SCIENTIFIC AMERICAN

THE UNCERTAINTY PRINCIPLE

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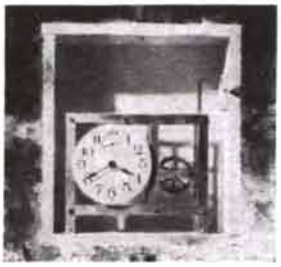

THE COVER

The painting on the cover depicts an apparatus which will not work but which has nonetheless been useful to physicists. It was invented by Albert Einstein to perform a "thought experiment" which he hoped would show the error of Werner Heisenberg's principle of uncertainty (*see page 51*). The apparatus consists of an ideal box which will contain radiant energy indefinitely. The box is suspended from a spring; its weight can be measured on the scale at left. Inside the box is a clockwork mechanism which at a given instant can open the shutter at upper right and allow a single photon of radiant energy to escape from the box. Einstein argued that the box could now be weighed again to obtain precise information about the photon. This would contradict the uncertainty principle. Niels Bohr later demonstrated, however, that the precision of the apparatus would be nullified by uncertainties of its operation.

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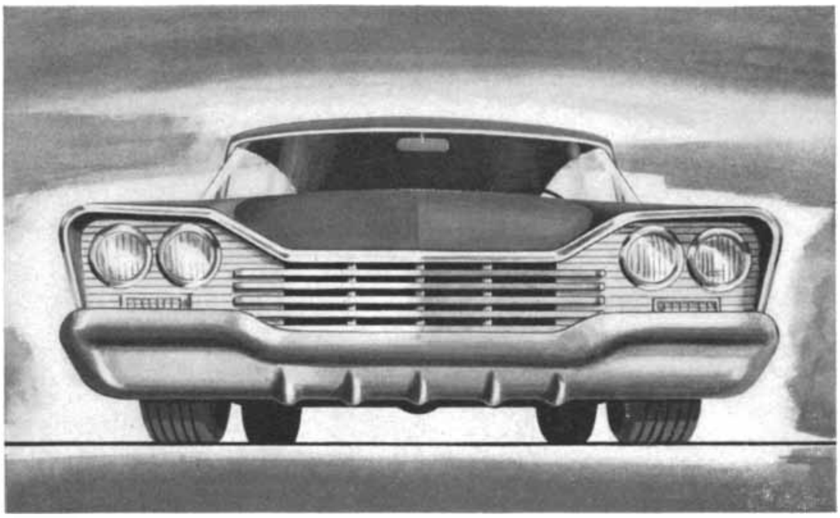
SILICONE NEWS

The Road Ahead: Silicones

- Increase Efficiency
- Reduce Upkeep Costs

WHAT'S AHEAD IN AUTOMOBILES?—*With '58 models newly sparkling in the nation's showrooms, auto men are turning their attention to future car designs. Whether the '59 and '60 editions will be fatter, finnier, or fuel-injected is anyone's guess . . . Detroit doesn't tell. But one thing certain is the increasing importance of Dow Corning Silicones in automobile performance. Silicones began appearing in cars only in recent years, but their application by designers has constantly increased: the future holds much more.*



NEW EFFICIENCY — In an unexpected place (the cooling fan) auto engineers have found a new source of usable horsepower. Ten or more horsepower per engine! And the discovery hinges on silicones.

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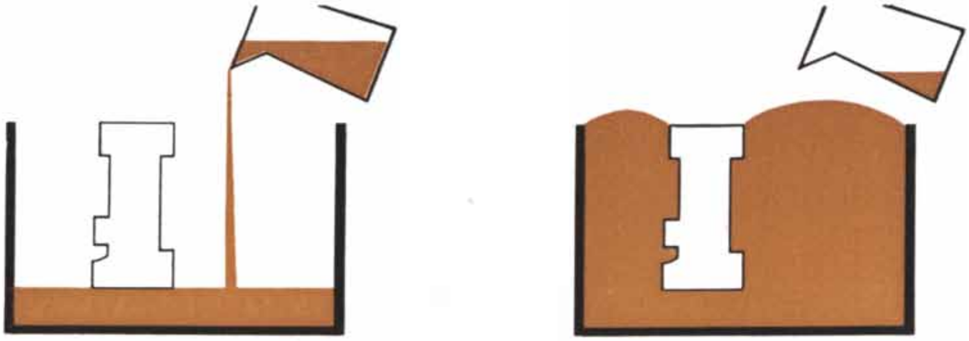

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LETTERS

Sirs:

The article by B. T. Matthias on superconductivity [SCIENTIFIC AMERICAN, November, 1957] contains some misleading statements in regard to theory which I would like to take this opportunity to correct. While it is true that there was no satisfactory explanation of superconductivity at the time Matthias did his interesting and important work on superconducting compounds, this is no longer the case. Last spring my colleagues L. N. Cooper and J. R. Schrieffer and I proposed a new theory which has been quite successful in accounting for the properties of superconductors, not only in a qualitative but also in a quantitative way. This theory is mentioned briefly in the article, but in context it appears as only an extension of previous work and of doubtful validity.

At the time Matthias's article was published only a brief and preliminary account of our theory had appeared in print. A comprehensive paper has now been published in *The Physical Review* (issue of December 1). Preprints of the latter paper have had a fairly wide distribution for the past several months, so that a number of physicists have had a chance to study it. No valid objections have been raised; there appears to be general agreement that our explanation is sound.

As stated in the article, there is still some question about mathematical rigor in parts of the theory. As is often the case in the solution of complex problems of this sort, some of the approximations made are based on physical rather than on purely mathematical reasoning. No doubt the mathematical rigor can and will be improved as time goes on. A number of physicists are working on different aspects of the problem now.

Since our explanation makes use of quantum theory, it is difficult to describe to the lay reader. It is based on interactions between electrons and vibrational motion of the atoms of the metal, although not in the way suggested in the article. Electrons do not "ride along on the lattice vibration as on a wave"; in fact, they are scattered about as much in superconductors as in normal metals. The difference is that scattering of individual electrons does not cause the current to decrease and give resistance in superconductors as it does in ordinary metals, but only gives rise to local fluctuations in current. According to our theory, a fraction of the electrons are associated in pairs, and it is an important feature that the net momentum be precisely the same for each of these pairs. In the absence of a magnetic field (practically, the magnetic field due to the current itself can be minimized by using a very thin film) current flows when the common momentum of the pairs is other than zero. Thermal fluctuations can cause pairs to break up or re-form, but such local fluctuations do not change the common momentum and thus the current; only a force which acts on all of the electrons at once can do so. Most currents in superconductors are associated with magnetic fields. The explanation of these diamagnetic currents follows along the lines originally suggested by Fritz London.

I believe it is fair to say that our theory goes well beyond an extension of previous work. In the formulation of our theory we were of course much aided by prior theoretical work of London, H. Fröhlich and others and by the vast amount of excellent experimental work done by many people, all of which served to indicate the path along which a satisfactory theory might be found. Our essential contribution was to show how the electronic structure of the superconducting state differs from that of the normal state. With this breakthrough we were able to calculate various superconducting properties for a simplified model. Theoretical results can be compared with experiments on real superconductors when the parameters of our model are determined empirically from appropriate measurements on the metal. One of these, the magnitude of the interaction which determines the transition, is evaluated from the transition temperature, T_c; the other two required are obtained from measurements in the normal state.

Since the transition temperature is sensitive to the details of electronic structure which are not well known in actual metals, a direct calculation of T_c from first principles is difficult. David Pines (*The Physical Review*, in press) has shown, however, that some of the empirical rules which Matthias found can be understood on the basis of our theory.

JOHN BARDEEN

Department of Physics
University of Illinois
Urbana, Illinois

Sirs:

At the time most of my article was written, the theory Professor Bardeen refers to was very new. As an experimentalist, I felt that it was not appropriate for me to attempt to evaluate recent theoretical developments. Nevertheless, the obviously great importance and wide acceptance of Bardeen, Cooper and Schrieffer's theory made it necessary to say something. The resulting compromise was bound to err on the side of caution. It is certainly much more appropriate for Professor Bardeen to discuss and evaluate his theory than for me to, and I am delighted that he has taken this opportunity to do so.

As he notes in his last paragraph, the occurrence of superconductors among chemical substances is naturally a very difficult theoretical question. After all, there is no good theory of the occurrence of phenomena—ferromagnetism, for example—which have been much better understood theoretically. Nonetheless the Bardeen, Cooper and Schrieffer theory has been much more successful in this field than any previous one.

B. T. MATTHIAS

Murray Hill Laboratory
Bell Telephone Laboratories
Murray Hill, N. J.

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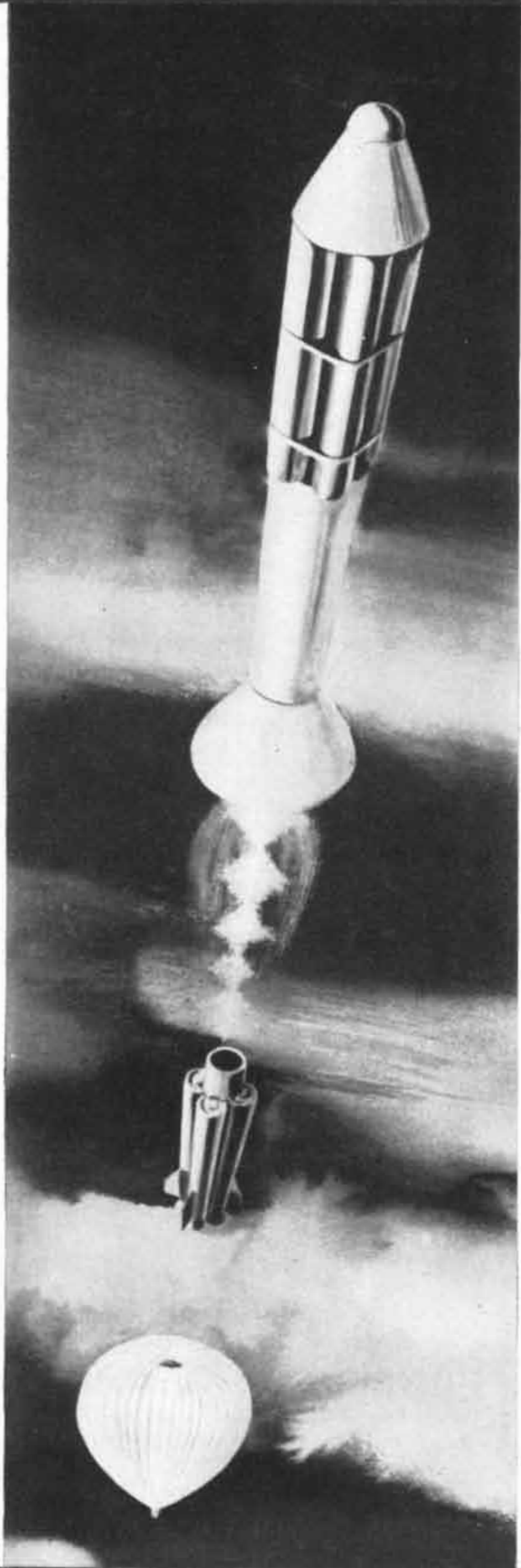

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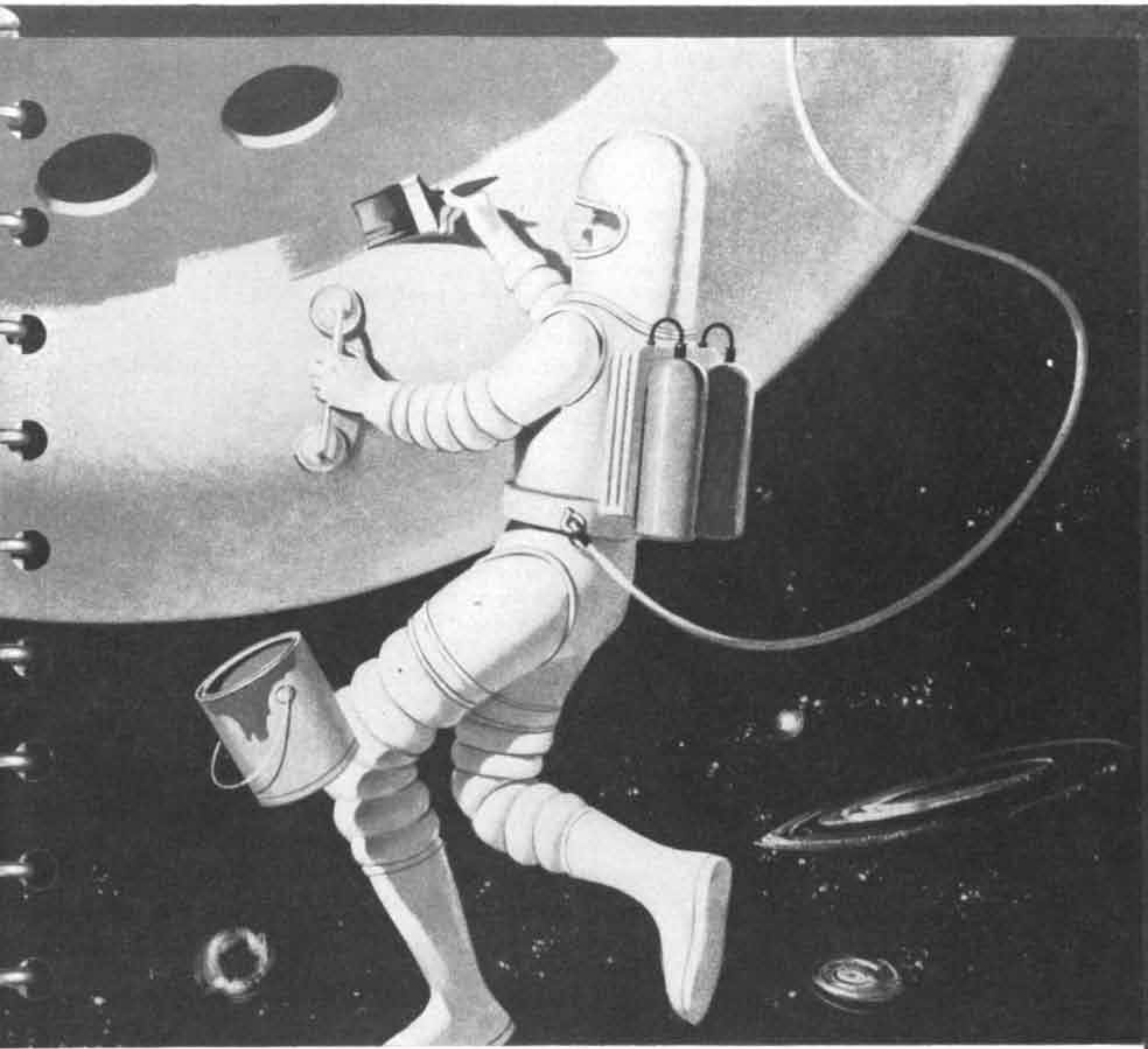


50 AND 100 YEARS AGO

JANUARY, 1908: "The progress of work during the year 1907 on the Panama Canal was such as to confirm the recent estimate of Secretary Taft and Colonel Goethals that this great work will be finished in six years' time. During the past twelvemonth there was excavated along the line of the canal a total of 16,764,095 cubic yards. Of this amount, about 11,000,000 cubic yards were removed by steam shovels and over 4,800,000 cubic yards by dredges. The greatest results, of course, were shown in the Culebra division, from which alone over 9,000,000 cubic yards were taken out. For the first time on record, the 2,000,000-cubic-yard limit of monthly excavation was reached and, indeed, passed. This occurred in December of last year, when 2,200,539 yards were removed. It now seems certain that the Culebra cut will not be the determining factor in the time of completion of the canal, but rather the vast and difficult work of building the Gatun locks."

"The *Tartar*, one of the five new 33-knot British destroyers, which had already, in its preliminary trials, broken the world's record for speed by attaining 35.952 knots on an Admiralty course, carried out its final speed trials in December, in the presence of various Admiralty officials. The vessel maintained the unprecedented speed of 35.363 knots throughout a continuous run of six hours' duration, thus covering a total distance of about 212 knots during this period. On six runs over the measured Admiralty knot during the six hours' run the mean speed proved to be 35.672 knots, and the best speed attained on any one run was 37.037 knots, thus creating still another record. The turbines of the *Tartar* are of the Parsons type, and steam is supplied by boilers using oil fuel."

"That the automobile has settled down to its approximate final type is suggested by the small and decreasing number of novelties which have made their appearance during the past year. And with this ultimate agreement upon a best type there has come a remarkable improvement in the quality of the product, both as to the material of construction, the reliability of operation, and the finish and general appearance. Wonderfully rapid has been the development of this most complicated machine to its present perfection. We may search in vain through the whole field of mechanical engineering to find a parallel, unless, indeed, it be in the scarcely less rapid development of the steam turbine. The composite automobile at the close of the year 1907 has a pressed-steel riveted frame; a 40-horse-power, 6-cylinder engine; magneto ignition, with the jump spark in reserve; it is water-cooled, with its pump driven by gears from the engine shaft; it has a three- or four-speed sliding gear of the selective type; a cone clutch, or if not that, one of the floating disk or ring type; the car body is distinguished by straight lines and a general simplicity and purity of outline and coloring. With reasonably careful handling and inspection, a car of this type, built by any of the first-class makers, affords as reliable a means of locomotion as exists to-day."

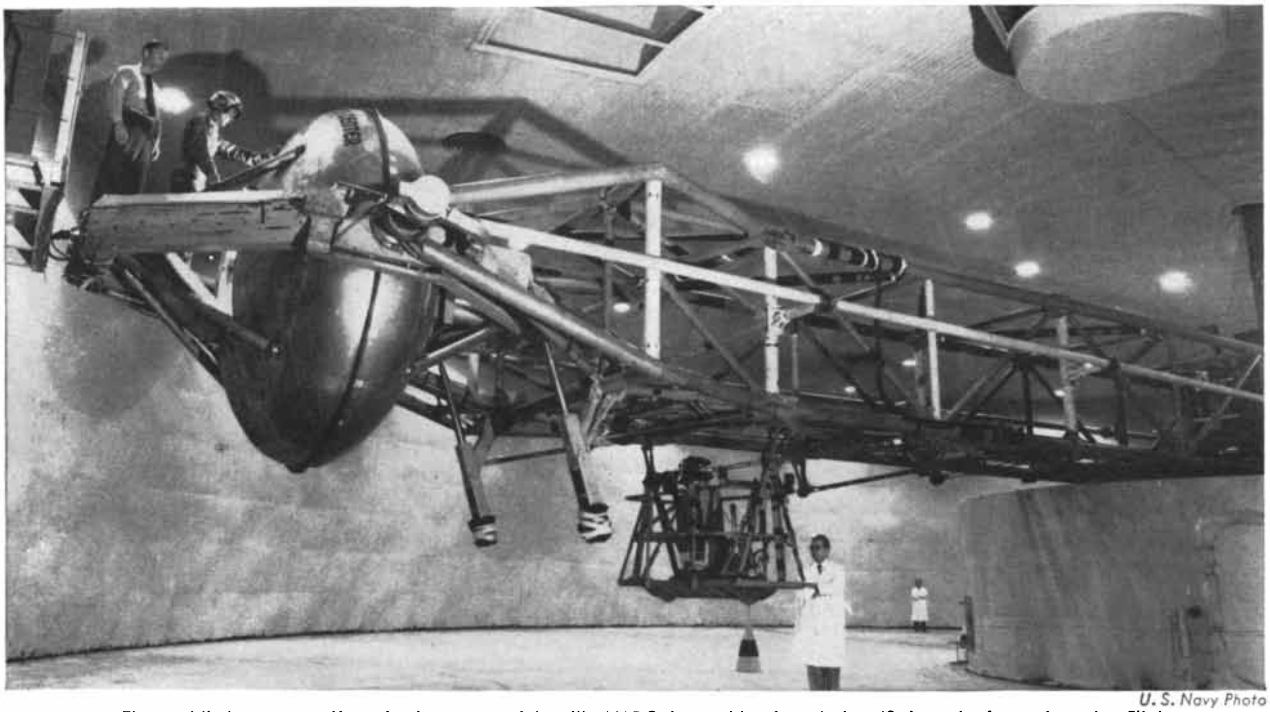
"On December 23 the Signal Corps issued specifications and invited bids for a heavier-than-air flying machine capable of traveling at the rate of 40 miles an hour in still air and carrying two men aggregating 350 pounds, as well as sufficient fuel for a flight of 125 miles. In taking this step, the War Department has recognized that a dynamic flying machine is now a reality; so our Government is now in advance of all foreign powers in the recognition of this fact. As no one has thus far come forward and won the Scientific American trophy for a flight of a kilometer in a straight line, however, it is extremely doubtful whether there will be any bidders to compete for the Government contract for such a machine."

"Three grammes of radium (about 46 grains), the largest quantity yet produced at one time, has been extracted by the Imperial Academy of Sciences of Vienna, from 10 tons of uranium and pitchblende given them by the Government from its mines in Bohemia, and although the crude material cost nothing, the extraction alone amounted to $10,000. This, however, cheapens the cost of radium considerably, for the three grammes, approximately, above mentioned, were obtained at one third the cost of previous products which, it has been estimated, would be worth not less than $3,000,000 an ounce. A small fraction of the yield has been presented to Sir William Ramsay, the English scientist. A part will be used by other researchers to test Prof. Ramsay's theory regarding the breaking up of radium into other elements."

JANUARY, 1858: "The following statistics will enable our readers to form some conception of the enormous consumption of gas, and of the extent to which this branch of industry has attained. Muspratt, in speaking of the influence of chemistry, says that in England 6,000,000 tuns of coal are annually employed for the manufacture of gas, and from 12,000,000 to 15,000,000 pounds sterling are expended in its production. In London alone 500,000 tuns of coal are annually used, producing 4,500,000,000 cubic feet of gas and 500,000 chaldrons of coke; of the latter, 125,000 chaldrons are consumed in manufacturing the gas, and the remainder is sold for fuel. Upwards of half a million houses in London burn gas."

"We see that the Chaffee patent is again before Congress, on a petition presented by Mr. Pugh of Ohio for its further extension. This may be regarded as the inauguratory operation of the patent lobby for the session, and the precursor of a host of other jobs of a more or less profitable kind. The amount of corruption that will be brought to bear on Congress during the present session will, we believe, be greater than has ever before been known. These patent extensions are an inexhaustible mine of wealth to the lobby speculators. Besides the Chaffee interest, there are some three or four others, such as the McCormick reaper, the Colt pistol and Hayward India rubber extensions, which are sufficient to make the fortunes of all concerned in them. In addition to these, there are land jobs and other fat pickings, from which trading politicians, starving journalists and idle lawyers can all glean something. Uncle Sam's estate may be compared to an Irish patrimony—it is entailed for the benefit of the hungry and needy."

"We Americans have manufactured 25,965 miles of railroad, which, if it could be stretched in one continuous line around the waist of Mother Earth, would still leave her about a thousand miles for a bow-knot."



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The NADC Aeronautical Instruments Laboratory at Johnsville is engaged in development and evaluation for the Army-Navy Instrumentation Program, and was first to develop the automatic artificial stability control for rotary wing aircraft. Other NADC projects include high-speed low-level cameras . . . techniques for underwater launching of guided missiles . . . and radio controlled drone planes carrying bombs, used so effectively against the enemy in Korea.

This defense center covers over 750 acres, including a Naval Air Station which provides aircraft for scientists carrying out their experimental missions. There are eight laboratory groups at Johnsville, specializing in computation; aircraft armament; systems for drones, missiles and other special aircraft; aviation medicine; air warfare research; aeronautical instrumentation; aero electronics; and experimental photography, a field unto itself.

Many unusual facilities are available to Johnsville's scientific staff of over 2,200 people. In addition to equipment such as the giant centrifuge illustrated, the center has one of the world's largest analog computers — the TYPHOON — which can handle an infinite variety of engineering and aerodynamic problems. Johnsville has a fabrication shop capable of manufacturing anything from a delicate instrument to a complete aircraft. Huge cold chambers are available to test equipment for use under conditions such as those encountered in Operation Deepfreeze, currently underway in the Antarctic. Johnsville is cooperating closely in the Geophysical Year — as well as turning out a wide variety of scientific developments for BuAer, the fleet, and Navy contractors.

This is one of a series of ads on the technical activities of the Department of Defense.

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THE AUTHORS

JOHN T. MENGEL and PAUL HERGET ("Tracking Satellites by Radio") represent the technical and scientific aspects of moon tracking: Mengel is top radio engineer of the Navy's Project Vanguard, while Herget, professor of astronomy at the University of Cincinnati, studies the orbits of small members of the solar system—including those launched by man. Mengel acquired a B.S. in physics from Union College in 1939, then worked on vacuum-tube development for the General Electric Company. This led to research during World War II on detection devices for ships, which led to a postwar job making the first research nose-shells for the V-2 rocket. In 1955, after several years at the Naval Research Laboratory he joined Operation Vanguard, where he now heads the Tracking and Guidance Branch. Herget received his undergraduate and graduate training at the University of Cincinnati, and has taught there since 1931. He saw wartime service at the U. S. Naval Observatory and at Oak Ridge, and is the author of a book entitled *Computation of Orbits.*

GRAHAM HOYLE ("The Leap of the Grasshopper") is a zoologist at the University of Glasgow. Although biology was his first scientific love, he took a wartime degree at the University of London in chemistry and physics. Then he joined the Ministry of Food to experiment on vegetable dehydration—a job he describes as "cramming tons of cabbage into a biscuit tin." Later Hoyle taught in a grammar school. Dissatisfied with this career, he returned to the University of London and started over again as a zoologist. There, intrigued by the problem of how insect nerves operate in spite of the high content of nerve-blocking potassium in insect blood, he began to perform experiments on grasshoppers.

SAMUEL A. SCHAAF, LAWRENCE TALBOT and LEE EDSON ("Ultra-high-Altitude Aerodynamics") are on the faculty of the University of California, where Schaaf and Talbot co-direct the Rarefied Gas Dynamics Project and Edson teaches technical writing. Schaaf, who also heads the University's aeronautics program, earned a Ph.D. in mathematics at California in 1944. In World War II, as a member of Richard Courant's applied mathematics group at New York University, he analyzed the operation of Germany's V-1 missile. Schaaf's hobby is golf. He says that he scores in the 70's because his training in aerodynamics enables him to predict the ball's trajectory. Talbot, who teaches mechanical engineering at Berkeley, is an expert on shock-wave structure. Now on sabbatical leave in France, he is conducting studies at the Mediterranean Institute of Thermodynamics at Nice and lecturing at the University of Paris. Edson, who has a B.S. in physics from the College of the City of New York, worked briefly in physical chemistry before joining the Navy Bureau of Ordnance laboratory as a technical editor. In addition to his teaching duties at Berkeley, he contributes frequently to national magazines.

GEORGE GAMOW ("The Principle of Uncertainty") was present at the birth of "the philosophy of uncertainty." As a graduate student of physics at the University of Leningrad in 1928, he found himself in hot water because "the research topic proposed by my professor was so boring that the work hardly made any progress." That summer Gamow took some courses at the University of Göttingen. While there he devised a quantum theory of radioactivity which shed new light on the structure of the atomic nucleus. Instead of returning to Leningrad he accepted an invitation from Niels Bohr, who had learned of his work, to spend a year at the University of Copenhagen on a fellowship provided by the Carlsberg brewing firm. The following year he worked with Ernest Rutherford at the University of Cambridge on a Rockefeller fellowship. At Cambridge he wrote his first book, entitled *Constitution of Atomic Nuclei and Radioactivity.* After two more years of teaching at Leningrad, Gamow attended the International Solvay Congress on Physics in Brussels and decided not to return to the U.S.S.R. In 1934 he accepted a professorship at George Washington University; in 1956 he became professor of physics at the University of Colorado. After Gamow came to the U. S., his interests shifted from pure nuclear physics to its applications in cosmology, and later to fundamental problems of biology.

ELIJAH ADAMS ("Barbiturates") was recently appointed professor and director of the pharmacology department of the Saint Louis University School of Medicine. A graduate of the Johns Hopkins University, he took his M.D. at the University of Rochester in 1942. He served as an Army physician during World War II, but on his return to civilian life he left medicine for research in enzyme biochemistry. Adams, who has been teaching pharmacology at the New York University College of Medicine, still finds biochemistry his main interest, but believes that the fields are merging "as biochemistry tends to become more physiologic and pharmacology more biochemical."

VERNON M. INGRAM ("How Do Genes Act?") studies molecular biology at the Cavendish Laboratory of the University of Cambridge, where he is employed by the Medical Research Council of Great Britain. There he developed the electrophoretic "fingerprinting" technique which he describes in his article, using it first to distinguish the hemoglobin of men, horses and whales. Ingram received a Ph.D. in organic chemistry from the University of London in 1949.

NORMAN GUTTMAN and HARRY I. KALISH ("Experiments in Discrimination") worked together at Duke University, where Guttman is associate professor of psychology. Guttman studied philosophy at the University of Minnesota, then began his career as an experimental psychologist on a wartime project, directed by B. F. Skinner, to train animals to guide air-to-ground missiles. He has a Ph.D. from Indiana University and has worked at Duke since 1951 on grants from the National Institute of Mental Health. Kalish is a clinical psychologist trained at the University of Iowa. He is now an associate professor at Adelphi College.

WILLIS E. PEQUEGNAT ("Whales, Plankton and Man") is professor of zoology at Pomona College. There he devotes most of his time to the study of offshore life. "I was among the first biologists to use the aqualung," he reports. "Actually this was probably motivated by laziness. For me the aqualung meant liberation from wading expeditions at the low-tide cycles, which in California in the summer come during the dark early hours of the day. Now my assistant and I regularly don our diving gear, which includes an underwater tape-recorder and flash camera, and study the reefs down to depths of 100 feet." The many discoveries they have made have led to a research project supported by the Office of Naval Research. When he is not teaching, Pequegnat devotes his attention to the 14,000 chickens on a poultry ranch which he owns in partnership with three other Pomona professors.

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CUSTOMER	REACTOR TYPE	POWER LEVEL
*Battelle Memorial Institute, Columbus, Ohio	Pool-Type	1000 KW
Industrial Reactor Laboratories, Inc., Plainsboro, N. J.	Pool-Type	5000 KW
University of Buffalo, Buffalo, New York	Pool-Type	1000 KW
*Technical University of Munich, Munich, Germany	Pool-Type	1000 KW
*International Exhibition, Het Atoom, Amsterdam, Netherlands	Tank-Type, Demonstration	10 KW
Japanese Atomic Energy Research Institute, Tokai-Mura, Japan	Heavy Water, Tank-Type	10,000 KW
McMaster University, Hamilton, Ontario	Pool-Type	1000 KW
Greek Atomic Energy Commission, Aghia Paraskevi, Greece	Pool-Type	1000 KW
Union Carbide Corp., Sterling Forest, New York	Pool-Type	5000 KW
Societa Ricerche Impianti Nucleari, Milan, Italy	Pool-Type	1000 KW
AMF-GNE Educator, University of Florida, Gainesville, Florida	Training	10 KW
Portuguese AEC, Lisbon, Portugal	Pool-Type	1000 KW

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Herbert Spencer...on the genesis of science

"Without further argument it will, we think, be admitted that the sciences are none of them separately evolved — are none of them independent either logically or historically; but that all of them have, in a greater or less degree, required aid and reciprocated it. Indeed, it needs but to throw aside hypotheses, and contemplate the mixed character of surrounding phenomena, to see at once that these notions of division and succession in the kinds of knowledge are simply scientific fictions: good, if regarded merely as aids to study; bad, if regarded as representing realities in Nature. No facts whatever are presented to our senses uncombined with other facts — no facts whatever but are in some degree disguised by accompanying facts: disguised in such a manner that all must be partially understood before any one can be understood."

—*The Genesis of Science, 1854*

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Established 1845 **SCIENTIFIC AMERICAN** January, 1958 Volume 198 Number 1

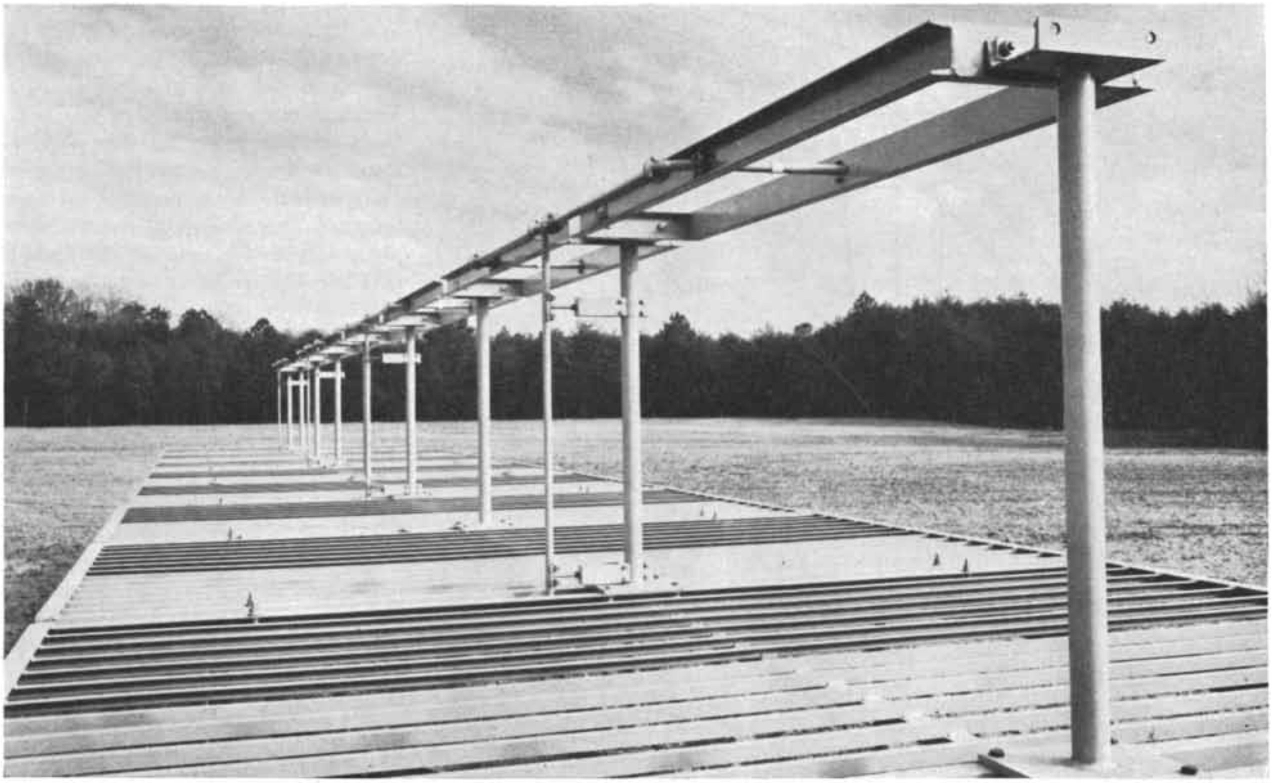
Tracking Satellites by Radio

The fastest, most reliable way to detect an artificial satellite and initially to determine its orbit is by radio. A far-flung system called Minitrack has been established for this purpose

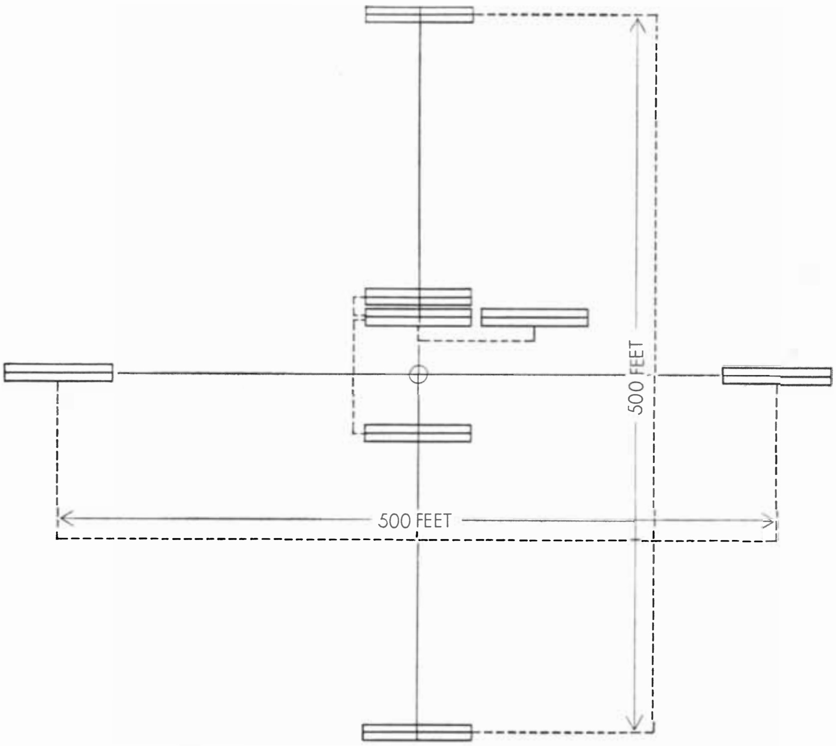
by John T. Mengel and Paul Herget

The man-made satellites are in a sense creatures of the radio age. One might almost say that were it not for radio, there would be little point in sending them up. It is by the agency of radio that we receive most of the information the satellites are collecting at the borders of space. And without radio we would have very great difficulty in observing them at all. They can be seen only at intervals during their flight under special conditions; we have to rely primarily on the beeps or whining song of their tiny radio transmitters to track the objects and find out where to look for them. Indeed, radio makes it possible to follow them even when they are too small to be visible.

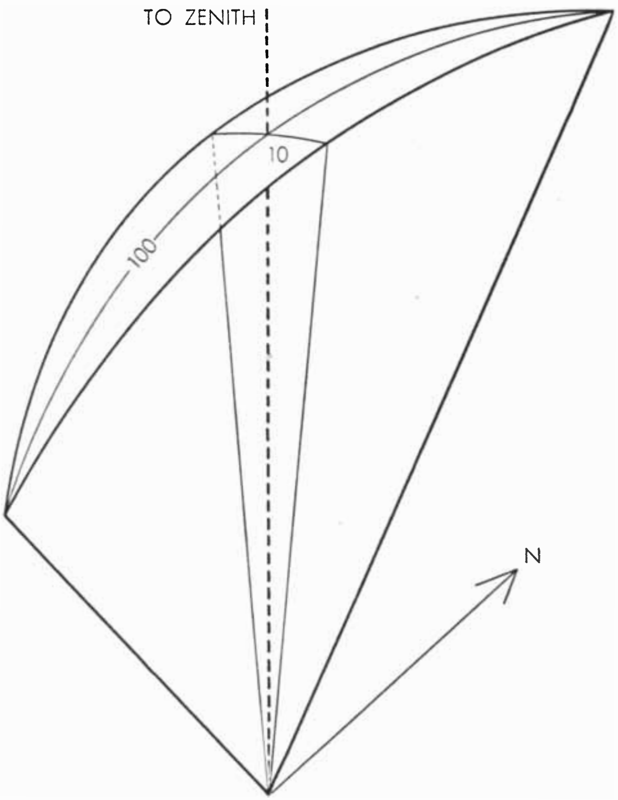
Tracking an object by radio is not, however, a simple matter. It is like trying to follow an airplane whizzing across the sky which we can hear but cannot see. Just as our ears are a much less precise instrument for location than our



MINITRACK ANTENNA, mounted on steel posts, is an array 60 feet long and 10 feet wide. The strips underneath the antenna proper form a reflecting screen. The long dimension, which provides a beam of radio reception 10 degrees wide, runs east-west.



ANTENNA SYSTEM of a Minitrack station is made up of eight individual antennas connected to form three pairs in the north-south direction and two pairs in the east-west. The outermost pairs in each direction are 500 feet apart. The north-south inner pairs are separated by distances of 64 and 12 feet. The spacing of the east-west inner pair is 64 feet.



RADIO-RECEPTION PATTERN of the Minitrack antenna array is a fan-shaped beam which is 100 degrees wide from north to south and only 10 degrees wide from east to west.

eyes, so radio is a severely handicapped instrument for pin-pointing an object. That ways have nevertheless been found to use it successfully for tracking is a tribute to the ingenuity and sophistication of the present radio art. This article will describe the main features of the system tracking the satellites. It is called "Minitrack" ("mini" denoting the miniature size of the satellite's transmitters).

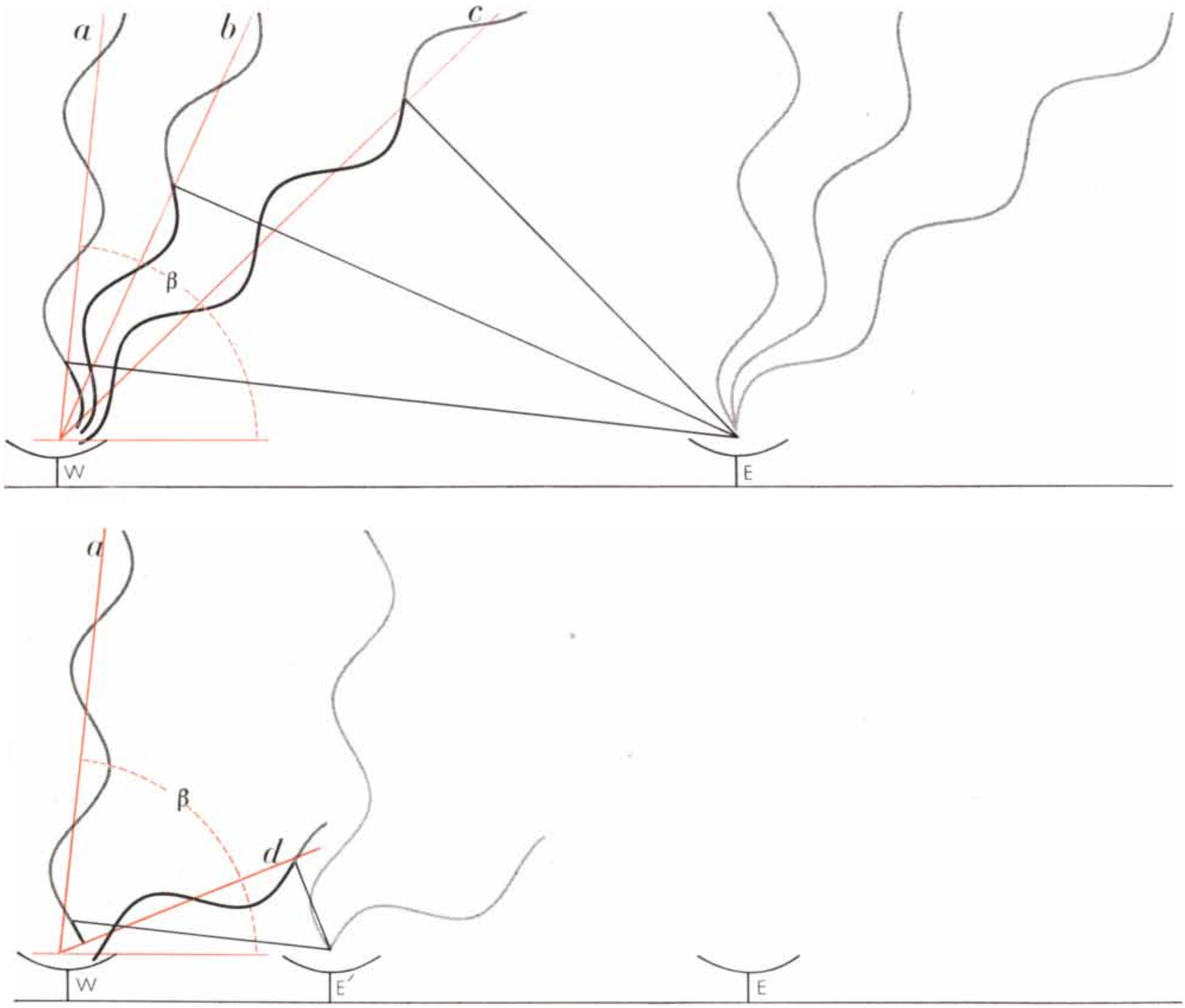
Minitrack is the ears of the satellite program, as "Moonwatch" is its eyes [see "Observations of Satellite I," by Fred L. Whipple and J. Allen Hynek; SCIENTIFIC AMERICAN, December, 1957]. The antennas of the Minitrack stations in fact function much like ears. An individual locates the source of a sound by virtue of the phase differences in the sound waves, arriving at different times at his two ears. Similarly the listening units of the Minitrack system are pairs of receiving antennas, set a measured distance apart, which indicate the direction of the signal by phase differences in the radio waves [*see diagram at left*].

The direction, in terms of its angle to the baseline between the two antennas, is calculated from the phase difference by a simple triangulation method. If the waves arriving at the two antennas are out of phase by a third of a wavelength, for example, this gives us a measure of the extra distance they traveled to the farther antenna, and we can then determine the angle to the baseline. However, in order to find the actual length of the extra distance we must know whether it represents only one third of a wavelength or one and a third or two and a third or some larger number plus one third. To resolve the ambiguity, we set up other pairs of antennas, spaced closer together. They give us shorter fractional phase differences, and, on the basis of whether the resulting directions fall within the reception pattern, we can determine the number of wavelengths involved [*see diagrams on opposite page*]. The reception pattern of a Minitrack station is a fan-shaped beam stretching 100 degrees north and south and 10 degrees east and west. In the long direction of the beam we have three pairs of antennas, spaced respectively 500, 64 and 12 feet apart; in the narrower east-west dimension, two pairs with spacings of 500 and 64 feet. The north-south and east-west determinations give us two angles which locate the actual direction of the satellite.

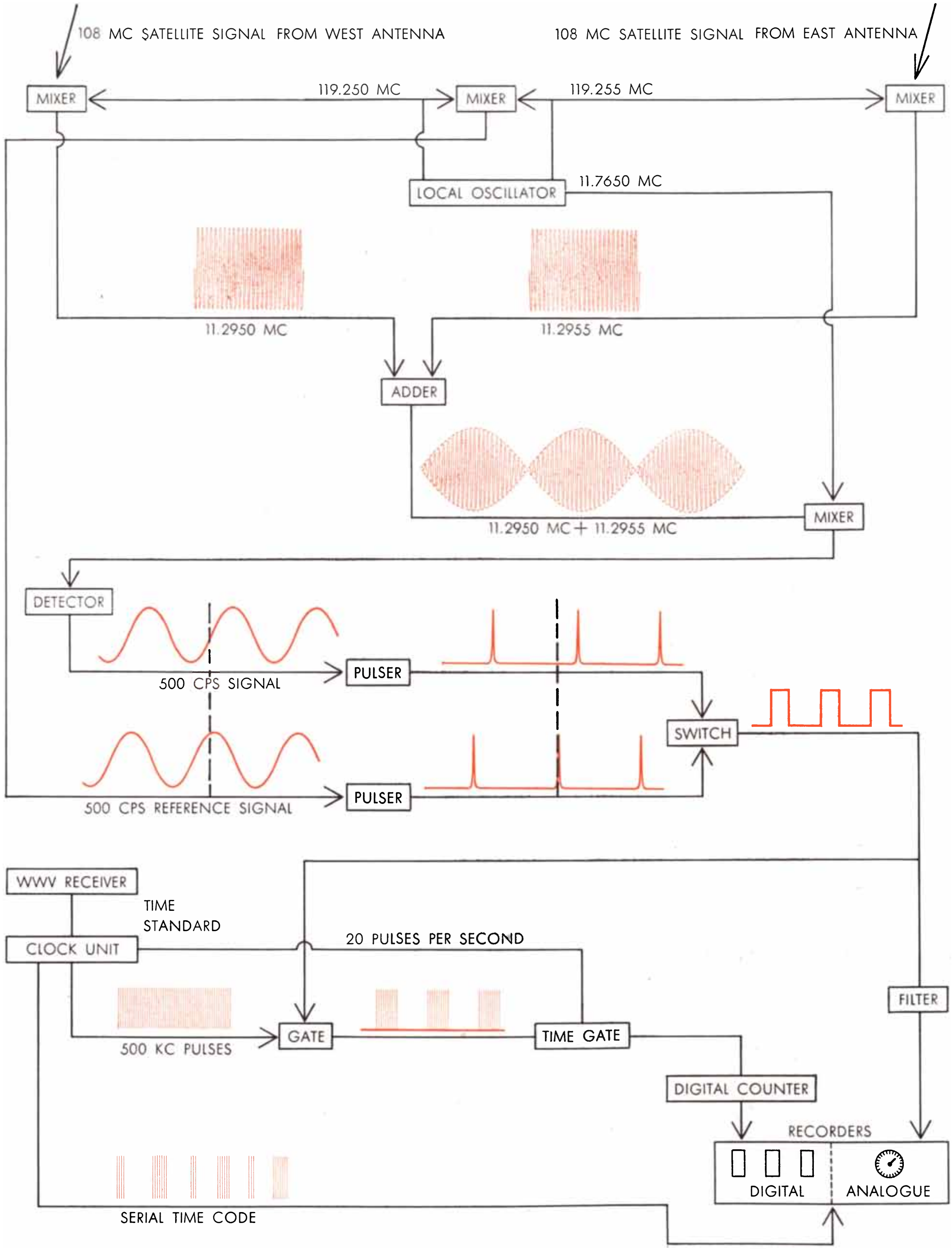
To determine the orbit of the satellite in space, its positions must be located in relation to a stationary set of coordinates, based on the fixed stars.

Therefore our directions must be related to such coordinates. The most convenient center for our set of coordinates is the center of the earth, the point toward which the satellite is always attracted [*see diagram on page 28*]. We find the direction from the center of the earth to the satellite by determining the directions from the earth's center to the station and from the station to the satellite. The first of these directions, with respect to the coordinate system, is determined by the latitude of the station and the time of day at which the observation is made. The second should be measured with respect to baselines running exactly north-south and east-west. In practice it is not easy to align the antennas so precisely. Instead we "calibrate" the station after it is set up, to determine the corrections that must be applied to its readings. This is done with the aid of an airplane carrying a Minitrack transmitter and a small flashing light which is turned on and off from the ground station by radio. The plane is flown at night through all parts of the antenna pattern, and the radio direction is measured by the method we have described. At the same time a telescope set up at the intersection of the north-south and east-west lines photographs the flashing light against the background of the stars. The discrepancy between the radio directions and the true directions with respect to the stars is applied as a correction to the readings taken at the station.

These readings are obtained by means of an electronic circuit which amplifies, mixes and compares the signals from an antenna pair and finally produces an electrical output proportional to the phase difference. The output is fed to a recorder which reads directly in degrees (360 degrees corresponds to a complete wavelength). Greater accuracy is provided by another record in which the phase difference is recorded to one thousandth of a wavelength and the time of observation to one thousandth of a second. From these figures we can fix the



DIRECTION TO SATELLITE (*angle beta*) is determined by the difference in phase between radio waves arriving at each of two antennas. At top the most distant pair of east (E) and west (W) antennas are shown schematically. If the satellite is in the direction marked *a*, its radio waves will travel about one third of a wavelength farther to W than to E. However, waves from direction *b* would travel one and one third extra wavelengths, and those from *c* two and one third. The Minitrack system cannot distinguish among these directions. To resolve the ambiguity a closer pair of antennas (*bottom*) is used. Here the first ambiguous direction, containing an extra whole wavelength, is shown by the arrow *d*. This lies outside the antenna pattern. Hence the close antennas "see" only direction *a*. Therefore the uncertainty in the observations from the distant antennas is eliminated. The true direction can only be *a*.



