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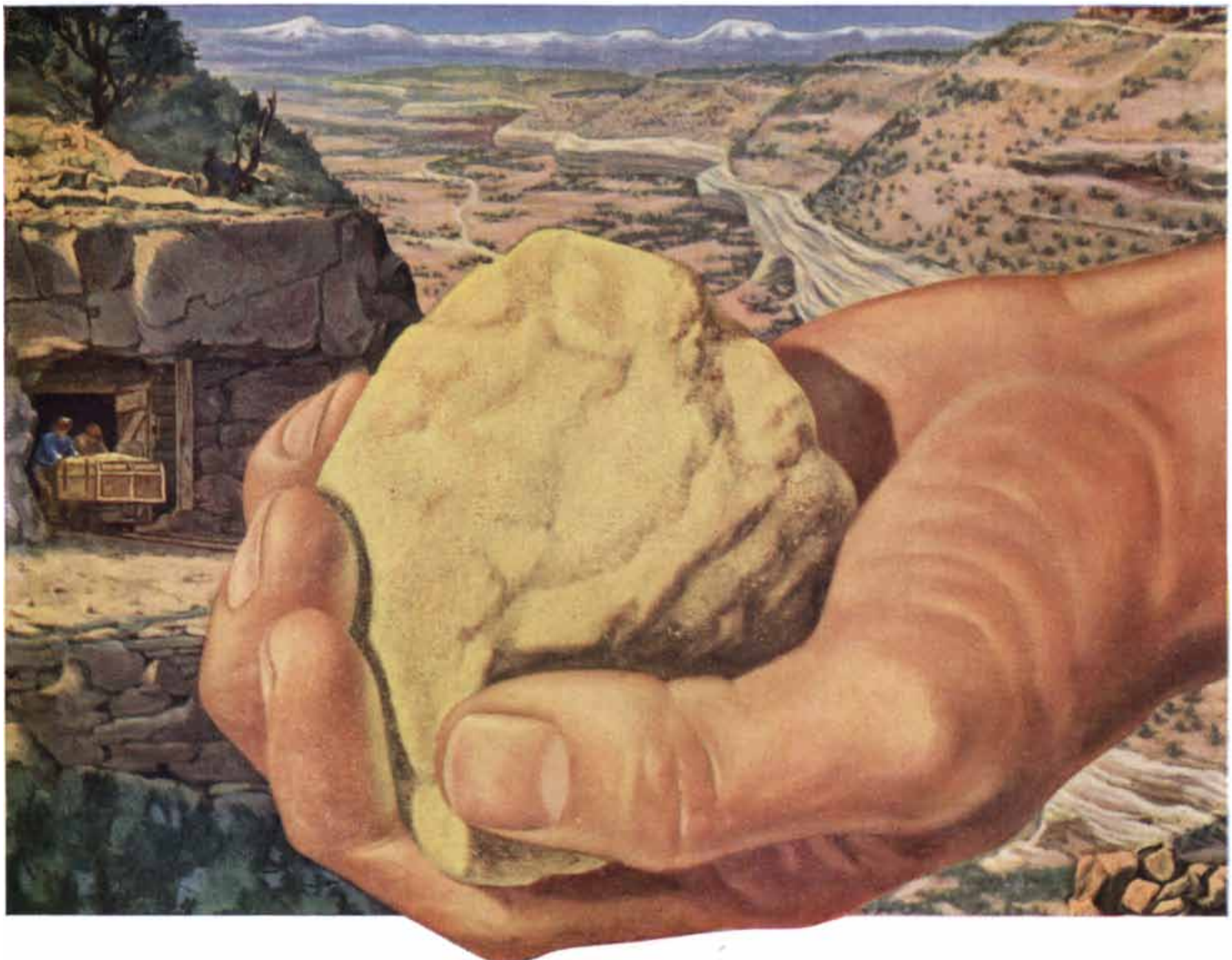

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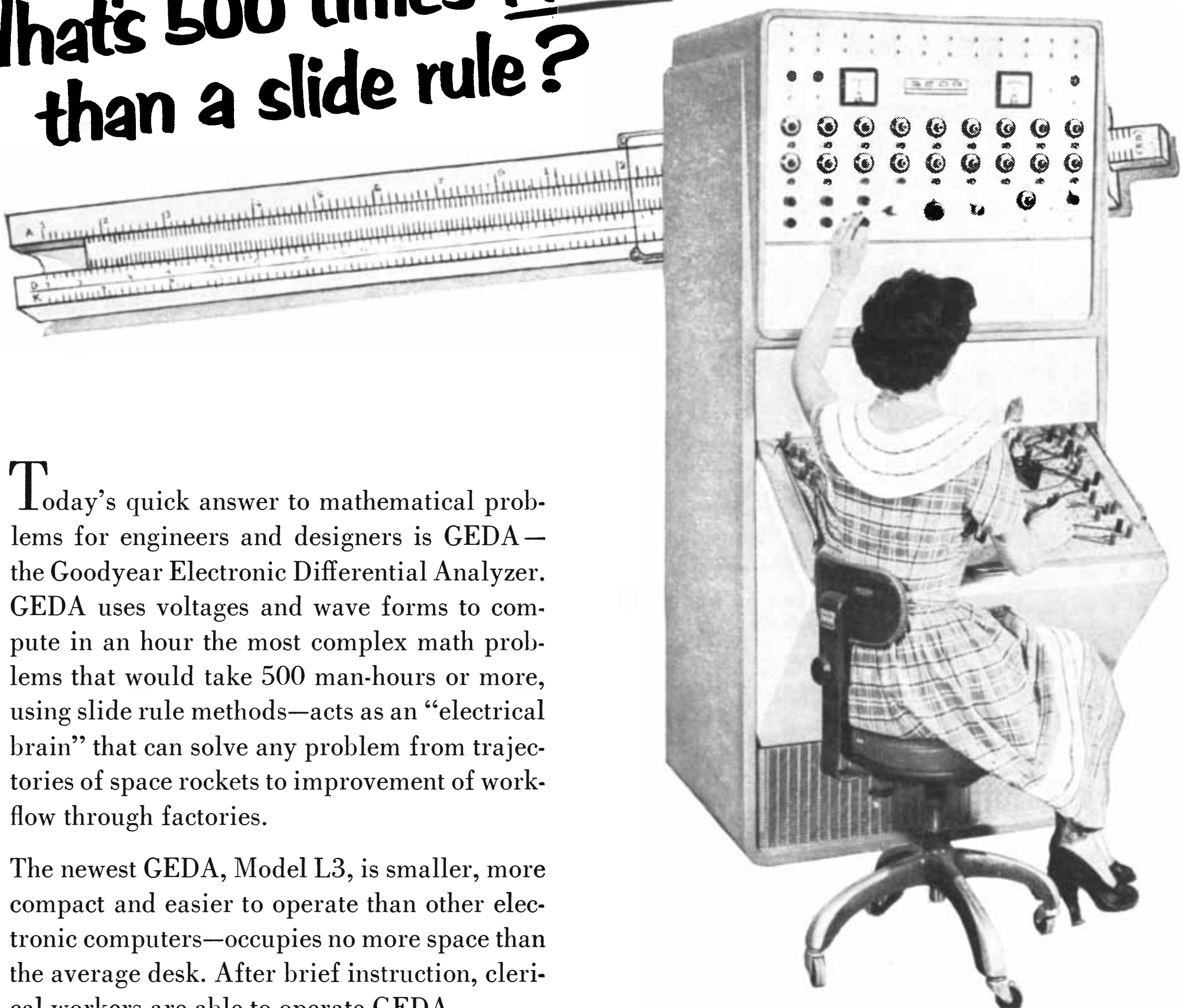

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LETTERS

Sirs:

I was surprised to find Don D. Jackson's article entitled "Psychotherapy for Schizophrenia" in your January issue. It is very unfortunate that so many misleading articles on psychiatry and psychology are constantly being published in daily papers and popular magazines. *Scientific American* has the reputation of giving accurate accounts on what is going on in the various fields of science in a way which the educated layman can understand.

Even a very careful article dealing with serious illnesses like cancer or tuberculosis can hardly avoid exciting great hopes in patients or their relatives despite due emphasis on the experimental nature of any kind of new treatment. Dr. Jackson at least uses the word "perhaps" as a certain limitation of his claim: "It may perhaps be said that the psychotherapy of schizophrenia has been the outstanding achievement of psychiatry in the last 10 years." Only a very few psychiatrists, adherents to a certain school of thought, would consider such a statement somewhat justifiable. By far the majority of psychiatrists and even psychoanalysts would treat acute schizophrenics with insulin and/or electroshock therapy and apply some form of psychotherapy during and after the shock treatments. It is correct that "a large proportion of shock-treated patients sooner or later relapse." No psychiatrist will deny that. But still shock treatment, as crude a method as it still is, shows at least "dramatic immediate results" (as Dr. Jackson puts it), and it seems that psychotherapy, occupational

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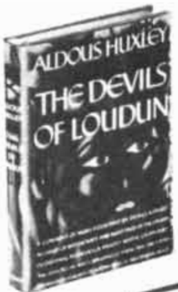

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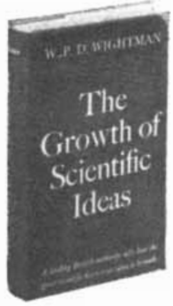

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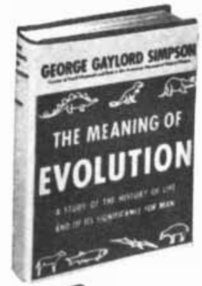

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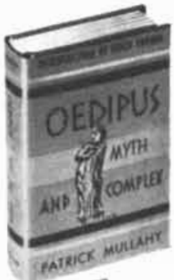

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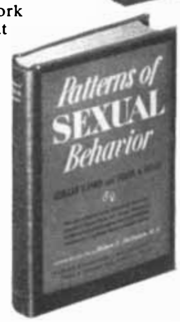

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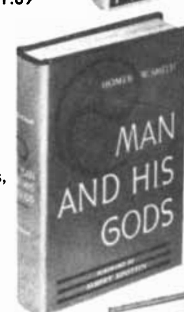

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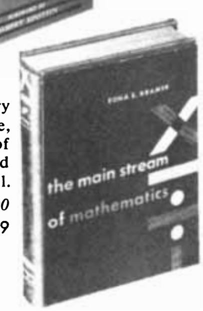

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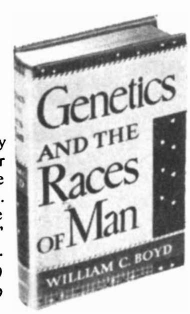

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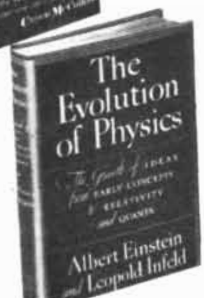

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therapy and manipulating the patient's environment *after* the shocks produce some more lasting recoveries. Only by observing thousands of cases for many years will it be possible to evaluate this form of treatment more thoroughly.

Since Dr. Jackson is such an enthusiastic advocate of psychotherapy for schizophrenia, one would expect that he would give some clear data on the results. But all he says is: "As to the results of the treatment of schizophrenia by psychotherapy, statistics are scarce, and when available are often misleading." Then he claims that "certain gifted therapists" have achieved striking results: 80 to 90 per cent of the patients have been brought out of the obviously psychotic state. In the next sentence he says: "There are no follow-up studies to indicate how large a percentage of those patients maintained their health."

If one considers that, according to Dr. Jackson, "the treatment takes at least two years, and usually longer," and considering also the well-known fact that patients, after a first episode (breakdown) of schizophrenia, recuperate spontaneously in a great percentage of cases, psychotherapy of schizophrenia seems to be highly impractical and uneconomical on anything but an experimental basis.

It is furthermore difficult to explain how Dr. Jackson can deny, in the light of mounting evidence brought forth by studies in genetics and on identical twins, that hereditary predisposition is an extremely important factor in patients afflicted with schizophrenia. This factor does not exclude the possibility of treatment, but it makes it most unlikely that psychotherapy alone can be the method of choice.

I am afraid that Dr. Jackson's article may add unnecessarily to the confusion and concern of the relatives of psychotics. Freud was too good a clinician not to know that psychoanalysis has its limitations and cannot be applied successfully in the treatment of schizophrenics. He believed that future research would make new forms of medical treatment available which might produce more effective results. Now there is at least a promising beginning in this direction. . . .

MAX GRUENTHAL, M. D.

New York, N. Y.

Sirs:

If I knew of "very distinct and favorable follow-up studies on shock-treated schizophrenics," I would be in a better position to answer Dr. Gruenthal's letter. However, I know of no such studies that can be regarded without skepticism. The reason for this is that such studies generally fail to take into account the multiple interpersonal factors that are

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part and parcel of any psychotic's treatment. Even the most enthusiastic reports I have seen regarding the use of shock therapy in schizophrenia are those where the treatment was instituted in acute young schizophrenics, where the recovery rate without any shock treatment is very high. In depressions it is another matter. One reason for my statement (that most therapists believe there will be a higher percentage of permanent recoveries among patients treated with psychotherapy than those with shock therapy) is that hospitals specializing in psychoanalytic psychotherapy of schizophrenics are filled with patients who have had up to 200 and sometimes 300 electric-shock treatments and as many as 100 insulin comas. Some of these patients do recover under psychotherapy and have shown a distinct inability to recover under shock therapy.

I would certainly agree, since psychotherapy takes so long and since it is "uneconomical," that at present it is on an "experimental" basis. However, there are a large number of people who can afford such treatment, and it is also being instituted in many of the large veterans' and some state hospitals. It is a little difficult to say just what "economy" means in the frame of reference of mental illness. If the rehospitalization rate is decreased by psychotherapy, then it may be that it is economical when compared to maintaining the cost of hospitalization for the rest of a patient's life. Add to this the fact that patients with psychotherapeutic insight may have a less harmful effect on their children, and again we may have a factor that makes psychotherapy more economical than is supposed.

Dr. Gruenthal mentions the "mounting evidence brought forth by studies in genetics and on identical twins." Dr. Gruenthal may not be aware that this evidence is regarded by some expert statisticians as unconvincing. I would refer him, for example, to the articles by Nicholas Pastore in the *Psychological Bulletin* during 1949 and 1952.

I certainly agree that Freud was a good clinician; however, even such a genius as he had certain blind spots. Later in his life, however, he made an attempt to correct this blind spot by stating that he felt psychoanalysis could be modified successfully to treat psychotics. I mention this because many people try to use Freud against his followers.

In conclusion let me say that I cannot go along with Dr. Gruenthal's enthusiasm for "exact data on various forms of treatment" since the exactness of such data is very questionable when one deals with human beings.

DON D. JACKSON, M. D.

Palo Alto Clinic
Palo Alto, Calif.

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The engineer has been so busy doing things that he has not brought his story to the people of our country. Therefore they do not recognize the importance of his story, and thus far his recognition has been a problem for him alone. But today the seriousness of our world situation has taken the problem out of his hands. It is now a problem for the nation—engineers must be conserved for engineering, and their numbers must be increased.

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There is an imperative need for this understanding if our nation is to advance its present world position. The creative ability of the engineer is meeting its greatest challenge. But now the engineer must create another new product: a universal and spontaneous recognition of the engineering profession.

General Electric Review

★

S. P. NEWBERRY

General Engineering Laboratory

In the early excitement of the electron microscope, research workers joined in a mad rush to obtain higher and higher magnification pictures. Nearly five years elapsed before it became generally recognized that magnifications of 10 to 100 thousand times were far too great to correlate results with previous magnifications, usually less than one thousand times.

A practical idea of the difference in magnification can be gained by considering the ⅛-inch, 200-mesh specimen grid of the electron microscope. At 1000 times magnification its image is 10 feet across, and a single mesh opening is approximately 2″ square. Now at 100 thousand times magnification the screen is more than ⅕-mile across and the individual mesh opening is over 17 feet. An 8″ x 10″ picture obtained at 100 thousand times represents a sampling of only .2% of the area of a mesh opening and only 2/100,000% of the tiny ⅛″ specimen we started out to explore. Experience has taught us that we must increase magnification in gradual steps of about 3X per step if we are to form a definite conclusion of how the minute structures are correlated with the over-all structure. Indeed, when we change methods of viewing or methods of specimen preparation, it is often necessary to compare pictures at the same magnification, actually superimposing identical fields of view, so we may maintain continuity with past knowledge.

After finding out that the highest magnification is not always the best, the electron microscopist has another important lesson to learn. He must realize that he cannot live in an "ivory tower," solving problems by crystal gazing in his microscope. He must work with the people who have the problems in the shop. He must help them to choose and prepare samples, and they must help him interpret what he photographs. He should encourage the use of other equipment to support or check his own findings. The electron microscope adds the very important element of vision to problems which depend upon the ultrafine structure of matter, but it does not give all the answers by itself.

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Electronics Division

THE FUTURE OF TELEVISION: UHF television—which is essentially television in a new segment of the radio spectrum—presents a challenging opportunity to American ingenuity both in engineering development and from the standpoint of programming, education, and commercial enterprise. No longer will telecasting be limited by unavailability of frequencies, but the limit on the number of TV stations will rather be placed on the ability of the broadcaster to obtain his fair share of the audience. UHF TV makes possible a truly competitive system of telecasting in accordance with American democratic principles. It will some day blanket the country with reliable television signals from thousands of television towers.

G-E Educational Service News

You can put your confidence in—

GENERAL ELECTRIC

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1903: "It has been discovered that certain glands, such as the thyroid, the suprarenal, the pancreas and others, manufacture and return to the blood specific substances, differing with the different glands but of important use to the body, and the absence of which leads to profound consequences. These substances were called internal secretions. Thus, removal or suspension of the function of the thyroid gland, and hence the loss of its internal secretion, reduces the body to a serious pathological state, long recognized by the name myxedema. Of similar causation is the peculiar condition called cretinism, which is characterized by a physical and mental stunting of the growing individual. If absence of a substance is the cause of a disease, supplying that substance ought to effect a cure, and such was found to be the case. Administering to the afflicted individual the fresh thyroid gland of animals or a properly prepared extract of such gland, was found to alleviate or cure myxedema, and other instances of the efficiency of glandular products were recorded. As a possible instance of this may be mentioned the idea, recently suggested by Professor Herter of New York, that the suprarenal gland by means of its internal secretion may control the manufacture of sugar by the cells of the pancreas, an idea which, if proved true, may bear significantly on the causation and treatment of diabetes."

"The great question of astronomy is the complete and rigorous test of the Newtonian law of gravitation. This law has represented observations so well during a century and a half that it is a general belief that the law will prove true for all time and that it will be found to govern the motions of the stars as well as those of our solar system. We know that the law of gravitation is modified in the motions of the matter that forms the tails of comets. There is an anomaly in the theory of Mercury which the law does not explain, and the motion of our moon is not yet represented by theory."

"If the electron has an invariable charge, and a positive ion is always a single atom from which an electron has

"Check your air, Sir?"

Air compressor and tank are at right. Long cylinders on rack dry air before it enters cables.

He's checking the air pressure in a branch cable, one of scores serving a town. The readings along the cable are plotted as a graph to find low-pressure points which indicate a break in the protecting sheath.

Master meters keep watch over the various cable networks which leave a telephone office in all directions to serve a community. Air enters the system at 7 pounds pressure, but may drop to 2 pounds in outermost sections—still enough to keep dampness out.

To keep voices traveling strongly through telephone cables, you have to keep water *out*. This calls for speed in locating and repairing cable sheath leaks—a hard job where cable networks fork and branch to serve every neighborhood and street.

At Bell Telephone Laboratories, a team of mechanical and electrical engineers devised a way to fill a complex cable system with dry air under continuous pressure. Pressure readings at selected points detect cracks or holes, however small. Repairman can reach the spot before service is impaired.

It's another example of how Bell Laboratories works out ways to keep your telephone service reliable—and to keep down the cost to you.

BELL TELEPHONE LABORATORIES

Improving telephone service for America provides careers for creative men in mechanical engineering been split, it is reasonable to suppose that the positive electron will also have an invariable charge. It should, therefore, show a ratio e/m varying only with the atomic weight, and the ratio should change from one substance to another in a manner solely depending upon the known atomic weight of the substance. W. Wien has for some time been endeavoring to discover such a regular variation in the canal rays. But all the experiments hitherto made show that there is no abrupt transition from one value to another. We must, therefore, either assume that the positive electron can be bound to a number of material molecules, or that it can be subdivided."

"President Hugo Winckler, of the University of Berlin, has just published a translation of the code of Hammurabi, taken from a stele discovered a few months ago by the French expedition that has been for years engaged in archaeological researches in Susa, the ancient capital of Persia, under the direction of Professor De Morgan. Professor Winckler gives it as his opinion that the inscription is doubtless the most important find that has ever been made in Babylonian literature. The inscription was found on a block 2.25 meters in height, taken from the old royal castle in Susa."

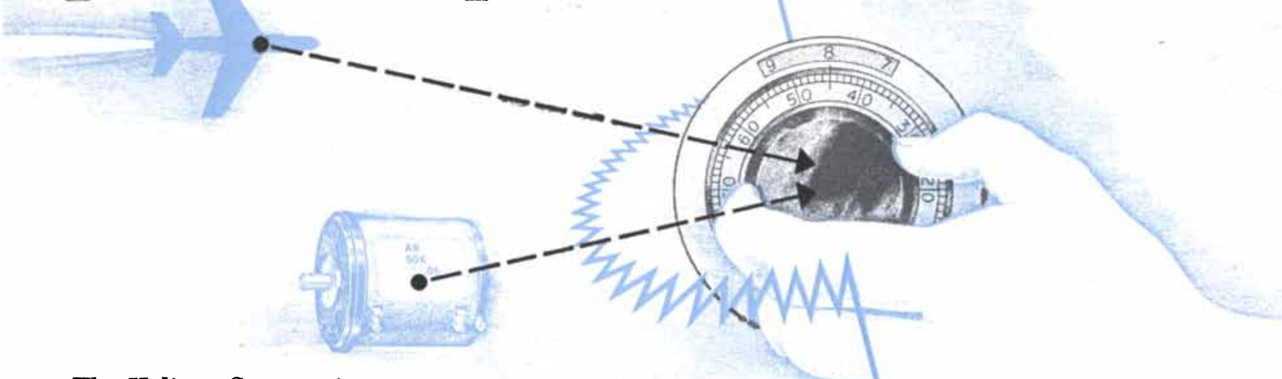
"A new automobile speed record of 27 seconds for the kilometer was made by the Hon. C. S. Rolls in Welbeck Park, Nottinghamshire, England, on February 26. A 72 h.p. Mors racer was used, and the rate at which it traveled was equal to 83 miles an hour."

"The Peary Arctic Club is trying to fit out another expedition early in the spring. Some time ago Lieut. Peary said $100,000 would fit out an expedition; now he thinks that $200,000 is necessary, or at least $150,000. With such backing he is confident that he could reach the Pole."

"In the decennial publication of the University of Chicago may be found a suggestion by Professor Michelson of a new method of determining the velocity of light. The Professor reviews previous results, contrasts astronomical, electrical and optical methods and processes. Instead of the revolving toothed wheel of Fizeau, he suggests the use of a stationary grating, and by a double reflection of light from stationary and revolving mirrors, proposes to measure the eclipses the light suffers from the gratings. Figures accompany the original article, which make the author's plan clear. He estimates that the velocity of light can be measured to a probable error of only 5 kilometers per second."

"After many attempts had been made to determine the velocities of stars rela-

Pioneers in Precision



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These fine quality **MPB** ball bearings are manufactured under exclusive and exacting production procedures as conceived and developed by **MPB** designers and engineers. Many designs and sizes of miniature ball bearings initially developed at **MPB** are now internationally standardized. Over a million **MPB** ball bearings have been installed in devices operating under unusual conditions . . . extreme temperature range . . . shock . . . continuous high load capacity . . . limited space in project miniaturization.

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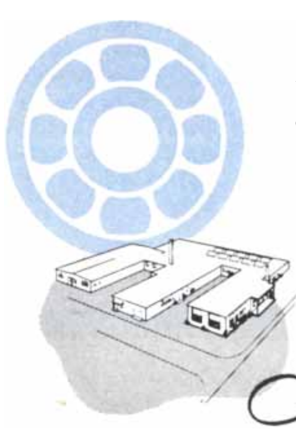

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save space weight friction

tive to the earth, Professor W. W. Campbell of the Lick Observatory adopted a very ingenious method which gave valuable results. When a luminous body which is moving away from the observer is examined in a spectroscope the lines which appear in its spectrum will be shifted out of their true position in one direction, but are moved to the other side if the body is approaching the observer. Similar effects are observed if the body be stationary and the observer's position changes. The degrees of displacement of the lines enable one to determine the rate of motion in the line of sight."

"The government of the Punjab province of India has commenced an undertaking which when completed in five months' time will be the largest bacteriological enterprise the world has yet seen—the inoculation of 7,000,000 persons for protection against the plague, the only beneficial course yet discovered to insure immunity from this disease. The serum is being supplied from England in 14,000 flasks, and will entail the manufacture of four huge sterilizers costing $1,500 each, the planning of a new system of pipes and sinks for extra gas and water. A very good idea of the prevalence of the disease in India, and the high mortality that accompanies it, may be formed from the fact that in the third week of August there were 3,547 fatal cases. England has now been combatting this disease for nearly six years, and no remedy attempted has proved successful except inoculation."

"A typhoid antitoxin serum invented by Dr. Allen Macfayden and indorsed by no less a person than Lord Lister is the latest medical discovery. Dr. Macfayden is the director of the Jenner Institute of Preventive Medicine. He has found that by crushing the cells of the typhoid bacillus in liquid air the intracellular juices are not only obtained without living organisms but are also rendered highly toxic. When injected into living animals these juices produce a blood serum which acts as an antidote against the poison generated by the typhoid bacillus. The novel feature in this process is the use of liquid air, the function of which is not understood as yet."

SCIENTIFIC AMERICAN

MARCH, 1853: "Mr. Walker, from the Select Committee of the Senate to which were referred memorials from the claimants of [the] etherization [discovery], has reported as follows: '. . . the credit and honor of the discovery belong to one of the following persons, all citizens of the United States,

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viz., W. T. G. Morton, Horace Wells or Charles T. Jackson; but as to the particular one to whom the discovery should be awarded, the testimony before the Committee is not sufficiently clear, and they think the point should not be settled by Congress without a judicial inquiry.'"

"The business of putting provisions in hermetically sealed cans has become an important one in Portland, Me."

"The astronomical prize given yearly by the French Society has been divided for 1852 between the five astronomers who have discovered seven planets in the course of the past year, *viz.*, Hind of London, de Gasparis of Naples, Luther of Blik, near Dusseldorf, Chacornac of Marseilles and Goldschmidt of Paris."

"Mr. Faraday, in a late lecture before the Royal Institution upon the Magnetic Forces, made the following important announcement: 'A German astronomer has for many years been watching the spots on the sun, and daily recording the result. While our German friend was busy with his group of sun-spots, an Englishman was busy with the variations of the magnetic needle. On comparing his tabular results with those of the German astronomer, he found that the variations of the magnetic needle corresponded with the variations of the sun-spots—that in the years when the groups were at their maximum, the variations of the needle were at their maximum, and so on through their series. This relation may be coincident merely, or derivative; if the latter, then do we connect astral and terrestrial magnetism, and new researches of science are open to us.'"

"Experiments have been lately made at Chicago to ascertain the amount of oxygen necessary to support life. Six hundred persons having been placed in a hall in one of the hotels of that city, all the doors and windows were closed. At the end of the third half-hour it was found unsafe to continue the experiment any longer."

"The manufacture of tin plate is one of which England can truly boast, as she is the heart and complete monopolist of it. She supplies the world with it, and no country uses so much as our own. There is more tin plate used in the U. S. than there is in England, and the consumption of it is increasing rapidly. The price of the article has greatly advanced, and so far as we know no attempt has ever been made to manufacture it in this country. If it can be done profitably, there is a wide field open for some enterprising company; if not, the article should be admitted duty free, as it interferes with none of our manufacturing interests, and we have now a surplus revenue."

THE AUTHORS

A. G. DALTON ("The Practice of Quality Control") is close to the fountainhead of statistical product control methods in industry. As superintendent of quality control in the Western Electric Company, where many of the original techniques were worked out, he is responsible for maintaining a continuous quality audit of that company's myriad of products. A Britisher by birth, he came to the U. S. in 1919, after a hitch as lieutenant in the Royal Engineers Signal Service, and took his first job in a Mississippi lumber company. There he pressed so hard for the electrification of sawmill operations that his employer suggested he might have a brighter future in the electrical equipment field. Going to work for Western Electric, he became interested in quality control while hunting down defective elements in dial systems. In 1928 this interest transferred him to the Bell Telephone Laboratories, where a group was working on basic statistical methods. In 1943 he transferred back to Western Electric.

OTTO STRUVE ("The Evolution of Stars"), chairman of the Berkeley Astronomical Department of the University of California, comes from a long line of astronomers. His father, Ludwig Struve, was director of the Russian observatory at Kharkov. Grandfather Otto I was director of the Pulkovo Observatory, a post which he had taken over from *his* father, F. G. W. Struve, the first of the astronomical Struves. F. G. W. was a Dane who had fled to Russia to avoid service in Napoleon's army. He founded the Pulkovo Observatory, which in its time was hailed by a U. S. contemporary as "the astronomical capital of the world." The present Otto graduated from the University of Kharkov, fought in the Russian Army in World War I and in the White Russian forces after the revolution. Coming to the U. S. in 1921, he acquired a Ph.D. in astrophysics at the University of Chicago in three years, and remained at the Yerkes Observatory for many years before going to California in 1950.

MARTIN D. KAMEN ("Discoveries in Nitrogen Fixation") is a biochemist who teaches radiation biology at Washington University Medical School and, among other things, does research on photosynthetic reactions in microorganisms. "Nothing in my formal training," he says, "prepared me for such a career." When he went to the University of Chicago in 1930, he was interested mainly in music and literature, but he switched to chemistry on the basis of a freshman course and emerged six years later with a Ph.D. in physical chemistry. The uni-

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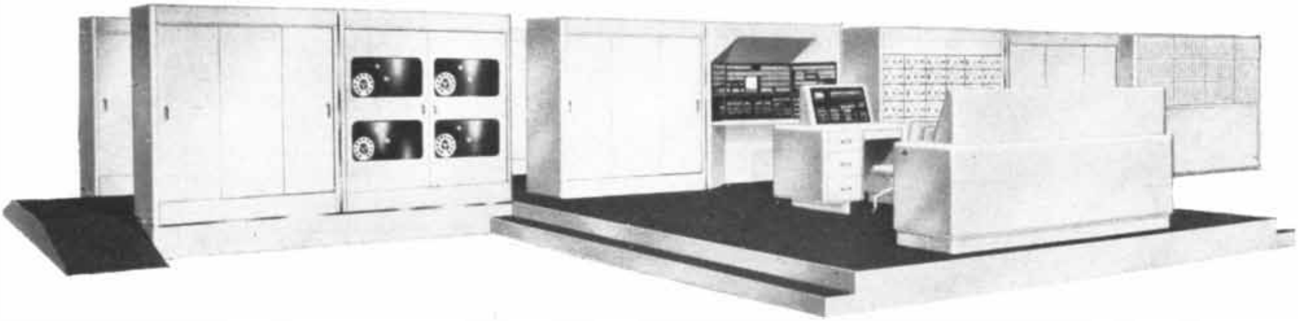

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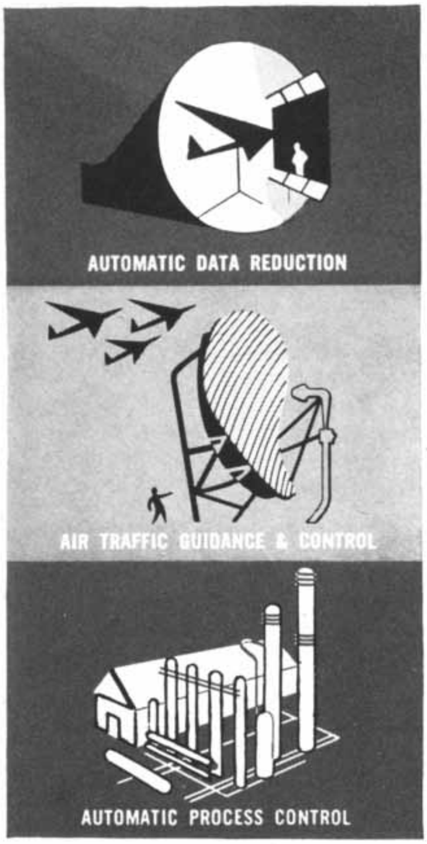

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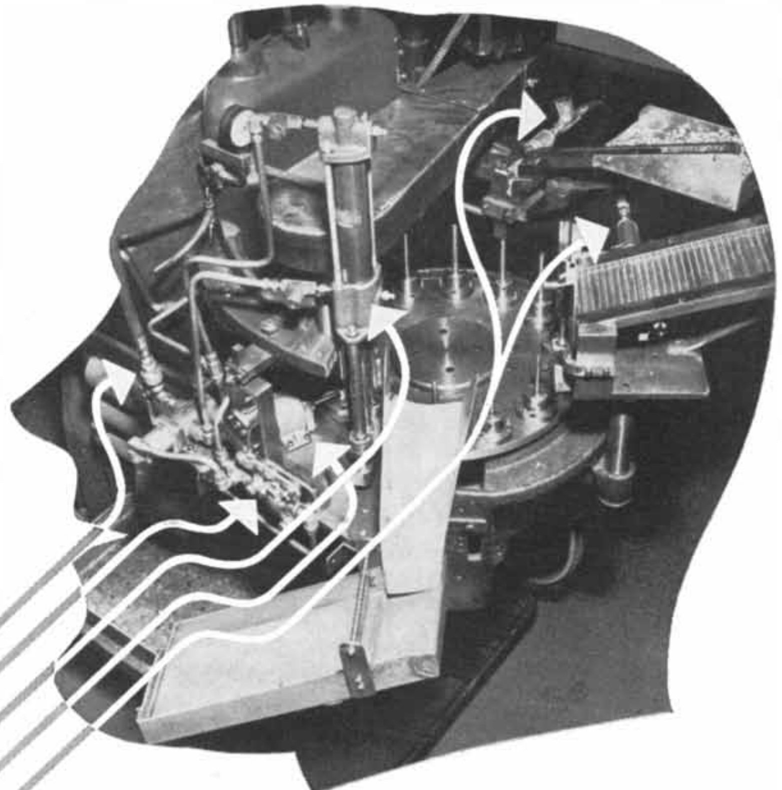
versity was then planning to build a cyclotron and urged him to go to the University of California to get experience under E. O. Lawrence, inventor of that instrument. There Kamen met Samuel Ruben, a young scientist pioneering in the field of radioactive tracer analysis in biology. Kamen teamed up with Ruben to study photosynthesis by this new technique, and never went back to Chicago. In 1940 the team discovered a new isotope of carbon: C-14. Before they could do much with it, the war separated them: Kamen went to the Manhattan District, Ruben into the Chemical Warfare Service, where he lost his life in a laboratory accident. Kamen returned alone to California in 1945 with "practically all the C-14 available." He was soon offered an associate professorship at Washington University, and there he has carried on his studies of photosynthesis and metabolism.

W. K. LIVINGSTON ("What Is Pain?"), professor of surgery at the University of Oregon Medical School, first became interested in pain as a surgical intern in 1920. Just out of Harvard Medical School, he had joined the staff of Massachusetts General Hospital. He was asked to "open a colostomy." Not knowing how to go about the operation, he enlisted the aid of a senior intern. Before Livingston's and the unanesthetized patient's horrified eyes, the senior heated a soldering iron and plunged the red-hot iron into the patient's exposed intestine. The patient felt no pain. Why, asked Livingston, should an organ capable of feeling pain under other circumstances be completely insensitive to such injury? At the University of Oregon, which he joined in 1947, he has studied pain mechanisms in a special clinic. He is the author of a book, *Pain Mechanisms.* As might be suspected from the graphic detail with which he embellishes the story of the injured fisherman in his article, Livingston likes to fish.

ALFRED O. C. NIER ("The Mass Spectrometer"), professor of physics at the University of Minnesota, built his first mass spectrometer as a graduate student at Minnesota. "I found that I had in my hands," he says, "the best instrument then in existence for studying isotopes." In 1935, a year before getting his doctorate, he found the extremely rare isotope of potassium, K-40. While Nier was at Harvard the following year on a National Research Council fellowship, his work attracted the attention of G. P. Baxter, the venerable authority on atomic weights. Baxter prepared special compounds for him, including uranium tetrachloride, with which Nier determined for the first time the relative abundance of isotopes U-235 and U-238. When he returned to Minnesota in 1938, it wasn't long before he had to

The Machine that breathes



This tapping machine had been discarded. But it was put back on the line as a fully automatic, high production machine—because a mechanic used ingenuity, imagination . . . *and a simple combination of pneumatic controls.*

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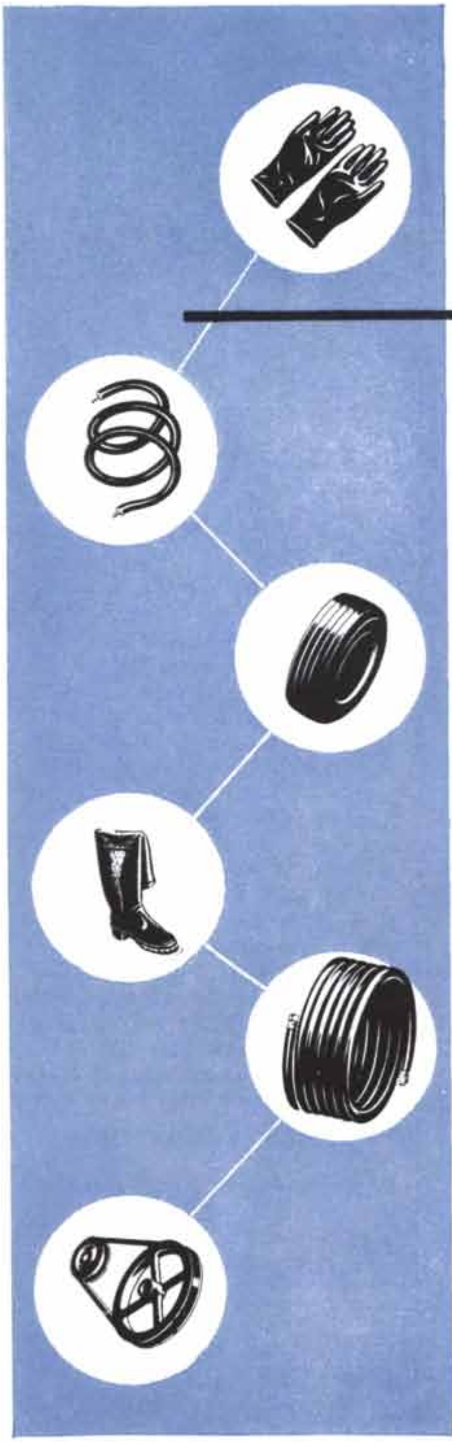
Address____ take up the uranium problem again. It was Nier who, by separating pure U-235 and U-238 with the mass spectrometer, made it possible to settle the question as to which was the fissionable isotope. He worked during the war with the Manhattan District and the Kellex Corporation, builder of the U-235 gaseous diffusion plant at Oak Ridge.

PAUL B. WEISZ ("The Embryologist and the Protozoon") is associate professor of biology at Brown University. He was born in Vienna in 1921. Educated at McGill University in Canada, where he received a Ph.D. degree in zoology in 1946, he has specialized in embryology and has done extensive and unusual work in this field with protozoa as research subjects. Weisz is in charge of the introductory course in general biology at Brown; he has written a textbook on the subject to be published early next year.

CONSTANCE REID ("Perfect Numbers") is a California free-lance writer and housewife who has always had a lively interest in mathematics. Her only professional experience in mathematics, she tells us, was teaching "a very elementary form of arithmetic to the more backward sailors at the U. S. Naval Training Station in San Diego." Before her marriage Mrs. Reid, a graduate of the University of California, taught English and Journalism at San Diego Junior College. She is the author of *Slacks and Callouses*, a book about women in the aircraft industry. Currently her writing has to be worked in between feedings of her three-month-old daughter.

RICHARD A. HOWARD ("Captain Bligh and the Breadfruit") has a botanist's interest in West Indian plant life that has taken him to 75 islands of the Caribbean. He once retraced the steps of a 17th-century French biologist through Haiti and the Dominican Republic, finding in out-of-the-way places plants which had not been collected since the Frenchman sketched them in 1693. Howard put his knowledge of jungle flora to military use early in the war by teaching doctors assigned to the Pacific how to distinguish between useful and harmful plants in that area. Eventually this grew into a full-scale course on jungle survival for Air Force crews. He took his pupils into the Florida Everglades and showed them how to get by on the products of the land. For originating this training program he was awarded the Legion of Merit. After the war he wrote a summary entitled "999 Survived," and he is still consultant to the military on search, rescue and survival problems. Howard took his Ph.D. in biology at Harvard in 1942 and taught there until last month, when he went to the University of Connecticut as professor of botany.



RUBBER GROWS ON IDEAS. In fact, one idea—vulcanizing—virtually created an industry. Since then, new ideas and ingredients have fitted rubber for more and more uses. Today more than a thousand different chemicals and other raw materials are used by over twelve hundred companies to make *5 billion dollars* worth of rubber products annually.

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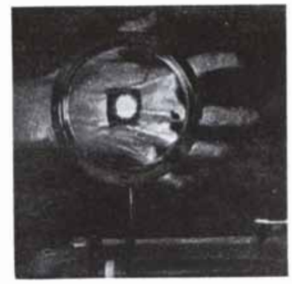

THE COVER

The painting on the cover illustrates the principle of the dolorimeter, a device for the measurement of pain (*see page* 59). At the upper left is the hand of an experimental subject. On the back of the hand is painted a square of India ink, in the center of which is focused an intense spot of heat radiation generated by a 500-watt incandescent lamp. The intensity of the radiation is regulated by the rheostat at the lower right. By increasing the intensity of the radiation until the subject feels pain, the pain threshold can be measured. Similarly, by increasing the intensity of the radiation beyond this threshold, the experimenter can measure the smallest amount of radiation that will cause the subject to feel more pain. The objects in the painting are part of a crude experimental dolorimeter. As developed by James D. Hardy, Harold G. Wolff and Helen Goodell at the Cornell University Medical College, the instrument is now made in a complete unit.

THE ILLUSTRATIONS

Cover painting by Stanley Meltzoff

Page	Source
30-33	Irving Geis
35	Mount Wilson and Palomar Observatories
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78-80	Anne Marie Jauss
84	National Bureau of Standards
89-94	Courtesy Richard A. Howard
96	From R. U. Light: *Focus on Africa.* American Geographical Society
105-110	Roger Hayward

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Fig. 1. Photomicrograph of sheet with large irregular grains. Printing quality not up to par.

Fig. 2. Changes in plating conditions produced crystals more columnar in shape. A step in the right direction.

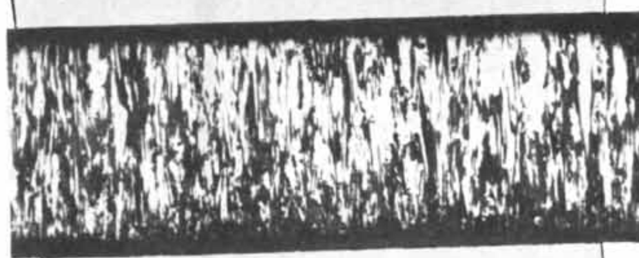

Fig. 3. Here is the structure that was found to give consistently good results. The copper deposit is of intermediate hardness and contains long, thin columnar crystals.

research at work!

A LABORATORY CAN SHORTEN THE SEARCH FOR A BETTER PROCESS

Copper, a basic and important requisite for the printing of Sunday magazines for metropolitan newspapers, has—since the introduction of rotogravure printing process in the United States—suffered from cylinder wear marks which have kept the industry puzzled, and often resulted in defective printing to such an extent that blemishes in printing were easily discernible to the eye—and although not too disfiguring, there remained the necessity for their elimination for the purpose of perfecting the gravure printing operation. In collaboration with a publisher, owner of one of the most modern plants in the world, Revere Copper and Brass solved this perplexing problem and is continuing to contribute to the technical improvement of the rotogravure printing process.

In preparing cylinders for printing roto sections, copper is plated on them before engraving. The electroplating of copper is rather an old process, and its techniques are well understood. By varying current density and composition of the solution, many different types of copper deposit can be obtained. But which of the various methods would give the best results in this case? Rather than engage in a lengthy process of trial and error, the publisher, who felt that the crystal structure of the deposited copper held the key, asked us if we would collaborate.

What Were the Crystals Like?

Sheets of copper resulting from different plating techniques were sent to Research, which not only made photomicrographs of the grain structure, but also determined tensile strength and hardness. As was expected, there were large variations. Some specimens had large and irregular crystals; in others, they were long and thin, like fibers standing on end. In tensile strength, the range was from about 31,000 to 56,000 p.s.i. Diamond Pyramid hardness numbers ran from 62.9 to 141.5.

Over a period of time five different sets of samples were submitted to the laboratory, which made detailed reports on each. By correlating these with his own records, the publisher was able to evaluate the effects of changes in plating techniques. The field of his investigation became narrower after each laboratory report, and in the end it was possible for him to obtain medium-hard, fine grain deposits which require little grinding and polishing. These results now are duplicated daily on a commercial basis. Today the publisher is noted for the exceptionally fine printing quality of his rotogravure sections. The newspaper is The Inquirer, Philadelphia, Pa.

If You Do Not Have a Laboratory

This is an outstanding example of the value of applied research. Many companies occasionally need information that can only be supplied by a laboratory, but are not justified in spending the large sums required to buy and maintain scientific equipment, and to employ qualified research personnel. These firms naturally seek outside sources of the data they require. Revere was glad to cooperate in this instance, because it produces large quantities of copper anodes for plating, and has both the equipment and the experience to make thorough tests of electro-deposited copper sheets or layers.

* * *

The Revere Research Department operates a laboratory that contains the latest scientific equipment, including the spectrograph and X-ray diffraction apparatus. If you feel the need of laboratory work on copper and its alloys, or aluminum alloys, please get in touch with the nearest Revere Sales Office.

