electrodes set in transparent plastic. In the hooked ends of the electrodes at the bottom lies the nerve. Tied with thread, it extends from the second electrode to about halfway between the ninth and tenth (*at the right*).



OSCILLOSCOPE is used at the Columbia University College of Physicians and Surgeons to study the frog sciatic-nerve preparation depicted on the preceding page. The electrodes holding the nerve have been set in the transparent plastic box at the bottom. In order to establish the electrical circuit necessary to study the nerve, two pairs of electrodes must be connected to it. Here eight electrodes are in contact with the nerve, but only four of them are connected to the oscilloscope by the wires at the lower left and the lower right. The other electrodes may also be connected, however, to study various segments of the nerve. The trace on the cathode-ray tube at the top indicates a monophasic nerve impulse (*see photographs of nerve potentials on page 62*).

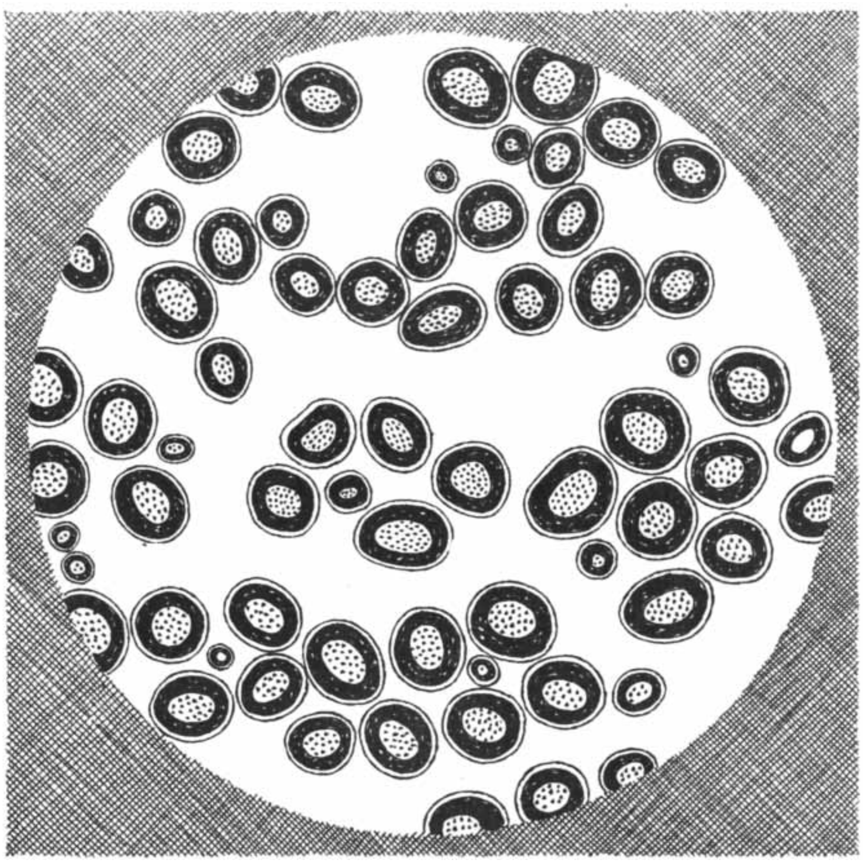
ing of this observation became a matter of fierce dispute between Galvani and the physicist Alessandro Volta, and not until some 60 years later was it clearly proved that nerve and muscle cells actually possess electrical charge and are capable of generating an electric current. Carlo Matteucci of Pisa and Emil Du Bois-Reymond of Berlin managed to measure and study these tiny electric currents with galvanometers. But the transient electrical changes that take place at any one point of a nerve fiber are so brief (no more than a few thousandths of a second) that no really precise measurement of them was possible until the development of the modern rapid oscillograph and the cathode-ray tube.

The Nerve Signal

What do we see when we take an electric record of a nerve impulse? The usual procedure is to dissect a frog nerve and place it on two pairs of electrodes. One pair, the "transmitter," is used to stimulate the nerve with an electric pulse; the other pair, the "receiver," is applied at various remote points along the nerve to find out what happens to the velocity and strength of the signal as it travels along. Nowadays we employ an electrostatic cathode-ray tube on which the signal appears as a deflection of some point on a horizontal luminous line which serves as a "time base," so that we get an accurate measurement of the elapsed time of the signal's journey from the transmitting to the receiving point.

We apply a brief electric shock to the nerve from our stimulating electrodes and gradually increase its strength. When it reaches a certain strength, known as the "threshold," we suddenly see an electric wave recorded on the oscilloscope. It arrives after a delay which represents the time the signal has spent in traveling along the nerve from the first to the second pair of electrodes. The signal travels at constant velocity, as we can show by receiving it at various distances from the source. In a frog's motor nerve the speed of travel is about 60 to 100 feet per second; in the fastest fibers of warm-blooded animals the nerve impulse may travel as fast as 300 feet per second.

Now if we strengthen the electrical stimulus, the strength of the signal transmitted by the nerve will also increase—up to a certain maximum. This would suggest that the response of a nerve may vary in degree. But the frog nerve in our experiment is made up of thousands of small nerve fibers, packed tightly together in a bundle. Many years ago some physiologists suggested that the variable size of the response might be due simply to variations in the number of fibers brought into play; they argued that an



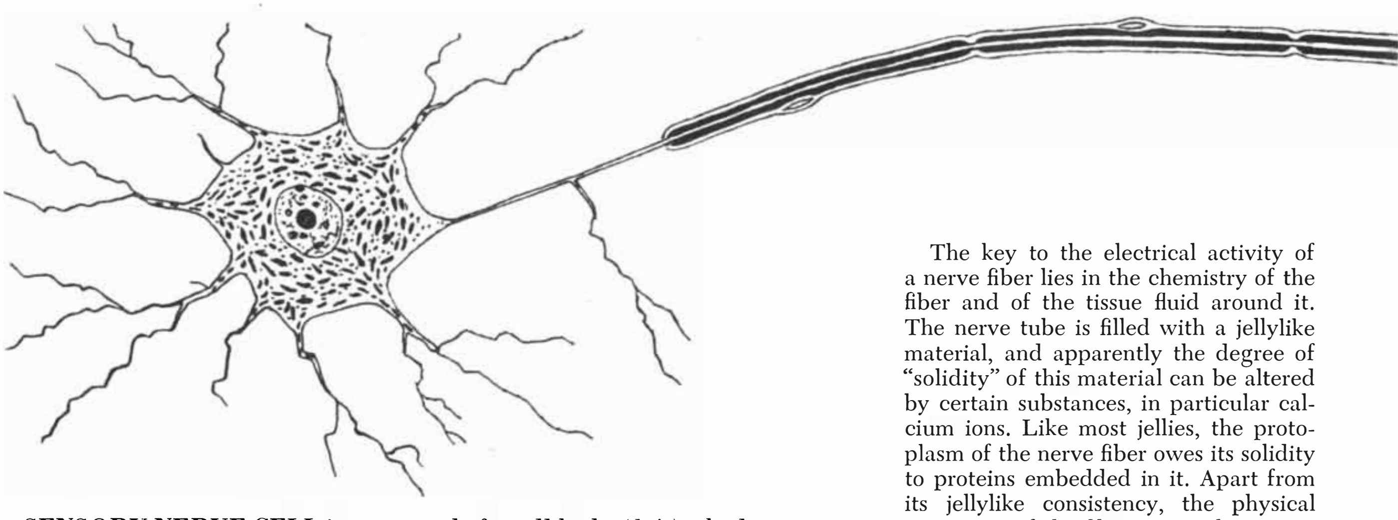
NERVE is composed of many fibers, each the axone of a nerve cell. This drawing shows the fibers in a section across the sciatic nerve of a cat.

individual fiber probably responded in an "all-or-nothing" fashion—as a match, on being struck, either lights or does not light, depending on whether it has reached the kindling point. Clearly the question could be settled only by investigating the reaction of a single, isolated nerve fiber. Among the first to do this were E. D. Adrian and B. C. Matthews of Cambridge University and D. W. Bronk of Philadelphia, who managed to isolate single fibers under the dissecting microscope. Later it was discovered that some animals, notably the squid, possessed giant nerve fibers which could be studied more easily. And in recent years the physiologist R. W. Gerard and his colleagues at the University of Chicago have developed an ingenious technique for studying the responses of single fibers without going to the trouble of dissecting and isolating them; they use as electrodes submicroscopic micropipettes which can be inserted into a small individual fiber.

What does the experiment on a single fiber show? We insert the tip of a micropipette into the surface of the fiber and find that the fiber interior is electrically charged—some 80 to 90 thousandths of a volt negative with respect to the outside bath. We now apply a brief electric stimulus. Up to a certain strength, there is no response. But as soon as the strength of the stimulus exceeds the "threshold" of our fiber, we observe a large electrical wave. The strength of the response is about 130 thousandths of a volt. Now no matter how much we increase the strength of our stimulus, the size and shape of the electric response is always exactly the same. It is either there in full strength or not there at all. Clearly, then, the propagated impulse in a single fiber is an all-or-none event—a triggered process which is set off like an explosion when the stimulus exceeds the "ignition point" of the fiber.

Thus we have our first solid clue to the nature of the nerve message. It is a standard impulse which in many ways resembles the dot of an elementary communication code. All complicated messages are composed of patterns of the standard dots. To overcome the limitations imposed by this rather rigid and stereotyped system, we have been supplied with a vast number of separate communication channels—many thousands of nerve fibers running side by side in each bundle. The meaning of a composite nerve message depends primarily upon the particular "private lines" that have been selected and upon their peripheral and central connections. Within any single fiber the meaning can be varied only by selecting a suitable pattern of intervals between successive dots.

By a variation of our experiment we



SENSORY NERVE CELL is composed of a cell body (*left*), the long process of the axone and nerve endings (*right*). The cell shown in this schematic drawing is medullated, *i.e.*, its axone is covered with a segmented sheath.

can elucidate a second important fact about the nerve impulse. We apply two electric shocks to a nerve fiber in rapid succession. If the second stimulus comes within one or two thousandths of a second after the first, our nerve fiber does not respond: it must have a little rest pause after one impulse to be able to conduct the next. This short period of enforced silence, known as the "refractory period," imposes some interesting limitations upon the practical use to which we may put our nervous communication channels. For example, because of the refractory period a nerve fiber normally can carry only one-way traffic. Any impulses that happened to travel in opposite directions would be stopped and extinguished at the point where they met, for each impulse would have left in its wake a refractory region which could not be traversed by its advancing opposite number. But of course our nervous system is designed to overcome this difficulty; it is supplied with a multitude of channels, so that messages can flow without embarrassment in different directions and to many diverse stations.

The nerve impulse, then, is an electrical signal fired along a nerve fiber. What is the source of electricity? How do we keep the batteries of our cells charged throughout the years of our life? And how exactly does the electric current propagate itself along the whole length of a nerve? During recent years much work has been devoted to these questions in many countries, and we have a good part of the answer.

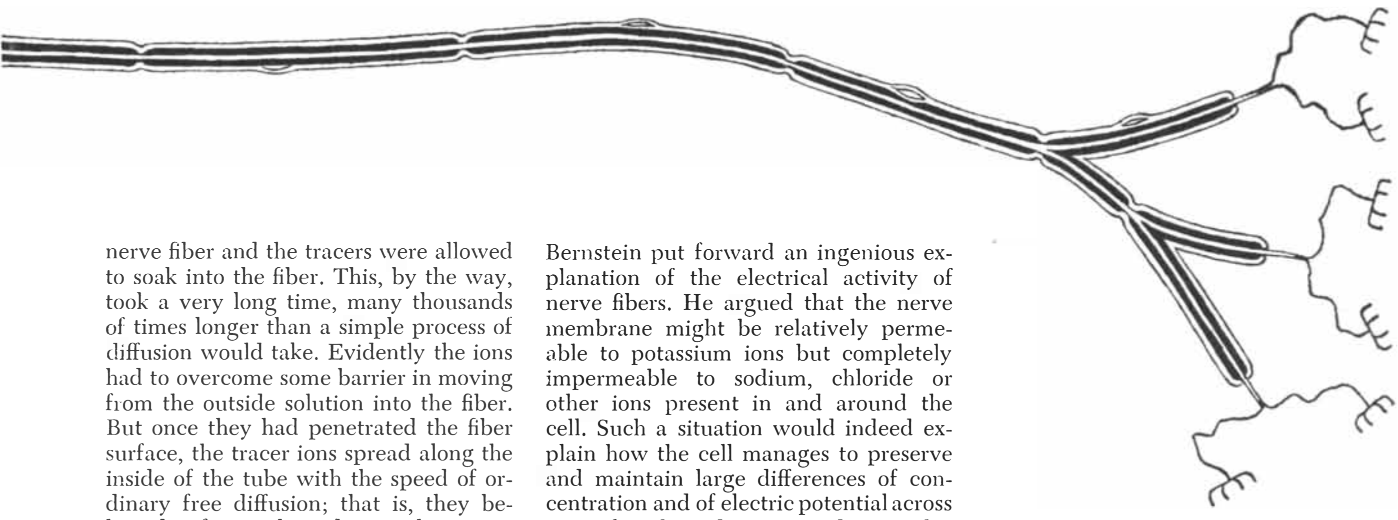
A Relay System

Some 80 years ago a German physiologist named L. Hermann put forward a remarkable theory. It was known that an electric current could excite nerve tissue and that excited nerve tissue could generate electric current. Putting these two facts together, Hermann suggested that a nerve message travels by steps: a stimulated portion of nerve generates electric current which in turn excites the next portion of nerve which again generates current, and so a wave of electric excitation travels right down to the end of the nerve, much as the process of ignition travels along the length of a fuse by local point-to-point excitation. Hermann's intuitive idea is now known to be correct, and much recent research has been done on the mechanism of the process by which the wave of excitation propagates itself.

A nerve fiber, or axone, is a very long thin tube which grows as a tentacle from a cell body in the brain or spinal cord to make contact with some distant point, such as a muscle or the skin. The fibers vary from less than a 30 thousandth to a thirtieth of an inch in diameter; most human motor and sensory fibers are about a thousandth of an inch thick. In the limbs of large animals the fibers reach a length of several feet. To the electrical engineer this is nothing out of the ordinary; transmission wires or cables are of course many millions of times as long as they are thick. But it is quite a different matter for a microscopic cell body to grow such enormously extended processes and to be responsible for their continued care and maintenance! And there is no doubt that the small cell body, hidden somewhere in the spinal cord, continues to look after the long fiber that belongs to it, for any injury which interrupts the connection to the parent cell causes the whole of the fiber beyond the cut-off point to become inexcitable and die within a few days. Evidently the life of a nerve fiber depends on some physical or chemical principle continually transmitted from the parent cell, but what this is we do not know, and it remains one of our baffling problems.

The key to the electrical activity of a nerve fiber lies in the chemistry of the fiber and of the tissue fluid around it. The nerve tube is filled with a jellylike material, and apparently the degree of "solidity" of this material can be altered by certain substances, in particular calcium ions. Like most jellies, the protoplasm of the nerve fiber owes its solidity to proteins embedded in it. Apart from its jellylike consistency, the physical properties of the fiber material are very similar to those of the outside fluid. Both consist mostly of water with a small quantity of salt dissolved in it, and both are fairly good electrolytic conductors: ions move about at nearly the same speed in both materials. A nerve fiber is usually in osmotic equilibrium with its surroundings; that is, the concentration of dissolved particles inside and outside the fiber is approximately the same. If the salt solution on the outside is diluted a little, water enters the fiber and causes it to swell until a new osmotic equilibrium is re-established.

But in spite of this physical resemblance, the chemical make-up of the fiber interior differs greatly from that of the surrounding fluid. For example, the salt in the surrounding fluid is composed mostly (90 per cent) of sodium and chloride ions, whereas inside the fiber the ions are mainly potassium and various positively charged organic ions, with sodium and chloride amounting to less than 10 per cent. We are not surprised to find organic ions, for we know that the cell is a chemical factory which can manufacture various organic substances. But how are we to explain the nerve cell's preference for potassium over sodium? Naturally there have been several theories about this, and we are still far from final agreement on the matter. The most obvious thing to suggest is that potassium may have a special chemical affinity to the cell structure and be firmly bound by some of the protein material. This, however, cannot be the correct explanation, because potassium ions must be present as "free agents" inside the cell; otherwise it would be difficult to explain how the interior of the cell can exert its relatively high osmotic pressure or possess its relatively high electric conductivity. The Cambridge physiologists A. L. Hodgkin and R. D. Keynes have recently proved the mobility of the potassium ions by means of radioactive potassium tracers. A small drop of fluid containing radioactive potassium was placed on a



nerve fiber and the tracers were allowed to soak into the fiber. This, by the way, took a very long time, many thousands of times longer than a simple process of diffusion would take. Evidently the ions had to overcome some barrier in moving from the outside solution into the fiber. But once they had penetrated the fiber surface, the tracer ions spread along the inside of the tube with the speed of ordinary free diffusion; that is, they behaved as free, unbound ions. The matter was subjected to a further test by applying an electric potential difference along the axis of the nerve and watching the speed with which the labeled ions moved toward the cathode. The result of this experiment confirmed that the internal potassium ions were free electrical agents and moved without hindrance once they had got inside the cell.

Now there are two main classes of nerve fibers: one kind is enclosed in a "medullary" sheath, and the other lacks such a sheath. This experiment was performed on non-medullated fibers. These fibers are almost naked, and their surface is freely exposed to the surrounding tissue fluid. Yet the experiment shows that they must have some kind of membrane that acts as a highly resistant barrier to the movement of ions.

The Membrane

This nerve membrane is a fascinating object; it is probably the most delicate and most important part of the nerve cell, and the one most intimately connected with the transmission of signals along the fiber. It has vexed many scientists, however, and some have questioned its existence, because it has not been possible to demonstrate or identify it by direct optical means. It is probably a very thin surface layer made of fatty material only one or two molecules thick —so thin that it would be impossible to examine it even with the most powerful optical instruments. In spite of this disability several of its physical properties have been measured, and most nerve physiologists regard it as just as real, and just as indispensable to an understanding of nerve activity, as are the equally invisible atoms and electrons to understanding the properties of matter.

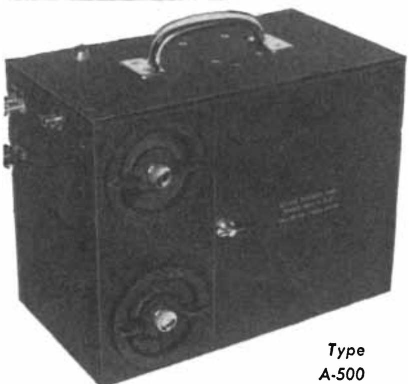
We know, for instance, that the surface membrane of the nerve fiber is "selectively permeable": it allows some chemical substances to pass much more readily than others. At the beginning of this century the German physiologist S. Bernstein put forward an ingenious explanation of the electrical activity of nerve fibers. He argued that the nerve membrane might be relatively permeable to potassium ions but completely impermeable to sodium, chloride or other ions present in and around the cell. Such a situation would indeed explain how the cell manages to preserve and maintain large differences of concentration and of electric potential across its surface boundary. According to this theory, potassium ions concentrated inside the cell would tend to diffuse out of it, but they are held in by the electrostatic attraction of the organic negative ions, which cannot pass out through the membrane. On the other hand, sodium ions cannot enter to make up for any deficit of positive charges inside the cell. Thus the inside of the cell is more negative (by about one tenth of a volt) than the surrounding fluid. In a nerve cell at rest the pressure of the potassium ions to get out is balanced by the electrical pressure inward. Bernstein imagined that this balance of forces is a delicately poised affair. Whenever an electric current is passed through a nerve, decreasing the strength of the electric field across the membrane at the cathode, the balance is upset. Bernstein suggested that the excitation is a breakdown of stability of the membrane which might take the form of a sudden increase in its ion permeability. For a moment other ions besides potassium could pass through it relatively freely. As a result the electric field across the fiber membrane would suddenly collapse. Such a temporary "depolarization" of the electrically charged membrane could account for the action potential, or excitation, of the nerve.

The Bernstein theory was bold and ingenious, and for some 40 years was accepted by most physiologists as a very satisfactory explanation of the electrical phenomena in nerve fibers. But by 1940 the investigations of research workers began to disturb the theory. The first shock came when E. J. Conway, professor of biochemistry at Dublin, showed that the surface membrane of muscle fibers is certainly permeable to chloride ions, much as to potassium. And when investigators began to test the permeability of the membrane with radioactive tracers, they discovered that it was permeable to sodium ions as well, though less so than to potassium. While the concentration of potassium ions inside the cell and of sodium ions outside remains constant, there is a steady flux of these substances in and out of the cell. All three species of ions—potassium, chloride and sodium—move continually to and fro across the membrane.