MINITRACK CIRCUITS convert the phase difference between signals arriving at each pair of antennas to a form in which it can be recorded on tape. Incoming signals (*top*) are mixed with the output of a local oscillator and combined to form a wave which pulsates at 500 cycles per second. A pure 500-cycle signal is extracted for comparison with a 500-cycle reference signal generated in the system. The two signals, which have the same phase relationship as the original radio waves, are converted to a pulsating current (*rectangular wave-form at right center*). The width of the pulses depends on the phase difference. This current is fed into an analogue indicator and is also mixed with a 500-kilocycle signal to provide a digital, or numerical, reading of the phase difference.

direction of the satellite to within 20 seconds of space angle (one 180th of a degree).

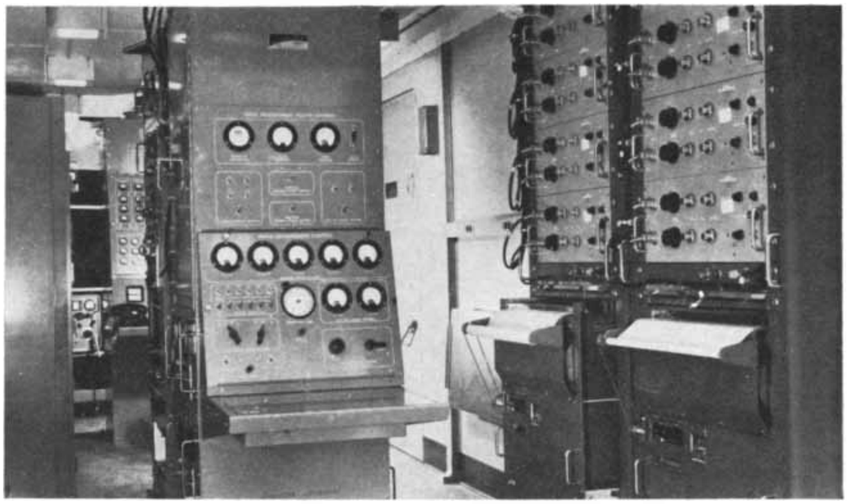
The Minitrack system was set up as part of the U. S. Vanguard project. All the Vanguard satellites will be fired from Cape Canaveral, Fla. They are to be shot into an east-west course near the equatorial region, and the angle at which they can be fired is limited to within 35 degrees of the Equator because of the presence of the Bahama Islands offshore. The picket line of Minitrack stations across their expected path is strung out in a north-south line up the west coast of South America and the east coast of North America [*see map on next page*]. Seven stations form this picket line, and there are four others scattered over the world—in San Diego, the British West Indies, South Africa and Australia. With this arrangement we have a 90 per cent chance of intercepting every pass of a satellite which is higher than 300 miles.

Observations from all Minitrack stations are transmitted by teletype to the Vanguard Control Center at the Naval Research Laboratory in Washington. After being inspected for errors the message tapes are sent to a computing center, where their information is automatically transferred to punched cards which are fed into an IBM-704 electronic calculator.

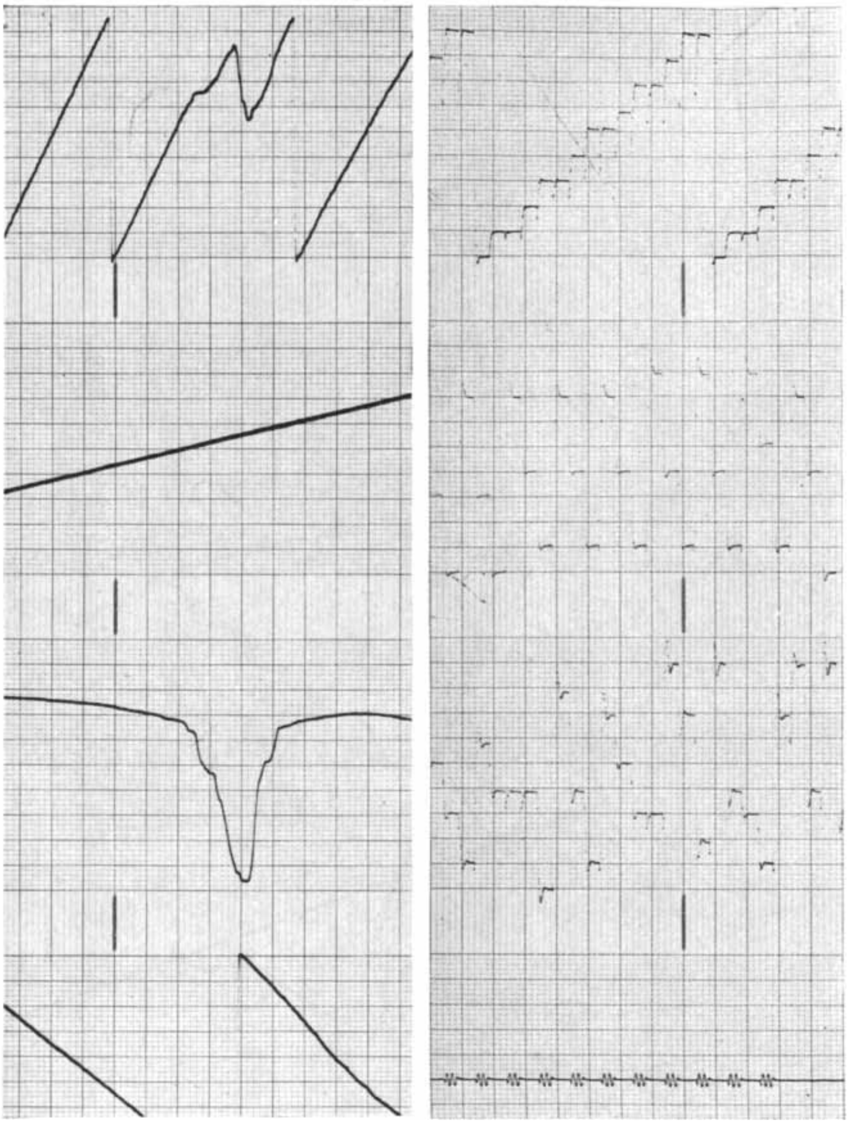
Already stored in the machine are the calibration formula for each station and correction factors to take care of certain systematic errors such as the bending of the radio signal as it passes through the ionosphere. The computer applies these corrections and "smooths" the resulting figures to compensate for random errors. In a few thousandths of a second it supplies the direction and distance from the center of the earth to the observing station and the direction from the station to the satellite. As observations on various points along the path are collected, the machine inserts them into the formulas from which the orbit is calculated.

Adding corrections for atmospheric drag and for the wobble of the orbit due to the bulge of the Equator, the 704 computes the satellite's minute-by-minute position at a rate 150 times faster than the actual progress of the vehicle. As the satellite makes more and more revolutions around the earth, the computer corrects the orbit.

On Friday, October 4, 1957, the Minitrack system was practically complete, awaiting the final check-out of

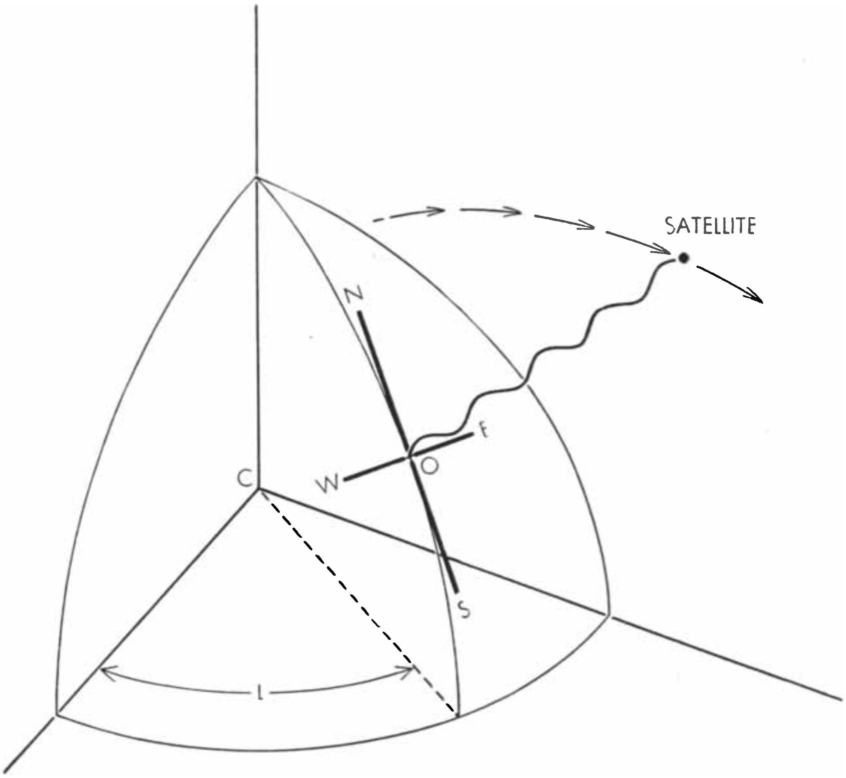


INTERIOR OF TRAILER at Minitrack station contains the radio receivers and other electronic circuits. Recording tapes can be seen at the bottom of the consoles at the right.



SECTIONS OF RECORDING TAPES from a Minitrack station show variations in phase angle as lines on a graph in the analogue presentation (*left*) and as specific numbers in the digital presentation (*right*). Intermittent pulses at bottom of digital record are time code.

MINITRACK STATIONS are located at the numbered points on this map. The solid curve shows the expected path of U. S. satellite; the broken curve, the path of Soviet satellites.



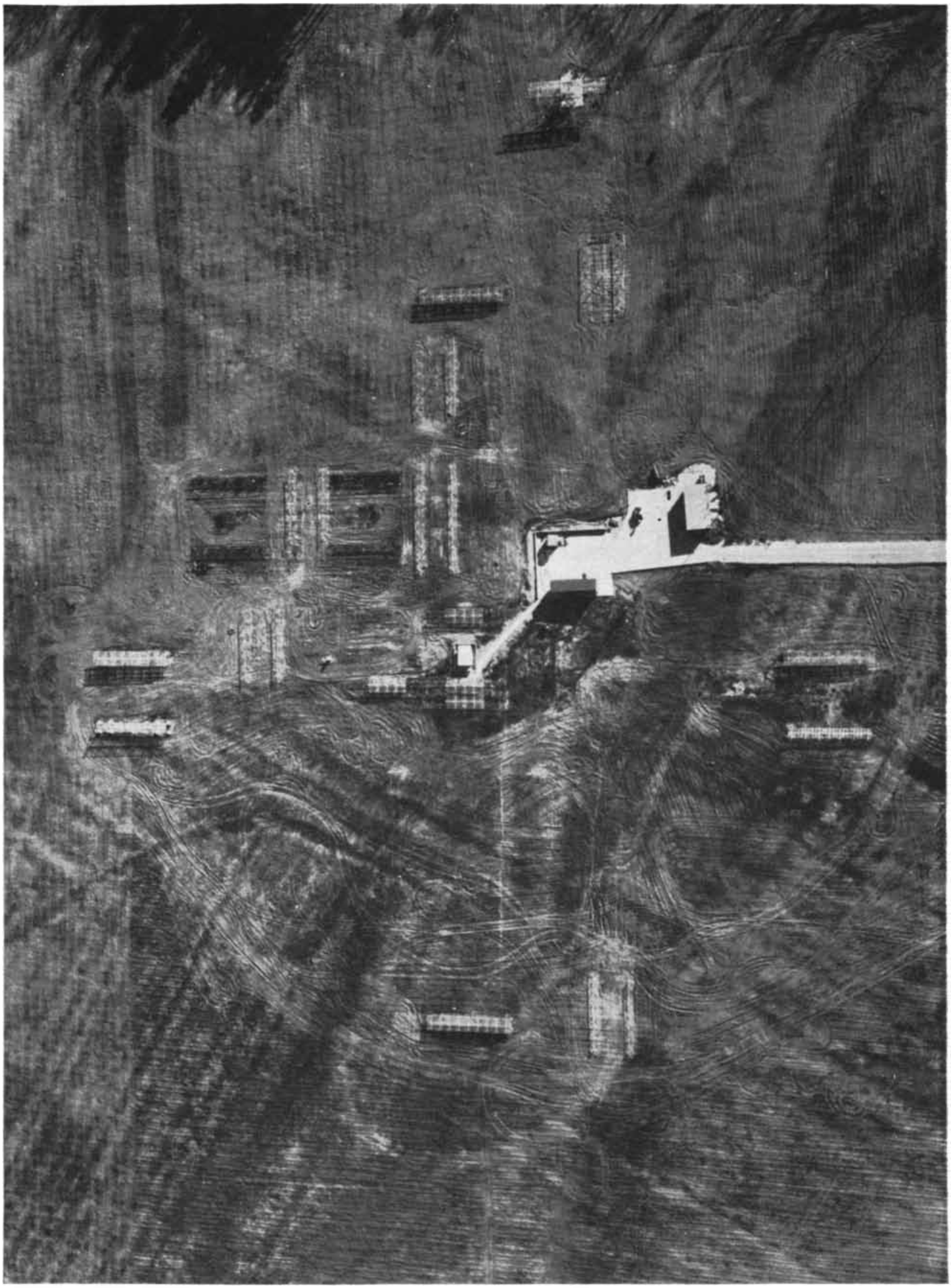
COORDINATE SYSTEM within which a satellite's orbit is calculated has its center at the center of the earth (C). Hence the measured direction from a Minitrack station (O) to a satellite must be combined with the direction from O to C. This is determined by the latitude of O and by the angle L, which depends on the time at which the measurement is made.

some of the teletype links and the calibration of some of the stations. All the equipment was set up to operate on 108 megacycles, the frequency recommended by the International Committee for the International Geophysical Year. But as is now well known, the U.S.S.R.'s sputniks threw disorder into these preparations. The launching of Sputnik I brought a scramble to convert the Minitrack equipment to receive its 20- and 40-megacycle signals.

The first concern was to put as many stations as possible into operation at once, before the satellite's transmitter gave out. Instructions sent by teletype and equipment flown by the U. S. Army enabled most of the stations to convert to reception at 40 megacycles within a few days, but accurate tracking was impossible without new antennas. Before Sputnick I's batteries died, the N.R.L. was able to supply newly designed antennas to the Blossom Point, Lima and San Diego stations. These stations collected good tracking data on Sputnicks I and II.

The experience with the first two Soviet satellites provided a valuable shakedown for the Minitrack system. Besides this, the low frequencies used by the Soviet satellites yielded information about the ionosphere. We had chosen the 108-megacycle frequency for satellites because it would give a more accurate indication of direction than the lower frequencies. The ionosphere bends a 40-megacycle beam seven times more sharply than a 108-megacycle beam, and the refraction of a 20-megacycle beam is four times worse yet. However, the displacement of the satellite's apparent direction from its true direction can tell us a great deal about the properties of the ionosphere. Thus our tracking of the sputnicks has furnished us with a large body of data from which we shall be able to make deductions about the electrified layer and its effects on radio waves.

But the Minitrack system was designed primarily for the U. S. satellites, and it is on these that it will demonstrate its full accuracy and utility. We expect that we shall be able to plot the paths of these objects very promptly after they are launched—even before they have reached their orbits. This is true even though the Minitrack system can measure only angles and directions, not distances. The "ears" of radio have become almost as good a "seeing" and tracking instrument as our eyes, thanks to the marvelous advances of radio electronics and computing machines.



STATION AT BLOSSOM POINT in Maryland is photographed from the air. Some of the antennas (*oblong shapes*) are for regular Minitrack system, some for Soviet satellites and some for other projects. Road runs approximately west-northwest toward right.

The Leap of the Grasshopper

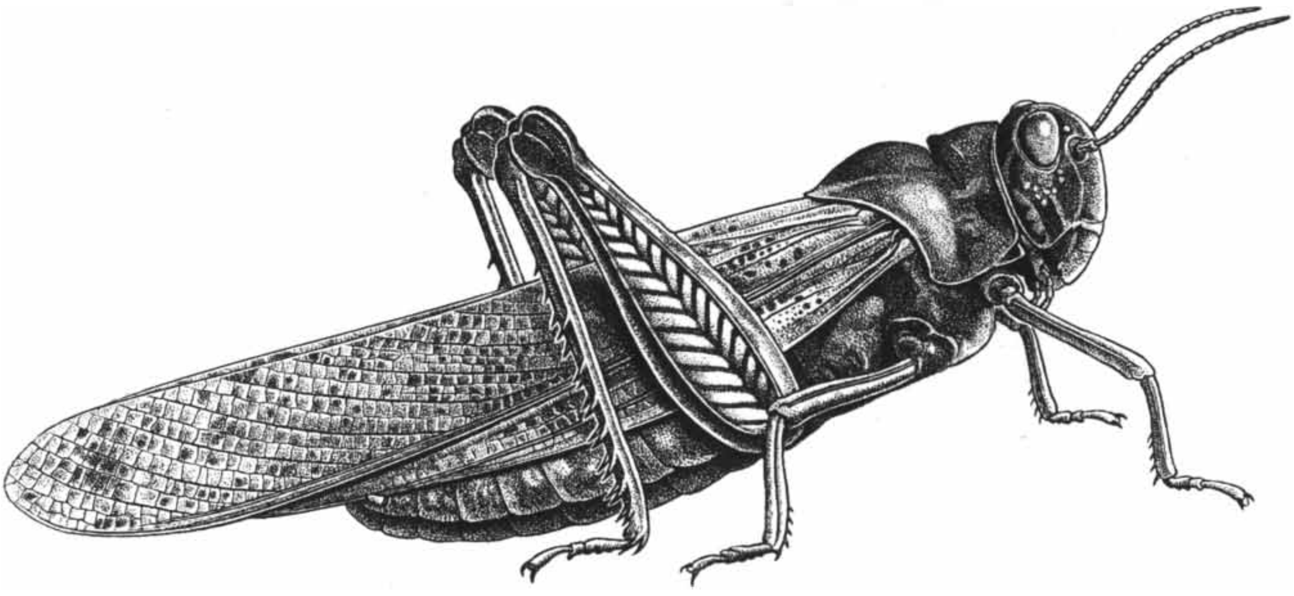
A grasshopper can leap 20 times its body length. The physiology of this remarkable performance is studied both for its intrinsic interest and for its usefulness in improving control of the insect

by Graham Hoyle

The grasshopper's jump is one of the most remarkable performances in the biological world. The little animal can leap about 10 times its body length in a vertical jump or 20 times its length (almost one meter) horizontally. If a man were able to perform in proportion, he could jump over a five-story building or cover 100 yards in just three hops. The grasshopper's leap is an extremely inviting subject for study, for it is always a source of amazement and delight to learn how nature contrives the living mechanisms that make such feats possible. Aside from sheer curiosity, we have other good reasons for looking into the physiology of the grasshopper. Even today plagues of locusts (short-horn grasshoppers) are capable of bringing one eighth of the world's population to the edge of starvation. To gain effective control over these terrifying insects we shall need to learn all we can about their habits and biology. The grasshopper seems a particularly good subject for studying the action of insecticides, especially on the nervous system.

Let us look first at the jump itself. We must do this with a slow-motion camera, because the leap is too fast for the eye to follow. Preparing to jump, the grasshopper raises the front of its body on its forelegs and cocks its rear legs by squatting with the femurs (thighs) doubled against the tibiae (shins). The insect then rears up on its hindlegs and takes off; this process takes only one thirtieth of a second. It may jump almost straight up or forward at an angle as flat as 40 degrees. Once in the air a grasshopper has no control over its trajectory, unless it uses its wings. It often spins head over heels and sometimes lands on its back. Although it lands at high speed, there is no damaging crash, because the insect is so light.

Now let us have a closer look at the mechanics of the jump. The jumping legs of a grasshopper are very different from the legs of most other insects and from its own forelegs. In the standing position the thigh and shin of its hindlegs are bent to an acute angle, instead of the usual wide angle [*see drawing below*]. The hindlegs are much longer and larger than the others. They are used for pushing, not pulling. This reverses both the role and the size of the extensor and flexor muscles: the extensor muscles are much larger than the flexors in the hindlegs of a grasshopper. Furthermore, jumping also calls for an evo-



CAROLINA GRASSHOPPER (*Dissosteira carolina*) illustrates the powerful hindlegs which grasshoppers use for jumping. These legs differ from those of most other insects in that the angle between the femur (thigh) and tibia (shin) is not obtuse but acute.

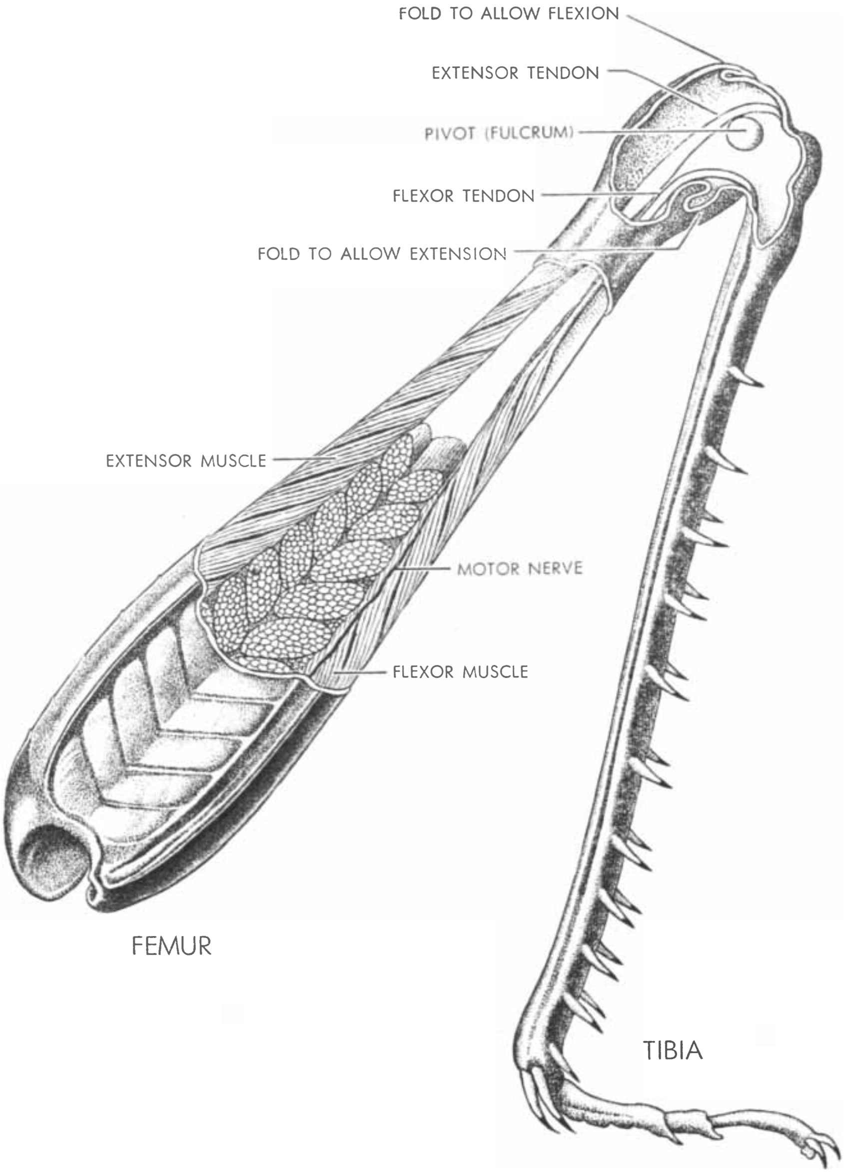
lutionary adaptation of the nervous system designed to activate both hindlegs to act simultaneously, instead of alternately as in walking.

The grasshopper's nervous system presents some interesting questions when we come to consider the powerful yet delicately controlled muscles with which it achieves its prodigious leaps.

A medium-sized locust, four to five centimeters long, can jump to a height of about 45 centimeters (18 inches). On elementary dynamic principles we can calculate that to reach this height the take-off velocity of the animal must be about 10 feet per second. Again by simple dynamics we can compute that a two-gram locust jumping to a height of 45 centimeters at an angle of 60 degrees must have a take-off thrust of about 30 grams—15 grams with each leg. Thus the thrust of a locust's leg amounts to some eight times the animal's total weight. (The maximum thrust of a man's leg is only about twice his body weight.) We have confirmed this calculation by experiments. An adult locust, stimulated to the jump reflex, can easily raise a 20-gram weight attached to its foot.

The grasshopper's leg muscles are so powerful that at maximum tension they can snap the tendons like threads. If you hold a strong jumper in your hand with its legs doubled so that it cannot extend its tibiae, and produce a jump contraction of the muscles by the proper stimulus, you will hear a faint but sharp click—the breaking of the tendons. After this experiment the animal can never jump again.

We can compute just how strong the jumping muscles are. When the tibia extends (in jumping or lifting a weight), it pivots around a pair of small knobs at the knee [*see diagram at right*]. Now the tendon of the jumping muscle (extensor) is attached at a point about one millimeter or less away from this fulcrum. The tibia of a large grasshopper is some 30 millimeters long. Thus when the jumping muscle in the femur works to lift a weight attached to the foot, at the other end of the tibia, it is operating on the short end of a lever at a disadvantage of 30 or 40 to 1. To raise a load of 20 grams, it must develop a power of about 800 grams. The grasshopper weighs only two grams, and its muscle is only one fiftieth of that—1/25 of a gram. Consequently the tiny muscle exerts the astonishing power of some 20,000 grams per gram of its own weight. The only known muscles in the whole animal world that equal this power are the shell-closing muscles of the clam—

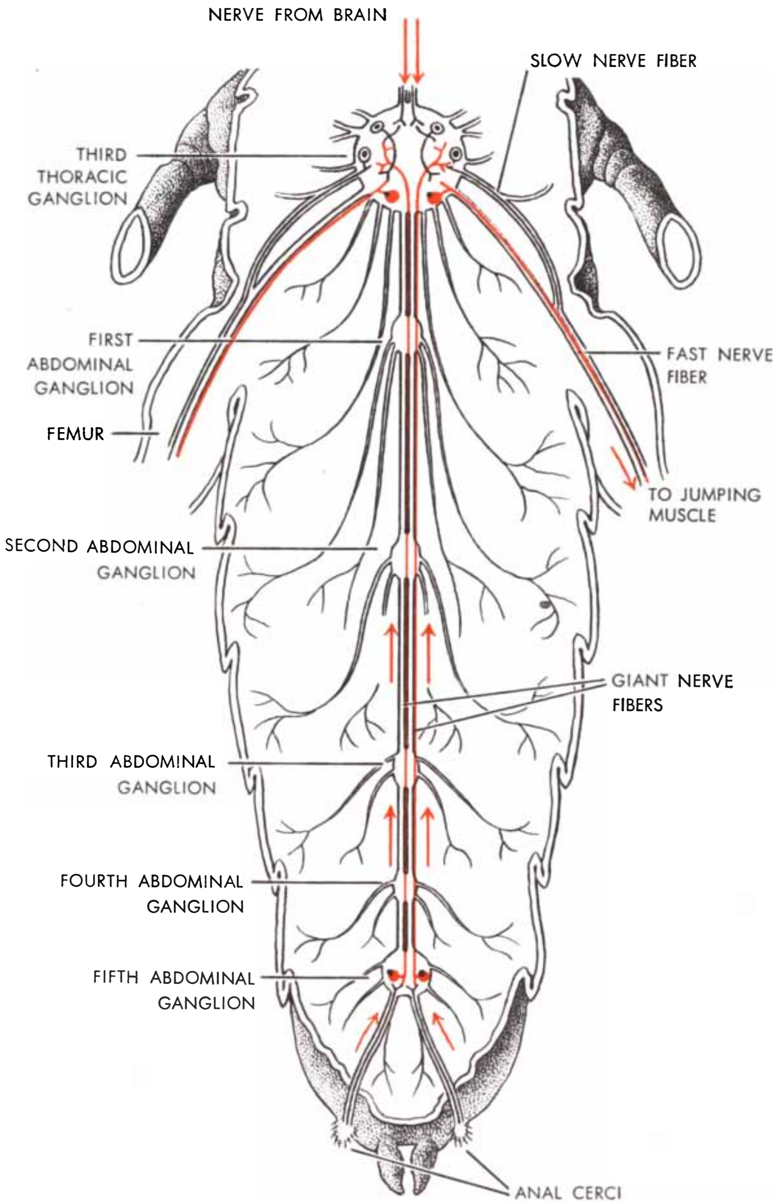


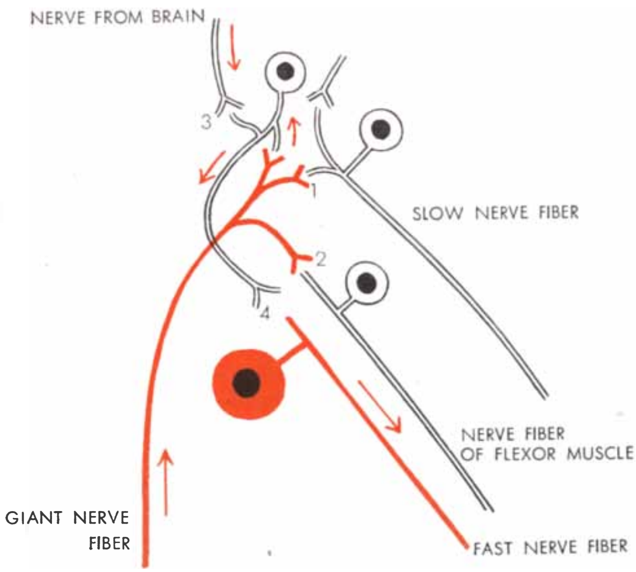
HINDLEG OF THE GRASSHOPPER also has the unusual feature of an extensor muscle (which straightens the leg) that is larger than the flexor muscle (which bends it). The short fibers of the extensor muscle are attached at one end to the external skeleton of the grasshopper and at the other end to a stout tendon which runs down the middle of the femur.

but the grasshopper's muscles work far more rapidly than the clam's. The muscles of man develop, at most, only about 2,000 grams of power per gram of weight. Experiments on locusts have shown that in flying, as in the jump, the locust's muscles can perform 10 times more work, in proportion to size, than human muscles working at top speed [see "The Flight of Locusts," by Torkel Weis-Fogh; SCIENTIFIC AMERICAN, March, 1956].

Two features of mechanical design account for the efficiency and enormous power of the grasshopper's jumping muscle. First, the muscle fibers are very short—about 1.5 millimeters, or one twentieth of an inch. Secondly, they are arranged like the fibrils of a feather along the whole length of the femur, attached to the external skeleton of the insect's leg and to a long, broad tendon inside the leg [*see diagram above*]. Thus the load is distributed evenly over the whole limb. Such an even distribution is impossible in a vertebrate structure, where the skeleton (*i.e.*, bone) is inside, although some of the shoulder muscles of vertebrates come close to achieving it.

Obviously the grasshopper needs a very precise regulating system to control its powerful muscles. In fact, the





animal shows a perfection of control which is altogether astonishing. It can contract the same muscle either with great power or so delicately that it barely moves a hairspring, and the contractions can be so slow as to be scarcely detectable or so fast that the eye cannot follow the animal's movement. And this remarkable range of control is achieved with an extremely simple nerve apparatus, consisting of just two fibers!

With refined techniques, using isolated nerve-muscle preparations, I have been able to analyze this nervous control experimentally.

What causes a grasshopper to jump in the first place? Here we are on somewhat speculative ground. A swarm of locusts basking quietly in the sun in a field may suddenly take off all at once without any obvious reason. Sometimes this happens when a cloud passes over the sun, but often there is no apparent stimulus that might account for it. In a cage a grasshopper left quietly alone seldom jumps. When it is hungry, or when the cage is crowded with grasshoppers, jumping becomes far more frequent. In this situation the animals seem to be in a tense state which makes them jump in response to stimuli that they would otherwise ignore. Sometimes the approach of a person in the laboratory will cause all the insects to jump wildly. Yet we must suppose that grasshoppers exercise some discrimination among stimuli, else the enormous expenditure of energy required for their leaps would soon exhaust them. It seems that usually the animal "decides" to leap; in other words, its jump is not a simple reflex action but is controlled by a mechanism of inhibition. No doubt this inhibition is not always applied correctly. I have seen grasshoppers which, placed on a hot plate in an experiment, scorched to death instead of jumping—as if they

PATHWAYS OF NERVES that cause the extensor muscles to contract are traced at left in color. Stimulation of the anal cerci, two sensory organs located at the tip of the abdomen, causes impulses to travel up giant nerve fibers to the third thoracic ganglion. In this ganglion, part of which is enlarged at the bottom of the diagram, nerves connect with the brain and with the muscles of the jumping leg. The impulse from the giant nerve fiber (1) inhibits the slow fiber of the leg to stop the walking movement, (2) stimulates the flexor muscle to cock the leg, (3) is reinforced by impulses from the brain, and then finally (4) fires the fast nerve fiber which actually sets off the jump.

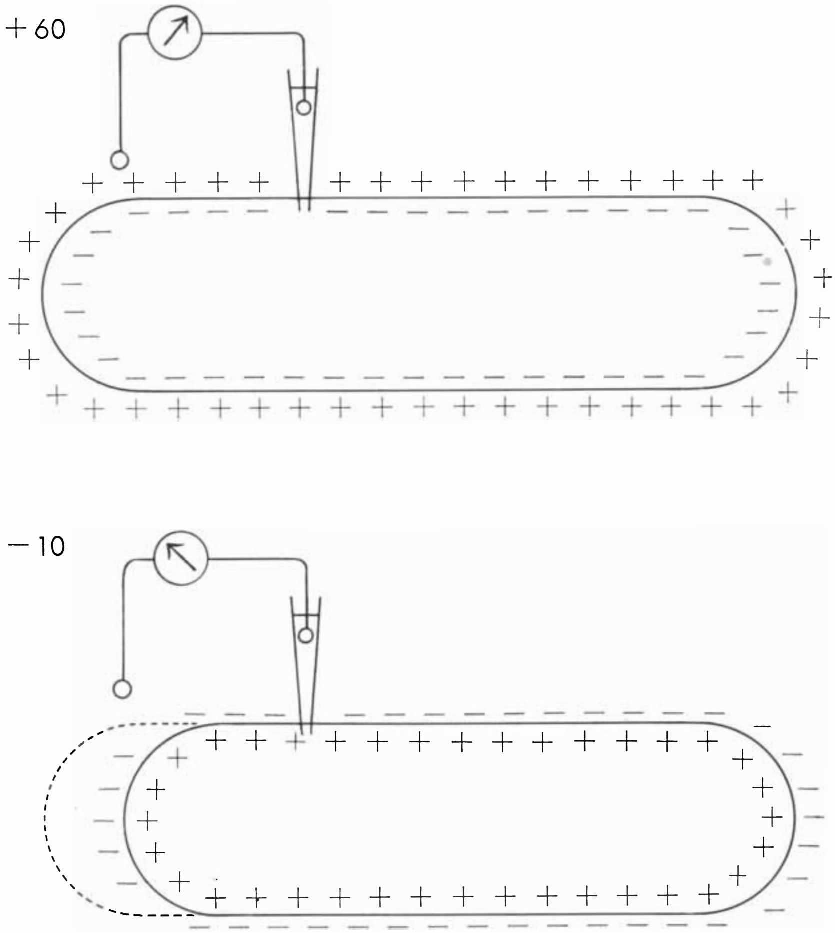
were reduced to a state of indecision by the conflict between the danger and their love of warmth.

We have found that one thing which will almost invariably make grasshoppers jump is stimulation of the pair of antennae (anal cerci) at the tip of the insect's abdomen. These sense organs respond to any slight change of air pressure—sound waves, the approach of a predator or a gentle puff of air. We use this as a standard stimulus to examine the responses of the nervous system.

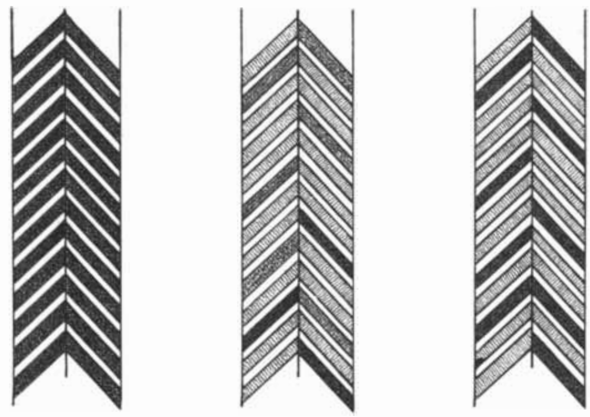
When a grasshopper is so stimulated, nervous impulses travel very rapidly by way of giant sensory nerves to the motor nerves that actuate the jumping muscles. Now these motor nerves are a greatly stripped-down model of a motor system. In a higher animal such as man, each muscle is controlled by hundreds of motor nerve fibers, the degree of the muscle's response being determined by the number of nerve fibers that fire. But the tiny, slender grasshopper cannot house any such elaborate system. In fact, it gets along excellently with just two nerve fibers for its jumping muscle. One, a "fast" fiber, has to do only with jumping. The other, a "slow" fiber, controls walking and other nonjumping movements of the leg.

What happens when sensory impulses calling for a jump arrive at the motor nerve centers? Before the animal can jump, it must stop walking. The first impulse therefore inhibits the slow nerve fiber and puts it out of action. Next it excites the flexor muscles to draw the jumping legs into the cocked position. Thirdly, the sensory message, combined with others from the brain, acts on the fast jumping nerve fiber. The message may restrain this nerve, saying in effect: "Disregard this stimulus; it is irrelevant." Or it may warn: "Get ready; if you receive another message like this one, act on it immediately, for it is really urgent." Now, when a second burst of impulses comes, the nerve fiber fires immediately. The grasshopper instantly rears up and takes off.

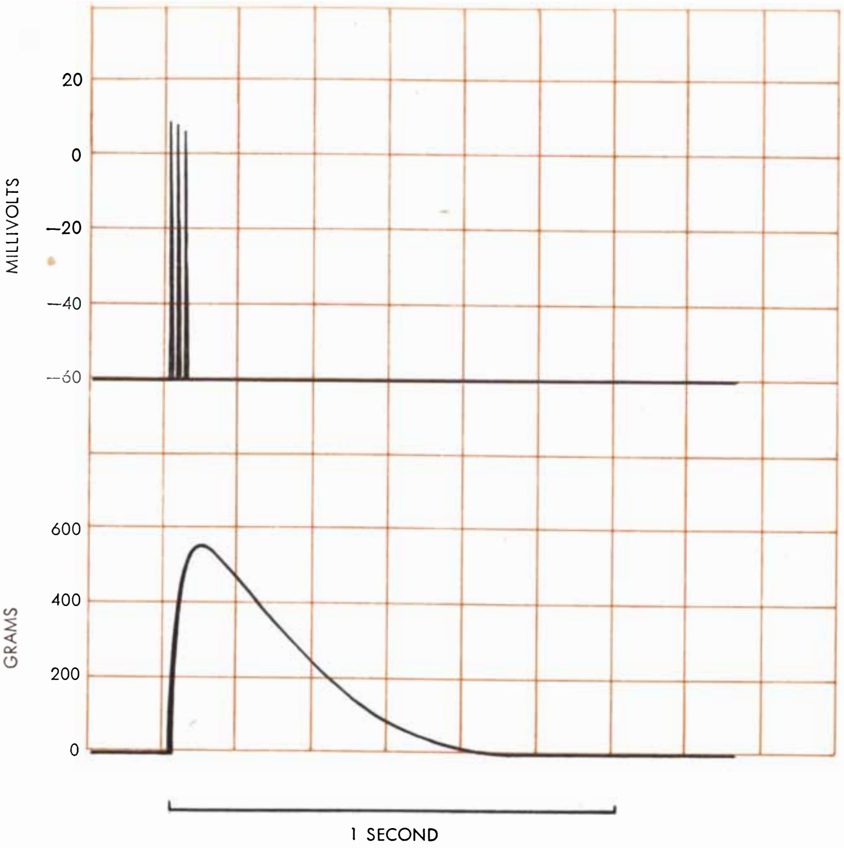
How vigorously the insect jumps will depend on how many impulses the muscle gets within the one thirtieth of a second interval while it is rearing up to leap. If only one impulse arrives in that time, the animal merely hops. (Hopping and walking is the normal mode of locomotion of immature grasshoppers.) If two impulses come, the grasshopper makes a moderate jump, for the impulses sum up to increase the strength of the twitch contraction of the jumping mus-

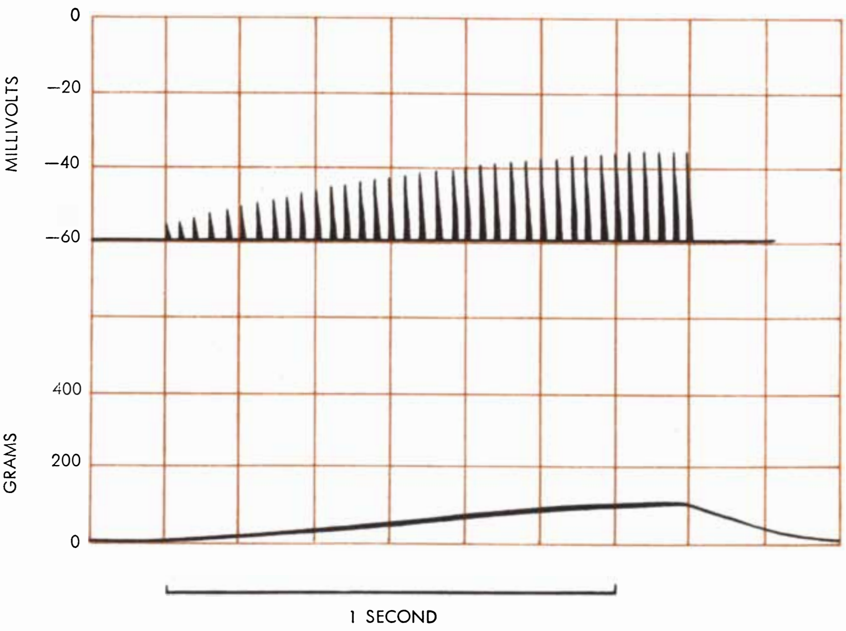


VOLTAGE OF A MUSCLE FIBER is the difference in charge between its inner and outer surfaces. In order to measure it the tip of a tiny glass electrode is placed so that it just penetrates the surface of the muscle cell, and a second electrode is placed in the fluid bathing the cell. When the cell is at rest (*top*), its outer surface is positive with respect to the inner surface; the voltage recorded on the meter between the two electrodes is some 60 millivolts. When the cell is excited to contract (*bottom*), the voltage falls and reverses slightly; the inner surface of the cell is positive with respect to the outer surface by about 10 millivolts.



CONTRACTION OF THE MUSCLE FIBERS in response to slow and fast motor nerves is shown in this diagram. All fibers contract vigorously (*indicated by dark shading*) when the fast nerve is stimulated (*left*). The fibers respond in variable fashion to an impulse from the slow nerve (*center*) and most of them respond very weakly (*light shading*). If the slow nerve is stimulated repeatedly (*right*), the responding fibers contract more strongly.





MUSCLE REACTIONS to slow and fast nerve fibers are contrasted in these charts. The top line of each chart shows the change in electrical charge of the muscle fiber as measured with an internal electrode; the lower line shows the tension of the muscle in grams. Stimulation of the fast fiber (*upper chart*) immediately produces the maximum electrical change and almost immediately the maximum tension of the muscle. Stimulation of the slow nerve (*lower chart*) produces much less electrical change and tension, but the values rise somewhat as the stimulation is repeated, as is the case when the grasshopper runs or walks.

cle. The maximum jump is elicited by three impulses.

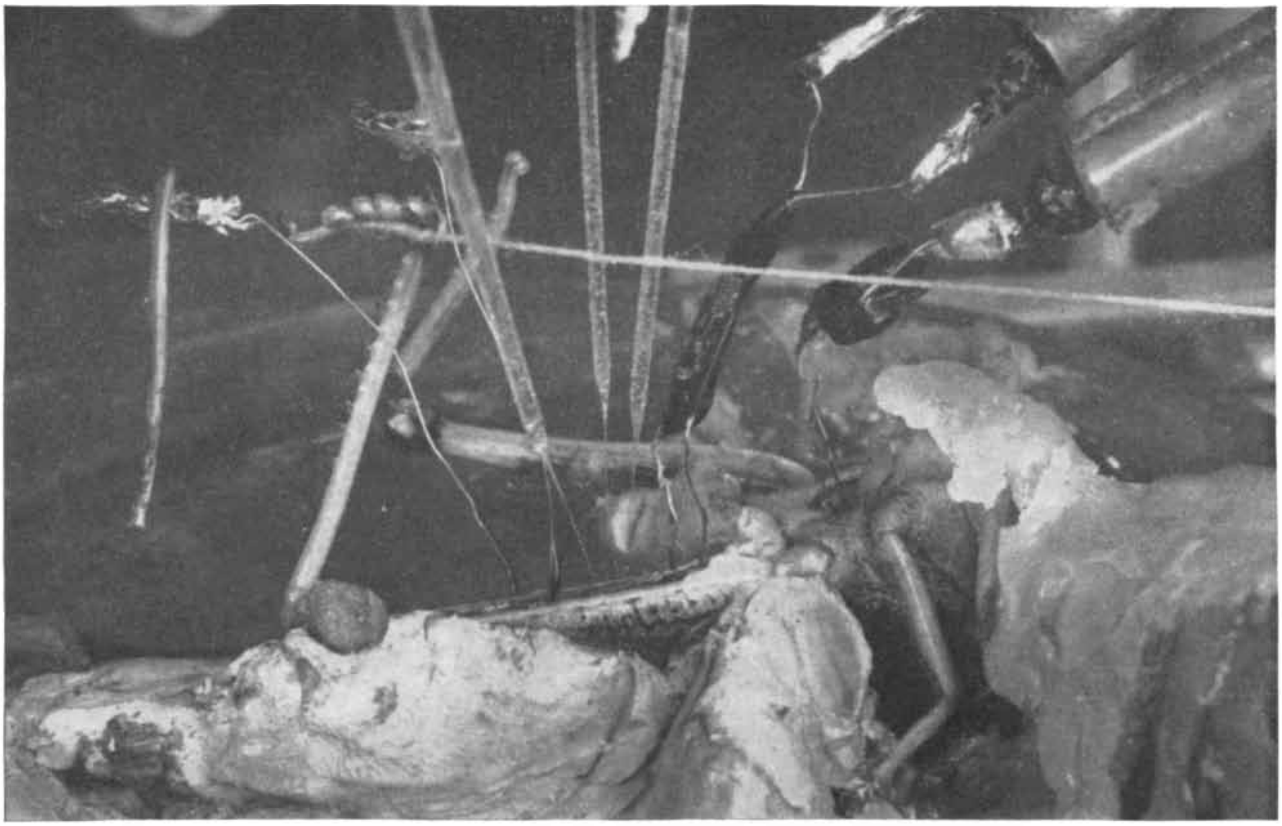
There are some 3,500 muscle fibers in an average-sized grasshopper's jumping leg. Every one of them must be fully activated almost instantaneously if the animal is to make its tremendous leap. This is taken care of by a most efficient mechanism. Each muscle fiber has not one nerve connection, as in vertebrate animals, but several nerve attachments, evenly spaced along its length. Thus the fast-traveling nerve message excites the whole muscle fiber very rapidly.

We now have to answer the question: How is it that the slow nerve, acting on these same fast muscle fibers, can produce the much milder leg movements that the animal uses in walking? We have studied the question by stimulating the fast and the slow nerves separately and examining their respective effects on the fibers of the jumping muscle. By means of micromanipulated glass capillary electrodes with extremely fine tips (only about half a micron in diameter) we measure electric potentials in individual muscle cells to follow the effects of stimulation in detail.

In a muscle fiber at rest there is a potential difference of about one sixteenth of a volt between the outside of the fiber membrane and the inside. A nerve impulse arriving at the fiber causes the potential difference to drop, and the fiber then contracts. When we stimulate the fast nerve with a single electric pulse, the nerve impulse breaks down the potential difference in the muscle fibers to zero or even reverses it slightly. But when we activate the slow nerve in the same way, the electrical changes in the muscle fibers are much smaller. Some muscle fibers show a substantial change of voltage; some, hardly any at all.

We have to give the slow nerve several shocks in quick succession to make as many as one third of the muscle fibers contract appreciably. The faster the rate of excitation, the faster the muscle contracts. At a frequency of 20 pulses per second via the slow nerve the grasshopper's leg slowly extends its tibia. At 50 per second it makes walking movements; at 100 per second it moves as fast as if it were running. But it never twitches powerfully enough for a jump.

So we see how the grasshopper's nervous system exercises a finely graded control over muscles which, gram for gram, are about the most powerful in the animal kingdom. All this it accomplishes with only two motor nerve fibers—a superb example of natural economy.



CLOSEUP OF GRASSHOPPER PREPARATION shows the positions of the electrodes. Those on the right stimulate the nerve; those on the left record the electrical response of the muscle. Muscle tension is recorded by means of the thread tied to the leg.

WEIGHT OF 20 GRAMS IS LIFTED by the hindleg of a grasshopper weighing only 1.8 grams. The tension of the leg muscle during this feat must reach approximately 500 grams. The insect is held upside down for the experiment by means of Plasticine.

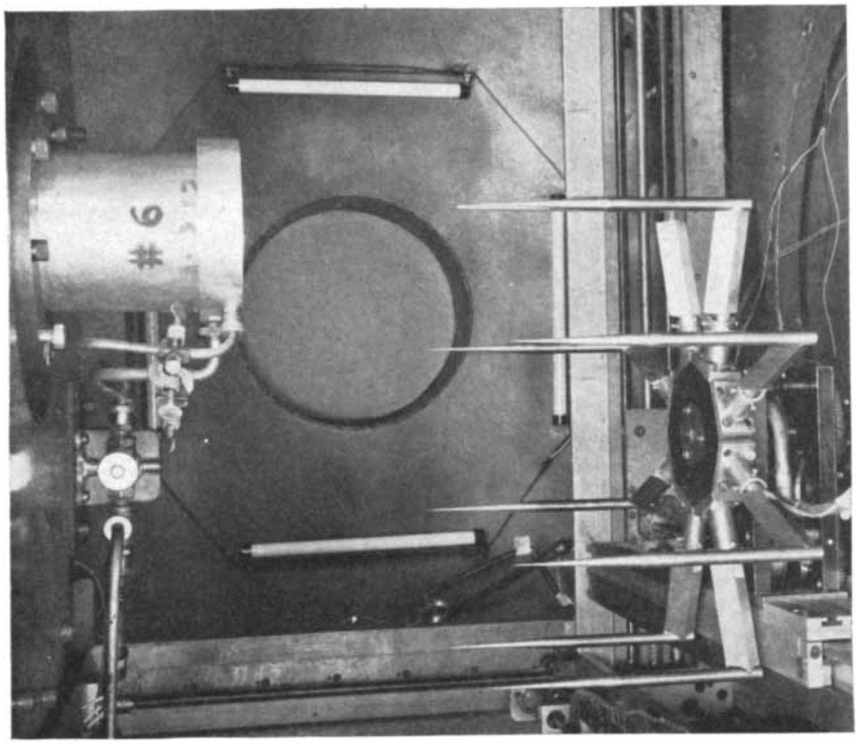
ULTRAHIGH-ALTITUDE AERODYNAMICS

At low altitudes the air streaming past a flying object behaves as a true fluid, but at altitudes above 40 miles the object is struck by individual atoms and molecules

by Samuel A. Schaaf, Lawrence Talbot and Lee Edson

Man's rockets and satellites are flying today in a new medium. The upper air is unlike any fluid in which our vehicles have ever moved before. What happens, aerodynamically, to an object flying 50 or 100 miles above the earth's surface? Do the familiar rules of aerodynamics still apply, or does a designer need to consider new rules?