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SCIENTIFIC AMERICAN

Established 1845

CONTENTS FOR MARCH, 1953 VOL. 188, NO. 3

ARTICLES

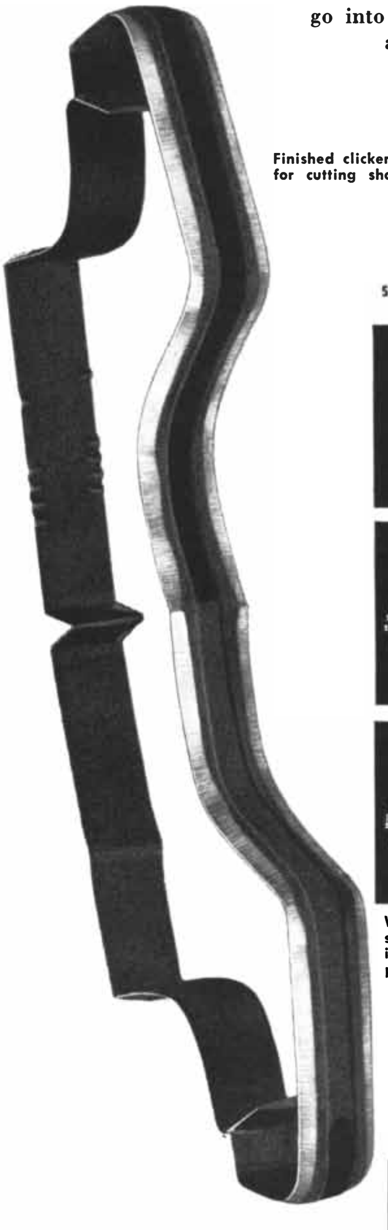
DEPARTMENTS

What's Happening at CRUCIBLE

about clicker die steel

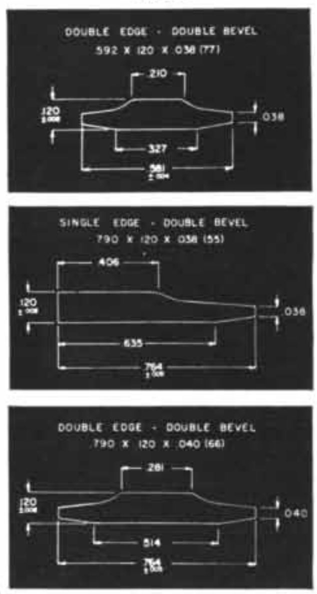
what it is

Clicker die steel is a special cold rolled alloy steel. It is used in making clicker dies for cutting leather, rubber, plastic, felt and fabrics of other compositions that go into the making of shoes and similar products.



Finished clicker die ready for cutting shoe leather.

Some of the clicker die steel standard shapes.



Wider shapes are used when dies are sized by surface grinding after forming and welding. Standard widths are provided when the dies are not to be surface ground.

how it is used

Clicker die steel is furnished to the die maker in either single or double edged form in one of several standard shapes. The die maker first shapes the die by bending the die steel to a pattern that provides the desired configuration, and then welds the two ends at a corner. He finishes the die by grinding a bevel on the outside of the cutting edge and filing the inside edge. Before the finished die is hardened and tempered, the die maker forms identification marks — combinations of circles and squares — in the cutting edge so that the material cut from it may be easily identified as to its size and style.

In the cutting operation, the leather or other material is placed on an oak block in the bed of the clicker machine. Then the die is placed by hand on the material which is cut as the aluminum faced head of the machine presses the die through it. The clicking sound which the head makes as it strikes the die is where the term "clicker machine" derived its name.

what it is composed of

Clicker die steel as produced by the Crucible Steel Company of America is a controlled electric steel in which the combination of carbon and alloy is designed for maximum toughness and proper hardness after heat treatment.

Experience has proved that cold finished clicker die steel is superior to hot rolled material for sizes approximately ¾ inch and narrower because of its lower degree of surface decarburization which permits the use of slightly thinner sections. Cold finished material also has a better surface finish with closer width and thickness tolerances and thinner edges that require less grinding and filing to complete the die.

CRUCIBLE'S engineering service

As with clicker die steel, the Crucible Steel Company of America is the leading producer of special purpose steels. If you have a problem in specialty steels, our staff of field metallurgists with over 50 years experience in fine steel making is available to help you solve it. Crucible Steel Company of America, General Sales and Operating Offices, Oliver Building, Pittsburgh, Pa.

CRUCIBLE **first name in special purpose steels**

53 *years of Fine steelmaking*

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National Drawn Works, East Liverpool, Ohio • Sanderson-Halcomb Works, Syracuse, N. Y. • Trent Tube Company, East Troy, Wisconsin

SCIENTIFIC AMERICAN
MARCH, 1953 VOL. 188, NO. 3

The Practice of Quality Control

The statistical analysis of manufacturing processes has become a powerful tool of technology. An account of how its principles are now applied in the factory

by A. G. Dalton

STATISTICAL quality control has been employed to some extent for a quarter of a century, but only recently have the mists surrounding the rather formidable adjective "statistical" begun to clear. And only recently has industry generally come to see the potentialities of such methods for the solution of production problems.

What kind of problems? Let us consider a simple operation such as boiling eggs. Some people like their eggs boiled hard, some soft, some medium. Probably the most common desire is for medium-boiled eggs. Various mechanical egg-timing devices on the market indicate that the generally accepted average time for boiling an egg neither too hard nor too soft is three and a half minutes. However, even if we consistently boil our eggs for precisely that length of time, they don't always turn out medium boiled. Sometimes they are too congealed, at other times too runny.

Undoubtedly variations in the size or weight of eggs have much to do with this variability. Differences in the age of the eggs, in their original temperature, in the number of eggs put into the pot at one time, in the amount of water, in the atmospheric pressure, in the length of time they remain unopened after cooking—all these factors may influence whether they turn out medium boiled or not. If it seemed worth while, we could go to some lengths to find out how much these many variables might be controlled to produce more uniformly cooked eggs. We might establish a number of control points for individual variables: the size or weight of the eggs, their temperature immediately before boiling, and so forth. Some controls might have an important influence on the quality of the end product, others a negligible effect; all would cost something in time, effort and money. Through such experiments we can weigh the costs of controlling undesirable variables against the benefits. Will we enjoy our eggs more? Will we, if we are restaurateurs, sell more? Will we have fewer complaints and fewer eggs returned to the kitchen?

This problem of achieving a desired uniformity of product or service is a common one in industry, applying to baked plastics and machined gears, to toasters and bicycles, to railroad schedules and telephones. In industry, of course, the problem is much more complicated than in the home, but essentially it yields to the same methods we might have used to determine why eggs boiled for equal lengths of time don't always come out alike.

THE NEED FOR statistical quality control derives from the inability of hens and manufacturers to make two or more things exactly alike, however hard they may try. It is these differences among units of product that cause trouble. If large enough, particularly in materials or subassembly parts, the variations may make fabrication or assembly difficult, costly or impossible. Even if small enough to go undetected, they may still lead to customer dissatisfaction. This dissatisfaction may mean only that the customer, a creature of habit, is disturbed by changes in product. Such changes may have nothing to do with actual quality, but they are all part of the problem.

Differences in product may come from one or both of two general types of causes. One kind is the normal, chance variability of materials, machines, temperatures, atmospheric conditions, manual operations, measuring devices and other factors entering into the manufacture of an item. These variations are inherent to some degree in all processes converting raw materials into useful products, and it usually costs something to reduce their effects. The other category covers other-than-chance causes of variations, as opposed to expected random fluctuations. This group includes extraordinary variations in materials or machine operation, interruptions of the power supply, operators' carelessness or lack of skill, rough handling, poor organization of the work, and so on. Harmful combinations of chance causes also may be included in this category. Once identified, the other-than-chance causes can often be eliminated at little or no expense.

The first step in the problem of improving the uniformity of a product is to determine what kinds of differences are occurring and to what extent. The only way to find out is by inspection, which is a problem in itself. To inspect every single item produced is often impracticable, sometimes would be damaging to the product and in any case would still leave the reliability of the results open to question, because of inevitable errors of measurement and judgment. Hence inspection is often restricted to random samples, and the results are interpreted by application of the laws of probability. The effect of human error is reduced and reliability greatly improved by this method.

Further complicating the problem is the fact that every product has many characteristics, in each of which some differences will occur. Pencils, for instance, have weight, length, thickness, color, hardness of graphite, hardness of wood and other properties. The only

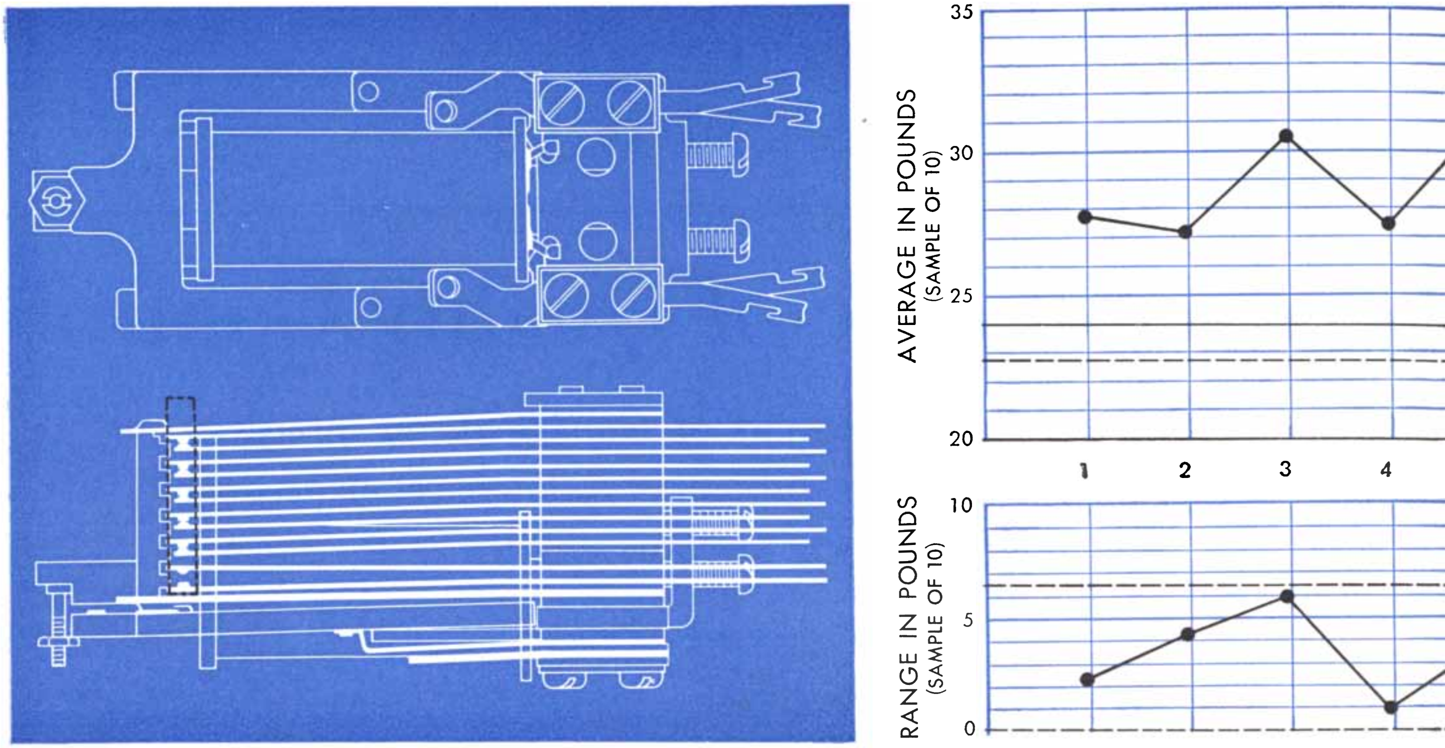


CHART is used to control the strength of the welds which fasten the contacts to the springs of an electric relay. At the left is a drawing of the relay from the top and side; the contacts are within the dotted black line at the far left. The curves at the right reflect the changes in the average strength of welds made by one machine over a period of 18 hours. Once an hour a sample of 10 welded contacts is taken from the output of each machine for testing. The test consists of measuring the number of pounds of force required to

variable of concern to consumers may be the hardness of the point. To the manufacturer, however, irregularities in length may be sufficient to disrupt packaging; variations in the wood may introduce tooling difficulties. Fortunately product characteristics are not all of equal importance, and their variabilities are not all likely to be of the same magnitude. With reliable inspection reports before us, we can proceed to sort them out and by statistical analysis find out what, if anything, we should do about the variations in our product.

IN ITS simplest form this analysis means plotting the inspection results on charts and comparing their distribution pattern with a normal law curve, in which the values are distributed uniformly around the average. The analyst selects upper and lower control limits, such that if any inspection results fall outside the limits, it is assumed that other-than-chance causes are affecting the process. Once in a great while this assumption may be incorrect, but the margin of error is comfortingly small.

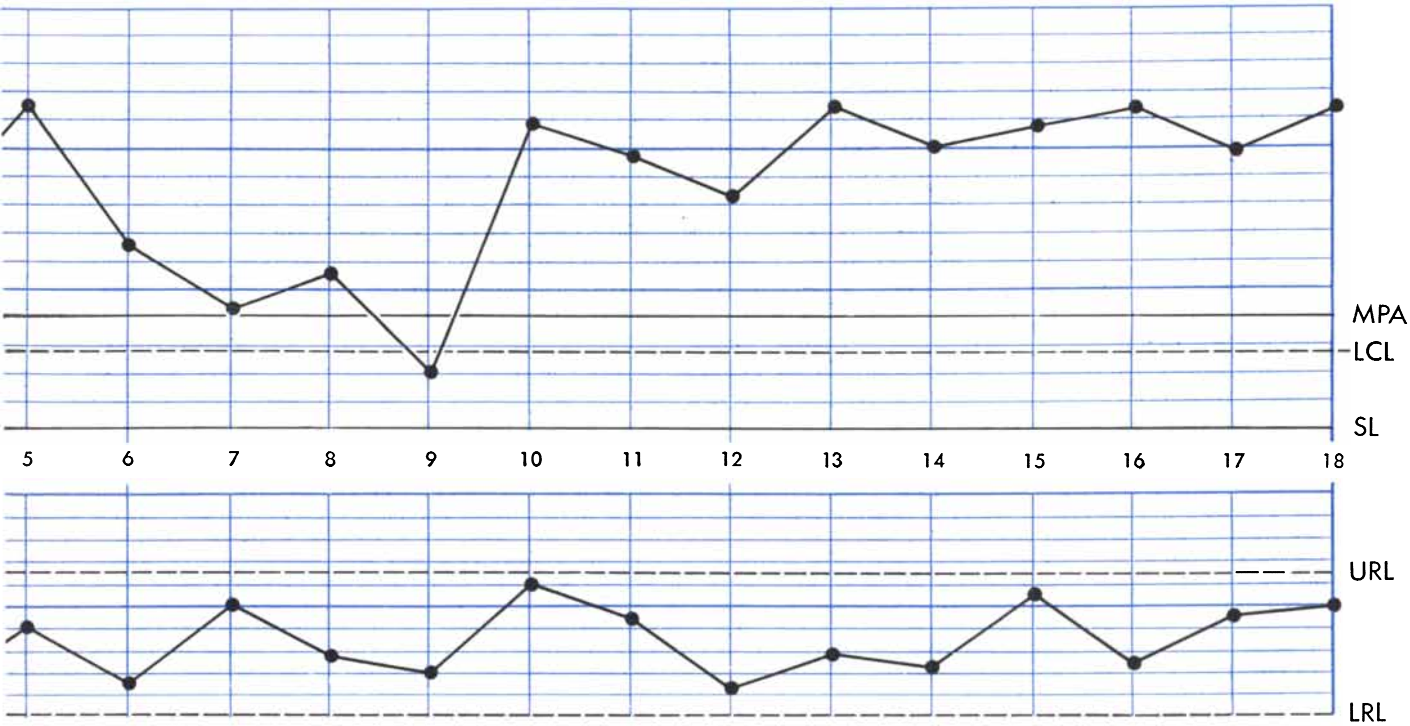
Thus from the charts we can see whether variations in product derive from chance causes inherent in the process or from other-than-chance causes. If all are chance variations, but some are large enough to trouble us or our customers, we have only two choices of action. We can live with the condition so long as we can sell the product; or we can change the process, weighing the penalties of not changing it against the often considerable costs of improving it. If, as is more likely, many of the troublesome variations are due to other-than-chance causes, then a series of exploratory actions should be undertaken.

Control points, involving some kind of informative inspection and record keeping, can be set up at almost every step of production from raw materials to finished product, to find out at what stage things are going wrong. Since even the simplest product may undergo many stages, the cost of analyzing the product at every stage might well be prohibitive. Hence engineering judgment must step in to select the most promising points of control; *i.e.*, those which will result in the largest saving of waste. After experiments on the usefulness of various control points, the most effective are retained as routine inspection stations.

We shall consider here three important applications of statistical quality control: (1) to give warning of abnormal behavior in a process, (2) to diagnose the underlying causes of a wasteful process, and (3) to establish economical inspection plans.

AS AN EXAMPLE of the first, let me cite a process in the manufacture of a product used in the Bell Telephone System. The product is the electric relays, made in the millions by the Western Electric Company, whose function is to make, break or transfer electrical circuits in telephone offices. These relays have a number of contact springs, which are pulled together or separated as the relay is electrically energized or released. The contact points, often of semiprecious metal, are electrically welded to the ends of the relay springs and must withstand millions of shocks and slight rubbings as the relay releases and operates over a normal lifetime. If one of these points broke off, it might interrupt telephone service and mean a major job of replacement or repair. Specifications have been established defining the strength of a satisfactory weld in terms of the minimum pull required to break a contact point loose from the spring. The problem is, how can we be sure that the process is consistently producing welds that meet this specification?

At each welding machine we establish a control station which will let us know immediately when the machine or any other element in the process falters. The operations at a control station are as follows. A sample of 10 units is selected from each hour's production. The welded contacts are torn from the springs, and the amount of force required in each instance is recorded. The results are plotted on a chart to provide a continuing record of two things: (1) the average strength of each 10-unit sample,



tear each contact from its spring. The curve at the top indicates how the average strength of the sample welds varied. The letters MPA at the far right stand for the minimum permissible average for the process; LCL, for the lower control limit; SL for the specification minimum limit for a single weld. At the ninth hour the average strength of the sample welds fell below the lower control limit; corrective action was then taken. The bottom curve shows range of the samples. URL stands for upper range control limit; LRL for lower range limit.

and (2) the range from the strongest to the weakest unit. Statistical control limits also are put on the chart. The control limits are so calculated that if any average value falls outside them, it indicates that the margin between the average strength and the minimum required is too narrow. The control limits for range are so calculated that when units begin to fall outside these limits, this also indicates that other-than-chance causes have intervened. Only when both the average and the range stay within their respective control limits is there adequate assurance that the welds made during the period in which the sample was taken are satisfactory. Whenever an average or range value of a sample falls outside the control limits, we know that we must stop the welding machine and look for the causes.

At this stage of manufacture the spring plus welded contact has some cash value, but the value is very small in comparison with the cost of the completed relay. Therefore, the cost of maintaining a system of control at each welding machine represents a very small insurance payment against the much greater penalties that would be paid if defective parts were not detected and went on into the finished product. Moreover, so long as the samples are statistically satisfactory, we need not interrupt operation of the process or reset the welding machines, which means a saving in time, labor and the useful life of the machines.

THIS EXAMPLE shows how statistical quality control can provide reliable warning signals on a production line. The following example will illustrate the second application: how statistical methods are used to diagnose and eliminate the causes of abnormally low production yields in a simple product—in this case carbon inserts for a tiny protector block. These blocks are used to protect home telephones from lightning discharge or an accidental power contact with the telephone lines. It was found that in the manufacture of these inserts the basic cause of rejections was irregularity in their dimensions. Several operations are involved, including molding the carbon, two separate firings, cementing in a porcelain cup and gauging for size. The major losses occurred during inspection after the second firing, in which about 60 per cent of the inserts were rejected for shrinkage and softness. A more informative inspection procedure was instituted, and statistical analyses of the results showed that the trouble was in the average value rather than in the range of values after this step in the process. To raise the average, changes were made in processing the carbon powder and in the molding dies. The result was a harder insert, with a more favorable average length and no harmful increase in the spread between the highest and lowest values. The changes reduced losses after the second firing from about 60 per cent to .2 per cent.

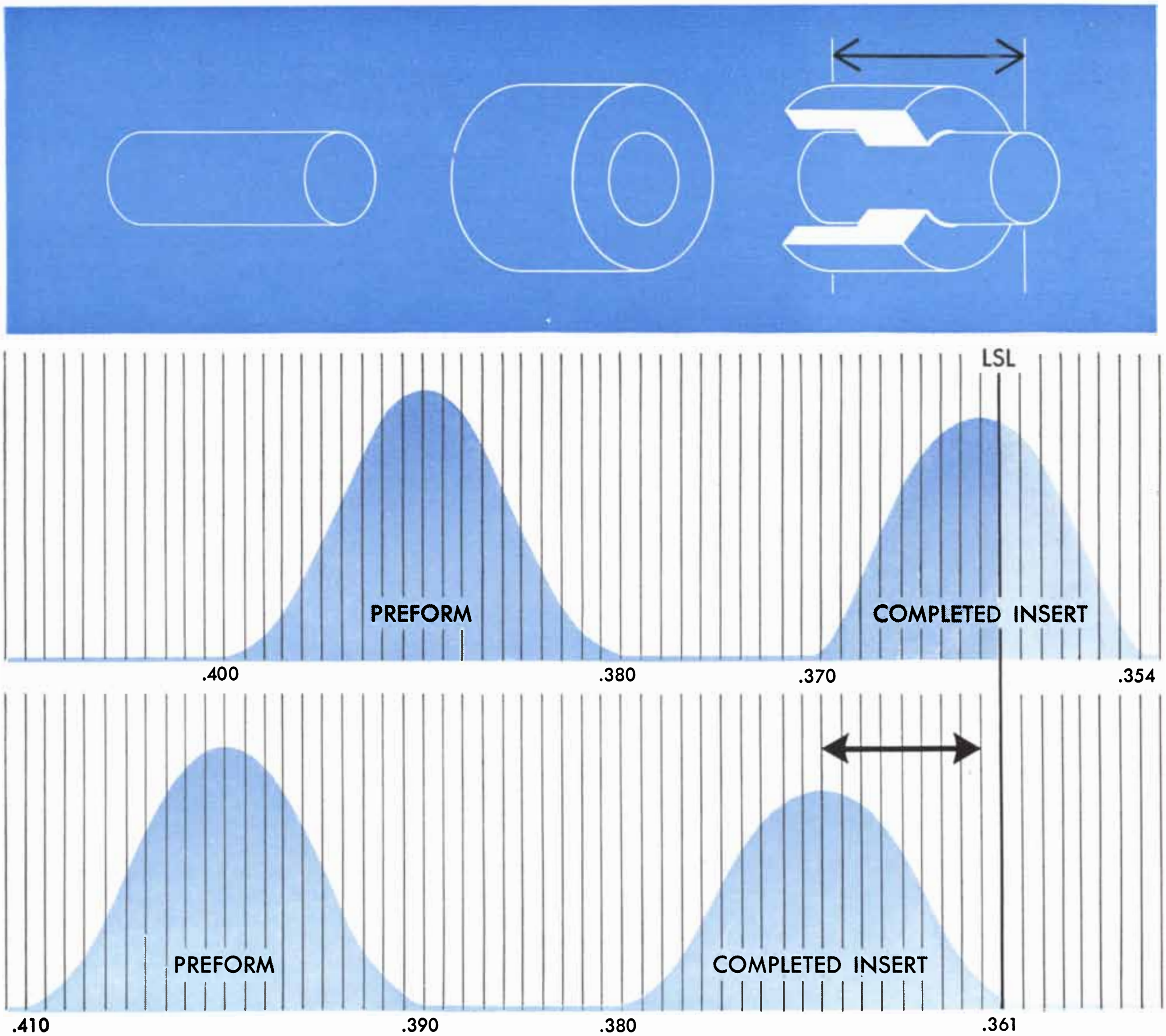
For the statistical analyses six experimental control points had been established. Four of these were kept, to give early warnings of any temporary hitch in the process. The total time spent in investigating and statistically analyzing the problem was less than three months. The results: a reduction of waste from 75 to 15 per cent, an increase in yield from 5,000 satisfactory units a day to 25,000, and reduction of the labor force by three operators and five inspectors.

Experience indicates that these spectacular results from a relatively inexpensive study are by no means exceptional. Almost limitless opportunities exist throughout industry for securing impressive benefits from the use of statistical quality control in diagnosing harmful irregularities.

A THIRD area for the use of statistical quality control is in planning economical inspection procedures. Inspection *per se* adds nothing to a product and is often regarded as a necessary evil. In many instances it gets this bad name from being used so extensively as a sorting operation to separate bad units from good. Occasionally this may be economical, but not often. It is economical only when a manufacturing plant is unable to produce a high enough percentage of acceptable items, and the cost of improving the facilities to a point where sorting operations are unnecessary exceeds the cost of sorting. In sorting operations as much or even more inspection time is usually expended on good items as on bad, giving rise to the age-old question, "Why don't we confine inspections to the bad units and stop wasting money looking at the good ones?" While statistical quality control cannot entirely eliminate such waste, it can often substantially reduce inspection costs on "good product."

When a plant's output regularly contains an acceptably small percentage of defects, inspection can safely be limited to those operations necessary to verify maintenance of this performance. Sampling inspections of this kind are essentially informative. They can be made very sensitive to any change in the manufacturing process and will thus provide timely warnings of any imminent degradation of product. They are also far cheaper than sorting inspections, since they involve looking at or measuring a relatively small percentage of the output.

It is important to recognize, however, that any sampling plan involves the risk that the sample may not be truly representative. If the quality of the sample is below that of the lot from which it comes, the lot may be rejected unnecessarily. On the other hand, if the sample is better than the lot as a whole, the consumer may get a product of marginal



DISTRIBUTION CURVES were used to study the production of carbon inserts for protector blocks, used to protect telephones from lightning. At the upper right is a cutaway drawing of the insert; its length is indicated by the black arrow above it. The insert is made with a carbon rod (*top left*) which is given two firing operations and is then cemented into a porcelain cup (*top center*). The over-all length of the insert is given in fractions of an inch by the horizontal coordinate of the chart. The two curves in the top chart show the distribution of the lengths of sample inserts taken from one month's production. The curve labeled "preform" gives the distribution of the lengths before the inserts were fired; the curve labeled "completed insert" gives the distribution after firing. The letters LSL at the top of the chart stand for lower specification limit. It was found that a large number of completed inserts were rejected because their lengths were below this limit (*light blue area on curve at upper right of chart*). By altering the manufacturing process so that the distribution of the preform inserts was moved to the left, as shown at the bottom, the distribution of the completed inserts was also shifted to a more favorable position and the rejects were sharply curtailed. The black arrow above the curve at lower right shows the distance the distribution pattern of the completed inserts was shifted.

quality. Sampling inspections can be used to protect the "lot" quality or the "average" quality. In either case random samples are drawn from specific lots, and a lot is accepted when the number of defects in the sample is no greater than an allowable number. That number is based on a calculated risk chosen as tolerable. If the allowable number of defects is exceeded, each unit in the lot is then inspected individually.

Sometimes a system of double sampling is used. Instead of accepting or rejecting a lot on the basis of a single sample, the inspector first takes a smaller sample and applies a stricter test: *i.e.*, it must have fewer defective items. If this standard is met, the lot is accepted, and the inspection effort is minimal. If the first sample does not meet this strict test, a second sample is taken, usually of substantially larger size, and for both samples combined the allowable number of defective items is larger. Double sampling, properly applied, usually results in a net saving in the number of units that have to be inspected.

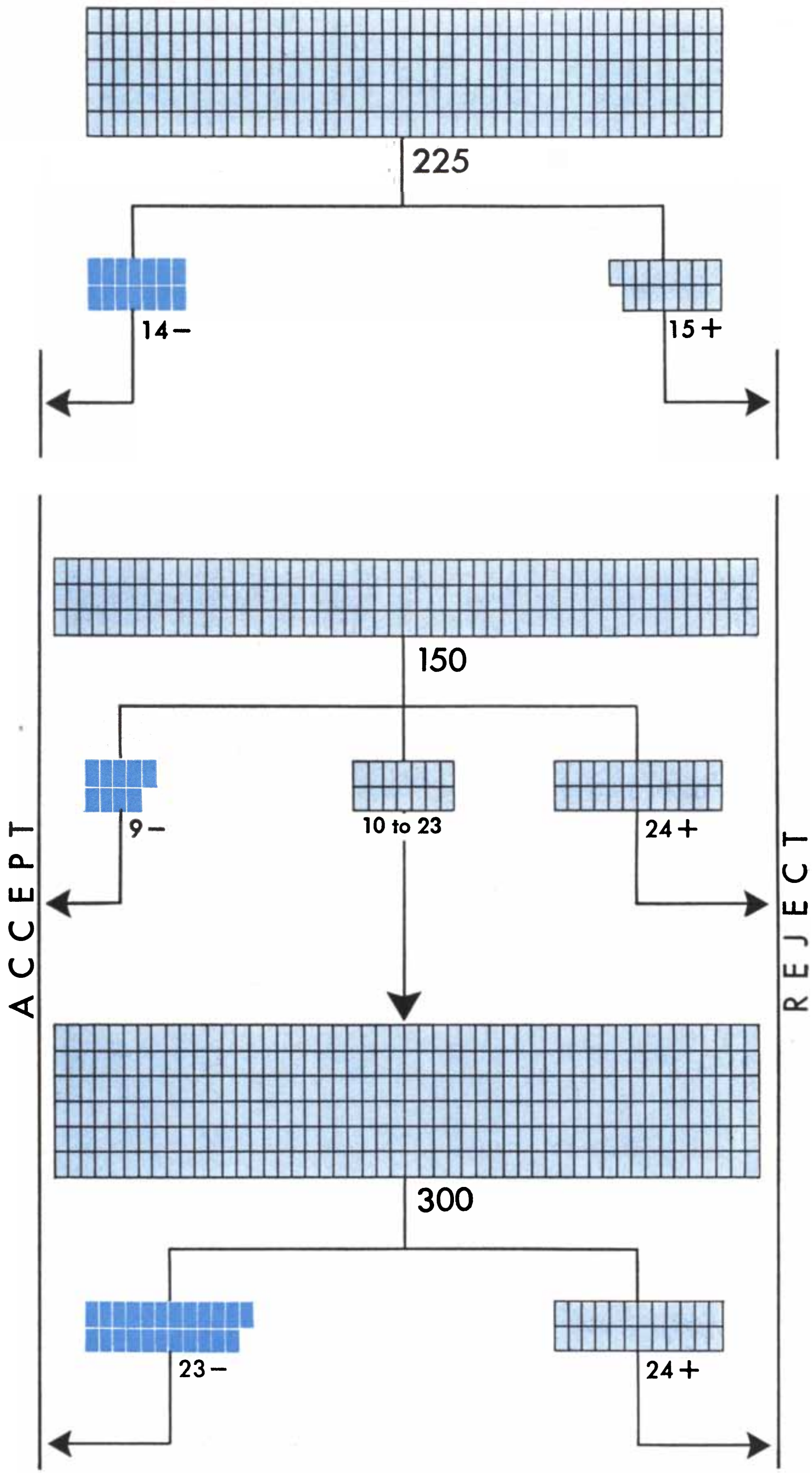
Double sampling in turn may be extended to multiple or sequential sampling, using a larger series of sampling trials. However, in many instances the greater complexity, the chances for misapplication and the extra bookkeeping tend to cancel the theoretical economies of sequential sampling.

In any of these sampling procedures the relationship between lot sizes and sample sizes is not constant. From a small lot one needs a relatively larger percentage sample than from a large one. When a process consistently produces well above the quality requirement, it is usually advantageous to sample large lots, because the chances of a lot's being rejected are small. When the process is less consistent or dependable it may be better to test small lots.

When sampling plans are properly applied, the economies in inspection time are not the only benefits. Sampling inspections also provide a continuing historical record of the capabilities of a process or a machine, which may be helpful to engineers planning the production of similar products. Such records can help consumers as well, for when a producer can furnish evidence that the quality of a product is consistently controlled at the specified level, his customers can reduce or eliminate their own inspections of incoming products.

STATISTICAL quality control is invaluable for giving warning of impending trouble, and its warnings must be heeded. However drastic it may seem to have to curtail or stop production and search for the remedy, it must be remembered that the cheapest thing to do about an unsatisfactory product is not to make it.

Ω



SINGLE AND DOUBLE SAMPLING are illustrated by this chart. In single sampling (*top*) a sample of 225 items might be taken from a much larger lot. If 14 or fewer were defective, the lot would be accepted; if 15 or more were defective, it would be rejected. In double sampling (*bottom*) the initial sample would be smaller, perhaps 150 items. If 9 or fewer were defective, the lot would be accepted; if 24 or more were defective, it would be rejected. If, however, from 10 to 23 were defective, a second sample, in this case one twice as large as the first, would be taken. Then if 23 or fewer defective units were found in the first and second samples combined, the lot would be accepted; if 24 or more were found, it would be rejected.

The Evolution of Stars

Many astronomers believe that stars may be old, middle-aged or young. New studies indicate that the age of some may be less than a million years

by Otto Struve

FOR CENTURIES men assumed that the stars were ageless. They noted that during the thousands of years of recorded observation the constellations have held their places almost unchanged in the sky. But we have been learning that the stars are not as stable as they seem to the naked eye. Individual stars vary in brightness from time to time, and some are subject to the violent and sometimes catastrophic explosions that produce novae and supernovae. In recent years astronomers have found more and more reasons to believe that the stars may be of widely varying ages. Some, it is true, are the oldest and most permanent things we know, but others may be much more transient. They brighten the sky for a small fraction of the life of a galaxy and then disappear into some other form of matter—not necessarily a form we recognize as such.

Our new insight into the age of stars stems from our new knowledge of how these bodies produce their energy. The process, which involves the nuclear transformation of hydrogen atoms into helium atoms, is believed to be substantially the same for all stars. But the speed of the reaction differs greatly from one star to another, and the transformation can be seen in a number of different stages. We can orient ourselves in this evolutionary development by starting with the sun, the star about which we know the most and in which we have the greatest immediate interest.

The solar energy that reaches the earth can easily be measured. We expose a cubic centimeter of water to a direct beam of sunlight and note how long it takes to raise the temperature of the water one degree centigrade. We correct this measurement to take account of the part of the sun's rays screened out by the earth's atmosphere. We thus determine that the solar energy received by our planet amounts to two calories per square centimeter per minute. One calorie is equivalent to about 40 million ergs. An erg is a very small amount of energy: it is about the amount that a moderately slow mosquito transfers when it collides with your forehead—and this does not include the sting! Fortunately the arithmetical device of expressing large numbers as exponents of 10 makes it feasible to use this physical unit. The resulting numbers are so deceptively simple, however, that it is easy to forget the staggering quantities of energy put out by the stars.

Every square centimeter of the earth, then, receives solar energy at the rate of about a million ergs per second, and if we apply this figure to an entire sphere around the sun with a radius equal to our distance from it, we can calculate the sun's total energy output. It comes to 4×10^{33} ergs per second. The mass of the sun is 2×10^{33} grams. Therefore each gram of the sun's substance yields, on the average, two ergs per gram per second, not for just a second or a year but for ages and eons! The solar system is believed to be about three billion years old; in that time every gram of the sun has already produced 2×10^{17} ergs. The energy production of the sun is, therefore, at least five million times more efficient than any reaction known to chemists.

IT WAS essentially this reasoning that led astronomers and physicists to discover the nuclear processes by which the stars generate energy. When four atoms of hydrogen combine to form one atom of helium, a little less than 1 per cent of the original weight of the four hydrogen atoms is converted into energy. We know that the sun has some 10^{33} grams of hydrogen left, hydrogen constituting about half of its present mass. From this we can calculate that at its present rate the sun will go on shining for more than 100 billion years.

As stars go, the sun is a relatively slow burner. The most brilliant stars in the sky, such as Rigel and Deneb, are pouring out energy at the rate of not two ergs but 10,000 ergs per gram per second. Assuming that they are fueled by the same process as the sun and that half of their present substance is hydrogen, these stars have a maximum life expectancy of only about 20 million years.

Actually their lives may be much shorter. In making our estimates we have assumed that a star can transform all of its hydrogen into helium. But it takes a temperature of about 20 million degrees to make the reaction go, and such temperatures exist only near the center of a star. Hence if a star is to burn all its hydrogen, its material must mix freely so that the surface hydrogen can reach the center. Such mixing may take place in rapidly rotating stars. In a star that rotates slowly, however, probably relatively little mixing occurs. One evidence of that is the abundance of lithium in the atmosphere of the sun, a slowly rotating star. If there were free mixing in the sun, all the lithium would long ago have been transformed to heavier elements by the heat in the interior.

If only the hydrogen in the central core of a star is available as fuel, we must cut the estimate of the lifetime of such stars to about one tenth. On this basis the sun's life expectancy would be about 10 billion years, and that of Rigel and Deneb would be only one or two million years. Astronomically speaking, this is a very short time indeed.

In a million years a star could not travel far, as astronomical distances go. Consequently some of the bright stars in our neighborhood in the Milky Way must have been born not far from where they are at present, and new ones may even now be in the process of birth before our very eyes.

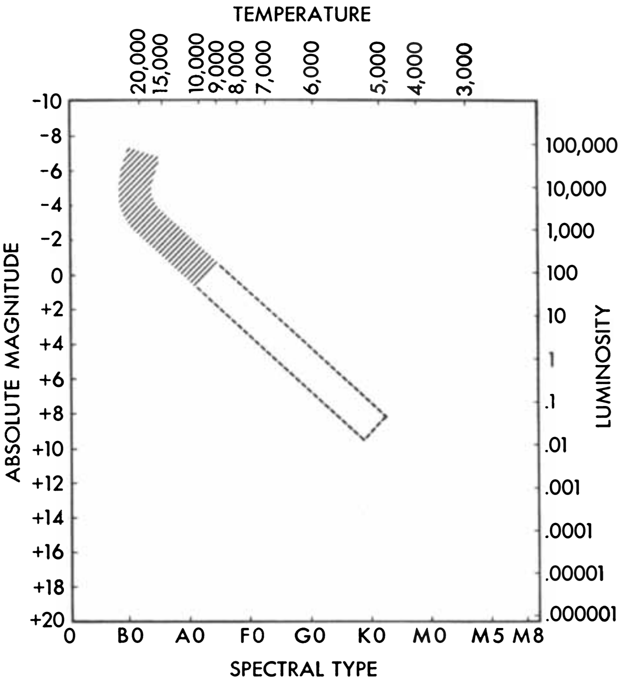
Many astronomers do not agree that new stars are constantly being formed. The German astrophysicist C. F. von Weizsäcker argues that all the stars in our galaxy must have condensed at about the same time from the original gas and dust, and that present bright stars acquired their luminosity by picking up material from clouds of interstellar matter through which they have recently passed. This process, based on the highly controversial accretion theory of the British astronomers Fred Hoyle, R. A. Lyttleton and Herman Bondi, is called "rejuvenation" by von Weizsäcker.

Whether we call them young or rejuvenated, we can undoubtedly place stars such as Rigel and Deneb in a different class from old stars such as the sun. One place to look for clues to the origin and evolution of the hot young stars is in clusters of them, where we can assume that most of the stars are about the same age. One such cluster is located in the constellation Perseus, and a group of stars in this cluster has recently given startling confirmation of the youthful-star theory.

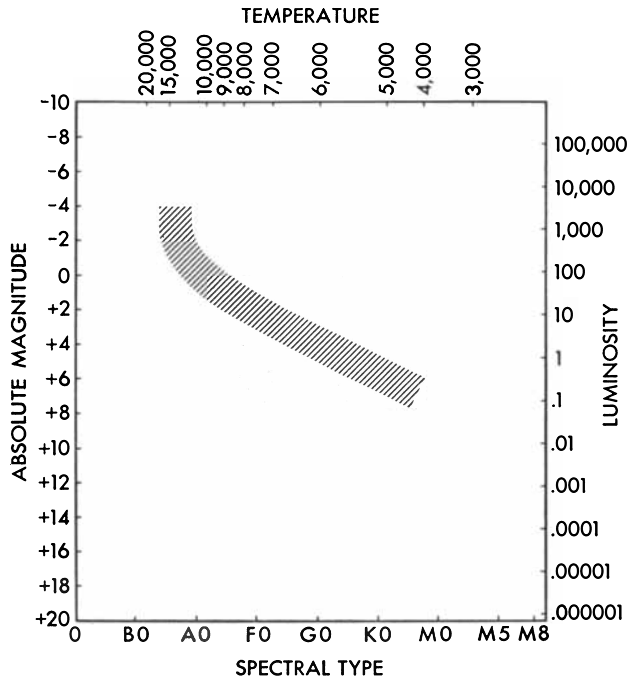
Five years ago the Soviet astronomer V. A. Ambarzumian called to our attention very loose groupings of stars which he called "associations." The stars in these associations are relatively few and spaced widely apart. Ambarzumian showed that the gravitational force within such an association is too small to keep it together. We may assume that

PLEIADES are an "open" cluster which may be middle-aged. This photograph, made by the 18-inch Schmidt camera on Palomar Mountain, shows their nebulosity.

MESSIER 3, or M3, is a globular cluster of stars which one theory suggests are old. This photograph was made by the 200-inch Hale telescope on Palomar Mountain.



DOUBLE CLUSTER in Perseus has a color-brightness diagram in which stars fall within a "main sequence." Within the dotted line are stars that are not observed.



PLEIADES have a diagram in which the upper end of the main sequence has moved to the right. Blue giants are at the upper left; red dwarfs, at the lower right.

the individual stars in such a group move according to Newton's first law of motion; that is, they travel at a uniform rate without any significant gravitational interference from other stars. Last year the Dutch astronomer A. Blaauw studied a typical association of hot stars in Perseus (the one dominated by the star Zeta Persei) and found the stars moving apart at the rate of about 7½ miles per second. At this rate it would have taken the group only about one million years to expand from a single compact mass to its present spread of roughly 500 light-years. Thus it appears that the association is approximately a million years old.

Blaauw has since found similar expanding associations in other constellations. One in Lacerta is four million years old, and one in Ursa Major, about 45 million years. Other clusters are undoubtedly much older.

What made the associations start expanding? Ambarzumian once suggested that they might have come from the explosion of large, dark prestellar masses of some unknown type, but at the recent meeting of the International Astronomical Union in Rome he and other Soviet astronomers argued that they may have originated in the conventional way from clouds of dust.

The most convincing piece of information regarding the distinction between young and old stars comes from the work of Walter Baade of the Mount Wilson and Palomar Observatories. In the great Andromeda galaxy young stars are always found close to clouds of gas and dust. Together they form the spiral arms of the galaxy. According to Baade, the dust and gas are the primordial medium of which the arms were formed. Old stars appear between the spiral arms and also above and below the spiral's plane of symmetry. They predominate near the nucleus of the galaxy. There is no gas or dust in that area; it was presumably used up in the process of star formation. The purest brand of old stars is now to be found in the so-called globular clusters—densely packed groupings of several hundred thousand stars each. These clusters also are free of diffuse interstellar stuff. They contain so many stars that they do not dissolve easily, as do the much more dispersed galactic clusters. Their own gravitation will keep the globular clusters tightly together for billions of years. Since they contain no dust or free gas, their stars cannot undergo rejuvenation.

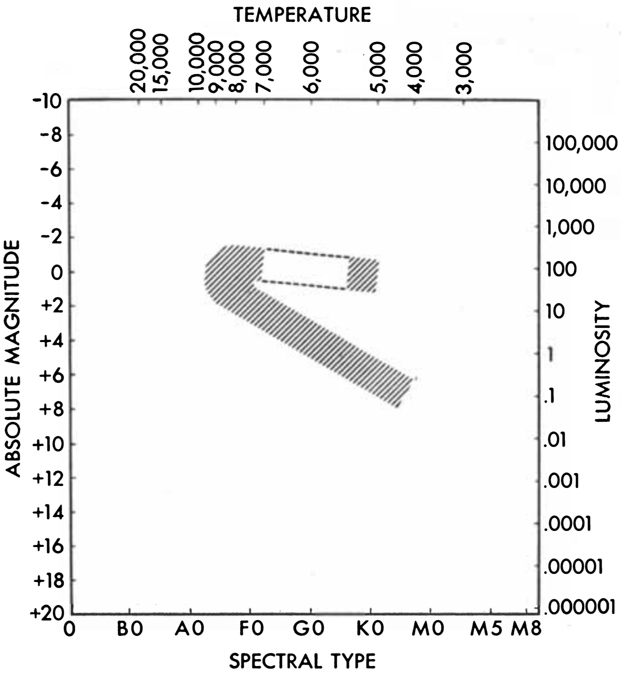
FOR AN over-all picture of the evolution of stars the most useful instrument is the color-brightness diagram, on which stars are plotted according to their intrinsic brightness (energy output) and color (surface temperature). In any group of stars, be it galaxy or cluster, most of the stars fall within what is called the main sequence, a narrow band running diagonally from the upper left to the lower right of the chart [*see diagrams on these two pages*]. The sequence begins with young, blue, hot stars at the upper left and ends with old, red, cool stars at the lower right.

Just how, or at what stage in its evolution, a star gets into the main sequence is unknown. But let us suppose that a group of stars has evolved in such a manner as to occupy the main sequence. What will be the later history of these stars, as shown by the color-brightness diagram? Consider the diagrams of three star groups: the young double cluster in Perseus, the middle-aged Pleiades and the older Hyades.

In all three cases the lower part of the main sequence, showing the population of cool red dwarfs, is much the same. This is understandable, since even young stars of this type do not change a great deal in the course of time. But the upper part of the band is different for the three star groups: this segment bends to the right as we pass from Perseus through the Pleiades to the Hyades. From this we infer that the evolutionary path of a young star follows a horizontal track to the right. In other words, its intrinsic brightness, or energy output, remains about the same, but its temperature drops.

In the Milky Way the stars lying close to the sun are a mixture of all ages. Their color-brightness diagram shows a tremendously greater abundance of red dwarfs than do the diagrams of the three clusters. This suggests that all three clusters are relatively young compared to the sun. They would disperse before they had had time to reach an advanced age. But their stars continue to evolve, and some of them may become red giants, or, as Hoyle and others have suggested, may explode, shed part of their mass and end up as white dwarfs.