The embarrassing question that now confronts us is: How *does* the nerve cell manage to hold down its concentration of sodium ions against the combined forces of diffusion and electrical pressure? We do not yet know. It is generally believed that the resting cell may operate a "sodium pump" which continually drives out sodium ions as fast as they enter. When we speak of a "resting" nerve fiber, all we mean is that the fiber is resting from its usual business of conducting impulses. It is not completely idle; on the contrary it is continually turning over chemical energy and producing heat, even in the absence of signaling activity. No doubt one reason for this continuous turnover is that the cell could not maintain its chemical composition and structure without some expenditure of energy. Fortunately the rate at which sodium ions tend to leak in through the membrane is extremely low, so that the energy required to pump it out is small—well within the working capacity and chemical resources of the resting cell.

The Cable

Let us stop and sum up what we know about the resting nerve. We have an electrically charged cell, and the source of its electricity appears to be the twofold process which (1) keeps positive sodium ions outside, by pumping them out, and (2) builds up and retains fairly large negative ions inside. In this way a separation of electric charges occurs at the cell surface, the inside being made negative relative to the outside. The potassium and chloride then distribute themselves according to this force: potassium is electrically attracted by the interior of the cell, chloride is re-



jected, and this goes on until the concentration gradients of these ions balance the electrical force. So long as the cell is capable of pumping out sodium and building up and retaining its organic negative ions, this state of affairs will continue unimpaired.

Now one interesting aspect of this setup is the fact that the surface membrane offers a very high resistance to the movement of ions in general. We are inevitably reminded of a communication cable. Measurement of the electric conductivity of the various components of a nerve fiber shows that the interior of the fiber behaves like a reasonably good electric conductor, while the membrane has high resistance to direct current (though it allows high-frequency alternating current to pass readily). This setup bears a rather remarkable resemblance to an electric submarine cable: in both cases we have long cylindrical transmission lines containing an electrically conducting core which is separated from the conducting outside fluid by an insulating sheath. The resemblance, however, is only superficial.

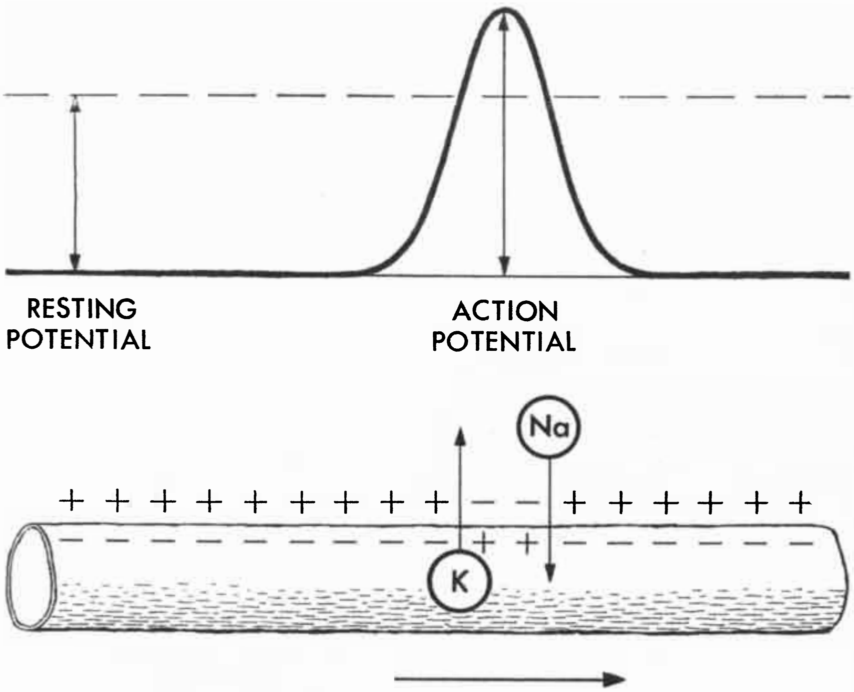
Since the days of Hermann some of the foremost nerve physiologists have considered it worth while to study and analyze the properties of nerve fibers from the point of view of the cable engineer—to find out what the possibilities and deficiencies of a nerve, regarded simply as a passive length of miniature cable, really are. The purpose of a marine cable is to transmit a signal over a very long distance, without fading or loss of clarity. To achieve this a thick insulating sheath is needed, of low capacity and high resistance, so that no leakage of signal strength can occur between the metal core of the cable and the surrounding ocean. It is equally important to provide thick, well-conducting copper strands inside the sheath, so that the electric signal does not lose too much energy as it travels along the core. In all these respects—the dimensions, the gauges and quality of material—our nerve fibers do not seem particularly well endowed for the purpose of long-distance communication. It is true that our nerve signals are not required to travel across the Atlantic Ocean, but a brief subthreshold Morse dot applied to a nerve fiber becomes blurred and indistinguishable after traveling only a tenth of an inch along the fiber, and at a distance of a fifth of an inch from its point of origin the signal has almost completely vanished! Our nerve fibers are very bad cables and could not be used for communication over the long distances in our body, were it not for the fact that they have a booster mechanism which constantly regenerates the signal as it passes along.

The nerve fiber is in effect a chain of relay stations—a device with which the communications engineer is thoroughly familiar. Each point along the fiber receives an electric signal from the preceding point, boosts it to full strength and so enables it to travel a little farther. It is a peculiar combination of a cable (of very defective properties) with an automatic relay mechanism distributed all along the transmission line. Before the electric signal has had a chance to lose its strength it stimulates the fiber, releases local energy resources and is renewed. The electric potential difference across one point of the fiber membrane serves to excite the region ahead, with the result that this region now contributes, at its own expense, a greatly amplified electric signal, capable of spreading to and exciting the next region.

Experiments have fully confirmed this concept of how a nerve fiber transmits a signal. To prove it experimentally one question that must be put to a test is: Does the excitation of a point on the fiber actually generate enough current to excite the next? Direct measurement shows that it does indeed—several times as much as is needed. Hodgkin at Cambridge and R. Lorente de No at the Rockefeller Institute for Medical Research investigated this question in another way; they undertook to find out what it would take to block the passage of the signal. They did this by anesthetizing a stretch of nerve with cold or a drug. Anesthesia makes nerve fiber inexcitable but does not interfere with its ability to conduct a signal cable-fashion. As we have seen, the nerve is a poor cable and the signal quickly loses strength as it travels. The experimenters found that to block a signal they had to anesthetize a sufficiently long stretch of nerve so that the signal lost 90 per cent of its strength before it reached the next excitable point; otherwise it would jump the block. In other words, just a little more than 10 per cent of the current generated by nerve is sufficient to excite normal nerve fiber.

The Explosion

After the proof that the nerve impulse has ample power to regenerate itself from point to point, the next question is: How is the regeneration accomplished? We have already likened nerve excitation to an explosion, and it may be helpful to consider the analogy of the reaction of an explosive gas mixture. Let us take a mixture of hydrogen and oxygen and heat it. If we supply heat at a certain near-threshold rate, here and there a few molecules of hydrogen and oxygen will become excited and react, producing additional heat and raising the temperature further. We have the beginnings of an incipient explosion. But the process is not yet self-sustaining; if we turn off the outside heat supply at this stage, the gas will cool. If we heat the gas to a slightly higher temperature, it may for a little while burn slowly by



ACTION POTENTIAL WAVE (*top*) **spreads along the surface of a nerve fiber** (*bottom*)**. During the rise of the action potential, sodium ions (Na) enter the fiber and make it positive; during the resting state of the nerve the outward pressure of potassium ions (K) keeps fiber interior negative.**

itself (without outside heat) at a rate which exactly balances the loss of heat to the cooler surroundings. At this point a very minute addition of heat will cause the whole gas to explode and burn itself out.

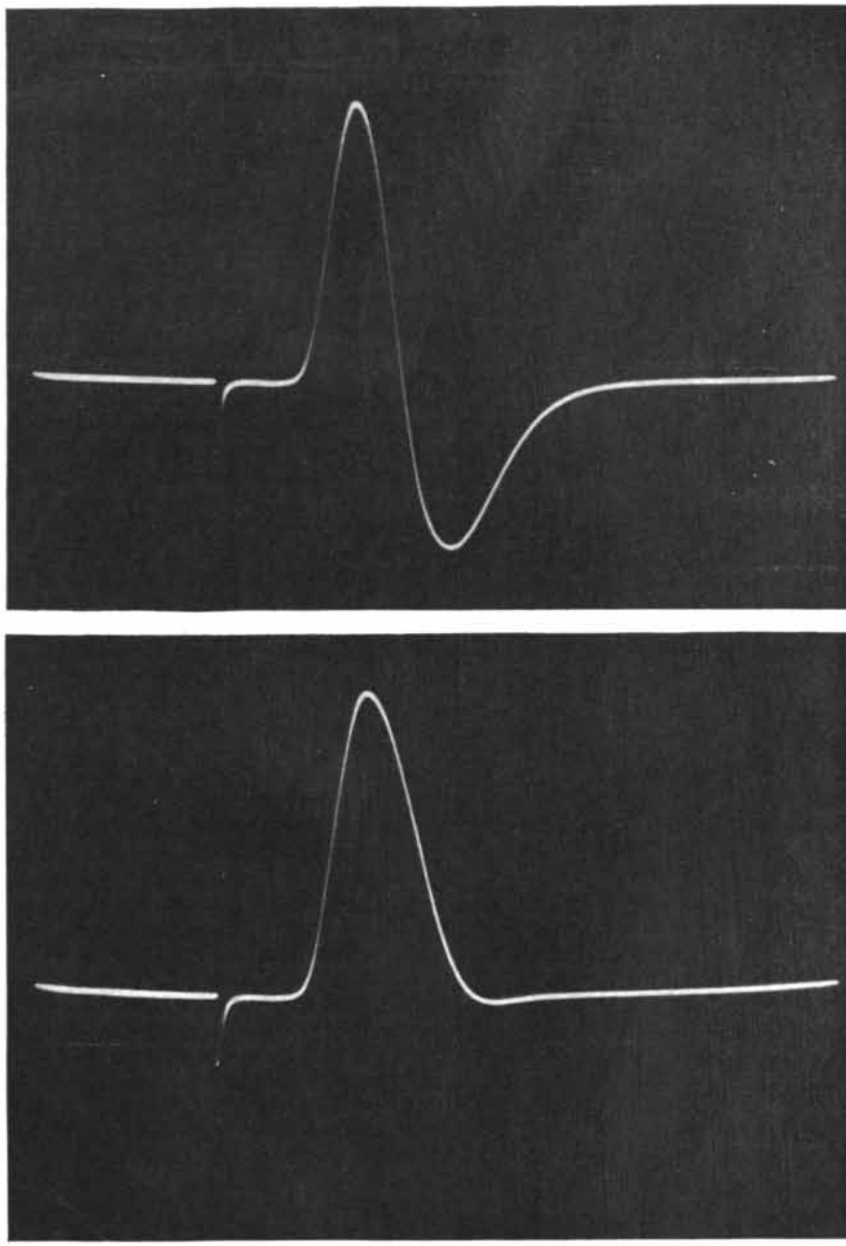
Now a similar reversible process occurs when we apply a pulse of current to a nerve membrane. The current tends to reduce the electric potential across the membrane. Up to a certain strength of applied current, the nerve recovers its original potential as soon as the pulse of current ends. But just below the threshold of excitation of the nerve, we see signs of a partial reaction, like the beginning of an explosive process. And above the threshold the process becomes self-generating: the applied current reduces the membrane potential; this starts some reaction in the membrane which reduces the potential further, and the chain proceeds rapidly in an explosive manner.

The Ions

What is this reaction, and how does it operate? Bernstein had suggested that the electric nerve impulse makes the membrane permeable to ions other than potassium, as a result of which the potential across the membrane drops to zero. In 1938 K. S. Cole and H. J. Curtis at Columbia University and the Marine Biological Laboratory in Woods Hole, Mass., obtained some exciting evidence which at first seemed to provide enormous support for Bernstein's theory: they found that the passage of an impulse through a nerve membrane reduced its electrical resistance 40-fold, *i.e.*, made it 40 times more permeable to the passage of ions. But within a year Hodgkin and A. F. Huxley at Cambridge discovered a disconcerting fact: that the potential across the membrane does not become zero but is reversed, the interior becoming positive instead of negative. This ruled out the theory that the membrane simply "breaks down" and becomes equally permeable to all ions. If all ions could pass equally freely through the membrane, the charges on both sides of it should become neutralized, not reversed.

Eventually Hodgkin and Huxley suggested a way out of the dilemma. Suppose, they proposed, that during the excitation of the nerve the membrane momentarily becomes much more permeable to sodium ions than to any other ions. Then the pressure of sodium ions rushing into the nerve interior will reverse the membrane potential, which in the resting state is determined by the potassium pressure from the inside out.

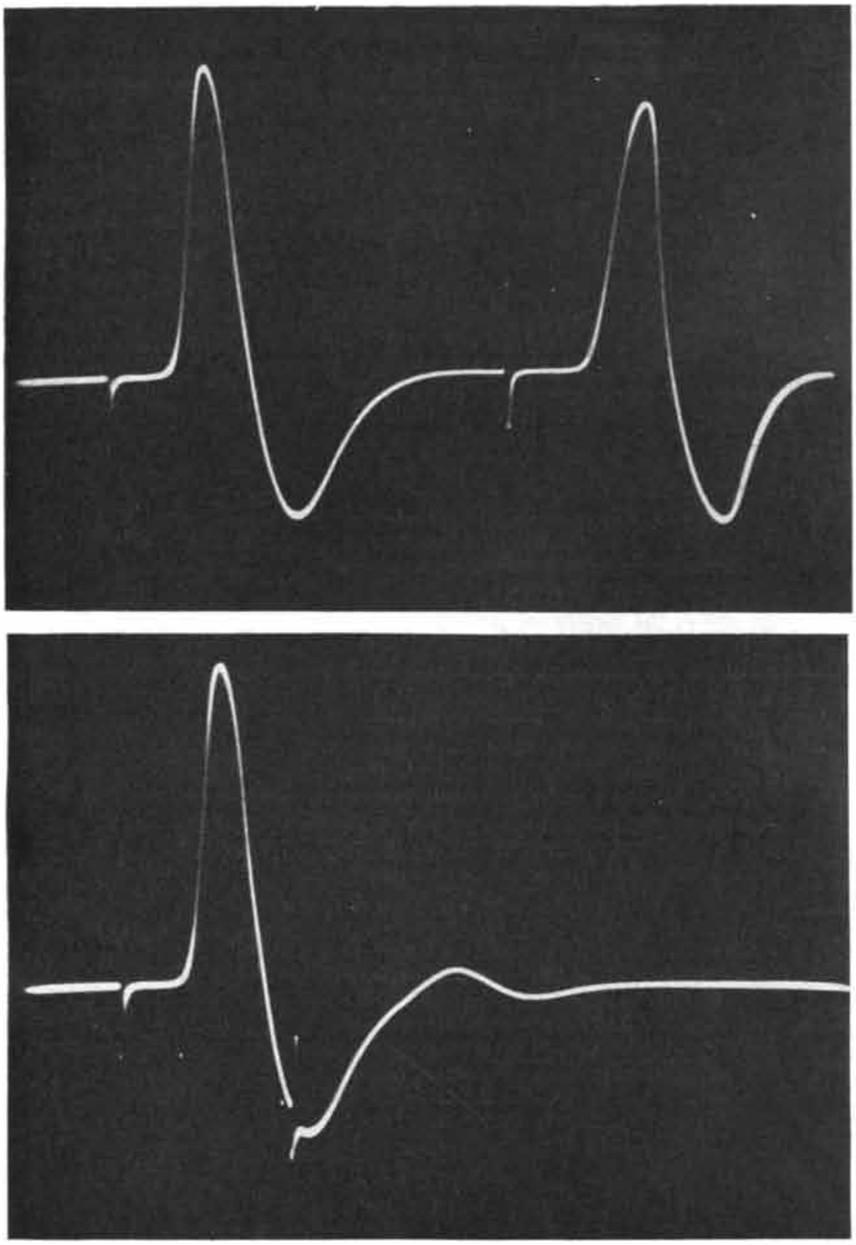
This modern "sodium theory" assumes that the sodium permeability of the nerve membrane is a delicately balanced affair and depends upon the electric field to which the membrane material is subjected. When a current passes through the membrane, partially discharging the membrane surface and thus reducing the electric field, this makes the membrane more permeable to sodium. Positive sodium ions begin to flow inward and further reduce the negative charge on the inside. Thus the electric field across the membrane is further re-



ACTION POTENTIAL of a frog nerve is made visible by the oscilloscope. At the top is a diphasic potential: the peak represents the potential passing the first of two electrodes; the valley, the reversal of the wave after it passes the second electrode. At the bottom is a monophasic potential, which is observed when the fiber is interrupted between the electrodes. The amplitude of the monophasic wave is about .02 volt; its duration, about .0015 second.

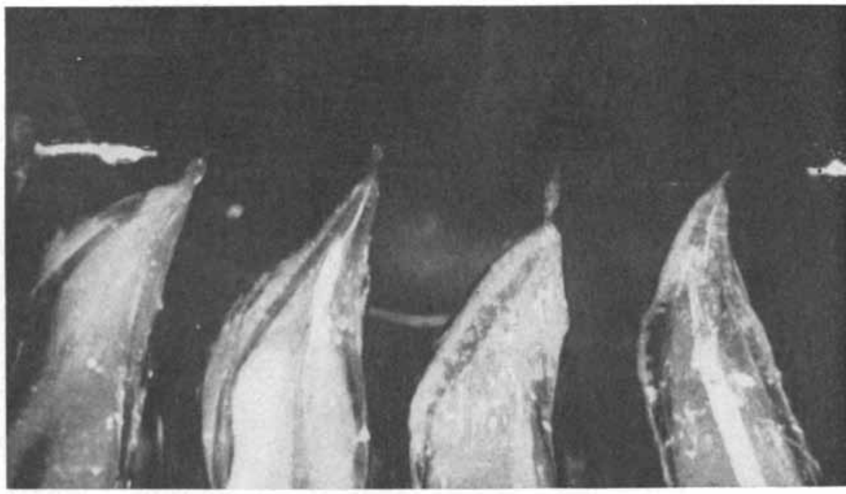
duced, the sodium permeability continues to rise, more sodium enters, and we have the elements of a self-reinforcing chain reaction. The flow of sodium into the fiber continues until the fiber interior has been charged up to such a high positive level that sodium ions are electrostatically repelled. This new equilibrium is precisely the reverse of the resting potassium potential. Now we can understand the basis of the all-or-none reaction of nerve cells: they generate no current until the "ignition point" is approached. Once this point is passed, the production of "sodium current" proceeds toward saturation and runs through a cycle of its own no longer under the control of the original stimulus.

It would take too long to describe all the experiments that have been carried out to test the "sodium story." For one thing, it has been proved that many types of nerve fibers require sodium in the tissue fluid to conduct impulses. Secondly, the height of the action potential can be varied over a wide range by altering the amount of sodium on the outside of the membrane, and quantitatively it follows the predictions of the theory. Third, measurements of the passage of sodium into the fiber interior during a series of impulses have shown that it is



REFRACTORY PERIOD of nerve is illustrated by applying two stimuli to frog nerve in rapid succession. At the top are two diphasic action potentials resulting from stimuli about .007 second apart. At the bottom is the record of two stimuli .003 second apart: the nerve is unable to respond to the second stimulus. The small break in the record before each of these potentials is an "artifact" caused by current used to stimulate the nerve.

sufficient in quantity to account for the strength of the action current. Finally, in an ingenious series of experiments Hodgkin and Huxley have been able to measure the rate of sodium transfer across a cylinder of nerve membrane, when the electric field as well as the external sodium concentration was varied over a wide and carefully controlled range. A number of interesting facts emerged. When the electric field was suddenly reduced from the normal resting level to zero, a sudden rush of sodium ions occurred down their concentration gradient; normally they flowed into the fiber, but when the outside concentration had been reduced to a level below that inside the fiber, the flux of sodium was reversed! It seems clear, therefore, that the critical change during electric stimulation is indeed an increase of permeability to sodium ions—permeability in either direction. Another important fact which emerged is that the sudden flow of sodium ions is only a transient change: after one or two thousandths of a second it is automatically "switched off" again and converted into an increased flow of potassium ions! Why this is so remains mysterious, but it certainly serves an extremely useful purpose. The accelerated outflow of po-



SINGLE NERVE FIBER from the limb of a crab is mounted on four electrodes consisting of agar wicks. Diameter of fiber is about .003 millimeter.

tassium allows the membrane potential to return rapidly to the original resting level, so that the nerve can repeat the firing of its brief, sharp electric signal almost immediately.