These questions have been under study at several centers in the U. S. since World War II. The first theoretical work on "rarefied gas dynamics" was done by Hsue-Shen Tsien of the California Institute of Technology in 1946, and experimental laboratories were later set up at the University of California and at the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics near Sunnyvale, Calif. Both at Berkeley and at the Ames Lab special wind tunnels have been built to investigate the behavior of models in rarefied air. This article is an account of some of the things we have learned in the experiments at Berkeley.

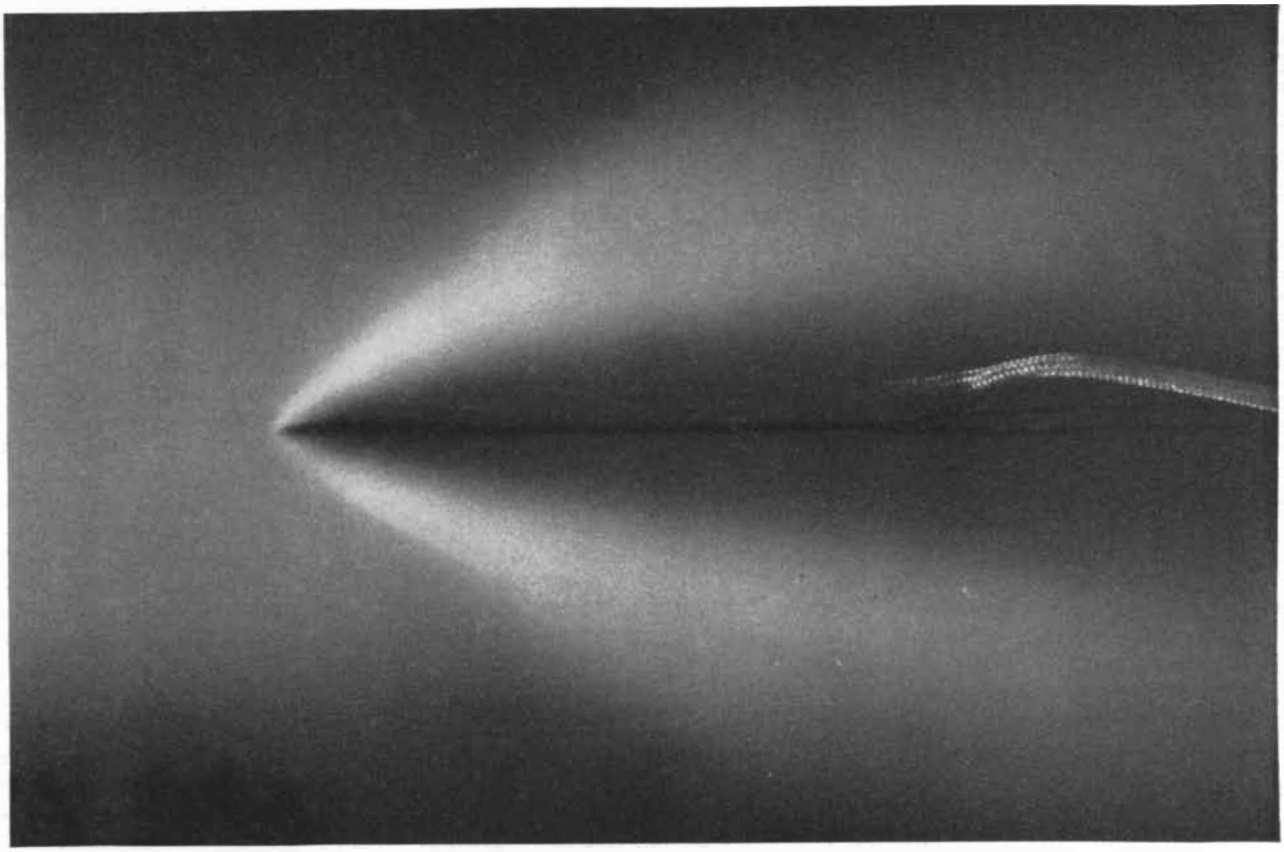


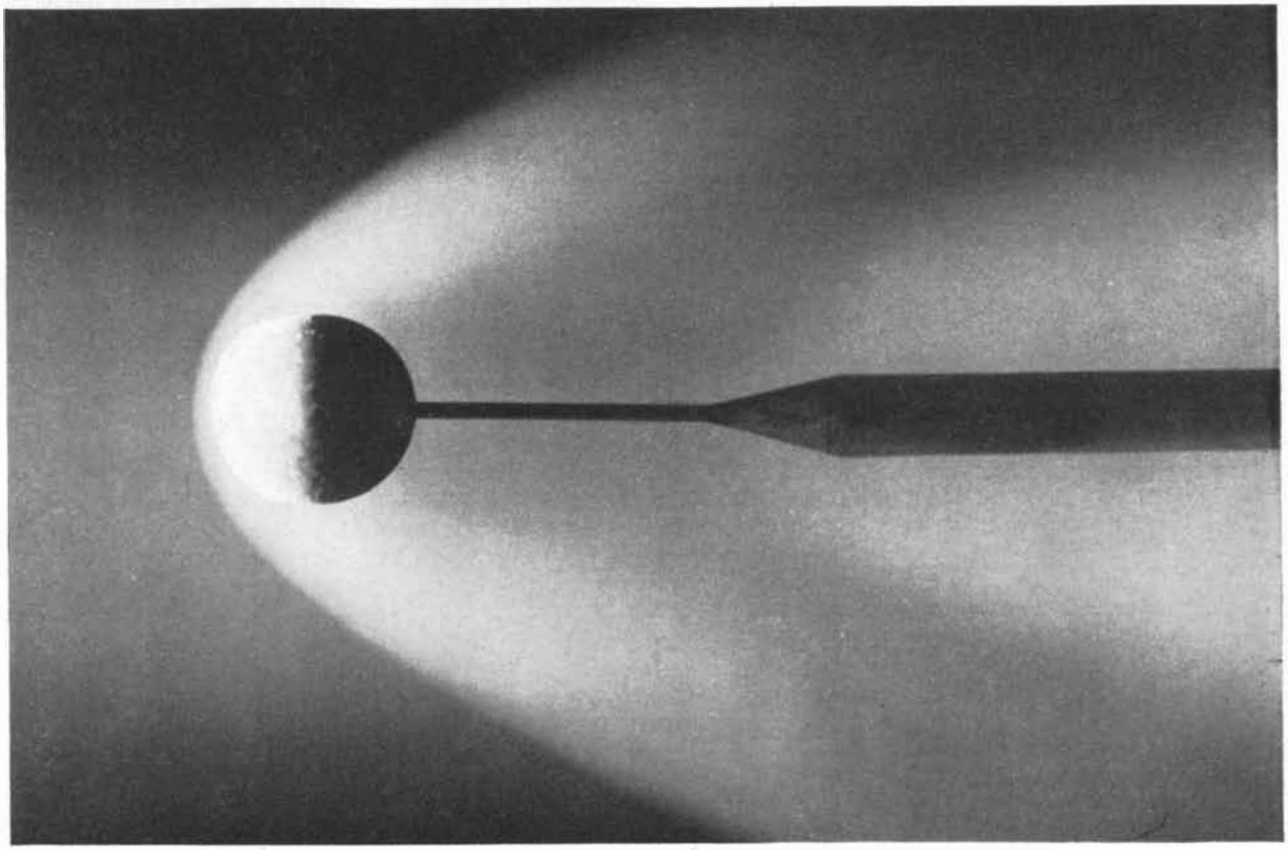
SPECIAL SUPERSONIC WIND TUNNEL is used at the University of California to study the dynamics of rarefied air. The nozzle which admits the rarefied air to the test section of the tunnel is at upper left. At right are eight models tested in the tunnel. They are mounted on a rotating head so that each can be tested without reducing the vacuum in the tunnel.

In ordinary aerodynamics we can regard the air as a continuous fluid, like water or oil. But as soon as man began to probe into the high atmosphere with jet airplanes and rockets, aerodynamicists became aware that in these thin regions they must begin to pay attention not only to the gross behavior of air but also to the behavior of its individual molecules.

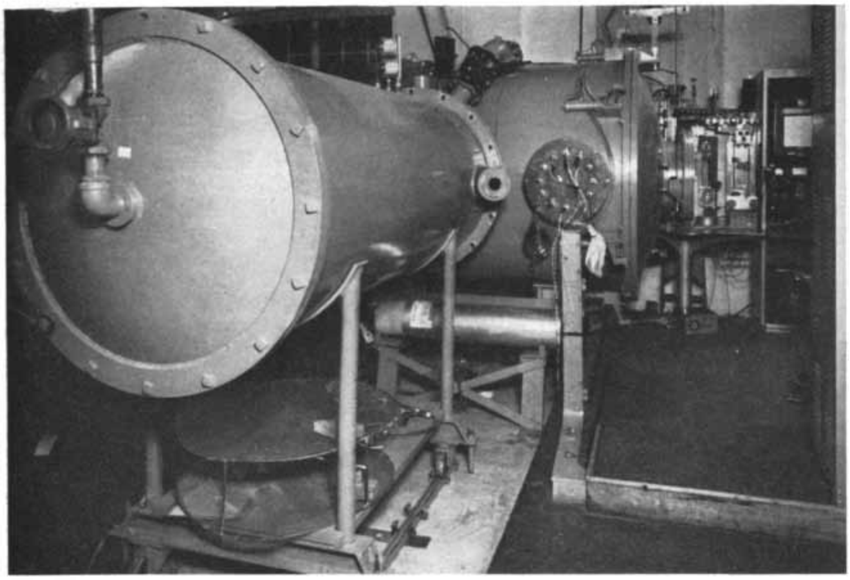
To illustrate why, let us take an imaginary flight in a rocket rising from the ground at 10 times the speed of sound (Mach 10). It starts in the dense sea-level air, consisting mainly of nitrogen and oxygen molecules [*see illustration on page* 39]. The density here is some 10^{19} molecules per cubic inch, and the molecules' mean free path (the average distance one will travel before colliding with another) is less than four millionths of an inch. They are packed so tightly together that a practically continuous film of air molecules forms over the surface of the rocket. This thin envelope of air, called the boundary layer, moves with the rocket, and we say that its velocity (with respect to the rocket surface) is zero. Ahead of the moving body a shock wave develops. In these circumstances we can calculate the lift and air resistance, or drag, by the ordinary laws and formulas of fluid mechanics.

At about 40 miles above the earth's surface the rocket encounters a new atmospheric situation. The medium changes from a practically continuous fluid, like water, to a spray of molecules, like rainfall. The mean free path of the air molecules is still pretty short—only a fraction of an inch—but we can no longer consider the boundary layer a stationary sheet, with the molecules at rest with respect to the rocket surface. Molecules strike the surface of the rocket and re-

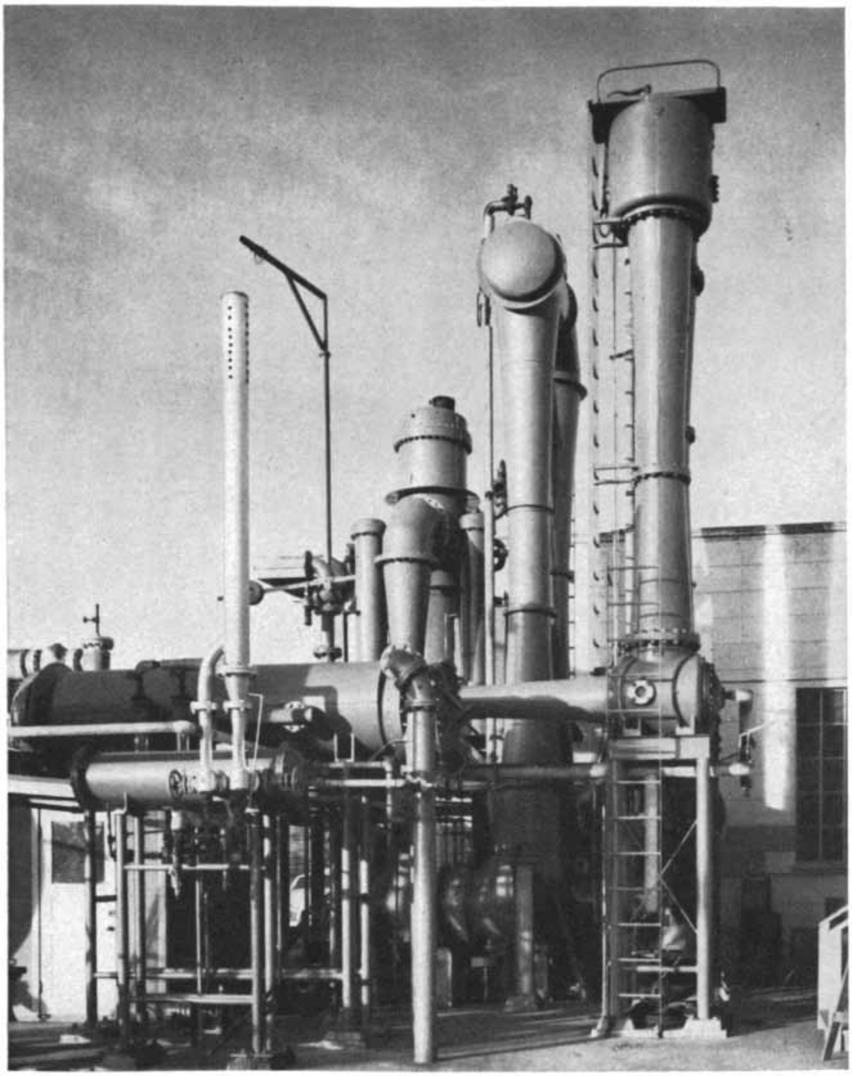




FLAT PLATE AND SPHERE are photographed in the University of California supersonic wind tunnel. The luminous shock wave around each model is fuzzy because of the low density of the air. The air is made luminous by means of an arc-produced discharge.



AIR IS INJECTED into the supersonic wind tunnel through the pipe at left. Its pressure is 1 to 20 millimeters of mercury. The test section is the cylindrical chamber at right center.



AIR IS EVACUATED from the tunnel by large vacuum pumps, parts of which appear in this exterior view of the tunnel. The pressure in the test section is .04 to .2 mm. of mercury.

bound from it. We say that the gas has begun to slip. As a result the aerodynamic characteristics of the medium change somewhat, and we must take the slip factor into account.

At 70 miles above the earth's surface the rainstorm of air molecules and atoms begins to thin out further to a drizzle. The molecules' mean free path is considerably longer—of about the same order as the thickness of the boundary layer, which has grown thick enough to "swallow up" the rocket [*see illustration on page 41*]. The battering of the rocket's surface by the molecules now becomes an important influence on the flight of the rocket. The mathematical analysis of this effect is very complex, and it has not yet been fully worked out.

At 90 miles the rocket emerges from this "transition" zone into a region—almost at the very edge of space—where the air molecules are so sparse that no boundary layer forms at all. The air density is only one trillionth of that at sea level, and the mean free path of the molecules is more than seven feet. (They are spaced much closer than this, but seven feet is the average distance they travel in their random movement between collisions.)

Here the rocket's flight produces no shock wave, and air molecules therefore run into the body without warning. We can draw a comparison with automobiles encountering a stop light. On a highway with dense traffic a motorist gets advance notice of a stop light by the pile-up of cars ahead. Similarly in dense air a freely moving molecule is forewarned of the approaching rocket by its air pile-up, or shock wave. But when traffic is sparse, a motorist is not warned or stopped until he comes to the light itself. It is the same with air molecules in the sparse outer air: they are not prepared for the rocket before they actually hit its surface.

This creates a radically new aerodynamic situation. We are no longer dealing with boundary layers and flow lines but only with the impacts of particles hitting the rocket surface. In this rarefied air the drag of the rocket, and the heating effect of its flight, have to be calculated on the basis of its collisions with individual molecules.

The importance of this effect at various altitudes is measured by something called the Knudsen, or K, number—so named in honor of the Danish physicist Martin Knudsen. Essentially the K number represents the ratio of the mean free path of air molecules to either a dimension of the flying body (*e.g.*, the diameter of a rocket) or the thickness of its boundary layer. (Actually it is expressed as the ratio of the Mach number to the Reynolds number, a measure of viscosity.) At sea level the K number is close to zero. But at high altitudes, where the mean free path of a molecule is many times greater than the dimensions of the flying object, K becomes a comparatively large number.

In our special wind tunnel at the University of California we have been investigating the behavior of air in the four ranges of K numbers: continuous flow, slip flow, the transition zone and bombardment by individual molecules. The tunnel simulates flight conditions up to altitudes as high as 60 miles.

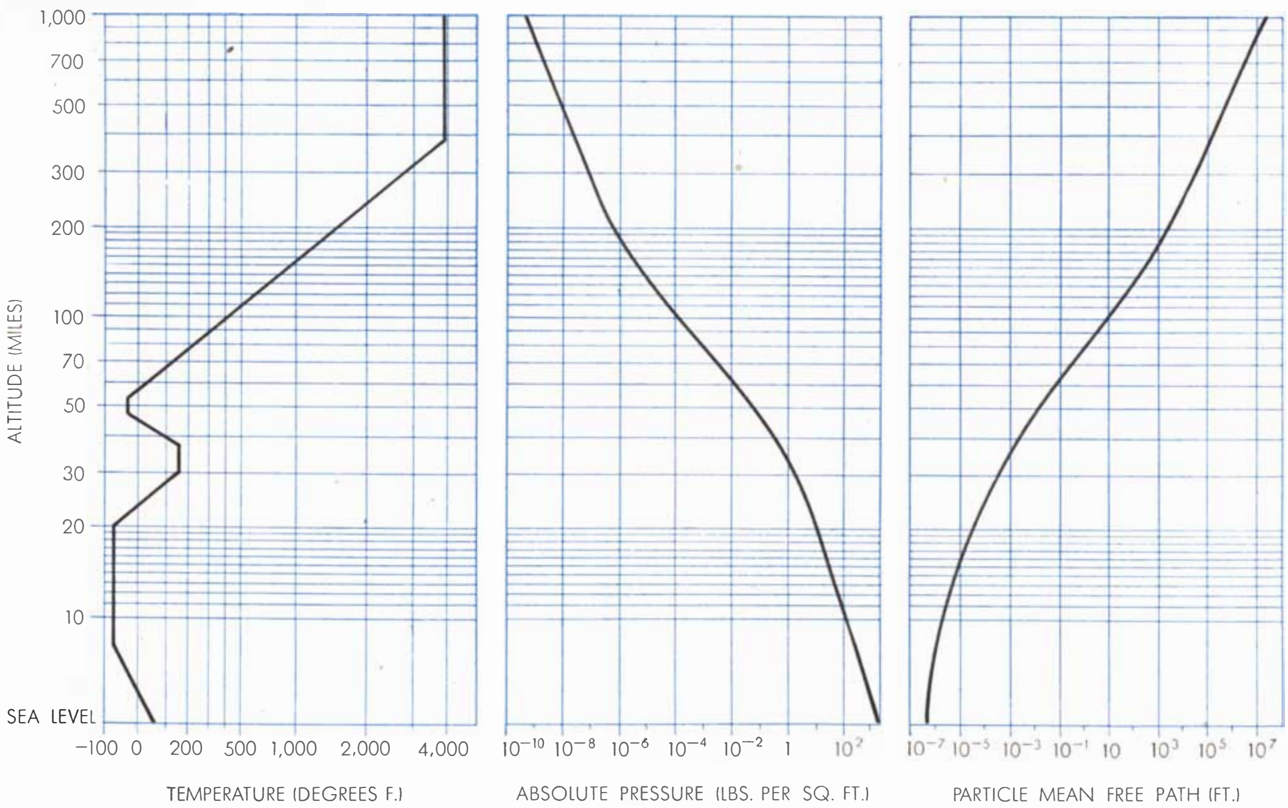
The tunnel is essentially a pipe, 20 feet long and three feet in diameter, in which the air is reduced to low density by vacuum pumps [*see photograph on page 36*]. In the test section, where the model is placed, the density amounts only to a pressure of one twenty-fifth to one fifth of a millimeter of mercury—less than one thousandth of the sea-level atmospheric pressure. Into this chamber dried air at a pressure of one to 20 millimeters is injected through a nozzle. The speed of air flow is controlled by the size of the nozzle opening. We have produced air speeds up to Mach 6 in the test area. The models we have tested include basic shapes such as cones, cylinders, spheres and flat plates.

To observe and measure the effects in this strange new realm, it has been necessary to develop new kinds of apparatus and measuring devices. The instruments employed with the tunnel include manometers and gauges which can measure very small pressures, and microbalances that weigh lift and drag in terms of millionths of a gram. In order to make it possible to photograph flow patterns, we use an electric discharge which makes the flowing air glow like the northern lights. The glow lasts for a few tenths of a second—long enough for the glowing gas to flow through the nozzle and past the model and to be photographed through portholes in the tunnel.

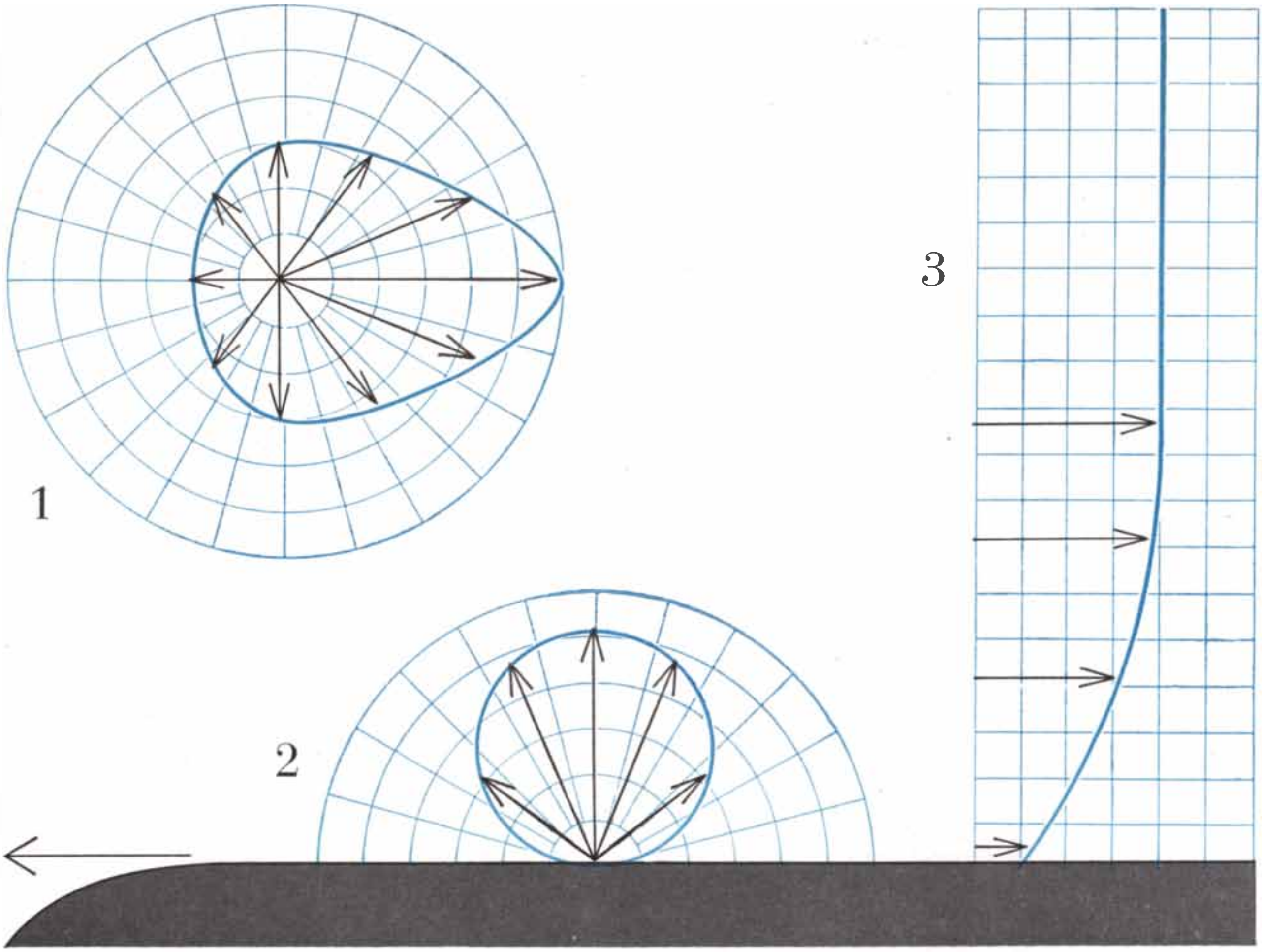
Another new device was developed by Frank Hurlbut, a member of our group, to study the effect of free molecules striking the surface of a model. His apparatus can direct a beam of gas molecules at the surface from different angles and measure the energy and momentum of the molecules rebounding from the surface in each case. To appreciate how delicate these measurements have to be, you must realize that we are dealing with pressure differences of the order of one 10-billionth of a millimeter against a background of one 10-millionth of a millimeter.

F. S. Sherman devised an instrument which probes the inside of a shock wave. His probe is a small platinum filament which can be thrust into the shock-wave region in front of the model. The filament is heated electrically. Its temperature changes with changes in the speed of air flow. Since the electrical resistance of a wire depends on its temperature, variations of the air speed in the shock wave can be recorded. By this device Sherman has been able to measure the variations of flow within a shock wave, thus providing us with the first direct measurement of shock-wave structure. We have thereby been able to learn something about the stress-strain relationships in an object flying through the slip-flow region, where the shock wave is thick enough to permit exploration.

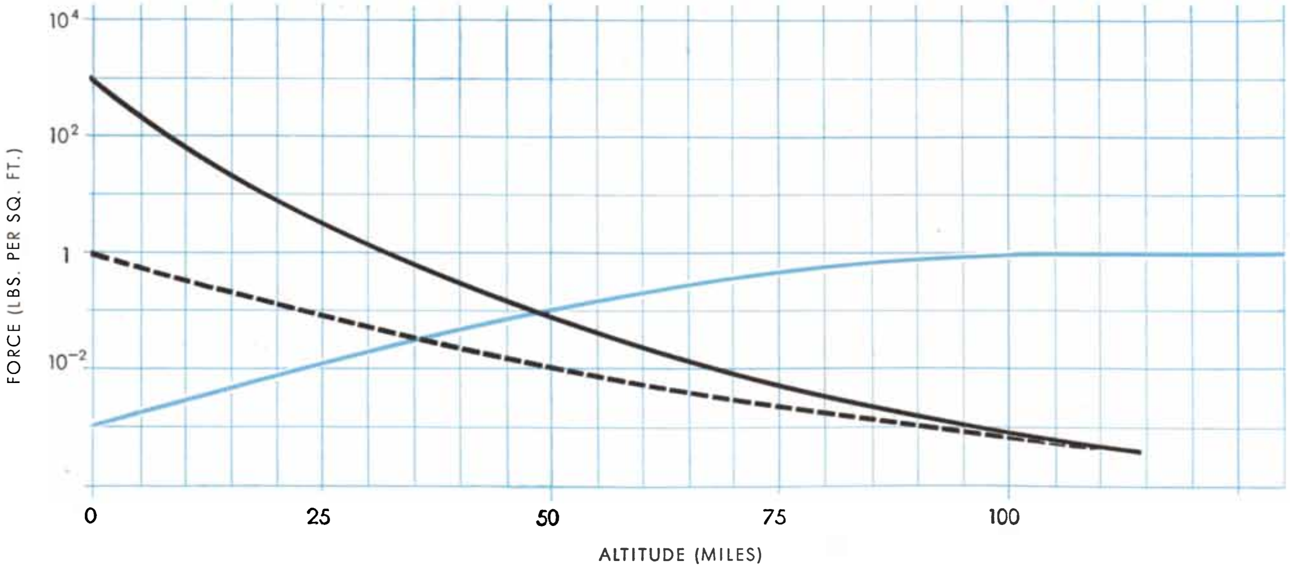
Our tunnel tests have already given answers to several important questions about high-speed flight in rarefied



THREE CHARACTERISTICS of air are plotted against altitude. The temperature curve is somewhat speculative. Absolute pressure refers to pressure above a vacuum. Particle mean free path is the mean distance traveled by atoms or molecules between collisions.



MEAN VELOCITY OF MOLECULES near a moving surface is influenced by the fact that molecules which strike the surface tend to stick to it. Here the surface is at bottom; it is moving from right to left. At left (1) is a polar graph suggesting the distribution in the velocity of molecules in a free stream. In center (2) is a similar graph suggesting the distribution in the velocity of molecules which have stuck to the surface and then escaped from it. At right (3) is a rectangular graph which combines these two distributions to show the mean velocity of all molecules in the vicinity of the object. The mean velocity of the molecules near the surface is low, *i.e.*, they form a "boundary layer." At an altitude of around 40 miles the boundary layer begins to slip along the surface of the object (*short arrow at bottom of rectangular graph*). At higher altitudes the boundary layer disappears entirely.

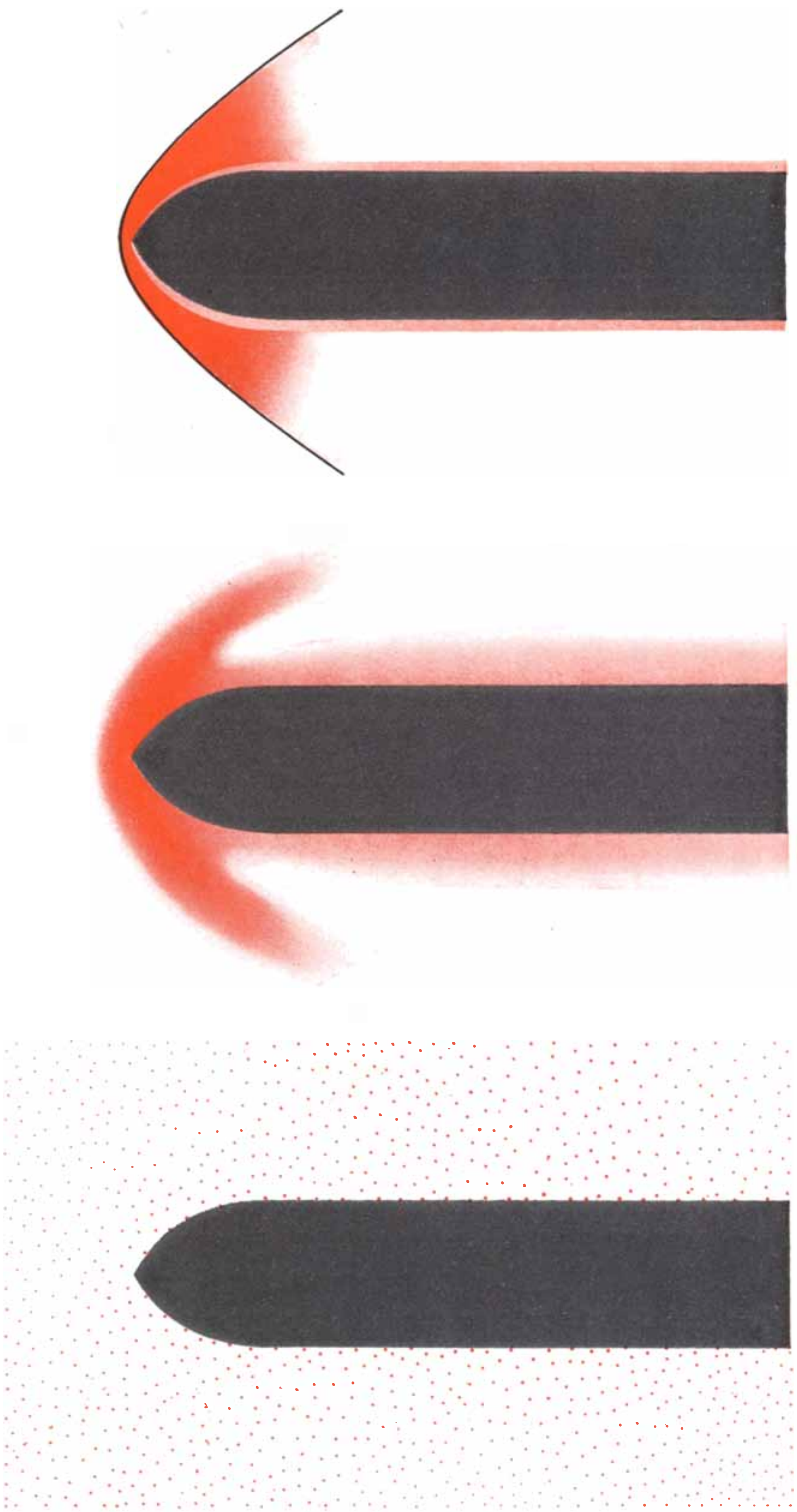


SKIN FRICTION (*broken curve*) at low altitudes is unimportant in comparison with the pressure on a surface (*solid black curve*). At higher altitudes the ratio of pressure to skin friction (*colored curve*) increases, requiring a new set of aerodynamic coefficients.

air. One of these is the question of heating. The "heat barrier" is today a major concern in aviation and rocketry. It puts a limit on the speed of airplanes and creates a re-entry problem for rockets and satellites returning to earth. In the dense lower levels of the atmosphere, a fast-moving object heats up quickly by friction with the air, and it will burn to a crisp if its speed is high enough. Now one might suppose that in the rarefied higher air, where friction diminishes, the heating effect will be less. It does, in fact, proceed at a slower rate. But our tests have also shown, surprisingly, that in very thin air the impacts of the molecules will have a greater ultimate heating effect on the surface of a body than friction with the denser air of low altitudes does at the same flight-velocity.

It is not hard to figure out the explanation. We must remember that in rarefied air the molecules rain against the body and deliver their energy directly to its surface, because there is no boundary-layer cushion around it. Picture now a certain volume of this air. It has a certain energy content, measured by the average velocity of the random motions of its molecules. But the individual molecules vary in speed: the volume contains fast-moving and slow-moving molecules. Now the interesting fact is that in a given unit of time a body moving through the volume is battered by a disproportionate number of fast molecules. In other words, the air delivers a greater-than-average flux of energy to the surface of the body. We can perhaps make this clearer by a simple analogy. Suppose that a crowd of men and women is approaching an observer. There are exactly as many men as women. We assume that each man possesses four times more energy than each woman. Thus a group of three men and three women within the crowd represents 15 units of energy. Now suppose that the men begin to walk twice as fast as the women. As the crowd passes the observer, twice as many men as women arrive in a unit of time (the men and women in the spread-out crowd were evenly distributed at various distances from the observer to begin with). Each unit of six people passing the observer therefore contains four men and two women. This unit possesses not 15 but 18 units of energy. And the analogy roughly describes how it is that a crowd of air molecules hitting the surface of a body at high altitudes delivers more energy than we would expect from the crowd's general energy content.

If the heating effect on a body is

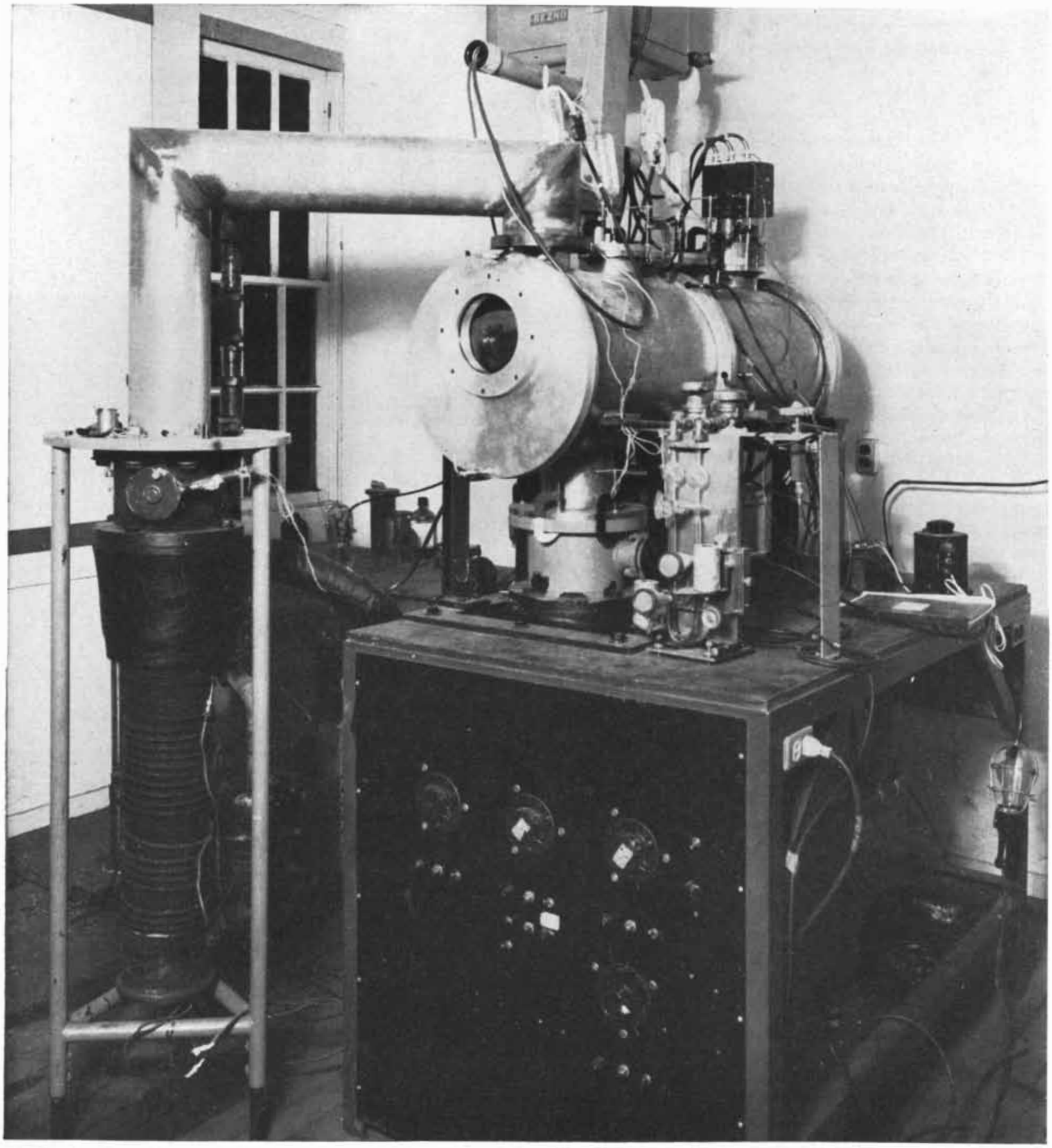


EFFECT OF DENSITY on the flow of air around an object is depicted in these drawings. At low altitudes (*top*) the object is coated with a boundary layer and a sharp shock wave forms in front of it. At altitudes between 40 and 90 miles (*middle*) the boundary layer thickens but is less dense and begins to slip. At altitudes higher than 90 miles (*bottom*) the density of the air is so low that neither a boundary layer nor a shock wave forms.

greater in rarefied air than in dense air, should we expect it to be more likely that the body will burn up? Not necessarily. There is a counteracting factor. In thin air the body loses heat by radiation at a faster rate, in proportion to the rate of heating, than in denser air surroundings. Our calculations suggest that heating should be within manageable bounds, even at very high flight-speeds, in the slip-flow region 40 miles up. To study this possibility we are modifying our wind tunnel and apparatus to permit experiments at low-density air temperatures as high as nearly 20,000 degrees.

Among other high-altitude problems we have investigated or plan to investigate in the wind tunnel are the effects of skin friction (the shearing force of the air upon the skin of the craft) and the possible aerodynamic effects of the circumstance that in the high atmosphere oxygen is broken down by sunlight from molecules to atoms.

The laboratory studies are beginning to give us an over-all picture of the aerodynamic conditions at high altitudes. They are providing quantitative data which should be helpful to the designers of vehicles and missiles that will fly to the borders of our atmosphere and beyond.



MOLECULAR-BEAM APPARATUS was developed by Frank Hurlbut of the University of California to measure the effects of molecular bombardment of the surface of a model. It measures pressure differences of the order of one 10-billionth of a millimeter.

Kodak reports on:

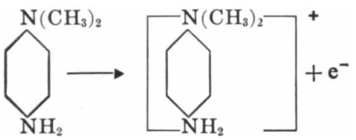
oxidation and the ills of the spirit . . . a bid for free service from scientific Americans . . . taming temperature variations

Crazy!

During the past spring we noted a sharp upturn in the volume of our correspondence with psychiatrists. They all wanted to know whether we could supply the compound N,N-dimethyl-p-phenylenediamine dihydrochloride. In accordance with practice in the retailing game when you don't have exactly what the customer asks for, we replied to each that we would be happy to supply the monohydrochloride at $2.20 for 25 grams. This rejoinder got us nowhere.

Thus rebuffed (and deservedly so), we dipped a little into the fast-breaking literature of the borderland between chemistry and the ills of the spirit.

We learned about ceruloplasmin. It's an oxidation-promoting enzyme, a protein that accounts for most of the copper in the body. In *Science* for January 18, 1957 (*125*,-117) appeared evidence that ceruloplasmin runs high in serum of schizophrenic patients, as adduced from an increased rate and depth of color development in the *in vitro* reaction



Here we found a region with landmarks familiar indeed to anyone who has thought deeply about photographic developers. p-Phenylenediamine is parent to a numerous family of aromatic amines that assume color when oxidized. Stability is enhanced by various substitutions and in the dry crystalline state by conversion to some salt or other.

If, in this case, the author chose to have two methyl groups on one of the amine nitrogens and, instead of one, two molecules of HCl to preserve his reagent on the shelf until ready for use, that was his privilege. So also is it the inalienable right of any neurophysiologist who wishes to pursue this line of laboratory investigation to be able to buy this dihydrochloride ready made without bothering to add the appropriate quantity of HCl to a solution of the base or the monohydrochloride. (The right may be exercised by purchase from us of *N,N-Dimethyl-p-phenylenediamine Dihydrochloride* (Eastman 7423) at $3.05 for 25 grams.)

And now, alongside one group of wise men who explain the tension of the times in terms of socio-economic forces and another group of wise men who watch the war between the id, the ego, and the super-ego, there stands huddled in stimulating talk a new group of wise men who point out that the tranquillizing chlorpromazine and Rauwolfia alkaloids are potent oxidase inhibitors. But even they seem largely to agree that anybody who at this time would depend solely on these enzymatic measurements for a positive diagnosis of schizophrenia is crazy.

"Eastman Organic Chemicals, List No. 40" contains a long catalog of many substances other than ceruloplasmin for which we offer reagents and abstracts on their use. This alone is worth the space in your bookcase. For a copy of List No. 40 (which also catalogs some 3600 available compounds) write to Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).

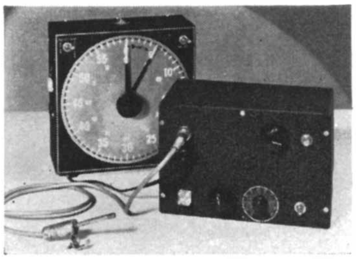
Get thee to a marker

Scattered over the land area of the United States lie more than 100,000 U. S. Coast and Geodetic Survey triangulation station markers. The Smithsonian Astrophysical Observatory and the U. S. National Committee for the International Geophysical Year would be grateful if you would arrange to have a camera over one of these markers at a time when some artificial satellite or other is in view, and photograph it. The camera should be tripod-mounted and cover at least a 4″ x 5″ negative with a 5″ or 6″ lens, *f*/4.5 or faster. The observer should have sufficient dexterity or cleverness at home-made instrumentation so that he can interrupt his trace for a few seconds and know the start of his interruption within 0.1 second against the time signals broadcast by Radio Station WWV. In addition to a reliable radio he needs a certain attitude.

The possessor of the requisite attitude does not consider himself traduced by the big surprise of October 4, 1957. On the contrary, he is pleased at the opportunity thrown his way when the large plans for optical tracking equipment proved too ponderous for the blistering pace set by our eager IGY collaborators on the other side of the barbed wire. He thinks it would be a healthy thing if it turned out that simple equipment, skillfully operated with amateur enthusiasm, could reveal almost as much about the shape of the earth and its gravitational field as had been expected of the optical heavy artillery.

If you are game, write to W. F. Swann, Eastman Kodak Company, Rochester 4, N. Y. Ask him for the details of the "Phototrack" assignment that the Society of Photographic Scientists and Engineers is issuing to scientific Americans.

Arrhenius's clock



Time, as told by this clock, elapses at a rate that is temperature-dependent in the same way as the rate of a chemical reaction is temperature-dependent. Sensing is done by the thermistor probe, which goes into the reaction vessel. It's handy in a photographic lab because by time compensation it tames a ± 4 F temperature variation to the equivalent of ± 0.2 F control. Arrhenius, who wrote the equation but wasn't as hipped on photography as we are, would have been pleased.

Though we don't manufacture these for sale, we'll be glad to furnish a reprint that tells how we made ours. Drop a note to Eastman Kodak Company, Special Sensitized Goods Division, Rochester 4, N. Y.

Prices quoted are subject to change without notice.

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

Kodak
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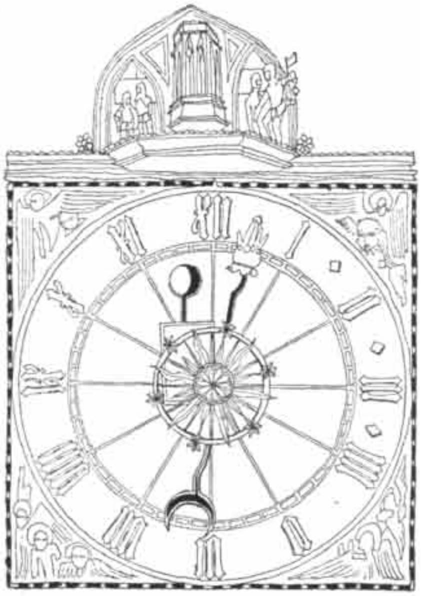


SCIENCE AND

A Department of Science

A bill to reorganize and enlarge the Federal Government's science activities is being drafted by the staff of the Senate Committee on Government Operations. The proposed legislation, in its preliminary form, provides for the creation of a Department of Science and Technology headed by a new Cabinet officer. In addition it would set up a Federal science academy patterned after the military service academies, and establish "a broad system of science scholarships and proper incentives to instructors in existing schools, colleges and universities."

The Senate Committee staff said it had found little or no coordination or exchange of information between Federal agencies carrying on scientific activities. The result is "unnecessary duplications and waste of scientific personnel in many instances." The Committee suggested that the new science department be given jurisdiction over the National Science Foundation, the Smithsonian Institution, the Office of Technical Services, the National Bureau of Standards, the Patent Office, the Weather Bureau and the Civil Aeronautics Administration's Air Navigation Program. The report also recommended that the science department set up a central clearing house for information, where foreign journals would be systematically analyzed, translated and abstracted.

Recommendations on scientific development also came from other quarters of the Government last month. A Senate subcommittee on preparedness, holding hearings on the missile program, heard testimony from Vannevar Bush, Edward Teller and others on the necessity for intensifying science education. The President's Committee on Scientists and Engineers submitted a report calling for improvement of science teaching in secondary schools, higher salaries for science teachers and more efficient utilization of scientists and engineers.

Research Budget

The U. S. Government will budget a record \$3.3 billion for scientific development and research in 1958, according to a National Science Foundation report. This represents an increase of \$20 million over 1957 and \$680 million over 1956.

Scientific development will account for 60 per cent of the total 1958 expenditure, applied research for 32 per cent, basic research for 8 per cent. More than three quarters of the funds will go to the Department of Defense (\$2,111 million) and the Atomic Energy Commission (\$672 million). The Department of Defense is expected to allocate 1.6 per cent of its grant to basic research. Amounts allotted to other agencies include \$200 million to the Department of Health, Education and Welfare, \$132 million to the Department of Agriculture and \$47 million to the National Science Foundation. Much of the NSF's grant, about \$30 million higher than the 1956 figure, is accountable to the Foundation's participation in the International Geophysical Year.

Enrico Fermi Award

The Enrico Fermi award for 1957 was presented last month to Ernest O. Lawrence, director of the University of California's Radiation Laboratory at Berkeley and inventor, in 1929, of the cyclotron. The \$50,000 award was created in 1954 by the Atomic Energy Commission; it is presented in recognition of "especially meritorious contributions to the development, use or control of atomic energy." Lawrence received the Nobel prize for physics in 1939.

Education in the U.S.S.R.

A detailed study of the Soviet Union educational system was published last month by the U. S. Department of

Health, Education and Welfare. Entitled "Education in the U.S.S.R.," the report underscored the size and intensity of the program as well as its emphasis on training in science and mathematics.

Soviet secondary schools are now graduating 1.5 million students per year (as against 1.3 million in the U. S.), and the number is increasing. All students cover a prescribed course which includes mathematics through introductory calculus, geography, biology, physics, chemistry and astronomy. Enrollment at the college and university level is 1.9 million (the U. S. figure is three million). Seventy per cent of the advanced degrees conferred are in science and technology. An additional two million students attend semi-professional schools to train as technical assistants in engineering, science, medicine and other professions.

Soviet children attend kindergarten until the age of seven and proceed to an integrated program of primary and secondary education, of which the first seven years are compulsory. In the cities and industrial centers the total course is 10 years; the government intends to extend this program to all communities by 1960. Schools are in session six days a week for about 10 months of the year, and the 10-year course affords about the same number of class hours as does the 12-year program in the U. S.

Starting biology in the fourth grade and physics and chemistry in the seventh, Soviet children study these subjects "cyclically," covering more advanced material each successive year. The work of the last two years includes practical engineering, shop practice and frequent inspection trips to industrial and agricultural centers. All students take one foreign language, beginning in the fifth grade. About 40 per cent are studying English and 40 per cent study German.

The physical facilities of the primary-secondary system have not grown as rapidly as enrollment, and most of the schools are on double sessions. Teacher training has more than kept pace, however; the average class size has been reduced from 28.6 in 1940 to 17 in 1956.

Supplementing the regular schools are many programs for those with special needs. There are part-time and night schools for working youths and adults, correspondence courses for rural areas, schools for the artistically gifted and for deaf, blind and otherwise physically handicapped children. Bright students are grouped together to work under the supervision of university teachers.

Entrance to college or a semi-professional school, according to the report, is predicated on "a satisfactory political record" and, except for the highest-ranking applicants, on competitive examinations. In higher education, courses of from four to six years are offered in five major fields: engineering, agriculture, economics and social science, education and medicine. Instruction hours, including those devoted to political indoctrination, average 1,000 to 1,300 per year, more than twice the usual amount in U. S. colleges. Curricula are standardized. Tuition is free and students are paid a living stipend which is increased as a reward for superior work and withdrawn for failure to maintain a satisfactory record.

The U. S. Welfare Department's study of the system emphasizes the strict political controls. Soviet police take part in the administrative organization and maintain a constant "surveillance . . . on the political reliability of administrative personnel, teachers, students and the others—the minister on down through the lowest in rank." Textbooks are sometimes removed for revision to conform with changes in ideological outlook. Teachers "try to stick to undisputed facts," postponing "synthesis and interpretation . . . until such time as the official point of view has been announced—sometimes just in time to prepare for examinations."

Translating Soviet Science

Extensive translation and circulation of scientific material from the U.S.S.R. and other countries in its sphere is the aim of the Pergamon Institute, a nonprofit foundation recently organized in New York and London. The group is already publishing English translations of several important Soviet professional journals and in coming months expects to bring out a score of books by leading Soviet scientists. It reports excellent cooperation from these authors.