The original red dwarfs of the clusters remain what they were before, and it may be argued that we cannot distin-



HYADES have a diagram in which a group of stars has moved away from the upper end of the main sequence. The members of this detached group are red giants.

guish a young red dwarf in a cluster that was formed a million years ago from a red dwarf of the solar neighborhood—the sun itself is a good example—that is 3,000 times as old. This conclusion is one that some astronomers, including myself, find difficult to accept. It seems hard to believe that in three billion years the old stars would remain unaltered, showing no effects of their long rotation or of cosmic accidents such as the birth of planets, collisions between planets or encounters between planets and stars.

Now let us examine the schematic diagram of a globular cluster, known as M3. Here the upper part of the main sequence wanders off to the right in an unexplained manner. A. R. Sandage and Martin Schwarzschild of Mount Wilson have developed a theory of evolution which attempts to account for the major features of the diagram. About five billion years ago, they suggest, all stars of this globular cluster were young and were located upon the conventional main sequence. Its color-brightness diagram then resembled that of the double cluster in Perseus. There being no material for rejuvenation, the stars started evolving by converting their hydrogen into helium—the hotter ones rapidly, the cooler ones slowly. Since the mixing of gases was not thorough, the conversion process did not proceed at a steady pace. After the hydrogen in the core of a hot star was exhausted, the conversion of hydrogen to helium continued in a relatively thin shell around this core of "nuclear ashes." During these changes the radius of the star increased enormously. All these transitions produced the variations in luminosity and temperature indicated by the somewhat meandering path of the M3 main sequence.

The giants in the neighborhood of our sun fall below the top right-hand sequence of M3. This may indicate that there are real structural differences between our stars and those of a globular cluster. Perhaps their chemical composition was not the same to begin with.

WE ARE not sure that the surface composition of stars tells us anything about their interiors. On the surface there are marked differences among stars. Some have a relatively large abundance of the carbon isotope C-13, a product of the carbon cycle by which hydrogen is converted to helium. Perhaps this is a sign of good mixing.

Most interesting was the discovery last year by Paul W. Merrill of Mount Wilson that there are perceptible amounts of the radioactive element technetium in certain cool stars. Technetium is so unstable that it has practically disappeared in nature on our earth, yet Merrill's observations indicate that it is at least as abundant in these stars as the stable element molybdenum. Hence these stars cannot be much older than 100,000 years. Perhaps we shall ultimately be forced to accept even such a short lifetime for a star.

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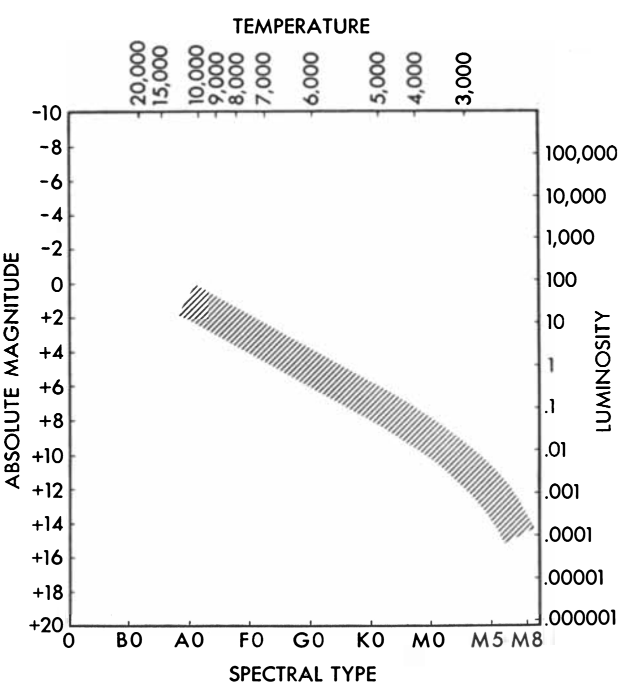
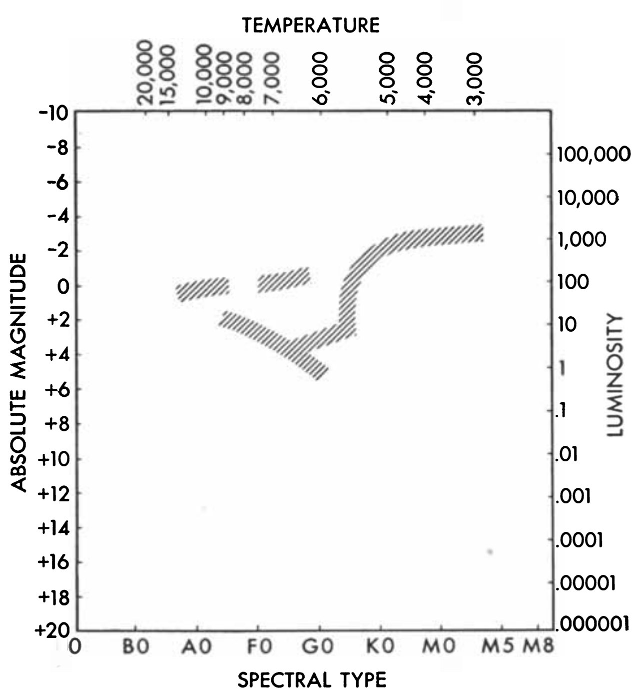


STARS NEAR THE SUN (within a distance of 10 parsecs) have a diagram which reflects their preponderance of red dwarfs. The sun is located near the middle.



MESSIER 3 has a diagram with only a stub of the main sequence. The branching sequence at the right contains red giants; the detached groups at left are blue giants.

DISCOVERIES IN NITROGEN FIXATION

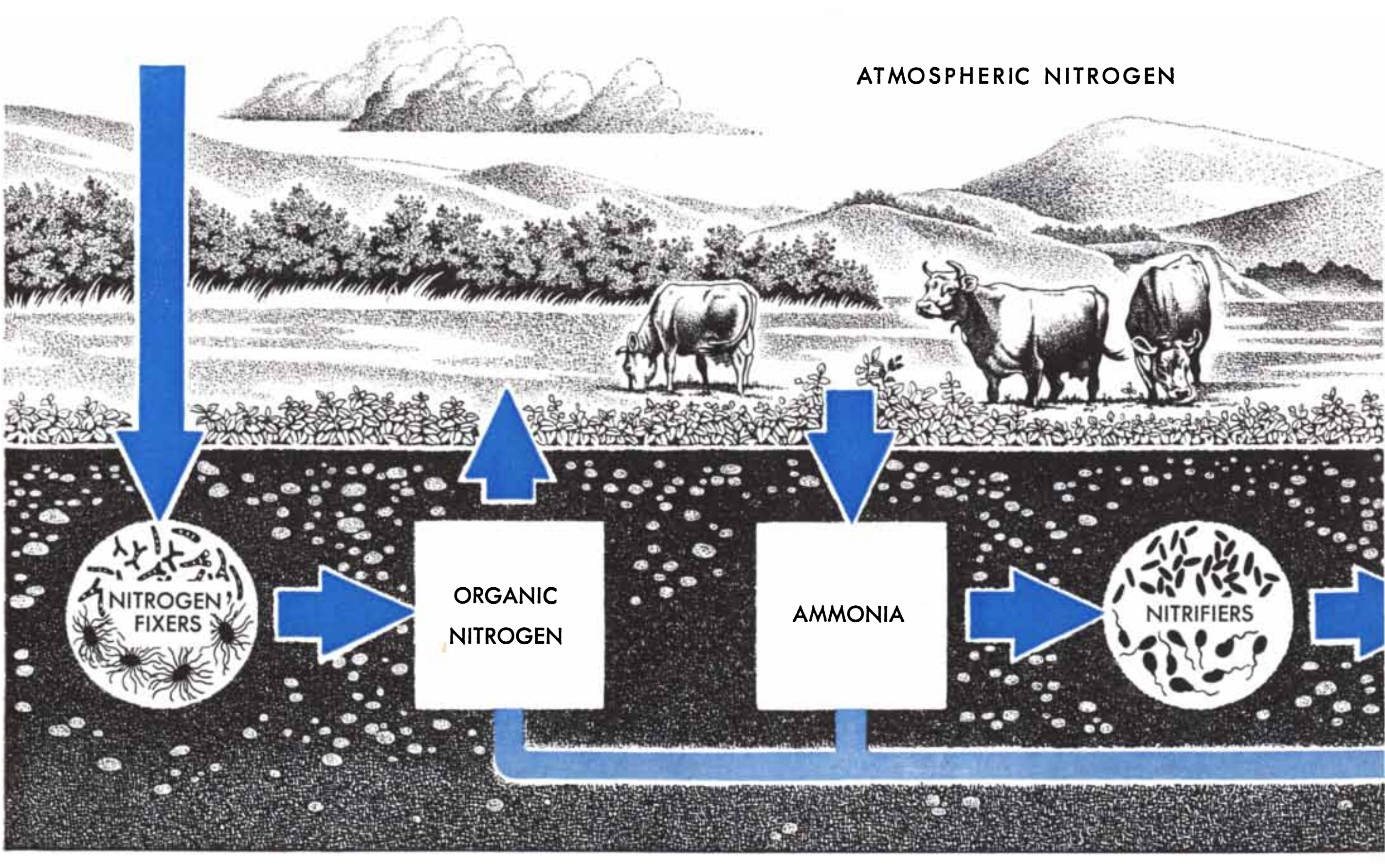
Until recently only a few microorganisms were thought to fix the nitrogen of the atmosphere in the form essential to higher plant and animal life. Now a number of others have been found

by Martin D. Kamen

NITROGEN tantalizes mankind with the paradox of poverty in the midst of plenty. All living things on this planet—animal and vegetable—must have nitrogen in their food. The earth's atmosphere contains far more than enough nitrogen to satisfy the requirements; there are some 20 million tons of it in the air over each square mile of the earth's surface. Yet the free nitrogen in the air is so difficult to incorporate into foodstuffs that man must engage in back-breaking toil to conserve the comparatively small amount that nature captures and fixes in the soil.

To be sure, it is fortunate that nitrogen is chemically inert. If it were less reluctant to combine with other elements (and its thermodynamic relations indicate that it has the potentiality of being much more active than it ordinarily is), it might readily combine with water to form nitric acid. As some authorities on thermodynamics have pointed out, "it is to be hoped that nature will not discover a catalyst for this reaction," for if it did, the oceans would turn into dilute nitric acid—a catastrophe certainly as horrible as any visualized in speculations about atomic warfare.

Nature handles nitrogen—prodding it out of its chemical sluggishness and controlling its tendency to react rapidly



NITROGEN CYCLE begins in the atmosphere. The element is fixed by bacteria in the form required by higher plants and animals. When the plants and animals die, their nitrogen compounds decay into ammonia. Nitrithereafter—by means of a complicated cycle [*see illustration below*]. Certain organisms in soil and water, called "nitrogen fixers," take up the air's free nitrogen and combine it in organic compounds which are suitable for plant or animal food. Other organisms, called "nitrifiers," convert this organic nitrogen into the mineral nitrates required by plants. Still others, the "denitrifiers," decompose dead organisms and eventually return free nitrogen to the air. Some nitrogen also is lost by washing of soil and sewage into the sea.

This continual leakage of nitrogen to the atmosphere poses one of the most important problems for the survival of living forms on the earth. Man has begun to try to stop the drain by artificial methods of recapture, but his processes for combining nitrogen with other substances are expensive and succeed only in making the simplest nitrogen compounds, such as ammonium salts, nitrates, urea and cyanamide. To make up our losses and recombine nitrogen in the forms in which plants and animals need it, we are almost entirely dependent on the nitrogen-fixing organisms.

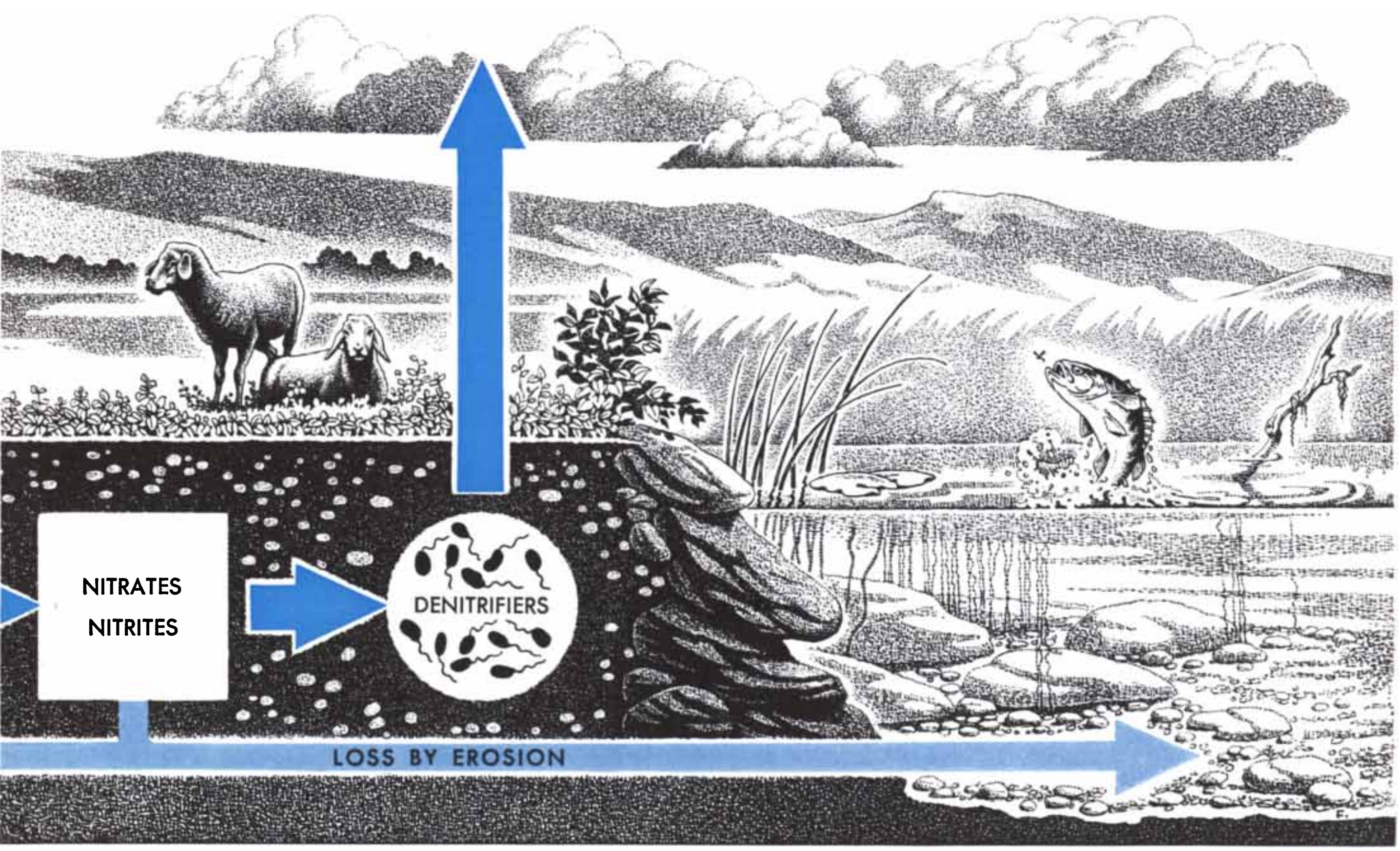
Nature's nitrogen cycle is as important to us as the carbon cycle of photosynthesis, by which plants recapture carbon dioxide from the air and convert the carbon into organic compounds. The nitrogen fixers and the photosynthetic organisms, linked in a majestic partnership, keep the living economy of the earth solvent.

WHAT ARE these natural allies of man in the struggle to wrest nitrogen from the atmosphere, and how do they do it? Obviously this is a matter of considerable importance to mankind. Unfortunately we know much less about nitrogen fixation than we do about photosynthesis, which has not yet yielded all its secrets. Within the last three years, however, there has been more progress in our knowledge of nitrogen fixers than had been made in all the previous history of research on the subject.

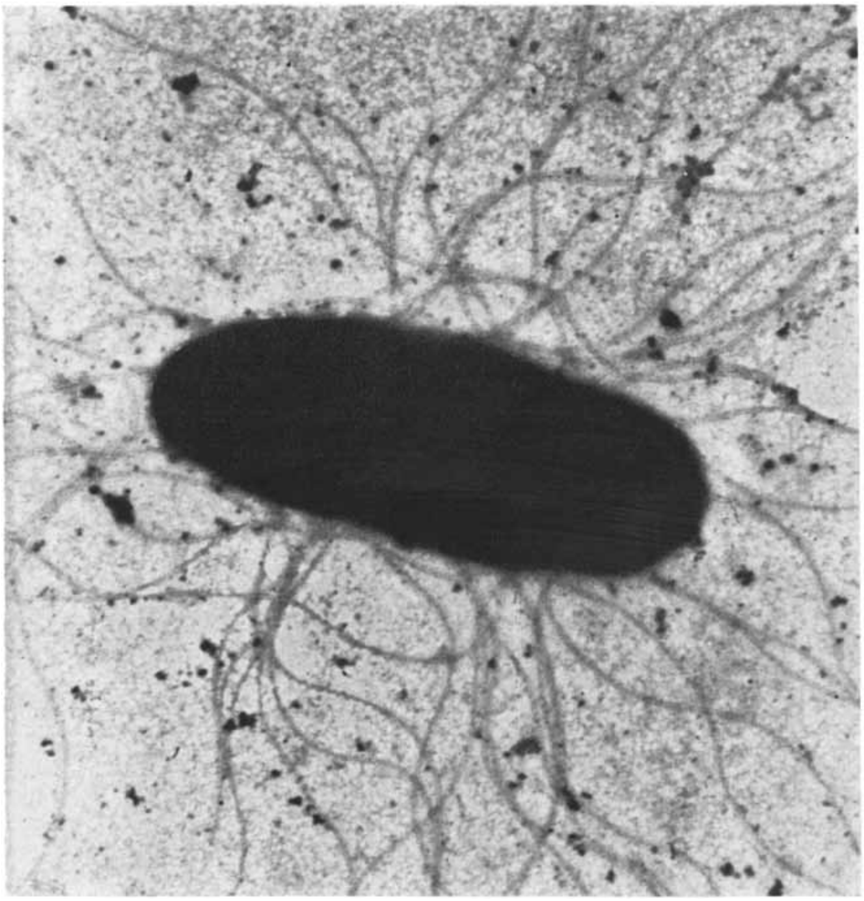
Until 1949 it was generally believed that very few microorganisms had the ability to fix nitrogen. The best-known were the bacteria belonging to the genus *Rhizobium*, which inhabit the root nodules of leguminous plants such as peas, barley and oats. Then there were some free-living organisms, mostly lumped in a genus called *Azotobacter*, which means simply nitrogen-fixing bacteria. There were also a few known species of nitrogen-fixing bacteria that live in the absence of oxygen, for example, species of the genus *Clostridium*, some members of which are the active agents in gas gangrene and tetanus. Finally the primitive plants called blue-green algae were known to carry out nitrogen fixation under certain conditions.

Then in 1949 and immediately afterwards came a flurry of discovery which turned up undreamed numbers of other organisms that fix nitrogen. It began with a chance finding by Howard Gest and the author during a research into a subject seemingly totally unrelated to nitrogen fixation.

We were studying the phosphate metabolism of the purple bacterium *Rhodospirillum rubrum*, which has been described in a previous article in this magazine ["Purple Bacteria," by Roderick K. Clayton and Max Delbrück; November, 1951]. Rhodospirillum is one of the many genera of photosynthetic bacteria. These bacteria, like the green plants, depend on light for growth, but instead of yielding oxygen they produce carbon dioxide and other carbon compounds as they break down organic material. We were attempting to establish the nature of the carbon compounds in which *R. rubrum* first stores the energy of light. Reasoning from analogy with what was known about processes such as muscle contraction, we deduced that certain organic phosphate compounds



fying bacteria convert the ammonia into nitrates and nitrites. These compounds are decomposed by denitrifying bacteria, and their nitrogen is returned to the air. Some of the compounded nitrogen is washed into the sea.



AZOTOBACTER VINELANDII is one of the nitrogen-fixing bacteria that have been known for some time. This electron micrograph, which enlarges the bacterium 16,000 diameters, was made by A. W. Hofer and R. F. Baker.

RHODOSPIRILLUM RUBRUM is one of the recently discovered nitrogen fixers. This electron micrograph, which enlarges two of the bacteria 15,000 diameters, was made by Katharine Polevitzky Zworykin and Robert Picard.

might be involved. In the effort to identify and locate these compounds we supplied isotopically labeled (tracer) phosphate to actively metabolizing cells of *R. rubrum* under illumination.

We found, however, that when the organisms were grown in the usual media, they produced large excess amounts of unstable phosphate which broke down during separation for chemical analysis and made it impossible to tell where the labeled phosphate had originally been taken up. We therefore had the problem of finding a diet which would allow the organisms to make only the minimum amount of phosphate required for growth. Fortunately S. H. Hutner of the Haskins Laboratories in New York had developed a completely synthetic medium for the growth of *R. rubrum* which could be adapted to our purpose simply by reduction of its phosphate content.

The dread St. Louis summer was approaching, and to make the new experiment Gest repaired to the Hopkins Marine Station at Pacific Grove, Calif., where facilities had been placed at our disposal. He grew *R. rubrum* in the modified Hutner medium in glass-stoppered bottles. The source of carbon in the medium was the sodium salt of malic acid. When *R. rubrum* breaks down this malate to take carbon, it liberates the alkaline sodium and some carbon dioxide. Carbon dioxide is soluble in alkali; hence it should promptly be dissolved in the liquid. But Gest found that considerable amounts of gas were forming in the stoppered bottles: a thick froth appeared on the liquid. He quickly ascertained that the gas was hydrogen. The organisms were producing about as much hydrogen as carbon dioxide. This was altogether mystifying, for not only had the formation of hydrogen never been observed before during photosynthetic metabolism, but it was known that these bacteria possessed an active system for taking up molecular hydrogen in the presence of carbon dioxide. Although there were large amounts of carbon dioxide in the bottles, free molecular hydrogen was still being evolved.

IN THE AUTUMN Gest and I tackled this mystery in our home laboratory at Washington University in St. Louis. What had begun as a routine project in phosphate nutrition had evolved quite unexpectedly into a totally different sort of research. We dropped the original inquiry in order to investigate the new phenomenon.

We soon discovered that when ammonia salts were used as a source of nitrogen for the bacteria, instead of the glutamic acid of Hutner's formula, hydrogen formation was inhibited. These observations made it easy to understand why hydrogen production had not been noted before in the many researches with cultures of *R. rubrum*. The nitrogen source customarily employed had been ammonia! Our inadvertent substitution of glutamic acid for ammonia, by adoption of Hutner's medium, had been responsible for the discovery of the ability of *R. rubrum* to produce hydrogen photochemically.

We learned that hydrogen production could be supported not only by glutamic acid but by other amino acids and a large variety of carbon compounds. As a test compound for further researches we fixed on malic acid, the acid in apples. We proceeded to try to measure the production of hydrogen and carbon by the bacteria, and for these measurements we used a manometer (a device for recording pressure). The manometer vessel was filled, as is customary, with the inert gas nitrogen. We now experienced our second shock. Organisms which had been producing hydrogen quite vigorously in the usual bottle cultures stopped doing so on being transferred to the manometer vessels. At first we supposed that some contaminant in the nitrogen, probably traces of oxygen or carbon monoxide, was responsible. But after weeks of futile experimentation, involving laborious purification of the nitrogen, we concluded that no contaminating gas could account for the situation.

We finally decided to substitute other inert gases—helium and argon—for nitrogen in the manometer vessels. Now *R. rubrum* resumed producing hydrogen as before! We found further that the addition of a little nitrogen to the argon or helium promptly stopped their hydrogen production. In effect, then, molecular nitrogen appeared to be acting like ammonia with respect to the formation of hydrogen.

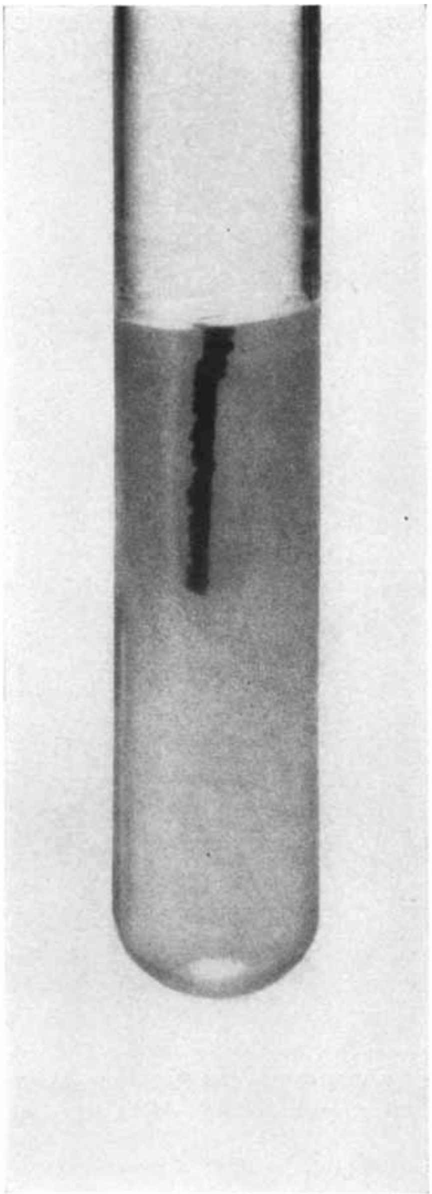
The fact that molecular nitrogen exerted such a profound effect on the metabolism of *R. rubrum* indicated strongly that this organism might fix nitrogen. Further experiments showed it not only might but did! This demonstration immediately generated the suspicion that many other photosynthetic bacteria might possess the same ability. It was known, for instance, that a purple sulfur bacterium belonging to the genus *Chromatium* produced hydrogen in a manner similar to that noted in *R. rubrum*, and hydrogen production appeared to be common to all photosynthetic bacteria.

At the University of Wisconsin P. W. Wilson, in collaboration with R. H. Burris and E. S. Lindstrom, soon confirmed that not only *R. rubrum* but many representative species of photosynthetic bacteria were nitrogen fixers. Nor did the matter end at this point. From the University of Washington in Seattle Esther Duchow and H. C. Douglas sent to Wisconsin certain peculiar microbes which behaved metabolically like non-sulfur photosynthetic bacteria, though they did not resemble such bacteria. These organisms too were found to fix nitrogen.

We may pause in our chronicle at this point to remark on a fascinating historical sidelight provided in a recent article by H. Derx of the Treub Laboratory in Buitenzorg, Indonesia. Derx points out that when the Dutch bacteriologist M. W. Beijerinck discovered *Azotobacter* in 1901 he was struck by the remarkable similarities between his new organism and the photosynthetic bacterium Chromatium. Although Chromatium was not known to fix nitrogen, Beijerinck was strongly convinced that some intimate relationship between Chromatium and his new organisms would be found. We see now that his intuition was solidly based—both Azotobacter and Chromatium are nitrogen fixers. This is a good example of how the intuitions of great researchers such as Beijerinck probe deeper than they originally appear to, and of how discoveries in science rarely fail to cast a shadow before them.

THE SUDDEN emergence of nitrogen fixation in a group of organisms so widely diversified and widely distributed as photosynthetic bacteria stimulated a re-examination of the classification of bacteria. Many of the organisms classified as Azotobacter because of their nitrogen-fixing ability differ from typical Azotobacter species in appearance, in their *p*H requirements, in the types of cultures they form, and so on. Derx, noting the apparently widespread occurrence of the nitrogen-fixing property, argued that nitrogen fixation should not be considered an over-riding criterion for bacterial classification. He proposed that on the basis of morphology and physiology some of these organisms should be classified as a new genus, for which he suggested the name *Beijerinckia*.

The number of bacteria found to be capable of nitrogen fixation steadily increases. At Wisconsin Wilson and E. D. Rosenblum studied Clostridium with sensitive tracer techniques and learned that the old contention that only a few species of this organism could fix nitrogen was untrue; of 15 species examined all but three actually do fix nitrogen. In 1951 F. D. Sisler and Claude E. ZoBell at the Scripps Institute of Oceanography in California obtained evidence of nitrogen fixation by the so-called "sulfate reducers"—organisms belonging to the genus *Desulfovibrio*. These bacteria can thrive only when oxygen is excluded from their environment. They were first isolated by Beijerinck in 1895 from canal mud and soil, and have since been found in marine sediments, in the brine of oil wells at great depths, in the water at the bottom of gasoline storage tanks and in other widely assorted places. They are often blamed for the corrosion of iron conduits, the breakdown of concrete, the destruction of large numbers of fish in the ocean and other damaging activities. These organisms make sulfide, sulfur and organic sulfur compounds as products of their metabolism. The cultures have the odor of bad eggs. Investigating the utilization of hydrogen by these organisms, Sisler and ZoBell incubated the organisms in glass-stoppered bottles of sea water with hydrogen gas in the space over the liquid. They also used a control flask with nitrogen instead of hydrogen in this space. The nitrogen disappeared from the gas phase at a rate which could not be accounted for by solution or diffusion. Growth experiments with molecular nitrogen confirmed that nitrogen fixation was taking place. Thus Desul-



"STAB" CULTURE of nitrogen-fixing *Rhodospirillum rubrum* grows on a nutrient medium in a test tube.

CULTURE BOTTLE is inoculated with *Rhodospirillum rubrum* (*left*). After two days the culture has turned purple (*right*). Gas evolved by the bacteria has forced some of the medium past the stopper of the bottle.

fovibrio turned out to be not such a bad egg after all!

PROBABLY many more nitrogen fixers remain to be discovered. The number already found presents us with a radically altered picture of potentialities in the operation of the nitrogen cycle. The root-inhabiting Rhizobia and other land organisms with which we have long been acquainted undoubtedly play a major role in maintaining the cycle, but it now appears that the oceans also may be vast reservoirs for nitrogen fixation. Possibly the organisms in the seas, including blue-green algae, fix even more nitrogen than do those in the world's soil. A great deal of nitrogen fixation may also be going on in tropical jungles, swamps and lakes. It has long been known that rice fields, for example, may remain fertile for long periods without fertilization. The Indian investigator P. K. De showed in 1938 that certain blue-green algae living in the soil of rice fields in India were very active nitrogen fixers, and concluded that they were probably the main agents in maintaining the fertility of the fields.

This classic demonstration of the importance of the blue-green algae has since been reinforced by work on the physiology and nutritional characteristics of a wide variety of them. These algae, by virtue of being both photosynthetic and nitrogen-fixing organisms, can thrive under conditions that permit no other form of life. That this is so has been shown in a number of instances. They are often the first organisms to colonize areas denuded of life, such as bare rock and soil. Within a few years after the volcanic explosion of Krakatoa in 1883, for instance, the pumice and volcanic ash had been repopulated by these dark green, gelatinous algae. Blue-green algae also are believed to contribute importantly to the production of living materials in fresh water—a fact which harasses resort operators at scenic lakes, which are often covered with profuse growths of noxious "blooms" as a result of the activities of these algae.

In hardiness and physiological versatility the photosynthetic bacteria are comparable to the algae. It may be, therefore, that the fertility of the Indian rice fields is not due solely to the algae, as De suggested, but also in part to photosynthetic bacteria.

Other potential sites of nitrogen fixation are the environments in which the sulfate-reducing organisms like to live. This is not to say that every concrete piling or iron conduit sunk in the earth becomes an inadvertent possible source of agricultural fertilization, but man may very well learn how to take useful advantage of what he learns about the capacities of these organisms.

The discovery that nitrogen can be fixed by so many more organisms than we had suspected opens up exciting vistas. We can look forward to the possibility that we may some day be able to exploit the power of these organisms, just as we have already done with Rhizobia, and so help nature's nitrogen cycle to enrich our earth.

Ω

Kodak reports to laboratories on:

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Information on processing Kodak Blue Base Reversal Films is available from Eastman Kodak Company, Sales Service Division, Rochester 4, N. Y.

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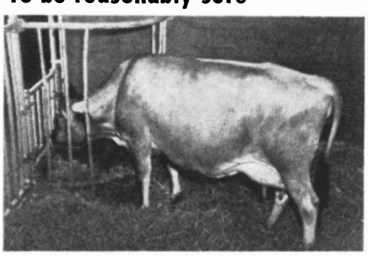


From *Country Gentleman* we have recently learned that one of our products is good for spotting pregnant cows. You permit a urine sample from the bossy in question to stand at room temperature, then add a saturated aqueous solution of *Indophenol Sodium Salt*. If green turns out to be the prevailing color note, rejoicing is in order. This method told the truth 91% of the time in one herd of 136 cows. All we know about it is what we read in *Country Gentleman* (September '52, p. 57).

Indophenol Sodium Salt *is just one of over 3500 Eastman Organic Chemicals. For a copy of our catalog, write Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y.*

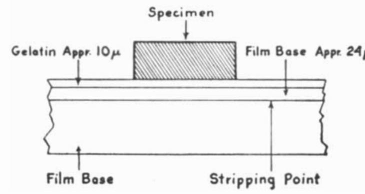
Fast, blue-sensitive plate

It might seem that a panchromatic photographic material should be more sensitive to tungsten light (3000 K) than a "color blind" one that quits with the end of the blue third of the spectrum. Not necessarily so. We make a plate of the latter category that is as fast as our famous Kodak Super Panchro Press Plate—as much as twice as fast for exposure times of the order of several hours. It's the Kodak Spectroscopic Plate, Type 103-0, admired by spectroscopists for its moderate, uniform sensitometric gradient all the way from 2400A to 4400A. Manufacture of these plates has been confined within the ivy-covered walls of our Emulsion Research Laboratory because the plates seemed to be of somewhat academic interest. We couldn't have been wronger. Lots and lots of people want high white-light sensitivity with the convenience of handling by reasonable safelight illumination (Kodak Wratten Series 2) and don't need to preserve tonal relationships in flesh, foliage, and fabrics. To serve them by immediate shipment of a highly uniform product, we have switched Type 103-0 to our regular plate manufacturing department. (They have ivy on their walls too, but their machinery has more capacity.)

Kodak Spectroscopic Plates are sold by the Kodak Industrial Dealer in your area. If he has not already been supplying them to you, your note to Eastman Kodak Company, Industrial Photographic Division, Rochester 4, N. Y., will bring full information and get your shipment moving to your dealer.

Frozen section

Having crowed at left about high photographic sensitivity, we are equally pleased to announce Kodak Frozen Section Stripping Film, which has no sensitivity whatsoever. As diagrammed below, it consists of 10 microns of plain soft gelatin on a 24-micron cellulose acetate film base atop a conventionally thick film base that serves as a strippable carrier until the thick film is removed and the gelatin is stuck to a frozen tissue section in the pathology laboratory. The thin cellulose acetate provides support for the tissue during the slicing stroke of the microtome, so that undistorted sections as little as 5



microns thick may be obtained with no extraordinary manipulative skill from fragile tissues such as fatty tumors, thyroid glands, and lymph nodes. If the gelatin is prestained with thionine or toluidine blue, the stain is transferred to the tissue section quite satisfactorily, giving a finished slide from a CO_2-frozen specimen in about a minute. Photography has nothing to do with all this unless and until a photomicrograph is required. This method is the work of a very famous and versatile friend of ours, Dr. Vannevar Bush, whom you hear about much more frequently as a research administrator, engineer, computing machine pioneer, and philosopher.

Kodak Frozen Section Stripping Film comes in unperforated 35mm strips 25 feet long. To find out about acquiring a roll, write Eastman Kodak Company, Industrial Photographic Division, Rochester 4, N. Y. The paper by Dr. Bush and Richard E. Hewitt, which gives details of the method, appears in The American Journal of Pathology, *1952, XXVIII, No. 5, pp. 863-873.*

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

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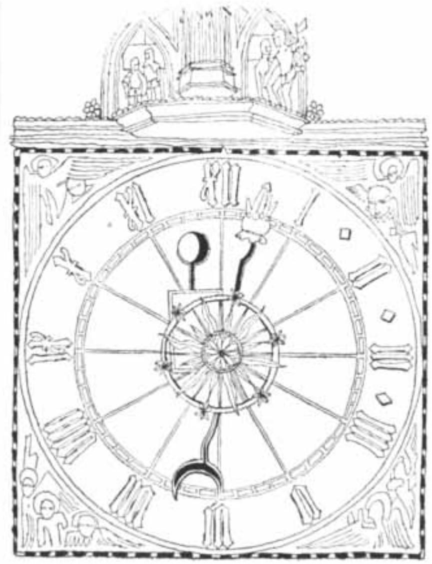
SCIENCE AND



Human Behavior

THE Ford Foundation has announced a new $3.5-million project for the study of social relations and human behavior. The six-year program will be organized around annual meetings at a Center for Advanced Study in Behavioral Sciences. Fifty scholars and scientists will be invited to these meetings for study and the exchange of information. It is expected that in this way the center will cut across the traditional departmental lines of academic research.

A board headed by Frank Stanton, president of the Columbia Broadcasting Company, will appoint a director for the project, select a site for the center and draw up a general policy of operation. Others on the board are Paul H. Buck, provost of Harvard University; F. F. Hill, provost of Cornell University; Clark Kerr, chancellor of the University of California at Berkeley; Robert K. Merton, chairman of the Department of Sociology at Columbia University; Robert R. Sears, professor of education and child psychology at Harvard University; Alan T. Waterman, director of the National Science Foundation and Theodore Yntema, vice-president for finance of the Ford Motor Company.

AEC Report

IN the U. S. atomic energy program the last half of 1952 was marked by the beginning of an enormous expansion in production facilities, long forward strides in nuclear power development, increases in uranium supplies and important "experiments contributing to thermonuclear weapons research," according to the 13th semi-annual report of the Atomic Energy Commission. The report pointed out that former President Truman in his last State of the Union message attributed "high and somber significance" to the November weapons tests at Eniwetok.

The current building program will raise the U. S. investment in atomic energy from $3.5 billion to $7.5 billion. The Commission is spending about $90 million a month on construction—some 5 per cent of the nation's total building outlay. By the first quarter of 1954 AEC construction will approximate 6.5 per cent of the national total.

The big expansion in plant is based on new uranium discoveries and the development of processes for extracting uranium from low-grade ores, says the Commission. Two new sources, South African gold ores and Florida phosphate rock, were exploited for the first time during the latter half of last year. Building of a plant to test extraction methods was begun at Grand Junction, Col.

By the end of 1952 the land-based prototype of the first atomic power plant for submarines had been "substantially completed" by the Westinghouse Electric Corporation, and work was begun on a second reactor, which is to go into the submarine *Nautilus*. A large materials-testing reactor went into service at the AEC testing station in Idaho. At Oak Ridge the first "homogeneous" (circulating fuel) reactor was put into operation; it is an experimental, low-power plant. Design of a ground facility to test nuclear power plants for aircraft was started, and "investigations . . . on aircraft propulsion yielded promising results."

Four groups of private companies that had studied reactor technology concluded that large power reactors "might be built in a few years . . . if weapon-grade plutonium were produced and bought by AEC at Hanford costs." One group is undertaking another year of research and development. A fifth industrial team has begun a year's survey of the power problem.

During the fiscal year ended last June 30 the Commission spent $427 million, about 73 per cent of its budget, on production of fissionable material and weapons, $60 million on reactor development and about the same amount on scientific research.

Among the scientific developments listed in the report:

A new type of cloud chamber, developed at the Brookhaven National Laboratory, can gather as much information in one day as could be obtained in six years with older instruments.

An economical, large-scale separation process now makes possible industrial preparation of single rare-earth elements of high purity.

Element 85, astatine, has been discovered in nature as a decay product of actinium. Until now it was known only as an artificially prepared element. Its half-life is 48 seconds.

Low-level irradiation of fruit flies increases their mutation rate but, contrary to expectations, results in a healthier population than the wild one from which the experimental group is taken.

The final section of the report is devoted to a discussion of weapons testing in Nevada. In describing the effects of a nuclear explosion the report gives a detailed account of a "nominal burst"—an explosion with the power of the Hiroshima bomb. At a distance of six miles the flash from the detonation is 100 times brighter than the sun; it can temporarily blind anyone who looks at it from as far as 30 miles away. Within a second after the explosion the "fireball" of incandescent air, built up to its maximum size of 450 feet, starts to rise like a balloon. In 10 seconds the fireball dies out and the mushroom cloud has begun to form. Thereafter the radioactive cloud slowly disperses over considerable distances. Explosions in Nevada are set off only when weather forecasts show that the cloud will not be blown directly over nearby inhabited areas. The Commission has set up an elaborate country-wide monitoring system to measure the radioactive "fall-out" from the explosion clouds. It reports that from the 20 nuclear explosions thus far set off in this country "no person has been exposed to a harmful amount of radiation fall-out," nor has a hazardous amount of radioactivity accumulated in the soil or in water supplies.

Reactor Information

COULD the Atomic Energy Commission safely release enough information on reactors to allow U. S. industry to develop a general atomic power program? J. G. Beckerley, director of classification for the Commission, discussed this question in a recent issue of *Nucleonics*.

Beckerley pointed out that to design reactors engineers would need "almost all reactor information," including such matters as the structure of fuel elements, the geometry of the reactor core, corrosion of fuel and means for preventing reactor failure. Any of these disclosures might fill a gap in the knowledge of engineers of other countries. Certain "fast-reactor data" might even reveal secrets about atomic weapons. The mere disclosure of the AEC's cost per gram of plutonium would provide information on how much weapons material the U. S.

is producing. "Knowledge of manpower and electrical power requirements, as well as capital costs, for any production site provides a good index to production costs. From the unit cost, production quantities are then readily deduced." Further, telling how to run a reactor to make "weapon-grade" material would reveal information about atomic weapons.

Beckerley suggests, however, that to permit industrial management to decide whether it wishes to undertake atomic power projects, it might be sufficient to declassify certain needed information that does not involve the design of the reactor itself.

Chemistry, Inc.

THE U. S. chemical industry is undergoing an expansion which by 1955 will make it two and a half times as large as it was in 1940, reports the Manufacturing Chemists' Association. Between 1940 and 1950 it added $8.5 billion to its plant investment, and it is halfway through a further $6 billion expansion which will create about 200,000 new jobs. The major part of the growth has been in plastics, synthetic fibers, detergents and agricultural and medicinal chemicals. Some of the large current projects are: an $88-million nylon fiber plant, a $66-million polyethylene plant, a $44-million antiknock fluid plant, a $30-million synthetic ammonia plant.

The center of chemical manufacturing is shifting from the Eastern seaboard to the South and West, reflecting the increasing importance of petroleum and natural gas as raw materials. For every dollar being spent on expansion in New England, for example, 23 are being invested in the Southwest.

Visas and Meetings

WITHIN recent months the U. S., partly or wholly because of its visa policy, has lost five international scientific meetings, according to a report by the President's Commission on Immigration and Naturalization. They were the International Congress of Psychology, the International Congress of Genetics, the International Astronomical Union, the International Federation of Documentation and the International Physiological Congress.

The President's Commission noted that temporary visitors, even if they are to be in the country only for a few hours, "must satisfy substantially all the health, financial, security and other requirements that apply to permanent immigrants." It agreed with the Manchester *Guardian* that: "This visa business is doing the U. S. incalculable harm and is undoing all the lavish propaganda about its noble leadership of the free world."

The same note was sounded at the recent annual meeting of the American Physical Society, which adopted a reso-

lution saying in part: "In the past few years the progress of American physics has been impeded by U. S. visa and passport restrictions. . . . The personal exchange of ideas and the collaboration with foreign scientists are essential sources of information and ideas which cannot be replaced by written correspondence or by the study of foreign publications. The present restrictions . . . are cutting deeply into this important source of our scientific production. . . . Had similar regulations been in force prior to 1942, it is questionable if the U. S. would have developed the atomic bomb or have made great advances in radar. . . . This loss to the U. S. is not compensated by any gain in the security of classified information, since the meetings from which the visitors are excluded are open scientific meetings on unrestricted subjects. . . . The Council strongly urges a more realistic approach by our government to the problem of travel restrictions, to the end that free scientific interchange shall not be impeded."

Expanding Universe

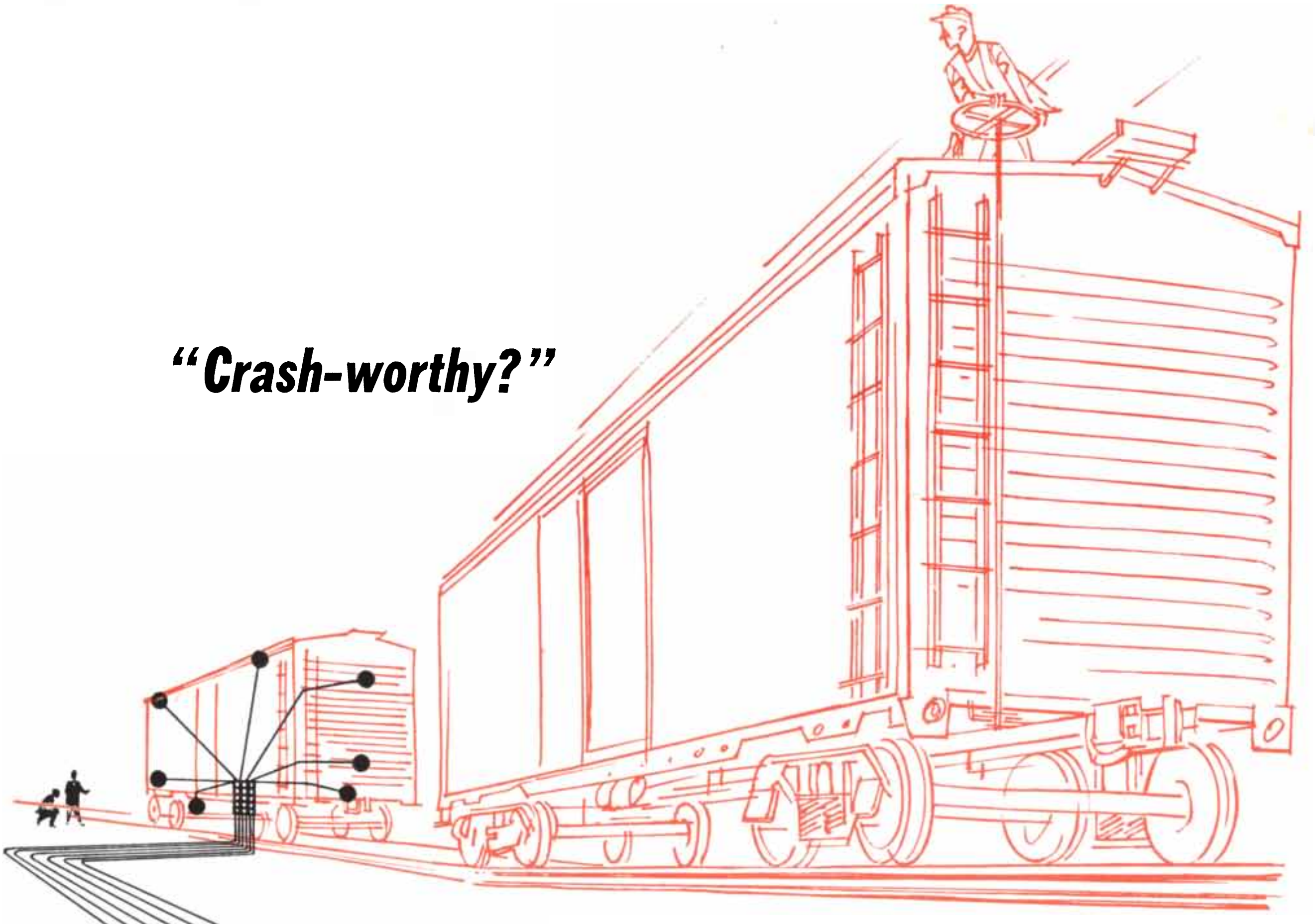
THE universe may be twice as large, and twice as old, as astronomers have supposed, Harlow Shapley of the Harvard College Observatory told a recent meeting of the American Astronomical Society. He and astronomers at the Mount Wilson and Palomar Observatories now believe that the yardsticks they have been using to measure space are incorrect.