We do not yet know why the permeability of the membrane to sodium varies with the electric field. It is quite probable that sodium moves across the membrane in several steps, not as free ions but perhaps attached to molecules within the fatty material of the membrane. In other words, a sodium ion may first combine with a negatively-charged "carrier molecule," which acts as a guide through the membrane, and then may jump off as a free ion again into the water on the inner surface. According to this theory, which is still only speculative, the negative carrier molecules may be held immobilized to the positive outer membrane surface when the electric field is large, and may become mobile when the electric field is reduced.

It hardly needs to be said that nerve physiologists do not all agree on these new ideas concerning the mechanism of the nerve impulse. Some distinguished experimenters prefer the idea that sodium and potassium act merely as "lubricants," rather than as direct carriers, of the transfer of charge across the fiber membrane. Others consider it possible that the charge may be transported across the membrane by hydrogen ions, or even by electrons, rather than by sodium and potassium ions. No doubt these issues will remain controversial for years to come.

The Sheathed Cable

There is, however, complete agreement on one matter: namely, that nerve signals are propagated step by step along the fiber by some electrochemical relay mechanism. In the case of non-medullated fibers the signal is relayed from point to adjacent point. The type of fiber that is enclosed in a thick medullary sheath operates its signal service in an even more interesting fashion. It has its relay stations distributed at relatively few points, namely at gaps in the medullary sheath, known as the "nodes of Ranvier." These points are spaced rather regularly along the fiber at intervals of one or a few millimeters. The sheathed sections between these points form a relatively good passive cable, as biological materials go. The development of a medullary sheath occurred at a relatively advanced stage of evolution and brought with it a great increase in the speed and economy of nerve-signal traffic. A medullated nerve fiber passes messages some 10 times as quickly, and with about a tenth of the expenditure of energy, as a non-medullated fiber of the same diameter. By providing an insulating, low-capacity sleeve, it restricts the expensive and time-consuming process of relaying to a few points along the line.

It is interesting to speculate on the alternative means that evolution might have chosen to speed up the rate of signaling in our nerve fibers. There could really have been only one alternative: to increase the diameter of the fibers. But its disadvantages are obvious. We need an enormous number of parallel private lines to pass the large number of vital messages between our brain center and the innumerable points on the periphery of the body. The eye alone has one million private telephone lines in the optic nerve. Without a medullary sheath, their diameter would have to be increased some 50-fold to retain their speed; but at 50 times their present size there would not be enough room in our head to accommodate this vast number of communication channels. It is fortunate indeed that nature managed to invent the segmented medullary sheath for us!

Bernhard Katz is professor of biophysics at University College in London.

"Client-Centered" Psychotherapy

In which a new approach to the treatment of troubled and neurotic people has led to an interesting series of objective studies in the effect of such treatment

by Carl R. Rogers

DURING the past dozen years a growing group of psychotherapists have been developing a new approach called client-centered therapy. As an integral part of our work, we have tried to develop objective ways of measuring the results of psychotherapy and, if possible, to ascertain some of the "laws" of human nature. By now we have made more than 60 such studies of the therapeutic process and its outcomes, and this article will report some of our results.

Client-centered therapy is built on two central hypotheses: (1) the individual has within him the capacity, at least latent, to understand the factors in his life that cause him unhappiness and pain, and to reorganize himself in such a way as to overcome those factors; (2) these powers will become effective if the therapist can establish with the client a relationship sufficiently warm, accepting and understanding. From these two convictions it follows that in practice we do not try to do something *to* the client. We do not diagnose his case, nor evaluate his personality; we do not prescribe

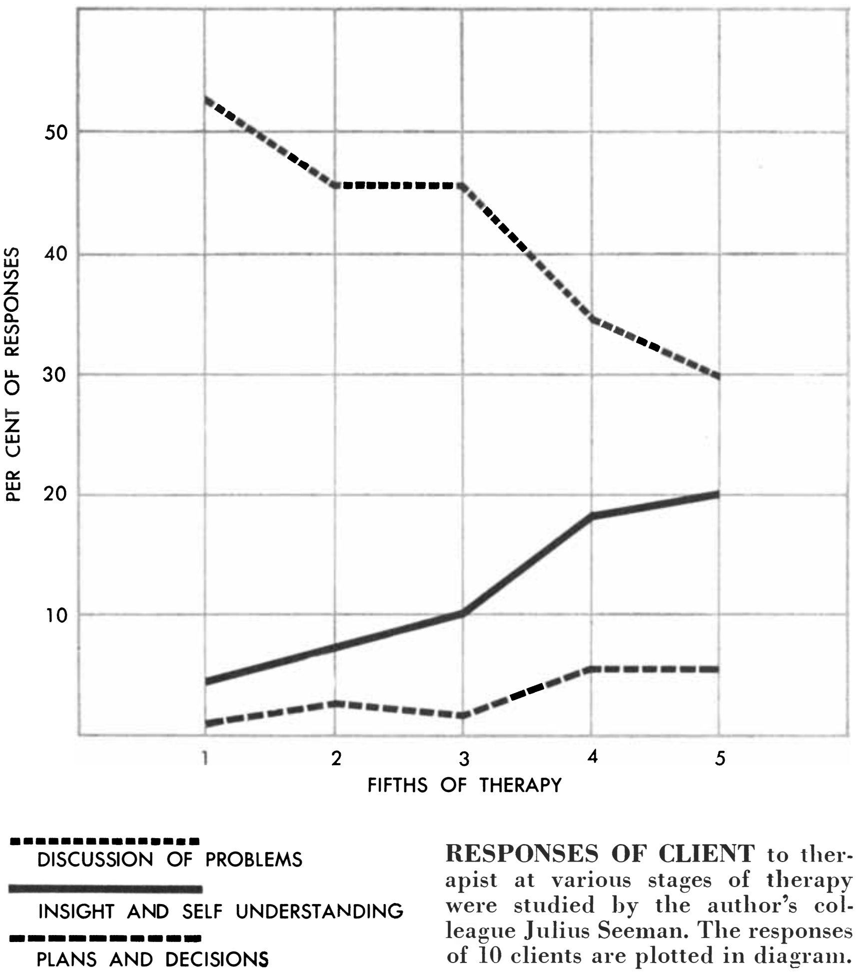
CLIENT TALKS TO THERAPIST across a desk, rather than from a couch, in client-centered therapy. A feeling of equality between the therapist and the client is considered the central feature of this form of therapy.

treatment, nor determine what changes are to be effected, nor set the goal that shall be defined as a cure. Instead the therapist approaches the client with a genuine respect for the person he now is and with a continuing appreciation of him as he changes during the association. He tries to see the client as the client sees himself, to look at problems through his eyes, to perceive with him his confusions, fears and ambitions. The therapist in such a relationship is not concerned with judging or making suggestions, but always strives to understand. In this atmosphere of complete psychological security the client can lay himself bare with no danger of being hurt. Protected by the conditions of therapy, he begins to reorganize the structure of self in accordance with reality and his own needs. We take this approach because we have found it to be a deeper and more effective method than any interventive procedures we might use to help the individual deal with life.

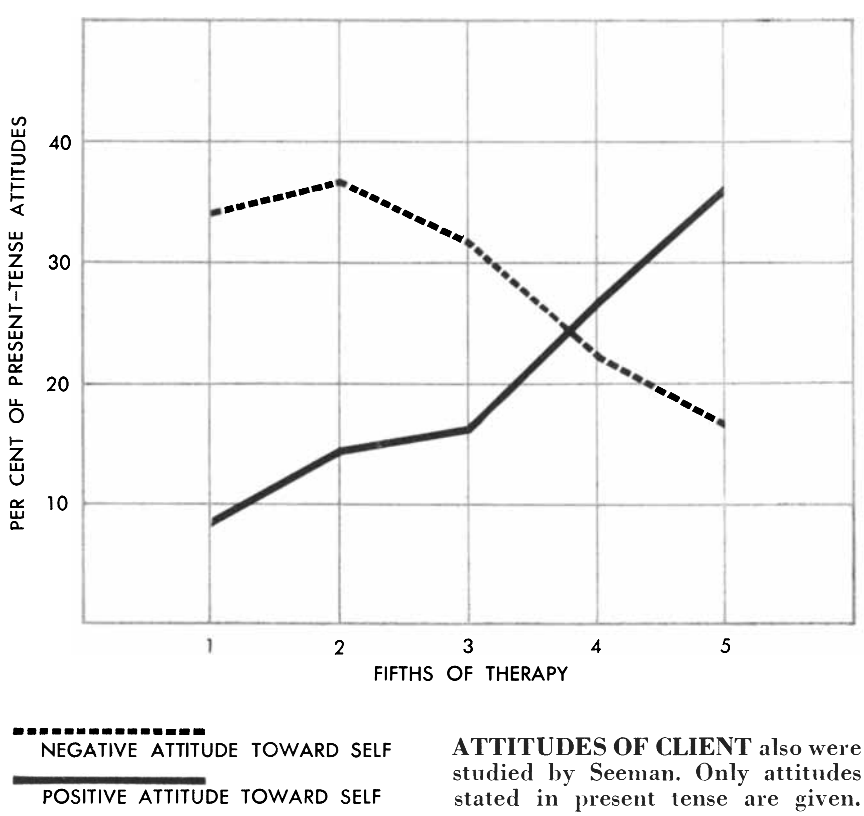
IT WAS in 1940 that this way of dealing with people in difficulty began to crystallize in the minds of our group, then at Ohio State University. From the outset we sought to bring a rigorous and objective point of view into psychotherapy. We wished to apply to our work the methods of psychology and the behavioral sciences. But how were we to do it? The process of psychotherapy is extremely subtle. Few experiences are more disturbingly complex than the relationship between an individual in need of personal help and the psychotherapist who is working with him. Can one measure the warm feeling that the therapist has toward his client? Is it possible to weigh the significance of a client's sobbing or of his long silences, or to gauge the meaning of an emotionally laden flow of words? In the nature of things psychotherapy and its results are subjective and seem immeasurable.

Moreover, we lacked even the raw material to study. The voluminous literature of psychiatry and psychoanalysis offers little in the way of objective data on the therapeutic process or the development of patients during treatment. Our first step, therefore, was to begin collecting such material in a form that would permit us to analyze it. We decided to make machine recordings of the sessions with clients. We were told that this was unethical, that no therapist could be genuine while being recorded, that what we proposed would ruin therapy. Nevertheless we recorded, at first single interviews, then the whole series of interviews covering a single case. Today we make dozens of recordings every week at the Counseling Center at the University of Chicago, and the practice has become by no means uncommon in psychotherapy.

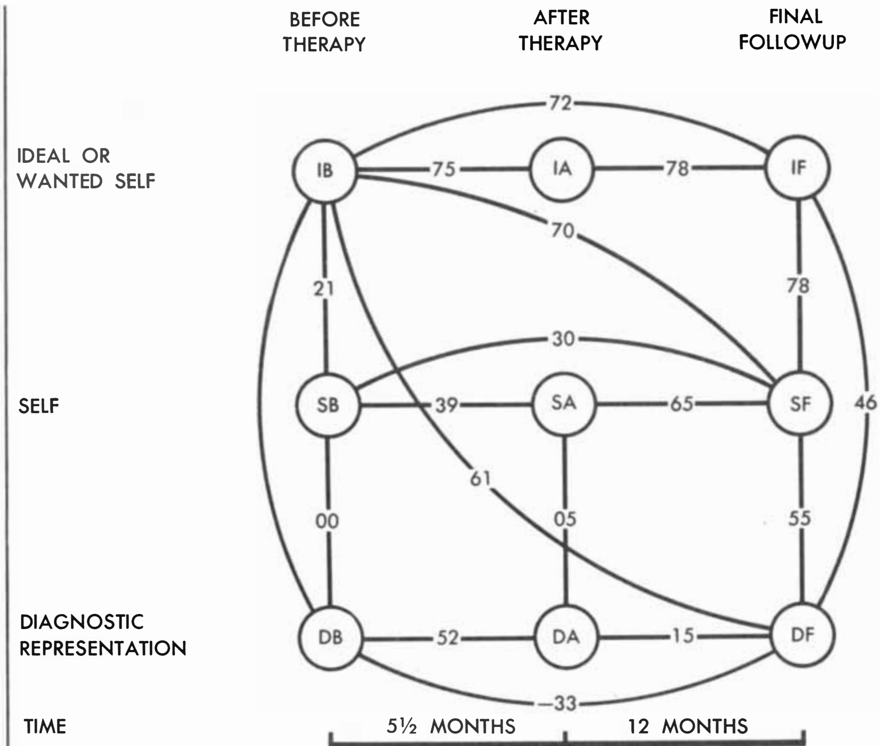
To analyze the recorded material, we



RESPONSES OF CLIENT to therapist at various stages of therapy were studied by the author's colleague Julius Seeman. The responses of 10 clients are plotted in diagram.



ATTITUDES OF CLIENT also were studied by Seeman. Only attitudes stated in present tense are given.



Q TEST consisted primarily of having clients sort cards bearing statements about themselves into piles according to how closely the statements agreed with their own opinions. This diagram represents three Q sorts by a female client: one by the client with respect to her ideal self, a second by the client with respect to her real self and a third by a diagnostician with respect to the client. The letter I stands for the ideal-self test; S, for the real-self test; D, for the diagnostic test. B stands for before therapy; A, after therapy; F, for final followup a year later. The number on the line between each pair of circles indicates the correlation between the two sorts in per cent.

began by establishing categories to classify the client's statements or attitudes. We defined and re-defined these categories until we found that various researchers, working independently, could classify the amorphous, often incoherent statements from the interviews with a high degree of consistency. The instrument was then ready for use.

William Snyder conducted one of our first studies and I can still recall the excitement with which we examined his results. Analyzing the several thousand client statements in six recorded cases, he found that an orderly process was evident in this material. Statements labeled as discussion of "problems" declined steadily from the beginning to the end of counseling, while statements of insight rose irregularly, with an upward spurt at the end. Discussion of plans, decisions and goals remained close to zero during the first half of therapy and increased sharply toward the end.

Such work as Snyder's, though it now seems crude and inadequate, gave the proof we needed that the unstructured material of the interviews could be measured, that the statements both of the client and of the counselor could be reliably categorized and analyzed. We could thus show that psychotherapy, far from being just "talk," had its own discoverable laws. Also, though we were not then clearly aware of it, the need for reliable categories was forcing us to use the "internal frame of reference," the client's view, as a basis for a scientific approach. We had to stay close to the client's own perception of his experience, because we could not agree among ourselves as to categories when we made inferences from his statements. Thus we embarked on a search for the laws that prevail in the client's private world of perception, and this has proved a fruitful exploration.

AS THE work progressed, client-centered therapy developed a theory of personality which is based on the image that a person holds of himself. By this "concept of self" we mean the individual's perceptions of his own characteristics and his relations to others, and the values he attaches to these perceptions. This conscious scheme of the self has a regulatory and guiding influence on behavior. Anxiety and maladjustment occur when it is threatened by a dim awareness of experiences contradictory

Adventurers in Research

Dr. W. E. Shoupp

SCIENTIST

After graduation from Miami University, Oxford, Ohio in 1931, he served as graduate assistant and instructor in physics at the University of Illinois where he received his degrees of Master of Arts in 1933, and Doctor of Philosophy in 1937. He joined Westinghouse in 1938 as a Research Fellow. In 1941, he became a research scientist in the Laboratory at East Pittsburgh and was made Manager of the Electronics Department at the Laboratory in 1943. Four years later, he was appointed Director of Research of the Westinghouse Atomic Power Division. He is now Director of Development of this Division.

At a meeting of scientists in 1938, several were discussing the use of nuclear energy as a possible source of large amounts of energy. Before the meeting was over, others joined in and the subject really became "hot". Among those engaging in the discussion was Dr. W. E. Shoupp, then a Research Fellow at the Westinghouse Research Laboratories.

Dr. Shoupp went back to the Laboratory, determined to find some answers to the subject. Making use of the new Westinghouse atom smasher, he and other nuclear scientists did some pioneering research, culminating in the discovery that a uranium atom could be split into two equal fragments by the impact of high-speed gamma rays, with commensurate release of large amounts of energy. This they called "photo-fission".

His work on the subject also included the determination of the amount of neutron energy required to cause uranium and thorium to fission. This contributed to the basic understanding of the nuclear fission process and to the development of the atomic bomb and atomic energy. Incidentally, the Lamp Laboratory of Westinghouse supplied pure uranium for the first nuclear reactor.

At the beginning of World War II, when radar was being considered, Dr. Shoupp and some associates built from scratch, a radar laboratory where tubes and application techniques were developed. They made a major contribution to radar, and equally important, radar jamming.

Dr. Shoupp is continuing his work regarding atomic energy as Director of Development of the Westinghouse Atomic Power Division. Current research work under his supervision includes developments in connection with an atomic energy plant for the first atomic submarine and another plant suitable for the propulsion of large vessels such as aircraft carriers.

A man of engaging personality, Dr. Shoupp has a keen sense of humor and the ability to inspire and develop those who work with him. He is particularly proud of the fact that Westinghouse has been able to attract to the work of atomic power development, scientists of the highest caliber. Westinghouse Electric Corp., Pittsburgh, Penna.

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to it. We view therapy, therefore, as the process by which the structure of the self is relaxed in the safety of the relationship with the therapist, and previously denied experiences are perceived and then integrated into an altered self.

We soon asked ourselves whether this theory of personality, which seemed to fit our subjective experiences in therapy, could be tested objectively. We found that certain measurable patterns did indeed emerge. For example, Julius Seeman, analyzing statements about the self in 10 recorded cases, discovered that during the first fifth of therapy clients expressed almost four times as many negative as positive self-attitudes, but by the last fifth of therapy positive statements were twice as frequent as negative ones.

Elizabeth Sheerer, in a more elaborate study, showed that not only did acceptance of and respect for the self rise during therapy, but this change was accompanied by an improved acceptance of and respect for others. In 10 recorded cases that she analyzed, there was a consistent, though slightly irregular, increase of self-acceptance, paralleled by a similar rise in the acceptance of others. The relevance of such findings to social psychology is evident. Do an individual's attitudes toward others—minority groups, foreigners and the like—reflect his attitudes toward himself? And can changes in such attitudes come about only through changes in his feelings of self-respect and acceptance? Sheerer's work does not answer these questions, but it blocks them out clearly for others to study.

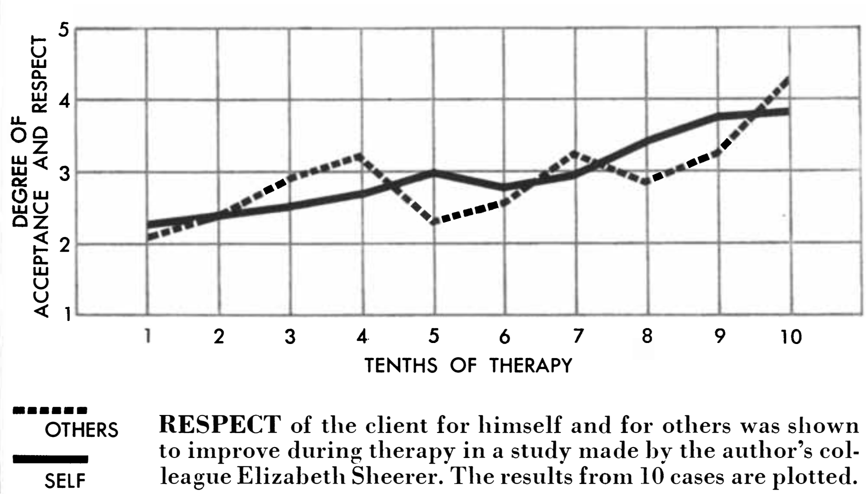
As our work became known, many psychologists expressed concern because most of our research was based simply upon what the client *said*. This criticism overlooked the fact that what a client says may reveal patterns as significant as in any other mode of behavior. We were ourselves eager, however, to test the changes in clients by external criteria, and we made several such studies.

Natalie Haimowitz gave the Rorschach inkblot test before and after therapy to 56 clients, 32 in individual therapy and 24 in group therapy, at the Counseling Center. Thirteen counselors were involved, all of them client-centered in their orientation. The study also included a control group of 15 subjects, similar to the therapy group in age, sex and education, who were not under treatment. Haimowitz developed 10 scales by which the Rorschach results could be evaluated objectively. They included the degree of anxiety, degree of dependency, relationship to reality, degree of spontaneity, and so on. She also applied an index of neuroticism developed by another worker.

Her research produced interesting results. After therapy the group of 56 clients showed an appreciable decrease in neuroticism and a significant improvement in nine of the 10 personality factors (all except the degree of spontaneity). On the other hand, the control group exhibited little or no change. Thus the Haimowitz study indicates that the alteration of basic personality produced by client-centered therapy can be measured by a technique that taps the unconscious aspects of personality.