The Institute offers to groups and individuals a free monthly list of all current articles and books in science, technology and medicine published in the Soviet bloc. It will also assist in teaching of the Russian language to students of science, engineering and medicine in Great Britain and the U. S. Pointing out that only 2 per cent of British scientists and an even smaller percentage of American scientists can read Russian, it plans to sponsor a symposium on the problem next summer.

Unspecialized Biology

A new journal called *Perspectives in Biology and Medicine*, designed to inspire workers in the biological sciences to "think beyond the confines of specialization," has recently put out its first issue. The quarterly, published by the University of Chicago Press, seeks to "communicate and stimulate original thought in the biological and medical sciences." Its editors are Dwight J. Ingle, a physiologist, and S. O. Waife, a specialist in internal medicine. Among the members of its international advisory board are Sir Henry Dale and G. E. W. Wolstenholme of Great Britain, U. S. von Euler of Sweden, B. A. Houssay of Argentina and Detlev W. Bronk, René J. Dubos, Peyton Rous, Otto Loewi, Richard H. Shryock and I. S. Ravdin of the U. S.

Chest X-Rays

The U. S. Public Health Service has recommended that the mass X-ray examination program for lung tuberculosis be discontinued. The decision was motivated by the growing concern with radiation exposure, coupled with the great strides that have been made in curing tuberculosis. In place of X-rays for all, the Service urged that the procedure be limited to persons who respond positively to "patch" tests and to low-income groups, hospital patients and persons known to have been exposed to tuberculosis.

Water-Soluble Plastics

A new field of high-polymer chemistry has been opened up with the development of water-soluble resins. At low concentrations the new materials can be completely dissolved in water; at higher concentrations they are reported to have greater thickening power than any other commercial material now available.

The new polymers were developed by the Union Carbide Corporation. They consist of long chains of from 10,000 to 100,000 molecules of ethylene oxide. Marketed under the name "Polyox," they have already been used experimentally as sizing materials for textiles. Their use in textiles could simplify the industry's stream-pollution problems; unlike present sizing materials, Polyox does not take up "biological oxygen" from the water.

Films made of Polyox, though easily soluble, resist atmospheric moisture well. This suggests a novel form of packaging for agricultural chemicals, inks or paints, which could simply be tossed into water, wrapper and all.

Snap-Brim Galaxy

The Milky Way apparently is not a flat disk but is tipped down on one side and up on the other, like the snap-brim of a man's hat. This is the conclusion of Australian radio astronomers who have been mapping the distribution of hydrogen in the galaxy. The downward tilt is on the side toward the Clouds of Magellan, our nearest extragalactic neighbors. Their gravitational attraction probably helps pull down the edge of our galaxy. However, the tilt is too big to be explained by gravity alone. It indicates that there may be other forces acting between neighboring galaxies.

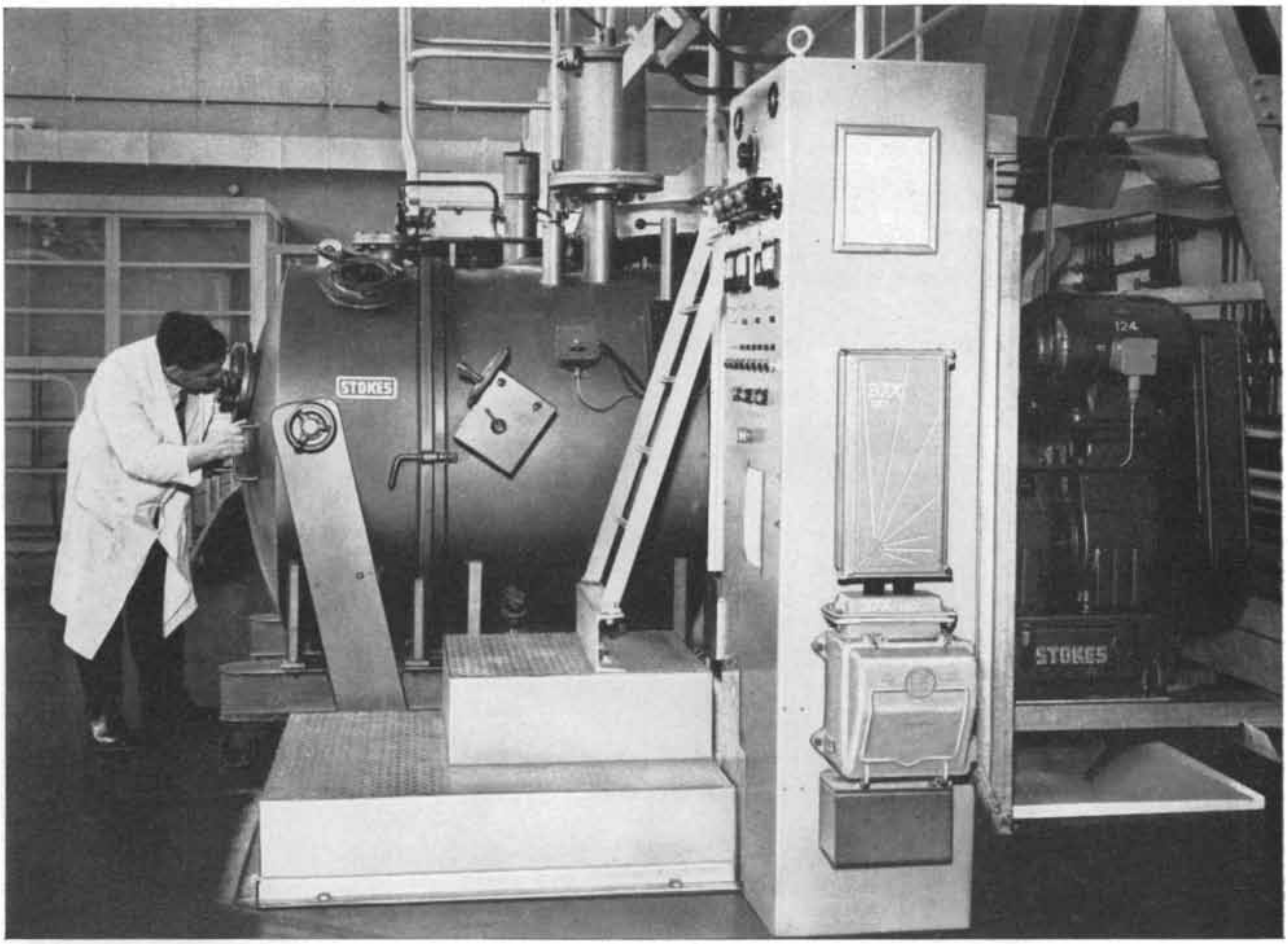
The measurements also confirm the spiral structure of our galaxy. Several distinct arms were mapped in the southern sky, but the regions between the arms seem to contain more gas than the corresponding parts of the northern sky. An assay of hydrogen over the whole Milky Way shows that it makes up 2 per cent of the total mass of the galaxy. At the outer edges of the galaxy, however, 50 per cent of the material is hydrogen.

The Australian survey was made by detecting the 21-centimeter radio waves emitted by neutral hydrogen in space. F. J. Kerr, J. V. Hindman and Martha Stahr Carpenter reported the results in *Nature*.

Age of Reason

At what age does a scientist do his best work? E. Manniche of the Washington Public Opinion Laboratory and G. Falk of the University of Washington, looking into this question, have found that the average age of Nobel prize winners in physics (*i.e.*, the age when they published their work) was 34, in chemistry 40, and in medicine 44. About 30 per cent of the physicists and 10 per cent of the chemists did their work before the age of 30.

The two investigators, analyzing their finding in *Behavioral Science*, suggest that physics has been a young man's game because discoveries in the past half-century of upheaval in the science have come from brilliant inspirations about new concepts rather than from patient accumulation of data.



"Harwell" uses Stokes Vacuum Furnace for nuclear fuels investigations

The United Kingdom's Atomic Energy Research Establishment at Harwell, Didcot, Berks., England, has had this Stokes Vacuum Furnace in successful operation since late 1956.

The furnace is used to investigate methods for simultaneously melting and pouring uranium under vacuums of 1-10 microns, at temperatures of 1200-1400° C. The work is part of an experimental investigation of pyrometallurgical processing for nuclear fuels as a possible alternative to "wet" chemical methods.

If you are planning to investigate the challenging potential of modern vacuum metallurgy—plan, too, to take advantage of the undisputed leadership in equipment and experience which Stokes can apply to your problem.

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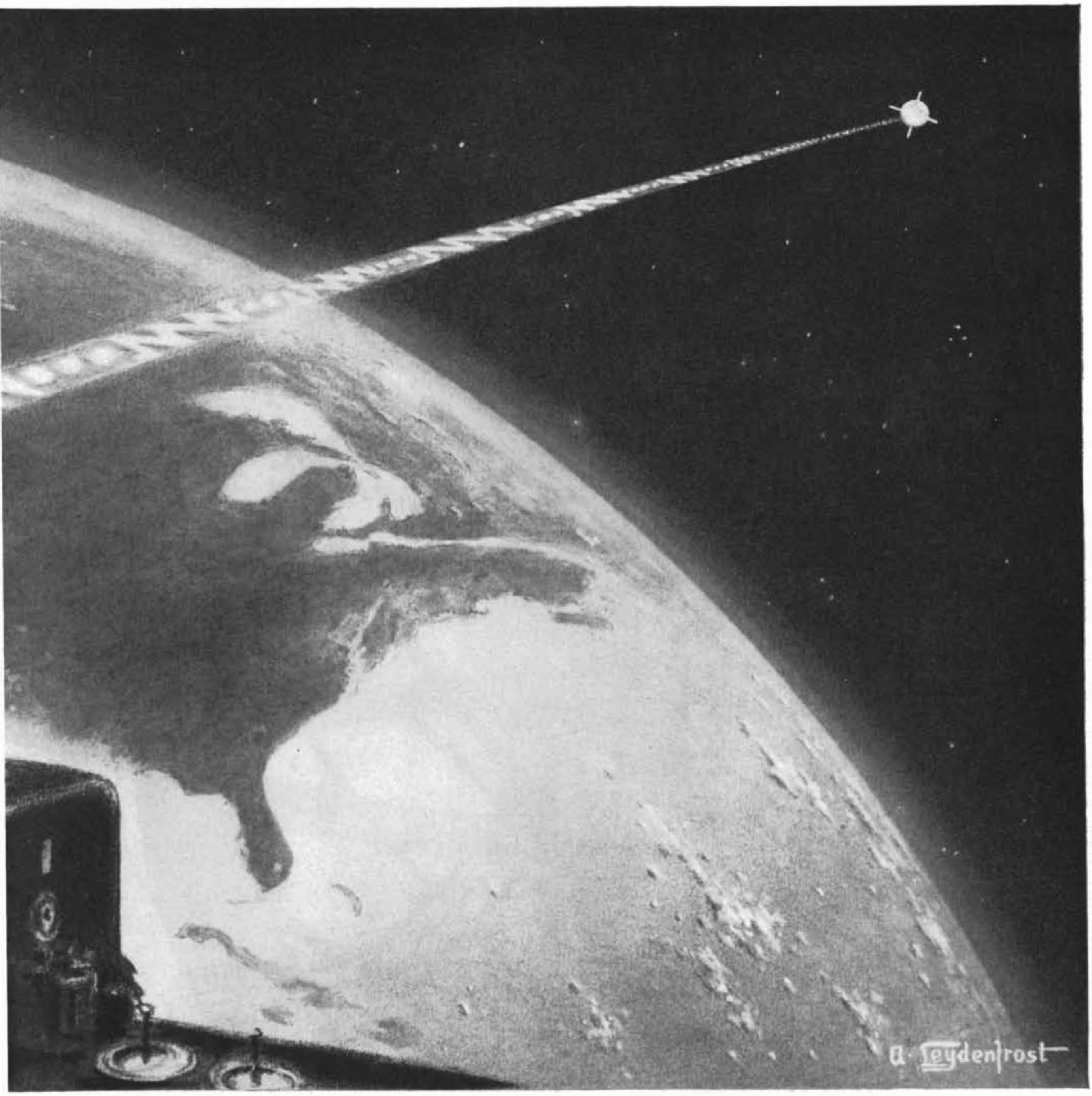

tetrafluoroethylene fiber is being used in non-lubricated bearings because of its *low coefficient of friction.*

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The Principle of Uncertainty

This rule of modern physics, which states that events at the atomic level cannot be observed with certainty, helps resolve the paradox that particles sometimes behave like waves and waves like particles

by George Gamow

It may seem a paradox that one of the cornerstones of modern physics is something called the principle of uncertainty. The idea of indeterminacy as a rule of science does, in fact, disturb many 20th-century philosophers [*see book review on page 111*]. But the uncertainty principle has proved a powerful answer—so far the most fruitful—to important questions in present-day physics. It is a timely moment to review how physicists arrived at the principle and to explore its meaning.

Our starting point is the classical view of the motion of a body. The concept of the trajectory of a moving object is as old as the human mind. The prehistoric caveman who threw a stone or a spear had a mental picture of its flight which told him that if he threw it in the right direction with the right speed, it would hit his prey. This basic idea of a trajectory became the foundation of men's concepts concerning the nature of motion, and in the 18th and 19th centuries mathematicians were able, on these principles, to calculate the motions of the planets with an accuracy to within an infinitesimal fraction of 1 per cent. But at the break of the 20th century a fundamental revolution occurred in physics. Men suddenly discovered that the classical laws of mechanics and energy which worked perfectly within the realm of ordinary experience did not work so well in the realm of the great cosmos on the one hand or the interior of the atom on the other. To resolve the baffling contradictions that turned up, Albert Einstein created a new relativistic view of space, time and motion, while explorers of the atom produced the quantum theory. The new ideas were so strange that they contradicted common sense, just as the notion that the earth was round had violated common sense in an earlier day when men thought the earth must be flat as a pancake because their own backyards and the land and oceans as far as they could see appeared flat. But like Magellan, whose voyage around the world proved that the earth was a globe, physicists in the 20th century soon brought forth proof that the new theories were a better description of physical nature than the comfortable old classical ideas.

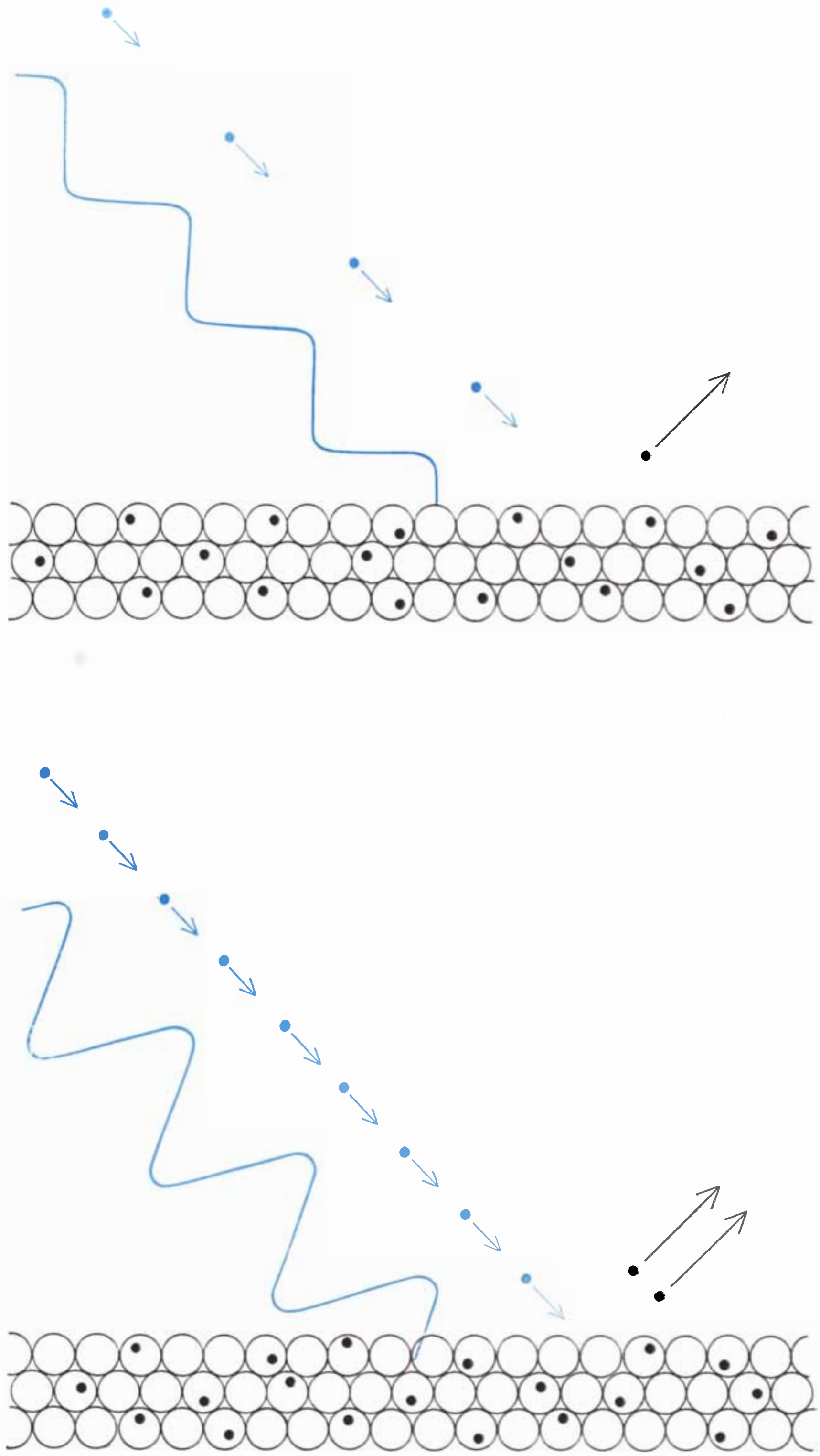
In the atomic realm, two discoveries especially confounded common sense and common experience. One was the behavior of light. As a result of work by Max Planck, Einstein and others, it developed that light was made up of discrete packets of energy, named photons. The energy of the photons varied with the frequency (or wavelength) of the light: it could be stated precisely as $h\nu$, h standing for Planck's constant and ν for the frequency. Matter emitted and absorbed light only in certain definite quanta (photons). Because even dim light consists of billions of photons, we cannot detect its "graininess." But the existence of photons, as well as their obedience to the rule that their energy depends on frequency, was elegantly proved by Einstein's analysis of the photoelectric effect (ejection of electrons from a metal surface by light) and by Arthur Holly Compton's discovery of the "Compton effect" (changes in the frequency of X-rays when they lose energy in collisions with electrons).

Waves or Particles?

The proof of the existence of photons placed the classical theory of light in a very awkward position. Light was supposed to be made up of waves, and its properties of interference and diffraction showed that it did behave like waves. Yet here it was behaving like particles! To resolve this crisis, physicists had to accept the bizarre notion that light had the nature, at one and the same time, both of waves and of particles. They tried to picture it as a stream of photons which was given a wave motion by some kind of guiding "field." The picture admittedly was unsatisfactory, but it was the best they could do.

If this flew in the face of common sense, there was worse to come. It next turned out that particles behave like waves! The embarrassment grew out of Niels Bohr's famous model of the atom. He pictured the electrons as whirling around the nucleus in certain prescribed orbits: that is, they were permitted to possess only certain quanta of mechanical energy. When an electron dropped from one orbit to another, it gave up a quantum of energy in the form of light—a photon.

It was not clear what kept the electrons in their orbits or why they should occupy precisely the orbits that they did, but Louis de Broglie of France soon came forward with an answer. He suggested that the electrons were guided by waves that accompanied their motion. The nature of these "waves" was, of course, mysterious, but de Broglie found striking mathematical support for his idea. Bohr had noted that if his model was correct, the distances of the successive electron orbits from the nucleus of the atoms must be in the ratio of the squares of whole numbers—that is, 1, 4, 9, 16 and so on. This indicated the relative lengths of the circular orbits. If the motions of the electrons were guided by waves, then obviously in each orbit the length of the waves had to be such that some whole number of waves fitted exactly into the length of the orbit [*see diagram on page 54*]. Taking the hydrogen atom as a simple case, de Broglie calculated that the postulated pilot waves would fit in Bohr's orbits if the



PHOTOELECTRIC EFFECT demonstrates that light waves also behave like particles. The circles in this diagram are the atoms of a metal. The black dots within the circles are electrons which can be expelled from the metal by light. The wavy lines are light waves; the colored dots, their associated particles or quanta. In the top picture light expels a single electron from the metal. In the bottom picture light of the same wavelength but greater intensity expels two electrons, each of which has the same energy as that of the first electron. This is explained on the basis that although there are more quanta associated with the second light wave, each quantum has the same energy as each quantum associated with the first light wave. On the basis of classical physics, which does not include the quantum concept, the wave of greater intensity or amplitude should expel electrons of greater energy.

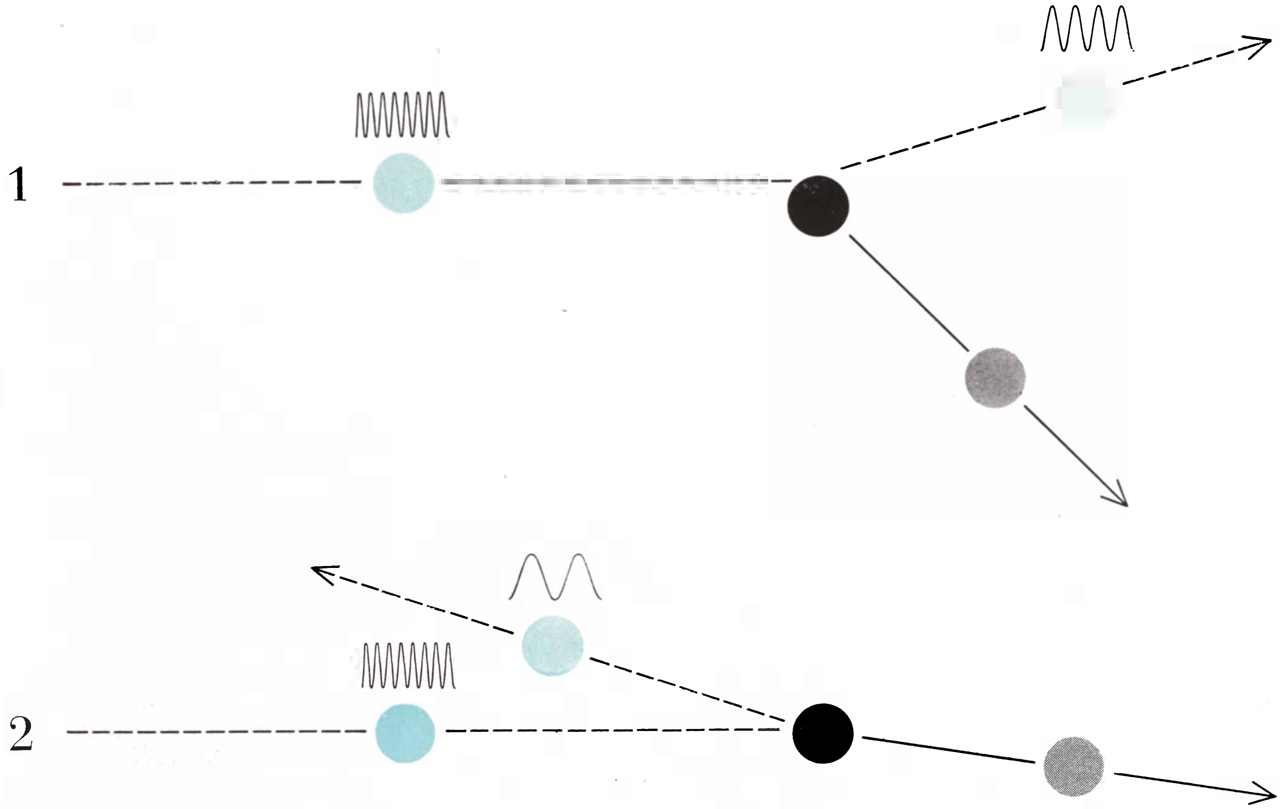
length of the wave in each case was precisely equal to Planck's constant divided by the mass and the velocity of the electron in that orbit.

From this basic idea of de Broglie, developed further by Erwin Schrödinger, came the system called "wave mechanics," a powerful theoretical tool in explaining the dynamics of the atom. Very shortly, however, the existence of de Broglie's pilot waves was demonstrated by a proof more tangible than mathematical consistency. C. J. Davisson and L. H. Germer of the Bell Telephone Laboratories performed their historic experiment showing that a beam of electrons reflected from a crystal produces a diffraction pattern—the acid test of wave motion [see "Davisson and Germer," by Karl K. Darrow; SCIENTIFIC AMERICAN, May, 1948]. And the "wavelength" of the electrons agreed exactly with de Broglie's formula.

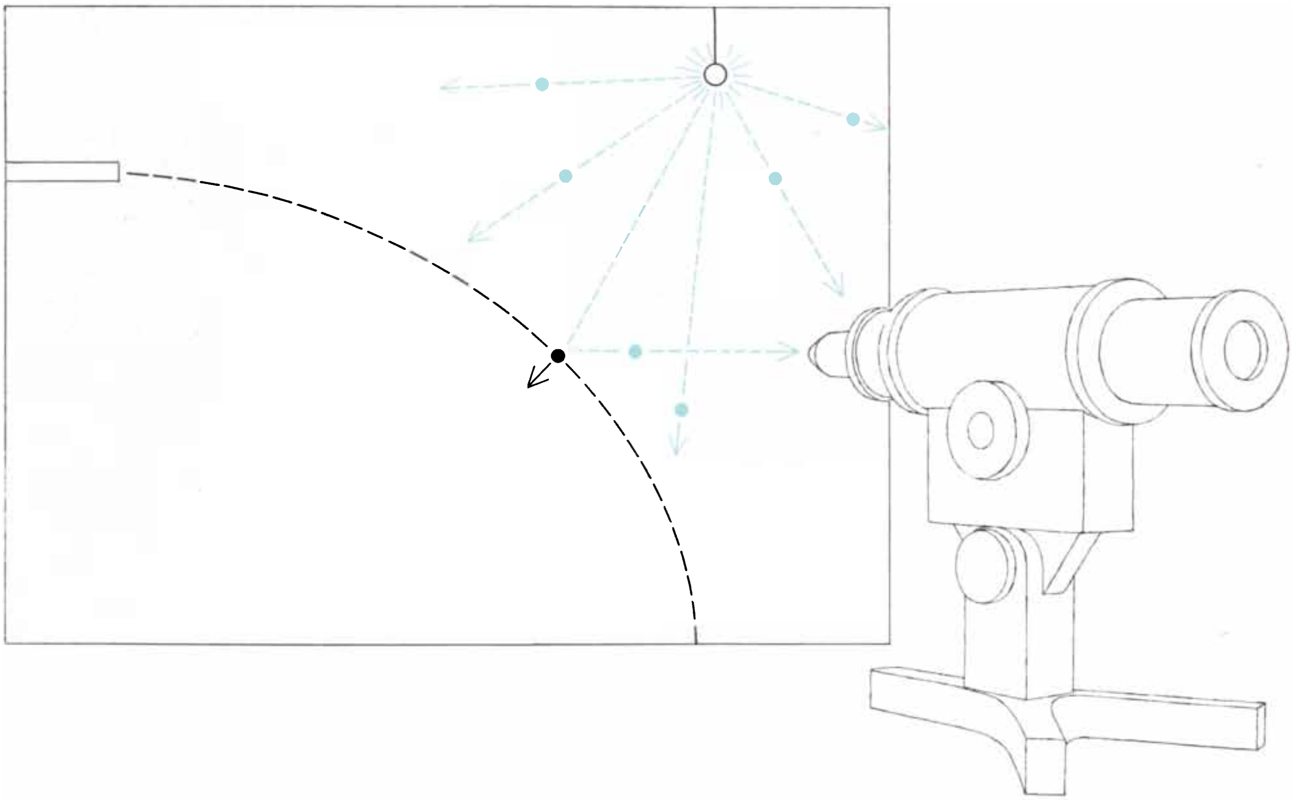
So the distinction between waves and particles all but vanished. Light waves behaved like particles, and particles behaved like waves. Common sense reeled. Whereas in the good old classical physics waves were waves and particles were particles, now one had to deal with waves possessing properties of particles and particles possessing properties of waves. Classical lines of thought could not cope with such a paradox. It was at this point that Werner Heisenberg entered to rescue common sense from total confusion. His solution was the principle of uncertainty.

A Thought Experiment

Heisenberg went back to the root of the trouble: the attempt to apply ordinary rules and methods of observation to phenomena on the atomic scale. In the world of everyday experience we can observe any phenomenon and measure its properties without influencing the phenomenon in question to any significant extent. To be sure, if we try to measure the temperature of a demitasse with a bathtub thermometer, the instrument will absorb so much heat from the coffee that it will change the coffee's temperature substantially. But with a small chemical thermometer we may get a sufficiently accurate reading. We can measure the temperature of an object as small as a living cell with a miniature thermocouple, which has almost negligible heat capacity. But in the atomic world we can never overlook the disturbance caused by the introduction of the measuring apparatus. The energies on this scale are so small that even the most



COMPTON EFFECT shows that X-ray quanta (*colored balls*) deflected by electrons (*black balls*) lose energy according to their angle of deflection. That is, a quantum deflected at a large angle (1) retains more energy than one deflected at a small angle (2).



THOUGHT EXPERIMENT of Werner Heisenberg imagined a microscope which would detect a single electron (*black dot*) by means of single quanta. This illustrated his principle that phenomena at the atomic level cannot be observed without changing them.

gently performed measurement may result in substantial disturbances of the phenomenon under observation, and we cannot guarantee that the results of measurements actually describe what would have happened in the absence of the measuring devices. The observer and his instruments become an integral part of the phenomenon under investigation. Even in principle there is no such thing as a physical phenomenon *per se*. In all cases there is an absolutely unavoidable interaction between the observer and the phenomenon.

Heisenberg illustrated this by a detailed consideration of the problem of trying to track the motion of a material particle. In the gross world we can follow the flight of a ping-pong ball without affecting its trajectory one iota. We know that light exerts pressure on the ball, but we do not have to play ping-pong in a dark room (assuming it were possible), because the pressure of light is much too small to make any difference in the ball's flight. But substitute an electron for the ping-pong ball, and the situation becomes quite different. Heisenberg examined the situation with a *Gedankenexperiment* ("thought experiment"), a device which was first used by Einstein in his discussion of the theory of relativity.

In such an exercise the experimenter is allowed an "ideal workshop" in which he can make any kind of instrument or gadget—provided that its design and functioning do not contradict basic laws of physics. For example, he can have a rocket that moves with almost the speed of light, but not more than the speed of light; or he may use a light source which emits just a single photon, but not half a photon. Heisenberg equipped himself with an ideal setup for observing the flight of an electron. He imagined an electron gun which could shoot a single electron horizontally in a completely evacuated chamber—barren of even a single air molecule! His light came from an ideal source which could emit photons of any desired wavelength and in any desired number. And he could watch the movement of the electron in the chamber through an ideal microscope which could be tuned at will over the whole range of the spectrum, from the longest radio waves to the shortest gamma rays.

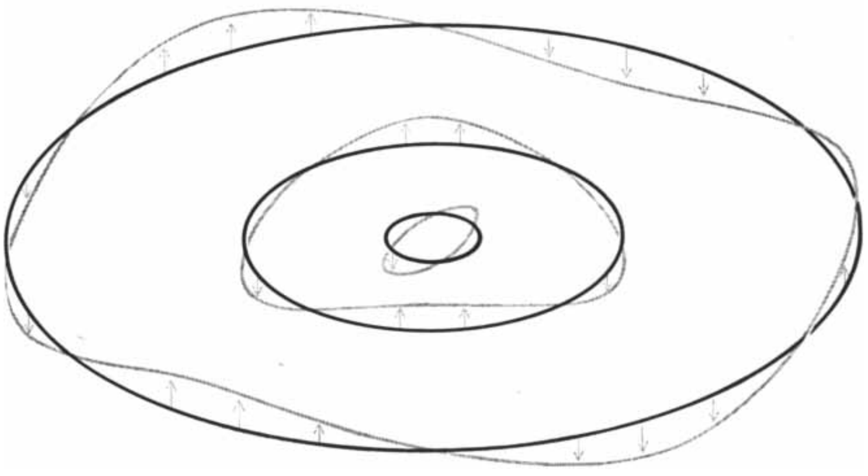
The Errant Electron

What will happen when an electron is fired in the chamber? According to our classical textbooks on mechanics, the particle should follow a trajectory known as a parabola. But actually, the moment a photon strikes it the electron will recoil and change its velocity. Observing the particle at successive points in its motion, we shall find it taking a zigzag course because of the photon impacts. Let us, then, since we have an ideally flexible instrument, minimize the impacts by reducing the photons' energy, which we can do by using light of lower frequency. In fact, by going to the limit of infinitely low frequency (which is possible in our apparatus) we can make the disturbance of the electron's motion as small as we wish. But here comes a new difficulty. The longer the wavelength of the light, the less able we are to define the object, because of the diffraction effect. So we can no longer find the exact position of the electron at any given instant. Heisenberg showed that the combined uncertainty in position and in velocity (*i.e.*, the product of the two uncertainties) can never be smaller than Planck's constant divided by the mass of the particle.

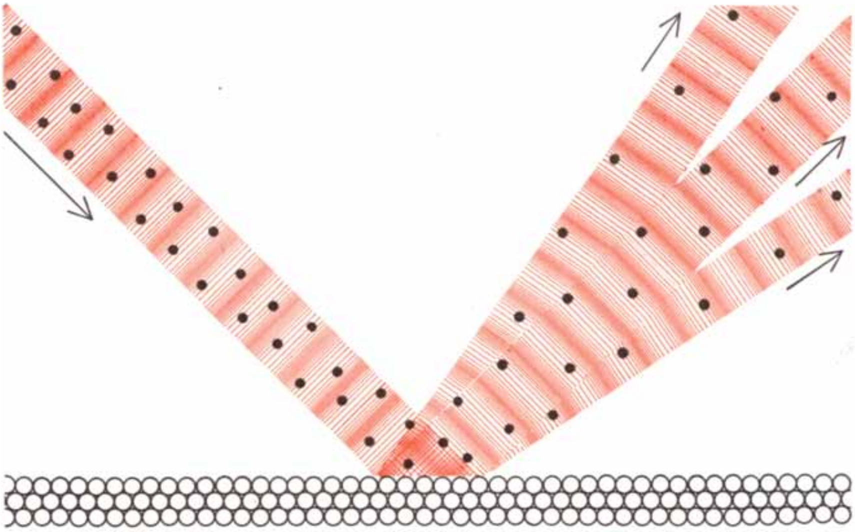
So with very short waves we can define the positions of a moving particle sharply but will interfere greatly with its velocity, while with very long waves we can determine its undisturbed velocity but become very uncertain about its positions. Now we can choose a middle ground between these uncertainties. If we use some optimal intermediate wavelength of light, we will disturb the particle's trajectory only moderately and still be able to define its path to a fairly close approximation [*see diagrams at top of pages 56 and 57*]. The observed path, expressed in classical terms, will not be a sharp line, but at least it will be confined within a band. Describing the trajectory of an electron in this way gives us no difficulty in a case such as a television picture tube, where the "thickness" of the electron's path to the screen is very much smaller than the diameter of the spot formed on the screen by the electron beam. Here we can represent the electron's trajectory satisfactorily by a line. But we cannot describe the orbit of an electron inside an atom in the same terms. The band of uncertainty is about as wide as the distance of the orbit from the nucleus!

Suppose we give up the attempt to track a moving particle with light and try the cloud-chamber method instead. In our hypothetical workshop we build an ideal "cloud chamber" which is completely evacuated of material particles but is filled with very tiny imaginary "indicators" that become "activated" whenever an electron passes close by. The activated indicators would show the track of the moving particle just as water droplets do in a real cloud chamber [*see diagram at bottom of page 56*].

Classical mechanics would say that in principle the indicators could be made small enough and delicately responsive enough so that they would subtract no significant amount of energy from the moving particle and we could observe its trajectory with any desired precision. But quantum mechanics finds a fundamental objection to this procedure. One of its rules is: The smaller the system, the larger its quanta (minimum amount) of energy. Thus as the size of the "indicators" was reduced (for more precise measurement of the electron's positions), they would take more energy from the passing particle. The situation is quite analogous to the fatal difficulty



ELECTRON WAVES fitted into discrete orbits were suggested by Louis de Broglie as the explanation of the discrete energy levels of the atom. In this schematic diagram the inner orbit consists of one wave; the second orbit, of two waves; the outer orbit, of three waves. The radii of the orbits would be in the ratio of those numbers squared: one, four and nine.



ELECTRON WAVES WERE DISCOVERED by C. J. Davisson and L. H. Germer when they observed that a beam of electrons (*left*) was deflected at several discrete angles (*right*) by a crystal lattice (*bottom*). This is characteristic of diffraction, a wave phenomenon.

in trying to track a particle by means of light, and we again arrive at the same relation for the uncertainties.

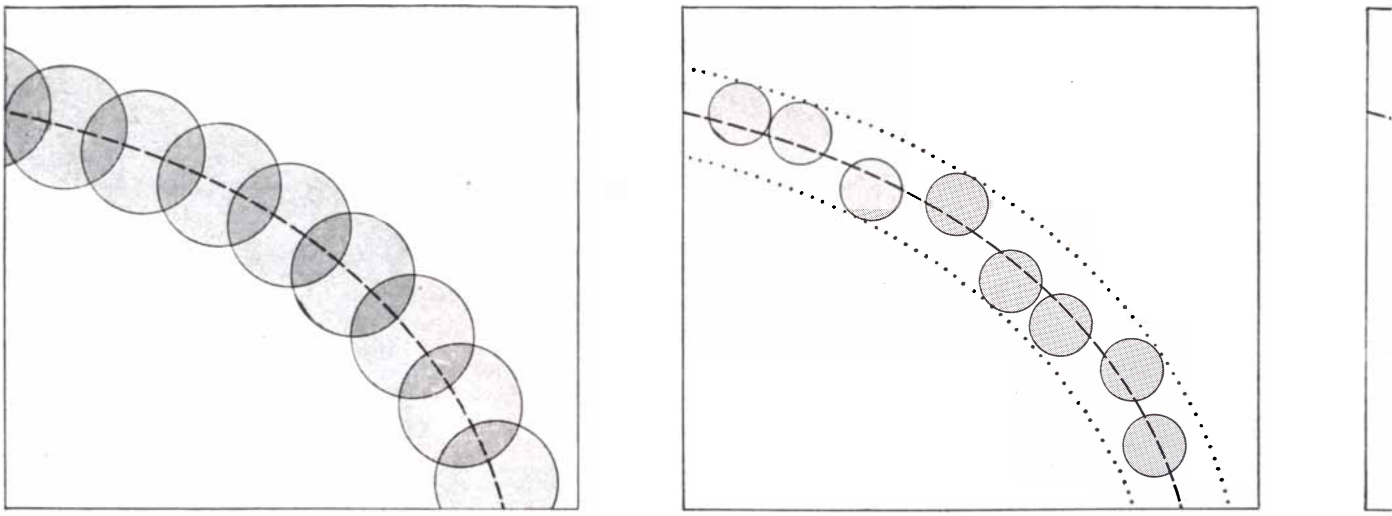
Particles Guided by Waves

Where does all this leave us? Heisenberg concluded that at the atomic level we must give up the notion of the trajectory of an object as a mathematical (*i.e.*, infinitely thin) line. This concept is accurate enough when we deal with phenomena in the realm of ordinary experience, where we can think of a moving object as held in its path by a kind of railroad track. But in the small world of photons and the atom, individual motions and events are not so firmly predetermined. Photons and material particles such as electrons and protons move over a range under the guidance of waves. The important point is that the guidance is performed in a probabilistic rather than a strictly deterministic way. We can measure only the *probability* that a photon will strike a given point on a screen, or that a material particle will be found in a given place at a given instant.

I must make clear that the word "probability" here is used in a rather different sense from the way it is usually understood in classical physics and everyday life. When we say in a game of poker that there is a certain probability of drawing a royal flush, we mean only that we have to estimate the chances because we do not know the arrangement of the cards in the pack. If we knew exactly how the cards were stacked, we could predict definitely whether we would get a royal flush or not. Classical physics assumed that the same was true of a problem such as the behavior of a gas: its behavior had to be described on the basis of statistical probability only because of incomplete knowledge—if we were given the positions and velocities of all the particles, we could predict events within the gas in full detail. The uncertainty principle cuts the ground from under that idea. We cannot predict the motions of individual particles because we can never know the initial conditions exactly in the first place. It is impossible *in principle* to obtain an exact measurement of both the position and the velocity of a particle on the atomic scale.

A look at Heisenberg's formula for measuring uncertainty shows why we can disregard the principle of uncertainty and safely trust the good old principle of determinism when we deal with matter on the macroscopic scale. The uncertainty, as I have mentioned, is equal to Planck's constant h divided by the mass of the particle. Planck's constant is an extremely small quantity: its numerical value amounts to only about 10^{-27} in centimeter-gram-second units. When we consider a particle weighing as much as one milligram, we can in principle simultaneously determine its position within a trillionth of a centimeter and its velocity within a trillionth of a centimeter per second—or 30 microns per century!

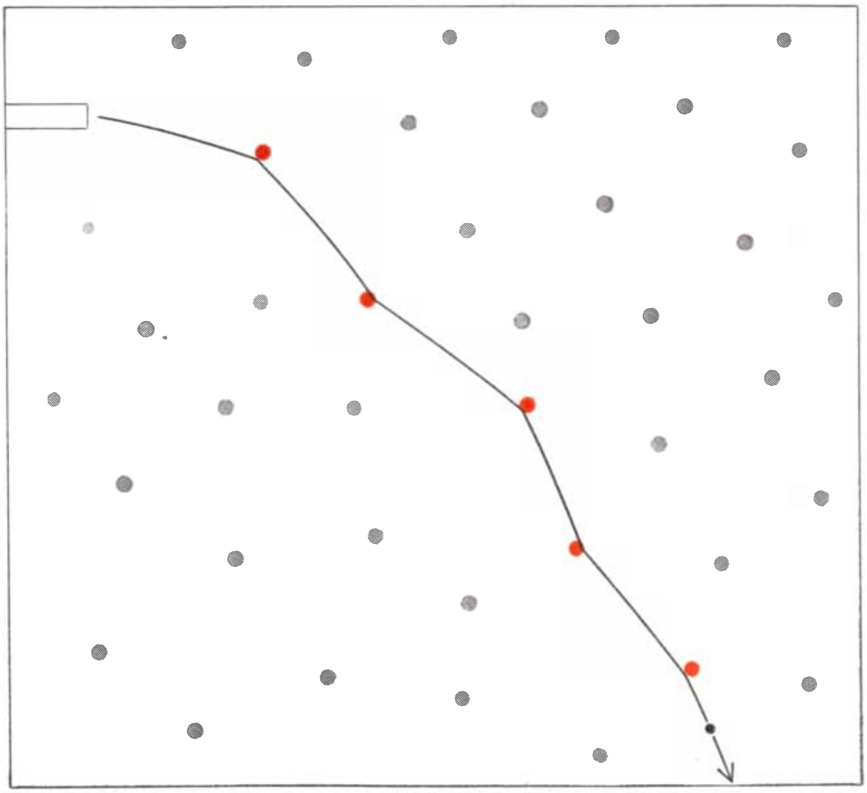
Heisenberg's principle was developed by Bohr into a new philosophy of physics. It called for a profound change in our ideas about the material world—ideas



TRAJECTORY OF A MOVING PARTICLE is schematically observed with quanta of three different wavelengths. The trajectory of the unobserved particle is indicated by the broken line in each drawing. At left the quanta have low energy and long wavelength; they disturb the trajectory of the particle very little but only hazily indicate its path. In center the quanta have medium energy and medium wavelength; they disturb the trajectory somewhat but narrow the indication of its path. At right the quanta have high energy

that we acquire in ordinary experience from early childhood. But it allowed many puzzles of atomic physics to make sense. Above all, it extricated us from the wave-particle paradox. The uncertainty principle showed that the wave and particle ideas are mutually complementary ways of describing nature.

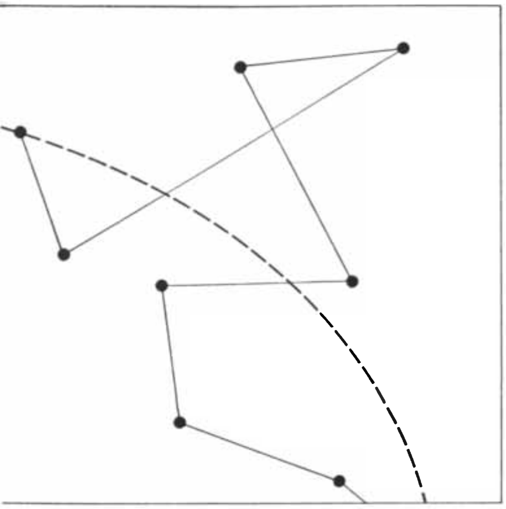
Many physicists readily accepted the new view. Others did not like it at all. To the latter group belonged Albert Einstein. His philosophical convictions about determinism did not permit him to elevate uncertainty to a principle. And just as skeptics were trying to find contradictions in his theory of relativity, Einstein tried to discover contradictions in the uncertainty principle of quantum physics. However, his efforts led only to strengthening of the principle of uncertainty. This is interestingly illustrated by an incident that took place at the sixth International Solvay Congress on Physics, in Brussels in 1930.



SMALL INDICATORS (*larger dots*) could be used to trace the path of a particle fired from a gun (*upper left*). But the smaller the indicators, the more they disturb the path.

In a discussion at which Bohr was present, Einstein performed a "thought experiment." Arguing that time was a fourth coordinate of space-time and that energy was a fourth component of momentum (mass times velocity), he said that Heisenberg's uncertainty equation implied that the uncertainty in time was related to the uncertainty in energy, the product of the two being at least equal to Planck's constant h. Einstein set out to prove that this was not the case—that the time and the energy could be determined without any uncertainty. Consider, he said, an ideal box, lined with perfect mirrors, which could hold radiant energy indefinitely. Weigh the box. Then at a chosen instant some time later a clockwork, preset like a time bomb, will open an ideal shutter to release just one photon. Now weigh the box again. The change of mass tells the energy of the emitted photon. In this manner, said Einstein, one could measure the energy emitted and the time it was released with any desired precision, in contradiction to the uncertainty principle.

The next morning, after an almost sleepless night, Bohr delivered a mortal blow to Einstein's disproof. He offered a counter thought experiment with an ideal apparatus of his own (which I



and short wavelength; each quantum sharply locates the particle but completely disturbs its trajectory. Thus the trajectory can at the most be only roughly approximated.

later actually built in wood and metal, as Bohr's student, for his use in lectures on the subject). Bohr attacked the question of weighing Einstein's box. A spring scale equipped with a pointer recording the weight on a vertical column placed alongside is, he said, as good as any. Now since the box must move vertically with a change in its weight, there will be an uncertainty in its vertical velocity and therefore an uncertainty in its height above the table, Bohr pointed out. Furthermore, the uncertainty about its elevation above the earth's surface will result in an uncertainty in the rate of the clock, for according to the theory of relativity the rate depends on the clock's relative position. Bohr proceeded to show that the uncertainties of time and of the change in the box's mass would indeed have the relation which Einstein had tried to disprove.

Einstein, bitten by his own argument, had to agree that Heisenberg's concept was free of internal contradictions, but to the very end of his life he refused to accept the uncertainty principle and remained hopeful that physics would some day return to the deterministic point of view.

During the past decade the validity of the uncertainty principle has been argued voluminously, both by writers who understand the problems at issue and by writers who do not. Up to the present this so-called "Copenhagen interpretation of the quantum theory" has stood its ground. In my opinion and in the opinion of many other theoretical physicists, the uncertainty principle will stand its ground indefinitely.

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BARBITURATES

They are among the most useful of all drugs. In small doses they act as sedatives; in larger doses they induce sleep; in still larger doses they are able to produce deep anesthesia

by Elijah Adams

The barbiturates are the most versatile of all depressant drugs. They can produce the whole range of effects from mild sedation to deep anesthesia—and death. They are among the oldest of the modern drugs. Long before reserpine and chlorpromazine, the barbiturates were being used as tranquilizers. Indeed, phenobarbital has been called "the poor man's reserpine." Had phenobarbital been introduced five years ago instead of half a century ago, it might have evoked the same burst of popular enthusiasm as greeted Miltown and its fashionable contemporaries. Not that the vogue of the barbiturates is any less spectacular, in terms of total production and consumption. The U. S. people take an estimated three to four billion doses of these drugs per year, on prescription by their physicians. The barbiturates rank near the top of the whole pharmacopoeia in value to medicine. They are also a national problem.

It was nearly a century ago that a young assistant of the great chemist August Kekulé in Ghent made the first of these compounds. In 1864 this young man, Adolf von Baeyer, combined urea (an animal waste product) with malonic acid (derived from the acid of apples) and obtained a new synthetic which was named "barbituric acid." There are several stories about how it got this name. The least apocryphal version relates that von Baeyer and his fellow chemists went to celebrate the discovery in a tavern where the town's artillery garrison was also celebrating the day of Saint Barbara, the saint of artillerists. An artillery officer is said to have christened the new substance by amalgamating "Barbara" with "urea."

Chemists proceeded to produce a great variety of derivatives of barbituric acid. The medical value of the substances was not realized, however, until 1903, when two other luminaries of German organic chemistry, Emil Fischer and Joseph von Mering, discovered that one of the compounds, diethylbarbituric acid, was very effective in putting dogs to sleep. Von Mering, it is said, promptly proposed that the substance be called veronal, because the most peaceful place he knew on earth was the city of Verona.

Within a few months of their report, "A New Class of Sleep-Inducers," physicians in Europe and the U. S. took up the new drugs enthusiastically. More and more uses for them were discovered. Veronal (barbital) was soon followed by phenobarbital, sold under the trade name Luminal. In all, more than 2,500 barbiturates were synthesized in the next half-century, and of these some two dozen won an important place in medicine. By 1955 the production of barbiturates in the U. S. alone amounted to 864,000 pounds—more than enough to provide 10 million adults with a sleeping pill every night of the year.

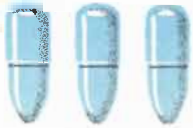
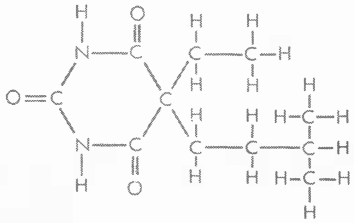
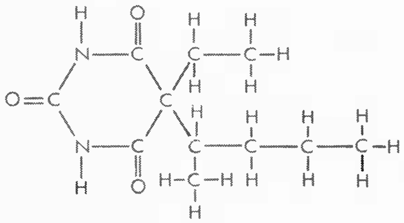
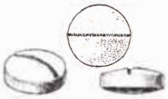
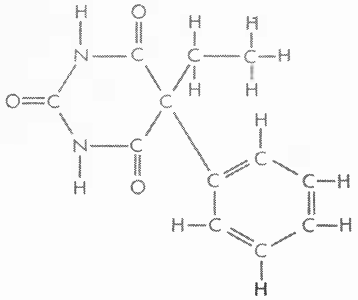
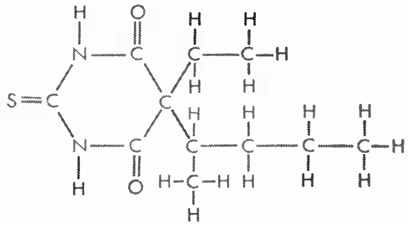
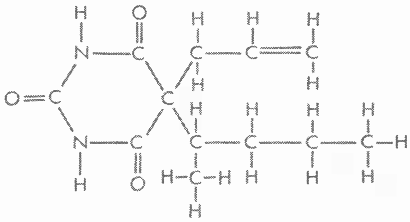
As is true of most drugs, we still do not know how the barbiturates work or exactly how their properties are related to their chemistry. The basic structure is a ring composed of four carbon atoms and two nitrogens [*see diagrams on page 64*]. Certain side chains added to the ring increase the drug's potency; in some instances the addition of a single carbon atom transforms an inactive form of the compound into an active one. Empirical analysis of the thousands of barbiturates has given us some practical information about relations between structure and activity. But by and large the mode of action of the drugs is an unsolved problem.