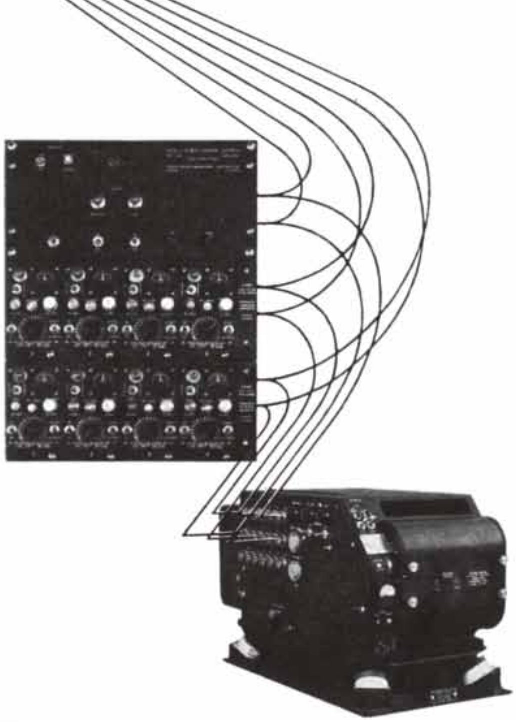
With the 200-inch telescope on Palomar Mountain Walter Baade has lately determined that the Great Nebula in Andromeda is about twice as far from us as used to be thought. Shapley's estimate arises out of recent accurate measurements of the brightness of the Magellanic Clouds, a pair of small galaxies in the southern sky formerly believed to be about 75,000 light-years from us. The measurements indicate that certain aggregations of stars in these clouds are globular clusters of the same type as those in the Milky Way. If their clusters are as bright as those in our own galaxy, they must be twice as far away as had been thought. That would mean that all the distances between galaxies must be doubled. If every galaxy is twice as far away as we had thought, it must also be twice as big.

As a consequence the Milky Way, which was supposed to be an exceptionally large galaxy, would be about the same size as the Andromeda nebula and many other galaxies. This is a relief to astronomers, who have been unable to see any reason for the local galaxy's being a giant freak.

The new estimate would clear up another discrepancy. On the basis of the universe's rate of expansion, it has been estimated to be about two billion years

"Crash-worthy?"





Pre-check with Consolidated Instrumentation

WHAT happens to structural members and car-body components when freight cars are subjected to the shock impacts and buffeting of hump-yard switching?

To determine stress distribution and to evaluate the effectiveness of shock protection devices, the Pullman-Standard Car Manufacturing Company selected a Consolidated 5-114 Recording Oscillograph, System D Amplifiers, and Bridge Balance as basic recording instruments.

Freight cars, loaded with sand and steel blocks at gross weights ranging from 46,400 pounds (empty) to 164,000 pounds (fully loaded) crashed together 185 times at speeds up to 10 miles per hour.

In this way the dynamics of simultaneous shocks, some as brief as one five-thousandth of a second, were permanently recorded in visual form. From such data will come design changes, giving protection against shock and vibration damage. Thus an improved product is achieved.

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Dynamic Recording Systems

such as the one shown here are designed and manufactured by Consolidated. Variations in the arrangement of the equipment are infinite. Applications are widely varied throughout industry and the sciences. A typical recording system includes pickups, amplifiers or bridge balances, and a recording oscillograph. Write for Bulletin CEC 1500B-X8 old, whereas geological evidence indicates that the earth is over three billion years old. The revised estimate of the universe's size would increase its age to four billion years.

Big Stars

SPEAKING of sizes, radio astronomers have just succeeded in measuring some of the radio stars, those large objects in the sky that cannot be seen but give evidence of their existence by broadcasting radio energy (*see* "Radio Stars," by A. C. B. Lovell; SCIENTIFIC AMERICAN, January). Their size cannot be measured with radio telescopes. Now R. Hanbury Brown, R. C. Jennison and M. K. Das Gupta at the Jodrell Bank Experiment Station in England have developed a new interferometer, using two antennas that feed into separate receivers connected by a radio link, which makes it possible to place the antennas as far apart as two and a half miles. With this instrument they have measured two of the strongest radio stars, the ones in Cygnus and in Cassiopeia, and found that they are several times larger than the full moon, thousands of times larger than visible stars.

Harnessing Sunlight

A CHEMICAL reaction that uses light energy to convert water into an explosive mixture of gaseous hydrogen and oxygen has been discovered by Lawrence J. Heidt of the Massachusetts Institute of Technology. Heidt and his collaborators are hopeful that the reaction, so far demonstrated only in the laboratory, can be developed into a large-scale process for turning sunlight into chemical energy.

The method employs a solution of the rare-earth element cerium. Cerous ions (plus-three valence) in the solution absorb light energy, react with water, are oxidized to ceric ions (plus-four valence) and release hydrogen. Ceric ions also absorb light, and in so doing are reduced to the plus-three state and release oxygen. Thus a mixture of ceric and cerous ions under the action of light will jump back and forth between the two states and go on releasing hydrogen and oxygen.

Heidt and Alan F. McMillan, describing their experiments in a recent issue of *Science*, said their laboratory trials had converted only one tenth of 1 per cent of the absorbed light into chemical energy. When the details of the reaction are better understood, however, Heidt sees "no obvious reason" why the efficiency cannot be increased enough to make the method economically important.

Machining by Photography

A NEW kind of photosensitive glass, which acts like a photographic emulsion and can be "machined" into

intricate shapes by exposure to ultraviolet light, has been developed by the Corning Glass Works. It is described by S. D. Stookey in *Industrial and Engineering Chemistry*.

The glass is a lithium silicate containing traces of cerium and silver as photosensitive ingredients. On exposure to a pattern of ultraviolet light the cerium and silver particles form a latent image throughout the glass, and the image is developed by heating the glass to about 1,100 degrees for about an hour, then putting it in a bath of hydrofluoric acid, which dissolves the exposed portions.

Using stencils, Corning engineers have made all sorts of complicated patterns in this glass; they have perforated some glass plates with thousands of tiny holes per square inch. The holes can have any cross-sectional shape, and they can be tapered to any angle by means of converging or diverging beams of light.

Stookey believes that the new process will prove useful in electronic and chemical equipment. He also suggests that such glass plates may be superior to metal plates in photoengraving. Unlike metal, the glass can be etched deeply on the lines of the image, without dissolving laterally.

Polio Vaccine?

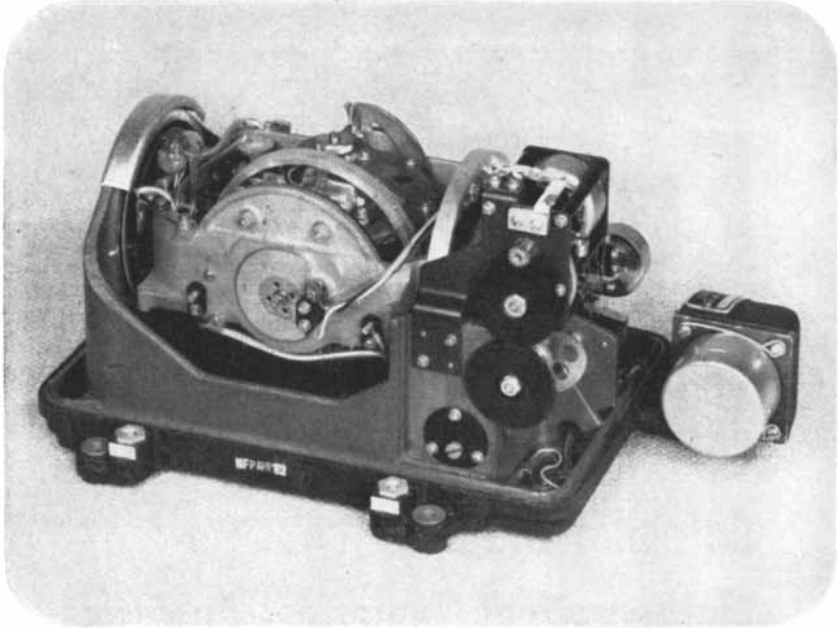
"TREMENDOUS progress" toward a safe and effective vaccine for poliomyelitis was announced last month by the National Foundation for Infantile Paralysis. Several laboratories working under March of Dimes grants have produced vaccines which in trials on experimental animals and a small number of human subjects have given immunity to all three types of polio virus.

The preparations contain viruses inactivated by treatment with formalin. The viruses are grown in cultures of nonnervous tissue, hence there is no danger that the vaccines will cause allergic encephalitis. The formalin-weakened viruses are injected together with "potentiating" mineral oil, which strengthens their ability to evoke the formation of antibodies.

Field tests of the new vaccines may be started this year. Meanwhile the foundation plans to use gamma globulin more extensively in combatting severe epidemics. Only about a million doses will be available, however. The Foundation intends to buy about half of this supply for distribution through an allocation board appointed by the National Research Council.

Fossil Virus

A SET of old test tubes mislaid some 35 years ago was found recently in a laboratory housecleaning at the University of Michigan, and the investigator who had lost them discovered to his as-



tonishment that viruses he had cultured in them were still alive.

The microbes were a deadly but unidentified strain of rat virus which Frederick G. Novy, a student of Louis Pasteur and one of the first U. S. bacteriologists, discovered in 1909. Novy kept his virus alive for 10 years by transmitting it from rat to rat. During a change of laboratory personnel in 1919 all the test animals were allowed to die, and nothing was left of the experiment but a few test tubes of dried blood containing the virus. Later the test tubes were lost.

When the test tubes turned up recently in a dusty corrugated box, they were taken around to Novy, now retired. Recognizing them as part of the long-abandoned virus experiment, he had the tubes and their contents ground up, glass and all. A salt solution was added and the filtrate was injected into five sets of rats. Three quarters of the rats died. Novy thereupon came out of retirement to continue his study of the killer. He has now obtained a look at it under an electron microscope—an instrument invented years after he stopped work with this virus.

First Americans

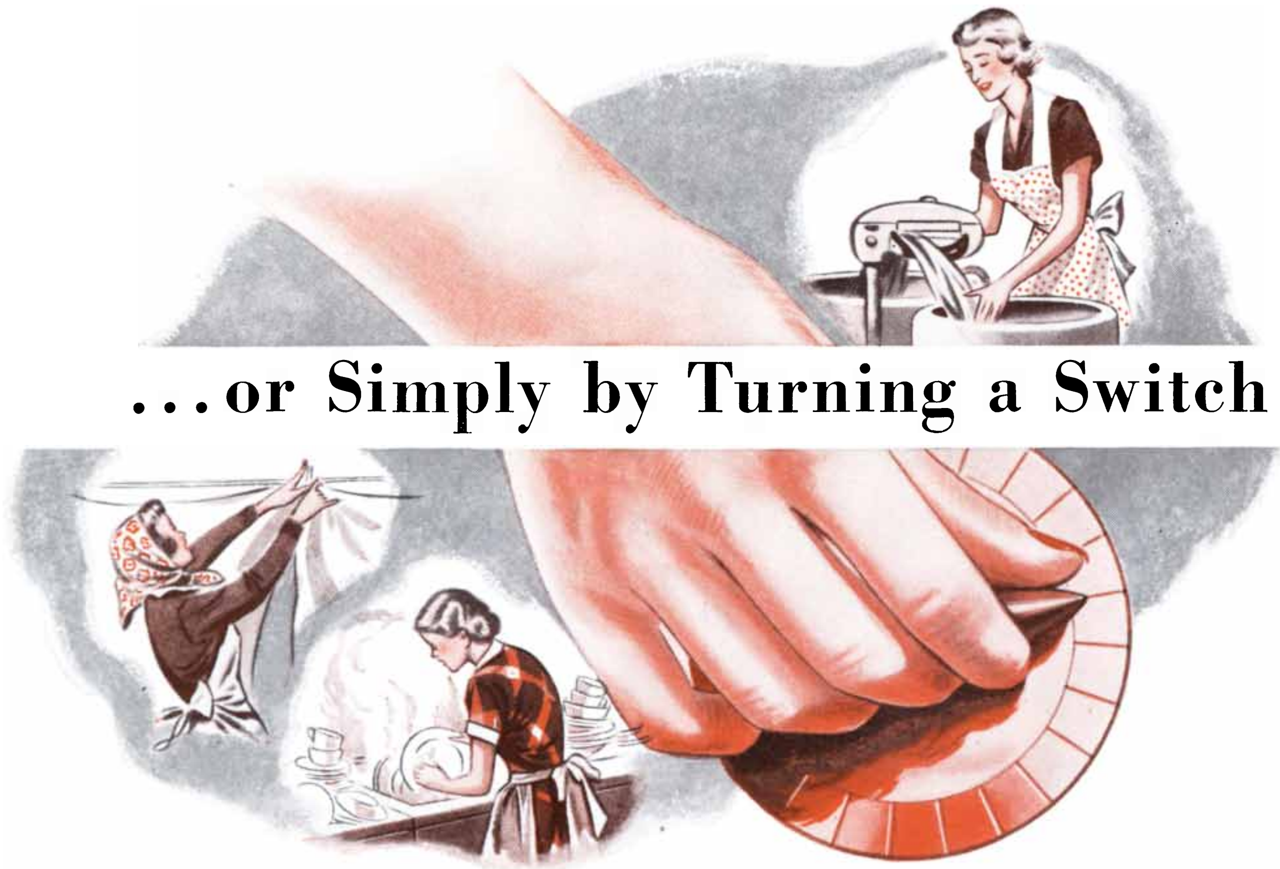
ARCHAEOLOGISTS in the U.S., who have been firmly convinced that man first set foot in America no more than 20,000 years ago, received a shock last month. George F. Carter, chairman of the Isaiah Bowman School of Geography at the Johns Hopkins University, said he had evidence that human beings have been in the Western Hemisphere at least 100,000 years.

The oldest signs of man found in North America have been stone tools unearthed at Folsom, N. M., and other places. They are some 10,000 years old, and most archaeologists have agreed that man probably arrived in America from Asia by crossing the Bering Straits on foot the last time they were dry, at the end of the fourth ice age some 10,000 to 20,000 years ago.

Carter now has discovered artifacts which he believes are much older. In gravel pits and a road cut near the coast at San Diego, Calif., he unearthed some rough-cut stones with, he says, sharp edges such as are never made by natural processes. His specimens were embedded in soil denoting a humid, glacial climate and in a terrace formed during the third interglacial period, which ended 100,000 years ago.

Carter observes that man could not have crossed the Bering Straits on foot during the third interglacial, because the waters were too high, and he surmises that the time of arrival may have been at the beginning of the third ice age, when the sea had receded enough to open the road and the climate was still mild enough for men to survive. That was about 400,000 years ago.

. . . or Simply by Turning a Switch



WHEN your wife turns on her automatic washer or dryer and heads for town, it's the timer switch that takes over the job of directing the work. It's the same way with your dishwasher. The switch handles the work . . . you catch an earlier show.

Yet, it was only a few years ago that the Mallory Timer Switch was introduced . . . the first mechanical brain that was small enough and smart enough to make these labor saving devices a reality. It packed into one small control, a unit that automatically directs the long, complicated series of washing and drying operations. It performed with such dependability that appliance manufacturers could assure users of trouble-free operation, year in and year out.

End of the story? No, indeed! Other Mallory switches control the fuel tank booster pumps on airplanes. They permit truck drivers to shift gears automatically—at the touch of a button. Heavy industrial motors can be switched quickly from one voltage to another. These are just a few of the ways that Mallory switches make everyday jobs easier. They are used for starting, timing, controlling, opening, closing and stopping a wide variety of devices.

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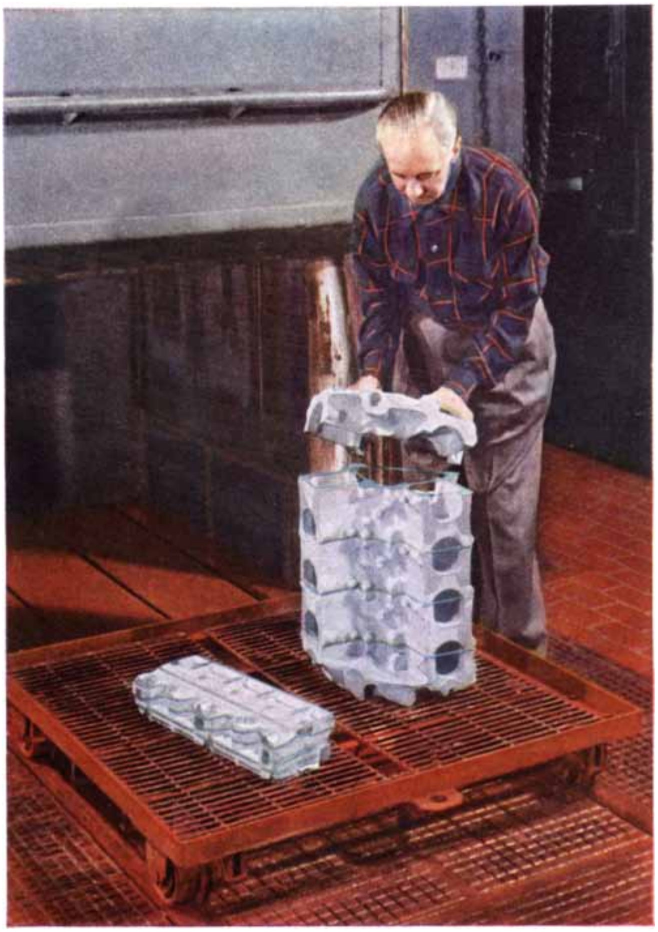
WE'RE CASTING IN SECTIONS



Why do a race-driver's eyes light up when he talks about aluminum engine blocks and heads? "Sweet, cool running . . . improve high-compression performance . . . the engine weighs 150 pounds less."

For these reasons, auto makers have wanted to use aluminum blocks and heads in passenger cars. But costs have been too high. So, it was big news to the industry when we said, "We have a new way to make aluminum blocks. The cost—slightly higher than iron ones!"

Engineers in our Development Division knew that the water passages in engine heads make casting expensive. Delicate, intricate cores are used to form these holes (Fig. 1). They often break. Frequently, they shift as the molten metal is poured around them. This ruins the casting.

Our idea was to design an engine in sections . . . like a sliced loaf of bread (Fig. 2). These small castings would be easier and less expensive to make. Then we would stack them up with

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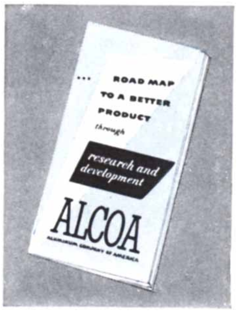
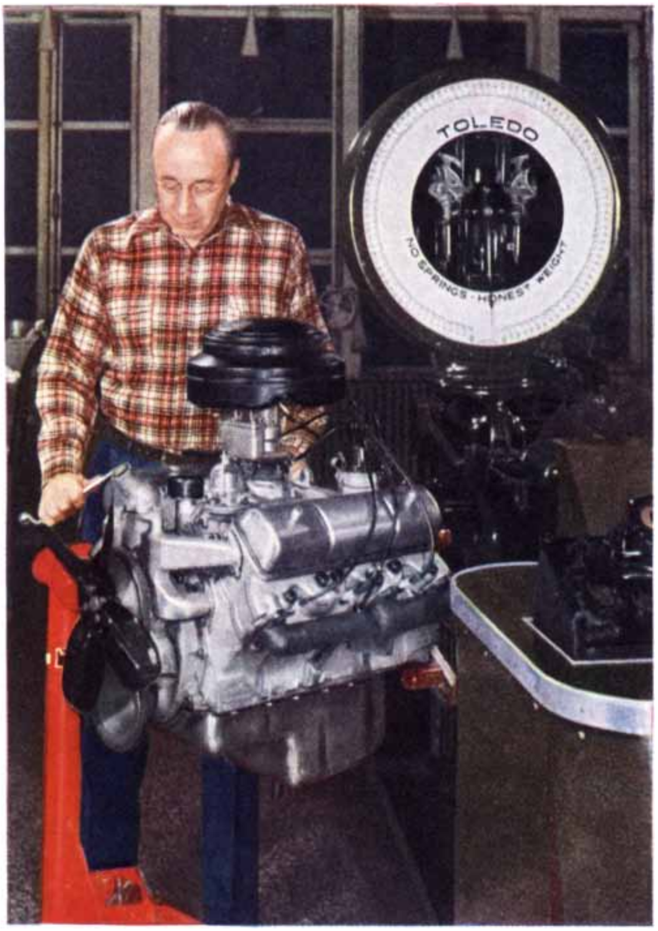
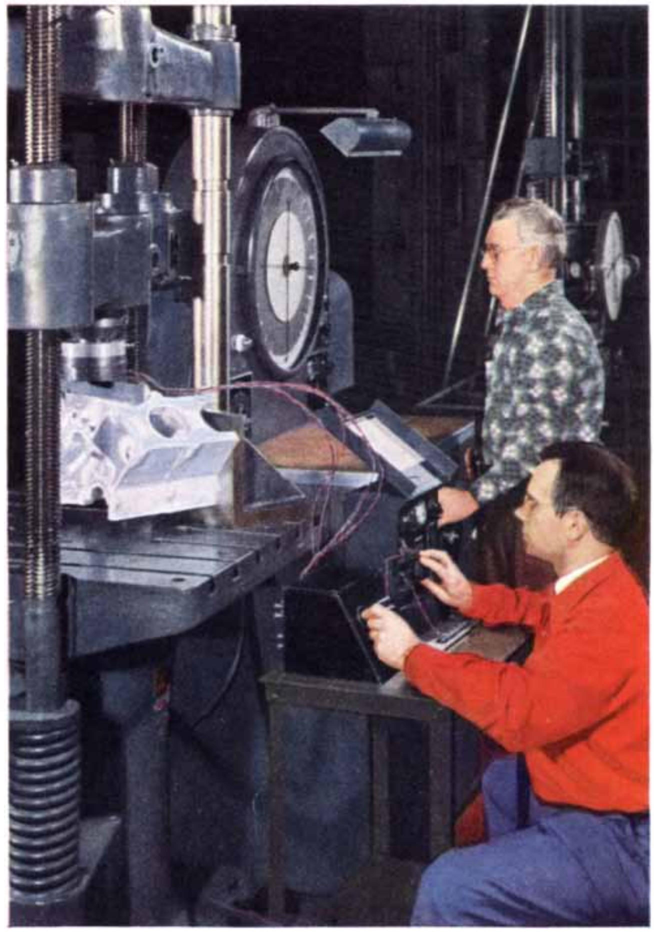


ENGINE HEADS OUT IN CLEVELAND





gaskets of brazing metal between.

A pass through a brazing furnace and presto, the casting would fuse into a complete head. No cores. No rejects. No clogged passages.

Putting the idea to work wasn't that easy. Alloy selection took time. Brazing temperatures were tricky. Even when we got sound castings, our job wasn't finished.

Perhaps the castings were too strong in some places, too weak in others. To find out, we coated them with brittle lacquer and assembled a complete engine (Fig. 3). We loaded it until the lacquer cracked and showed where stresses lurked. Castings were tested on tension-compression machines, using electric strain-gages to duplicate the pressures of actual operation (Fig. 4). Shaving a little metal here—adding a little there—we made the castings still stronger, more efficient.

The engines are now on test. Reports are downright spectacular.

MORAL: This problem has something in common with your product or process . . . the *way* it was solved. Did you notice that it was divided into four parts? First, the *Alcoa engineer* with automotive experience knew the problems of the industry. Then basic *Alcoa research* suggested alloys and procedure. *Alcoa testing equipment* proved the theories of basic research—made further refinements. Lastly, *Alcoa's process development labs* suggested ways to mass produce it.

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What Is Pain?

It is surprisingly difficult to answer the question because the perception of injury involves a subtle blend of physiological and psychological factors

by W. K. Livingston

EVERY FEELING person knows from personal experience what pain is, yet scientists have found it extraordinarily difficult to agree on a satisfactory definition for it. The question is not a metaphysical one. It has profound bearing on the search for ways to relieve pain and on basic human fears. Probably no subject in medical science interests people more than this one. They like to hear about new anesthetic agents, analgesic drugs and nerve operations to control pain; about "pain clinics" for the study of rare pain phenomena; about laboratory investigations of the physiology and psychology of pain. And pain is one of their chief concerns when they go to the doctor. They frequently question their physicians about the pains of cancer, heart disease and other feared maladies. They ask about their own immediate pains—how long they will last, how much worse they can get. In particular, they ask about the pain of dying.

There can be no definite answers to such queries until we learn the answers to certain more specific problems. The most penetrating questions about pain come from children rather than adults. A child's fear of the unknown is closely coupled with his experiences of pain. Whenever he has to face some new ordeal, his invariable query is, "Will it hurt?" If he sees some person with a disabling injury, he tries to imagine how it would feel to have the same injury. He wants to know how much it hurts to break a leg, to have a tooth pulled, to undergo a surgical operation, to be wounded in battle. His sympathy goes out spontaneously to injured people and injured animals. It even extends to inanimate objects to which he ascribes a personality. His curiosity about pain is insatiable. He wants to know how much it hurts a fish to be caught on a hook or to flop around in a boat, and he may even insist that the writhing of an angleworm impaled on the hook is evidence of great pain.

Naive as the child's questions may sound, they are fundamental. Transcribed into more formal terms, some of them might read: How far down the scale of animal life is there a conscious perception of pain? Are an animal's reactions to injury an accurate measure of pain? Is physical pain ever devoid of psychological factors? Can human pain be measured objectively? Why do certain emotional states make pain more tolerable, while others make it worse? Is pain compatible with unconsciousness? Does an anesthetic agent abolish pain or does it merely erase its memory? How often is death painful?

It is doubtful that these questions will ever be answered by anything better than speculation or personal opinion until there is some agreement as to what pain is. I have used the question, "What is pain?" for my title because I believe its answer is fundamental to understanding the phenomenon and is the only basis on which one can build his own philosophy about it.

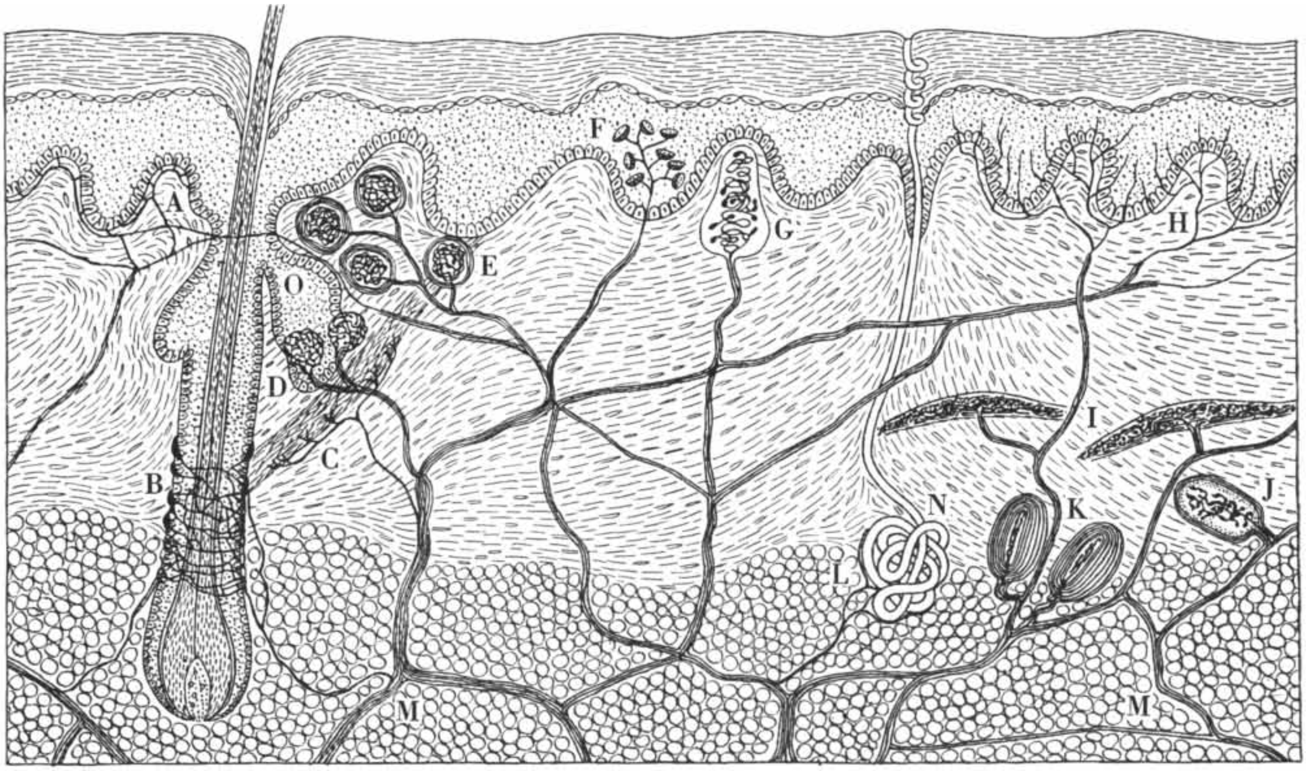
Injury without Pain

First let us consider a couple of specific cases to clarify the nature of the problem. A young woman is giving birth to her first baby. Her labor pains have become so severe that her obstetrician orders an anesthetic. She is given just enough to keep her in a state of "analgesia," meaning that she feels no pain but remains conscious. In this condition the woman ceases to complain about her pains or else talks about them in a dispassionate fashion, in spite of the fact that the force of the uterine contractions is steadily increasing. She answers questions and carries out the requests of the obstetrician in lending her assistance to the delivery of the baby. The only signs that she is not fully conscious may be a slight slurring of speech and the uninhibited nature of some of her remarks. A casual observer would say that she is mildly drunk. The remarkable feature of her analgesic state is that her pain perception should be so profoundly depressed while other perceptions and the "thinking" part of her brain are still functioning. When the delivery is over, she reports that under the anesthetic she felt no pain. That settles the matter for her, but it does not answer the observer's question of whether or not pain was present. We can see the problem more clearly by imagining what would have happened to this woman if the anesthetic had been deepened.

With just a slight increase in dosage the woman might have entered a state of excitement in which she was practically unconscious but the body would make heroic efforts to escape the stimulus. She would scream and struggle each time her uterus contracted. She would no longer cooperate with the obstetrician and her talk would become incoherent. If the anesthetic were further deepened, she would stop talking and struggling, but each contraction of the uterus would be accompanied by a rise in her blood pressure, a quickening of the heartbeat and other physical responses. A light touch on the cornea of her opened eye would make the lids twitch. If the anesthetic were deepened still more, these body responses would disappear one by one in an orderly sequence. Finally, the vital centers controlling the heartbeat and respiration would become depressed and her heart and breathing would stop, though for a brief time her nerves might still be capable of transmitting sensory signals. She would not yet be "dead," for strenuous measures might revive her, but after some minutes all possibility of resuscitation would be gone.

At what particular stage in this progression from complete consciousness to death did her pain disappear? Was it after the first few whiffs of the anesthetic, after her complaints of pain ceased, after she stopped struggling, after the disappearance of her corneal reflex, after the cessation of her heartbeat or only after she was irretrievably dead?

The second case presents a similar question under different circumstances. A fisherman is sitting in one of a line of boats stretching from one sand spit to another at the mouth of a river. He suddenly feels a smashing strike, and as he lunges back to set the hook, a large salmon breaks out of the water, shaking the hook in its mouth. He realizes that his best chance for landing the salmon



NERVE ENDINGS in the skin are the receptors of touch, heat, cold and pain. These and other structures are labeled as follows in this schematic drawing of a microscopic cross section of the skin: A indicates free nerve endings; B, nerve endings around a hair follicle; C, sympathetic nerve fibers supplying a small muscle; D, Ruffini's endings; E, Krause's end bulbs; F, Merkel's disks; G, Meissner's corpuscles; H, free endings; I, Ruffini's endings; J, Golgi-Mazzoni endings; K, Pacinian corpuscles; L, sympathetic fibers innervating a sweat gland; M, nerve trunks; N, sweat gland; O, sebaceous gland. The function of each type of ending is not known.

lies in getting ashore before his line runs out or becomes entangled with the lines of other fishermen in the neighboring boats. Fighting the salmon as he goes, he starts crossing from boat to boat to reach the spit. Once there, he runs far out on the beach and after a hard struggle lands his salmon. As he winds up his line, he looks down and sees that the wet sand under his right shoe is reddening. Then he notices a long rent in his trousers and is surprised to discover a deep cut in his leg. By the time he has improvised a dressing for this wound he has found other injuries: skin scraped off three knuckles, a friction burn on his right thumb and two massive bruises on his left thigh. He realizes that these injuries must have been sustained while he was crossing the line of boats. Yet he cannot recall having felt the slightest pain at the time.

There is nothing particularly unusual about this incident: people often are injured in battle or automobile accidents without being aware of it until afterwards. I have selected this case because the man was not dazed or in shock. He says he had "no pain." I would agree with him. I am unwilling to call anything pain unless it is perceived as such. In my opinion the woman in childbirth had no pain of any consequence after the first few whiffs of anesthetic.

The two cases make plain the fact that to resolve the issue we need a clear-cut decision as to what we mean by the words "pain" and "perception." One reason pain is so difficult to define is that it has so many different aspects. The word is derived from the Latin *poena*, meaning a penalty or punishment. The ancients thought of pain as something inflicted by the gods on anyone who incurred their displeasure. There is an echo of that attitude in the common lament: "What have I ever done that I must suffer this way?" The interpretation of pain varies with the point of view of the investigator or the sufferer. To the sociologist pain and the threat of pain are powerful instruments of learning and social preservation. To the biologist pain is a sensory signal which warns the individual when a harmful stimulus threatens injury. To a man with an incurable cancer, pain is a destructive force: his suffering began too late to serve as an effective warning and it did not stop after the warning had been given. To the physiologist pain is a sensation like sight or hearing, but he tends to ignore its conscious, perceptual aspects, because consciousness has, as yet, no physiological equivalents; one might say that he is studying the pain "signal." To the psychologist, on the other hand, the important thing about pain is the brain's translation of the signal into a sensory experience. He finds pain, like all perceptions, to be subjective, individual and modified by degrees of attention, emotional states and the conditioning influence of past experience.

To the layman the sensation of pain, which he has known all his life, seems a perfectly straightforward, noncontroversial matter. "Hot" and "sharp" were among the first words he learned; his earliest memories are associated with the pain of accidental injury and of parental discipline. When he was hurt, he struggled and cried out. He accepts these reactions as the natural manifestations of physical suffering. Experience has taught him that many different kinds of stimuli can cause pain, even those, such as heat, which are distinctly pleasant in moderate intensities. All parts of his body are sensitive to pain and he assumes that other people are equally sensitive. He knows that pain is caused by physical injury and believes that its intensity is proportional to the force of a blow, the heat of an iron or the depth of a wound.

This concept of pain as a physical quantum, measurable in terms of stimulus intensity or the body's response to injury, is a reasonable everyday interpretation. But there are many situations where it does not apply. Bullet wounds are usually painless, partly because the impact of the missile can temporarily paralyze nerve conduction. Superficial wounds usually are more painful than deep ones, because the skin is much more richly supplied with sensory nerve endings than are the deeper tissues. The internal organs can be cut, crushed or burned without causing the slightest distress. Then also there are enormous individual variations in sensitivity to pain. At one extreme are patients with such conditions as causalgia, facial neuralgia or postherpetic pain—conditions in which the skin becomes so sensitive that the lightest touch or even a breath of air precipitates an acute exacerbation of pain. At the other extreme are those unfortunate children who are constantly injuring themselves because they were born without the normal susceptibility to pain. Such a child may lean casually against a hot stove without showing signs of distress.

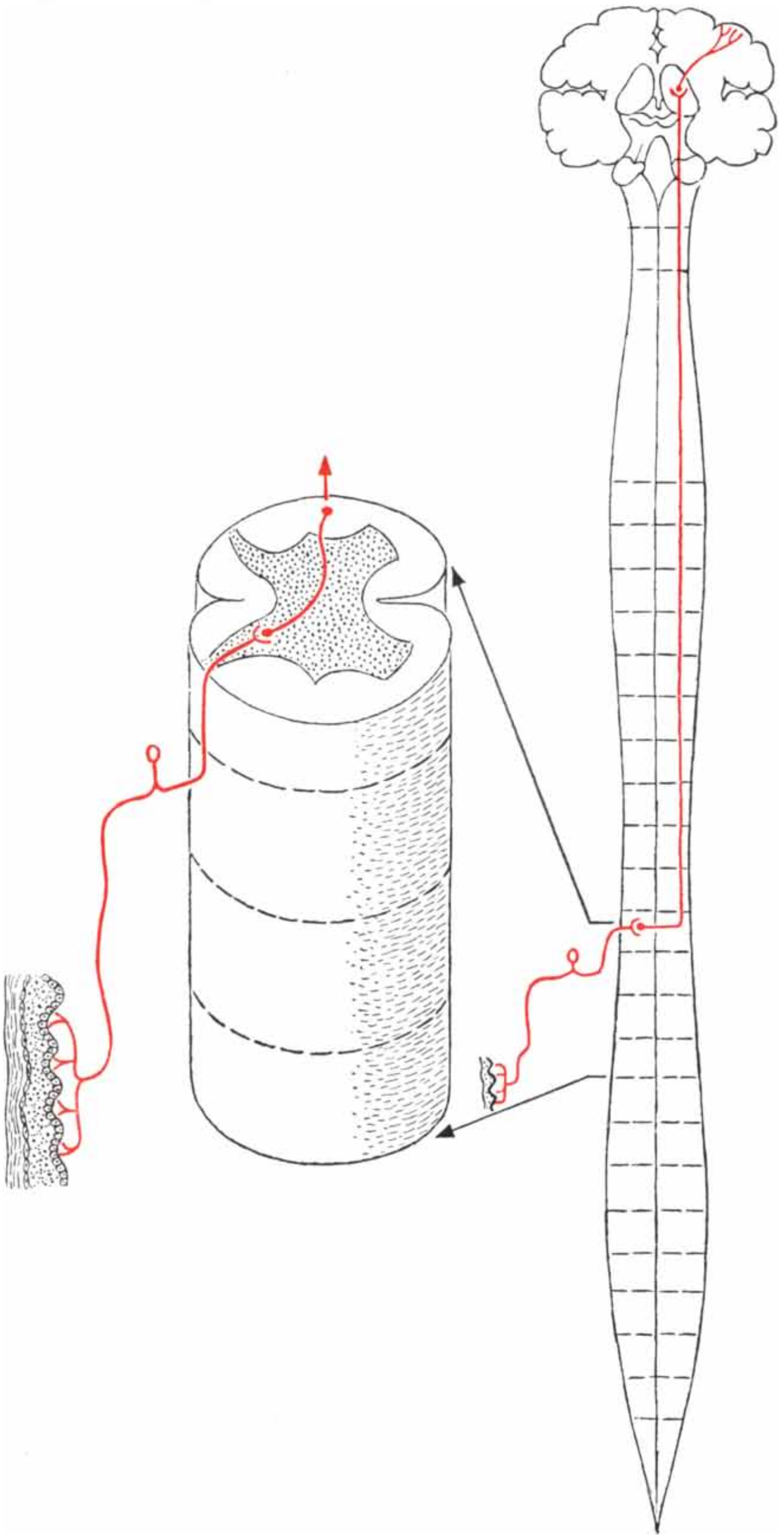
In the majority of instances pain *is* proportional to the injury. Therefore we are surprised when it differs noticeably from what we would have expected. We wonder why some insignificant-looking scar should give severe pain, or why a serious injury is not noticed in the excitement of an automobile accident. We attribute such exceptions to "psychic" causes and wish we had some reliable objective method for measuring pain.

A Scale of Pain

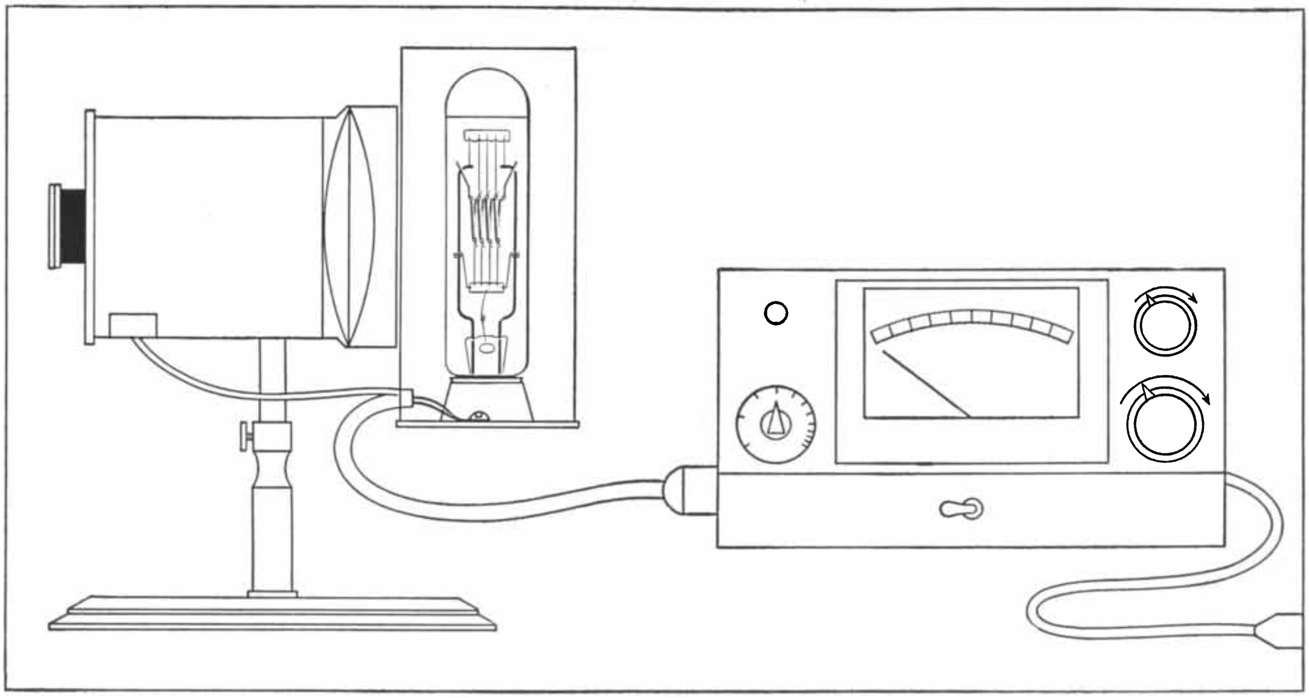
Attempts have been made to develop an objective scale of pain in terms of stimulus intensity. The stimulus used for eliciting pain may be an electric current, heat or some kind of pressure. These experiments show that most normal people have about the same threshold for pain. For instance, the average normal person begins to feel pain when heat applied to the skin reaches around 220 millicalories per square centimeter per second. For most people the threshold is within 5 per cent of that figure. This amount of heat will redden the skin after repeated tests, and it is close to the level of heat at which cells are irreversibly damaged.

Although people are fairly uniform in their perception threshold, they vary greatly in their tolerance of pain—that is, the amount of heat above the threshold that they will bear before pulling away from the testing instrument. A stoical person may endure heat which actually burns the skin. Once this burning point has been passed, the pain actually lessens, even though the heat level is raised, because the burning process destroys the sensory fibers in the skin, and the deeper tissues have fewer such fibers. Thus one might call the burning level the pain "ceiling."

In one method for measuring pain the levels of stimulus intensity between the threshold and the ceiling have been divided into 10 equal steps, called "dols," from the Latin *dolor*, meaning pain. This "dol scale" in the hands of experts has proved of some value in testing the efficacy of analgesic drugs, since it pro-



NERVE PATHWAY from the skin to the brain is shown in this schematic drawing. On the right side of the drawing are the spinal cord (here exaggerated in width) and the brain. The first nerve conducts an impulse from the skin to the spinal cord, a second conducts it up the spinal cord to the thalamus, and a third conducts it from the thalamus to the cerebral cortex. The detail drawing at the left shows how the first nerve cell enters the gray matter of the spinal cord and the second crosses the spinal cord.



DOLORIMETER is designed to measure the intensity of pain. It consists of a projector (*left*) which focuses the heat of a 500-watt lamp on a small area of skin, and a unit (*right*) with which the intensity of the heat radiation can be controlled and measured. The projector also has a shutter to control time of exposure.

vides a rough measure of the ability of a given drug to raise the threshold for pain perception. But the method is unreliable when attempts are made to measure human pains or to use test subjects who have not had intensive training in sensory discrimination. There are too many sources of error in the measurements and too many psychological factors involved to permit anyone to claim that this instrument truly measures pain. Even with trained subjects a placebo or some other form of suggestion may raise the pain threshold almost as much as does an analgesic drug.