Ten clients were retested a year after the end of therapy, and six of them showed further improvement at that time. The other four had either not gained or had regressed. These variations in development after therapy of course raise questions for further study.

William Thetford tried another type of objective measurement. He reasoned that the physiological responses of an individual's autonomic nervous system, reflecting his state of tension or anxiety, might provide a measure of the results of therapy. Thetford devised a standard frustration experience—failure to remember a long series of numbers—and set up equipment for measuring various physiological functions (*e. g.*, the heart rate) of the subject before, during and after this simple frustration. A group of 19 clients was tested before and after therapy, and their performance was



RESPECT of the client for himself and for others was shown to improve during therapy in a study made by the author's colleague Elizabeth Sheerer. The results from 10 cases are plotted.

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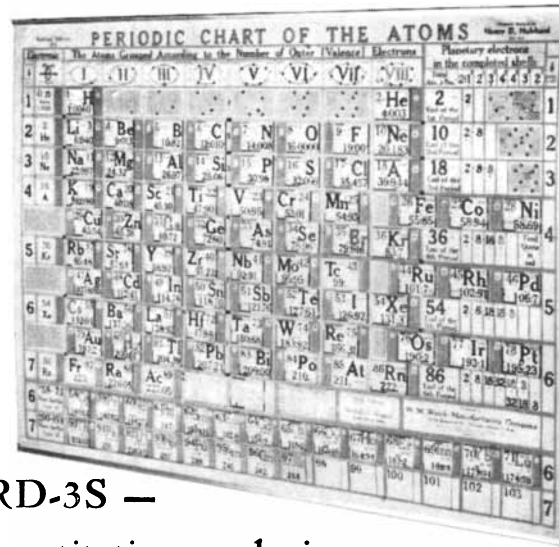

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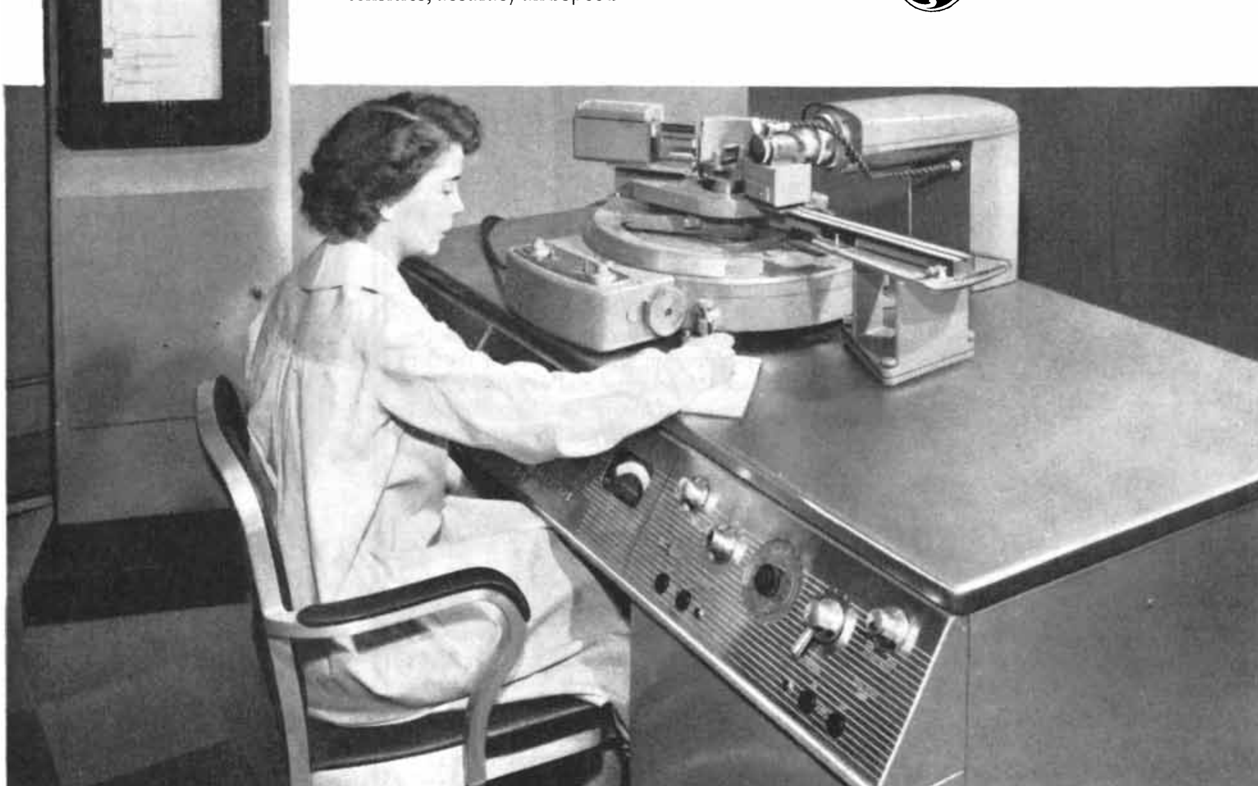

compared with that of a control group.

The reactions of the two groups were significantly different in two measures—heart rate and galvanic skin response. The therapy group after treatment developed a higher threshold to frustration and recovered their physiological balance more quickly after the emotional stress.

FROM necessarily crude beginnings our studies have improved steadily both in the refinement of technique and in the importance of the findings. In the first place, we have improved our controls. The usual scientific concept of the matched control group is not always applicable to research in psychotherapy. How does one match a client with a control whose personality and desire for therapy are substantially identical? It cannot be done, so we have overcome this obstacle by what we call the "own control" group. A client who requests therapy is tested in the ways demanded by a specific project on which we are engaged. He is then asked to wait for a period—perhaps 60 days—before beginning his interviews. He is tested a second time before therapy, again at its end and finally a year later. The period of delay between the first two tests provides us with a control subject, perfectly matched in every detail with the client who later enters therapy.

Another trend is the increasing breadth and depth of our hypotheses. For example, we suppose that if therapy alters the perception of self, of others and of the environment, it must alter the whole process by which an individual perceives. We are now subjecting this hypothesis to a series of tests which range from response to the simplest visual stimuli (where perception is a physiological characteristic of the organism) to more and more complex stimuli involving social factors. If our hypothesis is upheld, it will have implications for many fields, from optics to sociology.

We are also adopting testing methods more appropriate to our interests. One of these is the Q technique expounded by William Stephenson, formerly of Oxford University, which we have used to compare the internal and external frames of reference. One of our hypotheses is that therapy should produce an increasing agreement between the client's perception of himself and a psychologist's outside view of his personality. The Q technique operates as follows: We have printed on separate cards 100 self-descriptive statements, drawn from many interviews and covering the whole range of attitudes toward self. Some examples are: "I often feel guilty"; "I express my emotions freely"; "I am worthless"; "I am self-reliant"; "I usually like people"; "I am afraid of sex." The client is asked to sort these cards into nine piles, arranged according to how closely he thinks they describe him. This gives us a detailed picture of the self as perceived by the client. His second task is to re-sort the cards to represent the person he would like to be, his ideal self. The client does these two jobs of sorting before and after therapy and again a year later. Each time he evaluates himself, he is given a Thematic Apperception Test—a projective personality test composed of ambiguous pictures and designed to reveal the unconscious and conscious elements in his personality. These TAT responses, the stories he makes up to fit the pictures, are then turned over to a psychologist who knows nothing of the client or of the order in which the tests were given. The psychologist is asked to sort the Q cards into nine piles to represent his diagnosis of the client from each TAT test. We thus obtain a detailed and objective picture of the personality to correlate with the client's self-picture.

One of the first cases to which we applied this method was a woman in her late thirties, with many conflicts within herself and poor relationships with her husband and daughter. The results of the technique in her case are plotted in the diagram on page 68. Her ideal, the kind of person she wanted to be, was much the same before and after therapy. Before therapy there was no relationship between her picture of herself and that of the psychologist, and the psychologist's estimate of her was very different from her ideal. After therapy both the client's and the psychologist's estimate changed radically. A year after therapy her picture of herself and the diagnostician's picture of her were substantially the same, and there was also substantial agreement between his picture and her ideal.

In short, we may say that the client came to be substantially the person she wanted to be, both in her own estimate and that of the psychologist who read her TAT test. Here for the first time we have comparable measures of the person as he seems to himself, as he wants to be and as he is diagnosed by a psychologist. This detailed information contains some surprises: for example, one would not expect that the diagnostic picture would change more radically than the perception of self.

OUR 12 years of research have led us to the following conclusions about client-centered therapy: An effective relationship is one in which the therapist participates in the client's communication, meeting him with understanding and acceptance. The process is orderly; many of its elements can be specified. During therapy the attitudes toward the self change from predominantly negative to predominantly positive. Self-esteem improves; the personality becomes better integrated and more comfortable; the basic personality structure becomes more unified, less neurotic, more accepting of emotionality, more tolerant of stress, more objective in dealing with reality. The person adjusts better to training situations and on the job; he exhibits less tension.

There is objective research evidence for all of these statements, but a number of the studies need to be repeated with larger groups and better methodology. Like all statements based on scientific investigation, ours are open to stronger proof or later disproof.

We must, however, admit a major disappointment. Profitable as our research has been, it has not contributed importantly to our practice of psychotherapy. We had realized that knowledge of research could not, of itself, make therapists; but we had hoped that it would influence the way in which we carry on therapy. So far it has not worked out that way. Our research has often confirmed, but almost never initiated, elements of our practice. The major contribution of the research has been to increase our knowledge of the dynamics of personality and of the extent to which personality and behavior may be altered.

Put in simplest terms, we have been testing a general view that confidence in the human organism is justified. We have hypothesized that, if a person is given a psychological climate sufficiently warm and sympathetic to his private world, his previously latent perceptiveness, creativeness and capacity for dealing with reality will be released. Our studies to date indicate in a limited way that this hypothesis is valid. There is even a hint that the most striking characteristic of personality may be, not its stability, but its capacity for change.

A moment's thought will suggest some of the broad implications of such a position. If the individual can meet life's problems constructively when a suitable psychological atmosphere is provided, can the same capacity be expected of the group? If confidence in the individual is justified in therapy, is it justified in education? In industry? In government? What does it mean in situations of leadership? What are its implications for our philosophy of the nature of man? For our reliance upon the democratic process? Psychotherapy opens a window into the deepest chambers of the human personality. That is why many and varied groups are watching the theory, research and practice growing out of our basic hypothesis. And that is why we are soberly aware of our responsibility to test and retest each aspect of our thinking; to perfect increasingly rigorous methods; to make each study available for proof or disproof by workers in our own and other fields. It is a challenging pathway of scientific exploration.

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Is There an Infinity?

The great German mathematician Georg Cantor proved that, so far as mathematics is concerned, there is. Presenting a celebrated account of his ideas and their consequences

Since ancient times philosophers, theologians and mathematicians have occupied themselves with the subject of infinity. Zeno of Elea invented a group of famous paradoxes whose difficulties are connected with the concept; in their time such leading thinkers as Aristotle, Descartes, Leibnitz and Gauss grappled with the infinity problem without making any notable contributions to its clarification. The subject is admittedly complex and undeniably important. A firm grasp of the problems of infinity is essential to an understanding of the revolution in ideas that paved the way for the triumphant advance of modern mathematics, with important consequences to physics, cosmology and related sciences.

The following article is a condensed version of a lecture on infinity by a noted Austrian mathematician, Hans Hahn, delivered a few years ago before a general audience in Vienna. This is the first translation of the lecture into English. Hahn was a member of the celebrated Vienna Circle, a group of philosophers and scientists adhering to the philosophy of logical positivism, among whose founders were Otto Neurath and Rudolf Carnap. The Circle annually presented popular lectures on science, and this survey by Hahn of the concept of infinity is one of the best of the series.

Hahn began his lecture with a historical résumé (here omitted) and then launched his discussion with a description of the work of the founder of the modern mathematical theory of infinity, Georg Cantor.

by Hans Hahn

IT WAS Georg Cantor who in the years 1871-84 created a completely new and very special mathematical discipline, the theory of sets, in which was founded, for the first time in a thousand years of argument back and forth, a theory of infinity with all the incisiveness of modern mathematics. Like so many other new creations this one began with a very simple idea. Cantor asked himself: "What do we mean when we say of two finite sets that they consist of equally many things, that they have the same number, that they are equivalent?" Obviously nothing more than this: that between the members of the first set and those of the second a correspondence can be effected by which each member of the first set matches exactly a member of the second set, and likewise each member of the second set matches one of the first. A correspondence of this kind is called "reciprocally unique," or simply "one-to-one." The set of the fingers of the right hand is equivalent to the set of fingers of the left hand, since between the fingers of the right hand and those of the left hand a one-to-one pairing is possible. Such a correspondence is obtained, for instance, when we place the thumb on the thumb, the index finger on the index finger, and so on. But the set of both ears and the set of the fingers of one hand are not equivalent, since in this instance a one-to-one correspondence is obviously impossible; for if we attempt to place the fingers of one hand in correspondence with our ears, no matter how we contrive there will necessarily be some fingers left over to which no ears correspond. Now the number (or cardinal number) of a set is obviously a characteristic that it has in common with all equivalent sets, and by which it distinguishes itself from every set not equivalent to itself. The number 5, for instance, is the characteristic which all sets equivalent to the set of the fingers of one hand have in common, and which distinguishes them from all other sets.

Thus we have the following definitions: Two sets are called equivalent if between their respective members a one-to-one correspondence is possible; and the characteristic that one set has in common with all equivalent sets, and by which it distinguishes itself from all other sets not equivalent to itself, is called the (cardinal) number of that set. And now we make the fundamental assertion that in these definitions the finiteness of the sets considered is in no sense involved; the definitions can be applied as readily to infinite sets as to finite sets. The concepts "equivalent" and "cardinal number" are thereby transferred to sets of infinitely many objects. The cardinal numbers of finite sets, *i.e.*, the numbers 1, 2, 3 . . . are called natural numbers; the cardinal numbers of infinite sets Cantor calls "transfinite cardinal numbers."

But are there really any infinite sets? We can convince ourselves of this at once by a very simple example. There are obviously infinitely many different natural numbers; hence the set of all the natural numbers contains infinitely many members: it is an infinite set. Now then, those sets that are equivalent to the set of all natural numbers, whose members can be paired in a one-to-one correspondence with the natural numbers, are called denumerably infinite sets. . . . According to our definition all denumerably infinite sets have the same cardinal number; this cardinal number must now be given a name, just as the cardinal number of the set of the fingers on one hand was earlier given the name 5. Cantor gave this cardinal number the name "aleph-null," written $\aleph_0$. (Why he gave it this rather bizarre name will become clear later.) The number $\aleph_0$ is thus the first example of a transfinite cardinal number. Just as the statement "a set has the number 5" means that its members can be put in one-to-one correspondence with the fingers of the right hand, or—what amounts to the same thing—with the integers 1, 2, 3, 4, 5, so the statement "a set has the cardinal number $\aleph_0$" means that its members can be put in one-to-one correspondence with the totality of natural numbers.

If we look about us for examples of denumerably infinite sets, we arrive immediately at some highly surprising results. The set of all natural numbers is itself denumerably infinite; this is self-evident, for it was from this set that we defined the concept "denumerably infinite." But the set of all even numbers is also denumerably infinite, and has the same cardinal number $\aleph_0$ as the set of all natural numbers, though we would be inclined to think that there are far fewer even numbers than natural numbers. To prove this proposition we have only to put each natural number opposite its double (*see below*). It may clearly be seen that there is a one-to-one correspondence between all natural and all even numbers, and thereby our point is established. In exactly the same way it can be shown that the set of all odd numbers is denumerably infinite.

Even more surprising, perhaps, is the fact that the set of all pairs of natural numbers is denumerably infinite. In order to understand this we have merely to arrange the set of all pairs of natural numbers diagonally, whereupon we at once obtain a one-to-one correspondence between all natural numbers and all pairs of natural numbers (*see table at top of page 78*). From this follows the conclusion, which Cantor discovered while still a student, that the set of all rational fractions (*i.e.,* fractions in which the numerators and denominators are whole numbers, such as 1/2, 2/3, *etc.*) is also denumerably infinite, or equivalent to the set of all natural numbers, though again one might suppose that there are many, many more fractions than there are natural numbers. What is more, Cantor was able to prove that the set of all so-called algebraic numbers, that is, the set of all numbers that satisfy an algebraic equation of the form $a_0x^n + a_1x^{n-1} + \ldots + a_{n-1}x + a_n = 0$ with integral coefficients $a_0, a_1 \ldots a_n$, is denumerably infinite.

At this point the reader may ask whether, in the last analysis, *all* infinite sets are not denumerably infinite—that is, equivalent. If this were so, we should be sadly disappointed; for then, alongside the finite sets there would simply be infinite ones which would all be equivalent, and there would be nothing more to say about the matter. But in the year 1874 Cantor succeeded in proving that there are also infinite sets that are not denumerable; that is to say, there are other infinite numbers, transfinite cardinal numbers, differing from aleph-null. Specifically, Cantor proved that the set of all so-called real numbers (*i.e.,* composed of all whole numbers, plus all fractions, plus all irrational numbers) is non-denumerably infinite.

1	2	3	4	5	6	. . .
↕	↕	↕	↕	↕	↕	
2	4	6	8	10	12	. . .

Set of even numbers=all integers

[The essence of Hahn's account of Cantor's proof is that no comprehensive counting procedure can be devised for the entire set of real numbers, nor even for one of its proper subsets, such as all the real numbers lying between 0 and 1. While the members of a specifically described infinite set, such as all rational fractions or all algebraic numbers, can be paired off with the natural numbers, every attempt to construct a formula for counting the all-inclusive set of real numbers is invariably frustrated. No matter what counting scheme is adopted, it can be shown that some of the real numbers in the set so considered remain uncounted, which is to say that the scheme fails. It follows that an infinite set for which no counting method can be devised is non-countable, in other words non-denumerably infinite.]

It has thus been shown that the set of natural numbers and the set of real numbers are not equivalent; that these two sets have different cardinal numbers. The cardinal number of the set of real numbers Cantor called the "power of the continuum"; we shall designate it by c. Earlier it was noted that the set of all algebraic numbers is denumerably infinite, and we just now saw that the set of all real numbers is not denumerably infinite; hence there must be real numbers that are not algebraic. These are the so-called "transcendental" numbers, whose existence is demonstrated in the simplest way conceivable by Cantor's brilliant train of reasoning.

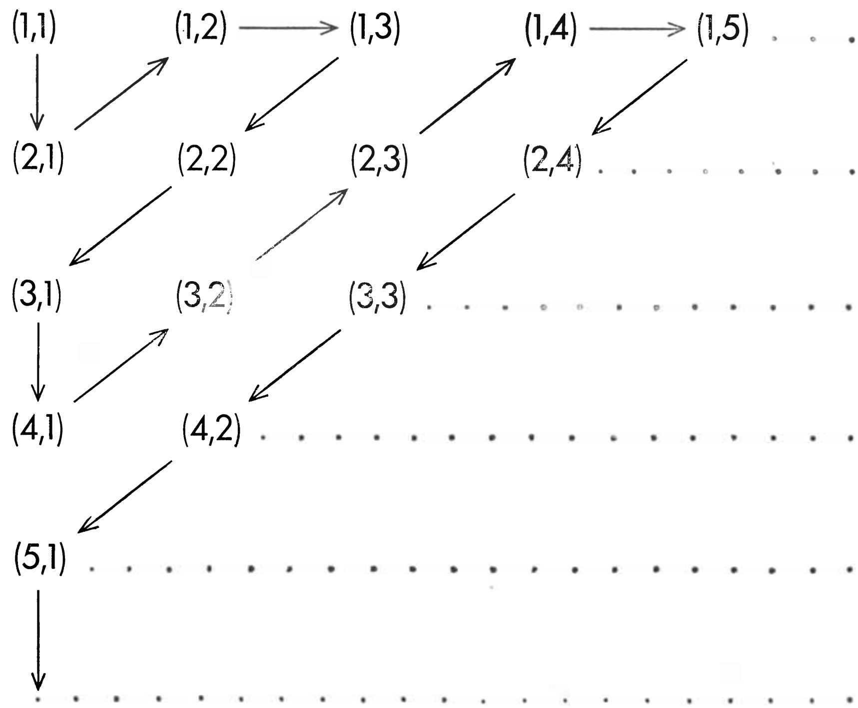
IT IS well known that the real numbers can be put in one-to-one correspondence with the points of a straight line; hence c is also the cardinal number of the set of all points of a straight line. Surprisingly Cantor was also able to prove that a one-to-one pairing is possible between the set of all points of a plane and the set of all points of a straight line. These two sets are thus equivalent; that is to say, c is also the cardinal number of the set of all points of a plane, though here too we should have thought that a plane would contain a great many more points than a straight line. In fact, as Cantor has shown, c is the cardinal number of *all* points of three-dimensional space, or even of a space of any number of dimensions.