We know a great deal, however, about the action itself. We can follow it best by examining the successive stages of the drugs' depressant effect on the central nervous system [see "Anesthesia," by Henry K. Beecher; SCIENTIFIC AMERICAN, January, 1957]. From this standpoint the barbiturates can be considered together as a group, for the differences among them are not fundamental and concern such matters as the speed and duration of the effect.

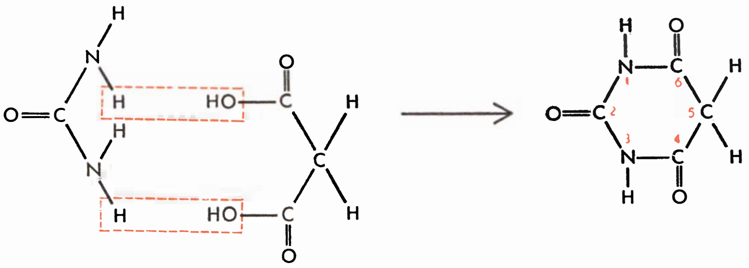
In small doses these drugs are sedatives, acting to reduce anxiety and to relieve psychogenic disorders—for example, certain types of hypertension and gastrointestinal pain. In this respect the barbiturates are yesterday's tranquilizers. They have now taken second place in popularity as sedatives to the newer tranquilizers.

At three to five times the sedative dose, the same barbiturate produces sleep. Barbiturates are still by far the most widely used drugs for this purpose, as millions of us know. Hardly any hospital patient has escaped his yellow or red capsule at evening, for it is an article of clinical faith that the patient needs chemical assistance to achieve sleep in his new environment. Another large block of users are the chronic travelers by plane and train. Finally there are the thousands of sufferers from insomnia who take the drugs habitually.

Many persons find barbiturate-induced sleep as refreshing as natural sleep. Others awake with a hangover, feeling drowsy, dizzy and suffering a headache. Tests show that, with or without symptoms, the barbiturates reduce efficiency: six to eight hours after a sleeping dose of sodium pentobarbital (Nembutal) the subjects perform below par on mental and memory tests. The various drugs act differently as sleep-

	FORMULA	NAMES	CHIEF USES	DURATION
		AMOBARBITAL (AMYTAL)	SEDATIVE HYPNOTIC	INTER-MEDIATE
		PENTOBARBITAL (NEMBUTAL)	HYPNOTIC	SHORT-ACTING
		PHENOBARBITAL (LUMINAL)	HYPNOTIC SEDATIVE ANTICONVULSANT	LONG-ACTING
		THIOPENTAL (PENTOTHAL)	ANESTHETIC	ULTRA SHORT-ACTING
		SECOBARBITAL (SECONAL)	HYPNOTIC	SHORT-ACTING

FIVE BARBITURATES are depicted at the left as they are commonly manufactured. As shown in the column of chemical structures, four of these drugs differ only in the chains of atoms attached to the carbon atom at the right side of their basic ring structure. The permutability of the basic barbiturate structure makes possible variations in speed and duration of its effect on the body.



BARBITURIC ACID (*right*), is made by combining urea (*left*) and malonic acid (*right*) with the elimination of water (*colored rectangles*). The barbiturate families arise from substitution of other substances for hydrogens at position 5 in the basic barbiturate structure.

producers. Some last for only three hours or less, others for six hours or more. The shorter-acting barbiturates (sodium pentobarbital, secobarbital) are appropriate for insomniacs who have trouble falling asleep; the longer-acting ones (barbital, phenobarbital) for people who go to sleep easily but awake after four to six hours. The latter drugs, however, are more likely to produce a hangover.

In large doses a barbiturate acts as an anesthetic. Not only does the patient become unconscious, but his spinal cord reflexes are depressed so that the muscles are relaxed and manageable for surgery. Like the gaseous anesthetics, the barbiturates depress the cerebral cortex first, then lower brain centers, next the spinal cord centers and finally the medullary centers controlling blood pressure and respiration.

The fast-acting barbiturates produce anesthesia more rapidly than ether: the patient passes from the waking state to anesthetic coma in a few moments. Sodium thiopental is the most widely used. It has important advantages over a gaseous anesthetic such as ether. Injected intravenously, it works rapidly, avoids the sense of suffocation, requires no special equipment, is free from the explosion hazard and from respiratory complications. A barbiturate anesthetic has, however, an outstanding disadvantage: the dose necessary for good muscular relaxation may seriously reduce oxygen supply to the tissues by depressing the brain center that drives respiration. Consequently for a long operation the barbiturate is often combined with a gaseous anesthetic; for a short one the dose is reduced and combined with a specific muscle-relaxing drug that has no brain-depressant action.

There are two other interesting uses of the barbiturates. One of them is in the field of psychology. As Henry Beecher observed in his article on anesthesia in Scientific American, an anesthetic can provide "planned access to levels of consciousness not ordinarily attainable except perhaps in dreams, in trances or in the reveries of true mystics." During World War II the barbiturates, particularly thiopental, were used for analysis and therapy for many thousands of GIs, who by this means relived and verbalized traumatic battle experiences which had been buried beyond voluntary recollection. The inhibition-relieving action of these drugs has also been employed by the police—in which application the press has given them the name of "truth serum," although they are neither a serum nor a guaranteed truth-producer.

The other important use of the drugs is for the control of epileptic convulsions. Certain of the barbiturates—phenobarbital, mephobarbital and methabarbital—can prevent or stop these seizures by depressing brain activity. Barbiturates can control not only the generalized convulsions of genuine (idiopathic) epilepsy—a disease afflicting almost a million persons in the U. S.—but also seizures induced by stimulating drugs or by bacterial toxins such as tetanus. The barbiturates and the convulsant drugs act in opposite fashion, and, curiously, each is used as an antidote for the other. Acute barbiturate poisoning is often treated with a stimulating drug such as pentylenetetrazol (Metrazol) or picrotoxin to bring the patient out of his coma; if the dose of the stimulant turns out to be too strong, producing convulsions, this in turn is treated with a dose of a fast-acting barbiturate!

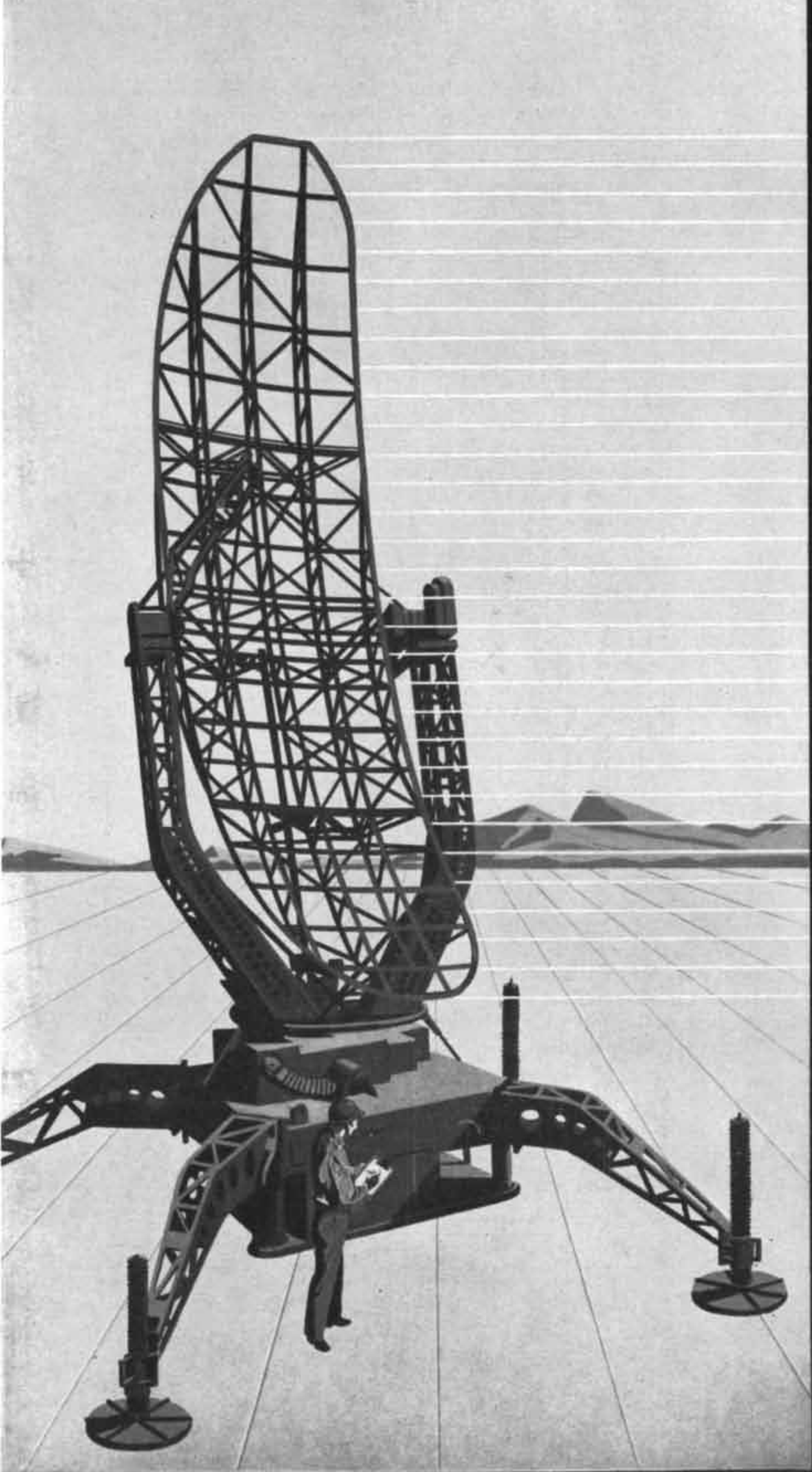
The toxic effects of barbiturates are subtle and sometimes unpredictable. For some patients even a comparatively small dose may be dangerous. The body gets rid of barbital and phenobarbital chiefly by excretion in the urine; for a person with damaged kidneys, therefore, these drugs become toxic. Pentobarbital and secobarbital, two of the most widely used barbiturates, are broken down in the liver. Given to a patient with a poorly functioning liver, they may produce a far longer sleep than desired.

Next to carbon monoxide, the barbiturates are the most popular suicide poison in the U. S. They account for one fifth of all the cases of acute drug poisoning, and most of these are suicide attempts. The barbiturates are not, as a matter of fact, a very efficient suicide agent: only about 8 per cent of those poisonees who arrive at hospitals die. But they are widely known and readily available, and they produce from 1,000 to 1,500 deaths in the U. S. each year.

Some of these deaths, though self-inflicted, are accidental. A British physician first called attention some years ago to a specific and probably common hazard. The person takes a small dose to go to sleep, and later, half asleep and confused, he swallows another, lethal dose. Some physicians now warn barbiturate-users not to keep their bottle of tablets on a night table, where they may stretch out a hand to take more while in the comatose state.

There is a comfortable margin of safety between the ordinary sleeping dose (a tenth of a gram for the average adult) and a definitely toxic dose (more than half a gram). The lethal dose is usually a gram and a half or more. Acute barbiturate poisoning has to be treated promptly. Unfortunately it is often not recognized in time, because the victim is thought to be merely in a deep sleep. The first step in treatment is to strengthen the victim's breathing, in a respirator if necessary. And a stimulant may have to be administered to restore the activity of the brain centers.

Are the barbiturates habit-forming? This much-debated question has been answered rather conclusively by recent studies. They can indeed produce addiction and chronic intoxication. The two chief criteria of addiction to a drug are a heightened tolerance to it and physical dependence on it, so that removal of the drug produces withdrawal symptoms. A morphine addict, for example, may be able to take many times the dose that would be lethal for a normal person, and he becomes acutely sick if the drug is stopped. Several years ago Havelock Fraser, Harris Isbell and their associates at the U. S. Public Health Service hospital for drug addicts in Lexington, Ky., made a thorough study of whether the barbiturates had these properties. Their investigation included experiments with human subjects who



were given large doses of barbiturates over a period of months and then abruptly taken off the drug.

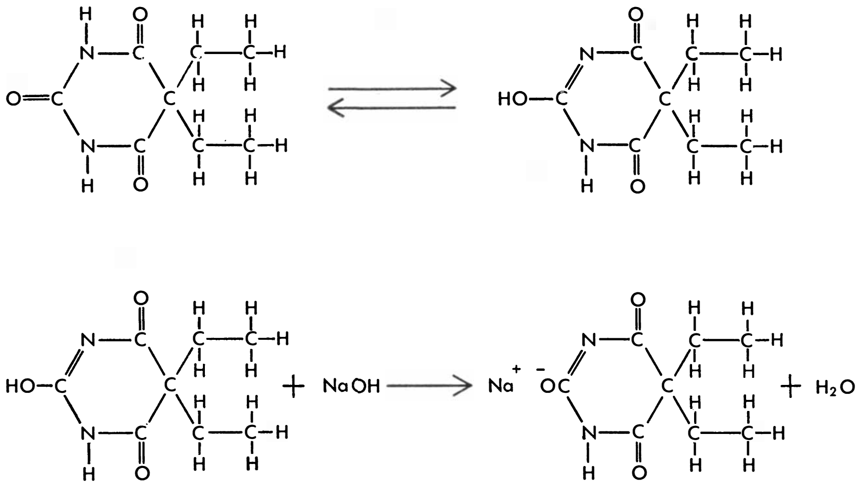
They found that the barbiturates acted as addicting drugs in every respect—physical and psychic. The men behaved like chronic alcoholics: they neglected their appearance and hygiene, became confused and quarrelsome, showed unpredictable mood swings and lost physical coordination and the mental discipline necessary for simple games. After abrupt withdrawal of the drug, the subjects began within a few hours to show signs of increasing apprehension and developed weakness, tremors, nausea and vomiting. In the next five days most of the subjects had convulsions like those of epilepsy and an acute psychosis such as alcoholics suffer, with delirium and violent hallucinations.

The Lexington investigators also made similar tests on dogs. They too exhibited withdrawal symptoms. In their "canine delirium" the dogs would stare at a blank wall and move their heads, eyes and ears as if responding to imaginary animals, people or objects; even while alone in a cage a dog would growl as if being attacked.

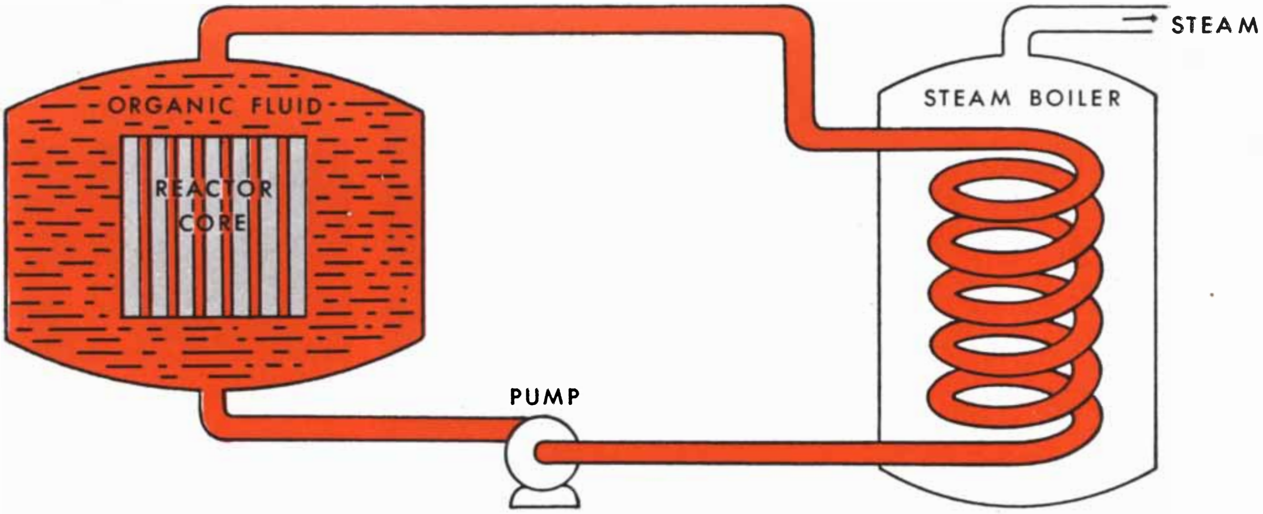
Stories in the press have greatly exaggerated the extent of barbiturate addiction in the U. S. "Thrill pills," "goof balls," "wild geronimos," "red devils" (secobarbital), "yellow jackets" (sodium pentobarbital), "blue heaven" (amobarbital)—all these terms certainly have a currency in a limited circle of addicts, but the number of addicts is not nearly so large as some of the stories have alleged. There are probably not more than 50,000 barbiturate addicts, compared with a million chronic alcoholics. Nevertheless, in view of the easy access to the barbiturates, the public does need to be alerted to their addictive property.

The saving fact is that it takes extraordinarily heavy use of these drugs to produce addiction. Subjects who have taken a fifth of a gram (twice the usual sleeping dose) every night for a year have shown no withdrawal symptoms after stopping the drug. In contrast, morphine, taken in the usual hospital doses for as short a time as 30 days, produces definite physical dependence. Moderate use of the barbiturates, in the doses prescribed by physicians, will not lead to addiction. Those who become addicts are probably, in the main, drug-users who turn to the barbiturates because they cannot get narcotics, alcoholics who seek relief from alcohol withdrawal and, in general, abnormal personalities who are addiction risks for any intoxication that will give psychic relief. Whether stricter Federal laws are needed to control misuse of the barbiturates has been a matter of considerable controversy.

Biologists look forward to the day when progress in medicine will make all present drugs, including the barbiturates, obsolete. Better understanding and treatment of the personal and social causes of anxiety should reduce our present reliance on chemical aids to tranquility and sleep. Meanwhile the barbiturates can teach us much about the functions of the brain and so help lead toward that more tranquil day.



SODIUM BARBITAL (*lower right*) can be made from barbital (*shown at top of diagram in its two forms*) by addition of sodium hydroxide ($NaOH$) and the elimination of water.



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How Do Genes Act?

In which the effect of a human mutation that causes a disease of the blood is traced to a change in one of the 300 amino acid units that make up the structure of the protein hemoglobin

by Vernon M. Ingram

During the last few years geneticists and biochemists have made exciting progress toward learning how heredity works. They have found more and more evidence that the substance of the genes is deoxyribonucleic acid (DNA). These studies have led to an extremely interesting hypothesis about how DNA controls the making of living material—that is, proteins. In this article I shall describe some experiments, carried out in recent months at the University of Cambridge, which not only provide strong support for this hypothesis but have actually pinpointed the chemical effects of certain genes, thus giving us our first detailed picture of gene action.

The meaning of these experiments will be clearer if we first review very briefly the main outlines of the present view of the chemistry of heredity, which has been discussed in many articles in SCIENTIFIC AMERICAN. The blueprints of heredity reside in the threadlike chromosomes, of which there are about 24 pairs in every human cell. Each chromosome contains several hundred genes, strung together in a row. The gene responsible for any particular trait has a specific position, or "locus," in the string. The present concept is that the backbone of the chromosome consists of long DNA molecules and that the genes are segments of these molecules. The DNA molecule is made up of two chains twined around each other in a helical structure and cross-linked by pairs of bases—adenine and thymine or guanine and cytosine. It is like an enormously long winding staircase, with the stair treads corresponding to these cross-links.

The DNA, according to the simple and attractive hypothesis that has excited so much recent attention, holds the key to the manufacture of proteins by the cell. Its structure controls the construction of the protein molecules for which it is responsible. It carries a kind of Morse code: that is to say, a given DNA has its bases arranged in a particular order, and this order determines the order in which amino acids fall into place in the corresponding protein molecule [see "Nucleic Acids," by F. H. C. Crick; SCIENTIFIC AMERICAN, September, 1957]. There are some 20 or more different amino acids. A protein molecule is made of hundreds or thousands of amino acid units, and all the evidence indicates that each protein owes its uniqueness to the specific sequence of its amino acids.

To sum up the theory: A segment of a DNA molecule (*i.e.*, a gene) carries the code for a protein or section of a protein molecule. Putting the hypothesis this way suggests a possible test for a gene's action. Suppose we have an abnormal protein arising from mutation of a gene. By chemical analysis of this deviant form and the normal protein we might discover how they differ. If we can determine this, we may learn what the site of the gene's action is and how large or how small a chemical change it has produced.

Such a protein is, in fact, conveniently available for study. It is the human hemoglobin molecule, the oxygen-carrying part of the red blood-cell. As readers of this magazine well know, several mutant forms of hemoglobin have been discovered in recent years. The best-known is the sickle cell form, responsible for sickle cell anemia. The discovery of this defect has been enormously fruitful to biological science in several fields [see "Sickle Cells and Evolution," by Anthony C. Allison; SCIENTIFIC AMERICAN, August, 1956]. Various researches, particularly those of J. V. Neel at the University of Michigan, have proved that the defect is hereditary, that it is traceable to the action of a single mutant gene and that the gene causes the synthesis of a hemoglobin chemically different from the normal form.

We undertook to track down this difference. To start with, the only definite sign of the chemical difference was the finding by Linus Pauling and his coworkers at the California Institute of Technology that the normal hemoglobin molecule and sickle cell hemoglobin have different electric charges, as shown by the technique called electrophoresis. Our problem was to find out precisely what part of the molecule was altered—this in a huge molecule consisting of some 8,000 atoms! The situation was not, however, quite as desperate as may appear. The hemoglobin molecule is made up of two identical halves, so we can confine ourselves to one half of it (only 4,000 atoms!). We are further favored by the fact that we can consider the atoms in groups rather than individually, the groups being amino acids. The half-molecule contains about 300 amino acid units, of 19 different kinds.

The problem thus resolved itself into trying to learn just how the arrangement of these 300 units in a sickle cell hemoglobin molecule differed from that in a normal molecule. It was a sufficiently formidable task. To work out the complete structure of the insulin molecule, with 51 amino acids, took a group of workers at Cambridge nearly 10 years! We did not venture to analyze the entire structure of hemoglobin. There were indications that the change to the abnormal molecule lay in some small section of it, and I attacked the problem by breaking the molecule down to small fragments, in the hope of locating the change in a single fragment. Whereas the chances of finding a small change are pretty remote in a molecule made of

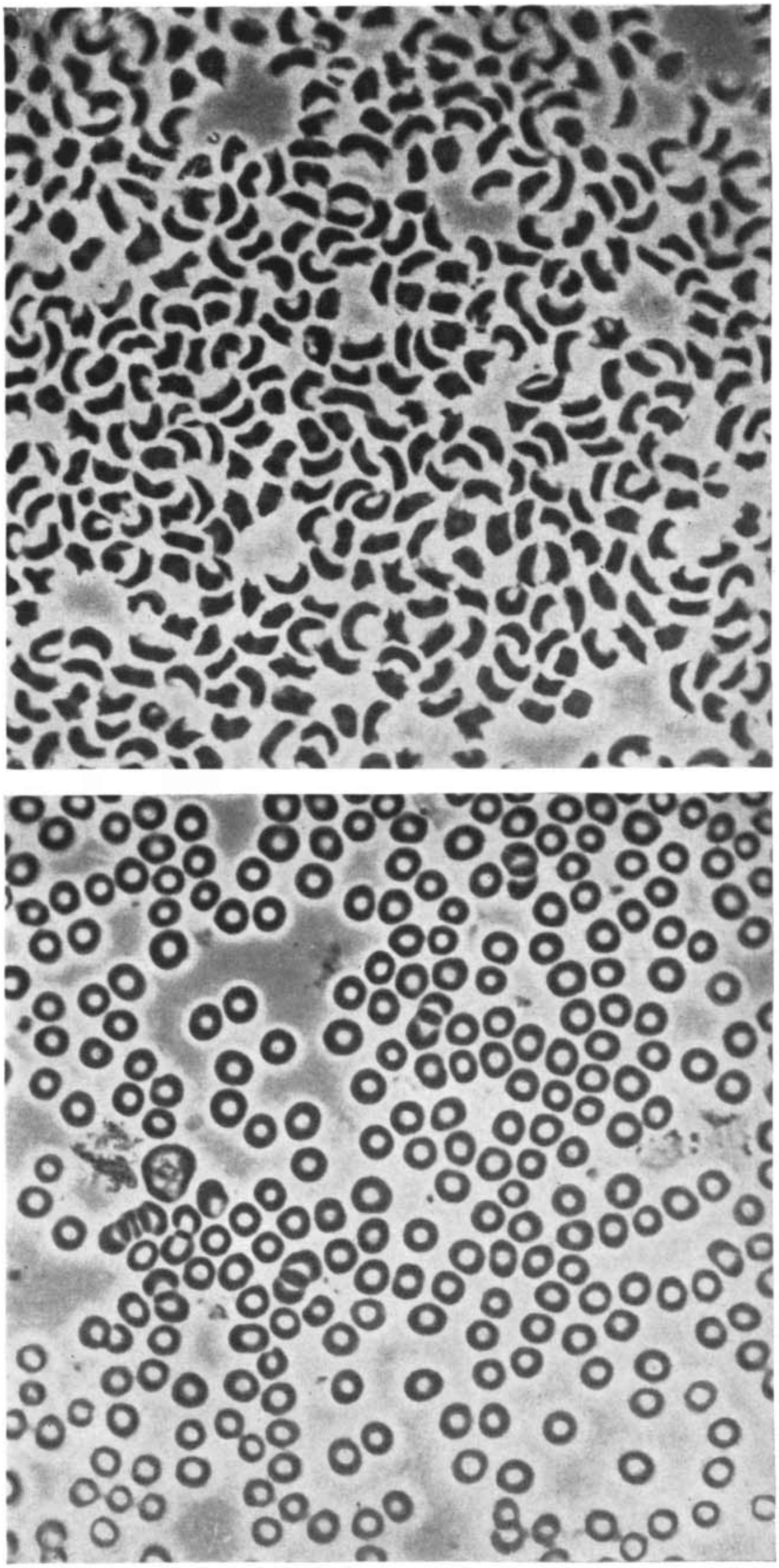
300 amino acid units, they should be much better in fragments consisting of, say, only 10 amino acids.

To break down the hemoglobin molecules we used trypsin, a digestive enzyme. Trypsin breaks an amino acid chain only at points where lysine or arginine occurs. Since the half-molecule of hemoglobin contains about 26 units of these two amino acids, we could expect to get about the same number of fragments. This proved to be the case: the molecule broke down to 28 fragments and a resistant "core" comprising about a quarter of the molecule. We removed the core in a centrifuge and proceeded to analyze the fragments—each a small group of amino acids, known as a peptide.

For this I employed a combination of electrophoresis and chromatography. First a drop of the solution containing the 28 peptides was deposited as a spot near the edge of a large sheet of moist filter paper. An electric current, passed along the edge of the paper, separated the fragments, for various peptides migrate at different speeds according to the electric charges they carry. There was now a line of spots, each consisting of several peptides. These were next separated by chromatography. The sheet was dried and hung so that the edge with the line of spots touched a liquid; as the liquid moved up the paper, the peptides of each spot migrated upward, again at different rates according to their constitution, and eventually each peptide came to rest as a distinct spot. The end result was a network of 28 spots on the paper, each representing a fragment of the broken molecule of hemoglobin. I call this map a "fingerprint" of the hemoglobin.

The next step, of course, was to compare the fingerprints of normal hemoglobin and the errant sickle cell form. They proved to be exactly alike in all respects except one: in the sickle cell fingerprint, one peptide (which I call the No. 4 peptide) was displaced slightly from the position it occupied in the normal fingerprint. The amount of displacement showed a difference in electrical charge similar to the difference between the whole sickle cell hemoglobin molecule and the normal one. We were therefore encouraged to believe that we were on the right track: that the entire difference between the molecules lay in this small fraction.

At this point I should interject that we have carefully analyzed the rest of the molecule—all the other fragments and the core—and we have been unable



RED BLOOD CELLS of an individual suffering from sickle cell anemia are enlarged 600 diameters in the phase-contrast photomicrograph at the top. Normal red cells are shown in the photomicrograph at the bottom. The distorted shape of the sickle cell is due to the fact that, when its defective hemoglobin molecules lose oxygen, they clump together in rods.

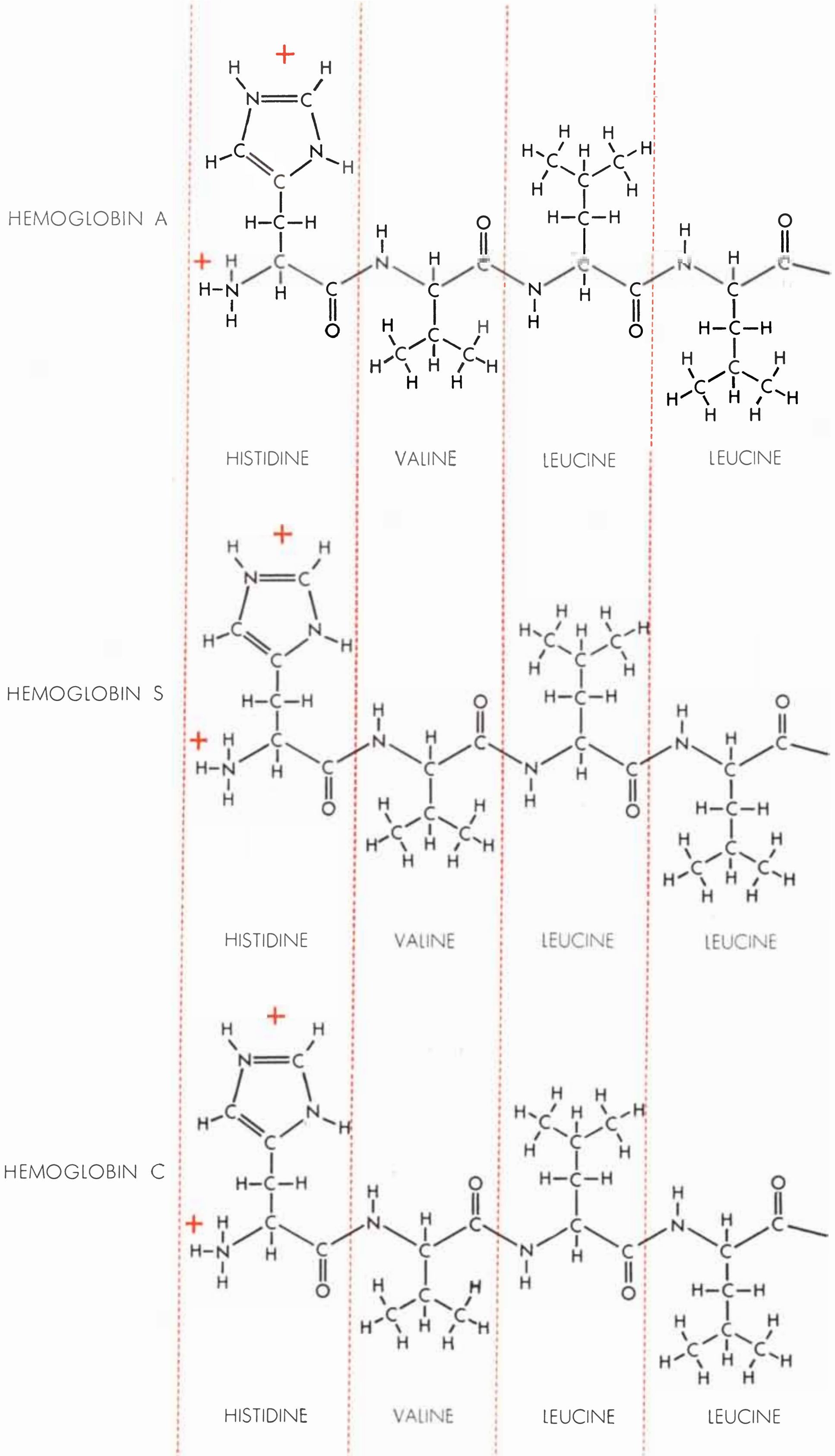
to find any difference between the normal and abnormal molecules in these other fractions. Whether these pieces are identical in structure cannot yet be decided, but they are the same in composition and it is reasonable to believe that they are identical in every way.

So peptide No. 4 became the center of our search for the chemical peculiarity in sickle cell hemoglobin. We now had to analyze the peptide, both in the normal and in the sickle cell molecule, to see what amino acids it was made of in each case. This was a very tedious business. We first had to purify the peptide, which involved cutting out the No. 4 spot on the paper, washing it off and running it again through the separation process of paper electrophoresis or chromatography. To get enough material for analysis we had to fingerprint dozens of batches of broken-down hemoglobin and purify their No. 4 peptides. Fortunately, with the very delicate methods of chemical analysis available nowadays a few thousandths of a gram of purified material was sufficient.

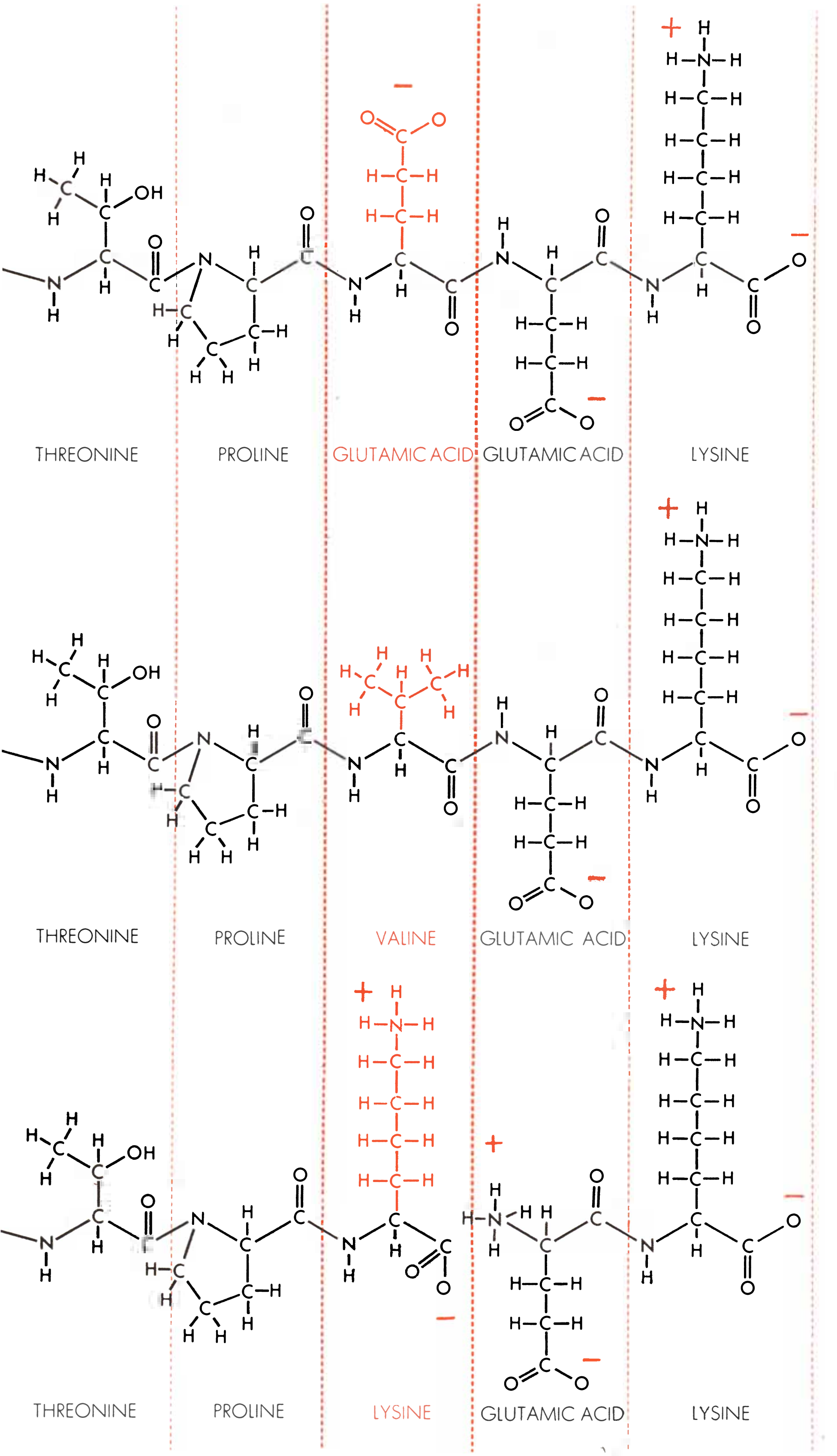
What did the analysis finally show? Both the normal and the sickle cell peptides turned out to contain the same types of amino acids: glutamic acid, valine, histidine, leucine, threonine, proline and lysine. But there was a difference in amount. The normal peptide had two glutamic acid units and a single valine, whereas the abnormal version had a single glutamic acid and a double dose of valine. In other words, in the sickle cell peptide a valine unit replaces a glutamic acid.

The next step was to find the order of arrangement of the amino acids in the peptide—a short chain of nine units. We broke the peptide down (this time with hydrochloric acid) into fragments consisting of from two to five amino acids. Step by step, sometimes peeling off one amino acid at a time, we determined the order of the amino acids in each fragment, and then we were able to fit the pieces together like a jigsaw puzzle to learn the sequence in the whole peptide. Thus we established that in the sickle cell peptide a valine unit occupies the place of the usual glutamic acid in the seventh position of the nine-unit sequence [*see diagrams at the right*]. A glutamic acid unit has an electrical charge; a valine unit has none. This explains the difference in the electrical charges on the two peptides.

Thus it appears that we have tracked down the difference between the sickle cell hemoglobin molecule and the normal one. According to all our evidence,



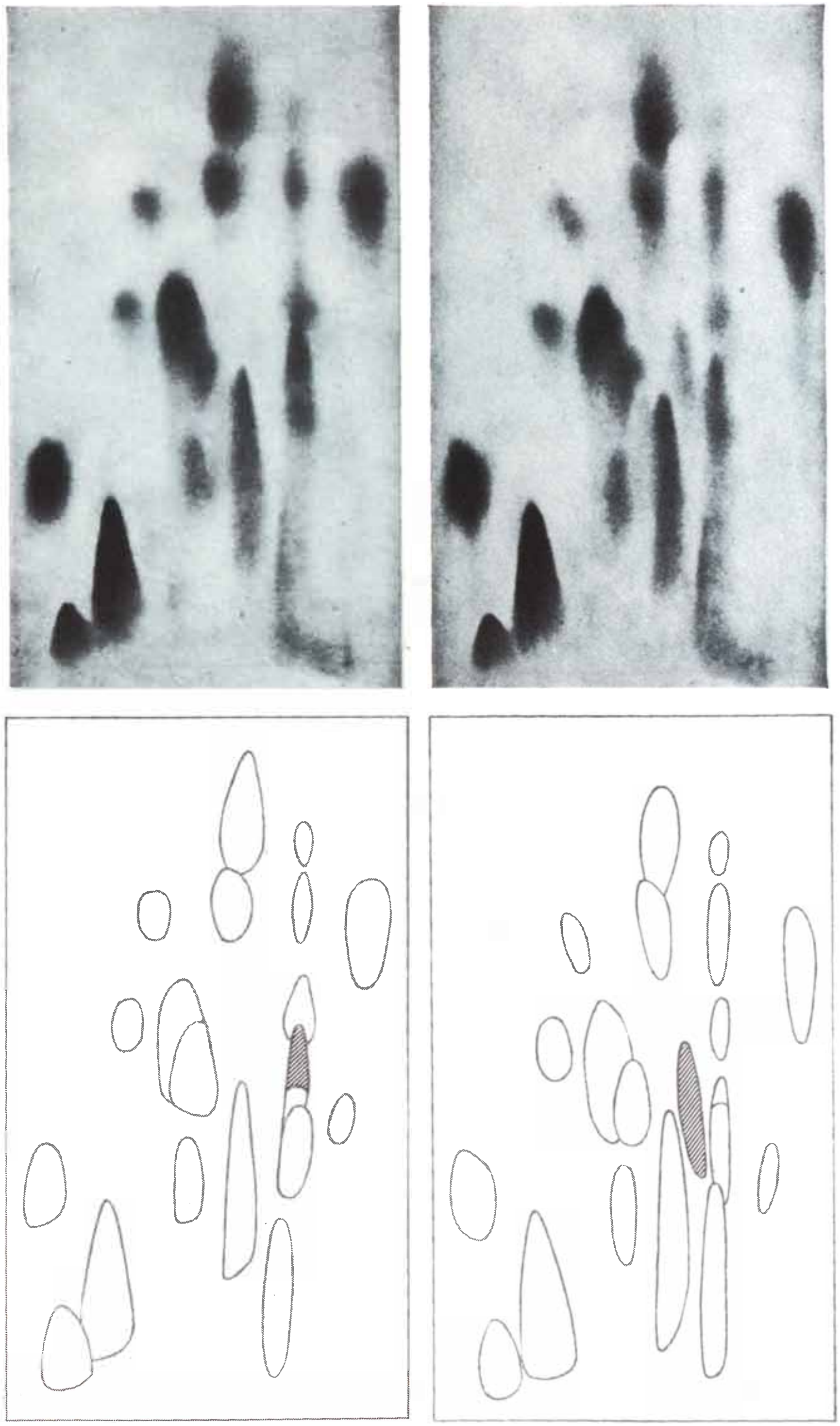
SHORT SECTION of the normal hemoglobin molecule (hemoglobin A) is depicted in the molecular diagram at the top of these two pages. The amino acid units of the molecule are set off by the vertical colored lines. The name of each amino acid is given below the diagram. The corresponding section of hemoglobin S, which is found in individuals suffering from sickle cell anemia, is second from the top. It differs from the normal molecule only in



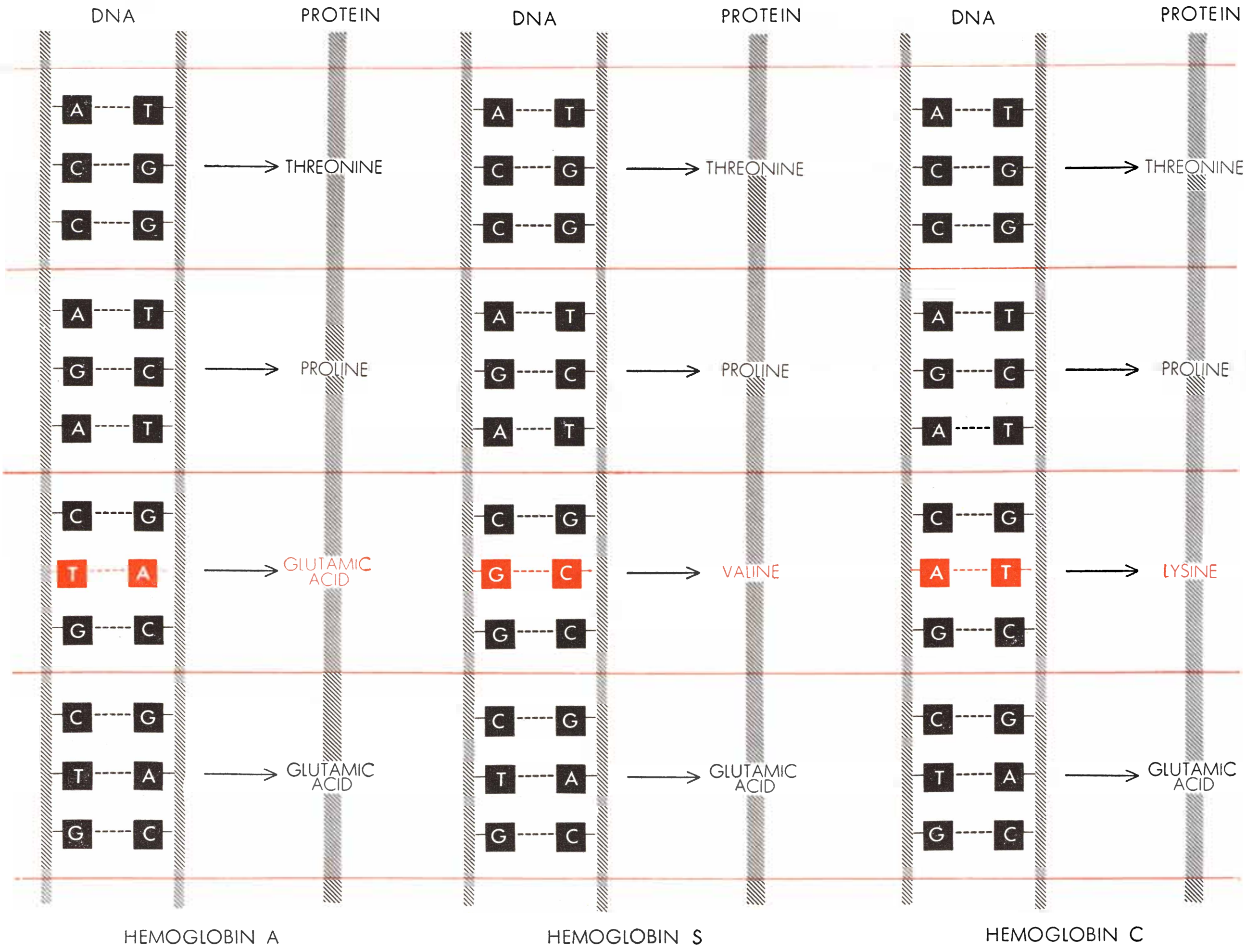
that a glutamic acid unit has been replaced by a valine unit. The same section of hemoglobin C, another abnormal form of the molecule, is at the bottom. It differs from the normal molecule only in that the same glutamic acid unit has been replaced by a lysine unit. The characteristic electric charge of certain groups of atoms in the chain is indicated by the colored plus and minus signs. The colored column here occupies the colored row on page 74.

the sole chemical difference is that in the abnormal molecule a valine is substituted for glutamic acid at one point. A change of one amino acid in nearly 300 is certainly a very small change indeed, and yet this slight alteration can be fatal to the unfortunate possessor of the errant hemoglobin. Equally remarkable is the fact that the sickle cell gene operates so delicately on the synthesis of a protein, changing just one amino acid and leaving the rest of the molecule's structure unaltered.

After I had worked through the sickle cell problem, my colleague John Hunt tackled another abnormal hemoglobin, known as hemoglobin C. This



"FINGERPRINTS" of fragmented hemoglobin were made by a combination of electrophoresis and chromatography. At top left is the fingerprint of normal hemoglobin; at top right, of hemoglobin S. The hatched spots in the diagrams show where they differ significantly.



HYPOTHETICAL SCHEME of how deoxyribonucleic acid (DNA) is related to hemoglobin A (normal hemoglobin), hemoglobin S and hemoglobin C is outlined. At the far left is a diagram of a short segment of DNA. The two chains of the DNA are joined by pairs of bases (*squares*). There are four bases: adenine (A), thymine (T), cytosine (C) and guanine (G). To the right of this diagram is a parallel diagram of the protein of hemoglobin A. The amino acid units of the protein are presumably related to segments of the DNA. In the mutated DNA which controls the synthesis of hemoglobin S and hemoglobin C the pairing of bases may be altered at one point (*shown by colored squares*). This might account for the difference in one amino acid of the three forms of hemoglobin.

deviant, rarer than the sickle cell form, was known to have parallel properties, and indeed there was genetic evidence that it derived from a mutation in the same part of the chromosome that is responsible for the sickle cell defect. Was it possible that the C gene altered the very same site in the hemoglobin molecule as the sickle cell gene? This seemed almost too pat to be true, but Hunt's chemical investigation fulfilled the expectation beyond all hope.

The fingerprint of hemoglobin C again showed a change only in the No. 4 peptide. But this time the abnormal peptide spot was not merely displaced but broke down into two separate spots. The chemical analysis showed why. It developed that in the hemoglobin C molecule the very same glutamic acid unit that gives way to valine in the sickle cell case is again replaced, this time by another amino acid—namely, lysine. Now lysine, as I have mentioned, offers a vulnerable point for splitting by trypsin. Thus the peptide I call No. 4 breaks into two at this point. There is a further significant fact. Whereas valine has no electrical charge, lysine does have one: it is positive. Since glutamic acid carries a negative charge, the substitution by positively charged lysine produces a greater electrical change in the molecule than occurs in the case of sickle cell hemoglobin.

The exciting point of these findings is that they demonstrate that we are apparently on the right track in our ideas about the mechanism of heredity. We can go on with more confidence to explore the possibilities raised by this work and the hypothesis it supports.

One question certainly calling for further study is why the change of a single amino acid alters the behavior of hemoglobin so drastically as to cause the severe sickle cell disease. We should also like to know more about changes brought about by other mutations of the hemoglobin gene or genes. Some elegant recent researches by Seymour Benzer of Purdue University have brought to light that a gene can mutate at 100 or more spots along its length. If we could correlate mutations at these spots with changes of the bases along the DNA molecule, and those changes in turn with a series of chemical alterations along the length of a protein molecule, we would be a long way toward understanding how heredity works. There is no way to make a systematic study of these matters with human genes, but it might be possible through experiments on microorganisms.

Dr. Charles P. Bean, B.A., University of Buffalo (1947), Ph.D. in physics, University of Illinois (1952), joined the General Electric Research Laboratory in 1951. As a member of the *Physical Metallurgy Section*, he has concerned himself primarily with studying the physical aspects of ferromagnetism.

The how and why of magnets

Dr. Charles P. Bean of the General Electric Research Laboratory contributes new understanding to an age-old problem of science

Magnetism, which amazed and confounded the early Greek philosophers, has been shorn of much of its mystery, but enough questions remain unanswered to hold the attention of many leading physicists throughout the world. One recognized authority on magnetism is Dr. Charles P. Bean, who describes his past work at the General Electric Research Laboratory as learning *how* things magnetize and his present interest as learning *why* materials are magnetic.

Dr. Bean's interests, past and present, have led him to the investigation of magnetic effects near absolute zero, theoretical studies of new magnets made from submicroscopic iron particles, and new observations of magnetic behavior in whiskers of "perfect" metal.

Through this and other work, he has helped establish important new understanding of the character and motion of *magnetic domains* — regions in which atoms, each one an elemental magnet, are all lined up in the same direction.

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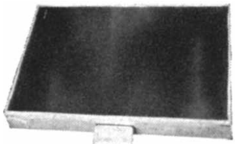
The long and the short of it ... a primer on optimum heating methods

Take a white-colored object and place it near an infrared lamp with a Kelvin rating of 2500°. Some *30%* of the radiant energy will be absorbed.

Next take an ordinary sheathed wire unit at 1000°K. The same object will absorb *70%* of the measurable output.

Now take a new PYREX® industrial radiant heating panel. It looks like this.



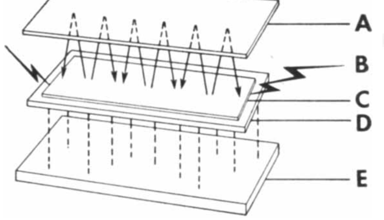
It operates at 600°K. and your white object will now absorb *90%* of the radiant energy.