Every thoughtful person will agree that the intensity of pain is not always proportional to the stimulus. He remembers injuries of his own that went unnoticed in the excitement of a fight, a competitive game or a serious accident. He may recall a toothache that seemed intolerable during the night when no help was available but which had almost disappeared the next morning when he reluctantly climbed into the dentist's chair. Nor are body responses reliable indices of pain. A dog will yelp and struggle as wildly from fear as from physical injury. The flopping about of the body of a decapitated chicken cannot mean that it suffers pain.

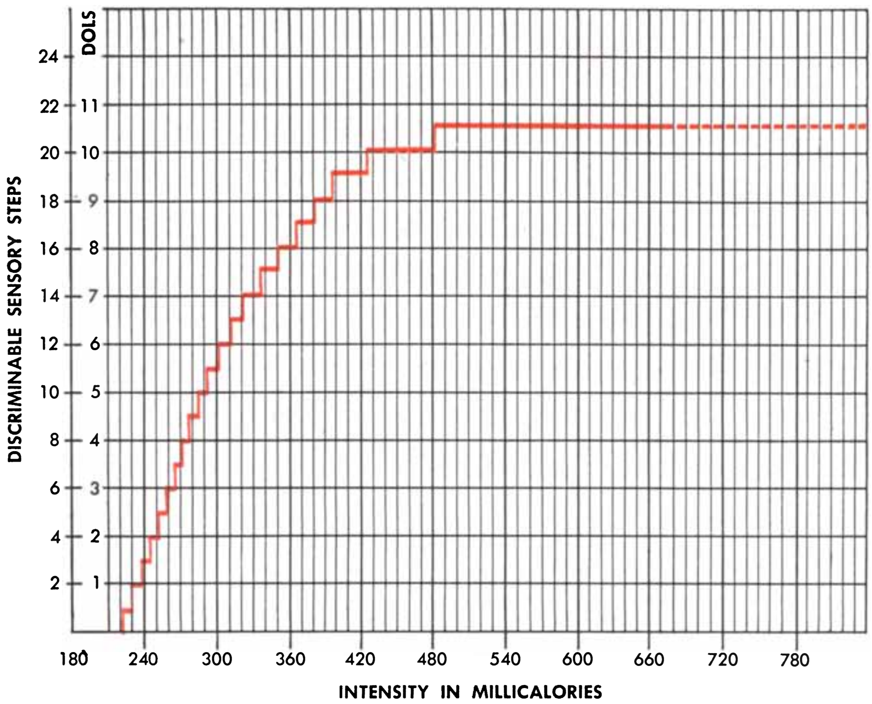
Such commonplace occurrences as these are what raise the question: "Is awareness of pain essential to its being called by that name?" The answer that my colleagues and I have made to this question is based, in part, on our clinical investigations of pain. We conduct a pain clinic in which we study selected patients with pains that are peculiarly resistant to treatment. Whenever our treatment is successful, we search for objective evidence to confirm the patient's subjective sense of improvement. In the experimental laboratory we are trying to locate the site where analgesic and anesthetic drugs act on the nervous system and to trace pain signals from, for example, the tooth of an anesthetized cat to its brain. These investigations can be mentioned only in passing, and much that follows deals with the work of others in the general field of sensory perception. Here, however, are some of the considerations on which our interpretation of pain is based.

Sensory Physiology

The sensory nerves carry a continuous stream of impulses to the central nervous system from all parts of the body. Most of the information we derive from the outside world comes by way of the "primary" sensations of sight, hearing, touch, taste and smell, each of which has its own system of nerves. The information is transmitted as a complex pattern of nerve impulses, which I shall refer to as a signal rather than a message. The impulses carried by any one nerve fiber have an amplitude characteristic of that fiber and can vary only in frequency. So far as we can tell with our present recording devices, the nerve impulses serving sight, hearing and all the other sensory systems are fundamentally of the same simple nature. However, each primary sensation has its own distinct system of specialized receptors, conducting pathways and brain centers. Therefore the activation of any part of the visual system results only in sensations of light; activation of the auditory system gives rise only to sound, and so on for each primary system.

Pain is frequently said to be a primary sensation. There was a time when heat and cold also were so considered. This idea developed after it was demonstrated that pressure on tiny spots in the skin could elicit discrete sensations of cold, heat, pain or touch. It was assumed that beneath each such spot would be found a specialized sensory ending for just one of these "four modalities of cutaneous sensibility." It was further assumed that all other sensations from skin stimulation must represent some combination of these primary modalities.

An examination of a bit of skin under a high-powered microscope indicates that the matter is not so simple. The deep layers of the skin contain a large number of sensory fibers of various sizes. Each fiber branches like a tree, and its branches interweave with the branches of many neighboring fibers. At the end of each branch is a sensory receptor characteristic of that particular fiber. These receptor endings range in complexity from highly organized structures of considerable size to "bare" undifferentiated fibrils with no more than a tiny knob at the tip. The intermingling of the fiber branches and the great number of different endings at any one skin spot suggests how difficult it would be to stimulate one ending or one fiber selectively. An ordinary stimulus, whether a pinprick, a light touch or pressure, invariably activates a large number of dif-



DOL SCALE is used to plot the intensity of pain against that of heat from the dolorimeter. Many experiments indicate that the smallest amount by which one intensity of pain can be distinguished from another is half a dol.

ferent sensory fibers. The evidence is inescapable that the sensations we describe as "touch" and "pain" must be derived from the concurrent activation of many different sensory fibers of various sizes and distribution.

The old idea that fine fibers with bare endings are exclusively responsible for pain sensation is no longer tenable. The pinna of the human ear is supplied solely by such receptors, yet from this area of skin it is possible to elicit sensations of heat, cold and touch. On the other hand, we know that pain may be carried by two different types of fibers. What is called "fast pain" is carried by relatively large, myelinated (sheathed) fibers of the type known as "A" fibers. The sensation they transmit is variously described as "bright," "sharp" and "pricking." Slow pain is carried by "C" fibers—very small fibers with little or no myelin covering. The sensation provoked by C fibers has been characterized as "lingering," "reverberating" and "burning." Anyone who has dropped a heavy object on his toes has felt both kinds of pain. First comes the sharp, well-localized fast pain, then an instant during which the pain seems to have passed over, then a throbbing slow pain which appears to spread beyond the toes into the whole foot.

The nerve impulses set up in different sensory fibers by a single skin stimulus do not remain together as they ascend the nerve. They travel at very different speeds, the fibers being of different diameters. The largest fibers of the A group carry impulses at more than 100 meters per second—about as fast as a DC-3 transport plane cruises. The smallest C-group fibers conduct impulses of very low amplitude at rates of little more than one meter per second—about as fast as a man walks. Thus the nerve signal set up by a single stimulus reaches the spinal cord as a complex pattern of many impulses, spread out in time and in spacing.

Within the cord the impulses are further altered when they transfer to the secondary neurons that carry them up to the brain. How much the pattern alters in character at this relay station depends not only on the fibers' connections with the secondary neurons but also on the activity going on within the spinal cord itself. The pattern can again be modified in another relay station in the thalamus. Finally, the perception eventually derived from the signal pattern depends in part on what is going on in the sensorium—the seat of sensation in the brain.

Interpretation of the Stimulus

This complex mechanism explains why it is so important to distinguish sharply between a signal and the perception ultimately derived from it. Abnormal conditions of the skin (*e.g.*, a sunburn), inflammatory conditions within the spinal cord (as in infantile paralysis), anything that happens to be going on within the relay stations or the sensorium—all this can profoundly alter the interpretation of a given stimulus.

This does not mean that the neural mechanism is a hit-or-miss affair. Under normal conditions the impulses follow prescribed pathways, and their pattern is not distorted at the relay stations. If the arrangement were not orderly, we should never be able to tell what part of the body was being stimulated or to describe as accurately as we usually can the qualities of the stimulating agent.

On the other hand, when we experience a sensation that we have never encountered before, what we perceive of it represents the best interpretation we are able to make of the signal at that particular moment. This interpretation depends on the accuracy of the information conveyed by the signal, the state of the sensorium at that instant and the conditioning influences of experience, childhood training and our personal sense of values.

There is no good reason to think that the sensory information brought to the brain of an infant differs materially from the data received by the brain of an adult. Both individuals may be "conscious" in the sense that they are awake and can respond to sensory stimuli. But the content of consciousness and the response must be quite different in the two cases. The adult interprets what he sees, hears and feels, while the infant scarcely seems to register any impressions. The very young infant acts almost as if it is blind, until it learns to control its eye movements so that it can focus on a stationary object or follow a moving object efficiently. A child learns to see in what appears to be a definite time sequence: first it sees something; then it knows that it sees something; finally it knows what that something may be.

People who are born blind and who gain sight by a surgical operation are unable to recognize objects until they have gone through a laborious learning process. In fact, it takes them longer than it does infants. For example, an adult who has always been blind may know triangles and squares from feeling their shapes, but he will not be able to distinguish one from the other by sight when he first sees them. An experimenter has in his hand a triangular board painted white on one side and yellow on the other. He shows the white side to the man who is just learning to see and asks what shape it is. The man does not know. He is told that it is a triangle and he accepts the idea after a laborious effort to see and count the three corners. Then the teacher puts the triangle behind his back, turns it over and presents the yellow side, again asking the man to tell its shape. The man no longer knows that it is a triangle.

One might conclude from this that there are two distinct kinds of sight perception, one the "pure" sensation of light and the other a psychic interpretation of what is seen. We might say that the infant sees "light" before it "sees" anything, or that it perceives physical pain before it has any psychic perception of its significance. But there is a great deal of evidence to indicate that such a distinction is artificial.

To perceive means to take knowledge of through the senses. The reliability and completeness of the knowledge derived from a particular sensory impression depends both on the accuracy of the information conveyed by the signal and on the ability of the individual to interpret that information. But the act of perceiving is not a two-stage affair of recognizing the raw sensation and then interpreting its meaning. It is doubtful that any perception, however elemental the stimulus, is ever completely devoid of meaning and emotional coloring. If an infant saw only "light" and not the light reflected from definite objects, it would never learn to recognize those objects. Similarly pain is never devoid of emotional coloring; indeed, its emotional content is what makes this sensation peculiarly difficult to evaluate.

The Role of the Brain

To learn, an individual must be able to store information derived from sensory perceptions. Just how the brain accomplishes this storage is a tremendously complex question which is engaging the attention of some of our best scientific minds today. Some groups are studying as models the modern computing machines, which store information by two principal methods: reverberating electronic circuits or some organic "trace," such as the molecular rearrangements of the wire in a wire recorder. Information within a closed electronic circuit can be reproduced only in response to a particular signal, and it is retained only so long as the reverberating circuit maintains its stability. The wire-recorder type of storage is more permanent: the information can be played back at any time until the trace is purposely erased by some newly inscribed molecular pattern.

The brain may utilize both of these methods of storage. However, it is doubtful that reverberating circuits could account for the capacity of the human brain to remember in detail events which took place many years earlier. It is more likely that long-term memory relies upon some kind of organic trace in the nerve cells or upon a rearrangement of the fiber endings in contact with individual cells. Possibly the learning process in an infant is associated with the formation of new cells and new fiber processes, while that in an older child and adult may be largely a reorganization of cell relationships. All that is known about the learning process in children and in experimental animals is consistent with the view that learning is a function of "growth" within the brain.

We predicate all of our actions on the assumption that the information we derive from our senses is accurate. But even though the information conveyed by each sensory system is as accurate as its momentary status can make it, it does not follow that our interpretation of the sensory impression is always correct. As we drive a car rapidly down a highway we may catch a fleeting glimpse of a pile of rags beside the road. Something about it suggests a man's body. Unless we go back and ascertain the facts, we may be unable to dispel the conviction that it was a man, that he was hurt, that he needed help. We may even imagine that we saw him move or heard him call for help. The conflicting descriptions that different people offer for the same object, whether it be an escaped criminal or a flying saucer, are commonplace illustrations of how visual perceptions can be misinterpreted.

Psychologists have produced convincing evidence to support the view that what we see is not an exact replica of "reality" but an assumption based on past experience. This is well illustrated by the experiments in visual illusions [see "Perception," by W. H. Ittelson and F. P. Kilpatrick; SCIENTIFIC AMERICAN, August, 1951]. An observer of the staged illusion is misled because his assumptions are based, not on the facts, but on what he has previously learned. A suggestion implanted in the observer's mind by the experimenter is often able to make him see a demonstration in a certain way, while another suggestion will make him see something entirely different in the same demonstration.

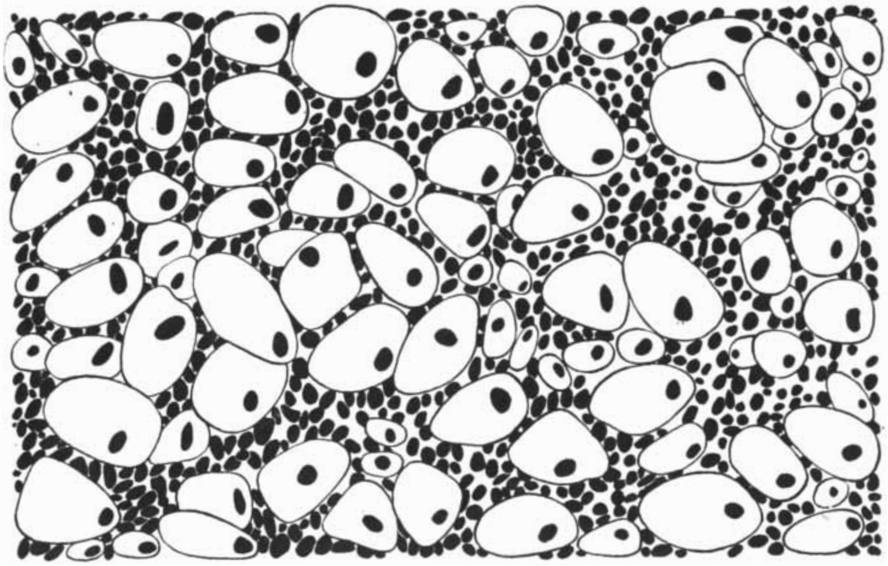
I believe that the interpretation of all sensory information is modified by the same factors that apply to visual perception. I am sure that this is true of pain perception. The interpretation an individual makes of a specific pain signal is an intrinsic part of the perception and a determining factor in its emotional tone.

A father is playing with his son at bedtime. The boy is almost undressed and the father holds out his pajamas. As the last garment comes off, the boy pushes the pajamas aside and dashes across the room. As he passes, the father slaps his bare bottom. The sting surprises the child and he looks back to see how the blow was meant. If the father is laughing, the chances are good that the boy laughs too, as if the slap were a pleasant part of the play. If the father looks and acts as if he meant the blow as a punishment, the boy clutches himself and howls as if badly hurt.

No physician doubts that the severity of a pain is modified by the patient's interpretation of it. If the patient has a morbid fear of cancer, every pain he develops is intensified because it suggests the onset of cancer. The pain that a child experiences is often conditioned by the fears, attitudes and afflictions of his parents. Indeed, parental influences may be decisive factors in determining the amount of pain their children will suffer from minor injuries throughout the rest of their lives.

The Seat of Consciousness

The use of drugs to alleviate suffering makes us all aware of the relationship between pain and the state of consciousness. But "consciousness" is even harder to define than pain, because there are so many kinds and degrees of consciousness and unconsciousness. No one knows where or how consciousness occurs. For a long time it was thought that the cerebral cortex was the seat of consciousness, since one part of the cortex was known to be the receiving station for vision, another for hearing, another for speech and still another for sensory-motor representation of the body parts. It was natural to associate consciousness with this "highest level" in the brain.



A AND C FIBERS are differentiated in this schematic cross section of a nerve. The black dots are the axones of the fibers. The A fibers are surrounded by a fatty sheath; the C fibers are covered with little or no sheath.

But we now know that any or all of these cortical centers can be destroyed without abolishing consciousness. At present, the best experimental evidence indicates that the area most essential to maintaining consciousness is a compartment below the cortex known as the diencephalon.

If the diencephalon is not actually the seat of consciousness, at least it must interact with other large areas of the brain to control the normal fluctuations in consciousness associated with sleeping and waking. It has recently been shown that this area of the brain contains an "arousal center." Destruction of this center in the brain of a cat or monkey will cause the animal to remain in an unconscious state that resembles normal sleep, though the operation does not interrupt the main sensory pathways for sight, hearing or pain. The animal can be awakened by a loud sound, by a bright light shined in its eyes or by the strong stimulation of a sensory nerve, but it soon lapses back into sleep. On the other hand, if the arousal center is left undisturbed, an animal sleeps and wakes in the normal sequence even when all the main sensory systems are cut so that the sensory signals, which we have always thought so important for the preservation of consciousness, cannot reach the sensorium by their usual direct route.

The seat of the arousal center is in a part of the brain known as the "reticular formation," a structure of relatively small nerve cells which lie outside the main pathways for motor and sensory conduction. It extends from the diencephalon downward throughout the length of the central nervous system. Until recently about all that was known about the function of the reticular formation was that its upper portion facilitates activities in many other parts of the brain and spinal cord, while a somewhat lower portion inhibits them. Now the arousal center has been found in the upper part of the formation. It acts upon the entire cerebral cortex at the same time. In contrast, any single sensory system influences only a limited area of the cortex. The arousal center's power to activate the cortex as a whole seems to be closely related to its capacity for waking a sleeping animal.

A sleeping individual is usually awakened quite readily by sensory stimulation, particularly if the stimulus is intense. Painful stimuli arouse the sleeper more effectively than either light or sound. It appears that the sensory signals do not themselves awaken the individual but activate the arousal center, by way of side branches from the main sensory pathways. It is possible that anesthetic drugs depress the arousal center of the reticular formation rather than the specific cortical centers. It is also possible that pain is related more closely to activity in the reticular formation than to a special "pain center" in the brain. What we need to explore these suggestions is a pain signal of sufficient intensity to be traceable into the brain.

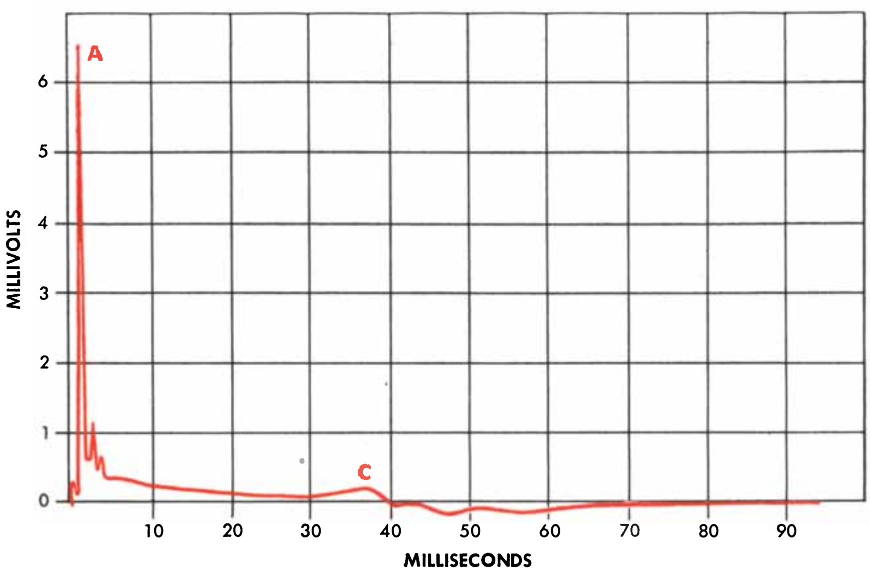
For various reasons the best sensory fibers on which to experiment are the A fibers, which transmit pain signals of the fast type. The sensory fibers in the pulp of the teeth seem to meet the specifications, and their endings are all of the undifferentiated type. The tooth pulp is exquisitely sensitive to mechanical, electrical and thermal stimulation. Its nerve fibers can be activated by an electrical pulse measured in hundredths of a millisecond. Experiments in the stimulation of these fibers are now being carried out on cats under deep Nembutal anesthesia. We can assume that the signal we are studying would be perceived as pain by the animals if they were conscious, because when we apply these same short pulses to our own amalgam-filled teeth, we experience a sharp stab of pain.

To date the experiments have progressed only to the point where secondary discharges have been recorded from the thalamus and the sensory-motor cortex of the brain. We have not yet traced the discharges from these receiving centers into the reticular formation or into other parts of the brain. But it looks as if tooth-pulp stimulation will be a valuable tool for finding out how the secondary influences may spread to other parts of the brain.

Pain as Protection

This presentation has indicated some of the difficulties encountered in any investigation of pain. We are handicapped from the outset by the lack of a clear-cut definition of the entity we are to study. The few definitions for pain that have been proposed tend to emphasize its protective function and make no mention of its harmful potentialities. The best of these definitions was suggested years ago by the English physiologist Sir Charles Sherrington. He said that pain was "the psychical adjunct of an imperative protective reflex." This statement says a great deal in few words, but it hardly defines pain, since it tells nothing of its nature beyond the fact that it is "psychical." The statement also conveys the impression that the important protective factor is the reflex, to which pain is merely an "adjunct." As far as the lower animals are concerned, this is probably true. But for thinking human beings pain assumes a much greater significance than it does for lower animals.

What are some of man's defenses against injury and how intimately are they related to one another? The simplest and most familiar is the withdrawal reflex. A man standing beside a hot stove happens to touch it with one hand. His arm muscles jerk the hand away



A AND C POTENTIALS are compared in amplitude and time. After a single stimulus, the A fibers give rise to the tall spike at left. The C fibers follow with the very small peak that appears between 30 and 40 milliseconds.

before he has time to feel any pain or to know what is happening. If he had fallen against the stove his muscular reflexes would have been more widespread and powerful. They would have taken the violent and irrepressible form that Sherrington refers to as the "imperative protective reflex." Perhaps the best example of their violence is seen at times during the excitement stage of anesthesia induction. The patient is just dropping off into unconsciousness when some inadvertent noxious stimulus sets off his muscular reflexes. The fact that consciousness has faded seems actually to heighten the response. It is as if all restraints had been removed and the nerve signal could produce its maximal effects.

The muscular reflexes are the body's first line of defense against injury. In many situations they effectively break contact with the offending stimulus. The withdrawal reflex takes place over the shortest possible route from the site of injury to the spinal cord and back again to the local musculature. The speed of the reflex tends to reduce tissue damage to a minimum.

A second line of defense is represented by visceral reflexes that involve the vital organs and glands of internal secretion. We are all familiar with the increase in the heartbeat and in respiration, the dilation of the pupils and the sense of tension throughout the body that accompanies pain. These are the more obvious manifestations of a chain reaction that mobilizes all of our resources to meet what may be an emergency situation. If the emergency is real, these preparations for "fight or flight" can spell the difference between life and death. They account for the almost superhuman feats of strength and agility that men sometimes perform in a crisis.

The third line of defense is the voluntary response to a situation. A noxious stimulus initiates a signal which is translated by the brain into a pain perception. Having felt the pain, the individual can find its source and decide on the basis of experience how to deal with the situation.

In the sense that a reflex response is much faster than a voluntary one, it affords a better protection against injury. But reflexes are always stereotyped and often totally inappropriate to the situation. They occur whether they can serve any useful purpose or not, and they may waste the body's resources. Under conditions of sustained or repeated injury the body may be so depleted that it no longer can withstand infection and new stresses. As a matter of fact, actual tissue injury need not be present to cause this exhaustion. Fear can do exactly the same thing. Often the threat of pain does a person more harm than the injuries that taught him to fear it.

The intimate relationship among these three lines of body defense, all activated by the same noxious stimulus, makes it easy to confuse them with one another. In our desire to find a method for measuring pain, we are tempted to identify pain with the measurable associated mechanisms—the noxious stimulus, the body response or the signal pattern on its way to the sensorium. To do so, I believe, is an error. As Sherrington says, pain is a psychical process. It represents some activity of the brain which cannot be fully accounted for as yet by experimental observations. The signal pattern is doubtless a part of the mechanisms from which perceptions are secondarily derived, but the process itself is beyond the reach of our present recording techniques. It seems to me to be just as misleading to identify pain with the signal pattern as it would be to identify an act directed by human intelligence with a reflex. Furthermore, clinical experience indicates that the psychic and physical factors that determine the intensity of a pain are inseparable components of a single sensory experience. It is so difficult to eliminate psychological factors from the simplest test for pain that I doubt we shall ever find a satisfactory method of objective measurement.

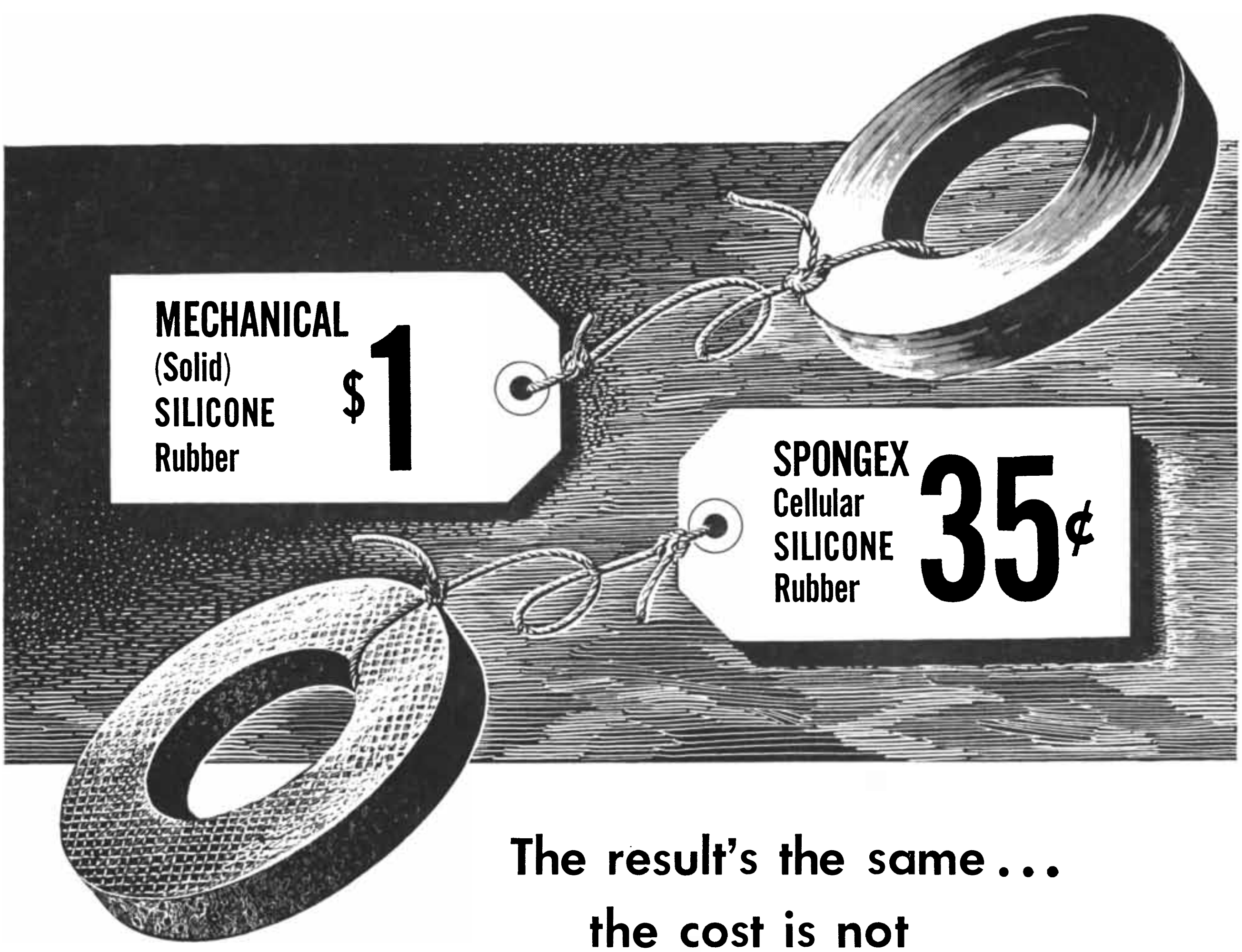
Pain and Death

Returning to the original question—What is pain?—I believe that we can accept the "common sense" answer. Pain is a perception. To be "perceived" means to be "felt." Certainly what counts most with my patient and what counts with me as his physician is the amount of pain he feels. When a patient needs a surgical operation and asks me to perform it, he does not ask how deeply the knife will cut, nor would he be concerned if I were to tell him that pain signals would continue to traverse his nervous system after he had gone to sleep. What he asks is, "How much will it hurt me?" He is really asking how much of the inevitable tissue injury he will consciously experience as pain.

Anything that depresses brain function impairs pain perception. It doesn't seem to make much difference whether the depression is due to drugs, excessive fatigue or any of the many factors that deprive the sensitive brain cells of their supply of oxygen. The brain cells involved in pain perception are selectively depressed by anesthetic and analgesic drugs, so that this sensation falls in intensity before other sensory perceptions are seriously impaired.

I am convinced that neither a dying man nor a person undergoing anesthesia feels any pain, though their groans and body movements, those physical manifestations which we so naturally associate with pain, may seem to support the contrary view.

With these convictions I can tell the man who fears death will be painful that dying is merely the closing event in a sequential loss of function which accompanies brain depression. Just as an exhausted mountain climber gratefully lies down on the rocks and goes to sleep under conditions that would be intolerable to him in his normal state, so a dying man may welcome death because it offers his exhausted body rest. Before all his senses fail, before he loses all power of speech and movement, before his heart stops beating, long before his nerves lose their capacity to transmit pain signals, the ability of his brain to translate these signals into pain perception has been lost. For pain is a product of consciousness in which the essential element is awareness.



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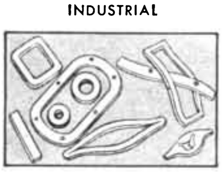

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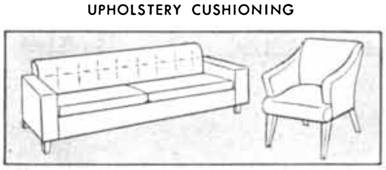

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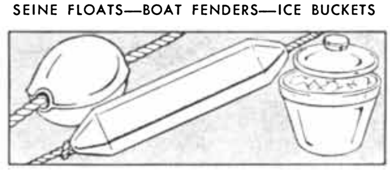

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THE MASS SPECTROMETER

This sensitive instrument sorts atoms and molecules of various weights by means of a magnetic field. Developed by physicists, it is now widely utilized in other sciences and in technology

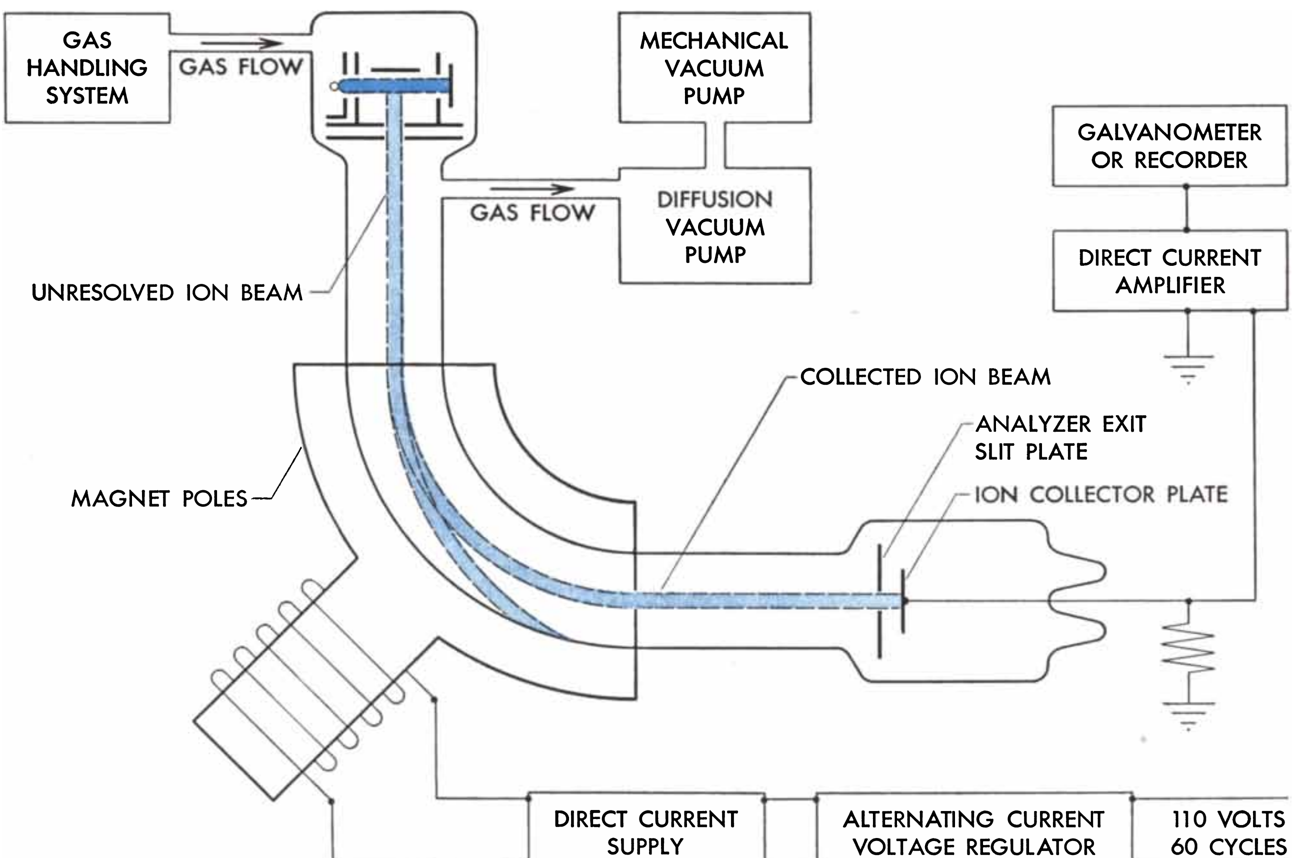
by Alfred O. C. Nier

THE MASS spectrometer is a classic example of the instrument that starts as a laboratory contrivance and becomes one of the great general tools of mankind. It grew out of the electrified glass tubes with which physicists liked to experiment in the late 1800s; today it is used as a research instrument in fields as widely diverse as chemistry, geology, biology and medicine, and is an indispensable piece of equipment in various industries. As recently as 1940 there were probably fewer than a dozen such instruments in operation in the world; now there are many hundreds, and their use steadily grows.

Basically the mass spectrometer is an instrument for sorting and identifying atoms or molecules. The particles are ionized (given an electric charge) and then fired across a magnetic field which bends their flight into a circular path. The heavier of two ions will fly in a wider arc than the lighter one and hit a different target. The instrument readily separates ions with very slight differences in weight. And since the speed of the particles, strength of the magnetic field and paths of flight are all accurately known, it is easy to calculate precisely the relative masses of the various ions.

A mass spectrometer sorts a mixed stream of ions by atomic weight just as a glass prism separates a beam of white light into a spectrum of its component colors or wavelengths of light. If the sorted ions are caught on a photographic plate, the apparatus is called a mass spectrograph; if they are detected and recorded by electrical means, it becomes a mass spectrometer.

The instrument can easily identify the



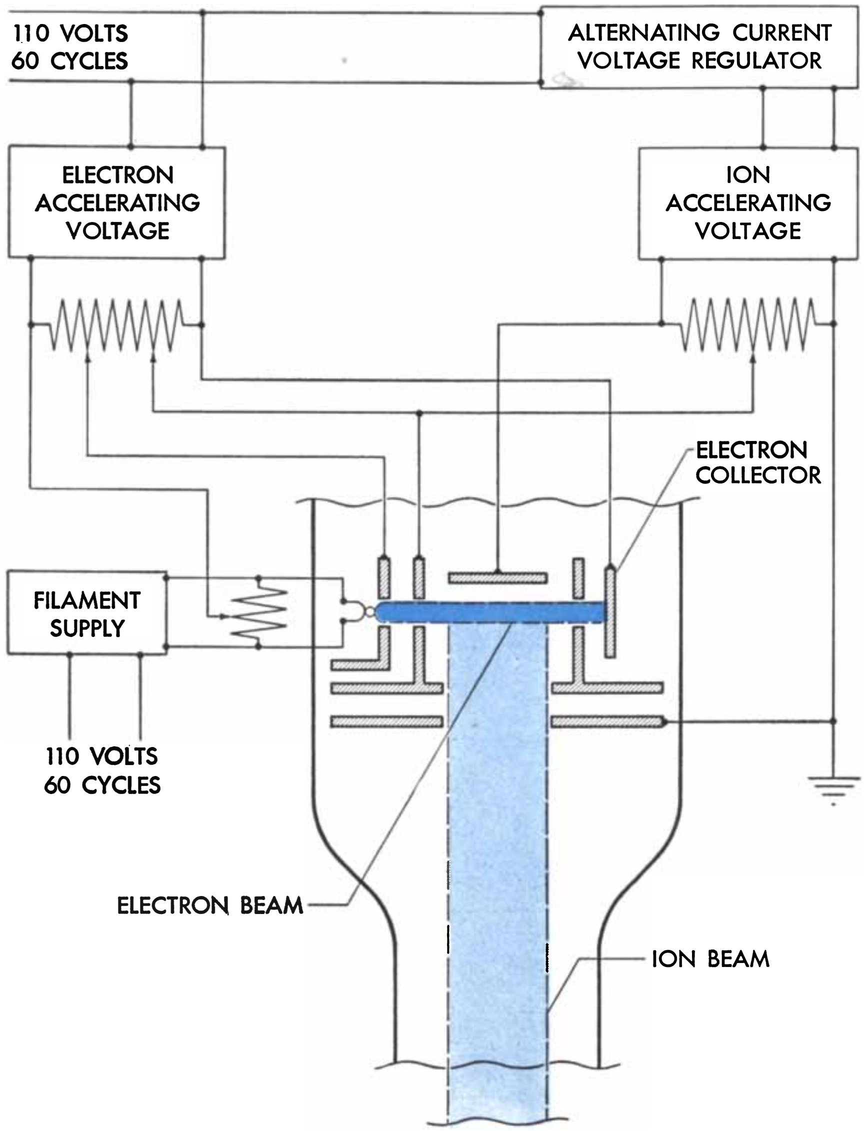
SCHEMATIC DIAGRAM of a mass spectrometer shows path of ions (*light blue*). Those that reach the collector plate signal their presence by a minute electric current. Adjusting the voltage that speeds ions down the tube, or the magnetic field that bends their path, brings ions of desired weight to the collector.

ingredients of air or any other gas and offers almost unlimited possibilities as a gas analyzer. It can analyze solids when they are converted to the gaseous form.

In principle the mass spectrometer goes back, as do so many powerful instruments today, to humble beginnings in the observations of research workers in the latter part of the last century. Physicists then were greatly interested in the study of electrical discharges in gases. To perform these studies they used a glass bulb having a pair of sealed-in metal electrodes, called anode and cathode. When a high voltage was applied across the electrodes and pressure in the bulb was reduced by pumping out some of its air or gas, the remaining gas became a conductor and glowed like a neon sign. From observations of this glow came some of our most fundamental and now familiar concepts of the nature of matter.

CHIEF among these were the discoveries of J. J. Thomson, who in 1897 began a famous series of experiments. Investigating the then mysterious cathode rays, which streamed from the negatively charged cathode in such a tube, Thomson determined that they were made up of particles. The individual particles always had the same mass and electric charge, regardless of the gas used in the discharge tube. Thus he discovered the electron, the smallest particle of matter, and opened the electronic age. He then turned to the anode rays seemingly coming from the positively charged anode. These also, he demonstrated, were streams of particles, but in their case the mass of the particles depended on the atomic weight of the gas in the tube. (Actually his anode rays were positively charged ions—atoms or molecules stripped of an electron by collisions in the electrical discharge.) Thomson thereby contributed to the growing chain of evidence that led to the realization that all matter is composed of atoms and that the weights of the atoms are directly proportional to what chemists had long recognized as the relative combining weights of the elements.

Thomson passed the positively charged anode rays through suitable combinations of electric and magnetic fields and found that the rays could be separated according to mass as the ions of different weights were pulled into different paths by the field forces. And in further exploration of the atomic weights of elements by this means he made another discovery. Chemists, in setting up their atomic weight scale, had arbitrarily taken oxygen as 16. The relative weights of the other elements tended to be integers also. But there were well-known discrepancies from this whole-number rule. For example, the rare atmospheric gas neon had an atomic weight of 20.2. In 1912 Thomson put a bit of pure neon in his apparatus and found that it consisted of not one type of atom but two, some with a weight of 22, many more with a weight of 20, averaging out to 20.2. Thus he established the fact that some elements have isotopes—atoms of slightly different weight but the same chemical nature.



DETAIL OF ION SOURCE shows electron beam that ionizes the gas to be analyzed and the slotted electrodes through which the ion beam emerges. Voltages applied to the electrodes determine speeds of electrons and ions.

Mass spectrometry flowered almost directly from the subsequent study of isotopes. In 1918 the late Arthur Dempster of the University of Chicago built the first mass spectrometer. He designed the instrument to measure the relative abundance of isotopes in various elements. A year later the English physicist F. W. Aston, a colleague of Thomson, made a mass spectrograph and began a systematic 20-year study of isotopes in the entire atomic table.

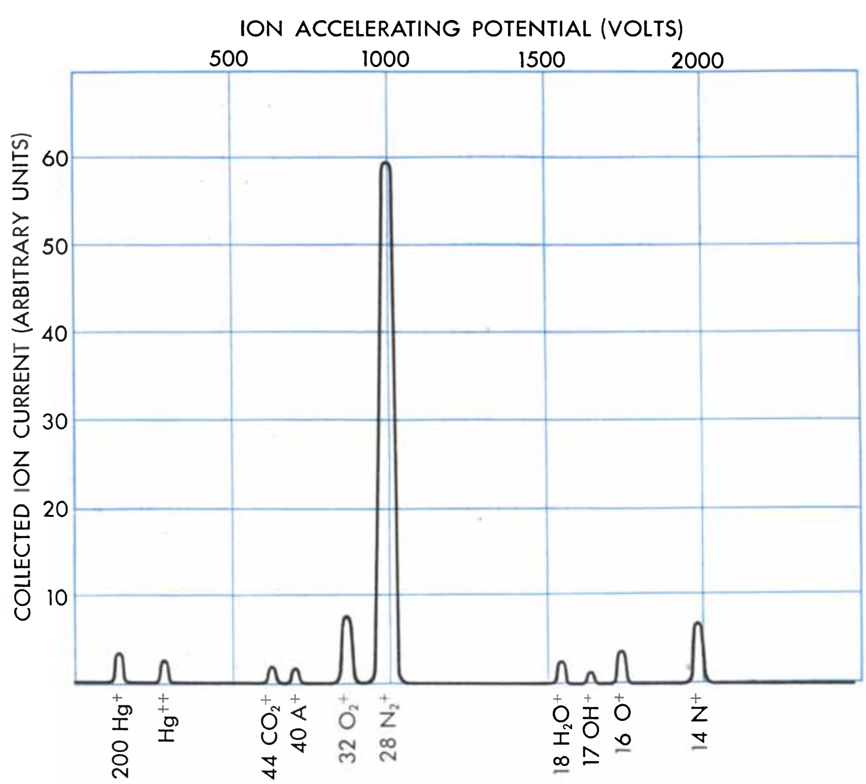
Although many of Aston's measurements of minute deviations in atomic masses are now superseded by more accurate ones, obtained with more refined apparatus, his patient work laid the basis for much of our knowledge of the structure and binding forces of the atomic nucleus. It was this work, combined with Einstein's famous equation on the equivalence of mass and energy, that made possible the calculation of the latent energy in atomic nuclei and the discovery of the fissionable isotope uranium 235. And the mass spectrometer was one of the methods used in the production of uranium 235 for the atomic bomb.

THE MEASUREMENT of atomic masses remains an exciting field of research. From it we should continue to learn much about the nature of nuclear forces. But our chief interest here is in the wider applications of mass spectroscopy. By now it has enabled us to measure the relative abundance of most, if not all, of the isotopes occurring in nature and of those produced artificially in the laboratory. The study of isotopic abundances has many valuable applications in other fields of science besides physics. In addition, the mass spectroscope's convenience as an analyzing instrument makes it an important industrial tool.

In the early instruments the gas to be analyzed was ionized by bombardment with electrons from an electrical discharge. Most modern mass spectrometers produce ions by a more stable and controlled means. In the commonest type of instrument, the electrons stream from a hot tungsten wire and are accelerated through a potential difference of about 100 volts to give them the kinetic energy required to ionize the gas molecules. The gas is admitted continuously into the vacuum chamber of the instrument through a small "leak." The chamber is continuously pumped so that the net pressure is reduced to about one billionth of an atmosphere—a pressure so low that once an ion is formed there is little likelihood it will collide with another ion or gas molecule before it is caught on the detecting plate.

The ions are fired into the magnetic field at high speed. This is done in one form of the instrument by directing them through slits in a pair of parallel metal plates, across which an electrical potential difference is applied. Emerging from the slit in the second plate, the ions coast in straight lines until they pass between the poles of the magnet. The magnetic force, exerted at right angles to their direction of motion, causes the ions to curve in circular paths. The radius of curvature depends on the number of electrons lost in ionization (usually one), the difference in potential through which the ions fell, the strength of the magnetic field and the atomic weight of the ions being measured. By adjusting either the magnetic field or the difference in potential, ions of any particular weight can be made to hit a predetermined target. This is a slit behind which is mounted a plate. The ions impinging on this plate set up a tiny electric current, which is measured by special instruments.

ONE of the practical applications of the mass spectrometer is in the petroleum industry. Here the molecules to be analyzed are organic gases made up of many atoms. When struck by the electrons, such molecules are shattered into ionized fragments. For a given energy of bombarding electrons, these fragments may be made to give a mass spectrum characteristic of the gas bombarded, down to the actual arrangement of atoms in the molecule and the number and types of atoms present. Thus mass spectrometry can distinguish between two or more different chemical compounds having the same molecular



SPECTRUM OF AIR is plotted in terms of accelerating voltage required to focus each ion. The electron bombardment has not only ionized the various air molecules but has split some of them apart, as is shown by presence of monatomic oxygen and nitrogen. Mercury comes from pump.

formula. This is extremely useful in the petroleum field, where many compounds are so nearly alike in properties that it is often difficult to identify them in a mixture by ordinary chemical means. Many oil refinery laboratories have set up spectrum patterns for hundreds of pure compounds and run routine analyses of mixtures having as many as several dozen components.