We have discovered two different transfinite cardinal numbers, $\aleph_0$ and c: the power of the denumerably infinite sets and the power of the continuum. Are there yet others? Yes, there certainly are infinitely many different transfinite cardinal numbers; for given any set M, a set with a higher cardinal number can at once be indicated, since the set of all possible subsets of M has a

Cantor's aleph-null

higher cardinal number than the set M itself. Take, for example, a set of three things, such as the set of the three figures 1, 2, 3. Its partial sets are the following: 1; 2; 3; 1, 2; 2, 3; 1, 3—thus the number of partial sets is more than three. Cantor has shown that this is generally true, even for infinite sets. For example, the set of all possible point-sets of a straight line has a higher cardinal number than the set of all points of the straight line; that is to say, its cardinal number is greater than c.

What is now desired is a general view of all possible transfinite cardinal numbers. As regards the cardinal numbers of finite sets, the natural numbers, the following simple situation prevails: Among such sets there is one that is the smallest, namely 1; and if a finite set M with the cardinal number m is given, a set with the next-larger cardinal number can be formed by adding one more object to the set M. What is the rule in this respect with regard to infinite sets? It can be shown without difficulty that among the transfinite cardinal numbers, as well as among the finite ones, there is one that is the smallest, namely $\aleph_0$, the power of denumerably infinite sets (though we must not think that this is self-evident, for among all positive fractions, for instance, there is none that is the smallest). It is, however, not so easy as it was in the case of finite sets to form the next-larger to a transfinite cardinal number; for whenever we add one more member to an infinite set we do not get a set of greater cardinality, only one of equal cardinality. But Cantor also solved this difficulty, by showing that there is a next-larger to every transfinite cardinal number . . . and by showing how it is obtained. We cannot go into his proof here, since this would take us too far into the realm of pure mathematics. It is enough for us to recognize the fact that there is a smallest transfinite cardinal number, namely $\aleph_0$; after this there is a next-larger, which is called $\aleph_1$; after



The denumerable infinity of pairs of numbers

this there is again a next-larger, which is $\aleph_2$, and so on. But this still does not exhaust the class of transfinite cardinals; for if it be assumed that we have formed the cardinal numbers $\aleph_0$, $\aleph_1$, $\aleph_2 \ldots \aleph_{10} \ldots \aleph_{100} \ldots \aleph_{1000} \ldots$ that is, all alephs ($\aleph_n$) whose index n is a natural number, then there is again a first transfinite cardinal number larger than any of these —Cantor called it $\aleph_\omega$—and a next-larger successor $\aleph_{\omega+1}$, and so on and on.

The successive alephs formed in this manner represent all possible transfinite cardinal numbers, and hence the power c of the continuum must occur among them. The question is which aleph is the power of the continuum. This is the famous problem of the continuum. We already know that it cannot be $\aleph_0$, since the set of all real numbers is non-denumerably infinite, that is to say, not equivalent to the set of natural numbers. Cantor took $\aleph_1$ to be the power of the continuum. The question, however, remains open. . . .

On the basis of this rather sketchy description of the structure of the theory of sets, the answer to the question, "Is there an infinity?" appears to be an unqualified "Yes." There are not only, as Leibnitz had already asserted, infinite sets, but there are even what Leibnitz had denied, infinite numbers, and it can also be shown that one can operate with them, in a manner similar to that used for finite natural numbers.

SO FAR we have dealt only with the question whether there are infinite sets and infinite numbers; but no less important, it would appear, is the question whether there are infinite extensions. This is usually phrased in the form: "Is space infinite?" Let us begin by treating this question also from a purely mathematical standpoint.

We must recognize at the outset that mathematics deals with very diverse kinds of space. Here, however, we are interested only in the so-called Riemann spaces, and in particular in the three-dimensional Riemann spaces. Their exact definition does not concern us; it is sufficient to make the point that such a Riemann space is a set of elements, or points, in which certain subsets, called "lines," are the objects of attention. By a process of calculation there can be assigned to every such line a positive number, called the length of the line, and among these lines there are certain ones of which every sufficiently small segment AB is shorter than every other line joining the points A,B. These lines are called the geodesics, or the straight lines of the space in question. Now it may be that in any particular Riemann space there are straight lines of arbitrarily great length; in that case we shall say that this space is of infinite extension. On the other hand, it may also be that in this particular Riemann space the length of all straight lines remains less than a fixed number; then we say that the space is of finite extension. Until the end of the 18th century only one kind of mathematical space was known, and hence it was simply called "space." This is the space whose geometry is taught in school and which we call Euclidean space, after the Greek mathematician Euclid, who was the first to develop the geometry of this space systematically. And from our definition above, this Euclidean space is of infinite extension.

There are, however, also three-dimensional Riemann spaces of finite extension; the best known of these are the so-called spherical spaces (and the closely related elliptical ones), which are three-dimensional analogues of a spherical surface. The surface of a sphere can be conceived as a two-dimensional Riemann space, whose geodesics, or "straight" lines, are arcs of great circles. (A great circle is a circle cut on the surface of a sphere by a plane passing through the center of the sphere, as for instance, the equator and the meridians of longitude on the earth.) If r is the radius of the sphere, then the full circumference of a great circle is $2\pi r$; that is to say, no great circle can be longer than $2\pi r$. Hence the sphere considered as two-dimensional Riemann space is a space of finite extension. With regard to three-dimensional spherical space the situation is fully analogous; this also is a space of finite extension. Nevertheless, it has no boundaries; one can keep walking along one of its straight lines without ever being stopped by a boundary of the space. After a finite time one simply comes back to the starting point, exactly as if one had kept moving farther and farther along a great circle of a spherical surface. In other words, we can make a circular tour of spherical space just as easily as we can make a circular tour of the earth.

Thus we see that in a mathematical sense there are spaces of infinite extension (*e.g.*, Euclidean space) and spaces of finite extension (*e.g.*, spherical and elliptical spaces). Yet this is not at all what most persons have in mind when they ask: "Is space infinite?" They are asking, rather: "Is the space in which our experience and in which physical events take place of finite or infinite extension?"

So long as no mathematical space other than Euclidean space was known, everyone naturally believed that the space of the physical world was Euclidean space infinitely extended. Kant, who explicitly formulated this view, held that the arrangement of our observations in Euclidean space was an intuitional necessity; the basic postulates of Euclidean geometry are synthetic, *a priori* judgments.

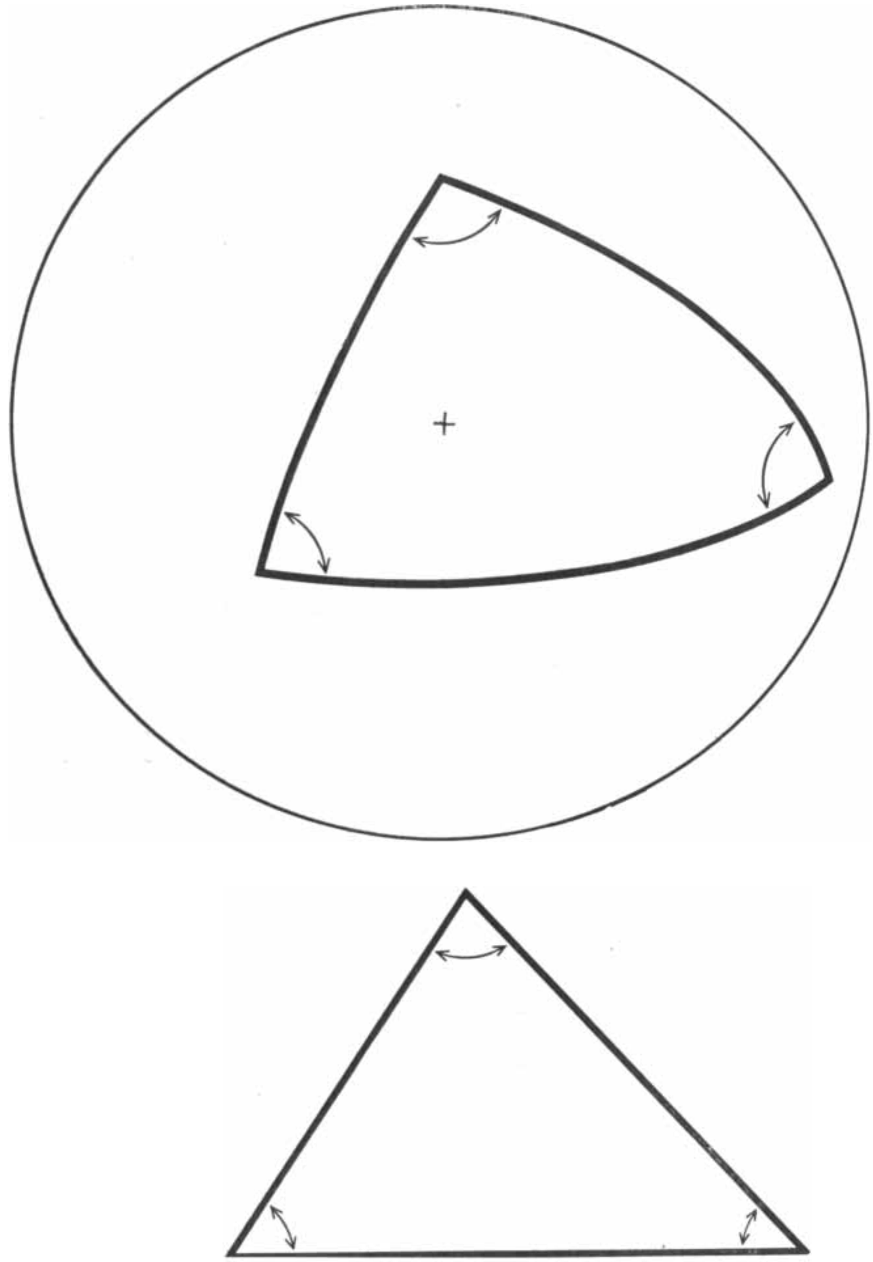
But when it was discovered that in a purely mathematical sense spaces other than Euclidean also "existed" (that is, led to no logical contradictions), men began to question the position that the space of the physical world must be Euclidean space. And the idea developed that it was a question of experience, that is, a question that must be decided by experiment, whether the space of the physical world was Euclidean or not. Gauss actually made such experiments. But after the work of Henri Poincaré, the great mathematician of the end of the 19th century, we know that the question expressed in this way has no meaning. To a considerable extent we have a free choice of the kind of mathematical space in which we arrange our observations. The question does not acquire meaning until it is decided how this arrangement is to be carried out. For the important thing about Riemann space is the manner in which each of its lines is assigned a length, that is, how lengths are measured in it. If we decide that measurements of length in the space of physical events shall be made in the way they have been made from earliest times, that is, by the application of "rigid" measuring rods, then there is meaning in the question whether the space of physical events, considered as a Riemann space, is Euclidean or non-Euclidean. And the same holds for the question whether it is of finite or infinite extension.

The answer that many perhaps are prompted to give, "Of course, by this method of measurement physical space becomes a mathematical space of infinite extension," would be somewhat too hasty. As background for a brief discussion of this problem we must first give a short and very simple statement of certain mathematical facts. Euclidean space is characterized by the fact that the sum of the three angles of a triangle in such space is 180 degrees. In spherical space the sum of the angles of every triangle is greater than 180 degrees, and the excess over 180 degrees is greater the larger the triangle is in relation to the sphere. In the surface of a sphere, the two-dimensional analogue of spherical space, this point is presented to us very clearly. On the surface of a sphere, as already mentioned, the counterpart of the straight-line triangle of spherical space is a triangle whose sides are arcs of great circles, and it is a well-known proposition of elementary geometry that the sum of the angles of a spherical triangle is greater than 180 degrees, and that the excess over 180 degrees is greater the larger the surface area of the triangle. If a further comparison be made of spherical triangles of equal area on spheres of different sizes, it may be seen at once that the excess of the sum of the angles over 180 degrees is greater the smaller the diameter of the sphere, which is to say, the greater the curvature of the sphere. This gave rise to the adoption of the following terminology (and here it is simply a matter of terminology, behind which nothing whatever secret is hidden): A mathematical space is called "curved" if there are triangles in it the sum of whose angles deviates from 180 degrees. It is "positively curved" if the sum of the angles of every triangle in it (as in elliptical and spherical spaces) is greater than 180 degrees, and "negatively curved" if the sum is less than 180 degrees—as is the case in the "hyperbolic" spaces discovered by Bolyai and Lobachevsky.

From the mathematical formulations of Einstein's General Theory of Relativity it now follows that, if the previously mentioned method of measurement is used as a basis, space in the vicinity of gravitating masses must be curved in a "gravitational field." The only gravitational field immediately accessible, that of the earth, is much too weak for us to be able to test this assertion directly. It has been possible, however, to prove it indirectly by the deflection of light rays—as determined during total eclipses—in the much stronger gravitational field of the sun. So far as our present experience goes, we can say that if, by using the measuring methods mentioned above, we turn the space of physical events into a mathematical Riemann space, this mathematical space will be curved, and its curvature will, in fact, vary from place to place, being greater in the vicinity of gravitating masses and smaller far from them.

TO RETURN to the question that concerns us: can we now say whether this space will be of finite or infinite extension? What has been said so far is not sufficient to give the answer; it is still necessary to make certain rather plausible assumptions. One such assumption is that matter is more or less evenly distributed throughout the entire space of the universe. The observations of astronomers to date can, at least with the help of a little good will, be brought into harmony with this assumption. Of course it can be true only when taken in the sense of a rough average, in somewhat the same sense as it can be said that a piece of ice has on the whole the same density throughout. Just as the mass of the ice is concentrated in a great many very small particles, separated by intervening spaces that are enormous in relation to the size of these particles, so the stars in world-space are separated by intervening spaces that are enormous in relation to the size of the stars. Let us make another quite plausible assumption, namely that by and large this average density of mass in the universe remains unchanged. We consider a piece of ice stationary, even though we know that the particles that constitute it are in active motion; we may likewise deem the universe to be stationary, even though we know the stars to be in active motion.

With these assumptions, then, it follows from the principles of the General Theory of Relativity that the mathematical space in which we are to interpret physical events must on the whole



Non-Euclidean triangle (top) *and Euclidean triangle* (bottom)

have the same curvature throughout. Such a space, however, like the surface of a sphere in two dimensions, is necessarily of finite extension. In other words, if we use as a basis the usual method of measuring length and wish to arrange physical events in a mathematical space, and if we make the two plausible assumptions mentioned above, the conclusion follows that this space must be of finite extension.

I said that the first of our assumptions, that of the equal density of mass throughout space, conforms somewhat with observations. Is this also true of the second assumption, as to the constant density of mass with respect to time? Until recently this opinion was tenable. Now, however, certain astronomical observations seem to indicate—again speaking in broad terms—that all heavenly bodies are moving away from us with a velocity that increases the greater their distance from us, the velocity of those farthest away being quite fantastic. But if this is so, the average density of mass in the universe cannot possibly be constant in time; instead it must continually become smaller. Then if the remaining features of our picture of the universe are maintained, it would mean that we must assume that the mathematical space in which we interpret physical events is variable in time. At every instant it would be a space with (on the average) a constant positive curvature, that is to say, of finite extension, but the curvature would be continually decreasing while the extension would be continually increasing. This interpre-

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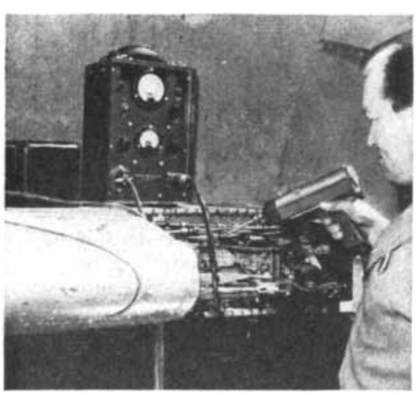

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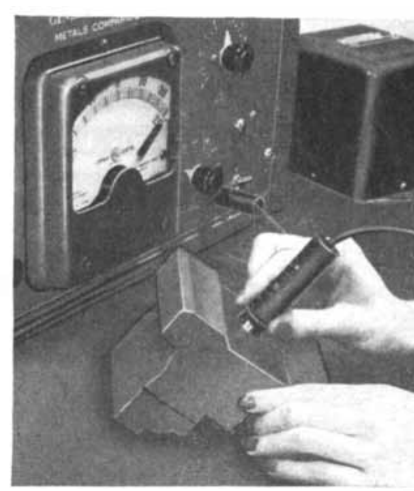


COMPARATOR used with test head on large or hard-to-get-at surfaces.

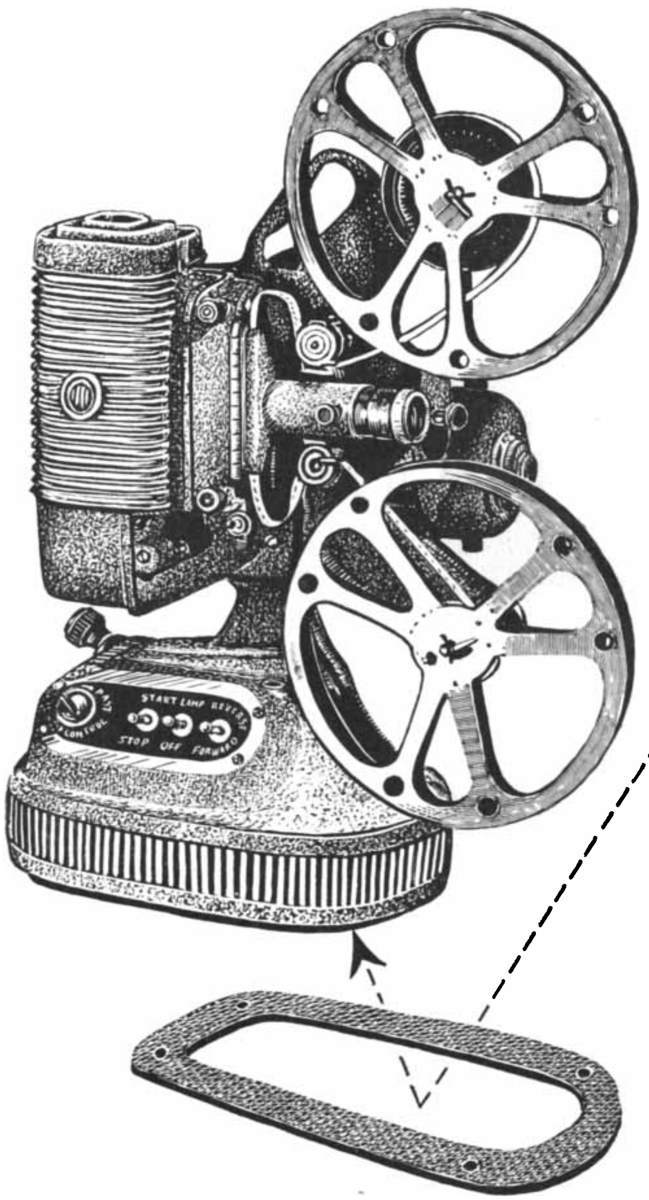
GENERAL ELECTRIC

tation of physical events turns out to be entirely workable and in accord with the General Theory of Relativity.

But is this the only theory consistent with our experience to date? I said before that the assumption that the space of the universe was on the whole of uniform density could fairly well be brought into harmony with astronomical observations. At the same time, these observations do not contradict the entirely different assumption that we and our system of fixed stars are situated in a region of space where there is a strong concentration of mass, while at increasing distances from this region the distribution of mass keeps getting sparser. This would lead us—still using the ordinary method of measuring length—to conceive of the physical world as situated in a space whose curvature becomes smaller and smaller at increasing distances from our fixed star system. Such a space can be of infinite extension.

Similarly the phenomenon that the stars are in general receding from us, with greater velocity the farther away they are, can be quite simply explained as follows: Assume that at some time many masses with completely different velocities were concentrated in a relatively small region of space, let us say in a sphere K. In the course of time these masses will then, each with its own particular velocity, move out of this region of the space. After a sufficient time has elapsed, those that have the greatest velocities will have moved farthest away from the sphere K, those with lesser velocities will be nearer to K, and those with the lowest velocities will still be very close to K or even within K. Then an observer within K, or at least not too far removed from K, will see the very picture of the stellar world that we have described above. The masses will on the whole be moving away from him, and those farthest away will be moving with the greatest velocities. We would thus have an interpretation of the physical world in an entirely different kind of mathematical space—that is to say, in an infinitely extended space.