Behind these differences lies the question of *wave length* emitted by each source. Infrared lamps peak at 1.2 microns; a sheathed unit like the one described hits 3. But the PYREX heater gives from 5 to 20 microns.

It's the *longer* wave lengths that make the difference. And *more* absorption means *more* effective heating per unit of energy expended.

These wave lengths offer you two distinct advantages: (1) all colors will absorb nearly the same amount of them—this means even heating regardless of color and (2) all colors will absorb these waves much more readily than they will the short wave lengths of lamps or sheath wires. With white colors, the absorption is greater with panels than lamps by a factor of nearly 4 to 1.

PYREX industrial radiant heaters have as their heart a panel of tempered *glass* that has a fused-in coating of thin conducting film. The panel is mounted in an aluminized steel frame. A self-contained unit, each heater comes with built-in aluminized steel reflector, mounting hangers, junction box and leads.



A. Reflector—aluminized steel
B. Electric current
C. Resistance element—conductive film
D. Heating element—tempered glass
E. Work—*all* materials except metallic reflectors

Because it's tempered the glass panel is *rugged;* it also is extremely corrosion resistant. Maintenance is a negligible factor since occasional dusting with a dry cloth is sufficient. If needed, heaters can be cleaned when cold by rubbing gently with a soft rag lightly dampened with alcohol.

PYREX radiant heating panels come in 8 different models, the smallest 11⅝″ square, the largest 23⅝″ square. (Note: rectangles are included in this selection.)

Watts per square inch go from 5.4 to 9.5 and the element itself (when measured in ambient air at 70°F.) runs from 550°F. to 660°F.

Heaters can be mounted horizontally, above *or* below work; vertical installations also possible and practical.

The heat you get from such units is *uniform* (because it's an *area* source) and *effective* (because of its *long* wave).

PYREX radiant heaters look like a real "hot" answer for drying, baking, curing, preheating—just about any application where you want to put the *heat* on and get the most for your investment in space and kilowatts.

Bulletin PE-60 gives the salient data on construction, installation, ventilation, wiring and controls, and maintenance. There's also a full story on where to get and how to use the Corning "Process Prover"—a "pilot" setup complete with percentage timer, pyrometer, variable table and such. PE-60 is free. Using the coupon facilitates matters.

15 gets you 75

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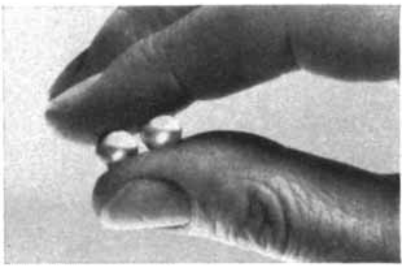
Take a few minutes to glance through "This Is Glass" for a sprightly review of this growth. Or brief your problem and let us see if we can't come up with a *glass* answer.

Rounding out the line

Possibility: Some day the writing tip of your ball point pen may be made of glass. *Certainty:* In sizes somewhat larger than those useful for such a purpose, glass balls are available *now* and in *quantity.*

Before final grinding and polishing they look like this.



Since a number of other materials have long been available in sphere form, this news may not appear so startling.

Still a number of considerations that may interest you are involved. First—*Continuous* production of *optical* quality glass was accomplished—no mean feat. Then, Corning developed a *new*, high-speed machine for forming small diameter glass balls.

With this machine now in operation, the following specifications pertain:

Basic data on glass balls

Diameter range	.133″ min.
	.425″ max.
Diameter tolerance .	±.012″
Sphericity of ball within	.008″

What can you do with bits of glass like this? So far interest has been evidenced for using them in finger tip spray dispensers, for hand lotions and cosmetics, valves for blood transfusion and oxygen equipment, and hydrolytic controls.

Corrosion resistant, small, noncontaminating, nonmagnetic, capable of taking a fine finish—glass balls await your evaluation.

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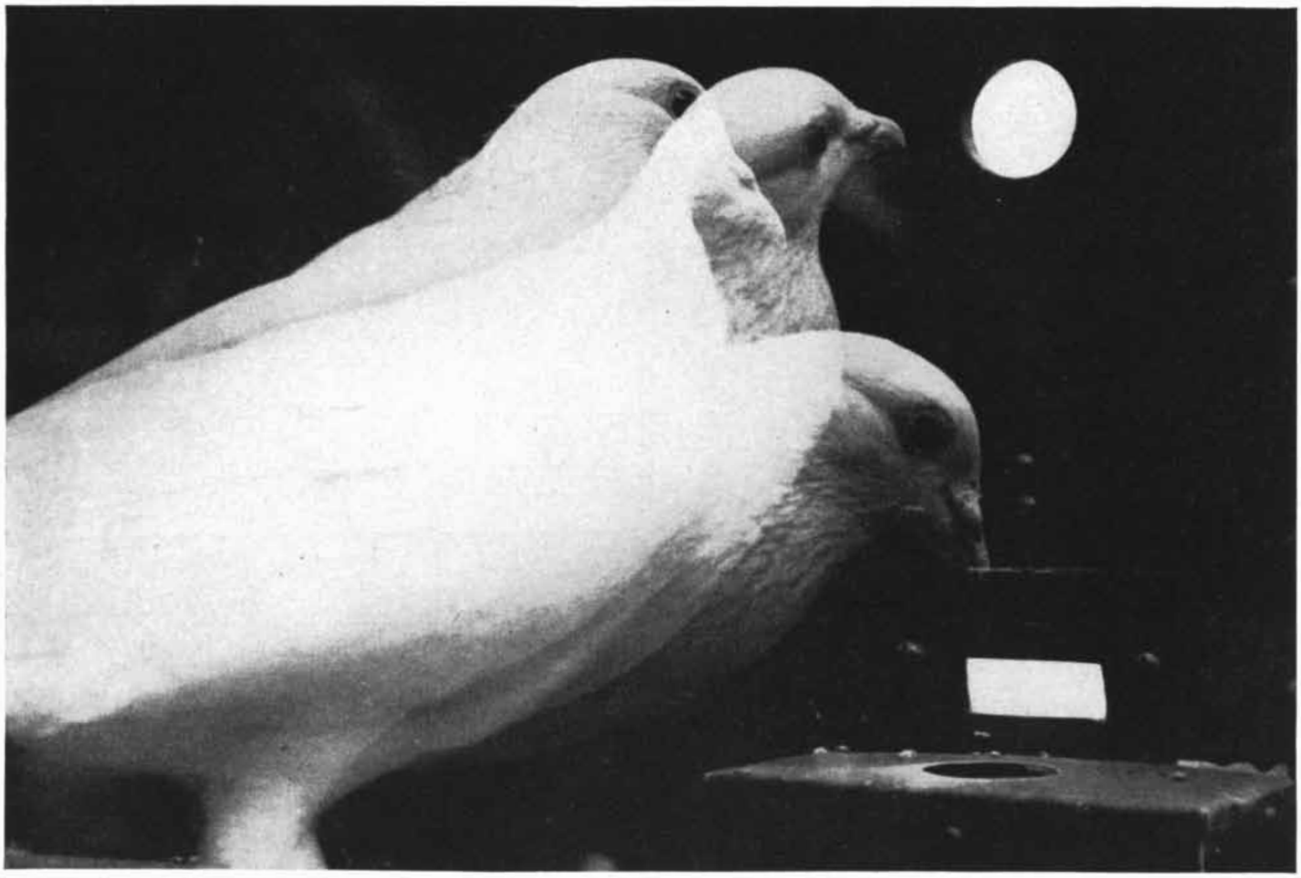
EXPERIMENTS IN DISCRIMINATION

A pigeon can be trained to peck when a light of a certain wavelength is flashed. It will also peck at lights of other wavelengths, but at a rate which declines in proportion to the difference in wavelength

by Norman Guttman and Harry I. Kalish

When you trade in your car for a new model, you do not need to take a refresher course in driving. The new car may have a different feel and call for somewhat different control motions, but as an experienced driver you easily adjust your training to the new situation and quickly come to operate the car with your usual skill. This is a simple case of "transfer of learning." But the nature of the transfer process is far from simple. Generations of psychologists have found it a thorny subject, full of disappointments and surprises. Often learning does not carry over where we might expect it to. Training received in the classroom may be of little avail in the factory or the office; the camp soldier may prove helpless in combat; the lessons learned on the playing fields of Eton have been known to fail in the Sudan. On the other hand, learning sometimes extends to unexpected areas in unexpected ways. This article will report some experiments that have cast interesting new light on the generalization of learning.

The particular transfer phenomenon that we have been studying is called "stimulus generalization." The term means that a learned response to a specific stimulus carries over to a whole class of similar or related stimuli. A child



PIGEON trained by Guttman and Kalish is shown in this multiple-exposure photograph. When a colored light appears in the transparent disk (*top*), the pigeon pecks at the disk. Once a minute, on the average, the food box (*bottom*) opens to reward a response.

seeing a group of nuns approaching in the street exclaimed: "Mommy, see the penguins!" This is a graphic illustration of stimulus generalization. (The class of "penguins" also includes, of course, men in formal dinner dress.)

The great physiologist Ivan P. Pavlov was the first to recognize and study stimulus generalization as a measurable phenomenon. In the course of his famous experiments on conditioned reflexes in dogs, he discovered that a dog which had been conditioned to salivate when a vibrator was applied to a point on its thigh would also salivate, though less copiously, when the vibrator was touched to other points on its skin. The response declined in a regular gradient from the conditioned point on the thigh: the farther from this point the vibrator was applied, the fewer drops of saliva the dog emitted.

The late Clark L. Hull of Yale University, with his co-worker Milton J. Bass, verified Pavlov's finding and extended the experiments to human subjects. They worked with the galvanic skin reflex—a momentary decrease in the skin's electrical resistance in response to stress (it is used in lie-detection machines). Almost any intense stimulus will produce this response. Using Yale undergraduates as subjects, Hull and Bass conditioned them so that a vibrator applied to the shoulder or the calf of the leg evoked the skin reflex, and then they tested the effect of vibrations at other points on the body. As in the experiments on dogs, the response diminished in intensity with distance from the original point of stimulation.

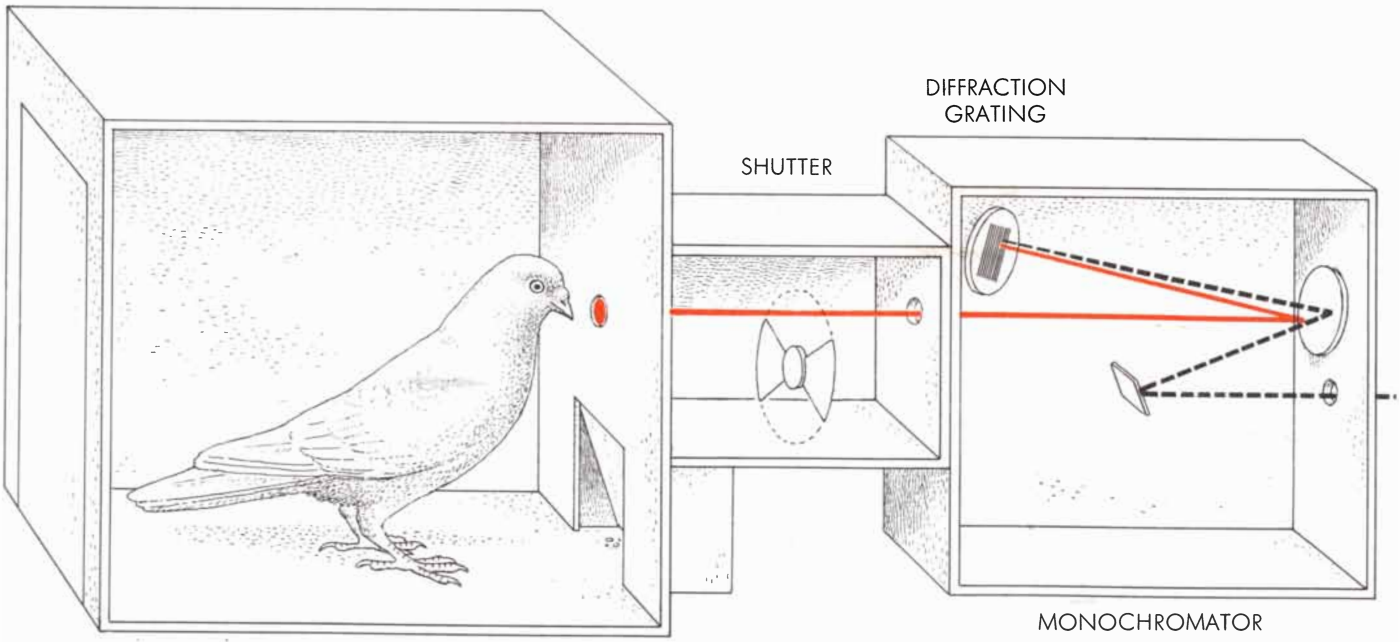
Later Carl I. Hovland of Yale and a number of other experimenters explored various stimuli and showed that there was a graded generalization of response to sounds and to visual stimuli—the response declining with changes in the pitch of the sound or in the brightness or size of the visual object.

Why the nervous system behaves in this way is still a mystery. Pavlov suggested the theory that when a stimulus excites its receptive center in the brain, the excitation spreads over the cerebrum, so that other portions of the brain respond to related stimuli in the same way as the stimulated point. But this idea fell to the ground when it was found that conditioning could be established successfully in animals whose cerebral cortex had been removed, and even in species of animals possessing no cerebrum at all. Nowadays psychologists are extremely cautious about speculating on the physiology of learning. They prefer the "black box" approach: put in a stimulus or put in training and see what comes out in behavior. They believe that studies of this kind will provide clues for finding out what happens inside the black box (*i.e.*, the nervous system).

Our group at Duke University decided to pursue the investigation of stimulus generalization with the spectrum of light as the testing instrument. If you condition an animal to respond to a certain wavelength of light, how far will its generalization of the stimulus extend from that wavelength? Generalization should certainly work within a given color: conditioned to respond to a deep green, say, the animal can be expected to respond also to a yellower green. But will it jump the dividing line between one color and the next—say from green to yellow? This seemed not very likely. Here discrimination might be expected to take the upper hand over generalization: the difference would seem greater than the kinship. If it is true, as many psychologists believe, that discrimination is the enemy of generalization—the less you can discriminate, the more you generalize—then generalization should stop more or less abruptly at the borders of the colors.

For our subject we chose the pigeon. This animal's ability to distinguish colors resembles man's. It is easy to train, and it clings to its trained behavior. Instead of Pavlov's conditioning method, we use the sensitive and powerful training technique developed by B. F. Skinner of Harvard University [see "How to Teach Animals," by B. F. Skinner, SCIENTIFIC AMERICAN, December, 1951; and "Pleasure Centers in the Brain," by James Olds, October, 1956].

We first train the pigeon to peck at light of a certain wavelength, presented in the form of an illuminated disk. The food reward for pecking the disk is given

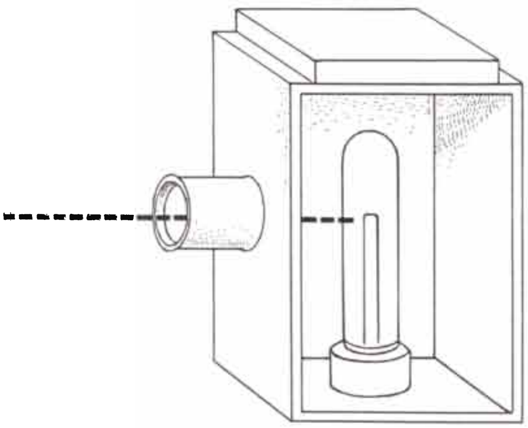


EXPERIMENTAL APPARATUS (similar to that in which the bird appears on the preceding page) is shown in this schematic drawing. The color of the light seen by the pigeon is changed by tilting the diffraction grating with respect to the beam of light.

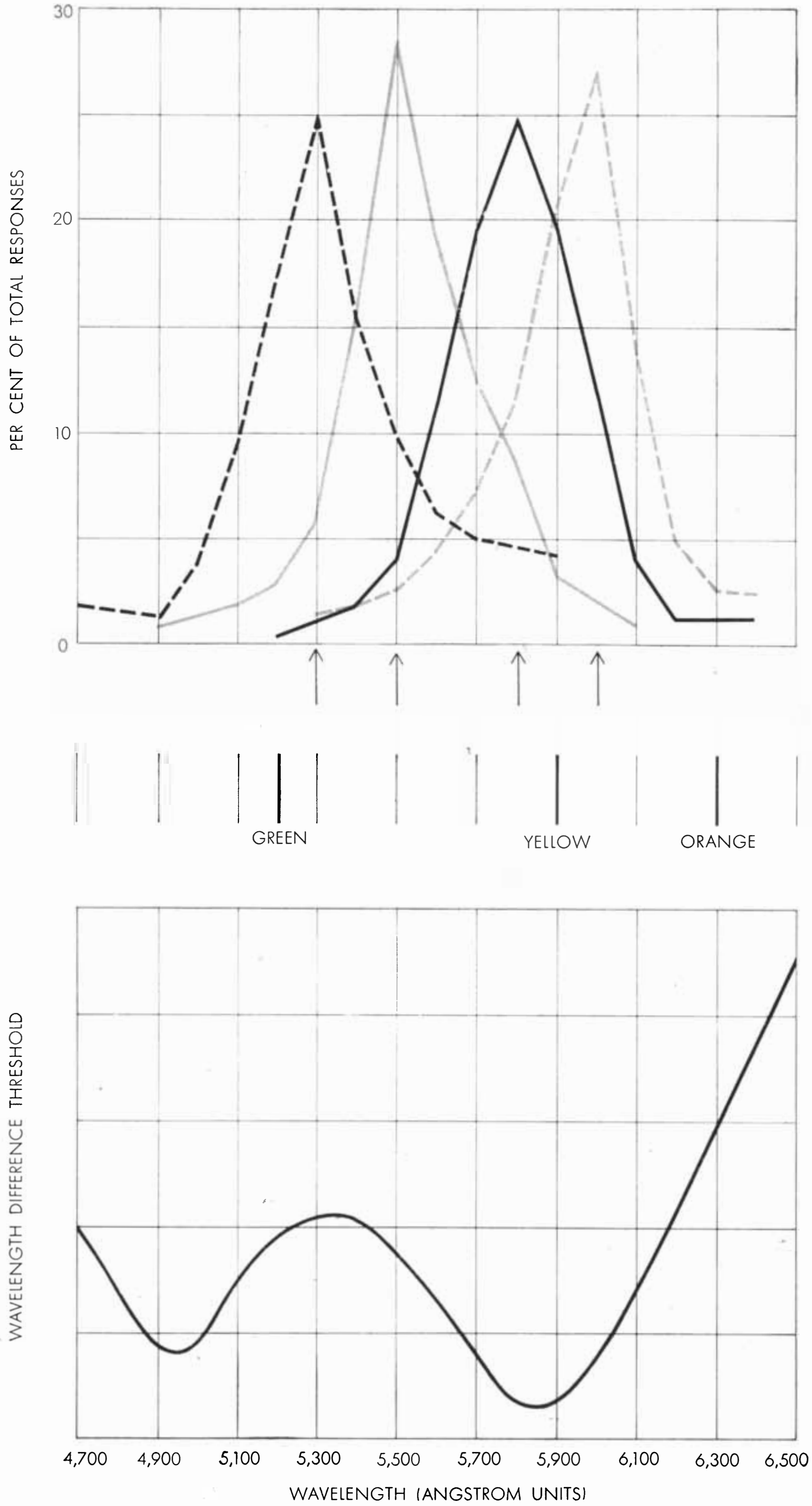
not for each response but on an irregular schedule, controlled by an automatic device which gives food for one response in each minute on the average. The main reason for this system is that we do not want the bird to "expect" a reward for every response, because that would interfere with the later generalization tests. Paradoxically, the irregular reward method produces an extremely eager response by the pigeon. After a few hours of training the bird pecks steadily at the rate of 4,000 to 6,000 times per hour! What is especially important for our purposes, the response persists strongly when we stop giving the reward. The pigeon continues to peck for several hours, at a slowly declining rate. During this period we can carry out extensive generalization tests.

A test consists in presenting the pigeon with monochromatic light at 10 or 12 wavelengths other than the one to which it was trained to respond. The test stimuli are distributed over a considerable range of the color spectrum. If, for instance, the bird was trained to a green at the wavelength of 5,500 Angstrom units, it may be tested on wavelengths ranging from 4,800 Angstroms (blue) to 6,200 Angstroms (orange). These are presented in random order. The whole series of wavelengths is repeated a dozen times, each time in a different order. The bird's response to each disk is measured by its rate of pecking.

When we tabulated the performances



The shutter enables the experimenter to black out the light while changing colors.



RESPONSES OF PIGEONS to wavelengths other than the one to which they have been trained to respond are related to the difference in wavelength and not to variations in the sensitivity of the pigeon's eye to various wavelengths. The curve at bottom shows this variation in sensitivity. Above this curve are the colors related to the wavelengths below it. Each of the four curves at top shows the responses of a pigeon trained to peck at the flash of a light of the wavelength at the top of the curve (*arrows*). The pecking responses of the pigeons to light of other wavelengths fall off regularly with the difference in wavelength.

of our pigeons on these tests, the results were not what we expected. In spite of the fact that the wavelengths had been shown in random order, the birds responded in a remarkably regular pattern according to the distance of each wavelength from the stimulus used in training. The curve of response was quite orderly: fast pecking at wavelengths close to the training stimulus, diminishing rates of pecking at more distant wavelengths [*see upper chart at the left*]. It was as if the pigeons were equipped with a frequency analyzer, accurately identifying each wavelength. In other words, they possess something like absolute pitch in the visual spectrum.

Even more remarkable, the curve of response crosses color boundaries without faltering. There is no abrupt drop in response as the curve passes from one color to another. And this is true no matter where in the spectrum the bird is tested: if it is trained in the green, the curve slopes down smoothly from green through yellow to orange; if it is trained to orange, it shows the same smoothly declining gradient back through yellow to green. Like a mechanical frequency analyzer, the bird appears to recognize wavelengths entirely without reference to color. Its performance is especially puzzling because experiments have shown that the pigeon, like man, can distinguish hues more sensitively in some parts of the spectrum than in others. Yet this varying capacity for discrimination does not affect the animal's stimulus generalization: throughout all regions of the spectrum in which it has been tested, it is uniformly guided only by wavelength. These findings have led us to believe that generalization and discrimination may not be simple opposites, as commonly supposed.

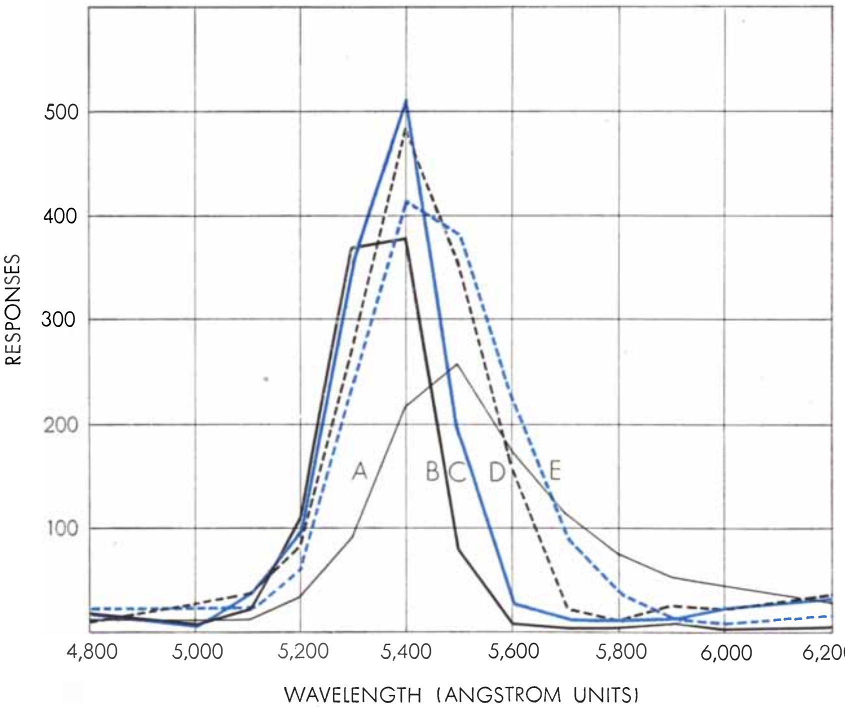
Harley M. Hanson of our laboratory has made an extensive investigation of how training in discrimination affects generalization. He trained pigeons to peck at one wavelength and to refrain from pecking at another. When this discrimination had been established, he tested their generalization of the positive stimulus and found that the curve of response was displaced away from the negative stimulus. The pigeon actually pecked at the highest rate at a wavelength different from the one to which it had been trained—that is, farther away from the negative stimulus. The size of this shift depended on the distance between the positive and negative stimuli. If the difference between them was 400 Angstroms, the peak shifted 50 Angstroms. If the two wave-

lengths between which the pigeon had been taught to discriminate were only 50 Angstroms apart (a very difficult discrimination which may take the pigeon as long as 10 hours to learn), the peak response shifted much farther away from the negative stimulus—about 150 or 200 Angstroms. In short, the pigeon's training in discrimination had not only extinguished a response but also enhanced its response to a new range of stimuli.

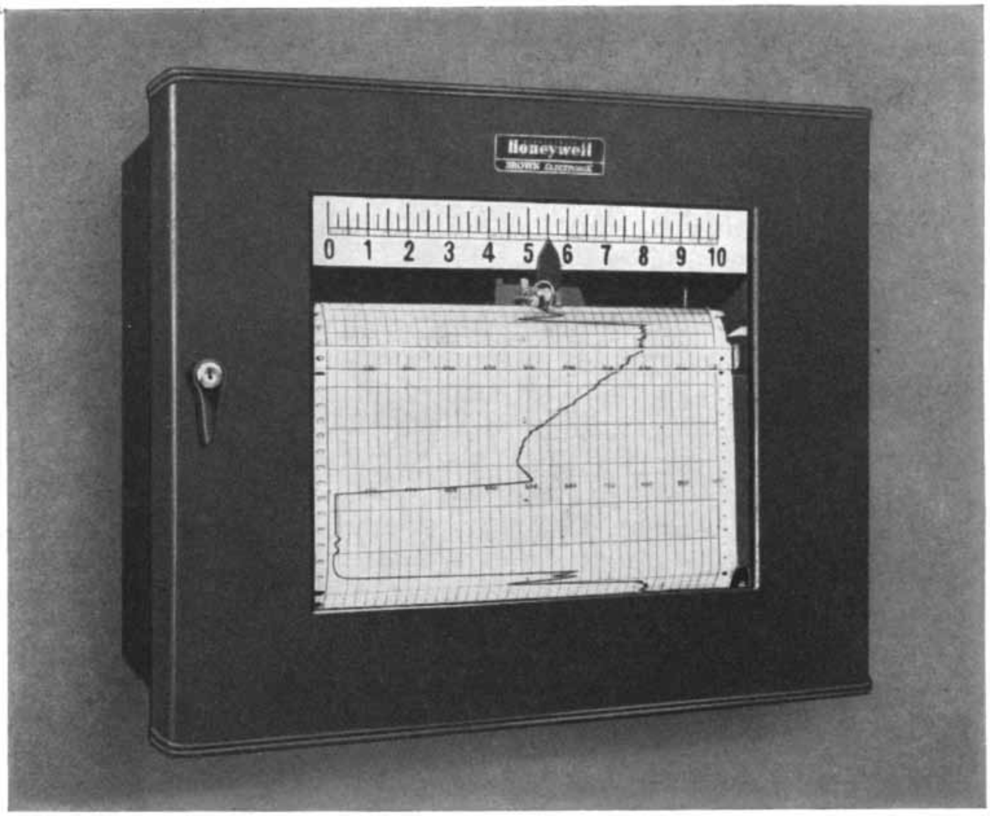
W. K. Honig of our group explored another question. What would happen if a trained pigeon was presented with a choice between two wavelengths shown at once (on separate disks)? Would it peck only one—the one closer to the wavelength at which it had been trained? Or would it peck both, giving more of its attention to the closer than to the farther one? Honig's pigeons took the latter course. They pecked both disks but pecked faster on the closer wavelength, in exactly the same ratio of preference as when the disks were presented at separate times.

One of our most important findings has to do with the intensification of the pigeons' responses with training. We found that as a pigeon's response to the conditioned stimulus increased, its response to the associated stimuli increased in the same ratio. For example, if its rate of pecking at the training wavelength rose from 20 to 40 times per minute, its rates for the other wavelengths also doubled. This simple multiplicative relation, first suggested by Hull in the general theory of behavior that he formulated 15 years ago, indicates that we are dealing with a fundamental property of behavior. It may have an important bearing on human conduct.

Neal E. Miller, the Yale psychologist, has suggested that intensification of drives such as hunger, fear or sexual excitement may heighten generalization and extend its range. Indeed, there is reason to believe that stresses of many kinds may have this effect in a multiplicative fashion. Under these circumstances a person would show exaggerated reactions to stimuli which ordinarily would evoke little or no response. In extreme cases the individual's responses would become so generalized that he would react indiscriminately to virtually all the stimuli in his environment, and go over to the bizarre reactions of the psychotic state. Thus stimulus generalization may be a useful concept in the study of psychopathology, as it is in investigations of normal learning processes.



DISPLACED CURVES of generalization are shown for pigeons taught to discriminate negative stimuli from a positive stimulus (a light of 5,500 Angstrom units). The curve of pigeon A (a control) was not displaced. Pigeon B, whose negative stimulus was 5,550 Angstrom units, has a curve displaced far to the left; C (*solid colored line*), D and E (*broken color*), with negative stimuli farther to the right, did not displace so far to the left.



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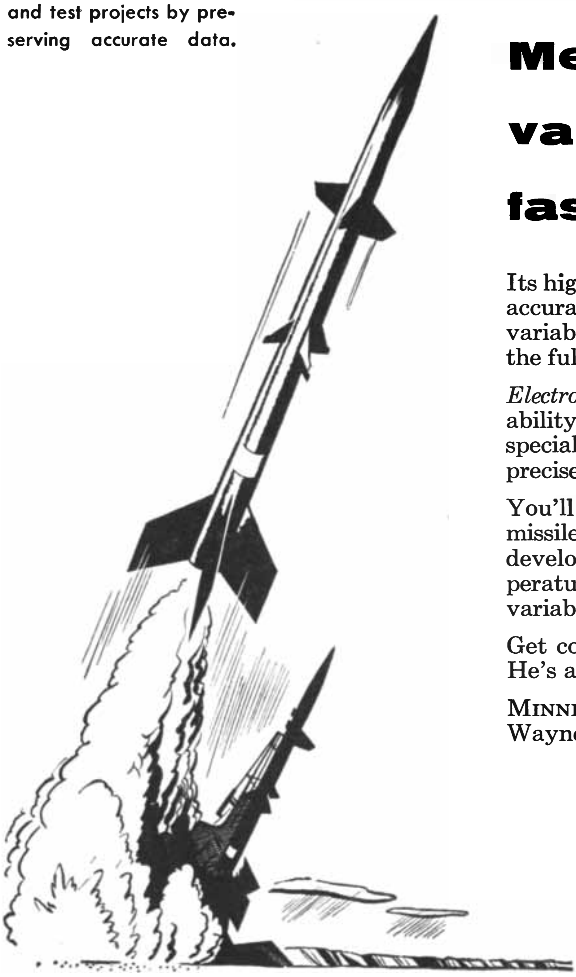

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WHALES, PLANKTON AND MAN

The whale feeds its enormous bulk by sifting out tons of tiny crustaceans from the ocean every day. More studies of whales and what they feed on may help solve the human food problem

by Willis E. Pequegnat

Among the "whale statements" in the prefatory pages of *Moby Dick* we find a quotation from Obed Macy's *History of Nantucket* which reads: "In the year 1690 some persons were on a high hill observing the whales spouting and sporting with each other, when one observed; there—pointing to the sea—is a green pasture where our children's grandchildren will go for bread."

Many people who are actively concerned with mankind's food problem think it is high time we made the Nantucketer's prophecy good. Of course to bake literal loaves of bread from seaweed would take some doing. But the whale feeds upon the plants of the sea only indirectly (by eating small herbivorous animals), and what is food for whales could also be food for man. The whale bears compelling testimony to the abundance of the ocean pasture. The sea is estimated to be as productive of organic food, acre for acre, as the land. With 70 per cent of the globe covered by oceans, in the aggregate the sea must produce five to 10 times as much living matter as the land. Yet we take only 1 per cent of our food from this source. Considering that half the world population lives on the edge of starvation and that we must feed 100,000 additional mouths every day, the sea's food potential cannot be neglected much longer.

We could, to begin with, increase our harvest from the sea by more intensive fishing for the conventional game. But I want to propose here a new kind of fishing which could be far more productive. My proposal admittedly is based on some purely theoretical deductions. But even if these deductions are only partly borne out, we may be able to open up at once a vast source of palatable high-protein food.

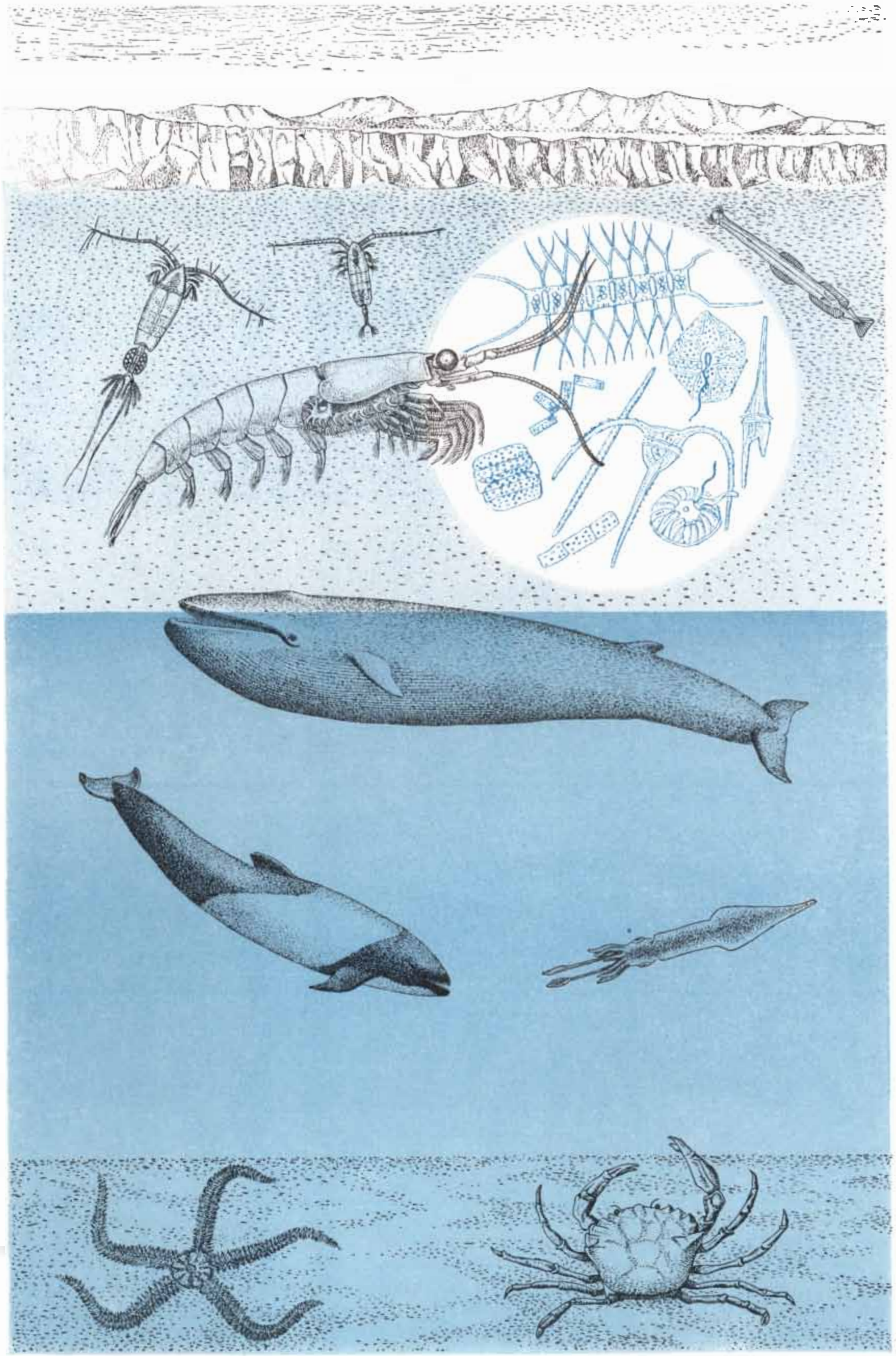
The whale's pasture is the upper, sunlit layer of the open ocean. The plant life of this zone consists mainly of microscopic floating organisms—the plants of the plankton. Principal among these plant organisms are the geometrically exquisite single-celled diatoms, housed in snowflakes of silica, and the whirling dinoflagellates, whose perpetual motion keeps them from sinking out of reach of the sunlight. These simple algae conduct the major portion of the photosynthesis that goes on in the ocean. They are the "grasses" of the sea. They synthesize carbohydrates, fats and proteins from carbon dioxide, sea water and certain nutrients. Under optimal conditions of light, temperature and nutrient supply, they may multiply to hundreds of thousands of cells per liter of water, clouding the water with a soupy "bloom"—yellow, green, red or brown, depending upon which species is dominant. At such times their prodigious capacity for multiplication becomes self-limiting, as they use up the supply of some critical nutrient or reduce the penetration of sunlight. More commonly the multiplication of the plant plankton is limited by the predation of the plankton animals that live upon it.

The smallest of these animals are single-celled protozoa which under the microscope look like tiny mollusks, encased in mineral shells of exotic design. The largest are wriggling crustaceans resembling small shrimp. Between these extremes of size is an endless variety of creatures, including the larval stages of many species of fish and of bottom-dwelling mollusks. Not all of these animals feed directly on the plants of the plankton; many of them prey on one another, the larger consuming the smaller. Finally the largest of the plankton animals are devoured by fishes, birds, seals and certain whales.

At each step in this food chain we must reckon with a considerable loss of organic matter. Only a small fraction of what an animal consumes goes to make up its substance. The rest is dissipated as energy in various forms, a large part of it being expended as mechanical energy in the creature's pursuit of its food. In general, 80 to 90 per cent of the organic matter is lost at each step. In the sea, as on the land, the hierarchy of predators forms a sharply narrowing pyramid. With 1,000 pounds of plant life at the base it shrinks to 100 pounds of animal plankton, then diminishes to 10 pounds of fish and is capped at its peak by only one pound of, say, sea lion.

Such calculation at once suggests that man might gain a great deal by short-cutting the food chain, perhaps going so far as to harvest the plant plankton directly. Except in a few regions, however, the plant plankton is too diffusely dispersed in the water. As a practical matter we need some animal to concentrate it for us. The ideal would be a plankton animal of appreciable size with a high rate of reproduction.

Now the whale makes exactly these requirements of its food supply. To achieve and maintain its huge bulk it must find its food close to the base of the pyramid. It is no accident that the most abundant species of whales, the baleen group, feed almost exclusively on a plankton animal. The baleen whales, among which is the blue or sulfur-bottom whale, the largest animal that has ever existed, are equipped with a mouth strainer, in the form of ingenious horny plates with fringed edges. When they scoop up their food in great mouthfuls of sea water, the strainer lets the plant plankton and small plankton animals escape but holds in the largest



FOOD RELATIONSHIPS among typical Antarctic ocean organisms are shown in this drawing. Plant plankton (*circle*) and the animal plankton which they nourish inhabit the sunlit upper layer. Swimming animals (nekton) include whales, porpoises and squid. Whales feed on krill (*top center*), porpoises on krill and squid. Benthic animals (crabs and starfish) inhabit the bottom (benthos); they feed on animal remains from the upper layers. Organic material is ultimately swept upward by currents to renew the cycle.

of them—a bright red, shrimplike crustacean named *Euphausia superba* and known to whalers as krill or whale food.

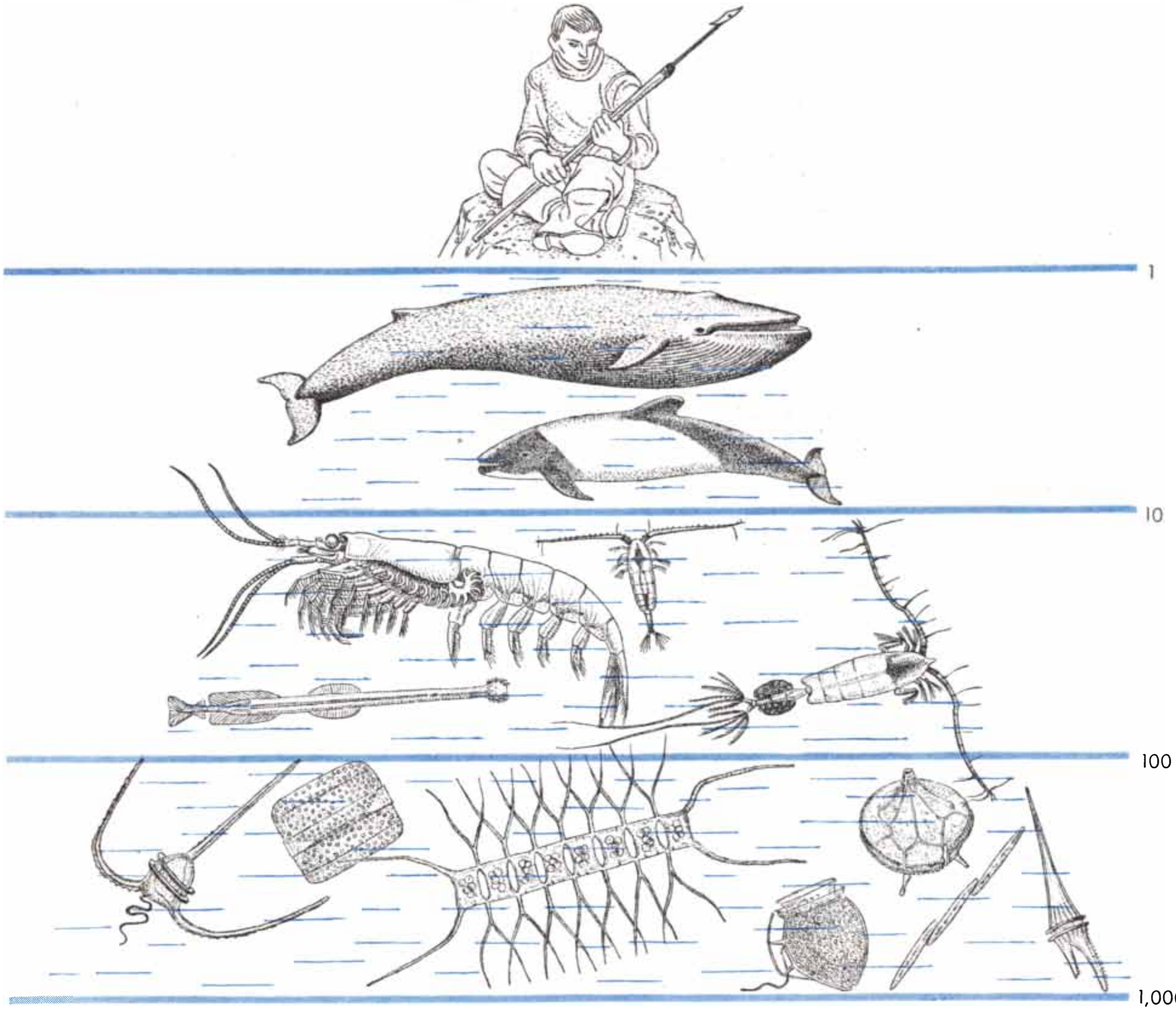
Krill is an admirable answer to the whale's food needs. In the first place, the animal is a herbivore, bringing the whale to within one step of the plant plankton. The crustacean has efficient equipment for collecting the tiny plants that serve as its food: its hind limbs sweep currents of water toward a net of hairlike bristles under the forepart of its body, where the plants are entrapped and then swept into the mouth. In the second place, the animal is large enough (up to two and a half inches long) and abundant enough to feed the whale's gigantic appetite.

In the Antarctic waters, where many baleen whales feed, krill grows in enormous quantity. Since it takes a good many krill to make a meal for a whale, it is fortunate that they live close to the surface and are easy to catch. Cousins of this crustacean in other oceans are found only at depths of several hundred feet. But krill confine themselves to a thin zone within about 30 feet of the surface. They swarm in shoals and windrows from a few square yards to half an acre in size. Sometimes they are so densely packed that they give a reddish hue to the water. Aggregations of such swarms may extend for hundreds of square miles. The whales browse in their midst, singly and in herds, consuming vast numbers of them. Yet despite the fact that krill is the principal or exclusive food not only of whales but also of some species of seals, penguins, many other oceanic birds and hordes of fishes, the creature maintains a huge population, breeding larvae all summer long.

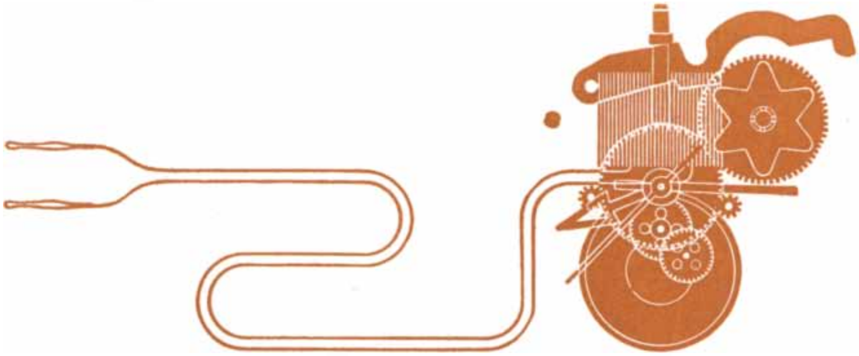
This plenteous animal surely deserves man's consideration as a possible food. To see whether it could fill the bill, we must answer several questions. Would it supply our nutritional requirements? Would people want to eat it? Is it abundant enough to give significant relief to the world food shortage? I have looked into each of these matters.

In connection with an entirely different line of study I had occasion to do a biochemical assay of krill. The animal proved to be fairly rich in protein and fats. It can be calculated that a pound of krill will yield at least 460 calories—about the same as other shellfish. The eyes of krill are unusually rich in vitamin A, a feature which might have by-product interest if the animal were fished on a large scale.

How palatable is krill? I happen to know of at least one occasion when people ate some krill (taking them from



SIMPLIFIED PYRAMID of Antarctic life begins with plant plankton (*bottom*) and ends with man. Energy loss at each step is about 90 per cent; 1,000 pounds of plant plankton produce 100 pounds of animal plankton, 10 pounds of whale and one pound of man.



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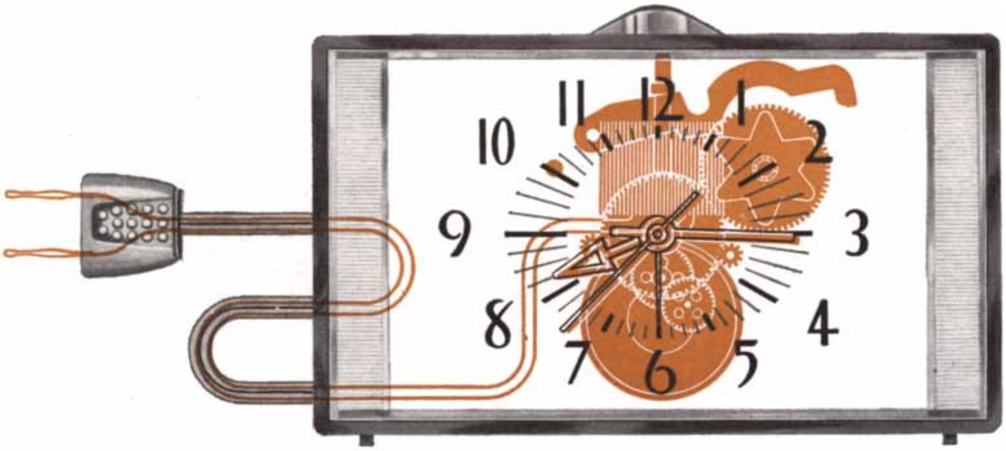

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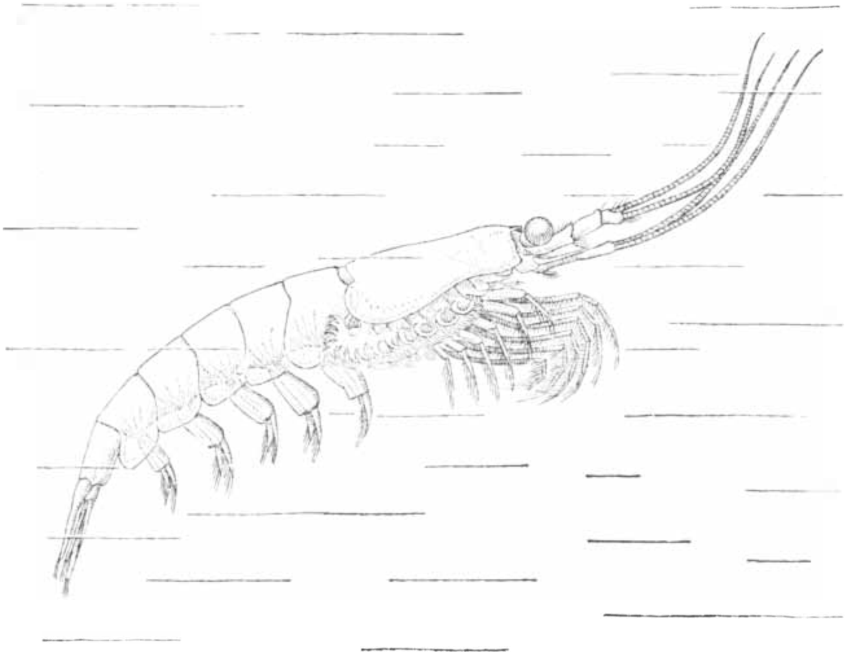


LOBSTER KRILL (*Euphausia superba*) is the largest of several related species consumed in enormous quantities by whales. Its forelimbs trap the plant plankton on which it feeds.

the freezer in my laboratory under the mistaken impression that they were shrimps). The consumers naturally were most uncommunicative, but I have reason to believe that the crustaceans were eaten with relish, and no untoward aftereffects were experienced. Their removal from the deep freezer can be taken also as a tribute to the appetizing appearance of these bright red animals.

As to their abundance in the sea, we must take an indirect census. Let us consult the whale, estimating its krill consumption from its energy requirements. I estimate, with advice from authorities on fluid dynamics, that an average-sized adult blue whale, weighing some 90 tons, develops about 10 horsepower when it swims at the moderate pace of four knots. (Whales have been observed to reach 12 knots easily.) Assuming that the muscles propelling the animal are about 20 per cent efficient in converting food into power, we can calculate that a blue whale needs about 780,000 calories per day for propulsion. To this we must add an energy allowance for maintenance of its body temperature and processes such as digestion and respiration. A rough estimate based on the whale's surface area puts this figure at 230,000 calories per day. The total so far, then, comes to more than a million calories per day. At about 460 calories per pound of krill, this means an average daily consumption of about 2,200 pounds—more than a ton of food.