Such analyses are usually made in laboratories on samples brought to the instrument. But a mass spectrometer can also be put directly into the process stream in a continuous-flow chemical plant to provide a continuous analysis and automatic feedback control of the composition of the process stream. The first notable application of this kind was in the U-235 gaseous-diffusion plant at Oak Ridge, where the process stream is continuously monitored by a battery of strategically placed instruments for traces of air, refrigerants and other contaminants that may leak into the system. Each instrument is pretuned to the impurities being watched, just as a push-button radio is pretuned to certain stations. A clock and switch arrangement puts the instrument through its preset tests in sequence. Each analysis takes 24 seconds, and a single instrument can make 3,600 determinations a day, using small samples of gas which total altogether only two cubic centimeters. The amounts of the impurities are automatically recorded on a single chart, which allows an operator to see the entire chemical analysis of the stream at any time and note any changes that have taken place in it.

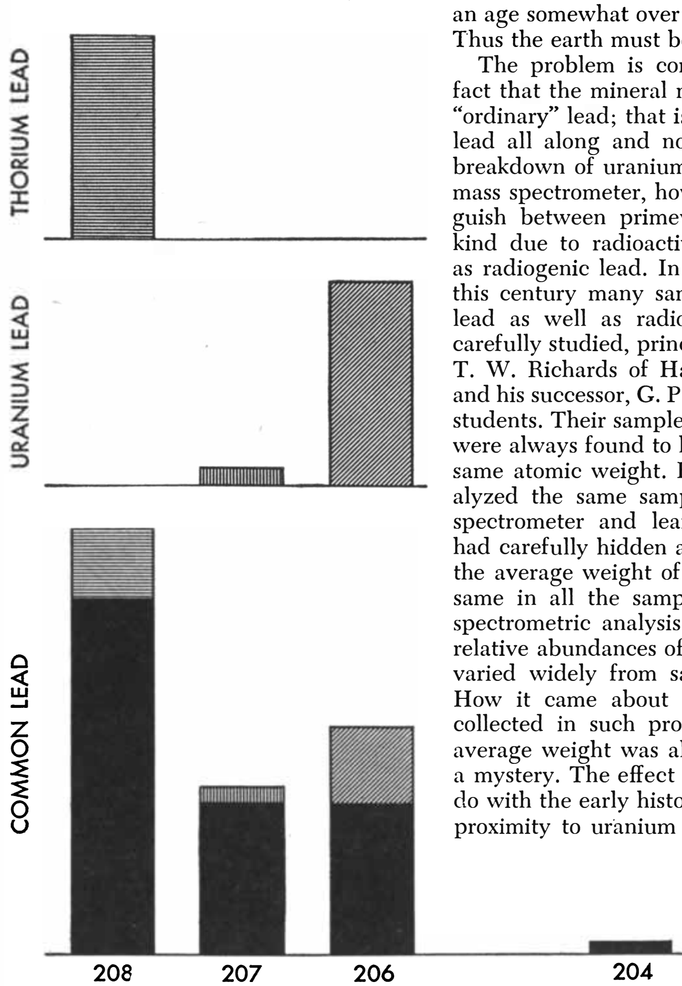
A portable mass spectrometer was developed to detect minute leaks in the system. The plant has miles of pipes, valves, vacuum pumps and vessels that must be kept tighter than those in any ordinary chemical plant. To have checked the completed plant for leaks by conventional means would have required about 1,000 test stations, each manned by a team working 8,000 hours to cover the million or so critical points in the system. With mass spectrometers acting as leak detectors the gigantic task was accomplished with only about 3 per cent of that effort. The plant was completed with great savings in time, materials and skilled manpower.

IN BIOLOGY the mass spectrometer has been useful for studying respiration, among other things. F. A. Hitchcock and his colleagues at Ohio State University have used a continuous-reading instrument to analyze the composition of respiratory gases under various conditions, including sudden changes in pressure. At the University of Minnesota Fletcher Miller and Allan Hemingway analyzed, with a special portable instrument, the rate of nitrogen elimination in patients suffering certain lung disorders, and other workers at the University have made continuous respiratory gas analyses during thoracic surgery. At the same institution the botanist Allan Brown and his students have examined metabolic gas exchanges in growing plants. Here the mass spectrometer follows continuously the composition of the gas surrounding the plants as the photosynthetic process takes place.

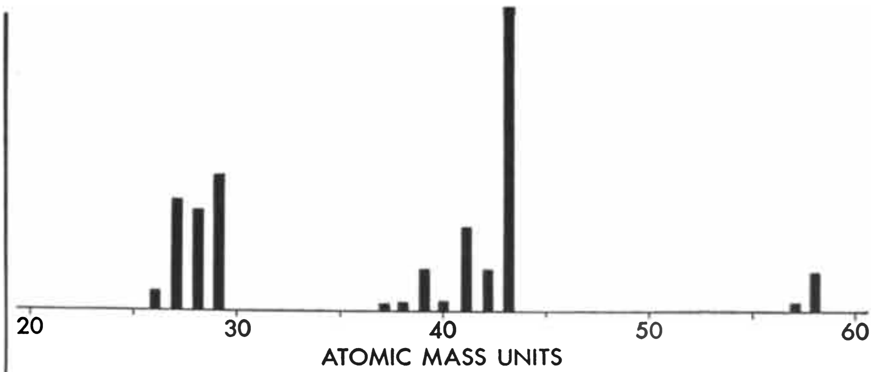
The mass spectrometer is an indispensable item of equipment in biological tracer experiments employing stable isotopes. For many investigations of metabolism stable isotopes are preferable to radioactive isotopes; for some they are the only ones available. For instance, nitrogen and oxygen, two important elements in biological studies, have no suitable radioactive isotopes but useful stable ones. The mass spectrometer can measure extremely small traces of an element; with it, for example, M. G. Inghram and his colleagues at the University of Chicago have determined within 10 per cent that the quartz in a sample of granite contains only one part of uranium in 10 million. Comparable precision has been obtained in measuring other trace elements.

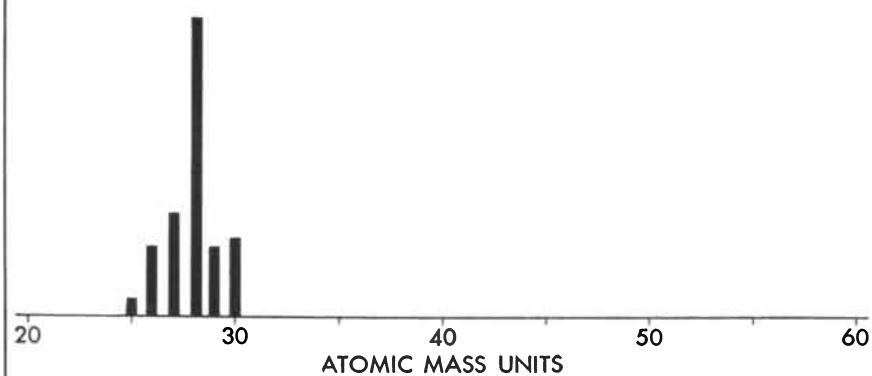
One of the most interesting uses of the mass spectrometer has been in reckoning the age of the earth. The method involves measuring the isotopic abundances of lead, the product of the breakdown of radioactive uranium and thorium, in the earth's rocks. In the long course of time uranium 238 decays to the lead isotope 206, and uranium 235 to lead 207. Thorium decays to lead 208. The rates at which these transformations take place are accurately known. Thus by making a chemical analysis of the amounts of uranium, thorium and lead in a sample of mineral, and determining the relative amounts of the three isotopes of lead, one can make three independent calculations of the age of the mineral. Once the ages of the uranium and thorium minerals are calculated, it becomes possible to estimate accurately the ages of the deposits in which they lay and thereby to set up an age scale for the various geological eras. The oldest minerals found so far have an age somewhat over two billion years. Thus the earth must be at least this old.

The problem is complicated by the fact that the mineral may contain some "ordinary" lead; that is, lead which was lead all along and not formed by the breakdown of uranium or thorium. The mass spectrometer, however, can distinguish between primeval lead and the kind due to radioactive decay, known as radiogenic lead. In the early part of this century many samples of ordinary lead as well as radiogenic lead were carefully studied, principally by the late T. W. Richards of Harvard University and his successor, G. P. Baxter, and their students. Their samples of ordinary lead were always found to have precisely the same atomic weight. But in 1937 I analyzed the same samples with a mass spectrometer and learned that nature had carefully hidden a secret. Although the average weight of the lead was the same in all the samples, the accurate spectrometric analysis showed that the relative abundances of the lead isotopes varied widely from sample to sample. How it came about that the isotopes collected in such proportions that the average weight was always the same is a mystery. The effect apparently has to do with the early history of the lead—its proximity to uranium and thorium—be-



SPECTRA OF LEAD from various sources show differences in isotopic content. Thorium decays to lead 208 (*top*); uranium 238 ends as lead 206; uranium 235 as lead 207 (*center*); natural lead (*bottom*) is a mixture of isotopes, which may vary from one deposit to another by as much as the shaded area in each bar, but which average to the same atomic weight.





HYDROCARBON SPECTRA for butane (*top*) and ethane (*bottom*) indicate relative abundance of molecular fragments after gas is broken up by electrons in spectrometer. Each pure hydrocarbon gives a unique picture.

fore it was laid down in the mineral in which it is now found. The problem requires far more investigation. Calculations made from the data so far available have led the eminent geologist Arthur Holmes of the University of Edinburgh to suggest that the actual age of the earth is close to 3.3 billion years.

The mass spectrometer has many other applications to problems in geophysics and geochemistry. One of the most engaging is employed by Harold Urey and associates at the University of Chicago in determining from the fossil shells of marine animals the temperature of the oceans in which they lived millions of years ago. Urey and his associates have shown that when calcium carbonate, the material forming the shells, is crystallized slowly in water, the ratio of rare oxygen 18 to common oxygen 16 in the carbonate will depend slightly upon the temperature of the water. The effect is very small: a change in temperature of one degree centigrade changes the ratio by only .02 per cent. Since oxygen normally contains only one part of O-18 to 500 parts of O-16, this change affects the atomic weight of oxygen by less than one 10-millionth of a unit of atomic weight. Nevertheless Urey and his colleagues, with the aid of a mass spectrometer, have found measurable isotopic differences in the oxygen extracted from fossil shells and have been able to calculate the temperatures of the oceans in which the animals lived—a valuable bit of evidence in reconstructing the early history of the earth. The technique has been perfected to the point where, by examining successive layers of an animal's shell, one can even determine seasonal variations in temperature and in some instances the time of year the animal died!

Other workers have investigated by mass spectrometry variations in the isotopic abundances of certain other elements, including boron, sulfur and helium. Several years ago one of my students, L. T. Aldrich, and I measured the abundance of the rare isotope helium 3 in various sources of helium and found that it ranged from 5 to 2,000 parts per 100 million—a 400-fold variation! Abundant helium 4 is a by-product of the radioactive decay of uranium and thorium, while helium 3 is the decay product of unstable hydrogen 3 (tritium). Tritium, in turn, is formed in various ways, including cosmic-ray bombardment. Hence the problem of explaining the variations is extremely complex.

TO THE MEN who developed the mass spectrometer—Thomson, Aston, Dempster, the late John T. Tate of Minnesota and others—workers in many fields today are much indebted. The specialists who have put the instrument to "practical" use already include petroleum chemists, atomic fuel producers, biologists, geologists—and the list will certainly grow far longer.

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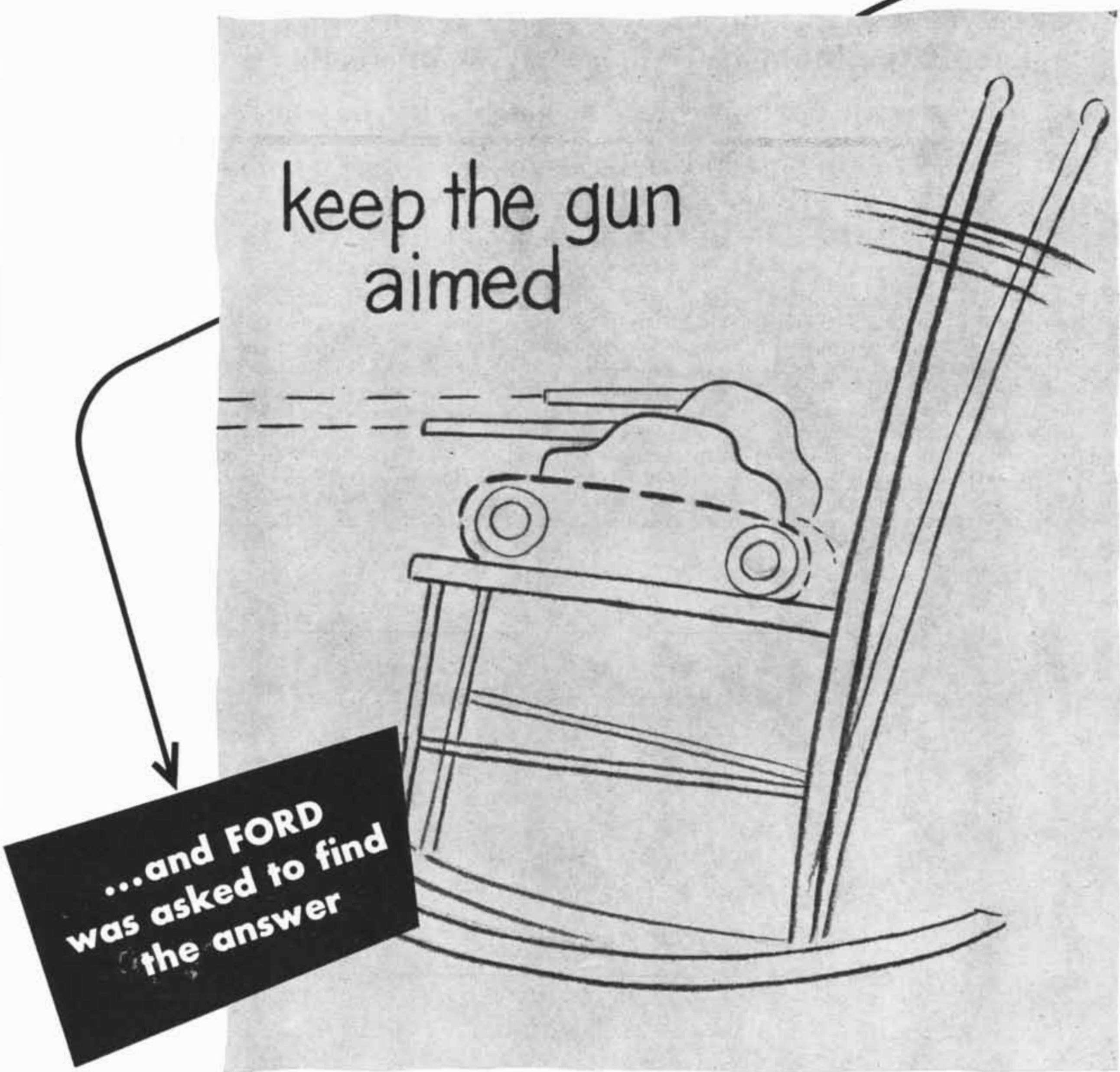
over rough terrain



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THE EMBRYOLOGIST AND THE PROTOZOON

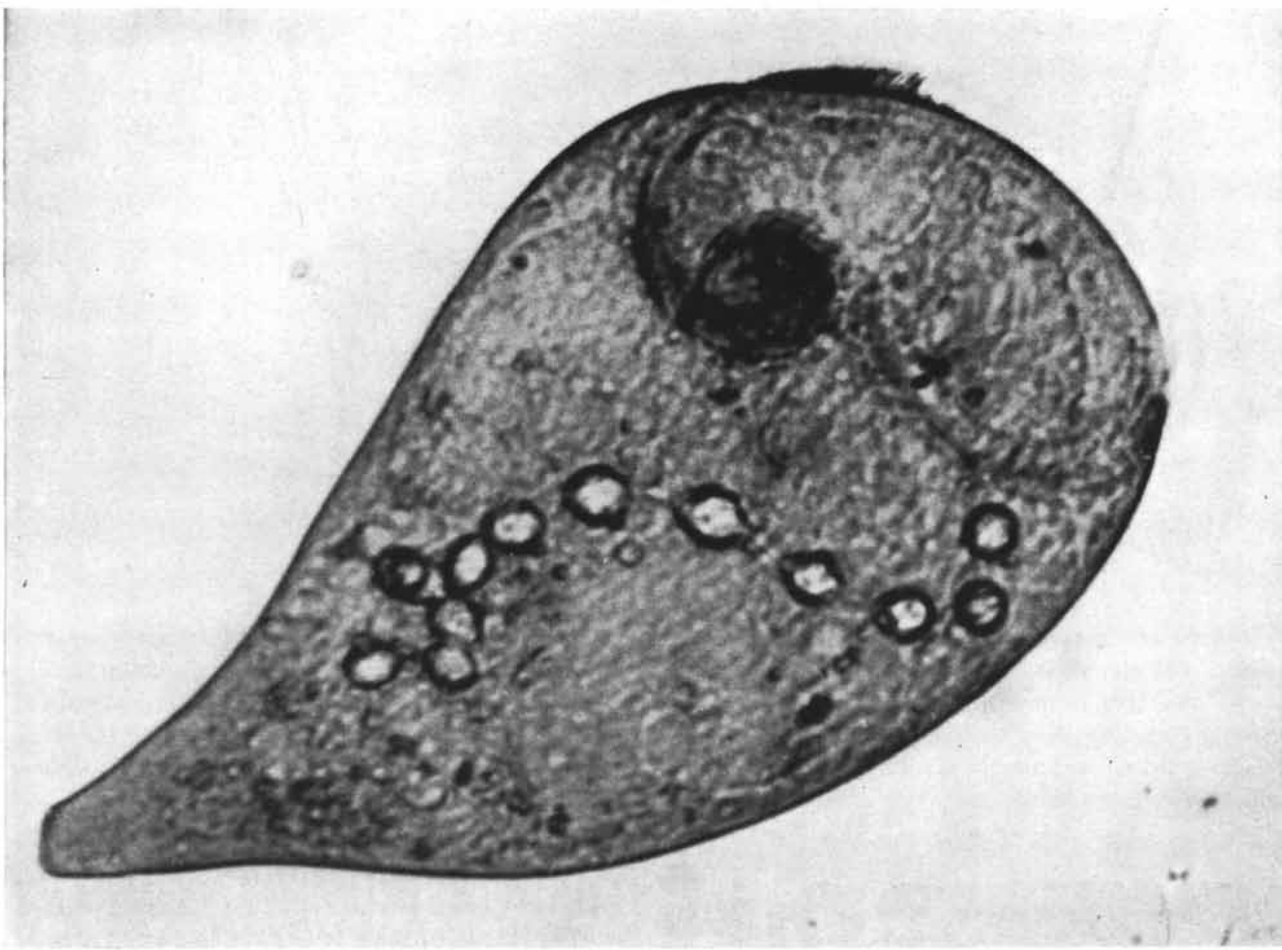
A tale of the biological laboratory. A one-celled animal is cut to pieces with curious results that clarify how a fertilized egg gives rise to the specialized tissues of a many-celled organism

by Paul B. Weisz

UNDER the microscope an embryologist is watching a tiny protozoon swimming in a dish of water. The animal is beautifully translucent and tinted a glassy green by minute emerald granules set into its surface. Rows of crystal-clear cilia oscillate rapidly in the water. As the animal glides forward in smooth, graceful curves, multicolored flashes of light glitter off its surface, as if reflected from a cloak of microscopic sequins. All the while the animal eagerly siphons into its gullet tiny bacteria, upon which it lives.

The reason the embryologist is looking at a protozoon, rather than at his usual fertilized eggs and embryos, is that he has a problem which he thinks the protozoon may help him to solve. The problem is cell differentiation. How does it happen that a big toe develops on the foot and not on the nose? How does it happen in an embryo that the right kinds of cells develop in the right places in just the right numbers?

He knows that the genes of a cell, those minute controllers of hereditary characteristics, determine the structure and function of that cell. He also knows that when a cell divides, the offspring cells inherit sets of genes which are identical with those of the original cell. Hence the structure and function of off-



THE PROTOZOON is the ciliate *Stentor coeruleus*. At its right end is the gullet through which, with the aid of cilia, it sucks particles of food. The beaded structure within the one-celled animal is its nucleus.

spring cells should be mutually identical. But they are not. When one of his single-celled, fertilized eggs divides, forming an embryo, and then divides again and again, some of the embryonic cells become big toe, others become nose, and so on. The cells of the embryo somehow "differentiate" along specialized lines.

This differentiation might be accounted for by gradual changes in the sets of genes as they pass from fertilized egg to successive cell generations, or by changes in the nongenic part of each cell or by a combination of both processes. But how test such hypotheses? A vast amount of research has been done during recent decades, in an attempt to find the correct answer. No clear answer has yet been forthcoming. This is partly because the direct investigation of individual cells in embryos is exceedingly difficult. The cells are extremely small; they cannot stand much surgical injury, and it is hard to keep the embryos alive through the experiments. Casting about for a new means of investigation, the embryologist has turned to protozoa. His problem involves the inner workings of cells, and protozoa are not only cells, but cells fairly easily propagated and experimented on.

THE embryologist takes some sewing needles, grinds their tips down to microscopic, razor-sharp points, and fastens these tiny scalpels into convenient holders. Then he goes to work on his protozoon. With a medicine dropper he catches the animal in a drop of water, pipettes the drop on a glass slide and places the slide under his microscope. There is the protozoon, unperturbedly swimming about, every feature clearly visible. The experimenter can easily make out in its interior the nucleus—an elongated, beaded structure containing the genes. He takes up two of his needle instruments and with one of them tries to spear the protozoon. It takes a bit of time, but soon the animal is pinned against the glass surface with featherlight pressure. This calls for considerable steadiness, for the slightest shaking of his hand would squash the speck of protoplasm and destroy it completely. Then, using the other needle as a knife, he cuts lightly across the waist of the animal, severing it in half.

Now there are two pieces. One possesses the gullet; the other is mouthless. Each contains a length of nucleus. Watching intently, the embryologist sees the wound surfaces on each piece contract, and then both pieces swim away, apparently none the worse for the experience. But what will happen next? Clearly the mouthless piece would starve if it continued in that state indefinitely.

After some five hours of watching, the embryologist's patience is rewarded. In one region of the forward part of the mouthless piece a tiny depression appears. Slowly but steadily this depression deepens and widens. As it deepens, it twists on its axis like an eddy in water, and in the walls of this funnel dense, dark green pigment accumulates. The whole new structure is a new gullet!

Thus the mouthless piece has regenerated. It has become quite indistinguishable from the other piece, which has had a gullet all along. Transferred back to their culture dish, the two pieces grow, and by the next day the embryologist happily notes that there are now two perfectly normal protozoa instead of one.

The investigator continues his cutting experiments on a more ambitious scale. He subdivides his animals into several pieces, cut at random, not just in two. And here he obtains some important results. Not every piece regenerates. Some are completely devoid of nuclear material. These never form new gullets, and die after a few hours. Then there are pieces that contain one or several nuclear beads. Among these, some regenerate and some do not. Careful examination shows that if a piece contains more than one nuclear bead, it always regenerates. But of those fragments containing only one bead, a few regenerate and a few do not.

This seems rather puzzling at first, but the embryologist thinks about it for a while, and then draws the following preliminary conclusions:

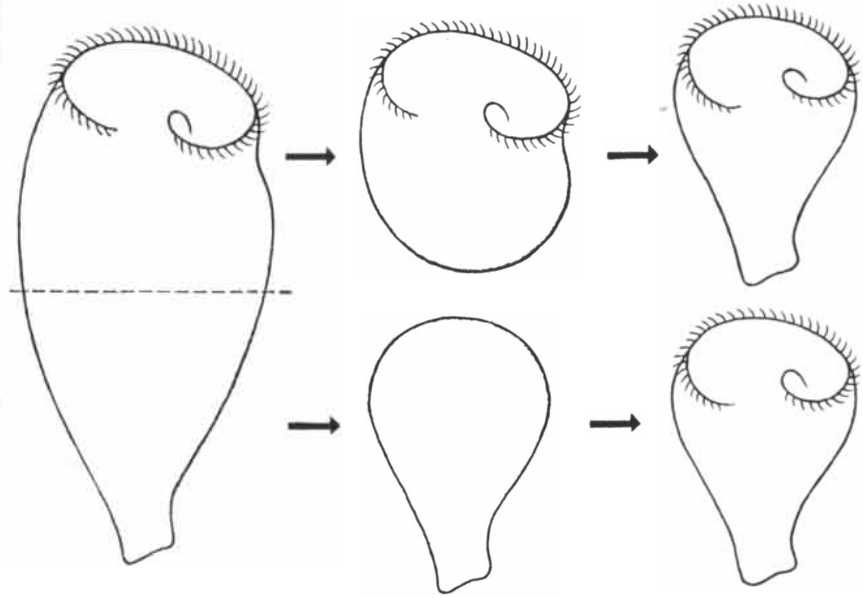
1. The regeneration process is one of cellular differentiation, for in acquiring a new gullet, the protozoon as a whole gains a very specific new character. This is quite comparable to the process in which a relatively indifferent cell, derived from a human fertilized egg, develops into a cell characteristic of big toes or of noses.

2. In the complete absence of nuclear material from a cell, regeneration (*i.e.*, differentiation) cannot occur. Since nuclear material contains genes, it may be inferred that genes are necessary for developmental processes.

3. Since some protozoan fragments having only one nuclear bead regenerate, just as those containing many beads do, it may be inferred that a single nuclear bead contains a complete set of the necessary genes. The existence of many nuclear beads in a normal animal thus probably means that several identical duplicate sets of genes are present.

4. Since, among fragments containing one nuclear bead, some regenerate and some do not, it may be inferred that certain nuclear beads are "active," in the sense of promoting regeneration, and some are "inactive." Perhaps the genes in the inactive beads are themselves somehow changed, or perhaps they remain active but their effects are blocked by some change within the bead.

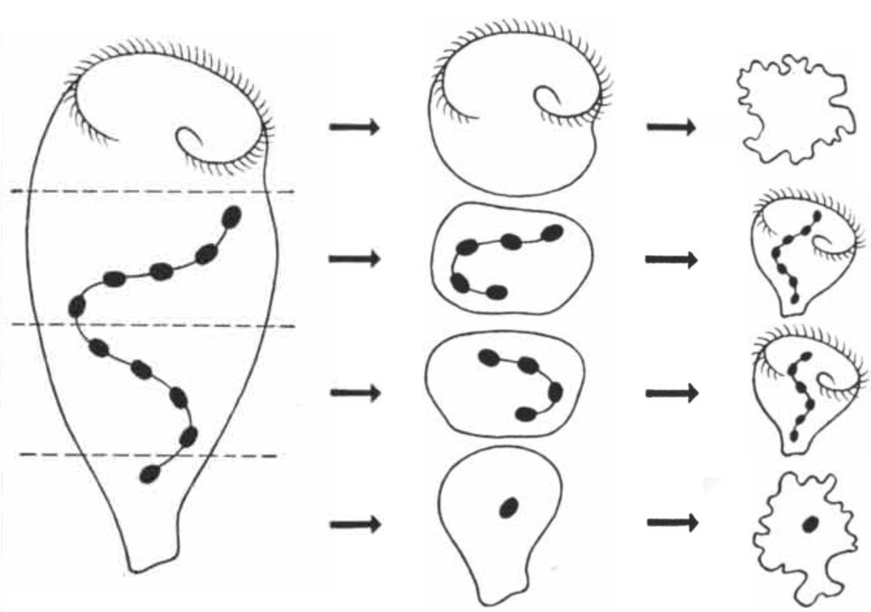
After pondering this, the embryologist asks himself two key questions. Why are some beads inactive? And in what region of the original elongated nucleus of the protozoon are such inactive beads



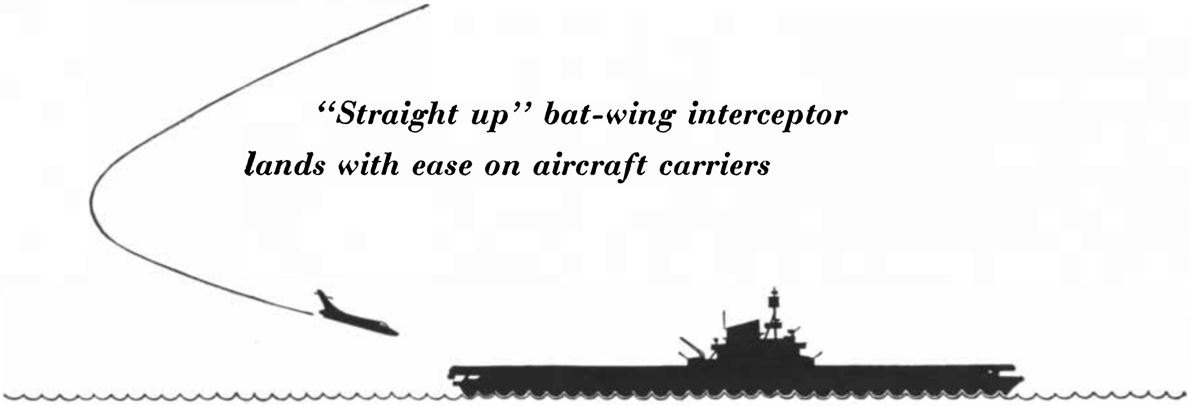
CUT IN HALF with a needle under the microscope, Stentor gives rise to two individuals. At first the one from the lower half lacks a gullet, but after five hours it grows one. The two protozoa are then indistinguishable.

located? To investigate the second question he cuts a protozoon into fragments in such a way that each fragment contains only one nuclear bead. The results leave no doubt. Pieces with nuclear beads from the front part of the original nucleus always develop a new gullet, but fragments from the hind part do not. What can this mean? Only one essential feature distinguishes the front part of the original protozoon from the hind part: the presence of gullet and associated structures. Thus the embryologist concludes tentatively that the gullet somehow keeps nuclear beads in its immediate vicinity in active operation, and that beads in the hind part of the animal become inactive because they are more remote from the gullet.

This evokes a glimmer of an exciting idea, particularly in the light of another important observation made in the earlier regeneration experiments. The embryologist noted then that whenever a fragment regenerated, a new gullet always formed in a precisely circumscribed region: namely, at one particular spot in the most forward part of a fragment. This spot was always identifiable beforehand as the forward terminus of a row of minuscule surface granules. In the intact protozoon this row



CUT SEVERAL TIMES, the protozoon gives rise to various fragments. Those containing one or more nuclear beads regenerate. Those containing no nuclear beads or only one of them near the tail do not regenerate.



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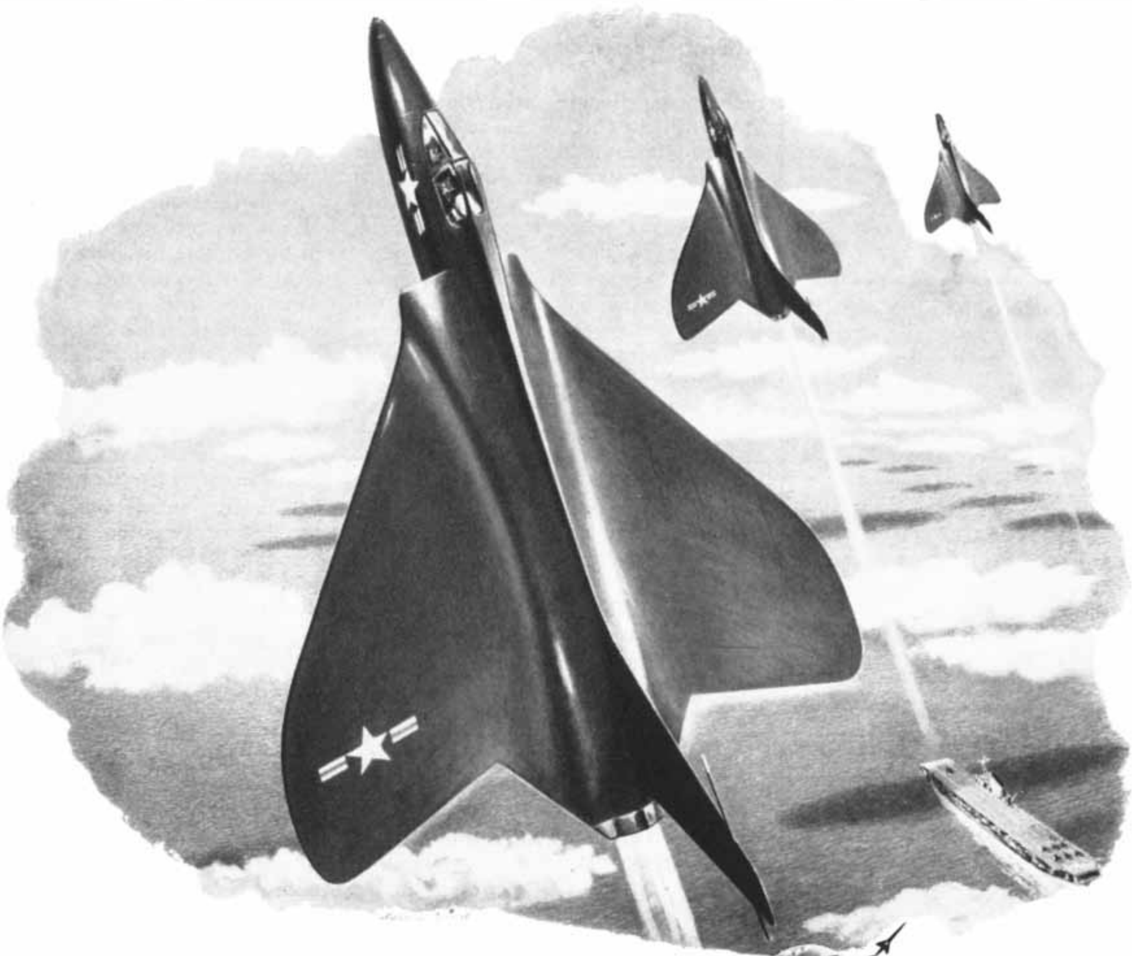

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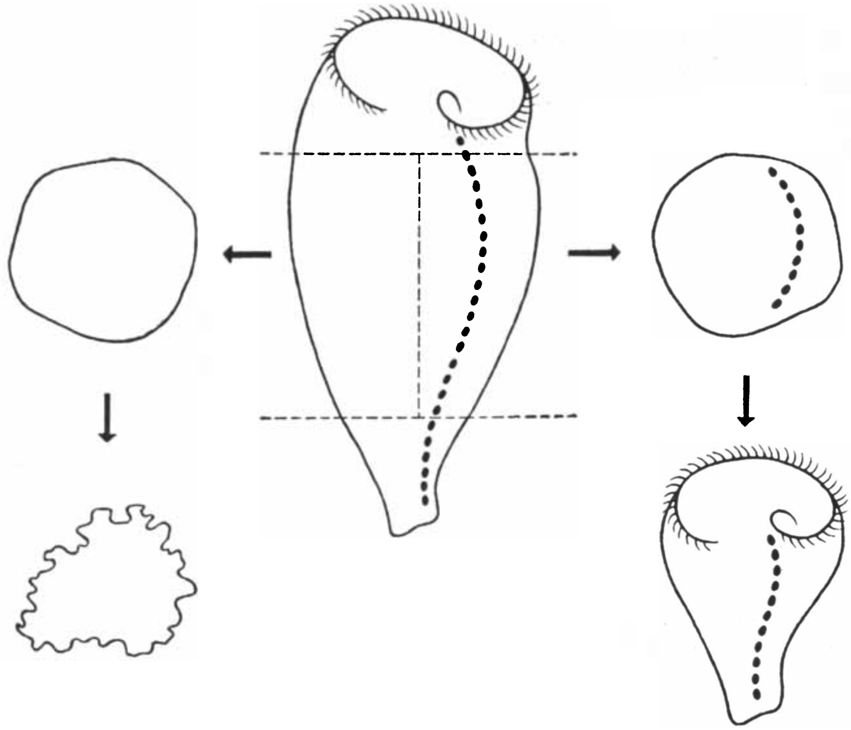

CUT LENGTHWISE, the protozoon is divided into a fragment that contains surface granules and one that does not. Even though it may contain nuclear beads, the fragment without granules does not regenerate.

ran the whole length of the animal, from gullet to hind end. When, in the course of cutting an animal up, a length of this granular row was incorporated into a fragment, then the new gullet always appeared at the free forward end of the length of granules.

Can it be that formation of a gullet is strictly dependent on the presence of such a free forward end, as well as being contingent on the presence of active nuclear beads? This can be checked fairly easily. The embryologist cuts away the entire row of granules from an intact animal. Then he processes this protozoon into fragments, taking care that active nuclear material is included in fragments to be studied. None of these pieces regenerates!

THE PARTS of the puzzle begin to fall into place in the embryologist's mind. He believes he needs just one more bit of information before he can picture the essential features of the differentiation process. What role does the granular row play in normal regeneration? Do the granules secrete something without which gullet formation would be impossible? Or are the granules themselves among the necessary building blocks in the construction of a gullet?

Painstaking examination of killed and stained fragments at various stages of regeneration, as well as search through the literature about earlier work, provides the answer: the granules are building blocks. They probably carry out secretory activity also, but for the question at issue the absence of granules from a fragment clearly amounts to the absence of bricks with which a new gullet might be constructed.

Now the embryologist believes he has all the key pieces of the puzzle and can fit them into a meaningful pattern. It is clear that regeneration depends on two conditions: presence of active nuclear beads and presence of surface granules. The nuclear material of a fragment secretes some substance which affects the surface granules in such a way that they build up into a new gullet. The gullet in turn acts back on the nuclear beads in its vicinity and keeps them active. Those too far away to be affected by this back action become inactive, meaning that they cannot promote gullet formation. This may explain why a protozoon possesses only one gullet, located in one particular region, rather than several gullets, distributed all over the body surface.

To learn that the nucleus of a cell contributes to the differentiation of that cell is not a startling discovery; this has long been known. What is rather more interesting is the demonstration that particular features of a cell may act back on the nucleus and determine to what extent that nucleus remains active. The nucleus, sometimes looked upon as the "absolute ruler" in a cell, now appears to be under the control of the very components which it controls! Evidently the rule of the nucleus is not absolute. On the contrary, a cell turns out to be a democratic institution, where "the gov-

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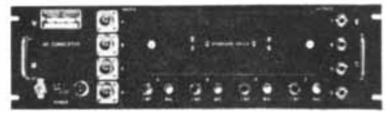
FOUR-CHANNEL
OSCILLOGRAPH RECORDING SYSTEM
(MODEL 67)

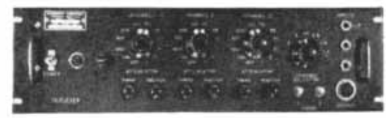
A

DC PREAMPLIFIER

AC PREAMPLIFIER



DC CONVERTER—for low level DC recording such as thermocouple output.



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B

DC (General Purpose) AMPLIFIER

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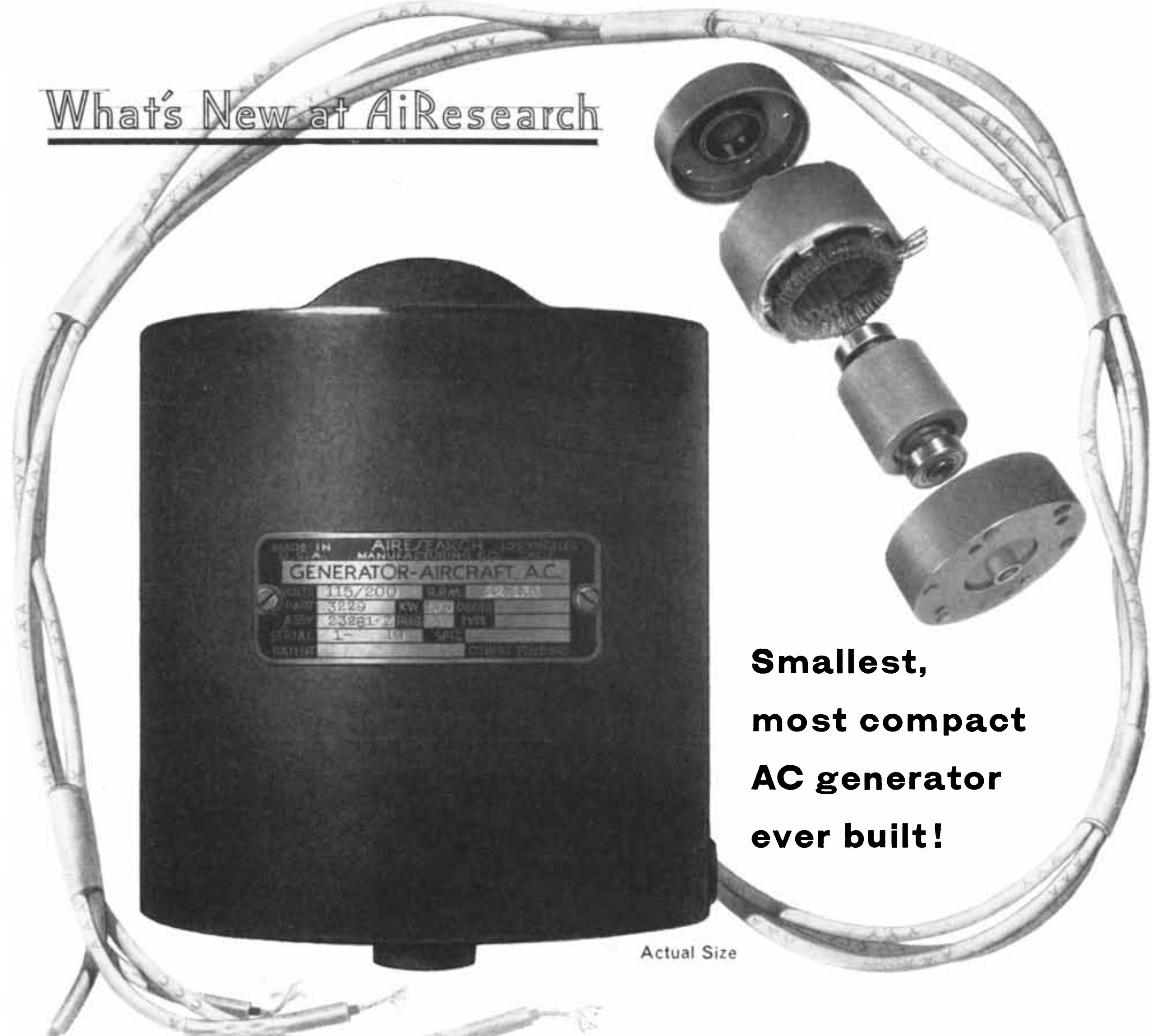
ernment controls the people and the people control the government."

The embryologist realizes quite clearly that his experiments provide only a tiny beginning of an answer to his original question about cellular events in embryos: *i.e.*, whether changes in the sets of genes (the nuclear management) or in the rest of the cell (the organization under that management) are chiefly responsible for differentiation. What his experiments have accomplished is to produce support for the view that differentiation of cells in the embryo is neither a matter of old managers with a new staff, nor a matter of new managers with an old staff. If anything, it is probably a matter of both. Moreover, he has produced some reasons to believe that the nuclei of certain embryonic cells actively promote the transformation of these cells into nose, but in so doing these nuclei may become inactive for the formation of anything but nose. By the same token, a nose cannot form in the vicinity of big toes, for the nuclei of the latter may have become inactive for the development of anything but big toes. Thus the embryo normally ends up with just the right number of toes and noses, situated in just the right places.

THE embryologist is well satisfied with his excursion into the realm of protozoa. One billion or more years ago, he muses, the ancient seas harbored primitive cellular life. From it evolved, on the one hand, many-celled organisms like man, and, on the other, modern protozoa. One might well guess that these two types of cell organization, having gone their separate ways for so immense a stretch of time, would differ today in more or less obvious ways. Perhaps most significantly, protozoan cells retain the high degree of independence of their ancestors, whereas individual human cells are now highly dependent on the other human cells making up an organism. Yet in a more fundamental sense protozoan and human cells are alike: all cells today perform certain operations to stay alive as cells, and these operations are inherited from their common ancestor, which plied the oceans eons ago.

Thus, the embryologist reflects, his embryonic cells and his protozoa share the same basic secret. His hunch that protozoa might give up that secret more readily than embryonic cells has been borne out. But he knows that much work will have to be done before it can be said that his, rather than some other, explanation of differentiation is the correct one. Therefore, like any responsible scientist, he proceeds to ask himself whether he can devise experiments which would either prove or disprove his interpretations. When last seen, the embryologist was busily at work.