IN SUMMARY we might very well say that the question, "Is the space of our physical world of infinite or of finite extension?" has no meaning as it stands. It does not become meaningful until we decide how we are to go about fitting the observed events of the physical world into a mathematical space, that is, what assumptions must be made and what logical requirements must be satisfied. And this in turn leads to the question, "Is a finite or an infinite mathematical space better adapted for the arrangement and interpretation of physical events?" At the present stage of our knowledge we cannot give any reasonably well-founded answer to this question. It appears that mathematical spaces of finite and of infinite extension



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are almost equally well suited for the interpretation of the observational data thus far accumulated.

Perhaps at this point confirmed "finitists" will say: "If this is so, we prefer the scheme based on a space of finite extension, since any theory incorporating the concept of infinity is wholly unacceptable to us." They are free to take this view if they wish, but they must not imagine thereby to have altogether rid themselves of infinity. For even the finitely extended Riemann spaces contain infinitely many points, and the mathematical treatment of time is such that each time-interval, however small, contains infinitely many time-points.

Must this necessarily be so? Are we in truth compelled to lay the scene of our experience in a mathematical space or in a mathematical time that consists of infinitely many points? I say no. In principle one might very well conceive of a physics in which there were only a finite number of space points and a finite number of time points—in the language of the theory of relativity, a finite number of "world points." In my opinion neither logic nor intuition nor experience can ever prove the impossibility of such a truly finite system of physics. It may be that the various theories of the atomic structure of matter, or today's quantum physics, are the first foreshadowings of a future finite physics. If it ever comes, then we shall have returned after a prodigious circular journey to one of the starting points of Western thought, that is, to the Pythagorean doctrine that everything in the world is governed by the natural numbers.

If the famous theorem of the right-angle triangle rightly bears the name of Pythagoras, then it was Pythagoras himself who shook the foundations of his doctrine that everything was governed by the natural numbers. For from the theorem of the right triangle there follows the existence of line segments that are incommensurable, that is, whose relationship with one another cannot be expressed by the natural numbers. And since no distinction was made between mathematical existence and physical existence, a finite physics appeared impossible. But if we are clear on the point that mathematical existence and physical existence mean basically different things; that physical existence can never follow from mathematical existence; that physical existence can in the last analysis be proved only by observation, and that the mathematical difference between rational and irrational forever transcends any possibility of observation—then we shall scarcely be able to deny the possibility in principle of a finite physics. Be that as it may, whether the future produces a finite physics or not, there will remain unimpaired the possibility and the grand beauty of a logic and a mathematics of the infinite.

BOOKS

The unusual and seductive universe of the late cosmologist E. A. Milne

by J. Bronowski

MODERN COSMOLOGY AND THE CHRISTIAN IDEA OF GOD, by E. A. Milne. Oxford University Press ($4.25).

To grasp the universe as a single coherent structure has been the dream of speculative thinkers since Greek times. It inspired Ptolemy and Galileo, the mechanics of Newton and Kant's theory of the evolution of the solar system. In the 19th century the problem of cosmology in the large almost dropped out of sight. It was revived by Einstein in 1916 when he at once (and characteristically) asked of his new theory of general relativity what model of the universe at large it implied.

No sooner had the question been asked than it was given dramatic force by the discovery in the 1920's that the universe is altogether less compact than we had even supposed. It is bigger and patchier, and it is on the move. The nebulae do not lie in our galaxy but far beyond, and each is a galaxy of its own. These galaxies seem to be racing away, faster as they are farther from us, to all the corners of space.

I say "seem to be racing away" because beneath many of the new cosmologies (and Milne's among them) is still hidden the feeling that this movement cannot be real. And of course it is right to remember that all such evidence is farfetched. We judge the distance of a nebula by the way its *supposed* brightness has dimmed on the journey to us. We judge the speed of the nebula away from us by the shift of its spectrum toward the red, which we interpret as a Doppler fall in pitch. On these remote grounds Hubble calculated in 1929 that the nebulae seem to be moving as if they had all left us, in random directions and with random speeds, about 2,000 million years ago. No one has since suggested a better way to read the evidence.

Milne was perhaps more determined than most astronomers not to be surprised by this result. He was a pupil of Eddington, and Eddington had been one of the first English champions of relativity and had taken part in the famous eclipse expedition of 1919 which confirmed that light is bent toward the sun. Eddington had been deeply impressed by Einstein's elucidation of the essential place held in all physical theory by the observer himself. As time went on this formed in Eddington the conviction that much of what we think we discover in the structure of nature is in fact imposed by the structure of our own thought. In some form this outlook passed from Eddington to his pupils, and, although much changed, it is powerful in Milne's work. Master and pupil were more sensitive to the change than to the likeness, and for a long time they were estranged. Indeed, when Milne called his work "kinematic relativity," Eddington said to me in conversation that Milne had forgotten what relativity was. The criticism was not unjust, for the hypothetical observers of Milne's theory are quite alien to the observational realism of relativity. Yet it missed the graver search for the content of human reason within all theories, which Eddington and Milne shared. It is therefore pleasant to find in this, Milne's last book, a warmth of manner toward Eddington's last work which shows that the breach between them was healed.

Even before 1930 Eddington had been trying to find relativity models of the universe, and distributions of matter in them, which expand of themselves. When another of his pupils, Georges Lemaître, found such a model (it is still the best relativity model) Eddington at once linked it with the flight of the nebulae, and wrote a brilliant book on the subject, *The Expanding Universe*, in 1932.

Milne took it for granted, as we all now do, that the flight of the nebulae is not merely away from us. In his own phrase, the theory "does not mean that we occupy a specially unpopular position in the universe." It would in fact be as difficult to persuade our century that we are the center of creation as it was once for Copernicus to avow that we are not. Milne held that our place in space is in every way typical; or, more cogently, that *the universe would look the same to us, in the large, no matter where we happened to be in it.* This is now called the cosmological principle. Milne was proud to acknowledge that it had been held earlier by Giordano Bruno, who insisted "that the eye being placed in any part of the Universe, the appearance would be still all one as unto us here." From this principle Bruno had deduced, very soundly, that there must be an infinity of worlds, and in consequence he was ceremonially burned as a heretic in 1600.

The cosmological principle, or, as I like to call it, Bruno's principle, has been most tersely put by Sir Edmund Whittaker: "It is impossible to tell where one is in the universe." Milne's theory is formed entirely on this. But before we can enlarge the principle to a theory, we must give some meaning to the word "where" and introduce the word "when." Milne took the second word as fundamental. He broke with relativity by refusing to give any meaning at all to "where" (that is, to distance) which does not derive from "when" (that is, from the comparison of times). There is only one fundamental operation in Milne's physics: it is looking at a clock. His geometry is built upon this, with the single assumption that we can tell one direction from another.

But looking at a clock is a tricky operation, and it took Milne and his pupils 15 years to work it out fully. Naturally we cannot assume that the clock keeps regular time. What meaning has the word "regular"? And is the meaning the same for the earth's orbit and for the orbit of an electron? Milne's theory, formed precisely to answer these questions, could not begin by begging them. He therefore supposed only that his observer marks the events that happen to him, one after another, with some arbitrary succession of increasing numbers. That is his clock. To measure the distance of any point from him, he watches how long it takes light to get there and back.

Plainly the central problem of Milne's theory now is: Can the arbitrary clocks of different observers, in different places, be made to tally in any sense at all? The observers can flash lights at one another's clocks and so see what time they showed when the light reached them. A pair of observers can then graduate their clocks afresh so that they tell, not indeed the same time, but symmetrical functions of each other's time. But in what kind of a universe can this be done, not merely for one pair of observers, but for all possible pairs of observers—that is, for the whole universe?

The question has an answer, and an elegant one. The answer is Milne's cosmology. But the answer is not easy to state, for we must describe a universe by distance as well as time, and in Milne's cosmology distances (and speeds) change of themselves when we change the scale of time. Therefore the important thing about the answer is not what it looks like, but the simpler fact that it is unique. There is only one kind of network of observers whose clocks hold together so that they continue to give consistent comparisons of times.

The time-scale in this remarkable result still has a degree of arbitrariness; it can be fanned out or furled by graduating one clock afresh, and the others will follow. Each scale at once imposes its own distances and speeds, and with them both the appearance and the history of its universe. Thus there is a scale of time t which gives a universe expanding uniformly from some definite zero or beginning of time. The nebulae in flight may be held to have this as their model. Or again there is a scale of time τ which gives a universe at rest; and since τ keeps step roughly with the logarithm of t, this universe goes back through infinite time.

On the t-scale the classical constants of nature no longer are all fixed: the constant of gravitation, Planck's constant and even angular momentum, increase with t. The Lorentz transformation holds in t-time, and Milne therefore took this to be the fundamental time-scale for electromagnetic and atomic processes. He linked τ-time with the more usual results of dynamics. For example, he showed that, on this time-scale, if a moving set of particles is to look the same to all observers, then it must obey both Newton's first law of motion and the law of inverse squares. And indeed, he derived a concept of mass from this analysis.

We are plainly discussing a theory on the grand scale, and Milne by no means stopped here, but carried it over to most of physics. On the day he died two years ago he had arrived in Dublin to lecture on possible relations between rotation and magnetism in the light of his theory. It is therefore natural to ask why Milne's work, in many ways so broad and powerful, has continued to leave astronomers uneasy and rather uninterested.

One of their criticisms is indicated by Eddington's remark that the language of Milne derives from relativity, but the thought does not. Relativity asks that real observers, moving at will and carrying out real operations, shall frame the laws of nature in the same way. By contrast Milne's observers are unreal, are carried along in the stream of the universe and watch not its laws but its appearance in the large—which is a tricky concept.

And yet I think this criticism of Milne is mistaken. For Milne was not trying to set up an operational system, in which the laws of nature are deduced only from feasible observations. He was making an axiomatic system, and the test of his axioms is not whether they themselves are practicable, but whether the theorems which flow from them check with the facts of nature. Huygens said this clearly long ago of his own work: "Here principles are tested by the consequences derived from them."

Milne often obscured this point by taking as either physically or logically evident what was in fact a hidden axiom, although a reasonable one. In the book under review here he insists that the universe must be so made that all observers can maintain consistent comparisons of time. This is a plausible axiom, but it does not become less an axiom for being grounded on the plea that only so can the universe be rational—that "God Himself is limited by reason in the divine act of creation. God cannot do the impossible."

I do not find fault with Milne's system because it is axiomatic, but I share with his critics a nagging feeling that it is unsettled and improvised. Milne was on the council of my college when I was a young lecturer, and I learned to admire his speed of mind whenever we talked of mathematics. Yet in his own work he seemed to me then, and seems now, too quick to find an explanation for an effect rather than build up an understanding from the inside. He lacked the power of self-criticism, and his theory went through too many experiments and changes to command confidence.

There is a sad postscript to this even in *Modern Cosmology.* For the only new work it presents is a correction of Milne's earlier explanation of the shift in the nebular spectra toward the red, in t-time and in τ-time. The correction does not greatly change Milne's first thoughts. In t-time, the shift is a true Doppler effect. In τ-time, the nebulae are at rest, but the frequency of the light is running down, so that it is redder when it is received than when it left its atom. The correction, I have said, is perhaps no great matter, though it makes labored and muddy reading. But this was once a high point of Milne's theory—the elegant demonstration that whether we look at the universe on the atomic or on the terrestrial scale of time, we shall see the same shift to the red with different eyes. In a sense Milne's cosmology was born from the red-shift, and took its stature from this duality. To have it touched up now is a sad confession of haste in the past.

Nevertheless the book as a whole is a handsome exposition, well argued, fresh from the pen (Milne died within a few days of finishing it) and full of good ideas. It gives no mathematics to speak of, and since Milne was not good at putting a mathematical argument into words or pictures, the argument is thin. But the main lines of thought are sharp, and their consequences are clearly stated. The book was to have been given as a course of lectures to an unspecialized public. They would have understood less than Milne hoped, but they would have liked the quick, absorbed, almost boyish lecturer with the big head and the big heart.

Like Eddington, Milne was a devout man. In the theme of his book he carries through what his title promises and relates his cosmology to the idea of God. In this context the idea has for him two parts: God the creator, and God the rational mind. He sees the Creator as the necessary cause at the zero of *t*-time; without Him time and space (that is, the flying apart of the galaxies) could not have begun. But the Creator is also bound by His nature to be rational: "Divine omnipotence itself would be impotent to select any one direction in preference to any other, or any one state of motion in preference to any other, in the divine act of creation." Such passages occur again and again, but it is difficult to see what the concept of the rational means in them, other than the need to conform to Milne's cosmology. The most pleasing argument is one based on the discovery, which I have already underlined, that there is essentially only one network of observers who can compare times consistently by Milne's method. Of this Milne says: "I think that the argument that the uniqueness of the universe implies an absence of rational alternatives in creation is a genuine argument for both the rationality and the oneness of God."

I cannot pretend much sympathy with such reasoning. In it the concept of creation (on one scale of time among an infinity) seems to me forced, and the concept of the rational seems to me human and even personal. Milne's outlook here is orthodox 18th-century deism. Like Bolingbroke and Paley, he sees the universe as God's clockwork, now wound and running on its own. Milne does allow God to experiment in biology and evolution, but I feel that this is because they are safely somebody else's subjects. And it is odd that so warm a man should have called these cold constructs "the Christian idea of God." The poet W. B. Yeats, finding philosophers in debate about such a godhead, once called it "an abstract Greek absurdity" —absurd to him, because passionless. Like Milne, I am fond of abstract Greek ways of thinking, but I do not think that they have the power to fashion a God in the image of the expanding universe.

J. Bronowski is Director of the Central Research Establishment of the British National Coal Board.

COSMOLOGY, by H. Bondi. Cambridge University Press ($4.50). One of the "Cambridge Monographs on Physics," a series devoted to results of recent research. Bondi, lecturer in mathematics at Cambridge University, describes the major cosmological theories: Newton's system, relativistic cosmology, kinematic relativity, the theories of Eddington, Dirac and Jordan and the "steady-state" theory put forward by Bondi and Gold in 1948. Besides giving a balanced and lucid (but not simple) explanation of each theoretical framework, the book furnishes full information on the observational aspects of the several cosmologies. An authoritative manual, ably written and well thought out, it offers a coherent view of a lively, important and healthily controversy-ridden branch of science.

OPTICKS, OR A TREATISE OF THE REFLECTIONS, REFRACTIONS, INFLECTIONS AND COLOURS OF LIGHT, by Sir Isaac Newton. Dover Publications, Inc. ($4.00). This masterpiece has suffered remarkable vicissitudes, finally to emerge as one of the most enduring of Newton's creations and certainly the most prophetic. Some of its main ideas (for example that white light is a mixture of rays of every variety of color) were vehemently attacked by Hooke when first uttered, with the result that Newton, always morbidly sensitive, was almost persuaded to forego all further research. The first edition of the book, published in 1704, was based upon a work completed 20 years earlier but destroyed by fire because Newton left a candle burning in his rooms when he went to chapel. Newton's corpuscular theory of light was so discredited by the middle of the 19th century that *Opticks* was regarded as possessing merely historical interest, yet today it is an underpinning for the entire edifice of physics. "In one person," says Einstein in a foreword to this volume, "he [Newton] combined the experimenter, the theorist, the mechanic and, not least, the artist in exposition." In none of his other writings are all these qualities as clearly displayed as in this essay, large parts of which any intelligent layman can enjoy.

THE CREATION OF THE UNIVERSE, by George Gamow. The Viking Press ($3.75). Gamow's report of the event runs something like this: About three billion years ago there was a "gigantic collapse" resulting in a super-dense cosmic mass. When this mass began to cool and expand, its primordial substance, which he calls ylem, underwent a brief period of "nuclear cooking" during which the elementary particles (neutrons, protons and electrons) began to stick to one another and to form the prototypes of all the atomic nuclei we know today. The ingredients of the universe were cooked in less than an hour under conditions "closely approximating those existing in the center of an exploding atomic bomb." The atomic gas continued to spread out in space but after a time, as the intense radiant energy diminished, the forces of gravity came into play. The homogeneous gas formed into clouds, the "proto-galaxies," and the "ponderable" matter in the interior of galaxies condensed into innumerable "proto-stars." Further contraction raised the temperature of the stars to a point where nuclear reactions between hydrogen and the lighter elements took place, and space, which had been dark, "became bright again, being illuminated by myriads of stars." The planets were formed from the material "left over" in the vicinity of the evolving proto-galaxies. Planetary bodies, being too small to generate their own nuclear energy, cooled off and developed rocky crusts and in due time organic life. That is where we come in. Gamow's excellent account is neither too difficult nor too easy and has the usual complement of Gamow jokes, none of which is particularly funny but most of which help the understanding. Perhaps the most striking thing about his book is the fact that, even with the discipline introduced into cosmology by systematic observation and the use of mathematics and other sciences, its hypotheses are as high, wide and handsome, not to say as varied and ingenious, as the breath-taking flights of poets and philosophers who have speculated on the subject since ancient times.

THE PHYSICAL BASIS OF LIFE, by J. D. Bernal. Routledge and Kegan Paul, Ltd. ($1.50). This book, based on a widely noticed lecture delivered in 1947 before the British Physical Society, has been properly described as a "brilliantly speculative survey" of a fascinating problem: the conditions under which inorganic substance was first transformed by physical and chemical action into living matter. It has been called "a physicist's approach to biology." Professor Bernal makes only the modest claim that he wrote it to get his own ideas clear "so as to be able to work out a more rational programme for biophysics." His conjectures, incorporating the writings of other workers—Haldane, Lwoff, Oparin, Dauvillier, among them—emphasize the problem of origin rather than such matters as form, growth and behavior. Once the earth had cooled sufficiently for water to condense, and atmospheric conditions were propitious, the stage was set, we are told, for the appearance of life, which, in Moleschott's classic phrase, "is woven out of air by light." The creation of primary photosynthetic life was in a sense an accident which could not occur again today, since the active agent—"the influx of solar radiation out to the far ultra-violet of 2,000 angstroms or less"—is no longer in operation. One of Bernal's most interesting speculations is that clay and quartz provided the adsorptive bed in which the concentration, polymerization and other processes of synthesis necessary for the evolution of the primitive molecules out of which life is constructed could take place. His book, though brief and difficult, is one of the most stimulating scientific essays of recent years.

A Guide to the History of Science, by George Sarton. Chronica Botanica Company ($7.50). Professor Sarton's book is in two parts, the first consisting of three lectures on the meaning and purpose of the history of science; the second presenting a bibliographic summary, together with certain related data, of the essential literature of the subject. The lectures add nothing really fresh to one's understanding. The bibliography is on the whole a disappointing effort from a scholar renowned for his broad and meticulous erudition. The section on scientific methods and the philosophy of science, for example, is an indiscriminate medley of important and trivial items, with notable omissions; the listing under "science and society" is so incomplete as to be almost valueless; the information offered on historical atlases and gazetteers is unsatisfactory; most regrettable of all, the bibliography is not annotated, which drastically limits its usefulness to the beginner. Sarton, apparently aware of the inadequacies of his bibliography, offers the explanation that the listings are based primarily upon his own library and his personal reading experience; errors and gaps are also ascribed to the fallibility of his memory. Despite its defects, it is the best available guide of its kind.

A Source Book in Chemistry: 1400-1900, by Henry M. Leicester and Herbert S. Klickstein. McGraw-Hill Book Company, Inc. ($7.50). A new member of an established series of source books on the history of science. The selections are landmarks in the development of chemical theory rather than descriptions of the discovery of individual elements, compounds or processes. While this is a reasonable standard of selection, the result is a less comprehensive and interesting anthology than others in the series.

Player Piano, by Kurt Vonnegut, Jr. Charles Scribner's Sons ($3.00). The subject of this novel of the future is automatic control, which was also the subject of the September Scientific American. In the magazine, the electronic computer and the feedback circuit were seen as new engineering tools of almost incalculable potentiality. In the novel, the possibilities have been largely realized and computers and feedbacks have become monstrous despots, served with religious awe by a small elite and hated by the demoralized and obsolete populace. This does not mean that the author of *Player Piano* hates science in general or engineers in particular. Nor does he assert the inevitability of his grisly utopia. He offers it simply as a logical possibility. The U. S. of *Player Piano*—perhaps 50 years hence—is a thorough despotism in which the people are slaves, not because they are useful, but because they are utterly useless. They walk the treadmill of a humiliating WPA or they serve time in an unarmed army. The hard-pressed elite, on the other hand, watch vigilantly that the orders of the master computer (lodged in Carlsbad Caverns) are faithfully observed, guard the automatic factories against sabotage and place love of the machine above love of God, of man or of the flesh. There are some flashes of hope in the closing pages, but on the whole it is a bleak optimism. Compared to such utopians as Huxley and Orwell, Vonnegut is moderate: there are no obscenities in his book, no psychotic cruelty and not much villainy. For that reason his particular version of the hell we may get if we don't watch out is as convincing as any yet conceived.