We are not yet finished, however. During its growth period (*i.e.*, the first five years of its life) a blue whale gains at the average rate of 90 pounds per day. So a growing whale needs another 600 to 800 pounds of krill per day, raising the total to a ton and a half. Now we have to double this figure to arrive at the actual daily consumption, because we have reason to believe the blue whale feeds only half the year. For the winter it leaves its feeding grounds in the Antarctic and migrates north to more temperate waters. Whale authorities believe that the whale does not feed to any appreciable extent outside the krill range in the Antarctic Ocean but lives through the half year on stored energy. The grand total of a growing blue whale's food intake while it feeds is, then, about three tons of krill per day!

Now we are in a position to estimate how much krill the whale population as a whole may consume. To judge the highest potential we have to go back to 1910, before whalers began to cut down the whale herds in the Antarctic. The population at that time is estimated to have been half a million. Half a million whales consuming three tons of krill per day for six months gives a total of 270 million tons of krill per year. Since it is highly unlikely that whales harvest more than 20 per cent of the krill in any given area, the total annual production of krill must have been at least 1,350 million tons. On the 3.5 million square miles of feeding grounds this averages to about 1,000 pounds per acre.

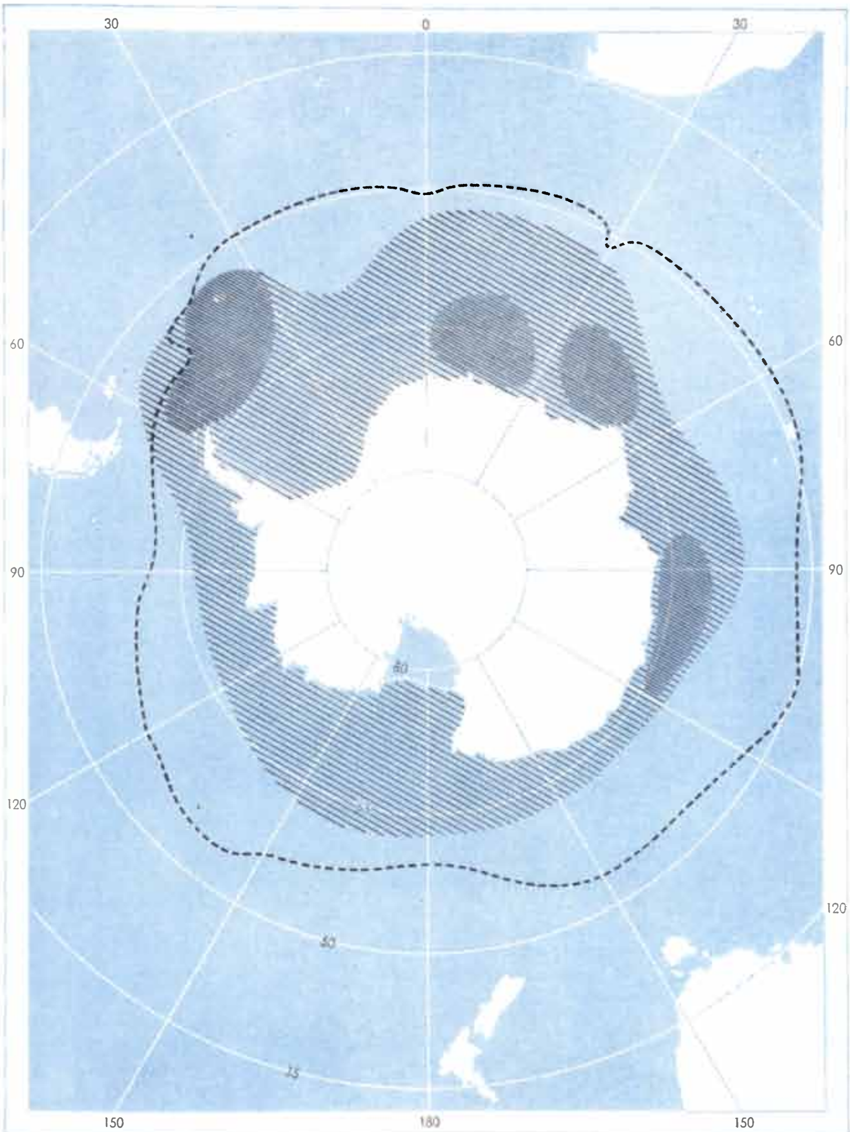
At that rate the krill crop in the ocean

bests the animal yield on land, for rich pasture land gives about 700 pounds of cattle and sheep per year. The comparison is apt, because these animals, like krill, are herbivorous, converting plants to meat. Krill is, by this token, a far more efficient producer of food than carnivorous fishes, which under cultivation in ponds yield only 100 to 250 pounds per acre per year.

The whale's example shows that we can reap vastly increased returns from the biological economy of the oceans. The 270 million tons of krill on which the Antarctic whales fed in their heyday would be more than enough to supply the annual requirements of the entire U. S. population.

There are growing indications that krill may be a timely subject. Some 250 ships and 16,000 men—the largest whaling fleet in history—are now operating in the Antarctic Ocean. They depend mainly on the fin whale. If and when this species follows the blue and humpback whales into near-extinction, whalers may find it worth while to turn their attention to krill. My own calculations, based on operating costs of ships, processing costs and a likely market price for krill, indicate that even today krill-trawling might be more profitable than whaling.

We ought to begin a scientific exploration of this promising possibility in the Antarctic Ocean. A pilot project in krill-fishing would enable scientists, engineers and businessmen to join hands in a project which would not only advance knowledge but might also develop a valuable source of food.



DISTRIBUTION OF KRILL around Antarctica in summer is shown by shading; heavier shading denotes denser concentrations. The broken line surrounds the "Antarctic convergence," within which upwelling nutrients support a luxuriant growth of plant plankton.

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58	CeO_2. CERIC OXIDE	215 216	99.8 99.9	0.2 (largely La + Pr + Nd). 0.1 (largely La + Pr + Nd).
59	Pr_6O_{11}. PRASEODYMIUM OXIDE	726 729.9	99 99.9	1 La + Nd + smaller amounts of Ce and Sm. 0.1 Ce + Nd.
60	Nd_2O_3. NEODYMIUM OXIDE	628 629 629.9	95 99 99.9	1-4 Pr, 1-4 Sm, 0.5-1 others. 0.1-0.4 Pr + 0.1-0.4 Sm + 0.5 others. 0.1 (largely Pr + Sm).
62	Sm_2O_3. SAMARIUM OXIDE	822 823	99 99.9	0.2-0.7 Gd, 0.2-0.6 Eu, and smaller amounts of others. 0.1 (largely Nd + Gd + Eu).
63	Eu_2O_3. EUROPIUM OXIDE	1012 1011	98-99 99.8	1-2 Sm + smaller amounts of Nd + Gd + others. 0.2 (largely Sm + Gd + Nd).
64	Gd_2O_3. GADOLINIUM OXIDE	928.9 929.9	99 99.9	1 Sm + Eu + trace Tb. 0.1 Sm + Eu + trace Tb.
65	Tb_4O_7. TERBIUM OXIDE	1803 1805	99 99.9	1 Gd + Dy + Y. 0.1 Gd + Dy + Y.
66	Dy_2O_3. DYSPROSIUM OXIDE	1703 1705	99 99.9	1 (largely Ho + Y + Tb + small amounts of others). 0.1 Ho + Y + traces of others.
67	Ho_2O_3. HOLMIUM OXIDE	1603 1605	99 99.9	1 (largely Er + Dy + small amounts of others). 0.1 Er + Dy + traces of others.
68	Er_2O_3. ERBIUM OXIDE	1303 1305	99 99.9	1 Ho + Dy + traces Yb and Y. 0.1 Ho + Tm.
69	Tm_2O_3. THULIUM OXIDE	1405 1403	99.9 99	0.1 Er + Yb + trace Lu. 1 Er + Yb + trace Lu
70	Yb_2O_3. YTTERBIUM OXIDE	1201 1202	99 99.9	1 Er + Tm + trace Lu. 0.1 Tm + trace Lu + Er.
71	Lu_2O_3. LUTETIUM OXIDE	1503 1505	99 99.9	1 Yb + Tm + traces of others. 0.1 Yb + Tm + traces of others.
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MATHEMATICAL GAMES

A collection of tantalizing fallacies of mathematics

by Martin Gardner

A mathematical paradox can be defined as a mathematical truth so startling that it is difficult to believe even after every step of its proof has been verified. Mathematical fallacies are equally astonishing assertions, but unlike mathematical paradoxes their proofs contain subtle errors. Every branch of mathematics, from simple arithmetic to modern topological set theory, has its share of these counterfeit arguments. The better ones are of course those with the most incredible conclusions and the best-camouflaged errors. Euclid devoted an entire book to geometrical fallacies, but his manuscript did not survive.

The following seven fallacies have been selected for their variety and interest. They will not be explained, but the reader may find it pleasant and instructive to seek out their errors.

Our first fallacy is an exceedingly elementary one. We shall introduce it by way of an amusing paradox which David Hilbert, the great German mathematician, liked to employ to illustrate one of the peculiar properties of aleph-null, the smallest of the transfinite numbers. It seems that the manager of a celestial hotel with an infinite number of rooms, all occupied, wishes to accommodate a new guest. He does so by moving each occupant to a room with the next highest number, thereby vacating Room 1. What can he do if an infinite number of new guests arrive? The undismayed manager simply shifts each occupant to a room that has a number twice as large as that of his first room; the guest in Room 1 goes to Room 2, the guest in 2 goes to 4, 3 to 6, 4 to 8, and so on. This opens up all the odd-numbered rooms, which will accommodate every one.

But is it really necessary that the number of occupied rooms be infinite before additional guests can be accommodated? The following doggerel from a late 19th-century British magazine tells how a clever innkeeper with nine empty rooms had no difficulty in providing separate lodgings for each of 10 travelers.

Ten weary, footsore travelers,
All in a woeful plight,
Sought shelter at a wayside inn
One dark and stormy night.

"Nine rooms, no more," the landlord said,
"Have I to offer you.
To each of eight a single bed,
But the ninth must serve for two."

A din arose. The troubled host
Could only scratch his head,
For of those tired men no two
Would occupy one bed.

The puzzled host was soon at ease—
He was a clever man—
And so to please his guests devised
This most ingenious plan.

In room marked A two men were placed,
The third was lodged in B,
The fourth to C was then assigned,
The fifth retired to D.

In E the sixth he tucked away,
In F the seventh man,
The eighth and ninth in G and H,
And then to A he ran,

Wherein the host, as I have said,
Had laid two travelers by;
Then taking one—the tenth and last—
He lodged him safe in I.

Nine single rooms—a room for each—
Were made to serve for ten;
And this it is that puzzles me
And many wiser men.

A slightly more sophisticated fallacy is the following algebraic proof that any number a is equal to a smaller number b.

$$a = b + c$$

Multiply both sides by a − b to obtain:

$$a^2 - ab = ab + ac - b^2 - bc$$

Move ac to the left side:

$$a^2 - ab - ac = ab - b^2 - bc$$

Factor:

$$a(a - b - c) = b(a - b - c)$$

Divide each side by a − b − c to get:

$$a = b$$

Manipulation of the imaginary number i (the square root of − 1) has many pitfalls, as witnessed by the following tantalizing proof:

$$\sqrt{-1} = \sqrt{-1}$$

$$\sqrt{\frac{1}{-1}} = \sqrt{\frac{-1}{1}}$$

$$\frac{\sqrt{1}}{\sqrt{-1}} = \frac{\sqrt{-1}}{\sqrt{1}}$$

$$\sqrt{1} \times \sqrt{1} = \sqrt{-1} \times \sqrt{-1}$$

$$1 = -1$$

In plane geometry most fallacies hinge on an improperly constructed diagram. Consider for example this perplexing demonstration that the front side of a polygon cut out of a piece of paper has an area which differs from that of the back side. The demonstration was devised by L. Vosburgh Lyons, a New York psychiatrist, to exploit a curious principle recently discovered by Paul Curry, also of New York.

First draw on a sheet of graph paper the 60-square-unit triangle shown at the top of the illustration on page 94. Cut along the lines to make six pieces, then color the back of each piece. If all six pieces are turned over and a colored triangle formed as shown in the middle of the illustration, it will be found that the triangle has developed a hole of two square units. In other words, its area has shrunk to 58 square units. If we turn three pieces so that their white sides are uppermost, leaving three colored pieces, we can form the figure shown at the bottom of the illustration. This has the in-

Who's top dog in inertial navigation?

Precision inertial navigation is the most exciting and technically advanced way to keep a moving air, land or sea vehicle on course. It does not use radio, radar, the stars, heat or magnetic reference. Highly accurate, its military use in missiles and aircraft may be the key to an effective deterrent weapon.

American Bosch Arma Corporation, through its ARMA Division, is a leader among companies making contributions to inertial navigation. As a result, ARMA was selected to design and produce the inertial guidance system for America's newest intercontinental ballistic missile: Titan. ARMA . . . Garden City, N. Y. A Division of American Bosch Arma Corporation.

There are unlimited employment opportunities in inertial navigation at ARMA.

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between area of 59 square units. Something is obviously wrong here, but what?

Probability theory swarms with plausible but specious lines of reasoning. Suppose you have just met your friend Jones and each of you is wearing a necktie that your wife gave you for Christmas. You begin to argue over which of you received the more expensive tie. You and Jones finally agree to settle the matter by visiting the store where both ties were bought and checking their value. The man who wins (that is, has the most expensive tie) must give his tie to the loser as a consolation.

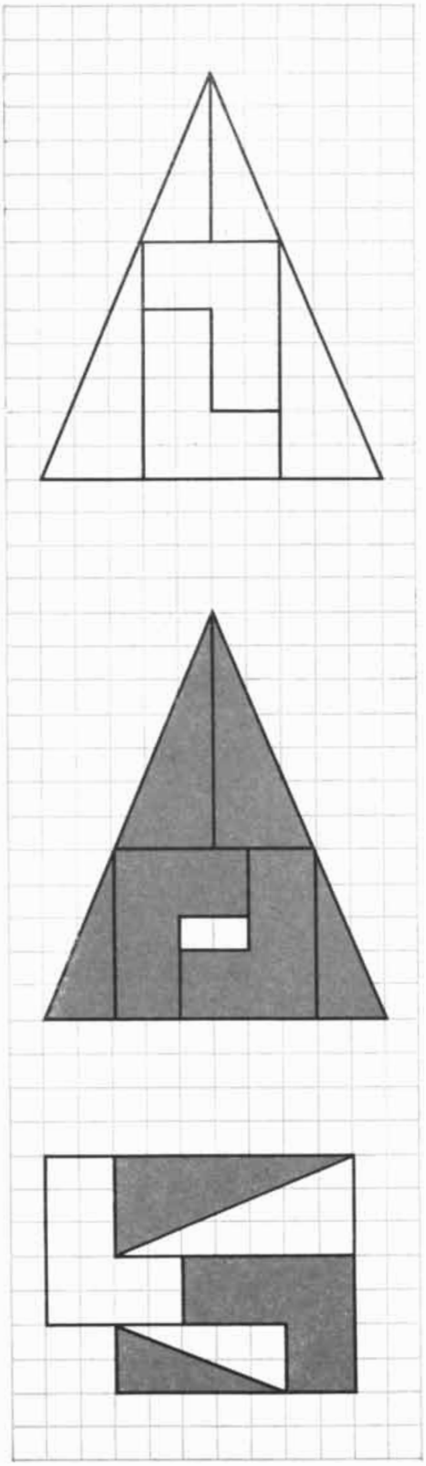
This is how you reason: "The chances that I will win the argument or lose it are equal. If I win, I will be poorer by the value of this tie I am wearing. But if I lose, I am sure to gain a more expensive tie. Therefore the contest is clearly to my advantage."

Of course Jones can reason in exactly the same way. How can a bet be favorable to both parties?

One of the most surprising paradoxes of topology is the fact that a torus (a doughnut-shaped surface) can be turned inside out through a hole in its side by stretching the surface without tearing it. There is no question about this. When the steps in the process were depicted in SCIENTIFIC AMERICAN for January, 1950, a New Jersey engineer actually shipped the magazine an inner tube which he had reversed. But if this can be done, then an even more remarkable fact seems to emerge.

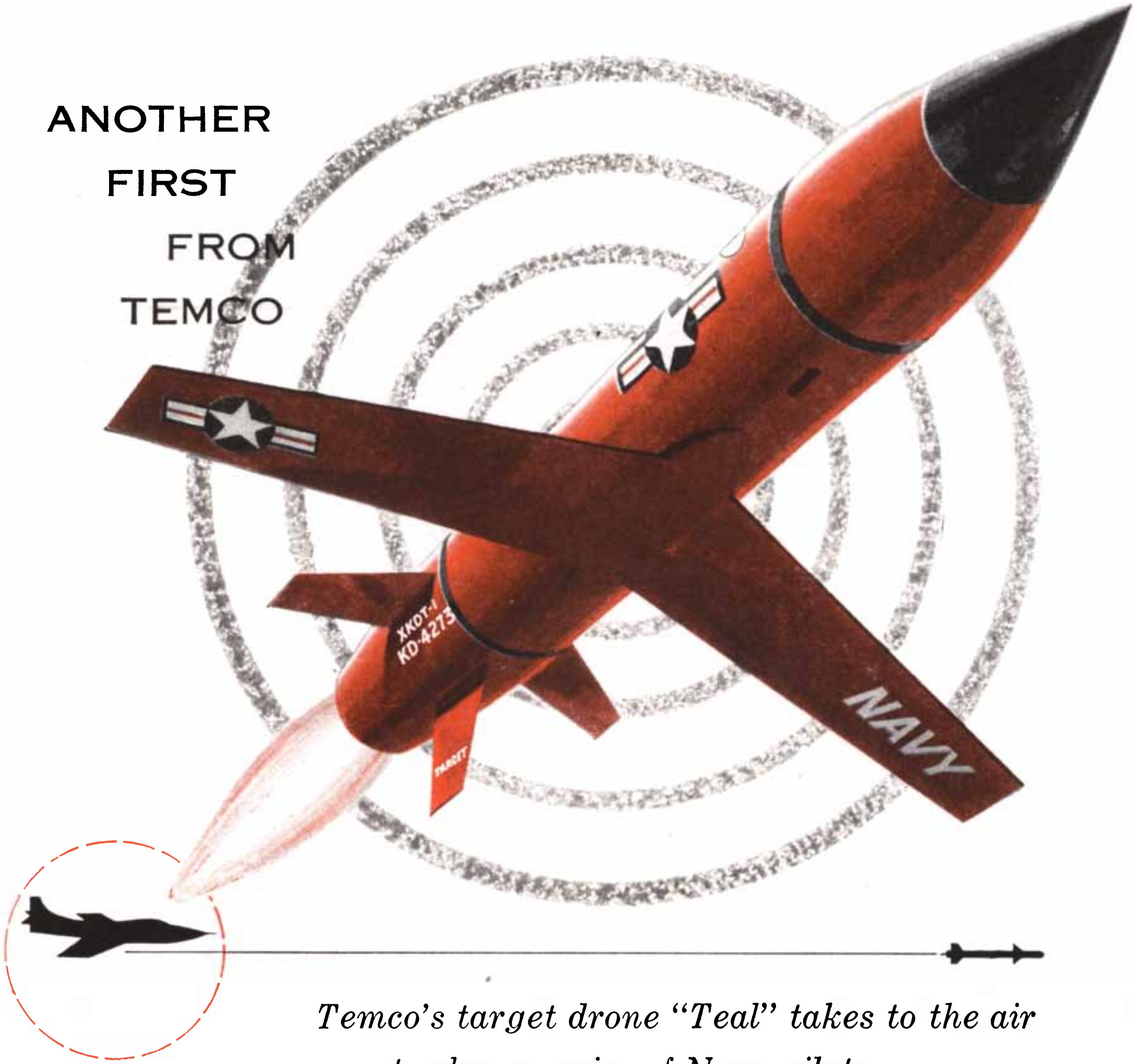
On the outside of a torus paint the ring at right in the upper illustration on page 96. On the inside of the same torus paint a second ring. These two closed curves are clearly linked. The torus is now turned inside out through the hole. As the bottom illustration shows, this moves the first ring to the inside and the second ring to the outside. The rings are no longer linked! This obviously violates a fundamental topological law which states that two linked curves cannot be separated without breaking one curve and passing the other through the break.

Our final fallacy, which draws on elementary number theory, concerns "interesting" *v.* "uninteresting" numbers. Numbers can of course be interesting in a variety of ways. The number 30 was interesting to George Moore when he wrote his famous tribute to "the woman of 30," the age at which he believed a married woman was most fascinating. To a number theorist 30 is more likely to be exciting because it is the largest integer such that all smaller integers with which it has no common divisor are prime numbers. The number 15,873 is intriguing because if you multiply it by any digit and then by 7, the result will consist entirely of the chosen digit. The number 142, 857 is even more fascinating. Multiply it by any digit from 1 through 6 and



A fallacy of plane geometry

ANOTHER FIRST FROM TEMCO



Temco's target drone "Teal" takes to the air to sharpen aim of Navy pilots

The XKDT-1, "Teal," designed and developed by Temco as a low-cost, expendable target system, recently made its initial flight to become the nation's first successful rocket-powered target drone. Carried aloft and launched by an F3H-2M Demon fighter at 20,000 feet, the "Teal" held a straight course for almost eight minutes . . . the first flight of such duration for a drone using solid-propellant fuel. Also, the event was the first successful controlled launching of such a device from swept-wing aircraft.

Capable of operating near the speed of sound at altitudes up to 50,000 feet, the "Teal" will serve as a target for air-to-air missiles and other defensive devices carried by Navy aircraft. It is a Temco development from initial concept to flight readiness, and an outstanding example of Temco's engineering and production capabilities.

The experienced engineer who seeks the challenge of a growing organization, plus the prestige of a soundly established company, will find *his* opportunity at Temco!

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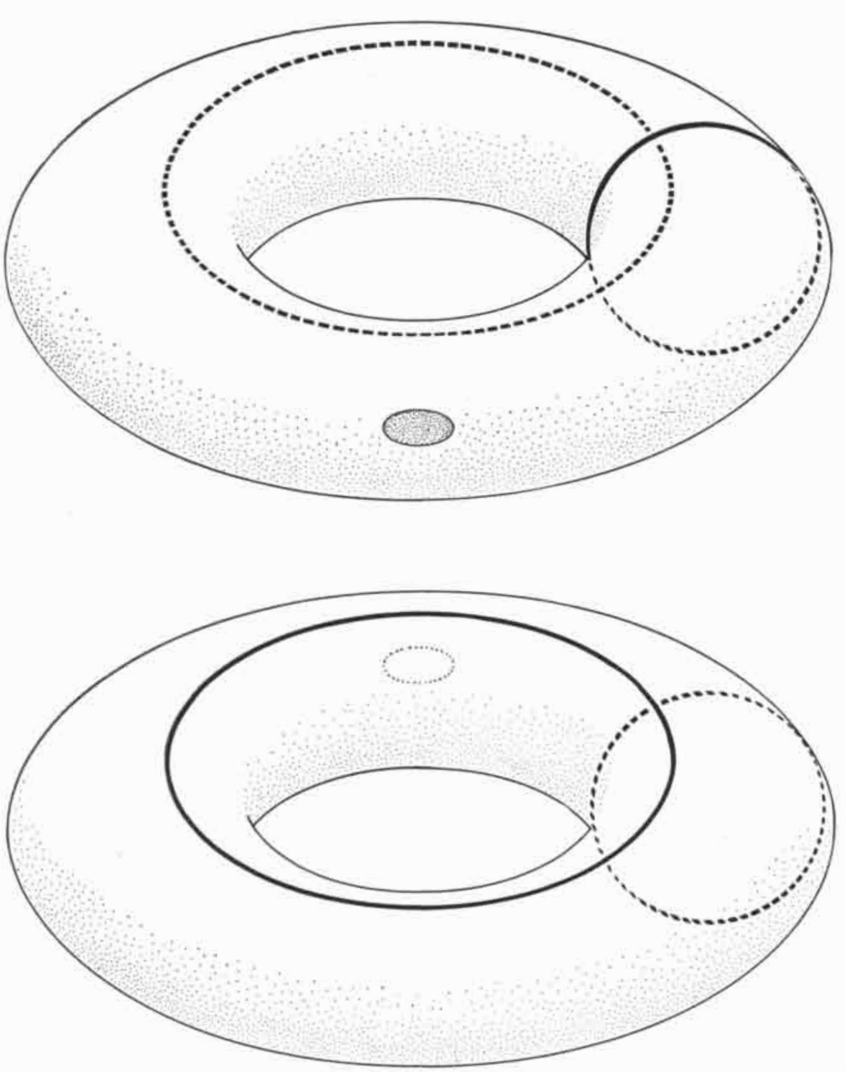
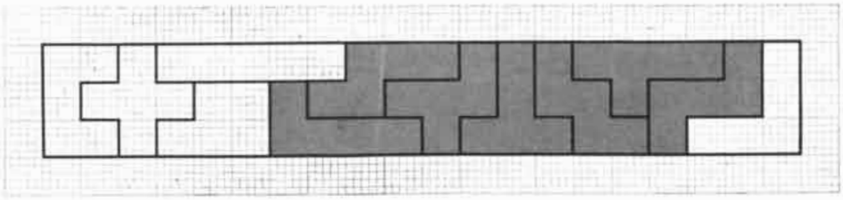


A fallacy of topology

you get the same six digits in the same cyclic order.

The question arises: Are there any uninteresting numbers? We can prove that there are none by the following simple steps. If there are dull numbers, we can then divide all numbers into two sets—interesting and dull. In the set of dull numbers there will be only one number that is the smallest. Since it is the smallest uninteresting number it becomes, *ipso facto*, an interesting number. We must therefore remove it from the dull set and place it in the other. But now there will be another smallest uninteresting number. Repeating this process will make any dull number interesting.

The solution to last month's pentomino problem is given in the illustration below. Note that the shaded section can be inverted to give a second solution. These two solutions are believed to be the only ones possible.



The solution to last month's pentomino problem

Ros Gilbert discusses RELIABILITY

Reliability deliberately incorporated into design, whether the design be for a complete system or for a single component, is the premium in the product that establishes the reputation of the designer and his creation. The customer usually assumes—and does rightfully expect—that the ultimate in presently available reliability is incorporated into any product he acquires. Indeed, this expectancy is so taken for granted that—as the indispensable base note in an orchestral reproduction—it is noticed only if missing.

The successful acceleration of electronics into new areas of application will depend upon our ability to produce reliable equipment. An acute awareness of reliability is therefore more significant than ever in electronic design. An Air Force Colonel recently remarked to the effect that: Present (postwar) electronics is five times as reliable as prewar electronics. But with twenty-five times as much of it, the end result is one-fifth the reliability!

Visions of a bright future in electronics reveal complexities transcending our wildest nightmares. To the imaginatively fertile mind the practicality of mass production of computer elements suggests unprecedented applications already within economic range. Prospects for a successful achievement are literally nonexistent, however, unless the reliability of individual components can be made to yield composite reliability in the great complexity of the ultimate solution. Consider our electronic monsters governing costly processes and the well-being of all the people! Sloppy concessions to reliability would be disastrous. Conversely, absolute reliability would warrant complexity without limit—a most appealing prospect for most of us.

Fate is frequently kind to the venturesome. And she has been particularly kind to those who experimented with, and perfected, transistors and magnetic devices to replace hot electronics components. In the present state of the art the solid state devices can be said to possess "intrinsic" reliability in that they do not suffer from scheduled deterioration as does a thermionic cathode or ionic device. This is indeed encouraging and would appear to spur application into hitherto neglected spheres where the inevitable decay of a tube's cathode formerly limited usefulness. Let not this use be indiscriminate, however, because secondary defects in solid state devices pose other problems which frequently limit the ultimate reliability to an unfavorable degree relative to hot electronics.

One such important defect has been established—the failure of solid state devices is related to intrinsic defects in material rather than to variable life time constants. This seemingly simple yet critical difference fosters the provocative notion of weeding out the culprits through extensive and exhaustive pretesting of components, of sub-systems or whole assemblies and, finally, during check-out in actual operation. Thus, it would seem as if a large, complex system using solid state devices—by the very nature of the beasts—could be made to become increasingly reliable with use almost without limit. An equivalent system composed of elements naturally deteriorating with time will, on the other hand as heretofore, always rapidly approach the critical operating reliability threshold.

Roswell W. Gilbert, Director of Research and Development, Daystrom, Inc., discusses the discipline of reliability.

This notion of perfection in components replacing hot electronics could well be used as the basis for a design discipline applying to solid state systems.

Our discipline would also dictate the use of, for instance, a plug connector, for easy replacement of a component, that is at least as reliable as the component to be used for the ultimate replacement.

Consistently defective materials will be improved by invoking the disciplines of chemistry and metallurgy to produce practically perfectly reliable elements. This process is in fact in high gear today.

Our goal, assuming diligent application of a rigorous discipline in design reliability, is to produce "twenty-five times as much electronics as today, and to make it twenty-five times as reliable."

THE AMATEUR SCIENTIST

Mostly about how to study artificial satellites without complex equipment

Conducted by C. L. Stong

Artificial satellites and their associated hardware have opened new horizons for the amateur scientist. Scores of amateurs are already participating in the Moonwatch and Moonbeam programs sponsored by the U. S. National Committee of the International Geophysical Year. These formal activities marshal the services of advanced amateurs to man elaborate stations which make observations of immediate scientific value. But the amateur does not need elaborate equipment to keep track of a satellite's path, or even to predict with fair accuracy how long a satellite will stay on orbit. Anyone can do it. Those most interested will doubtless acquire at least a low-power telescope or a pair of binoculars. Others will be able to settle for a pair of pocket mirrors, a sheet of glass and some adhesive tape. The amateur who prefers to make observations with a minimum of equipment can get into business with nothing more than three wooden slats and a stop watch.

These techniques require that the observer be outdoors, often before sunrise. For the comfort-loving amateur there is another means of keeping track of satellites, at least so long as they transmit radio signals. Many ordinary radio receivers have built-in converters which enable them to pick up the short waves broadcast by satellites. Even those receivers without converters are easy to adapt to short-wave reception. Converter units, available from dealers in "ham" radio supplies, are priced at about $50. Those amateurs who prefer to build their own converters will find complete instructions in *The Radio Amateur's Handbook*. Parts for a two-tube converter cost about $15.

Ralph H. Lovberg and Louis C. Burkhardt, physicists at the Los Alamos Scientific Laboratory, have suggested a way in which the amateur can determine the height of a satellite as it passes overhead. Their method is based on the Doppler shift, the apparent decrease of pitch noted when a source of sound, such as a train whistle, rushes past the observer. Radio-equipped satellites are in effect whistling objects. Their radio transmitters radiate signals at predetermined frequencies. In the case of the first two satellites the frequencies were approximately 20 and 40 megacycles per second. To measure the distance between the observer and a satellite, the signal from the satellite is tuned in on a radio receiver and mixed with a signal generated by a local oscillator of somewhat higher or lower frequency. The difference frequency is then amplified, fed into a loudspeaker and converted into sound. For example, when a signal of 40 megacycles is mixed with a locally generated signal of 39.997 megacycles, the amplified difference frequency of 3,000 cycles will produce a whistling sound pitched about two octaves above middle C. The period during which the pitch changes may last more than five minutes. The distance of the satellite is determined by measuring the pitch of the sound at brief intervals during this period, and noting the time at which each tone is identified. The frequency of the sound at each interval can be estimated by comparing it with the notes of a piano or, preferably, by following the whistle down the scale with an accurately calibrated audio-frequency oscillator. Whenever the signal and comparison tone (piano or oscillator) coincide (are in zero beat), the corresponding time should be recorded as read from the second hand of a watch or clock.

"In the case of our measurements of the first satellite," write Lovberg and Burkhardt, "we used a conventional Hallicrafter SX-28 receiver at 40 megacycles. The local beat-oscillator was left off and a surplus BC-221 frequency meter was coupled loosely (by means of a twist of insulated wire) to the antenna lead. The signal generator is set at approximately 3,000 cycles below the satellite frequency when the 'little traveler' is first detected. This results in an audible tone in the receiver output. The tone is now fed into a loudspeaker together with the output of an audio oscillator. In a typical run one sets the audio oscillator to a tone lower than that of the satellite, say 2,500 cycles per second, and waits for the satellite tone to drop to the same value. The zero beat between the two tones is first heard as a fluttering sound which diminishes in frequency to a slow swelling and fading of the 2,500-cycle note. At the instant the tone becomes steady, one records the time as well as the frequency (2,500 cycles in this instance) and quickly shifts the audio-frequency oscillator to, say, 2,400 cycles, and waits again for the matching of the tones.

"The resulting table of frequencies and times is then plotted as a curve like the one shown on page 102. This indicates the passage of the first satellite over Los Alamos, N. M., on October 13. Next we draw a line tangent to the curve at its steepest point. The slope of the tangent line represents the number of cycles per second that the frequency changes per second and varies in proportion to the distance of the satellite. If we call this slope m, then the distance of the closest approach of the satellite is given by the simple formula $d = fv^2/cm$. Here f equals the frequency of the satellite's transmitter (40 megacycles), v equals the velocity of the satellite in miles per second (about 4.9 miles), c is the speed of light in miles per second. The velocity v will vary somewhat from the 4.9-miles-per-second value, depending on such factors as the eccentricity of the satellite's orbit. The amateur may obtain fairly accurate velocity figures from agencies such as the Smithsonian Astrophysical Observatory. These figures are sometimes reported in the daily press."

It was by this method that Lovberg and Burkhardt learned that the first satellite was coming over Los Alamos at a height of about 170 miles at night and

260 miles during the day. The figures are in good agreement with those released by the Smithsonian Observatory.

An optical means of getting the same result is suggested by Walter Chestnut, a physicist at Brookhaven National Laboratory:

"If an object is in a stable, circular orbit around the earth, one may say that the gravitational force of the earth pulls the object with a force which equals its centrifugal force. The relation may be expressed in mathematical terms in such a way that the object's altitude may be determined by a simple measurement of the number of degrees traversed by the satellite in one second as the object passes overhead. This angular velocity may be measured by timing the transit of the satellite as it passes stars, the positions of which are known. If the amateur does not have a star chart, the angle can be easily measured by a fixed astrolabe, a triangle of wooden slats nailed together and supported as shown in the accompanying illustration [*at right*]. The astrolabe forms an angle of 10 degrees. The nails serve as sights; they should be painted white so that they will be clearly visible in poor illumination. The construction of the instrument should be as light as possible, because it must be swung into position quickly when a satellite is spotted. The two outer nails should be placed in line with the satellite's path and held steady. The number of seconds are then counted from the time the object appears to touch the first nail until it reaches the second one. The corresponding altitude in miles can then be read from the accompanying table [*see next page*].

"Readers may calculate their own table for astrolabes of other angles by the equation:

$$d_1 = 282\ t/a\ \sqrt{1 - .0705\ t/a}$$

In this equation d_1 equals the altitude of the satellite in miles; t is the time of transit in seconds for an angle of a degrees. For an astrolabe of 15 degrees and a transit time of 60 seconds the altitude would be $(282 \times 60/15 \times (\sqrt{1 - .0705 \times 60/15})$, or $1{,}128 \times .8474$ (956) miles. The same calculation is carried out for each value of time desired in the table.

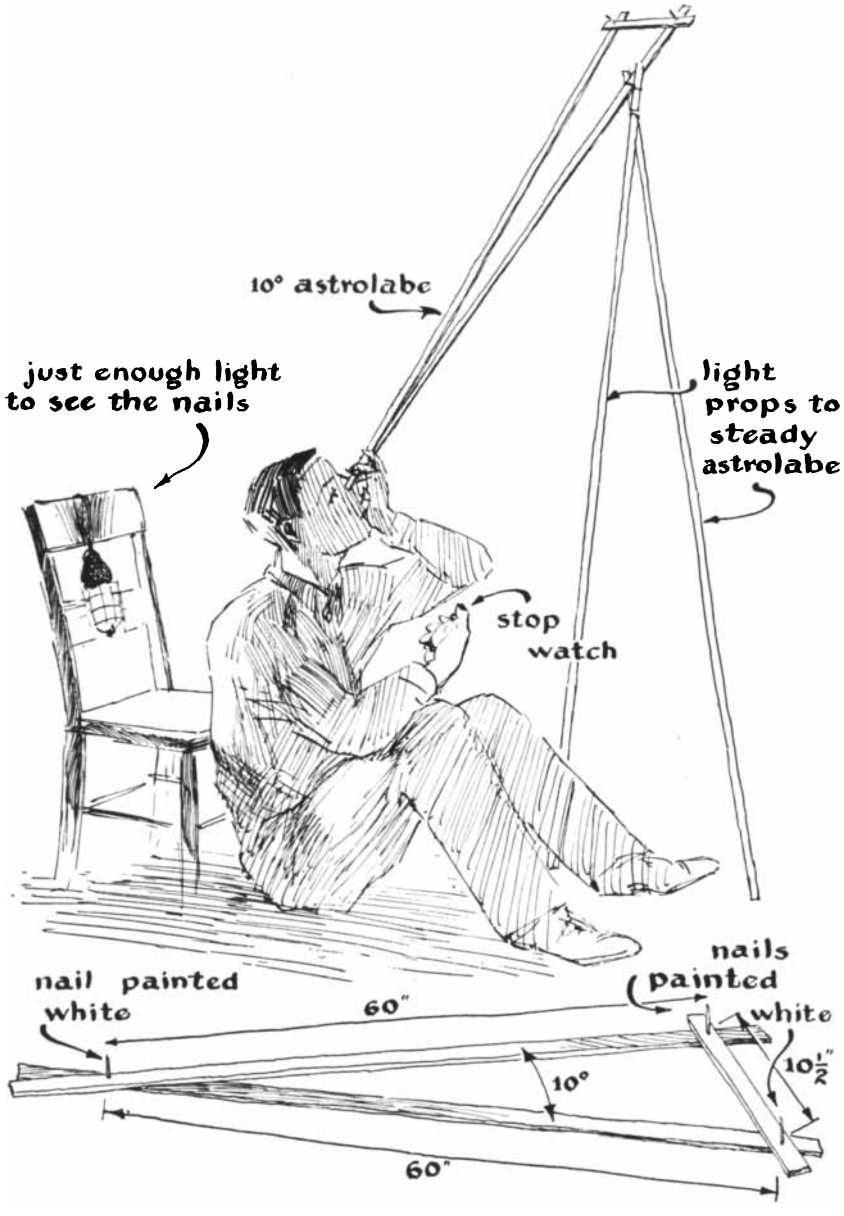
"Both the table and the equation assume that the satellite is observed within 15 degrees of the zenith. If the satellite is more than 15 degrees from the zenith, multiply the distance given in the table by the cosine of the angle between the orbit and the zenith. The equation and table also assume that the orbit is a circle. Most orbits, however, will be ellipses. But if one knows the maximum and minimum heights of the satellite, the table (and equation) can be corrected for ellipticity by the equation:

$$C = d_1\left(\frac{d_e - d_1}{2(4{,}000 + d_e)}\right)$$

In this equation d_1 is the altitude obtained from the table (or the first equation). C is the distance (in miles) to be added to d_1 if C is positive, or to be subtracted from d_1 if C is negative. The average of the maximum and minimum altitudes of the satellite is represented by d_e. In the case of Sputnik I the maximum and minimum altitudes were respectively 570 and 170 miles; d_e accordingly equals 370 miles.

"By following these instructions carefully the amateur can determine the altitude of a satellite with an accuracy of about 20 miles for every 1,000 miles of its height. The limits of error will doubtless be determined more by the accuracy of the observer's measurements than by errors of the method.

"We have observed the rocket of Sputnik I on two occasions. The first time we merely wanted to find out if it was really there. On the second look the astrolabe was propped against a convenient tree. As the rocket traveled from



A simple astrolabe to measure the speed of an artificial satellite one sighting nail of the astrolabe to the other, a transit time of 11.6 seconds was recorded. Unfortunately the tree swayed a little in the stiff morning breeze; this doubtless introduced an error of a few miles. The altitude for an 11.6-second transit, as it is read from the table, is 314 miles.

What about methods of measuring changes in the time it takes a satellite to make a trip around the world? As a satellite encounters atoms and molecules of the rarefied air at altitudes above 100 miles, it gradually loses speed. Paradoxically it appears to gain speed, because as it slows down it spirals closer to the earth and takes less time to complete its orbit. When the orbital time of a satellite decreases to about 87 minutes, the satellite will soon be consumed by friction with the lower atmosphere. Thus by timing the passage of a satellite during a few transits, its lifetime can be predicted. If the measurements can be made with good accuracy, two timings are sufficient for an approximate prediction.

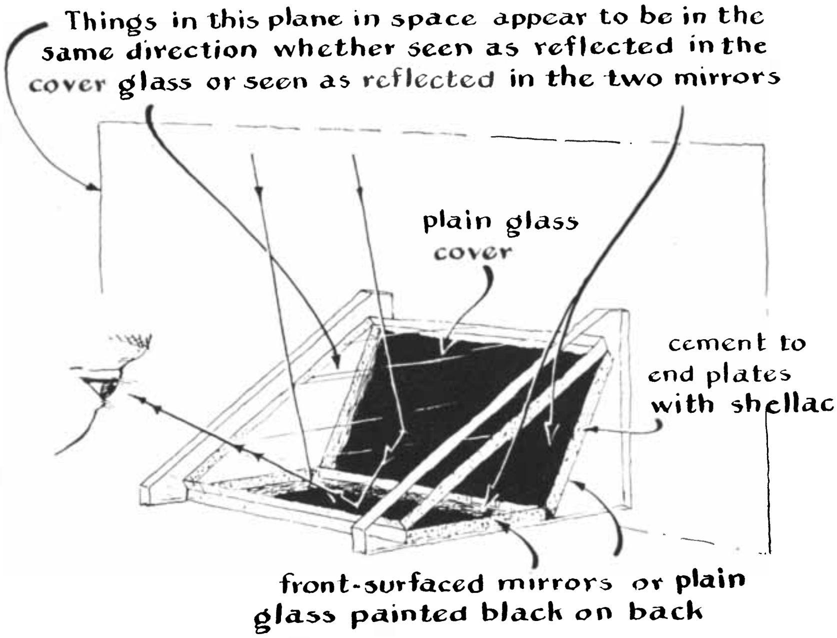
A convenient instrument for timing the orbit of a satellite is the dipleidoscope, a device invented about 1860 by an English barrister named J. M. Bloxam. It consists of a pair of mirrors tilted toward each other at an angle of somewhat more than 90 degrees and covered by a sheet of glass as depicted on this page. The three elements may be supported by a pair of end plates, as shown, or simply taped securely. Ideally the mirrors should be front-surface silvered and the cover glass should be silvered so that it reflects 38 per cent of the light striking it and passes the rest. But ordinary back-silvered mirrors (or even plain glass with a back-coating of black paint) will work, and the cover glass need not be silvered at all.

When the dipleidoscope is held at an angle which reflects light from the satellite into the eye, two images will be seen. One image is reflected by the cover glass, the other by the mirrors. As the satellite passes overhead, the two images move toward one another, merge and then pass out of the field of view in opposite directions. The time is recorded at the instant the images merge. The device should be set up in advance of the transit on a firm but easily adjusted support such as the ball-and-socket tripod head popular with photographers. The axis of the dipleidoscope should be adjusted roughly at a right angle to the anticipated path of the satellite. During one transit the instrument is adjusted so that the two images will merge. On the same transit the time is recorded. The instrument is then left undisturbed for a second observation during the next transit. In the case of Sputnik I observations made 24 hours apart would show the approximate apparent gain in time for 15 revolutions.

10 DEGREES TRANSIT TIME (SECONDS)	ALTITUDE (MILES)
2	56
3	84
4	112
5	138
6	166
7	193
8	219
9	246
10	273
12	325
14	375
16	426
18	477
20	526
25	650
30	770
35	890
40	1,000
50	1,225
60	1,450
70	1,660
80	1,860
90	2,060
100	2,250
120	2,620
140	2,980

Table of transit times and altitudes

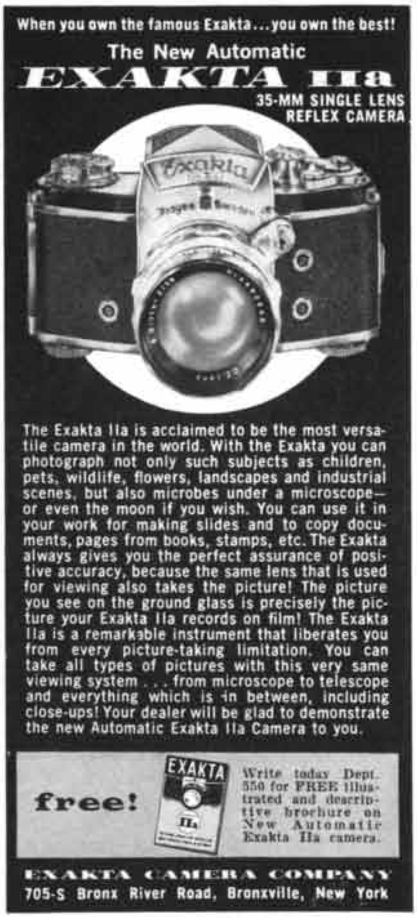
Most satellite observers will also want a good low-power, wide-field telescope. An inexpensive one of the type used by Moonwatch teams is depicted on page 102. It is designed for table-top use, the front-surfaced mirror being an anti-crick-in-the-neck feature for those who prefer to look down rather than up. The achromatic objective lens and Erfle eyepiece together retail for about $25.

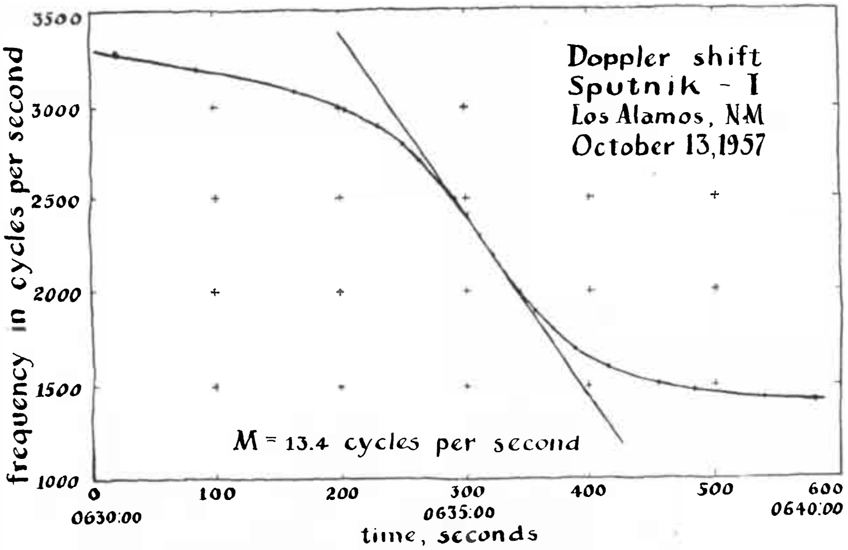


Dipleidoscope to measure the time required for a satellite to go around the earth

Roger Hayward, who makes the drawings which illustrate this department, is a restless intellect. Between assignments for "The Amateur Scientist" he is an architect, but he still finds time for multifarious activities ranging from the design of optical instruments to the making of decorative mobiles. One of his recent concerns has been to devise experiments which demonstrate the remarkable properties of the human eye.

"During the past few days," he writes, "I have been enjoying a brainstorm which might amuse other amateurs. It all started when I came across the description of an ingenious optical trick involving a mirror polished on the flank of a contact lens arranged so the observer's eye is presented with an image of a dark vertical line which remains fixed on the retina regardless of any eye movement. The general result of the experiment was that the image of the line kept disappearing. The image would be

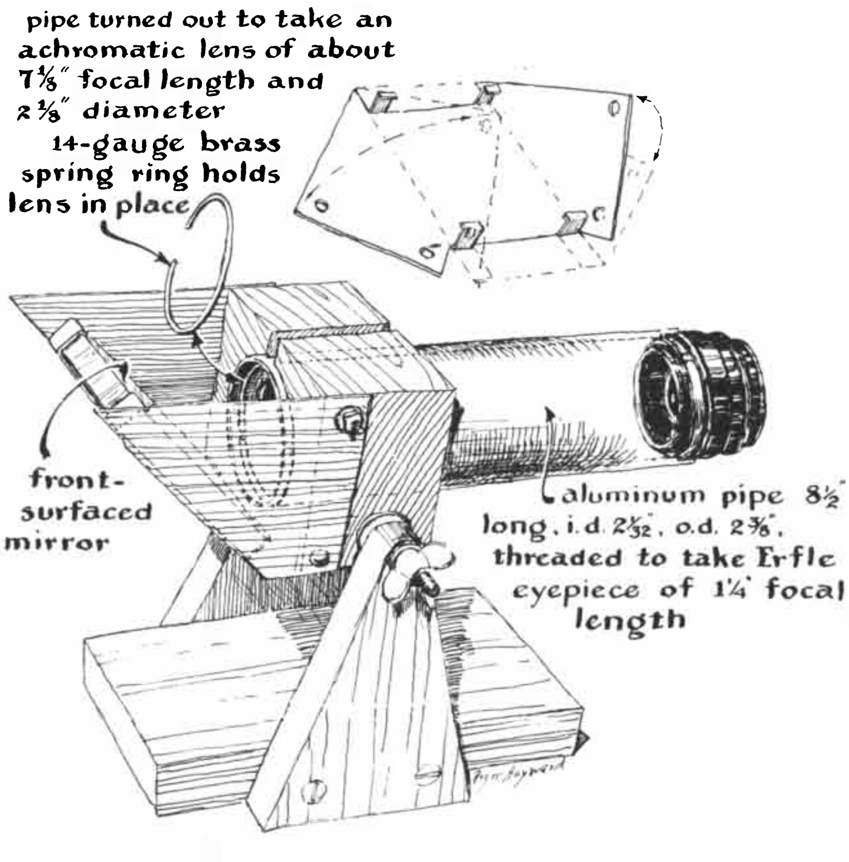




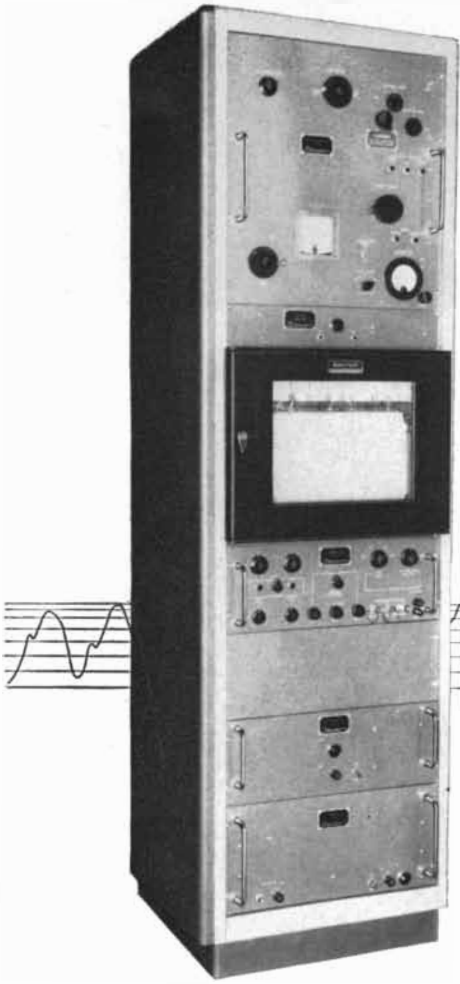
Curve for the determination of the height of a satellite

observed with distracting clarity for about a tenth of a second. Then it would disappear, reappearing now and then at irregular intervals. The conclusion was drawn that if any image is presented continuously to the eye without any relative motion with respect to the retina, the mind simply learns to ignore it. Although not specifically mentioned in the article, this sort of thing brings to mind the fact that visual acuity is greater for moving objects than for fixed ones.