What's New at AiResearch



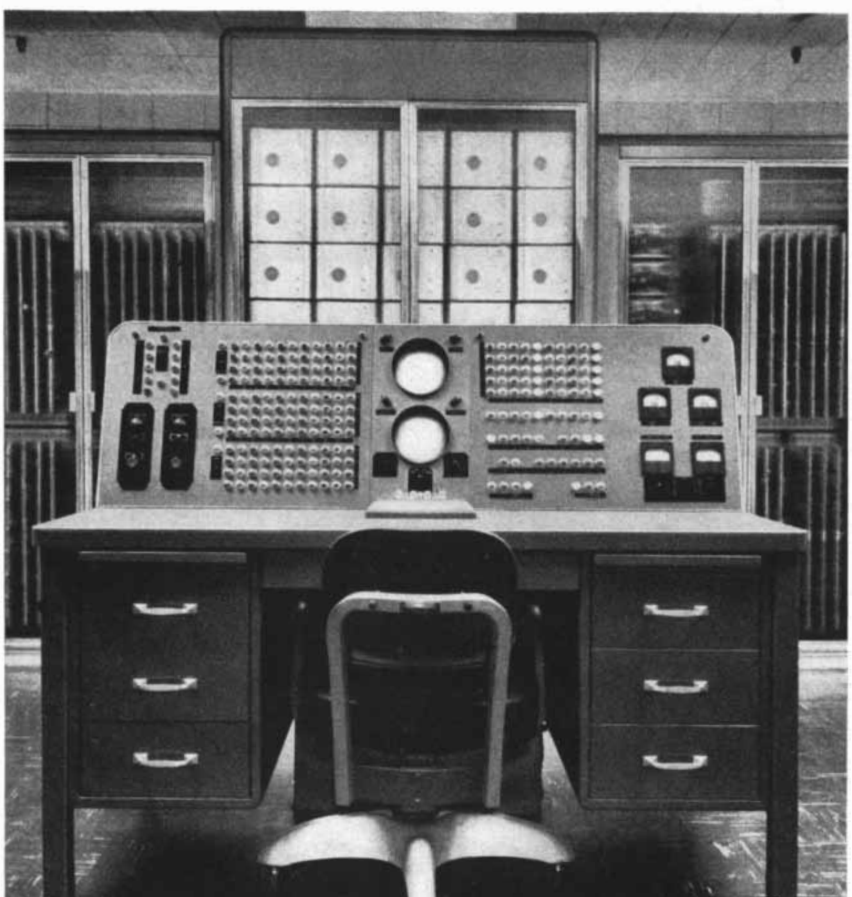
Actual Size

Perfect Numbers

Six is such a number: it is the sum of all numbers that divide it except itself. In 2,000 years 12 perfect numbers were found; now a computer has discovered five more

by Constance Reid

THE GREEKS, greatly intrigued by the fact that the number 6 is the sum of all its divisors except itself $(1+2+3)$, called it a "perfect" number. They wondered how many other such numbers there were. It was easy enough to ascertain by trial that the second perfect number was 28 $(1+2+4+7+14)$. The great Euclid was able to prove that in all cases where a number can be factored into the form $2^{n-1}(2^n-1)$ and 2^n-1 is a prime number, the number must be the sum of all its divisors except itself. Thus in the case of 6, n is 2 and $2^n-1=3$, a prime number; in the case of 28, n is 3 and $2^n-1=7$, again a prime number. With Euclid's formula it was no difficult matter to compute that the third and fourth perfect numbers were 496 $(n=5)$ and 8,128 $(n=7)$. But beyond that the computation became laborious, and in any event it was not proved that this rule included all the perfect numbers. Euclid left for future mathematicians a challenging question: How many perfect numbers are there?



COMPUTER used to find the new perfect numbers was the National Bureau of Standards' Western Automatic Computer, located in Los Angeles.

In more than 2,000 years mathematicians were able to turn up only 12 numbers that met the strict requirements for numerical perfection. Within the past year, however, the University of California mathematician R. M. Robinson has, with the aid of a modern computer, discovered five more. The discovery did not attract the attention of the press. Perfect numbers are not useful in the construction of atomic bombs. In fact, they are not useful at all. They are merely interesting, and their story is an interesting one.

For many centuries philosophers were more concerned with the ethical or religious significance of perfect numbers than with their mathematics. The Romans attached the number 6 to Venus, because it is the product of the two sexes—the odd (masculine) number 3 and the even (feminine) number 2. The ancient Hebrews explained that God chose to create the world in six days rather than in one because 6 is the more perfect number. The eighth-century English theologian Alcuin pointed out that the second origin of the human race, from the eight human beings on Noah's Ark, was less perfect than the first, 8 being an imperfect number. In the 12th century Rabbi Josef Ankin recommended the study of perfect numbers in a program for the "healing of souls."

THE mathematicians, meanwhile, had been making slow progress. The first four perfect numbers—6, 28, 496 and 8,128—had been known as early as the first century. Not until 14 centuries later was the fifth discovered. It was 33,550,336 $(n=13)$. Then in 1644 the French mathematician Marin Mersenne, a colleague of Descartes, announced six more at one clip, and thereby linked his name forever with perfect numbers. The numbers were now so large that they were necessarily described only by the prime number 2^n-1, or, more briefly, by the exponent, n, in Euclid's formula. The values of n for the 11 perfect numbers, including Mersenne's six new ones, were 2, 3, 5, 7, 13, 17, 19, 31, 67, 127 and 257. In other words, the largest prime in the series was the enormous number $2^{257}-1$.

It was obvious to other mathematicians that Mersenne could not have tested for primality all the numbers he had announced. But neither could they. At that time the only method of testing was to try every possible divisor of each number. By this laborious method mathematicians did test Mersenne's first eight numbers and found them prime.

It was the great Swiss mathematician Leonhard Euler who tested the eighth number ($2^{31}-1$). Euler also proved that all even perfect numbers must be of the form expressed by Euclid's theorem. No odd perfect number has ever been found, but it has never been proved that such a number cannot exist.

For more than 100 years the perfect number formed from the prime $2^{31}-1$ remained the largest proved. Then in 1876 the French mathematician Eduard Lucas worked out a method by which a possible prime could be tested without trying all potential divisors. At the same time he announced that he had tested $2^{127}-1$ by his method and found it prime.

According to Lucas, the number 2^n-1 is prime if, and only if, it divides the ($n-1$) term of a certain series. In this series the first number is 4 and each succeeding number is the square of the preceding one minus 2; in other words 4, 14, 194, 37,634, and so on. For example, to test the prime number 7 (2^3-1), one divides 7 into 14; the $n-1$ term in this case being the second number in the series, since n is 3. Since 7 divides evenly into 14, it is prime by Lucas' test.

Obviously even Lucas' short-cut method becomes rather unwieldy when, as in the case of $2^{127}-1$, one must divide 170,141,183,460,469,231,731,687,303,715,884,105,727 into the 126th term of Lucas' series. For such numbers, mathematicians use a short-cut of the short-cut: instead of squaring each term of the series, they square only the remainder after they have divided the number being tested into it.

Even with the help of Lucas' method mathematicians were not able to finish testing all of the possible Mersenne numbers until a few years ago. Their tally showed that Mersenne's list of perfect numbers was incorrect. He was right on nine numbers (those for which n is 2, 3, 5, 7, 13, 17, 19, 31 and 127), but he was wrong on two he had listed (those with the exponents 67 and 257), and he had missed three numbers in the series (with exponents 61, 89 and 107). Thus the list stood at 12, with $2^{126}(2^{127}-1)$ the largest known perfect number.

THEN on January 30 last year Robinson fed the problem to the National Bureau of Standards' Western Auto-

$$2(2^2-1)$$
$$2^2(2^3-1)$$
$$2^4(2^5-1)$$
$$2^6(2^7-1)$$
$$2^{12}(2^{13}-1)$$
$$2^{16}(2^{17}-1)$$
$$2^{18}(2^{19}-1)$$
$$2^{30}(2^{31}-1)$$
$$2^{60}(2^{61}-1)$$
$$2^{88}(2^{89}-1)$$
$$2^{106}(2^{107}-1)$$
$$2^{126}(2^{127}-1)$$
$$2^{520}(2^{521}-1)$$
$$2^{606}(2^{607}-1)$$
$$2^{1278}(2^{1279}-1)$$
$$2^{2202}(2^{2203}-1)$$
$$2^{2280}(2^{2281}-1)$$

LIST of perfect numbers stands at 17. The last five were added by SWAC.

matic Computer, known briefly as SWAC. This is a high-speed machine: it can do an addition of 36 binary digits in 64 millionths of a second. Robinson's job was to break down the Lucas method into a program of the 13 kinds of commands to which the SWAC responds. The job was complicated by the fact that, while the machine is built to handle numbers up to only 36 binary digits, the numbers he was working with ran to 2,300 such digits. It was, he found, very much like explaining to a human being how to multiply 100-digit numbers on a desk calculator built to handle 10. To tell SWAC how to test a possible prime by the Lucas method, 184 separate commands were necessary. The same program of commands, however, could be used for testing any number of the Mersenne type from 2^3-1 to $2^{2297}-1$.

The program of commands, coded and punched on paper tape, was placed in the machine's "memory." All that was then necessary to test the primality of any Mersenne number was to insert the exponent of the new number as it was to be tested. The machine could do the rest, even to typing out the result of the test—continuous zeros if the number was a prime.

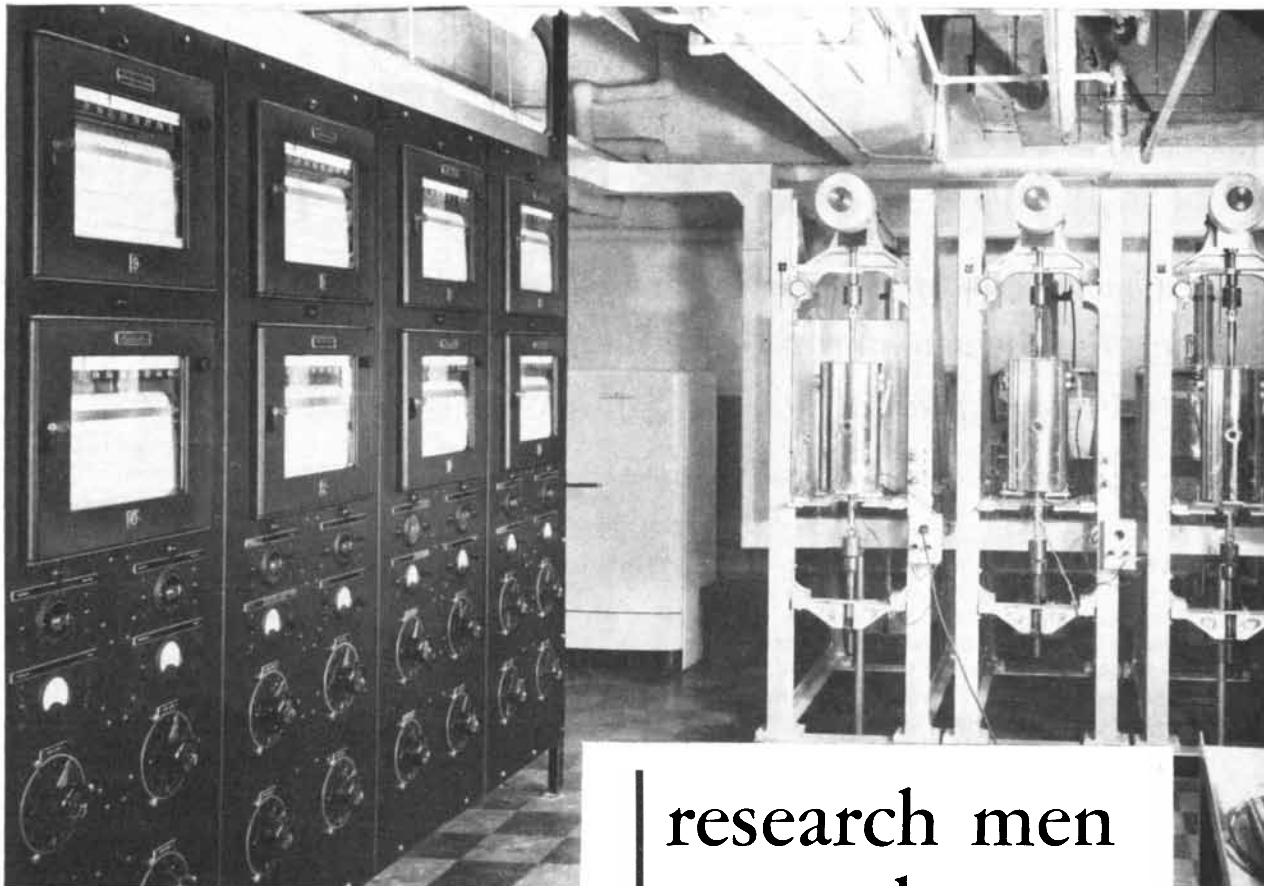
The first number to be tested was $2^{257}-1$, the largest of the 11 numbers announced by Mersenne. Twenty years before it had been found not prime by D. H. Lehmer, who worked two hours a day for a year with a desk calculator to do the test. It happened that this evening Lehmer himself, now the director of research at the Bureau of Standards' Institute for Numerical Analysis on the U.C.L.A. campus, was in the room. He saw the machine do in 48 seconds what had taken him an arduous 700 and some hours. But the machine got exactly the same result.

SWAC then continued on a list of larger possible primes. Mersenne had said that all eternity would not suffice to test whether a given number of 15 or 20 digits was prime. But within a few hours SWAC tested 42 numbers, the smallest of which had more than 80 digits. One by one it determined that they were not prime. Finally at 10 p.m. a string of zeros came up: the machine had found a new perfect number. Its prime was $2^{521}-1$. Just before midnight, 13 more numbers later, another prime came up: $2^{607}-1$. In the decimal system this is a number of 183 digits.

The machine continued testing numbers when opportunity afforded during the next few months. Last June the number $2^{1279}-1$ was found to be prime. In October, concluding the program, it established as prime the numbers $2^{2203}-1$ and $2^{2281}-1$. The latter is the largest prime number, of any form, now known.

The perfect numbers of which these primes are components are, of course, much larger—so large that in comparison with them conventionally "astronomical" numbers seem microscopic. Yet, by a proof as old as Euclid, mathematicians know that these numbers are the sum of all their divisors except themselves—just as surely as they know that $6=1+2+3$.

They still do not know, however, how many perfect numbers there are.



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Captain Bligh and the Breadfruit

The voyage of the Bounty, *which ended in the celebrated mutiny, was undertaken for an almost forgotten purpose: to bring a plant from the South Seas to the West Indies*

by Richard A. Howard

THE VOYAGE of the *Bounty*, Captain William Bligh commanding, has been celebrated in history and literature for its melodramatic end; not so widely known is the fact that its mission was as unusual as its conclusion was violent. Bligh was engaged in a project of considerable scientific and economic importance. He was attempting to transport live breadfruit trees from Tahiti, chief island of the Society group in the mid-South Pacific, to the British West Indies on the other side of the world.

The breadfruit project arose from the needs of the British planters in the West Indies. In the 18th century the islands of Jamaica, Barbados, St. Vincent, Grenada and Trinidad were planted extensively to sugar cane. The planters, regretting the amount of land and time occupied in raising food (cassava, taro and plantain) to feed their plantation slaves, thought they saw an answer in the breadfruit. News of this fabulous food had been brought to Europe by various South Seas explorers, including the adventurous Captain Cook. A British navigator, hydrographer and occasional buccaneer named William Dampier had written glowingly:

"The breadfruit (as we call it) grows on a large tree, as big and high as our largest apple-trees: It hath a spreading head, full of branches and dark leaves. The fruit grows on the boughs like apples; it is as big as a penny-loaf when wheat is at five shillings the bushel, it is of a round shape, and hath a thick tough rind. When the fruit is ripe it is yellow and soft, and the taste is sweet and pleasant. The natives at Guam use it for bread. They gather it, when full-grown, while it is green and hard; then they bake it in an oven, which scorcheth the rind and makes it black; but they scrape off the outside black crust, and there remains a tender thin crust; and the inside is soft, tender, and white like the crumb of penny-loaf. . . . The fruit lasts in season eight months in the year, during which the natives eat no other food of bread kind."

The West Indian planters were fascinated: the breadfruit crop would use relatively little land, and the plant spread rapidly, was not damaged by hurricanes, bore fruit almost the year around, required no cultivation and was well adapted to the Caribbean climate. The one serious difficulty was that the tree could not be grown from seed; it would have to be carried thousands of miles to be transplanted from the South Seas to the West Indies. This meant a voyage of several months around Cape Horn or the Cape of Good Hope, during which the delicate young tropical trees would have to be nurtured carefully and protected from the sea, the salt air and the cold of the low latitudes. The colonists called upon the mother country for help in transporting the plant.

SIR JOSEPH BANKS, president of the Royal Society, who had been naturalist on Cook's first voyage to the South Seas and knew the breadfruit at first hand, took up their cause. He persuaded King George III to charter a ship and chose as its master Captain Bligh, who also had sailed with Cook and had a keen interest in natural history. To accompany Bligh as guardians of the trees, Sir Joseph selected two horticulturists of the Kew Gardens named David Nelson and William Brown. He drew up elaborate instructions to assist them. The master and crew of the ship, he said, would have to give up its best accommodations and put up with some inconvenience to care for the plants.

"It is necessary that the cabin be appropriated to the sole purpose of making a kind of greenhouse, and the key of it given to the custody of the gardener. . . . No dogs, cats, monkeys, parrots, goats or indeed any animal whatever must be allowed on board except the hogs and fowls for the Company's use; and they must be carefully confined to their coops. Every precaution must be taken to prevent or destroy rats as often as convenient. As poison will constantly be used to destroy them and cockroaches, the crew must not complain if some of them who may die in the ceiling make an unpleasant smell."

The *Bounty* sailed from England on October 15, 1787. She set off on the route around South America, but she failed to round Cape Horn; after 30 days of battle with the wind and currents, Bligh turned her about and sailed across the South Atlantic to go the other route around the tip of Africa. He reached the Cape of Good Hope on May 22. There he spent 40 days repairing and restocking the ship, took aboard some fruit trees and other plants and then sailed for Tasmania, the large island immediately south of Australia. At Tasmania the *Bounty* stopped briefly to plant the African trees and to pick up fuel wood. On October 24, after a full year's voyage, the ship arrived at Tahiti.

Bligh was able to persuade the chiefs of the tribes on Tahiti to present some of their breadfruit trees as a gift to King George. Nelson and his assistant proceeded to pot the young plants in a shelter on the shore. Bligh, aware of the scientific interest taken in his voyage, made precise notes about the trees he was collecting: "The natives reckon eight kinds of breadfruit trees, each of which they distinguish by a different name. . . . In the first, fourth and eighth class the leaf differs from the rest; the fourth is more sinuated; the eighth has a large broad leaf, not at all sinuated. The difference in the fruit is principally in the first and eighth class. In the first the fruit is rather large and more of an oblong form; in the eighth it is round and not above half the size of the others."

The visit was not a matter of all take and no give. Bligh had brought some plants for the Tahitians, and he looked around eagerly to see what they had done with gifts from earlier voyages. "I had the satisfaction," he wrote, "to see, brought to me, a fruit which they had not, till we introduced it. And among the articles which they brought off to the ship and offered for sale, were capsicums, pumpkins and two young goats."

Among the new seeds he now gave them were melon, cucumber, salad greens, fruit stones and almonds. Also, "as they are very fond of sweet-smelling flowers with which the women delight to ornament themselves, I gave them some roseseed." However, on the following day he "had the mortification to see that our garden-ground had been much trodden."

On January 31, 1789, getting ready for the return voyage, Bligh wrote in his diary: "This morning I ordered all the chests to be taken on shore, and the inside of the ship to be washed with boiling water to kill the cockroaches. We were constantly obliged to be at great pains to keep the ship clear of vermin. . . . By the help of traps and good cats, we were freed from rats and mice." On March 31 Bligh noted: "Today all the plants are on board, being in 774 pots, 39 tubs and 24 boxes. The number of breadfruit plants was 1,015; besides which we had collected a number of other plants."

AT LENGTH on April 4, more than five months after its arrival at Tahiti, the *Bounty* was ready to sail for the West Indies. She set off westward for the Cape of Good Hope route. On April 27, after a brief stop at the Tonga island group, Bligh noted that "thus far, the voyage has advanced in a course of uninterrupted prosperity, and has been attended with many circumstances equally pleasing and satisfactory."

On the very next morning the famous mutiny broke out. The first thing Mr. Christian and his followers did after seizing the *Bounty* and putting off her captain was to throw the cargo overboard. Within a few hours the breadfruit were floating around in the Pacific.

Bligh's subsequent voyage of 3,600 miles in an open boat has become one of the epics of the sea. In October of 1789 he was in Batavia on his way home, and from there he wrote to Sir Joseph Banks:

"You will now, Sir, with all your generous endeavours for the public good, see an unfortunate end to the undertaking; and I feel very sensibly how you will receive the news. . . . To those, however, who may be disposed to blame, let them see I had in fact completed my undertaking. . . . I had most successfully got all my plants in a most flourishing and fine order. . . . I even rejected carrying stock for my own use, throwing away the hen-coops and every convenience. I roofed a place over the quarter-deck and filled it with plants, which I looked at with delight every day of my life."

Despite the disastrous end of the mission, Banks remained a staunch friend of Bligh. Shortly after the courts-martial of the mutineers in October, 1790, Banks began to appeal anew to the Ministry of the day, and in December, 1790, he gained approval for a second breadfruit voyage. Bligh was again picked for the job and this time given command of the *Providence*, a ship somewhat larger than the *Bounty*. She was to be accompanied by an armed brig, the *Assistance*. Two men from Kew Gardens, James Wiles and Christopher Smith, again went on the trip.

THE EXPEDITION sailed on August 3, 1791, and took the route around the Cape of Good Hope. Bligh reached Tasmania on February 8, 1792, and carried out some of his customary plantings. He found the date 1777 cut into trees by Cook and added the following inscription: "Near this tree Capt. William Bligh planted seven fruit trees in 1792: Messrs. S & W botanists." A few years later the French naturalist Jacques Labillardiere, seeing this inscription, was "scandalized by the despotism which condemned men of science to initials and gave a sea captain a monopoly of fame."

The *Providence* and the *Assistance* arrived at Tahiti on April 8, 1793. Their reception was pleasant. Arrangements were once more made to obtain breadfruit. Wiles and Smith built a shed on shore to shade the plants while they were being potted. After taking root, the plants were ferried out to the ship. At the end of three months Bligh noted with satisfaction: "All the plants are now in charming order, and spreading their leaves delightfully. I have completed nice airy spaces for them on the quarterdeck and galleries, and shall sail with every inch of space filled up." On July 18, as the ships were quitting Tahiti, the captain found time to report: "Upon a moderate calculation we suppose total of plants on board to number as follows: breadfruit 2,126, other plants 472, curiosity plants 36—total 2,634."

The expedition sailed west by way of the Fiji Islands and reached the coast of New Guinea on August 27. Ahead of them lay the dangerous passage through the Torres Strait between Australia and New Guinea. The commander of the *Assistance* wrote: "Every day now becomes more critical on account of the plants; a number of them have dropped

PORTRAIT OF BLIGH appears in his book *A Voyage to the South Sea.* In the background is the small boat in which he was set adrift by his crew.

YOUNG BREADFRUITS were photographed in a botanical garden on the Caribbean island of St. Vincent, where Bligh left his first breadfruit plants.

off and our prospect of getting through becomes very uncertain. . . . It is absolutely necessary to shorten their allowance of water so that in case we are foiled in finding a passage there may be enough left to save the ship's company during the time of beating back. The want of water is all we dread."

The passage from the Pacific Ocean to the Indian Ocean took 19 days, and the vessels put in at the island of Timor on October 3. Bligh was becoming worried about his cargo. He wrote: "I can assign no reason, but the loss of our breadfruit at this time amounted to 224 pots." After taking on other varieties of plants at Timor, the ships set off on the long slow passage across the Indian Ocean. The season was now well into winter. Bligh had fair weather on his trip around the Cape of Good Hope but encountered severe gales on the northward leg of the voyage along the west coast of Africa. As he approached the island of St. Helena, where a selection of breadfruit was to be delivered, he remarked: "My plants have been shut up close these few days past; they are nevertheless doing well, but these adverse winds are much against them." On December 11, he counted survivors and discovered that he had only 830 plants left of the original 2,634.

Bligh informed the governor of St. Helena that he had orders to "give him into his care ten breadfruit plants, and one of every kind (of which I had five) as would secure to the islands a lasting supply of this valuable fruit which our most gracious King had ordered to be planted there." Before leaving St. Helena, Bligh received a letter from the governor and his council, expressing their gratitude to the king and stating that the sight of the *Providence* "had raised in them an inexpressible degree of wonder and delight to contemplate a floating garden transported in luxuri-

ance from one extremity of the world to the other."

AFTER a rough passage across the South Atlantic, the *Providence* and her escort reached St. Vincent, their first port in the West Indies, on January 24, 1793. Arrangements were made for Negroes to carry the plants on their heads to the botanic garden two miles away. On the return trip they brought plants for Bligh to take to England.

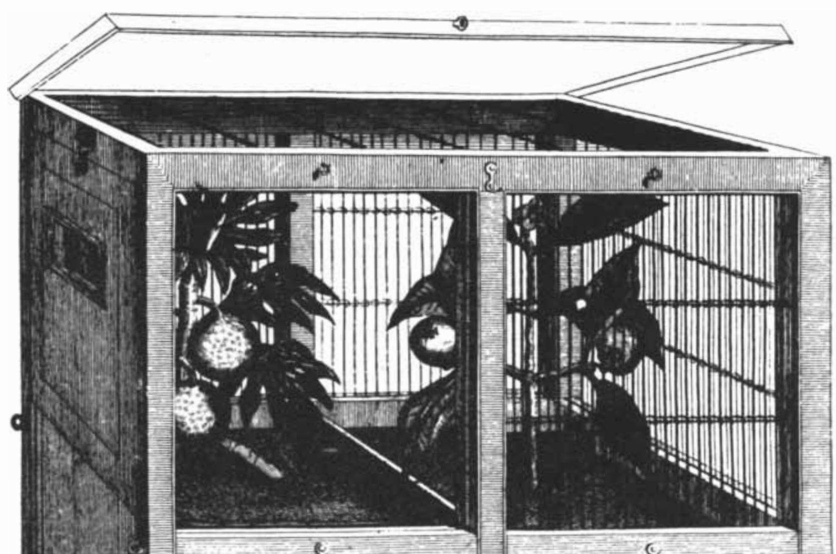
Bligh was warmly received by the planters of St. Vincent. He reported: "A deputation from the Council and Assembly awaited on me the day after my arrival and presented me with a resolution and request to accept a piece of plate valued at 100 guineas as a mark of their approbation and esteem. They likewise did me the honor to give a public dinner to all my officers. . . . I left in all 544 plants at this place, and I received, for his Majesty's garden at Kew, 465 pots and 2 tubs containing botanic plants."

Bligh's party left St. Vincent on January 30, 1794, and arrived several days later at Port Royal, Jamaica. There the remaining breadfruit trees were delivered and Bligh again received the ceremonious thanks of the community.

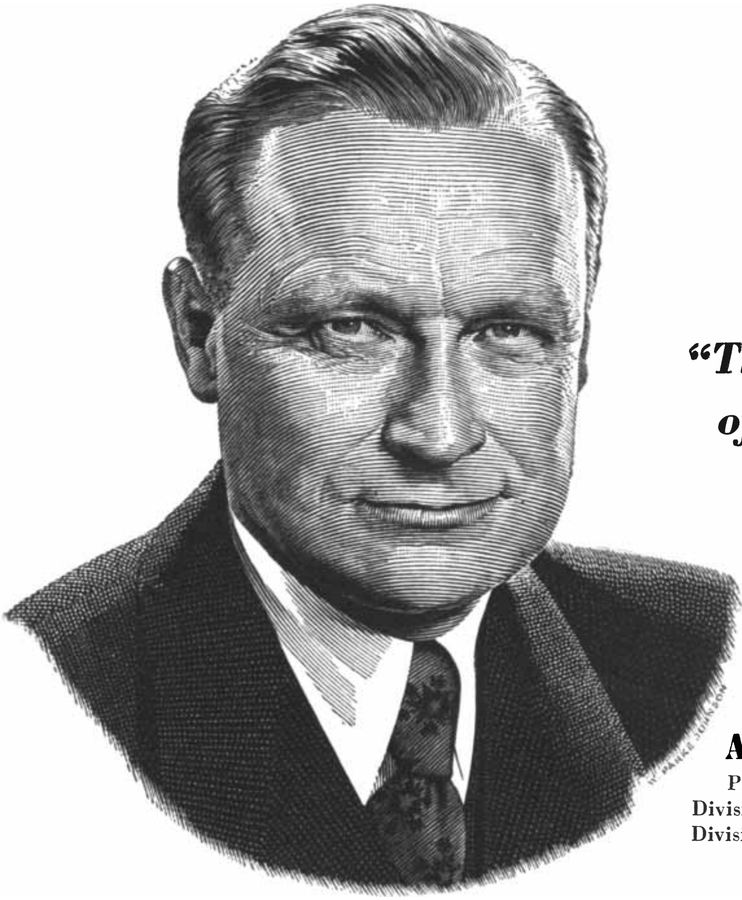
Thus on the second try Bligh completed successfully one of the most difficult transplantation undertakings in the history of commercial horticulture. The French had brought in a few breadfruit before he finished his second voyage, but Bligh has always received credit for the successful introduction of the plant. With the help of Banks, he had shown how the transporting job could be done, and it is probable that most of the trees growing in the West Indies today are the offspring of Bligh's stock.

After a few months' delay due to the outbreak of war with France, the *Providence* sailed for England on June 15, 1794. She carried from Jamaica specimens of the custard apple, avocado, cabbage tree, akee, wild mangosteen, naseberry and other plants. Altogether she brought 1,283 plants to Kew Gardens as the gleanings of her tropical voyage. On August 7 she dropped anchor at Deptford, her journey completed.

Little has been recorded of Bligh's reception in England. He was still disliked in many quarters for the *Bounty* episode, and his homecoming occasioned a renewal of hostile articles. But he apparently received a gold medal and in 1801 was elected a fellow of the Royal Society in consideration of his distinguished services to navigation and botany. Bligh remained in the Navy and



BREADFRUIT CAGE was designed to transport the plant from the South Seas. On the *Bounty*, however, most of the plants were carried in pots.



"The enthusiastic response of our employees . . ."

ALDEN G. ROACH
President, Columbia-Geneva Steel Division and Consolidated Western Steel Division, United States Steel Corporation

"It is most gratifying to me that the employees of the Columbia-Geneva Steel Division and the Consolidated Western Steel Division of United States Steel Corporation have accorded meaning to their belief that the security of our nation rests upon our cooperative effort. The enthusiastic response of our employees made me doubly glad we conducted a person-to-person canvass for the Payroll Savings Plan for U. S. Defense Bonds."

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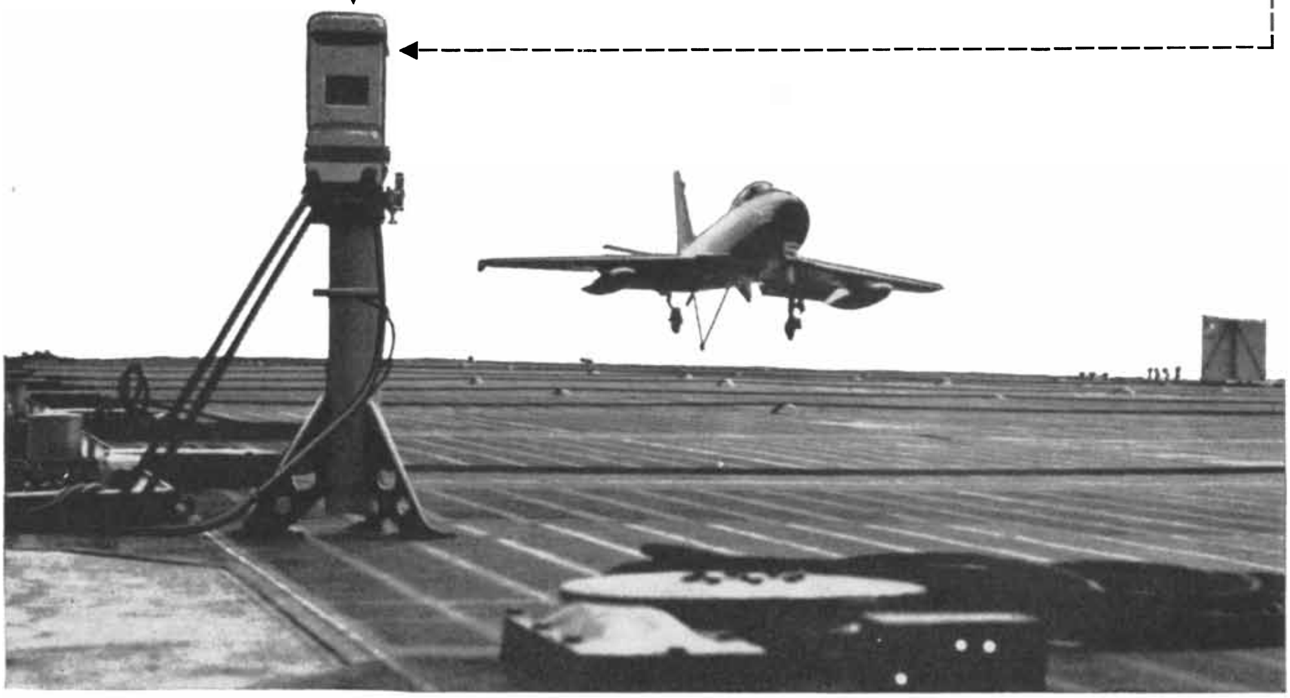
YOUNG BREADFRUIT TREE was photographed on Puerto Rico. The plant was brought to the West Indies to feed slaves, but they did not like it.

was eventually promoted to the rank of vice-admiral. For a short time, 1806-1810, he was governor of the colony in New South Wales. He died in 1817 at the age of 64.

CONSIDERING the eagerness with which the West Indian planters had sought the breadfruit, the islands' reception of it was disappointing. Hinton East, one of the proponents of the expedition and perhaps the leading planter and horticulturist in Jamaica at the time, had died shortly before the *Providence* arrived. The gardener Wiles, who stayed in the islands to superintend the cultivation of the new trees, wrote discouraged letters to Banks. Although the breadfruit trees eventually prospered in their new setting, they did not fulfill the planters' dreams. Apparently the Negro slaves did not care for the fruit. By 1850 breadfruit was being fed almost exclusively to pigs and poultry—with, however, excellent results.

More recently the breadfruit has staged a revival. Today West Indians, to whom the breadfruit is now a native tree, accept the fruit as a basic part of their diet. Although it has never become as important in the West Indies as it is in the South Seas, it is highly appreciated as an emergency food. It tides over a large part of the population during the periodic crop failures. Of 52 species of plants that Bligh brought to the West Indies, breadfruit has proved by far the most important.

BRIGHT MINDS CONJURE UP ELECTRONIC MENTAL GIANTS



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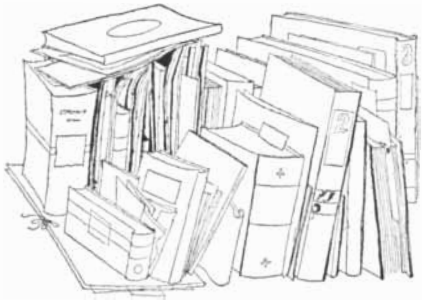


BOOKS

An aerial view of the earth and how man has changed it, not always for the best

by James R. Newman

OUR WORLD FROM THE AIR, by E. A. Gutkind. Doubleday & Company, Inc. ($7.50).

GUTKIND is an English architect, town planner and sociologist, known to American readers for two studies he contributed to the late Karl Mannheim's noted series, the *International Library of Sociology and Social Reconstruction*. His opinions on man's relationship to his environment—at least those I can understand—seem to me thoughtful and high-minded. Unfortunately he practices a high-flown and diffuse idiom, as if he felt the subject were too important for plain words. In this volume his ideas are transmitted mainly by pictures and come through with a minimum of noise. Starting with a brilliant conception, he has given it form in an exciting book. It is a remarkable collection of aerial photographs which tell far better than it has been told before the story of how man has changed the surface of the earth; how climate, contour and other features of the land have imposed habit and habitat upon him; how in time he has gained a limited dominion over his surroundings, and how he has used and misused this power. *Our World from the Air*, Lewis Mumford writes in his introduction, "gives a sense of man's common origin, his common problems, his common destiny." It is a book that stretches the mind and enlarges vision. It could not have come at a better time.

Gutkind makes four main groupings of his pictures. Each group corresponds to what the author defines as a stage of man's "changing attitude towards his environment." The primary motive for clearing the land, building or otherwise "altering the position of matter at the earth's surface" (to use Bertrand Russell's definition of "work") is survival. The first stage embraces the simple quest for food, shelter and protection. Examples of this—as of the other stages—can be observed in different parts of the world; the stages often overlap where different cultures, each possessing its own characteristic rate of development, encroach upon one another and diffuse.

Temporary shelters provide a clear illustration of a timeless need. Prehistoric man lived in caves and rock dwellings; in present-day Europe, Asia and Africa many people still live in caves. Primitive man lived in huts and tents, and so do countless thousands of people today: Arabian tribesmen in black tents laid out in concentric circles around desert watering places; American industrial workers in rectangular arrays of Quonset huts and trailers; vagabond American families in trailers that pursue the warm sun; Chinese in floating huts on the Pearl River. The Mongol nomad's home is an interesting example of the intersection of two cultures. This once fancy-free fellow "has become

An African village as seen from the air sedentary under the influence of the Chinese peasant." He used to live in a felt hut called a *yurt*, easily set up and taken down; he now builds himself a massive Chinese house plus a *yurt* and surrounds the whole with a heavy wall.

Many methods are employed for the protection of communities. Jericho and Troy had walls; atomic energy installations in New Mexico are surrounded by electrically charged fences; in Northern Rhodesia the Ba Ila village of Chief Mukobela consists of about 1,000 straw and mud huts almost touching each other in a large defensive circle; the German village of Buberow, east of the Elbe, forms a typical ring-fence design, the farms being laid out around a central square, "originally with only one exit." The site itself may afford protection. In Alaska Eskimo pile-dwellings perch like disheveled, long-legged birds on the sides of steep cliffs overhanging the sea. In the Great Swamp of Colombia are fishing villages built on stilts, where they are comparatively inaccessible. In the Euphrates and the Rhine, settlements snuggle on river islands. In Portugal the famous Castelo de Almourol rises from Roman and Moorish foundations on a pile of rocks at the confluence of the Zezere and Tajus rivers and broods over the countryside.

The hilltop is a favorite town site. Montecompatri in Italy is a superb architectural composition, its medieval houses like a worshipful congregation attending the great church on the crown of the hill. San Gemignano in Tuscany, with its magnificent fortified palaces of the Guelphs and Ghibellines crowded together in a narrow space, shows a sky line resembling that of New York. "In both cases," says Gutkind, "the power motive played a considerable part: power for power's sake and power for profits' sake."

Among the most striking of the walled places of Europe are those designed by the celebrated French military engineer the Marquis de Vauban; a notable example is Montlouis in France. Vauban was a contemporary of Molière; he was a young man when Descartes died; while he was building his fortifications, Lenôtre was designing the gardens of Versailles and Racine was writing his plays. Of this civilization, with its magnificent inconsistencies, Vauban was a true product. The fortresses he built were not only meant to do a practical job but by their massive and imposing elaborateness to symbolize authority. This dual theme of domination and protection repeatedly finds expression in the citadels designed by Vauban and his followers, and in grandiose edifices in Iran, China, Czechoslovakia, Sweden, Saudi Arabia, Peru, Denmark.

The defense unit is not always small, compact or based upon terrain. Sometimes entire countries have been walled in—a folly whose practice is not confined to ancient times. The most familiar example is the Great Wall of China, begun about 500 B.C. In the Middle East a 100-mile wall, erected shortly after Alexander's time, bisects the Turkomen Steppe from the Caspian Sea to the mountains in the east; its remains, and those of the rectangular forts linked with it, are still visible from the air. Peru had its Great Wall built on the knife-edge of great mountain spurs; "how far it stretches into the Andes has not yet been discovered." The most modern national wall was the preposterous Maginot Line. The airplane has made useless the Emperor of China's system of national protection. Today stone walls have been supplanted by radar networks—which warn the inhabitants of the approach of visitors but cannot keep them out.

Gutkind's second stage is called "confidence and adjustment." Men spread over the land and more systematically shape it to their use. The river Elbe is narrowed by jetties which have the effect of deepening it and preventing it from silting up. In China and South Africa and Siberia the land is scored with ditches to make it more fertile. In Holland the sea is pushed back and the land reclaimed to raise crops and build cities. In India and China the river levels are raised and the land is partially submerged to grow rice and mulberry trees. In Mexico floating islands called *chinampas*, covered with fertile soil, produce vegetables for the population of Tenochtitlan. In England Cambridgeshire farmers cultivate rectilinear fields laid out in Roman times. In the U.S.S.R. the featureless steppe is transformed into cultivable parallel strips arranged in blocks. In France, Italy and Switzerland the land is cultivated so intensively that scarcely a square yard of fertile soil on the steepest hillside escapes planting.

Rivers, bridges and roads bring men together, knit their interests, make them more dependent on each other, intensify their rivalries and promote trade, commerce, exploration, travel and war. Cities expand, their unity no longer artificially determined by defensive walls but rather by "some focus on which the life of the community is centered, whether it be the church, the palace or the market place." Social, political and economic circumstance play an increasing part in regulating the cities' growth.

Tatsienlu, on the Tibetan frontier, is a mountain-guarded city where the great caravans assemble. Looking at its picture from the air, one can understand the need for a city at this point, why it grew, why it took the shape it did, what held the community together. The Austrian town of Salzburg, descended from a pre-Roman settlement, was once a community with a fortified castle as its focal point of development; later, as the influence of the Church increased, churches, convents and the Archbishop's residence replaced the castle as the focal point. The Emperor's palace in Peiping—heaven only knows who lives in it *now*—is geographically as well as symbolically the center of the forbidden city. The unifying symbol of Athens was the Acropolis; of Isfahan, once the capital of Persia, the Shah's Square and Mosque. The Cathedral of Notre Dame, rising like an apostolic scepter on the Ile de la Cité in the Seine, stands on the island that was "the nucleus from which Paris originally grew, the meeting point of two important trade routes." In Norway the city of Bergen gained its leading position because of its excellent harbor—a circumstance which has contributed to the growth and prominence of countless other cities. Berne, Rome, Amsterdam, Venice—each in its own way, as the photographs clearly show, is a city whose architecture, layout and history have been determined by the water that surrounds or flows through it.

The stage of "confidence and adjustment" gradually deteriorates into what Gutkind calls "aggressiveness and disintegration." The population of the world begins "mightily to increase"; cities burst from their original confines and sprawl out; natural resources are consumed at a prodigious rate; the landscape is ravaged and despoiled. Lewis Mumford, in his admirable book *The Culture of Cities*, called the 15th century a turning point for Western civilization. The end of that century marked the beginning of the period of "mechanical integration and social disruption . . . [proceeding] side by side." Since the time structure differs for each culture, the stage of social disruption comes sooner to some communities than to others—soonest to those most advanced. (It came late to North America, but the progress from stage to stage took place at a syncopated rate.) "The result [of the rapid growth of cities]," wrote Mumford, "was not a temporary confusion and an occasional lapse in efficiency. What followed was a crystallization of chaos: disorder hardened uncouthly in metropolitan slum and industrial factory districts; and the exodus into the dormitory suburbs and factory spores that surrounded the growing cities merely widened the area of social derangement. The mechanized physical shell in every growing town took precedence over the civic nucleus: men became dissociated as citizens in the very process of coming together in imposing economic organizations. Even industry, which was supposedly served by this planless building and random physical organization, lost seriously in efficiency: it failed to produce a new urban form that served directly its complicated processes. As for the growing urban populations, they lacked the most elementary facilities for urban living, even sunlight and fresh air, to say nothing of the means to a more vivid social life. The new cities grew up without the benefit of coherent social knowledge or orderly social effort: they lacked the useful urban folkways of the Middle Ages or the confident esthetic command of the Baroque period: indeed, a 17th-century Dutch peasant, in his little village, knew more about the art of living in communities than a 19th-century municipal councilor in London or Berlin. . . . And where, as in North America, the loss was not alleviated by the continued presence of great monuments from the past and persistent habits of social living, the result was a raw, dissolute environment, and a narrow, constricted and baffled social life."

In the third section of Gutkind's book a group of striking photographs testifies to the truth of this indictment. New Orleans, a huge, formless city with a "veneer of geometric inlay" covering the paved earth, is "a desert of stone." It has to be viewed from the air to be properly judged—and condemned. Photographs taken from Gutkind's "magic helicopter" show the defacement of the landscape in many parts of the world: the open pits of the Premier Diamond Mine near Pretoria in the Transvaal; the hills of Pachuca in Mexico, honeycombed by centuries of clawing at the earth by Spaniards in search of silver; the evil-looking forest of oil derricks near Los Angeles; the jumble of miners' huts, dumps, railroad tracks, collieries, shacks and furnaces in the Pas-de-Calais of France; the dismal copper mining town of Butte, Mont.; the inhuman compounds of the Borsig factories and workers' homes in Berlin, of the Renault Works near Paris, of the potteries in Staffordshire, of the nickel refinery at Port Colborne in Canada. In Brabant, Belgium, where the famous grapes of Hoeylaert are matured in glass houses, the workers' dwellings are "a mere annexe"—grapes are tenderer than men.

A remarkable exemplar of dismal modern standardization is the modern "ribbon development," with houses set up, mile after mile, following the bend of the road. Such developments in the London area, in Kyushu, near Nagasaki, and in Queens County, New York, are shown here from the air. New York City and Chicago represent the worst in urban concentration, in the elaboration of mechanical skill without proper concern for human needs or values. Manhattan, for all its strange beauty and its valiant improvements in housing and highways, is a city fit neither for living nor working. Its spectacular buildings prove that men are ingenious rather than sensible. Only a complex system of express highways, elevated roads and cloverleaf junctions prevents its traffic from grinding to a dead stop. These devices show what can be done by rational methods to offset the effects of irrationality, and alleviate symptoms, but the disease remains.

Gutkind concludes his study with a brief pictorial survey of the stage of "responsibility and unification," which so far is more a promise than an actuality. Examples of rational exploitation and planning include the great Colorado, California and Tennessee Valley dams; the Ukrainian and Uzbek hydroelectric systems; contour plowing, strip-cropping and other land conservation methods; the decentralization of industry, and urban developments in which thought is given to man's need of light, air, recreation areas and the like. This is, regrettably, the weakest section in Gutkind's book. It is strange, for instance, that not a single illustration is given of town planning in the U. S., Great Britain, France or the Scandinavian countries.

The book has other shortcomings. There are numerous factual errors. Gutkind reports that Death Valley is 5,798 feet below sea level; my geographical dictionary gives the figure 280 feet, which sounds more plausible. Some of the picture captions are completely opaque. Gutkind's attempt to superimpose his theoretical scheme of social evolution on the photographs by grouping them neatly under various headings is artificial and often confusing.

Nonetheless, perspectives of compelling force emerge from this work. It gives coherence to vague impressions regarding the heterogeneity of lands and people. It emphasizes the complexity of social and economic problems, yet relieves the conviction that their solution is hopeless. One gains insight as to what men have in common, as to their essential dependence on each other, as to the dangers they face, the values and benefits they neglect. One becomes aware of the extent to which man now makes his own environment. His future depends on whether he can learn to control himself as well as he has learned to control fire, to harness social forces as cleverly as he now harnesses rivers.