THE PAPERS OF THOMAS JEFFERSON: Vol. 5, edited by Julian P. Boyd, Lyman H. Butterfield and Mina R. Bryan. Princeton University Press ($10.00). This volume of 700 pages, a new installment of the Princeton project, covers just three months of Jefferson's governorship of Virginia, from February to May, 1781. Jefferson was incapable of being dull, and the editors, as able exponents of enlightened scholarship, know how to make even routine correspondence interesting. The bulk of the book consists of letters to and from the Governor and deal mainly with the conduct of the war. Other correspondence touches on the affairs and complaints of the prickly Baron von Steuben, the famous Westover imbroglio (involving the charming and dubious Mary Willing Byrd), Lafayette's campaign, Clark's intended expedition against Detroit, investigations of hanky-panky in the War Office, the depredations of British troops in Virginia, the purchase by Governor Jefferson, for 15,068 pounds of tobacco, of an encyclopedia for public use, ratification of the Articles of Confederation, disaffection and disloyalty, and assorted matters that filled the days of this inexhaustible man.

THOMAS JEFFERSON: SCIENTIST, by Edwin T. Martin. Henry Schuman, Inc. ($4.00). This astigmatic biography fails to prove its title. Indeed, the author does not seem himself convinced that Jefferson was a scientist, for he stops repeatedly to assure us of his subject's right to the title. Jefferson never assumed it; he was an exact man and he called himself an amateur of science. The book meticulously describes Jefferson's inventions, systematic observations and scientific correspondence. It contains a genuinely interesting and entertaining account of his vigorous response to the charge by the Comte de Buffon that America's climate and soil could not support a vigorous fauna and that everything was small and puny there: in reply Jefferson shipped him a moose—in a doubtful state of preservation. The portrait of Jefferson here is that of a science-minded country gentleman, who invents an excellent plow, rigs his house with amusing gadgets, reads the thermometer conscientiously, is fascinated by large fossil bones—but is only a piece of the Jefferson who actually lived.

RUSSIA'S LOMONOSOV: CHEMIST, COURTIER, PHYSICIST, POET, by Boris N. Menshutkin. Princeton University Press ($4.00). A worshipful biography of Mikhail Vasilyevich Lomonosov (1711-1765), a man of talent, versatile interests, unflagging bumptiousness and unrivaled self-esteem. Born in the White Sea region, Lomonosov was trained in Germany as a metallurgist and returned to Russia as a teacher and experimenter in chemistry and physics. But these were not the half of his trades. He wrote poetry (most of it bad, judging from the excerpts in this book); contributed to the founding of scientific research and education in St. Petersburg; published a considerable number of books and papers on Russian grammar, philosophy, history, geography, mineralogy, thermometry, navigation, meteorology and philology; developed formulas for making colored glass; established a factory for mosaics; helped a colleague electrocute himself by erecting a machine to catch the lightning; and engaged in an almost endless succession of quarrels with his colleagues and superiors. Professor Menshutkin, a well-known Russian chemist who died in 1938, devoted a large part of his life to gaining recognition for what he considered to be Lomonosov's pioneering achievements in physical chemistry and other scientific theories. His biography is pleasant and interesting, but it offers no real proof that its subject was anywhere near as important as Menshutkin insists.

SPECIALIZED TECHNIQUES IN PSYCHOTHERAPY, edited by Gustav Bychowski and J. Louise Despert. Basic Books, Inc. ($5.00). Because the expense and length of psychoanalysis, and the scarcity of trained analysts, severely limit the number of people who can be given the full treatment, certain psychiatrists have developed shorter specialized techniques to make treatment available to more people. The articles in this book deal with some of these methods and developments: narco- and hypno-analysis, telepathy (from a psychodynamic viewpoint), art and group therapy, psychosomatics and special techniques for children, schizophrenics, stutterers, alcoholics, the disabled, sex offenders, depressives and borderline cases. The contributors to the book maintain an unusually high level of clarity and competence.

THE HAND IN PSYCHOLOGICAL DIAGNOSIS, by Charlotte Wolff. Philosophical Library ($7.50). A pioneering study in psychodiagnostics by the author of *The Human Hand.* Dr. Wolff has used her method of hand-diagnosis in the study of various mental disorders of psychic and organic origin. The shape and markings of the hand, its mobility and such products of its use as drawing and writing are the essential tools of her method. Dr. Wolff has reformulated many ideas expressed in her previous book to conform with new information she has gathered.

THE CONTRIBUTIONS OF HARRY STACK SULLIVAN, edited by Patrick Mullahy. Hermitage House ($3.50). This is a eulogistic collection of essays on the philosophy and clinical practices of the late Dr. Sullivan, who was a superb clinician with independence of mind and method, and whose contributions broadened psychiatry to include treatment of psychotics and obsessionals at a time when Freudian theory rejected these groups. He based his premises on social rather than biological phenomena, thus making the data of the social sciences an integral part of psychiatric thinking. The articles cover Sullivan's theoretical, clinical and social ideas. They are strikingly uneven. The most noteworthy are Clara Thompson's brief piece on Sullivan and psychoanalysis; Dr. White's paper on Sullivan's methods of treatment, which illustrates his ingenuity, inventiveness and unorthodoxy, and articles by Gardner Murphy and Elizabeth Cattell and by Charles S. Johnson which indicate the direction and breadth of his approach.

CHILDREN WHO HATE: THE DISORGANIZATION AND BREAKDOWN OF BEHAVIOR CONTROLS, by Fritz Redl and David Wineman. The Free Press ($3.50). A reader willing to plow through pages of introductory material and to digest a style unusually rich in jargon will be rewarded by valuable new material on the dynamics of behavior in delinquent children. Children who hate are those who have been so deprived by family and society that their personalities are disorganized and shredded almost before they are formed. Thus they can find no refuge in mere neuroses and cannot be treated by the methods used with neurotic children. The authors have had wide experience with such children in a full-time environment, and present new clinical evidence and theories regarding the best methods of cure.

THE AMATEUR SCIENTIST

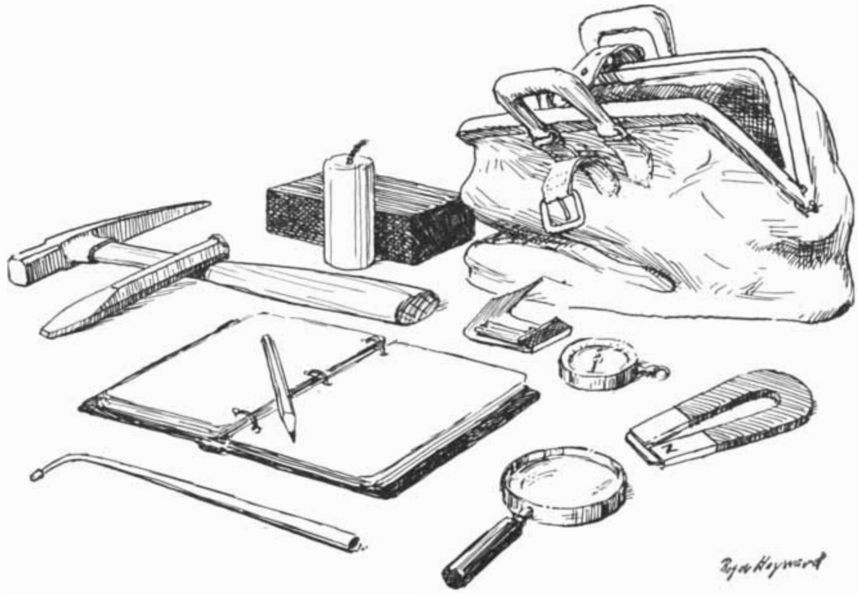
The study of rocks and the making of two relatively simple telescopes

Conducted by Albert G. Ingalls

AT ONE time or another nearly everyone starts a rock collection. It may begin with a curiously shaped stone picked up at the beach, a glittering fragment found along a mountain trail—any eye-catching bit from anywhere. Perhaps the specimen is clear, glass-like and flecked with yellow. Could it be gold? Stone after stone is lugged home and the collection grows, sometimes into a dust-catcher of considerable size. Then interest wanes and one fine day, about the time of spring house cleaning, the whole assortment is dumped on the trash pile, or, at best, becomes an ornamental border for the flower bed.

How different the history of such collections might be if those who do the collecting would spend a few hours learning how to read the stories written in the rocks. Thousands of amateur mineralogists have mastered this easy language, many with little more equipment than a keen pair of eyes, normal curiosity and any of a dozen or more excellent reference books. Collecting, studying and experimenting with minerals can be enjoyed throughout the year, and few avocations offer as much variety, activity and interest.

It has been said that a stone, when examined closely, will be found to be a mountain in miniature. Of many stones this is indeed true. If a fragment of common granite, for example, is viewed under a magnifying glass of reasonable power, its uniform gray or pink surface breaks up into innumerable discrete features. Some take the form of exquisitely shaped crystals, almost as hard as gem stones. Others are soft and can be split into thin sheets. Still others present a milky appearance and break into fragments that assume the spiral shape of a sea shell. In some specimens the minute mountain of granite appears to have been folded, cracked and cemented together again—features reproduced on a giant scale by real mountains. Once in a great while you may have the good luck to find a mineral ore and thus, in miniature, strike it rich. Incidentally, by the time the beginner has analyzed a half dozen stones he will develop much respect for the equipment that the lowly prospector carries beneath his hat. As Miss Elizabeth Morley, a school teacher and amateur mineralogist now living in retirement near Philadelphia, says, "There's a lot more to prospecting than a geologist's pick and grub stake!"



The tool kit of the amateur mineralogist

Miss Morley's mineral collection, which includes specimens ranging from talc to diamond, got its start one day in 1922 when one of her eighth-grade pupils asked for permission to demonstrate a crystal radio set before his class. Its galena crystal captured Miss Morley's imagination. When the wire "cat's whisker" was adjusted, music came out of the rock! Miss Morley never quite recovered from the astonishment of that moment, and she decided then and there to learn the how and why of the silvery bit of stone which at that time she could not even name.

In the course of learning that galena shares with a number of other minerals the curious property of conducting electrical currents more readily in one direction than the other, she also learned that it breaks into cube-shaped fragments when struck a sharp blow, that chemically it is a compound of sulfur and lead, that it has a hardness of 2.5 (it can be marked by the fingernail) and a specific gravity of 7.6. But the discovery that converted her to amateur mineralogy was the fact that the mineral kingdom, like the animal and vegetable kingdoms, has a taxonomy of its own which draws a distinction between individuals quite as sharp as that which locates man in one biological category and his pet fish in another.

Minerals today are classified according to their chemical composition, and beginners in mineralogy are urged to learn the classification system. Under this system most minerals can be labeled as a member of one of the following species: sulfide, oxide, halide, carbonate, borate, phosphate, sulfate, tungstate, molybdate, uranate or silicate. In each species there are thousands of individual minerals—metallic or non-metallic.

All minerals are chemical compounds made up of two or more of the 92 naturally occurring elements. Nine elements account for the great bulk of minerals, and indeed for 95 per cent of the earth's crust. They are oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium and hydrogen. In addition three others, though quantitatively small, are important components of minerals. These three are carbon, chlorine and sulfur.

Because most minerals are composed of a very few elements, many specimens can be identified at a glance. More than 99 per cent of the specimens collected by the average amateur can be analyzed without elaborate equipment or methods. Others require detailed examination. This usually begins with a test for hardness. The standard scale of hardness, ranging from 1 to 10, is based on the relative hardness of a selected group of minerals. From the softest to the hardest it runs:

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Sapphire (Corundum)
10. Diamond

Kits containing the first nine of these minerals in sizes handy for use in the field can be procured for a dollar or so from firms specializing in mineralogical equipment, such as Ward's Natural Science Establishment of Rochester, N. Y., and Eckert Mineral Research Co. of Florence, Colo. With a little experience the amateur can make a good estimate of hardness with the aid of quite ordinary materials. Minerals of hardness 1, for example, crush easily between the fingers and usually have the greasy feel of talcum powder. Those of hardness 2 can be scratched by the fingernail. A common pin will scratch the hardness 3 group and those of hardness 4 yield readily to the blade of a penknife. Members of group 5 are difficult to scratch with a knife. Those in group 6 will scratch a knife. The hardest particles in granite (quartz) are of hardness 7. Thus a specimen of granite is useful in estimating the hardness of materials lying beyond the range of 7. The hardness test should be made on a fresh surface exposed by chipping a small corner off the specimen, as weathering processes soften the surfaces of exposed rocks.

Having noted the specimen's hardness, the mineralogist next tests for streak. The specimen is rubbed against a small plate of unglazed porcelain or an equivalent material. Usually it makes a streak on the white porcelain surface This enables the mineralogist to see the true color of the specimen: thus a rock that appears brown to the eye may make a distinctly red mark on the white porcelain. This color, together with the specimen's hardness and other tests, will guide the collector to the identity of the specimen as tabulated in a reference text.

Next an estimate should be made of the specimen's general physical character. Some minerals can be flattened by a hammer, and thus are said to be malleable. Others, such as copper, can be stretched and therefore are ductile. If the specimen can be cut by a knife, like a piece of hard tar, and yet shatters under a sharp blow, it is sectile. Those that bend easily and remain bent are called flexible. Some forms of sandstone exhibit this characteristic. Others are brittle and shatter like glass when struck with a hammer or when bent beyond their yield point. Finally, many minerals, such as mica, are elastic.

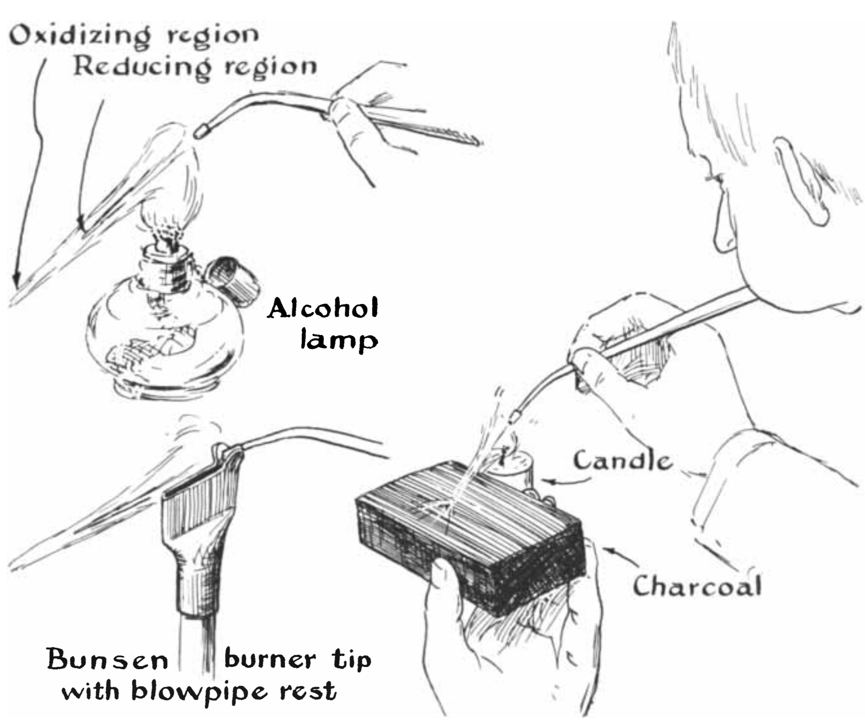
The next clue to identification is the mineral's density, which can often be estimated simply by hefting it; no one needs a sensitive balance to tell a block of lead ore from one of gypsum. An advanced amateur can easily construct his own balance for determining specific gravity with reasonable accuracy. Suspend a pan from a hook by a spring or rubber band. Put the rock specimen on the pan and measure the distance between the pan and the table over which it hangs. This distance is designated as N_1. Then carefully raise a wide-mouthed jar of water from below until the pan and the specimen are fully immersed in the water. The pan of course will rise higher above the table, as the weight on the spring is reduced by an amount equal to the weight of the displaced water. This higher position is measured and designated as N_2. The specific gravity of the specimen is found by subtracting N_1 from N_2 and dividing N_1 by the difference.

Specific gravities of minerals range from 1.7 (borax) to 8.1 (cinnabar) or more. The specific gravity of sulfur is 2.05; gypsum, 2.3; quartz, 2.66; feldspar, 2.6 to 2.75; talc, 2.8; diamond, 3.5. The densities of metals extend over a much wider range. Some of the common ones: magnesium, 1.8; aluminum, 2.5; zinc, 7.1; silver, 10.6; gold, 19.3; platinum, 21.5. Comparing the specific gravity of gold with that of quartz, the major constituent of sand, it is easy to see why the grains of precious metal settle so readily in the bottom of the prospector's pan and why the Jolly balance for determining specific gravity became almost the symbol of the assayer's office during the days of the great gold rush.

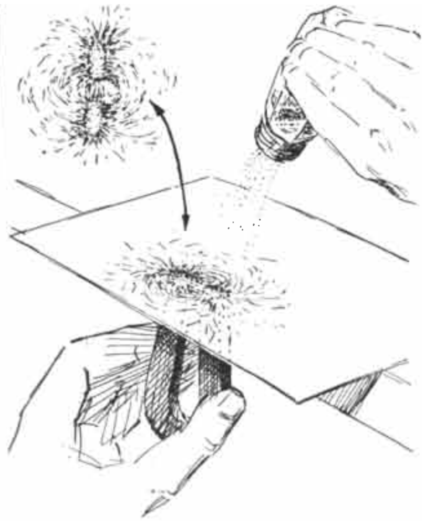
Other readily ascertained clues to a mineral's identity are its appearance under light (daylight and ultraviolet), its electrical and magnetic properties, its crystal structure, its taste and its odor.

Minerals reflect, absorb and transmit wavelengths of light according to their chemical structure. Hence each presents a characteristic surface texture and color. Some, like the silvery mineral galena, show a pronounced metallic luster; the color may range from light gray through silver, yellow and dark brown to purple. Others, chiefly the non-metallic minerals, show a glass-like luster that ranges through pearly and silky to glistening. Some are as transparent as clear glass; others appear milky or translucent, opalescent or iridescent.

One of the most striking optical prop-



Sources of flame for the blowpipe test



Test for magnetite

erties of many minerals is that of fluorescence: they glow in vivid, characteristic colors when exposed to ultraviolet light. The phenomenon was first observed as a property of fluorite many years ago. Unfortunately fluorescence is not very useful analytically. Some specimens of a given mineral fluoresce readily while others show little if any activity. Some respond to a limited range of wavelengths in the ultraviolet spectrum and others to the whole spectrum. Save for rare examples such as willemite from the vicinity of Franklin, N. J., which emits a bright green glow, fluorescence cannot be depended upon as an analytical test. Nevertheless, most amateur mineralogists own inexpensive ultraviolet lamps for use in displaying their collection.

A number of minerals exhibit electrical qualities. Galena, as mentioned previously, presents greater resistance to the flow of current in one direction than in the other. Thus it is a rectifier and can be used for the detection of radio waves and related electrical applications. This same property is characteristic of certain compounds of copper, silicon, germanium, uranium and others. Quartz and tourmaline in their crystalline forms show what is called piezoelectricity—an electrical effect produced by squeezing the specimen. This property, plus the fact that quartz is one of the most elastic materials found in nature, accounts for the extensive use of this mineral for generating small alternating electrical currents of constant frequency. Thin wafers of quartz, properly mounted in electrical circuits, can be made to vibrate at rates of 50 million pulses per second, and electrical clocks driven from quartz crystal oscillators keep time accurately to less than a second's deviation per year!

Lodestone is the classic example of a magnetic mineral. This naturally occurring magnet will pick up bits of iron or steel and in other ways behave like a horseshoe magnet. When powdered, its particles cling together, and iron filings sprinkled on paper covering a lodestone arrange themselves in the form of the specimen's magnetic pattern. Other minerals, containing iron, nickel or cobalt, also show magnetic properties—some being attracted to a magnet and others, like lodestone, behaving as a magnet.

As for taste and odor, halite (the prospector's name for ordinary salt) of course tastes salty; many potassium compounds taste bitter; those of aluminum cause the mouth to pucker; many iron compounds have a sour taste; a few varieties of limestone and other compounds of sulfur give off the odor of rotten eggs when crushed; some shales have a distinctive earthy odor; some minerals of arsenic smell like garlic.