Gutkind's pictures are wonderful solvents of prevailing dogmas. Look at the fields, villages and cities of China, look at them from high up and reflect upon the widely accepted opinion that the Chinese people are yearning to embrace the social, political and economic institutions of rural Ohio or Los Angeles. The decrepit phrase about the forest and the trees draws fresh life from these pages. The world seen from the air is the world for the first time seen whole—except possibly by angels. Seeing it whole is the prerequisite to understanding some of its "secrets," more useful secrets, I venture to say, than those of the atom.

THE STEAM LOCOMOTIVE IN AMERICA: ITS DEVELOPMENT IN THE TWENTIETH CENTURY, by Alfred W. Bruce. W. W. Norton & Company, Inc. ($7.50). The era of the steam locomotive is ended. Thousands of these power-

ful and majestic creatures are still at work, but in 1950 not a single new one was ordered, while the number of Diesel-electrics increased by 3,150. Mr. Bruce, formerly assistant vice-president in charge of engineering at the American Locomotive Company, surveys the entire field of development from the days of the "Stourbridge Lion," the first real locomotive to run on rails in America, to the Chesapeake and Ohio's giant No. 1304, "the last U. S. steam locomotive." There are many excellent photographs. It is an able survey, addressed largely to those with a special interest in the subject rather than to the general public.

IN THE NAME OF SCIENCE, by Martin Gardner. G. P. Putnam's Sons ($4.00). Mr. Gardner's historical survey of sundry fads, cults, hoaxes, fakers, charlatans and dedicated lunatics comes at a time when the higher foolishness—to use David Starr Jordan's phrase—is higher and more popular than ever before. Almost every branch of learning has its humbugs. The book describes cosmologies which even Bishop Wilberforce would have rejected; sexual theories to match every taste and to soothe or exacerbate every fear; strange systems of physics, chemistry, meteorology and geology; dietary theories which only a goat could survive; mass lunacy phenomena such as the Martian invasion scare, the flying saucer hallucinations and countless other aberrations. Most of them are profitable to their high priests, many are harmless, but a few are dangerous and malignant. The "spiral universe" of a certain George Francis Gillette, an American engineer (still living) has a special appeal. A sample of Gillette's exposition: "Each ultimote [the "ultimate unit" of the universe] is *simultaneously* an integral part of zillions of otherplane units and only thus is its *infinite* allplane velocity and energy subdivided into zillions of *finite* planar quotas of velocity and energy." Gardner has done a competent job of parading his freaks, but the book is as depressing as a two-hour visit to a side show.

MORPHOGENESIS: AN ESSAY ON DEVELOPMENT, by John Tyler Bonner. Princeton University Press ($5.00). The subject of Mr. Bonner's book is the development of living organisms: the growth of living matter, the movement of protoplasm which brings about characteristic form, the differentiation of cells and tissues, the attribute of polarity (*i.e.*, "the fact that all organisms in some way manifest an orientation, a headness and a tailness, some sort of symmetry"), the stability of the developmental process regardless of outer circumstances. He discusses a wide variety of examples of plant and animal life and considers the generalizations that might furnish a satisfactory explanation of major aspects of development. The most satisfactory generalization, he feels, is likely to be a "theory of micro-structure" which would reduce the problem of what happens in a gross biological phenomenon to what happens in its small units. Many biological events, Bonner suggests, can be explained in terms of physics and chemistry; some, however, cannot be so treated and may require an "intermediate micro-theory." This is a thoughtful, well-written book which may in some features be regarded as a sequel —reflecting more recent interpretations of morphogenesis—to D'Arcy Thompson's masterpiece *On Growth and Form.* Like Thompson's work, it is addressed to biologists, but is by no means closed to the general reader.

DIVIDED WE FOUGHT, edited by David Donald. The Macmillan Company ($10.00). This is a history of the Civil War in 500 photographs and drawings and an accompanying text which moves along swiftly with the illustrations and adds considerably to their meaning. The editor and his staff searched diligently through every major collection of pictorial materials, smaller museums and numerous scattered private holdings. The result is an admirably representative, fresh selection. It includes photographs by Brady and his assistants (Gardner, O'Sullivan and Barnard), by the famous Confederate photographer Cook, and by other photographers either less well known, or, unfortunately, anonymous. It also has an excellent group of sketches by the Waud brothers, by Edwin Forbes and by various Civil War artists whose vivid drawings of campaigns and battles appeared first in contemporary publications, notably *Harper's Weekly* and *Frank Leslie's Illustrated Newspaper*. The quality of the reproductions of photographs and drawings is uniformly excellent, and this is one of the main reasons why the book makes the Civil War seem almost as poignant and real as if it had happened in our generation.

JANE'S ALL THE WORLD'S AIRCRAFT—1952-53, compiled and edited by Leonard Bridgman. The McGraw-Hill Book Company, Inc. ($22.50). *Jane's* has had a sensible overhauling this year, in addition to the new illustrations and fresh information which bring it up to date. The index has been substantially enlarged and improved; the clumsy system of pagination has given way to the convenient method used in almost all other books; some of the less important sections have been reduced to a "caretaker status." Altogether this valuable reference annual has been made even more useful. Despite secrecy restrictions, a good deal of exciting material is presented about British, American and Russian jet fighters and fighter bombers, which more and more are coming to resemble various species of the now extinct order of pterodactyls. The Supermarine Swift (British) is one of the most beautiful and evil-looking birds yet to have appeared. The Soviet MIG-15 is said to be the superior of our F-86E at altitudes above 35,000 feet, although U. S. pilots have maintained superiority by "better training, greater aggressiveness, superior gun-sights and the use of the G-suit." The major event of 1952 in civil aviation was the opening in May of the first jet-liner service from London to Johannesburg. It is clear that production of the de Havilland Comets places the British well ahead of the U. S. in this field; *Jane's* quotes "a high American authority" as stating that it would take from five to seven years from the time an American manufacturer initiated a jet project to arrive at the point the British reached in starting their Comet South African service.

JANE'S FIGHTING SHIPS—1952-53, edited by Raymond V. B. Blackman. McGraw-Hill Book Company, Inc. ($22.50). Besides the usual meticulous revision, including the addition of some 450 new illustrations of recently launched or converted ships, the latest edition of this standard work furnishes interesting facts about the British, U.S. and U.S.S.R. rearmament programs, the renascence of Japan's navy, the proposal of a new category of U. S. flagship designed "for the sole purpose of administration," the reassembly of naval forces in the two Germanys (East and West, the former holding a temporary lead), the augmentation of the two Chinese navies (the Nationalists having about twice as many warships as Red China), and the sudden efflorescence of a South Korean navy—courtesy of the U. S.

AN INTRODUCTION TO SCIENTIFIC RESEARCH, by E. Bright Wilson, Jr. McGraw-Hill Book Company, Inc. ($6.00). An ably written, much needed handbook of experimental principles and methods. It considers such topics as the design of experiments and apparatus, the analysis of experimental data, statistical procedures, mathematical work and numerical computation. Mr. Wilson, Theodore William Richards Professor of Chemistry at Harvard University, exhibits not only a practical mastery of the subject but a nice philosophical turn of thought. He has given us a good book in which even the general reader can browse pleasurably.

JOURNAL OF RESEARCHES INTO THE GEOLOGY AND NATURAL HISTORY OF THE VARIOUS COUNTRIES VISITED BY H. M. S. BEAGLE, by Charles Darwin. Hafner Publishing Company ($7.50). In December, 1831, Darwin sailed from England aboard the *Beagle* bound for a survey trip in the Southern Hemisphere. The voyage, which lasted five years, was, as he later said, "by far the most important event in my life, and has determined my whole career." When the 22-year-old Darwin left England he was "a confident believer in the 'Mosaic' account of creation and apparently accepted Archbishop Ussher's decision that the earth dated from 4004 B.C. . . . Somewhere along the crooked coastline [of South America] Bishop Ussher's date of creation silently vanished as even remotely conceivable truth." At some point in the journey he also became convinced that "species are not immutable creations," unchanged since the beginning of the world. The young naturalist kept a journal recording his meticulous, wonderfully acute scientific observations, as well as the colorful story of his adventures. This memorable journal was first published in 1839. The Hafner Publishing Company makes it available once more in an excellent facsimile reprint.

PSYCHIATRY AND THE LAW, by Manfred S. Guttmacher and Henry Weihofen. W. W. Norton & Company, Inc. ($7.50). The first joint effort of a psychiatrist and a lawyer to interpret forensic psychiatry, this work is a valuable contribution. The authors have succeeded in supplying a source book and practical guide not only for practitioners but for interested lay readers as well. A description of the various categories of mental disorder is followed by a discussion of the areas of interaction between the lawyer and psychiatrist. Although tremendous advances have been made in psychiatric thinking in the past 50 years, existing legal codes are still based upon the early faulty psychology. The book examines basic issues between the legal and psychological points of view and cites relevant experimental work and case histories.

HISTORY OF AMERICAN PSYCHOLOGY, A. A. Roback. Library Publishers ($6.00). This is a frequently illuminating but highly subjective book. Roback dismisses rather than discusses certain aspects of psychology which differ from his own point of view, and also makes some factual errors. His treatment of historical figures at times runs counter to their generally acknowledged status. For example, he gives only superficial and unfair treatment to John B. Watson's contribution as the founder of behaviorism but accords a full chapter to the less known German psychologist Hugo Münsterberg. Although the author deals fully and fairly with some of the major figures, his efforts to do justice to certain neglected men and his concern with the prescientific era result in an unbalanced presentation. His work is a personal rather than an objective appraisal of the history of American psychology.

THE SENSATIONS, by Henri Pieron. Yale University Press ($6.00). France's foremost experimental psychologist has written an important book on the physiology of sensations. This is a revision and translation of the author's earlier work published in 1944. Pieron's discussion proceeds from the mechanisms of excitation to the bases of qualitative and quantitative discrimination. Although his scholarship is sound, the book does not provide a comprehensive treatment of the field. It places disproportionate emphasis upon European work and fails to take account of recent important advances made by American experimentalists. Still, for American readers who lack access to continental sources, this book will be of value.

POPULAR MECHANICS' PICTURE HISTORY OF AMERICAN TRANSPORTATION, edited by Edward L. Throm. Simon and Schuster ($5.00). A successor to a similar volume on the history of inventions, this is an equally entertaining book. Text and pictures convey a journalistically comprehensive view of the development of land and water vehicles, from dugout canoes to the latest automobile, which has such empathy with its owner that it sneezes in a draft and puts up its top automatically when it starts to rain. No one would take this book too seriously, which is just as well; it contains almost as many inaccuracies as it does colorful details.

THE SHORTER CAMBRIDGE MEDIEVAL HISTORY, by C. W. Previté-Orton. Cambridge University Press (2 volumes, $12.50). A condensed and revised version, by an outstanding scholar, of a famous cooperative work. "Shorter," lest you be misled, means 1,136 pages. The late Professor C. W. Previté-Orton was not merely the editor of this book: he made a considerable contribution of his own. By eliminating and rearranging material, by revising judgments and offering penetrating summaries, by rewriting with admirable literary skill, the author transformed a reference work into a reading book for students and the general public as well as for specialists. None of the 300 illustrations selected by S. H. Steinberg is hackneyed, and quite a few are of exceptional quality.

UNDERSTANDING CHILDREN'S PLAY, by Ruth E. Hartley, Lawrence K. Frank and Robert M. Goldenson. Columbia University Press ($3.50). An exploratory investigation of the meaning and uses of play to the preschool child. In block play, clay molding, finger-painting and dramatic play a child finds a means of expressing his personality, his fears, needs and difficulties. Play is also a way of intellectual and social learning. This book tells precisely how play accomplishes these things and what kinds of play are best suited to different personalities and needs. It deals with normal children as well as the more commonly studied disturbed child.

THE AMATEUR SCIENTIST

On scintillation counters and how a group of amateurs helped to build a planetarium

Conducted by Albert G. Ingalls

SINCE 1896, the year in which Henri Becquerel discovered that something emitted from pitchblende darkened a photographic plate, much work in experimental physics has gone into developing instruments for detecting and studying subatomic radiations. Pitchblende's mysterious emanations were soon found to be the spontaneous emission from radium of alpha, beta and gamma rays. The first two rays were identified as particles of matter, the last as waves of electromagnetic energy. Among their singular properties was the ability to ionize, or electrically charge and separate into positive and negative ions, the atoms of any material through which they passed. All the instruments developed within a decade or so of Becquerel's discovery made use of these ionic charges to detect the passage of the rays that created them. Some of the instruments immediately attracted the interest of amateurs in electronics.

One of these is the simple electroscope, which nearly every radio "ham" has built at one time or another. It consists of two facing strips of gold leaf suspended in a glass bottle from a wire thrust through the cork. When an electric charge, produced by rubbing a rod of hard rubber or glass with a bit of wool or silk, is transferred to the wire, the force of electrostatic repulsion causes the vanes to fly apart. As the charge leaks off, the vanes slowly collapse. Using this instrument, Pierre and Marie Curie observed that when they brought their samples of pitchblende near it, the rate of discharge increased, and they measured the relative activity of the samples by timing the discharge.

A second instrument, which soon came into extensive use, operated on a different principle, that of fluorescence. This is the ability of many substances to give off light of a characteristic color when exposed to certain radiations. In 1911 Ernest Rutherford, the noted British physicist, made use of this principle to measure gamma rays, using an X-ray fluoroscope screen coated with zinc sulfide powder, one of the early fluorescing materials. When he placed a small sample of radium in front of this glass screen in a darkened room, he could count tiny individual flashes of light on the zinc sulfide coating, each marking the impact of a ray from the sample. Clock manufacturers later exploited the same principle in making luminous dials of a paint composed of radium salt and a powdered phosphor. Examine one of these dials in the dark under a 15-power microscope and you will observe that the light is released in sharp bursts. Each scintillation is caused by the disintegration of one atom of radium.

Many amateurs have built a version of the Rutherford instrument called a "spinthariscope." This is a small box of convenient shape fitted with a zinc sulfide screen at one end, a magnifying lens at the other and a source of alpha particles in between (scraped, perhaps, from the luminous dial of a discarded clock). The radioactive material is enclosed in a matchhead-sized envelope of black paper, supported in line with the center of the lens and screen by a common pin or a short length of wire. The inner walls of the box should be painted dead black to kill reflection. The screen may be made by dusting zinc sulfide—Du Pont's silver activated zinc sulfide, Patterson Type 1101, is highly sensitive—on the sticky side of scotch tape. The sulfide side should face the radium. When the lens is held to the eye, the observer appears to be looking into the depths of a black sky filled with shifting patterns of exploding stars. Each faint flash marks the point where an alpha particle has crashed into the screen. The number of flashes will depend on the activity of the disintegrating radium and its distance from the screen. The best distance must be found by experiment. Readers who wish a sample of radioactive material for experiments may obtain one by sending a stamped, self-addressed envelope to SCIENTIFIC AMERICAN.

With the advent of the vacuum tube, greatly improved methods of measuring radioactivity were developed—instruments that could not only count rays or particles but also sort them according to type. Gases under low pressure become momentarily conductive when ionized by alpha, beta and gamma rays. A gas-filled tube fitted with a pair of electrodes will thus pass a pulse of current for each particle or ray passing through it. These pulses can be amplified and used to operate an electromechanical register. This principle led to the development of the mass spectrometer [*see page 68*], to the Geiger-Müller counter and, indirectly, to the new "crystal" counters now attracting much attention.

Of all subatomic detectors, however, the scintillation type remains the most versatile for research work. Linked up with a modern photomultiplier tube to do the counting, it responds easily to 100 million nuclear events per second, as against the Geiger counter's top rate of 2,000 per second. Moreover, its screen phosphors can be arranged to respond selectively to each kind of radiation, thus causing it to make qualitative distinctions between nuclear events, something a Geiger tube cannot do. With a scintillation counter even an amateur can measure cosmic rays, detect radioactive gases in the atmosphere and test the many naturally occurring radioactive minerals. In addition, he can test the fluorescent properties of gases, liquids and solids, an area in which much work remains to be done. Finally he can develop electronic circuits to meet a broad range of applications.

The photomultiplier tube and related circuitry have, in fact, revived interest in all scintillation counting. Here at last is a device more sensitive than the eye and able to watch and respond to millions of scintillations per second. It is essentially a photo-electric cell with built-in amplifier. Light falling on a sensitized electrode in the tube ejects one or more electrons. They cascade through a series of carefully positioned electrodes, each carrying a progressively higher positive charge. As these electrons knock "secondary" electrons from the intermediate electrodes, the cascade becomes an avalanche and a billion electrons reach the anode for each one ejected from the first electrode. Thereupon an amplified pulse of direct current flows from the output circuit of the tube.

The Radio Corporation of America Type 4646 photomultiplier employs 16 intermediate electrodes, called "dynodes," each charged to a progressively higher voltage in steps of about 100 volts. Some 1,700 volts are maintained across the tube. The flight of secondary electrons is confined to a series of short paths shaped by the contour of the dynodes, their physical arrangement, and the curving of the electrostatic field between them.

In terms of number of electrons, the output pulse is huge. Yet its current, when compared with that drawn by even a small Mazda lamp, is small. It can be measured directly with a cathode ray oscilloscope or other sensitive electrical instrument. But it does not have sufficient energy to drive electromechanical registers of the type used for recording nuclear events. Many pulses persist for only a few microseconds at best; hence they must be further amplified and prolonged by electronic circuits.

Circuits also serve to improve performance from the notoriously "noisy" photomultiplier tube. "Noise" appears in the tube's output as pulses which do not owe their origin to light but to electrons dislodged by heat, thermal agitation or other extraneous events. Noise pulses generally carry less energy than those from valid scintillations, and electronic circuits are designed to take advantage of this difference to sort them out. An amateur who enjoys working with electronic gear will find, even if he is a beginner, that the counter's circuits are easy to design and build. And the variety of things they can do will amaze him.

Assume that a photomultiplier tube has been mounted in a light-tight container with a phosphor screen sandwiched between the photocathode and a "window" of aluminum foil. The tube has been connected with a source of voltage prescribed by its manufacturer. The phosphor is being irradiated by a "hot" source, with the result that a mixture of noise and signal pulses is appearing at the output terminal. What kind of a circuit must be built to sift this electronic wheat from the chaff?

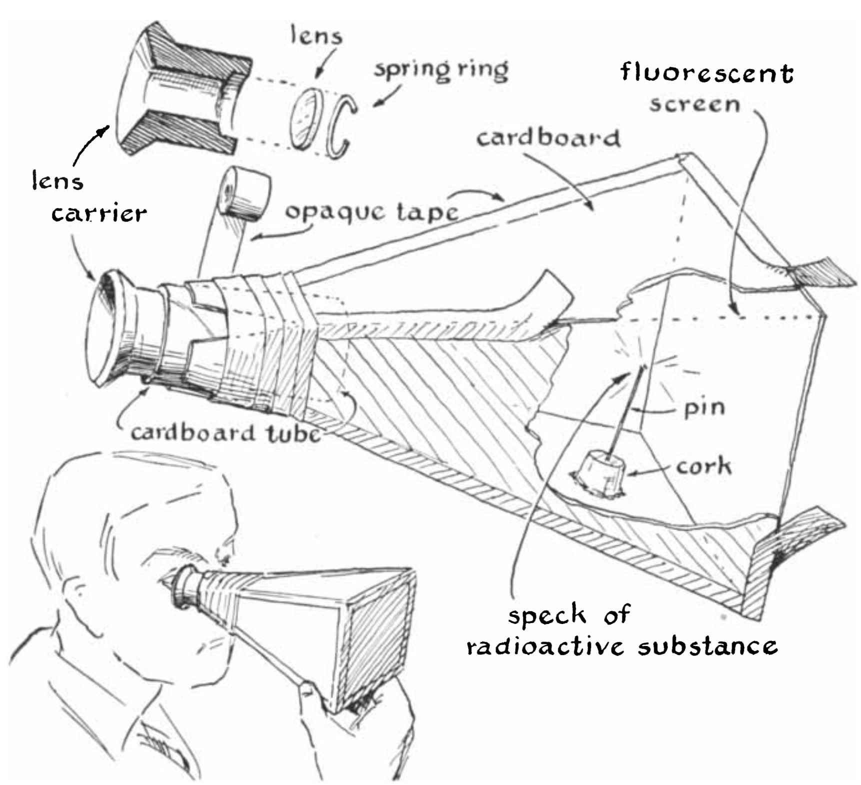
Within the past decade or so electronic engineers have developed special circuits for manipulating electrical pulses—the form of signal that has been exploited so successfully in radar, television and electronic computers. The new circuits can generate pulses, or clicks, at will, in almost any size, shape or frequency desired. The clicks can be added together, subtracted, sorted and reshaped. Most of the devices for doing this are easy to build.

A simple resistance-coupled amplifier usually follows the photomultiplier. The output of the tube is fed into the amplifier through a small condenser which passes the pulses but insulates the amplifier against the photomultiplier's high-anode voltage. Circuit details of such amplifiers are available in standard reference texts. They employ a few small condensers with companion resistors and one or more vacuum tubes. These can be taken from old radio sets or procured inexpensively on the war-surplus market.

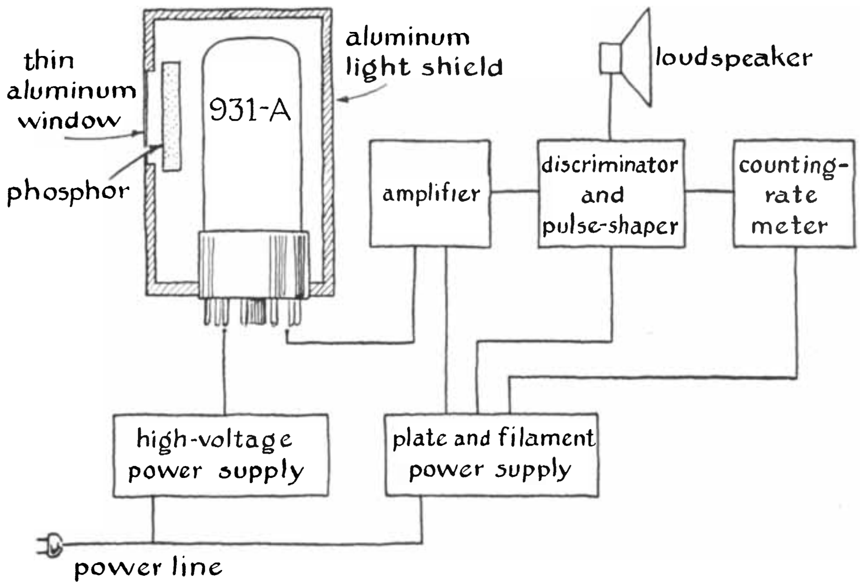
To sort the now amplified noise and signal pulses, the output of the amplifier is fed into an "amplitude discriminator." This unit employs a single vacuum tube and exploits the fact that such tubes can be made to reject weak signals. If the grid of a three-element tube, or triode, is charged with an increasing negative voltage, a point is finally reached when the charge on the grid just equals the negative potential of electrons ejected from the tube's heated cathode. The force of repulsion between the two charges returns electrons to the cathode, and none passes through the grid to the tube's anode or plate. Hence, with this value of negative charge on the grid, no current flows in the plate or output circuit and the tube is said to be "cut off" by its negative "bias." When biased to cutoff, the tube becomes an amplitude discriminator. Large positive pulses superimposed in the grid neutralize a portion of its negative charge, "swing" it positive, and hence permit electrons to flow through the grid from cathode to plate, and out into the circuit as an amplified image or "triggering" pulse. Positive pulses of low amplitude, however, cannot raise the grid above cutoff, and hence they have no effect on the output circuit. The designer can adjust the bias on the grid to any value desired and thus control the point at which it begins to discriminate.

Although the discriminator prevents pulses below a predetermined amplitude from flowing in the output, it passes signals above this value in a broad range of energies or sizes. The efficiency of the counter can be improved by "reshaping" these so that all are of equal voltage and current, and span equal time intervals. This is accomplished by means of a "pulse shaper," a circuit that takes pulses of random size and generates from them a uniform pulse, usually in the form of a single wave with a flat top and straight sides.

Ultimately these square waves must be counted by the electromechanical register. But these are sluggish instruments compared with pulse shapers. Those within reach of the average amateur's pocketbook are limited to about five counts per second. To operate the register, therefore, the amateur must construct one more circuit—a scaler. This unit is really an electronic dividing machine, telescoping the number of incoming pulses down to a half, a tenth, a thousandth or any other desired submultiple of the original pulses. Essentially the scaler uses the ability of a condenser to store electrical energy. Incoming pulses from the preceding circuit enter the condenser through a diode (a vacuum tube with only a cathode and a plate) which, acting as an electrical check valve, prevents their escape. As a series of pulses flows into the scaler a voltage builds up across the condenser step by step. Finally the growing charge attains a value sufficient to neutralize the negative bias on the grid of a following triode. When the cutoff point is reached,



A home-made spinthariscope for viewing scintillations



Block diagram of the circuit for a scintillation counter

the tube begins to conduct and the condenser discharges, sending a single pulse from the tube's output. The amount of the bias can be adjusted, of course, and any submultiple of the scintillation frequency can thus be selected.

The pulses from the scaler drive the electromechanical register. Most registers employ a set of index wheels, like those that show mileage on an automobile speedometer. They are driven by a ratchet actuated by a solenoid. Each pulse advances the ratchet one notch. Various registers designed for operation from vacuum tube circuits are available on the surplus market for a dollar or so. They range in speed of operation from 50 counts per second (Central Scientific Co.) to 5 counts per second (Western Electric Company). Some can be driven reliably by a few thousandths of an ampere. Several amateurs have built their own from discarded speedometers and old electromagnetic relays.

Scintillation counters range from light portable instruments to rack-mounted jobs weighing 1,000 pounds or more. Their physical proportions depend on the amateur's resources and the use he has in mind.

Robert Detenbeck of Kenmore, N. Y., a student at the University of Rochester, who has built a couple of counters, writes: "My first model included only the most essential circuits and used many modified war-surplus and radio-receiver parts. I was not sure that it would function properly and did not want to risk any more money than necessary. Hence the counter was not very compact, but no sacrifice in performance was necessary.

"Connections to all the vital points were brought out to jacks on the front panel for ease of measuring electrode and signal voltages. In order to find the optimum voltage to apply to the photomultiplier tube, the high-voltage supply was made variable. This control proved to be a more satisfactory method of varying the sensitivity of the instrument than a conventional audio-amplifier gain control, so I decided to include it in future models.

"The multiplier tube was even more sensitive than I had imagined it to be. When it was exposed to normal room illumination, the first vacuum tube of the amplifier following the multiplier was completely paralyzed. Any thoughts of carelessness in building a light-shield for the tube were dismissed. Light so dim that my eye could not detect it produced considerable random noise in the output.

"The first phosphor I used was a silver-activated zinc sulfide X-ray screen. For quite a while I was at a loss about what to use for window material—a material that would exclude light but pass alpha rays to the phosphor. Finally an old filter condenser furnished some aluminum foil about a thousandth of an inch thick. By careful selection I found a large piece without pinholes. The photomultiplier was mounted in a cylindrical container, the tube socket at one end and the aluminum window at the other, opposite the photocathode. On the first test a fairly hot sample of pitchblende indicated that the zinc sulfide screen was detecting alpha rays and some beta rays with enough efficiency to override the noise background. Zinc sulfide is opaque to its own phosphorescence. Hence scintillations produced inside the zinc sulfide crystals by deeply penetrating beta and gamma rays cannot escape to act on the photocathode. Therefore the next step was to try an organic phosphor. The prospect of obtaining a large block of naphthalene, which is transparent to its own scintillations, seemed quite formidable. Finally a simple and quite satisfactory solution presented itself. I bought some naphthalene flakes of the kind used as a moth repellent. The lot contained some large, clear, thick pieces. Although the flakes were doubtless too thin for efficient gamma ray detection, a cell was made from them to replace the zinc sulfide screen. The flakes detected beta rays with good efficiency and worked as well on gamma rays as a professional Geiger-Müller counter which I borrowed to make the comparison. The problem of making a window for the organic phosphor proved easy. Because of the greater penetrating power of beta and gamma rays, two layers of aluminum foil can be used, the solid portions of each foil masking the pinholes in the other.

"The success of the first model encouraged me to construct a second one, more compact, which I could move without the aid of a wheelbarrow. A more efficient layout, purchase of a few new parts and some sacrifice of appearance achieved a miracle of condensation. In addition, the second scintillation counter included a discriminator circuit which passed the pulses from the scintillations but blocked most of the relatively weaker noise pulses. Of course it was not perfect; it lost some signals and passed some noise. It is not easy to find simple information on counting circuits, but one good book, *Electronics Experimental Techniques*, by William C. Elmore and Matthew Sands (McGraw-Hill Book Company) gives complete circuit data on every piece of apparatus that I needed. I also used a circuit which gave uniformly shaped output pulses, so that the average charge they placed on a condenser per second could be measured. A counting-rate meter connected to the output then gave an indication of the intensity of the radiation striking the phosphor. With this model two other phosphors—cadmium tungstate and calcium tungstate crystals—were tried. The calcium tungstate gave consistently better results.

"My current problem is that I cannot find hours enough in the day to finish all the projects the scintillation counter suggests. I intend to build a lighter model than the second. I would like to experiment with counting circuits. Two vacuum tubes enable you to add, subtract, multiply, divide and do exponentials. You can integrate and differentiate without the use of tubes, and these are only a few of the special circuits I would like to try. Finally, I want to use my counter in the field. They tell me a lot of 'hot' rock is waiting to be found."

A GROUP of amateur and professional instrument makers in San Francisco now has the distinction of having built the first Zeiss-type planetarium projector in the world outside of the famous German factory of Carl Zeiss. Until recently there were only 27 Zeiss planetariums in existence, six of them located in the U. S. These six projectors were all built before World War II. The first was installed at Chicago in 1930, the next at Philadelphia in 1933, then Los Angeles and New York in 1935, Pittsburgh in 1939 and Chapel Hill, N. C., in 1949, the last being a secondhand instrument bought in Sweden.

When the San Francisco group started, it had only the most general information about the inner workings of a star-and-planet projector, though the Zeiss instrument had often been described—most technically in *American Machinist* in 1929. The modified projector built by this group is now the heart of the new Alexander F. Morrison Planetarium run by the California Academy of Sciences.

How all this came about is told in detail in the Academy's periodical, *Pacific Discovery*. Before the war the Academy had two men on its staff with a practical knowledge of scientific instrument making and design. One of these was G. Dallas Hanna, curator of paleontology, who had pursued instruments as a sideline, made improvements on the microscope and organized a well-equipped instrument shop. The second man was A. S. Getten, an experienced instrument maker, who maintained the institution's research equipment. During the war these two emptied a storeroom of fossils next to the shop and set up 50 workers to service U. S. Navy submarine periscopes, anti-aircraft gunsights, range finders and 6,000 binoculars. Other members of the Academy's staff also pitched in, including an ichthyologist, an aquatic biologist, a herpetologist and an operating engineer. When a serious shortage of personnel developed for the making of lenses, prisms and optical flats needed in the instruments, this department of SCIENTIFIC AMERICAN quickly put them in touch with nearby amateur telescope makers—a freight conductor, paleontologist, engineer, marine engineer and teletype specialist—who promptly became part of the Academy group. In four years this group manufactured 10,000 new optical parts for Navy instruments.

The enlarged group often talked optics, and the conversation always turned to planetariums. It was agreed that a planetarium was needed in San Francisco, but even before the war the cost of a Zeiss projector was more than $100,000, and no such money was then in sight. After the war, however, San Franciscans raised $500,000—$350,000 of it from the Alexander F. Morrisons, the rest from citizens of high and low degree, foundations, estates and school children—to build a planetarium. The projector itself had to be built in San Francisco because Carl Zeiss was in the Eastern Zone of Germany and could not supply one, not even the detailed plans for one.

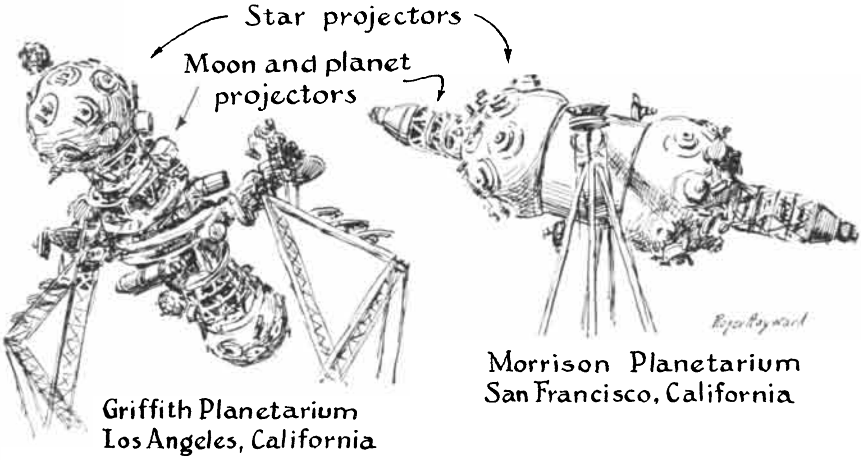
When it actually came to spending the funds on such a costly and admittedly experimental project as building a large instrument with 321 lenses and 25,000 parts, the Academy trustees were hesitant. They were hesitant until Russell W. Porter, a consultant on the project, surveyed the available equipment and skills and assured them that the Academy group could build a star projector equal to or better than the Zeiss. "That did it," says Academy Director Robert Cunningham Miller.

Hanna supervised the job, but he says that Getten, more than any other person, is responsible for the design of the projector and its driving mechanism, with intricate gear trains. It took four years to complete and cost $140,000, even though San Francisco firms gave materials and services free or at nominal price. "Everyone who worked on the instrument stayed to the end," says Hanna, "and all of us are still on speaking terms."

The drawing at the top of page 108 shows the most obvious differences between a typical Zeiss projector and the modification designed by the California Academy. In the dumbbell-shaped Zeiss, the moon and planet projectors are nearest the center, while the heavier star projectors are on the outer end of the dumbbell. In the Academy model, these positions are reversed, greatly reducing the likelihood of vibration when the 5,000-pound instrument is first set in latitude motion, and making it a more rugged instrument all around. The Academy projector is quieter in operation than the Zeiss and is the first in which, at the flick of a switch, a tape recording will take over (if the lecturer is called away or has a frog in his throat) and automatically put the mechanism through 250 successive stunts, stopping it at the end like an automatic washing machine.

In Zeiss projectors the star images are made by shining the central light through tiny, unrealistically round holes in metal plates. Hanna and his associates improve on this by projecting the light through irregular images on glass plates, made by laying tiny, irregular particles on the plates, then putting an opaque aluminized coating over the whole surface and brushing away the particles, leaving spots of clear glass. Thirty-two such plates are needed to cover the entire sky. The plates used are the flat backs of condensing lenses, mounted behind the 32 projecting lenses of the instrument. An immense amount of work went into their development.

First Leon E. Salanave, now a planetarium lecturer in astronomy, sorted out 3,800 stars from a star catalog and computed the positions of the stars on each plate within one thousandth of an inch in two directions. Then Frances M. Greeby of the staff sorted grains of Alundum for proper size and shape under a dissecting microscope—.015-inch particles for stars of the first magnitude down to .0015-inch grains for stars of

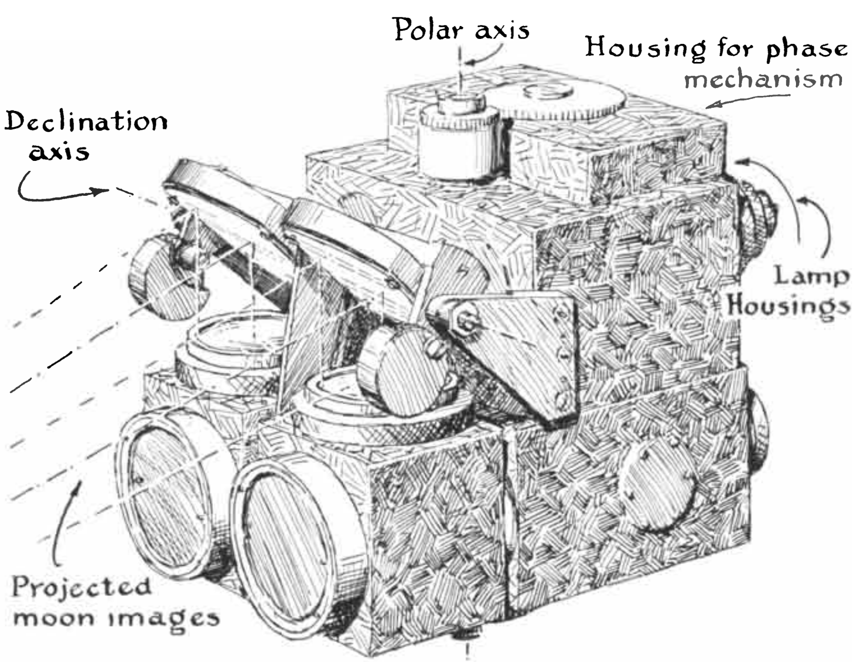


Old (left) and new (right) planetarium projectors

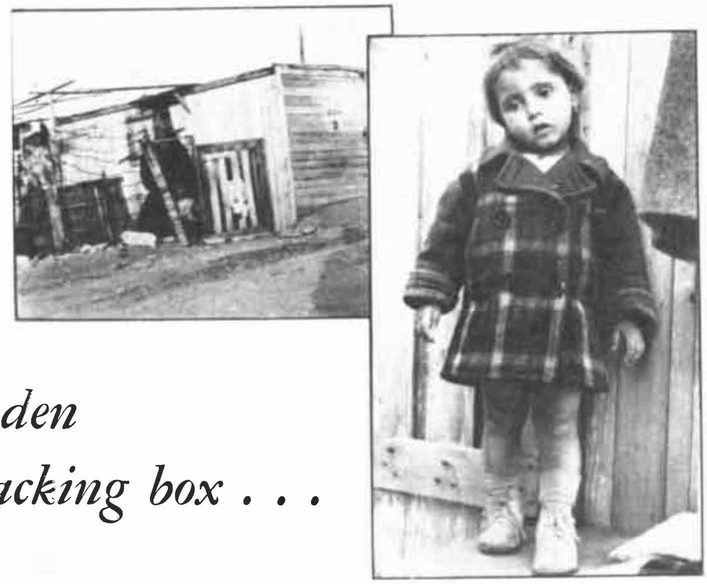
magnitude 5.80. (Twenty brighter stars were also made up in special projectors, some in color.) Another microscope with cross hairs in its eyepiece was equipped with right-angled micrometer screws so that it could be traversed and positioned accurately above the plates. Then a plate was put under the microscope and a grain of correct size pushed about on it with the extremely fine tip of a drawn glass rod until it was positioned under the cross hairs. This delicate operation was repeated 60 to 222 times per plate, each plate requiring three days of fatiguing work. The 3,800 holes thus produced, however, project as sharp images strikingly like stars as seen in the skies.

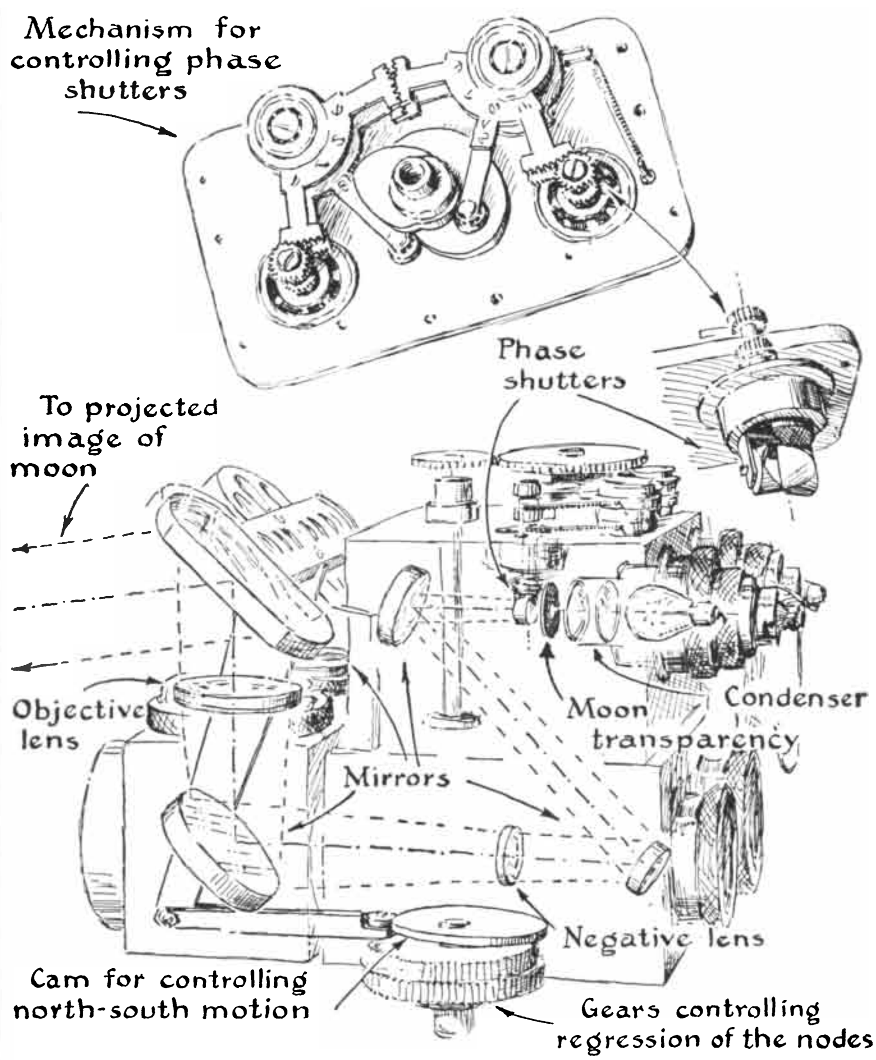
Until now the Academy instrument's moon projector has never been described. While it is the most complicated part of the apparatus—the "instrument designer's nightmare" according to Salanave—this is entirely the fault of the uncooperative, wobbly moon, whose motion it must simulate. Roger Hayward's drawings below and on page 110 make the mechanism relatively simple.

As on the Zeiss instrument, all projectors for moon and planets are double because the light from one of the halves is at times cut off by the framework needed to support the projector. Salanave writes: "In front of each projector lamp is a moon transparency. In front of these are phase shutters for changing the moon's phases. Next in the optical train come two pairs of fixed diagonal mirrors which help fold the optical train into available space, then negative lenses which increase the focal length from 13½ inches to 24 inches, more diagonal mirrors, and objective lenses that project images of the moon to movable mirrors on a common axis. These mirrors must be movable, because the moon, as it travels around the earth, moves five de-



The moon projector





Mechanism of the moon projector

grees each month, alternately north and south of the sun's apparent path in the sky, the ecliptic. Motion is translated to the mirrors from a gear to a cam and through a pushrod to an arm attached to them.

"Getten, designer of the projector, thought it would be nice to project an actual photograph of the moon instead of the featureless lunar disk of the Zeiss. It was found experimentally that a moon transparency twice the correct diameter best matched the appearance of the real moon. Fred Chappell of the Lick Observatory skillfully produced, from one of the Moore-Chappell series of lunar photographs, pairs of positive prints of proper size and matched diameter, density and contrast.

"The most complicated single detail to work out proved to be the mechanism for producing smooth variation of phase each planetarium month. This problem took over Getten's thought and labors for months. A single 'cup,' like those shown in the right-hand insert in the drawing above, would produce all phases in the waning and waxing moon (starting at full) in one half-rotation and then would repeat if continued another half-rotation—unhappily with the illuminated portion on the wrong side of the terminator. The use of two transparencies, each with its cup, promised to resolve this difficulty but required switching from one projected image to the other at bright full moon. It proved that no amount of care in adjusting lamps and lenses could eliminate a very noticeable jump in the image at change-over. Getten's final solution was two *pairs* of oppositely moving cups in front of the two transparencies. This made it possible to effect the change-over at the 'dark' of the moon when no light comes through.

"The topmost part of the drawing above shows the phase mechanism lifted off and half turned over. Each pair of cups has two unconnected though concentric gears. It is fun to study this out. The lower cam in the middle actuates both lower gears because the gears are inescapably tied together by gear segments pivoted at the ball bearings at the top. Later, as the cams are rotated, the upper cam actuates both upper gears in an opposite direction."

INDEX OF ADVERTISERS

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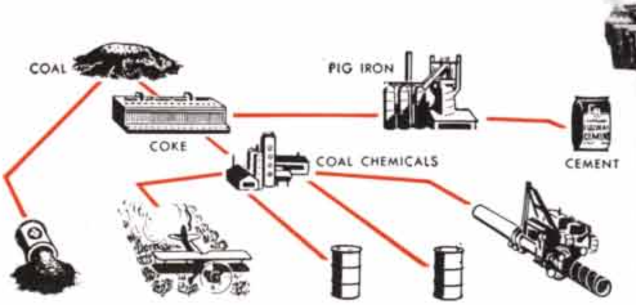
EVERY TIME this big unloading bucket bites into a bargeload of coal, we're starting another chemical miracle on its way to you. Your new synthetic fiber suit, the drug that "knocked" your flu so fast and the bright enamel on your new car could all have been born in the coal chemical recovery mains of our coke ovens.

But *this* may be the real miracle: From our coking operations we produce not only coke and coal chemicals, but we follow through with basic products like pig iron and cement on one hand and finished chemical products like Pittsburgh Insecticides and Dyestuffs on the other—all in *one continuous, interlocking operation.* This highly developed integration—and it now embraces ten operating divisions—requires considerable engineering skill and years to perfect. But the payoff is the unusual production efficiency and product quality control that have become synonymous with Pittsburgh Coke & Chemical.

W&D 4541



PITTSBURGH
COKE & CHEMICAL CO.
Grant Building - Pittsburgh 19, Pa.

Photograph by Nickolas Muray

A freight train 500 miles long!

Imagine a freight train 73,000 cars long – extending over 500 miles in length! It would reach all the way from New York to Cleveland or from Chicago to Kansas City.

That's what it would take to transport the 4,000,000 tons or more of supplies and materials handled by American Cyanamid Company's traffic department each year. Working in close cooperation with the nation's railroads, trucking companies, airlines and steamship companies, Cyanamid's traffic experts seek to insure the safe, dependable delivery of thousands of different products and materials. And they are responsible for the efficient direction of a transportation program that costs over $25,000,000 annually in freight charges.

This part of Cyanamid's operation, in which America's vast network of highly efficient transportation facilities plays such an important role, helps scores of chemical-using industries to meet your needs with better products at lower cost.

AMERICAN *Cyanamid* COMPANY

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