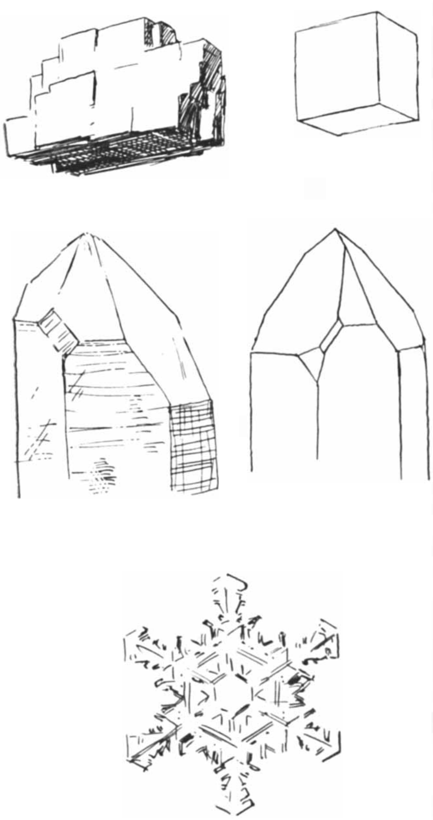
A pencil, notepaper and a reference book are all the equipment a beginner needs to start in mineralogy, but as he goes on he will add certain other simple articles and tools. One is a light, strong collecting bag, either of the knapsack type or with hand grips. Then he will want a trimming hammer, with a flat head for cold-chisel work and a sharp edge for trimming specimens; a cold chisel of tempered steel, about six inches long with a 5/8 inch cutting edge; a magnifying glass with a power of 7 to 14 diameters; a pocketknife; a streak plate of unglazed porcelain; chemical reagents, including dilute hydrochloric acid and cobalt nitrate or chloride, and a record book. This last is perhaps the most important item in the mineralogist's entire kit. An exceptionally good record book is available from the Eckert Co.; it provides for entering the complete history of each specimen, including the location where it was found, the date, its characteristics, a description of any experimental work made on the specimen and the results.

Unless one has access to a museum or other institution owning comprehensive collections, a good reference book listing the characteristics of the principal minerals is indispensable. For beginners in mineralogy an excellent work is *Minerals and How To Study Them*, by E. S. Dana and C. S. Hurlbut, published by John Wiley & Sons, Inc.

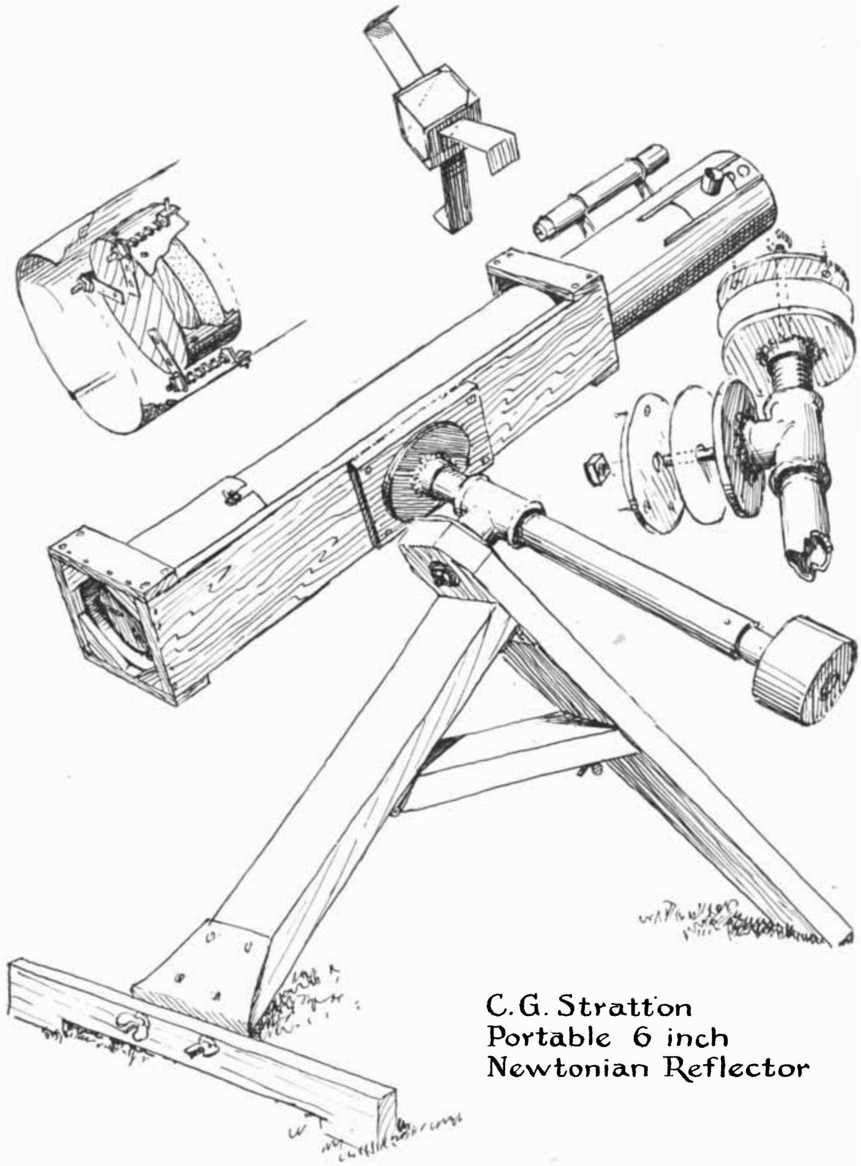
Many amateurs add a camera to their field kit. Often the geological character of the locale from which a specimen is taken helps in its identification. Moreover, photographs taken in the field and associated with the written history of specimens add greatly to the interest of collections.

As the collection grows it invites more elaborate experimental analysis, ranging from the detailed study of each specimen's crystallography to chemical and physical tests with the advanced techniques of the modern laboratory. Some of these may be undertaken successfully by the beginner who has a bit of spare room on his workbench. The simple blowpipe test, for example, yields powerful results. It requires a flame (candle, alcohol lamp or Bunsen burner), a small block of charcoal, a little powdered borax, a short length of nichrome wire and a tapered blowpipe. Blowing into the tube, the worker directs the flame onto a small fragment of the specimen lying on the charcoal block. The fusibility of the mineral is a clue to its identification; some minerals are readily fusible and others resist the hottest flame. The flame of the blowpipe is made up of two concentric cones, the outer one pale violet and the inner a bright blue. The inner cone is deficient in oxygen. When subjected to the heat of this cone, many metallic oxides give up their oxygen to the burning gas and are thereby reduced, or refined. Conversely the outer cone is rich in oxygen and will, therefore, oxidize many minerals. Such oxides differ in color from the original mineral, and reference books list these changes along with the other clues to the specimen's identity.

Similarly many specimens react characteristically when immersed in a solution of hot borax. To make this test a small loop is formed at the end of the nichrome wire. The loop is brought to a yellow heat with the blowpipe, dipped into the powdered borax and returned to the flame, where the powder adhering to the loop is melted. The red-hot globule of melted borax is then dipped into



Galena (top), *quartz* (middle), *snow*



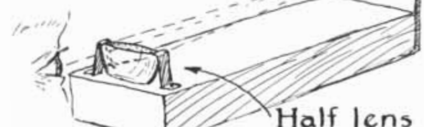
An inexpensive, efficient telescope that is easy to build

a crushed sample of the specimen and returned to the flame. As the sample enters into solution with the borax it reacts chemically and a characteristic color appears which changes, often radically, as the globule cools.

Within a surprisingly short time the beginner will learn to identify a large number of the rocks in his locality. He will meet or communicate with other collectors and exchange specimens not available in his immediate vicinity. And if he has a flair for experimental chemistry, he will discover that nature has stocked almost every hillside with an assortment of raw materials rivaling those carried by many supply houses—all free for the taking.

Where did these compounds originate? Under what conditions? How much time did nature lavish on their formation? In seeking answers to these questions the amateur may be lured into the broader field of geology—in which he will come to observe at first hand the frozen remains of creatures that disappeared from the earth long before the advent of man, to explore the ooze of ancient seas, to examine the explosive forces that have shaped our planet.

TO ENJOY the ownership of a homemade astronomical telescope it is not essential to equal in skill, means or equipment the experienced builders



The split-pupil collimator finder

of some of the larger, more elaborate instruments that are described in this department. Almost as much fun may be had with a much simpler instrument. The following are descriptions of two telescopes which can almost be built on a kitchen table.

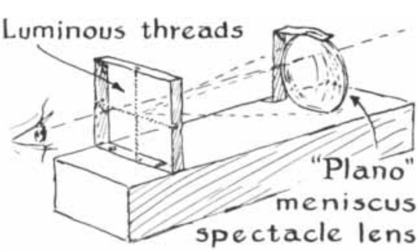
C. G. Stratton of the State Teachers College, River Falls, Wis., writes: "I have followed your amateur astronomy articles with great interest for many years. My modest but workable telescope was made by a beginner without access to a machine shop. Its six-inch mirror was made by my son Bill while in college. Having retired from teaching, I undertook the project of mounting it. Because trees and street lamps prevent the use of a telescope at home, it was designed to be portable. The mounting was made from 1½-inch pipe fittings. A local blacksmith welded a six-inch circular plate to the T for the polar axis and another to the pipe cap at the end of the declination axis, slightly dishing both plates. The shims are of tin. Before assembly the plates were ground together with Carborundum grains to gain a fairly continuous contact. The result was surprisingly good.

"The tube was made by the local tinner and is not a very good job. A stub tube holds the mirror and, being slightly larger than the main tube, slips over it. Thus it is easily removed for dustproof storage.

"Due to inexperience and uncertainty about the exact focal length of the mirror, I mounted the prism in a sleeve six inches long which fits snugly inside the tube and can be moved lengthwise in it.

"The prism is a 1½-inch section sawed from a war-surplus prism of greater width. The position of the eyepiece holder also is adjustable. It is mounted on a tin slider that uncovers a series of holes in the tube. It was well that these precautions were taken, as it was found that the focal length of the mirror was slightly less than was thought and that it was necessary to use two of these holes, one for the Ramdsen eyepiece and one for the Huygenian."

The tube of the Stratton telescope (*see drawing on opposite page*) rests in a wooden cradle in which it may be rotated freely to make the eyepiece accessible in all positions of the instrument, a luxury not afforded in many more elaborate ones. The builder cites as a mistake the position of the finder,



A finder based on a Navy sight

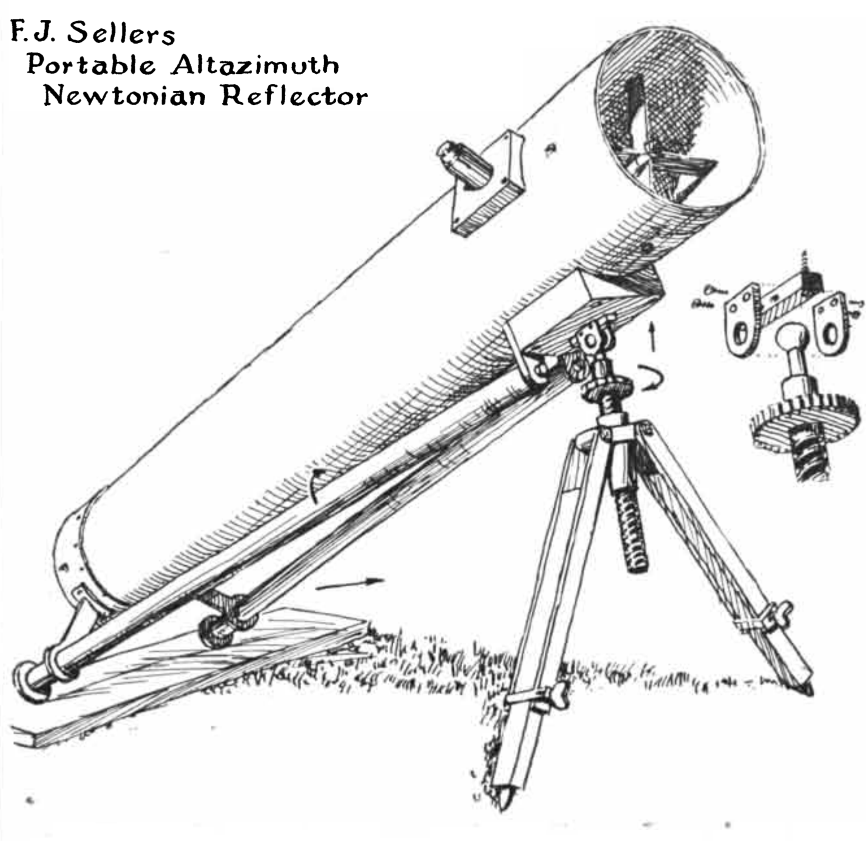
which should be close to the eyepiece. It was made of war-surplus lenses mounted in brass tubing from a bathroom fixture. Despite its chromatic aberration, it is efficient.

A TELESCOPE finder of a type not known to have been used by amateur astronomers is described by Stanley B. Rowson of Kansas City, Mo. "It is an adaptation," he says, "of the 'split pupil collimator' designed for aerial celestial navigation. The eye lens is a simple convex lens of three or four inches' focal length, cut exactly in half and mounted in a simple wooden block. The sight is placed exactly at the focus of the lens. The eye is placed so that the star being 'found' is seen just over the lens while the sight is seen through the lens. The projected junction of the two diagonal lines on the sight is made to coincide with the star as seen over the lens.

"The chief advantage of this finder is the fact that the eye placement is not critical. Because the sight is at the focus of the eye lens, the light from the sight leaves the eye lens in parallel lines. Therefore the apparent direction of the sight, and of the star, is the same no matter where the eye may happen to be behind the lens. This finder has been very satisfactory. Because it is so small, it can be mounted near the top of the tube and sighted with a minimum of stooping and neck-wringing."

To the illustration of Rowson's finder (*drawing at bottom of page 98*), Roger Hayward has added one of a somewhat more elaborate modification (*drawing on page 99*). He writes, "You look at the star through the concave side of the lens as shown. Since the lens has no power, the star appears in its usual place. Close to the face and at the focus of the concave side of the lens you place the cross hairs—big threads for night work. As a result you see reflected in the lens an image of the threads, apparently at infinity. It is best to place the eye at about the center of curvature of the lens, which is twice the focal distance. Ideally the lens should be half-silvered. Practically, if the sight is used against a dark sky and the threads are quite luminous or are illuminated from the side, the four per cent reflectivity of the one surface of the lens will be adequate. A meniscus negative lens also can be used, although the star field will be slightly diminished. A focal point for the threads can easily be found where there will be no parallax between the stars and the threads even when the eye is looking through any part of the lens."

THE STRATTON telescope described above has an equatorial mounting—one slanting axis parallel with that of the earth, so that once the tube is set in declination, only one axis need be used in following a star. If the same axes are respectively vertical and horizontal,



A telescope notable for its rigidity

both must be manipulated to keep the star in view. This is the altazimuth mounting, by some regarded as a step backward. One champion of the altazimuth mounting is F. J. Sellers, prominent in the British Astronomical Association. Thirty years ago, after building and using half a dozen different mountings, none of which had been portable and at the same time rigid, he built an altazimuth, found it good and described it in *The Journal of the British Astronomical Association.* Later he became widely known for his astronomical work and as the builder and user of one of the five spectrohelioscopes in Great Britain. So well do Sellers and others in the Association think of the mounting that the original description has been reprinted in *The Journal,* and so well does this department think of it that we are presenting here a drawing of it (*see opposite page*), made by Hayward from the original.

The two supporting lengths of tubing have enlarged ends that act as rollers. The observer sits with his knees under the tube, his left hand twisting and rolling the nearer rod away from him on the ground as the observed object moves across the sky. His right hand makes an occasional excursion to the hand wheel welded to the altitude screw. By extending the legs of the tripod or by spreading them forward, or both, the telescope can be quickly aimed at any object and kept smoothly and exactly on it.

The greatest advantage of this mounting is its freedom from vibration. Sellers says that "the rigidity is such that the hands may rest upon the controls during observation without causing vibration." As the hands are the greatest source of vibration in conventional telescopes, this says much in favor of his design. The basic reason for the freedom from vibration is that the tube is supported *at its ends,* while most others are supported at the middle with the ends free to vibrate.

"The smoothness of working and rigidity of this mounting are quite remarkable," Sellers says. After much experience with telescopes he concludes that "for purely observing purposes, apart from photography, with an eight-inch or ten-inch Newtonian reflector, a convenient altazimuth mount with slow motions is generally *more* convenient and efficient than an equatorial one."

The screw is a dining-table screw of pitch about half an inch, of a kind in use in Great Britain. As substitutes, piano stool screws or old-fashioned automobile jack screws are suggested, though their pitch is somewhat less. A screw of fine pitch would be a nuisance. In his drawing Hayward has substituted for the original a type of ball and socket joint that he once used on a spectrometer. It can be made to grasp the ball very snugly.

INDEX OF ADVERTISERS

NOVEMBER, 1952

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Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful. The lists are not intended as bibliographies of source material for the articles. The references selected will provide supplementary information.

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PROPAGATION OF POLIOMYELITIS VIRUS

What GENERAL ELECTRIC People Are Saying

G. B. WARREN

Turbine Division

THE ENGINEER IN PUBLIC LIFE: The value of the engineer in public life is measured by his knowledge of industrial engineering and power economics, his understanding of structures in the broad sense, and his honesty of approach, developed because he has learned that nature can't be cheated . . . can't be made to produce something for nothing.

A good engineer gets all the facts he can before deciding on a course of action, examines possible alternative courses and the results that would accrue, and tries to select the optimum. Qualifications for men in public service should be the same.

I believe we need the practical, informed, and so, intellectually honest, approach to public affairs that the engineer has brought to our private industrial affairs. This cannot, in my judgment, be obtained by the part-time attention of engineers on a layman basis in government, but must be obtained by professionally trained public administrators who will need much, but not all, of the technical training of the engineer, supplemented by the broader training required of this field.

University of Wisconsin
4th Annual Engineers' Day

★

E. D. TROUT

X-Ray Department

REDUCING X-RAY DOSAGE: Because of the increased portion of the total population now receiving radiation from so many sources, it may well be that the long term effects of doses too small to produce an acute effect are important. Certain it is that, in view of the increased use of radiation in all its forms to such a large percentage of our people, there is an obligation on the part of all who use radiation to subject the patient to as small a dose as is consistent with an adequate examination. Anything that can be done to reduce the dose will be a step in the right direction.

It is hoped that we will become aware of, and establish, limitations to prevent the nonacute and long term effects of small doses of radiation which presently appear to be nonreversible once the effect has been initiated and which may not be restricted in their influence to a single generation.

52nd Annual Meeting
American Roentgen Ray Society

★

J. C. AYDELOTT

Transportation Department

RAILROAD ELECTRIFICATION: In this country the trend is toward very heavy trains, and speeds are gradually increasing as road beds are improved and better riding cars replace the old ones. High horsepower to handle such trains in the future comes easily with electrification—provided we look ahead in the selection of a suitable system. It will be to no one's benefit to be tied to a system that inherently limits the horsepower that can be made available to a train, or a system that is not equally adaptable to high-horse-power locomotives and conversion of existing diesel-electric locomotives.

The urge to lower the cost of electrification is, of course, what prompts us to look hopefully at every possible system. But there are other proved ways of getting costs down that are far more effective than starting with a blank piece of paper and a new dream every time the question of railroad electrification comes up. I am referring, of course, to the genius of American repetitive manufacture. There is far greater benefit to be realized by standardization—both in manufacture and operation—than can ever be hoped for by hunting for a unique solution for a given set of conditions on a particular railroad.

G-E Review

W. E. JOHNSON

Nucleonics Division

THE SOCIAL IMPACT OF THE ATOMIC INDUSTRY: One concept of possibly great social importance is the fact that atomic energy gives us at last very definite evidence that there is nothing very substantial in the real world of ours. It will probably take decades and perhaps generations for a consciousness of the unsubstantial nature of the universe to sink into the minds of people and to influence their social conduct and their spiritual beliefs. The fact that all of the substantial matter in the bodies of all the people in New York City could be put into a single cubic inch and other similar information will, in due course, have its influence on the minds and the social consciousness of people.

One more effect on our social structure is that brought about by the economic impact of this industry. At the moment, I think we must admit that the economic effects are negative and that from the standpoint of usable products or productive power that might increase the wealth of the nation, we are still, so to speak, in the red. However, the future looks bright even here and it is almost a certainty that practical methods will be found to make use of nuclear energy for such things as propulsion of ships and submarines. If we look at this as a first major step toward an industrial type of application, we can look toward the long-term future of this industry with greater confidence.

Finally, with continued growth, increasing knowledge and sustained confidence in our own future, I think we shall soon find that achievement rather than destruction will be the measure of our progress.

Prof. Engineers Northwest Centennial
Portland, Oregon

You can put your confidence in—

GENERAL ELECTRIC

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