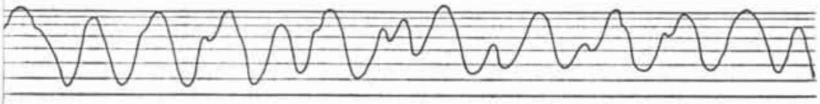
"It has also been observed that the human eye is always in motion. An irregular vibratory motion of from 5 to 25 seconds of arc in amplitude and from 10 to 100 cycles per second in frequency seems to be ever present, and appears to



A low-power, wide-field telescope to observe satellites



Automatic high-speed frequency analysis of taped data . . . permanently charted



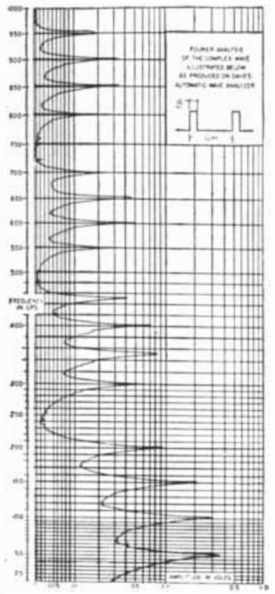
Do you have magnetic tape recorded data from vibration, noise, shock or flutter analysis of vehicles, aircraft, missiles or ships? . . . or seismic recordings, powerline disturbances, or other phenomena characterized by fluctuating data? Feed this tape recorded information to a Davies Automatic Wave Analyzer, flip the switch, and a complete Fourier series is automatically plotted and printed in permanent record form.

Davies Automatic Wave Analyzers can accurately plot these data as either amplitude-versus-frequency or power-versus-frequency. Davies Analyzers are also equipped with a "quick-look" facility. Series 9020 provides a quick analysis across its frequency range of 3 to 2,000 cps in only 15 minutes. Series 9050 will span 3 to 10,000 cps in just 15 minutes. Linear or square law output, as desired, is recorded by a Brown *ElectroniK* Potentiometer.

Multi-channel inputs permit analysis of as many as six channels simultaneously. By adding the Davies Input Switching Panel, a serial analysis of up to 14 channels can be made.

The Davies Automatic Wave Analyzer can process data in as little as 3% of the time required by digital methods, thus permitting the analysis of large samples, resulting in statistically reliable information.

Complete technical information and application data for the Davies Automatic Wave Analyzer can be had by requesting a copy of new Bulletin 9100—write to Minneapolis-Honeywell Regulator Co., Davies Laboratories Division, 10721 Hanna Street, Beltsville, Maryland.



From tape-recorded data—to permanent chart . . . a complete Fourier analysis in minimum time with maximum accuracy . . . with a Davies Laboratories Automatic Wave Analyzer.

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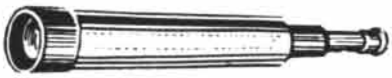
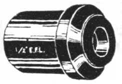
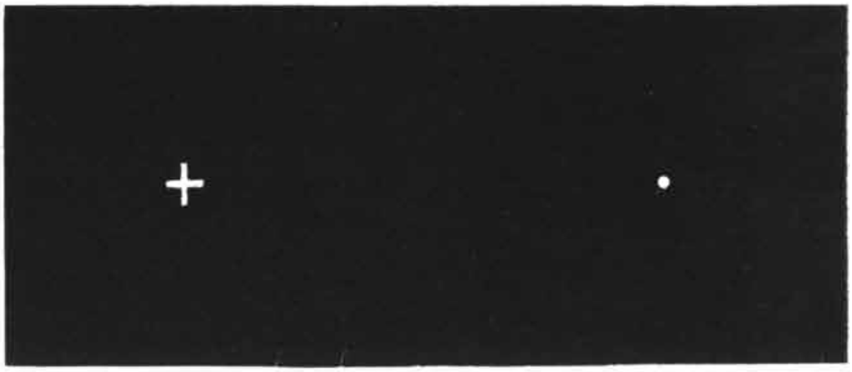




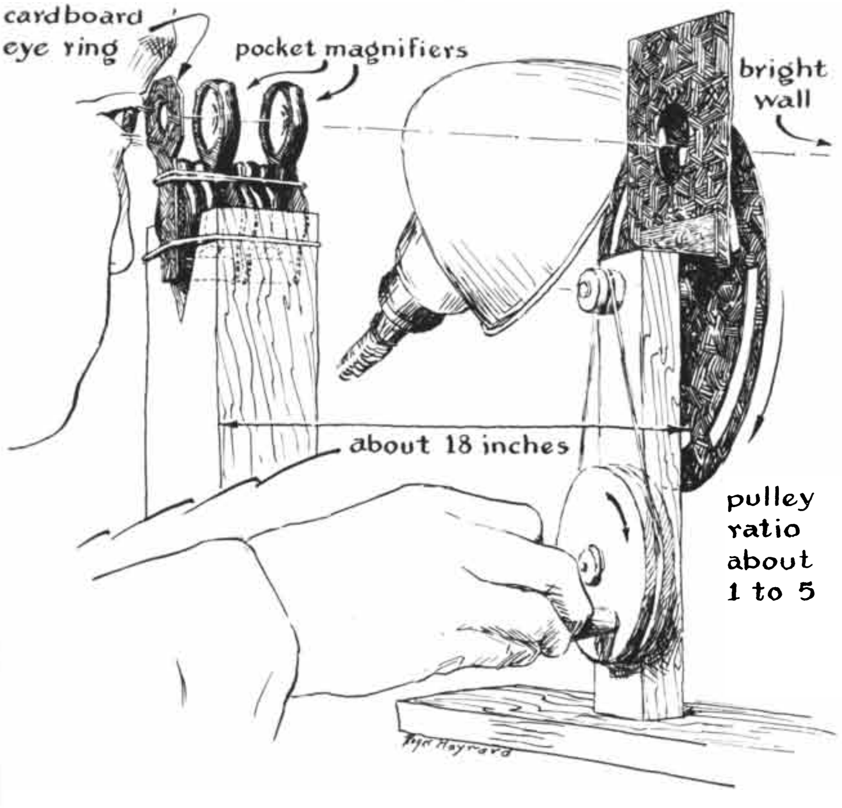


Test pattern to investigate the blind spot of the retina

be necessary to maintain consciousness of the background scenery. It is also well known that the retina is crisscrossed by a many-layered network of nerves and blood vessels which cast shadows on the light-sensitive cells. Yet we are not conscious of this complex obstruction between the lens and retina. According to physiologists the network which overlies the light-sensitive cells is about a thousandth of an inch thick.

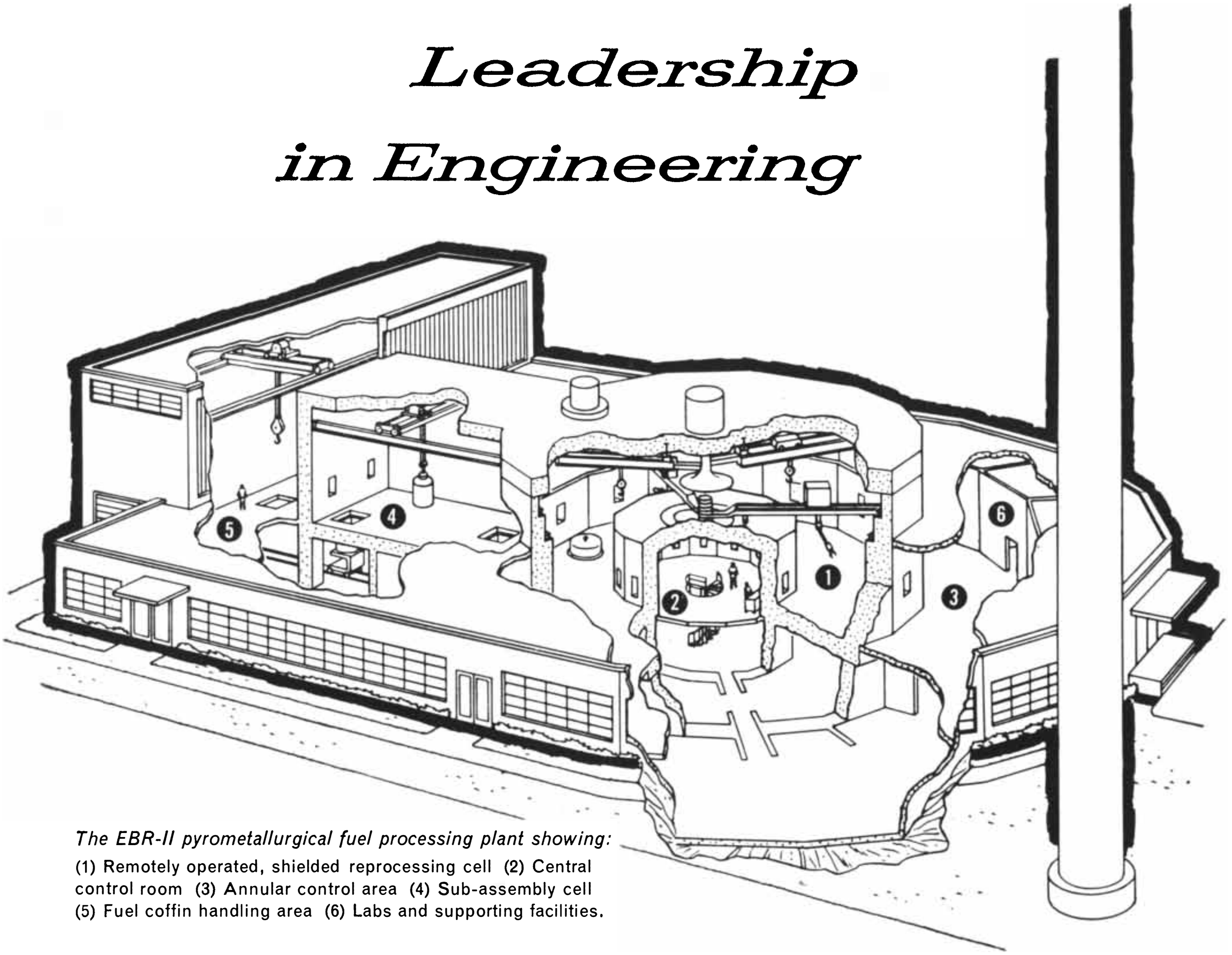
"This is where I come in. It seemed to me that if one could present the eye with a view of a uniform field of light, one without any detail, and arrange matters so that this view is perceived by light which would come alternately through the two sides of the pupil of the eye, then shadows cast by the blood vessels, nerves and so on could be made to fall alternately on different light receivers, and the flickering shadows would be perceived because of their movement. One would in effect see a vibrating silhouette of the obstructing network in his own eye.

"That the mind is capable of ignoring fixed blind spots is well established. A relatively large one, some seven degrees high, is situated about 15 degrees toward the nose from the center of attention. This feature marks the area where the nerves and blood vessels enter the eyeball. When both eyes are open, the



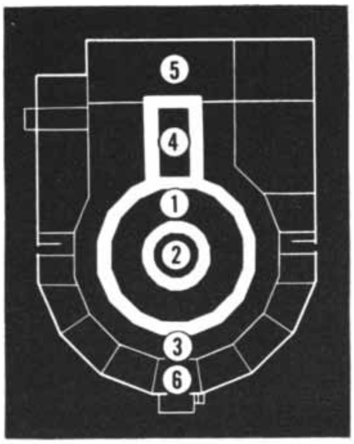
Apparatus to investigate the nerves and blood vessels of the retina

Leadership in Engineering



The EBR-II pyrometallurgical fuel processing plant showing:
(1) Remotely operated, shielded reprocessing cell (2) Central control room (3) Annular control area (4) Sub-assembly cell (5) Fuel coffin handling area (6) Labs and supporting facilities.

A unique pyrometallurgical reprocessing system which keeps the fissionable material in the metallic state will be integrated into Argonne's Experimental Breeder Reactor II Plant in Idaho. This system will be operated and maintained entirely by remote handling equipment. Here the highly radioactive spent fuel will be cleansed of the bulk of the fission products, reenriched, and fabricated into new fuel elements for return to the reactor. In the past, reprocessing of nuclear fuels has been separated from the reactor plant design and involved many chemical conversions. The design and development of this new fuel cycle is a joint effort of the Chemical Engineering, Metallurgy, Reactor Engineering, and Remote Control Engineering Divisions.



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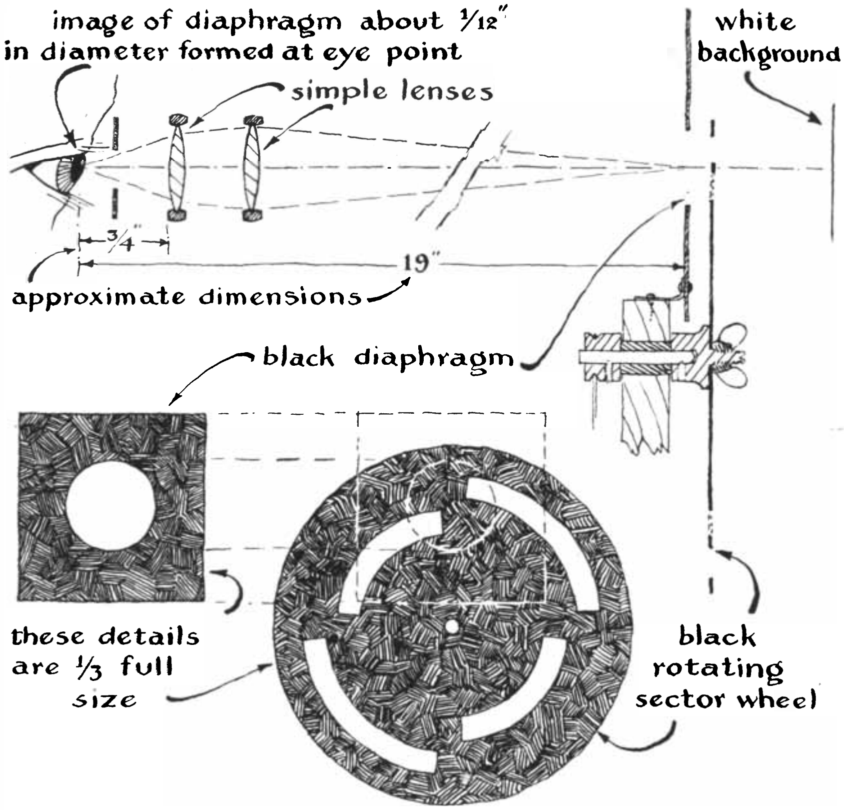


Details of apparatus to investigate the nerves and blood vessels of the retina

brain always fills in this blind spot with a continuum identical to the one surrounding it. Even when one eye is closed the brain does the best it can to fill in the missing portion of the scene. Hence the 'blind spot' is really blind only for those images which lie wholly within it. The effect can be observed with the aid of the accompanying drawing [*top of page 104*]. Close the right eye (or mask it with your hand) and with the left eye look directly at the white dot from a distance of about 15 inches. The page should be held so the dot is centered in front of the left eye, the cross being about 2 5/8 inches to the left. Both the dot and the cross will be seen, but attention should be centered on the dot. Now move the page gradually closer. At a distance of about 10 inches the cross will abruptly disappear. The image of the cross has entered the area of the blind spot. Continue moving the page closer. The cross will reappear at a distance of about six or seven inches. If the page is now held at a distance of about eight inches and moved from side to side, the same effect will be observed. By noting the distances at which the test pattern disappears, and taking the focal length of the eye lens into account, it is possible to compute the shape and area of your own blind spot.

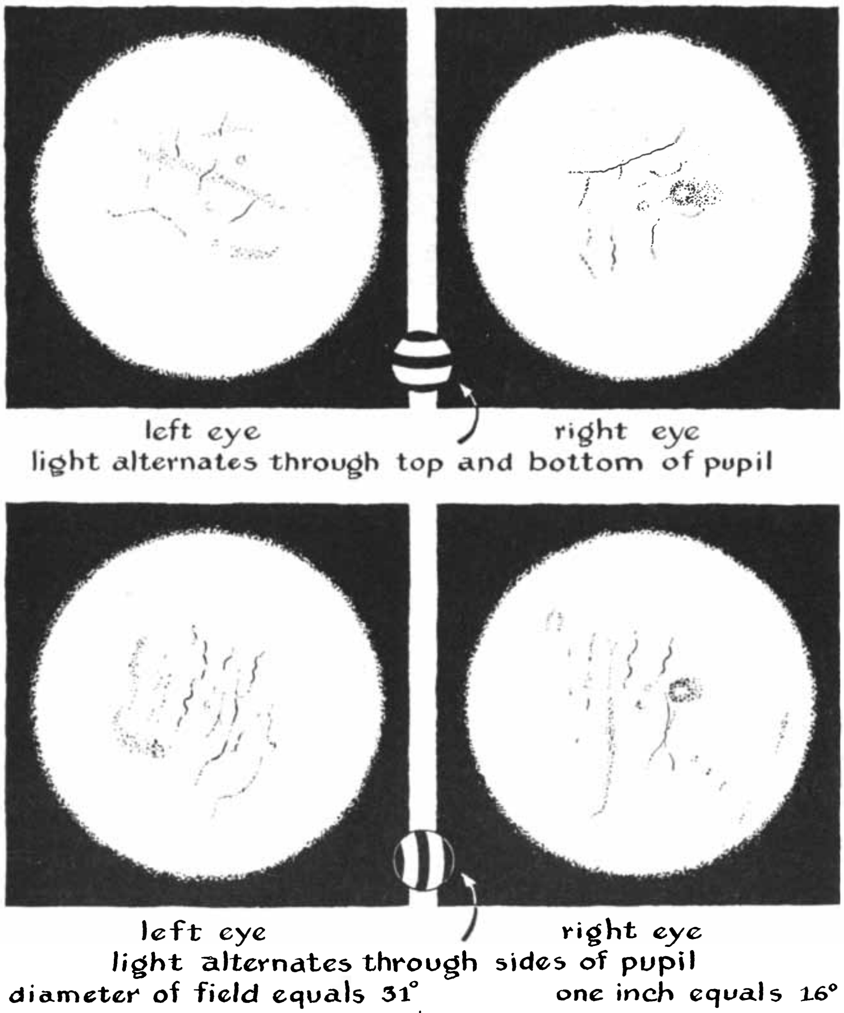
"The setup required for perceiving the network of blood vessels and nerves in your own eye involves somewhat more elaborate apparatus, but even so it is simple enough to suit most amateurs. A rotating disk with slots, or merely a disk painted black and white and masked by an aperture [*see page 104 and above*], is focused on the pupil of the eye. In effect the image created by the dark part of the disk alternately covers the two sides of the pupil, while the white portion alternately admits light to each side. Any lens system will serve to focus the image of the source on the pupil, such as a conventional eyepiece or even a pair of pocket magnifiers held together with rubber bands. An eye ring is handy for locating the eye point in space. This can be made from a narrow strip of cardboard as shown in the drawing. The painted disk should be turned at about 10 or 15 revolutions per second. I accomplished this with a hand-cranked pulley only because I did not happen to have a slow-speed motor at hand.

"The image of the network leaves something to be desired in the matter of contrast. Even with the flickering light the obstructions are not too easy to see. The silhouette appears as little more than a texture. A number of details disappear and reappear at irregular intervals

and are about as distinct as the small objects which appear and disappear, seemingly out of nowhere, when the gaze is fixed on the sky or a smooth surface without observable detail. Some of these, incidentally, are blood corpuscles.

"One of the jokers is that the picture presented to the consciousness seems to float about in space. If you try to bring any single detail into sharp view the whole pattern drifts because the details move with the eyeball. The fovea, the small area of the retina which provides the most acute vision, appears to be almost devoid of detail. I can see it by masking the rotating disk so that the flicker moves up and down (by fixing the circular diaphragm at the top of the disk instead of at the side). I see a patch about half a degree in diameter in the middle of the field of each eye. It does not appear during horizontal flickering. The patch is elliptical in shape and not as wide as it is high, perhaps two thirds as high as wide. It is covered by about 10 very fine wavy lines and seems to agree well with the published dimensions of the fovea. My center of visual attention is always at the *left* of the elliptical shape, regardless of which eye I use. One would naively suppose that the eyes would exhibit symmetry instead of this same handedness.

"Each person who makes this experiment will see his own retinal pattern. No other person can see it nor can it be photographed. If the observer wants to show his pattern to someone else he must draw it. This would seem to pose a problem somewhat like that of recording the features of the planet Mars, in which the few persons who can draw are the only ones capable of showing others what they think they see. If enough people make sketches of their own retinas, however, perhaps some conclusions can be drawn about the nature of the nervous network of the retina. At most the experiment might yield information about the structure of the retina. At least it will give the experimenter a view of something no one else can see."



Drawings of shadows cast on the retina by blood vessels and nerves

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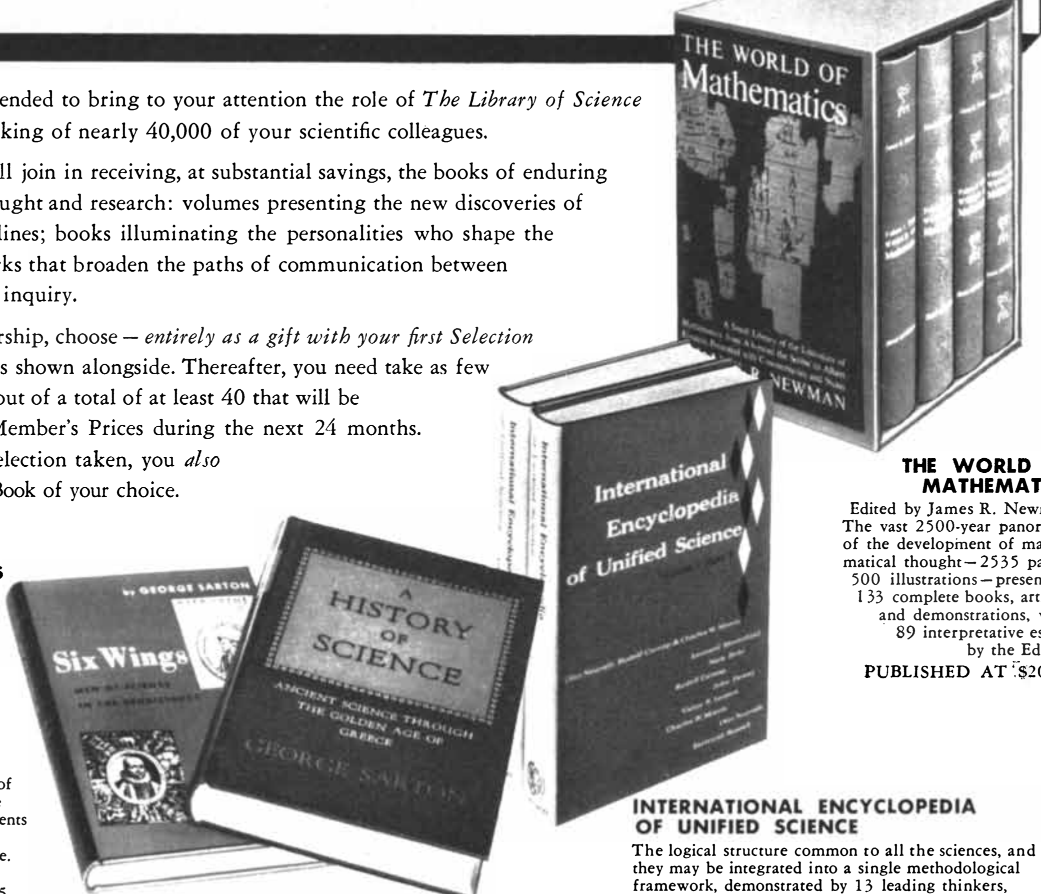

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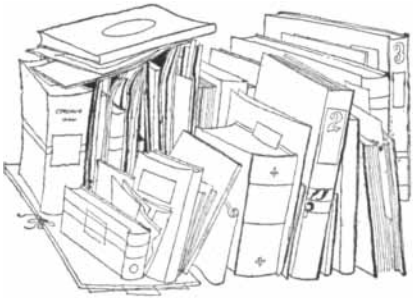

BOOKS

The argument of a physicist who does not accept the uncertainty principle

by James R. Newman

CAUSALITY AND CHANCE IN MODERN PHYSICS, by David Bohm. D. Van Nostrand Company, Inc. ($5).

In 1952 the physicist David Bohm published in *The Physical Review* two articles proposing a causal reinterpretation of quantum physics. Louis de Broglie had made the first effort in this direction some 25 years earlier, but criticism of his paper led him to abandon his theory. Bohm has now revived and enlarged it. He has suggested ways to overcome its major difficulties and has invented ingenious arguments and supplementary features. These results have encouraged de Broglie to take up again his original concept. Moreover, one of his younger colleagues, Jean-Pierre Vigier, has collaborated in research with Bohm, and together they have achieved a fresh interpretation of the statistical significance of Erwin Schrödinger's famous psi function in wave mechanics. In short, a small but gifted and determined group of investigators is devoting its efforts to a re-examination of the ruling doctrine of contemporary physics. Re-examination is perhaps too polite a term. The members of this group (which includes physicists other than these mentioned) are profoundly dissatisfied with the prevailing belief; they have a doctrine of their own which they hope will help to disenthrall the majority. In de Broglie's words, they aim to "rescue quantum physics from the *cul de sac* where it is at the moment." The struggle is not without drama.

The rebels' case is brilliantly argued in Bohm's book. He begins with a philosophical prologue on cause and chance which I shall pass over. Though I suspect it is dear to his heart, it is the least convincing section of his brief. Not so the historical account which comes next. Following Bohm's lucid recital—the penetrating judgments, the original analysis of the growth of ideas and their interaction—one sees how his interpretation of the history of physics has shaped his theories. It is as a historian, more than as a philosopher, that he succeeds in explaining himself.

To understand the problem of causality and chance in modern physics one must review the status of these notions in classical physics. A few landmarks must suffice. We may regard Newton's laws of motion as the supreme model of mechanistic determinism. These laws imply that, given the initial positions and velocities of the bodies in a system at a given instant of time, and the forces acting upon them, the future behavior of the system is determined and can be predicted for all time. In brute experience, of course, the implication is a fairy tale. There are no isolated systems. Our information about positions, velocities and forces is never complete. But in planetary astronomy the laws work very well, and in Newton's day there was no reason to suspect that they would not work perfectly both up above and here below.

Pierre Simon de Laplace converted this principle of mechanics into a universal principle. Everything in the world, he said, obeys Newton's laws. They applied, one might assume, to one's disposition and to the housemaid's knee as well as to a cannon ball and the water in a river. The universe consists of nothing but bodies moving through space. Democritus and Leucippus, the Greek atomists, had had the same idea, but lacked the advantage of Newton's insight; his laws, Laplace believed, made it possible to conceive of the world as a machine which is frictionless, can never break down or wear out and, having once been started, runs on forever in predestinate ways.

In this form the mechanistic philosophy was both a boon and a deterrent to further scientific progress. It narrowed and hardened thought (much as the indeterminacy principle does today); it promoted, on the other hand, a more quantitative, unified and dynamic point of view than had ever before flourished in science.

But the path of the mechanists was not smooth for long. Three major advances in physics shook confidence in Laplace's dream. The first was electromagnetic field theory. As men began to understand electricity and magnetism, and strove to formulate the basic laws of these phenomena, it became apparent that the Newtonian scheme needed to be supplemented. Newton's bodies occupied a definite region of space. (In some mysterious fashion, to be sure, their influence vaulted over space and acted at a distance, but the less said of this the better.) Electricity and magnetism, however, were incorporeal and could not, like butterflies, be fixed with pins. A new appurtenance had therefore to be added to the classical picture, namely electric and magnetic fields. These were defined as continuously distributed throughout space as a whole; at each point in space at each instant of time the components of the field were assumed to have definite values. Electric and magnetic fields are not independent: a moving charge is a current and produces a magnetic field; a magnet in motion produces an electric field. Moreover, fields act upon bodies. Fields and bodies therefore codetermine each other. To describe the traffic of the universe a combined set of laws was necessary: Newton's equations of motion and James Clerk Maxwell's equations which determine the interrelations of field quantities, fields and the motions of the charged bodies in the system. Mechanism was no longer simple.

Additional abstractions made it terrifyingly intricate. For a time imagination clung to the ether as the vehicle for electromagnetism; the Michelson-Morley experiment extinguished this solace. Since the field appeared to exist quite happily in empty space, carrying energy, momentum and angular momentum, it could simulate some of the properties of moving bodies. Einstein went further; he suggested that special kinds of fields (satisfying nonlinear equations) might exist, "having modes of action in which there would be pulselike concentrations of fields, which would stick together stably, and would act almost like small moving bodies." It is possible, he thought, that the fundamental particles of physics consist of nothing but such agglutinations.

Mechanism is a fighting faith; it did not succumb to field theory. There had been a miscalculation; certain factors had been overlooked. But this was not fatal. If the whole of nature could not be reduced to the motions of a few kinds of bodies, it could be reduced to the motions of a few kinds of bodies plus a few kinds of fields. (Or, if one followed Einstein, to a few kinds of fields alone.) Laplace's superman would merely have to include the infinity of variables of the field in his other calculations. He would then have no difficulty predicting future states. Mechanism is also a supple faith.

The molecular theory of heat and the kinetic theory of gases posed a second challenge by introducing a "qualitatively new aspect of the laws of nature." They forced recognition of the fact that what appear to be smooth, predictable events on the macroscopic level are in truth statistical averages of a vast aggregate of irregular, unpredictable events on the microscopic level. The mean pressure, for example, of a gas on the walls of a container depends almost entirely on the general properties (*e.g.*, mean density and mean kinetic energy) of the gas molecules as a group, and is insensitive to the motions and arrangements of the individual molecules. In the small there is an enormous number of irregularities and fluctuations, but on the average these offset one another and cancel out, the result being practically determinate mean values.

It is worth taking a moment to weigh the significance of this development. If we picture the universe as a large Newton-Laplace machine, we imagine any given sequence of motions as causally and mechanically linked. The corollary of this notion is that there is a continuity of the causal chain such that any effect is directly traceable to the events which produce it, however numerous, remote or complex. New factors, however, are introduced by the kinetic theory, which enrich the conceptual structure. For instance, Bohm says, we are justified "in speaking of a *macroscopic level* possessing a set of relatively autonomous qualities and satisfying a set of relatively autonomous relations which effectively constitute a set of *macroscopic causal laws*"—the laws of thermodynamics and macroscopic physics in general. As an illustration, consider the properties of a liquid. It flows; it wets things which it touches; it tends to maintain a certain volume. Its motions satisfy a set of basic hydrodynamic equations whose variables and constants express only large-scale properties such as pressure, temperature, density, velocity and the like. Now if we are interested in describing or predicting the behavior of a mass of water, we do not treat it as a crowd of molecules, but as an independent macroscopic entity, following laws appropriate to the macroscopic level. Does this mean that the properties and behavior of the water are independent of those of its molecular constituents? Not at all. But it does mean that the large-scale entity is not only insensitive to individual molecular gyrations, but has properties peculiar to itself which the molecules, under certain arrangements, create but do not themselves possess. Bohm offers this example: When a liquid has a certain density, its intermolecular forces are in balance. If the density is increased or lowered, repulsive or attractive intermolecular forces manifest themselves which, in either case, tend to bring the density back to its original value. With the forces in balance the liquid exhibits a stability of behavior; this stability is characteristic of macroscopic entities and is not an attribute of molecules.

Another point bearing on the mechanistic philosophy is the clarification of the relationship between qualitative and quantitative changes. Take the transformation from gas to liquid to solid. In a gas the molecules are in perpetual, chaotic motion. As the temperature is lowered, clusters of molecules begin to form, but they break up almost immediately because their mean kinetic energy is high. But as one approaches a certain critical temperature the clusters build up, on the average, faster than they disintegrate. Small droplets appear and the liquid phase gains the upper hand. Now the substance no longer fills the entire space available to it but occupies a certain characteristic and definite volume. A further drop in temperature is accompanied by an increase in density and viscosity. The atoms start to arrange themselves in regular and periodic lattices; crystals take shape. At first these too have a short life because of the disruptive effects of random thermal motion, but again, around a certain critical temperature, the intermolecular forces achieve the most stable possible configuration, namely the crystal lattice, and the liquid becomes a crystalline solid. In this state the substance tends to maintain a fixed shape, to polarize light, to exhibit its own special X-ray diffraction pattern.

It is clear, then, as Bohm states, that a series of quantitative changes—in the mean kinetic energy of molecular motion—has produced a series of qualitative changes in the properties of matter. Moreover, these new properties are subject to "new kinds of causal factors . . . which 'take control' of a certain domain of phenomena, with the result that there appear new laws and even new kinds of laws, which apply in the domain in question."

The third major advance to prompt a re-evaluation of classical mechanism was the introduction of probability and statistics in connection with the analysis of Brownian motion and the formulation of the laws of thermodynamics. The extension of insights embodied in the kinetic theory of gases, and the development of the mathematics of probability, greatly enlarged the understanding of the relationship between small-scale and large-scale phenomena. By a brilliant stratagem a pyramid of knowledge was erected on a platform of ignorance. Men accepted the chance character of events on the microscopic level; but chance, as they discovered, has its rhythms and symmetries. Once it was learned how to express them in symbols and to incorporate them into a calculus, it became possible to design reasonably determinate laws for the mean behavior of large aggregates.

"It seems probable to me," Newton wrote in his *Opticks*, "that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles, so very hard as never to wear or break in pieces, no ordinary power being able to divide what God Himself made *One*, in the first creation." So long as this belief persisted, the mechanistic philosophy was enormously persuasive; indeed, it had no reason to fear a competitor. Even after confidence in it had been eroded by advances in physics, ingenious arguments were found to support the mechanistic creed. Admitting that the particles of matter are neither solid, massy, hard nor impenetrable, that atoms are not the basic building blocks, and that every time a new particle is discovered it turns out to be a changeling, it is still reasonable to suppose that a fundamental law rules the universe. From this law it will be possible to deduce the properties of molecules, atoms, mesons and everyday matter.

Yet suspicion grew that mechanism was coming to the end of the line. The classical causal laws leaked like a sieve. Every attempt to describe matter and energy at a given level was disturbed by apparently random events at the level below. There was no known case of a causal law which was completely free from dependence on "contingencies introduced from outside the context of the

law in question." Moreover, even if such a law could be imagined, the problem would arise "of reciprocal relationships between levels and between qualitative and quantitative laws."

At the beginning of the 20th century a new theory was advanced to escape this dilemma. "Indeterminate mechanism," as Bohm calls it, represented a momentous concession. For the first time the notion was entertained of an element of "absolute arbitrariness and lawlessness" entering into physical events. It was possible still to picture the universe as a great machine, but it was a machine more like an "idealized roulette wheel" than a perfect watch. It was the very nature of the wheel to be unpredictable in individual results, yet on the average to yield quite regular distributions. In studying natural phenomena one might expect at every level to encounter irregularities and chance fluctuations. The further one probed the more one might learn of causes and motions, but at bottom was an irreducible arbitrariness. This did not of course extend to statistical aggregates: thus was science rescued from logical bankruptcy. To seek a fundamental, purely quantitative law which described the working of the universe remained a reasonable objective, but, when found, the law would be probabilistic and not deterministic.

It is interesting to observe how one dogma was advanced to replace another. Deterministic mechanism held that chance was merely the name of ignorance; that all was ruled by iron laws and iron linkages; that once these were fully known, statistics would no more be needed to explain the universe than to help a man ascertain how much money he had in his pocket. Indeterministic mechanism (as developed by the late Richard von Mises, and supported by the proponents of the usual interpretation of the quantum theory) held that all determinate laws are nothing more than "approximate and purely passive reflections of the probabilistic relationships associated with the laws of chance"; and that individual processes and events in the atomic domain are "completely lawless." The second dogma is even more unconvincing than the first. Mechanism of the first kind has no experimental basis; as a philosophic assumption, however, it is not at odds with the scientific spirit. Mechanism of the second kind also has no experimental basis, but as a philosophy it lies somewhere between a *credo quia absurdum* and a firm belief in industrious angels.

The quantum theory, says Bohm, was the first example in physics of "an essentially statistical theory." It did not assume that very small things obey the laws of classical mechanics, to which statistical considerations are applied for practical reasons. Instead it restricted itself entirely to statistical predictions, "without even raising the question as to what might be the laws of the individual systems that entered into the statistical aggregates treated in the theory."

Now physics took the final step in breaking with the past. Werner Heisenberg's uncertainty principle can be interpreted as a flat denial of causality in the atomic domain. It does not merely state that the causal links at this level are beyond man's power of detection; it clearly implies that the links do not exist. This was Heisenberg's own inference from his principle, an inference to which the majority of physicists subscribed. George Gamow's able discussion of this topic elsewhere in this issue makes it unnecessary for me to go into further detail, except to mention three points. The first is that Heisenberg's hand was strengthened by a theorem of the late John von Neumann, published in 1932. This theorem appeared to furnish a mathematical proof that it is impossible to conceive of a distribution of motions of "hidden" variables which would account for the behavior of an individual system at the atomic level; which is to say that, even if information about a system could be got without disturbing it by measurement, precise predictions about its future could not be made. The second point is that the usual interpretation of the quantum theory forsook the concept of continuity of motion, as well as causality. (This, by the way, offered a roundabout solution of Zeno's paradoxes.) The third point is that Niels Bohr introduced his principle of complementarity to preserve the logic of physics from ruin. The indeterminacy principle had ostensibly ruled out precisely definable conceptual models; Bohr proposed as a substitute the use of complementary pairs of imprecisely defined concepts such as waves and particles.

That indeterminacy is at the heart of things is a view for which a number of distinguished physicists, including Albert Einstein and Max Planck, felt no sympathy. De Broglie and Bohm share this skepticism, and are in fact convinced that there are serious flaws in the reasoning underlying the prevailing conclusions. Ernst Cassirer, as I pointed out last March in a review of his excellent book *Determinism and Indeterminism in Modern Physics*, rejected the idea that indeterminacy dooms causality. Bohm goes a good deal farther.

It may be, he says, that while the quantum theory, and with it the indeterminacy principle, are valid as high-degree approximations in a certain domain, "they both cease to have relevance in new domains below that in which the current theory is applicable." Accordingly one must try to construct a new model incorporating a "subquantum-mechanical level." If with the help of such a model all the phenomena can be explained which quantum mechanics explains, and in addition phenomena can be explained which quantum mechanics is unable to explain, a momentous breakthrough will have been achieved. It is to this hypothetical structure that Bohm has turned his mind.

Let us note a few of his main points. Assume a lower basement of the physical world, not yet discovered; assume, further, that hitherto "hidden variables" are at work in this basement. We may then conjecture that the statistical character of the quantum theory arises from random fluctuations of new kinds of entities existing at the lower level. Indeterminacy will in that case be a necessary attribute of phenomena at the quantum-mechanical level, simply because the motions of the entities which can be defined at that level alone are determined by factors (hidden variables) that cannot be so defined.

Does the indeterminacy principle as such rule out the possibility of a subquantum-mechanical level as merely an "empty metaphysical speculation"? No, says Bohm, for the principle has "nothing whatever to say about the precision that might be obtained in measurements that utilize physical processes taking place at a lower level." Is there any reason to believe in the existence of such processes? Bohm suggests they may be found in the domain of very high energies and of very short distances. This is the very domain in which quantum mechanics has exhibited serious shortcomings as a tool of investigation, thus leading to a "crisis" in microscopic physics. What of von Neumann's theorem, which can be interpreted to mean that a lower level is theoretically impossible? Here the refutation is directed to what Bohm regards as a defective assumption: namely, that in specifying the state of a system one cannot dispense with the aid of "observables" which satisfy certain rules of the quantum theory. On this assumption von Neumann tried to prove that no possible set of hidden variables would help describe the system more precisely than the current formulation of the quantum theory. But the assumption, according to Bohm, begs the question; for if a subquantum-mechanical level exists, it is not unreasonable to suppose that the entire scheme of "indispensable" observables is inappropriate to this level and must be replaced by "something very different." And with the observables go the infirmities peculiar to the quantum theory.

Imagine the following model. Connected with each "fundamental" particle of physics is "a body existing in a small region of space." The body can be conceived as a mathematical point. Inseparably associated with the body is a wave, assumed to be an oscillation in a new kind of field. The field is represented by Schrödinger's psi function, which now suddenly comes to life and instead of being a mere symbol for the calculation of probabilities represents something as real as the electromagnetic and gravitational fields. Between the psi field and the body there is interaction: the field exerts "a new kind" of quantum-mechanical force on the body, which is noticeable at the atomic level but not above it, and the body exerts a smaller but definite influence on the field. The nature of the field force is undefined, except that its tendency is to pull the body into regions where the value of the field is largest. There is, however, a resistance to this tendency, consisting of random motions of the body (analogous to Brownian motions). A possible source of these motions is random fluctuations in the field itself. (Electromagnetic fields, for example, undergo similar irregular oscillations.) One may suppose that the fluctuations are associated with properties of the field at a *subquantum-mechanical level*, or arise from interaction with entities existing at this lower level. On this hypothesis there are two forces at work: the fluctuations which cause the body to wander at random over "the whole space accessible to it," and the quantum-force which pulls the body to where the field is most intense. The result is a "mean distribution in a statistical ensemble of bodies," corresponding to Max Born's probability distribution. But notice that instead of accepting the distribution, as Born does, as an absolute and inexplicable property of matter, one can interpret it as the effect of subquantum-mechanical level random motions.

Bohm claims that the model yields results consistent with all the essential results of quantum theory. Take the business of wave-particle duality. A famous example from quantum theory shows that when electrons pass through a pair of slits and fall upon a screen, an interference pattern is formed as well as a series of discrete dots. Moreover, the closing of one of the slits appears mysteriously to influence even the particles that pass through the other. The cause of this anomaly is a forbidden subject in the usual interpretation. But the new model yields an explanation. The interference pattern is produced by the waves associated with the electron. The small body connected with the electron undergoes random motion and follows an irregular path. But passage of a large number of these bodies through the slit system produces a statistical pattern of dots at the screen, whose density is proportional to the field intensity. The "quantum-force," in other words, accounts for the concentration; the random motions (of lower-level origin) account for the irregularity of the array of particle images. And the enigmatic closing effect is assumed to mean that closing one slit influences the quantum-force acting on the particle as it moves between the slit system and the screen.

Bohm considers certain criticisms of this model, related to problems of electron spin, the theory of relativity and the basic implausibility of the postulated interaction of wave and particle. He gives an account of the modifications that have been introduced to meet the criticisms. In particular he describes the dovetailing of the model with quantum field-theory, and the support which the latter offers to the central hypothesis. In all he says Bohm is appropriately tentative. His weapon against dogmatism is openmindedness. But, as he points out, it is not enough to expose the weaknesses of current theories; a fresh theory is needed to disturb complacent slumber. If he should succeed in arousing his colleagues he can expect a formidable assault on his views. There is no doubt he can take care of himself.

A final word on his philosophical opinions. Bohm's basic notion is that nature is "qualitatively infinite." This means that the qualities that man has encountered in experience thus far in no sense limit or even foreshadow what he can expect to encounter as he continues to probe, to vary his methods, to flex his imagination. One detects in Bohm's views the strands of many older philosophies—from those of the pre-Socratics to that of Henri Bergson. The more creative physicists have in recent years cultivated philosophy. They are usually disinclined to admit to this weakness. But there is no escape, even if it be only to embrace anti-philosophic philosophies. For the physicist has come to realize that if he throws philosophy into the fire, his own subject goes along with it. In this century the professional philosophers have let the physicists get away with murder. It is a safe bet that no other group of scientists could have passed off and gained acceptance for such an extraordinary principle as complementarity, nor succeeded in elevating indeterminacy to a universal law. Bohm's challenging book perhaps marks the beginning of a retreat from high-flown obscurantism and a return to common sense in science. I use common sense as William Kingdon Clifford used it: science without priestly pretensions or dogmas.

Short Reviews

Sir Richard Gregory, by W. H. G. Armytage. St. Martin's Press ($5). The subject of Professor Armytage's skillful and devoted biography is the lovable, honorable and immensely energetic man who was connected with the great British scientific magazine *Nature* for 45 years (20 of them as its editor) and who devoted a very long life (he died in 1952, aged 89) to broadening the social connections of science, bringing scientists into public affairs and in all ways deploying "the forces of science in the cause of human advancement." Gregory was born in poverty, the son of a labor organizer. His early years were a struggle to support himself and to gain an education. At the Normal School of Science in South Kensington, to which he won a scholarship, he met H. G. Wells, with whom he formed a close friendship that lasted for 60 years and profoundly affected the thought of both men. (Gregory was the only person with whom Wells never quarreled, and Armytage describes him as Wells's shock-absorber.) Gregory became assistant to the editor of *Nature*, which offered him a unique and increasing opportunity to spread his views. He wrote textbooks (one of them with Wells), initiated the editorials in *Nature*, lectured extensively, worked for the sound popularization of science, contributed measurably to the growth in importance of the British Science Guild and the British Association for the Advancement of Science, and was directly responsible for the establishment in the latter organization of a new division for the Social and International Relations of Science. As a young man he had strong Socialist sympathies (though he declined an invitation to join the Fabian Society); throughout his life he remained an impassioned reformer. He was never gingerly, for example, about turning to the left for support of his cherished program of bringing scientists to the fore in politics. The British physicist and novelist C. P. Snow has written that Gregory was trusted by scientists and governments, and for years "was treated as the official conscience of science." One might ask how it came about that a man who was not a scientist, who was "not a specially exciting journalist," and who did not even hold a degree could gain this position. (Gregory received more honors, Snow remarks, than any creative scientist of the time except Ernest Rutherford.) The reason was in part that Gregory was the beneficiary of the brilliant successes of 20th-century science and of the recognition of its importance in modern life. But the main reason was Gregory's personal character: decency, modesty, generosity, sympathy and an unswerving devotion to enlightened ends. Men at every level in science and politics, men who rarely agreed with each other on any issue, respected him and could at least agree to follow his lead.

Records of the American-Australian Scientific Expedition to Arnhem Land. Vol. I: Art, Myth and Symbolism, by Charles P. Mountford. Cambridge University Press ($18.50). Arnhem Land, in the northern section of Australia, is an almost unknown country despite the fact that this part of the continent and the adjacent Gulf of Carpentaria were the first parts of Australia to be discovered—as early as 1606 by the Dutch explorer Willem Janszoon in the yacht *Duyfken*. Seventeen years later Jan Carstensz with his two ships *Pera* and *Arnhem* sailed along the shores of the region, and it is from the name of the latter vessel that the land takes its name. In 1948 a joint American-Australian expedition, staffed by members of the National Geographic Society and the Smithsonian Institution and by Australian scientists, established four research camps in different parts of Arnhem Land to study the natural history and ethnology of an island, a river and swamp environment, a seacoast location and a plateau area. Each place has its distinctive flora and fauna, each its special aboriginal culture determined by topography and resources available to support life. Eight months were spent in the field. Many thousands of plants, fish, birds and animals were gathered, as well as large numbers of aboriginal implements and weapons. Photographs and drawings were made of many cave paintings; a collection was assembled of bark paintings and string figures; motion pictures were made of aboriginal life and natural history. The present volume, the first of four, is a splendid record, profusely illustrated, of the aboriginal art of Arnhem Land—a basic art of abstract geometric designs overlaid by a "more advanced naturalistic art in which identifiable paintings of animals, birds, fish, reptiles and human beings predominate." One of the most curious forms of Arnhem expression is the so-called X-ray art in which the internal as well as the external details of the subject are shown. But there are other more complicated forms, displayed in this book, of paintings on bark, of figures carved in wood, molded in wax, drawn in wet sand and cut out of bark. Mountford describes the songs and myths associated with the paintings, aboriginal ceremonies, the relationship between social organization and design (for example, clan affiliations and totemic ancestors determined the designs in bark paintings and other art objects) and the astronomical myths of Arnhem Land. Three volumes still to come on anthropology and nutrition, botany and plant ecology, and natural history, will complete the record of this extraordinarily fruitful expedition.

An Introduction to Probability Theory and Its Applications, Vol. I, by William Feller. John Wiley & Sons, Inc. ($10.75). The second edition of this admirable book has much new material, including two new chapters. One of these contains results on the fluctuations in coin tossing which, as the author remarks, "are so amazing and so at variance with common intuition" that even his "sophisticated colleagues" doubted that coins actually misbehave as theory predicts. Two examples will bear this out. Suppose Peter and Paul engage in a prolonged series of coin tossings; it is generally expected, assuming a perfect coin, that the lead will seesaw between them and that each player will be ahead about half the time. This expectation is entirely wrong. Feller demonstrates that in 20,000 tossings it is about 88 times more probable that one player (Peter, say) leads in all 20,000 trials than that each player leads in 10,000 trials. "In general, the lead changes at such infrequent intervals that intuition is defied. No matter how long the series of tossings, the most probable number of changes of lead is zero." A related paradox illustrating the "arc sine law" states that if a coin is tossed once per second for a total of 365 days, the approximate probability is .05 (*i.e.*, one out of 20 cases)—"a significance level dear to statisticians"—that the more fortunate player will be in the lead for more than 364 days and 10 hours. These hair-raising results offer no consolation whatever to small- or big-time gamblers. They show that when things are going badly for you at poker, roulette, craps or whatnot, you can expect them to stay that way or get worse.

CONCEPTS OF FORCE, by Max Jammer. Harvard University Press ($5.50). The German humorist Wilhelm Busch, creator of that famous pair of small monsters Max and Moritz (whose descendants are the Katzenjammer Kids), once wrote a poem about the dynamics of a box on the ear. The poem describes how the clouter's hand, rich in potential energy, starts its swing and lands with "blitz" force on the ear; how the ear becomes red and hot; how the blow is sensed as pain and touches the "deepest core of the soul." This process, says Busch, is known to the scientist as a transformation of force. Busch's poem illustrates some of the difficulties which the historian of science must expect to encounter in examining the evolution of the concept of force; for this concept, one of the oldest and most important in scientific and philosophic thought, is very hard to define, is almost impossible to sever from its original connection with human will power, spiritual influence and muscular effort, is heavy with animistic and psychological encrustations, and "early became invested with a multitude of [other] extrascientific connotations that greatly influenced the interpretation of the concept until very recent times." Max Jammer, who wrote an excellent book on the concept of space, now follows with a companion study of the idea of force. He traces the history of the concept from its first appearance in mythological cosmology to its status in 20th-century physics. The task demands wide learning and critical acumen; more, it requires an ability to orient oneself in earlier climates of thought and to interpret the many nuances of meaning of the writers on mechanics who kept changing the definition of force in building their conceptual schemes. Jammer examines Kepler's search for a mathematical formulation of force, Galileo's investigation of the kinematic aspects of motion, Newton's profound insight into the problem, and the curious theological reinterpretation of his ideas by his successors. A clear analysis is presented of the influence of Newton's third law on the development of physics, and illuminating accounts are given of the dynamic theory of Gottfried Wilhelm von Leibniz, Ruggiero Boscovich's brilliant notion of point centers of force, and the ideas of, among others, Immanuel Kant, Ernst Mach, Heinrich Hertz, Gustav

Kirchhoff and Henri Poincaré. The book concludes with a discussion of modern trends toward eliminating the concept of force from physics. As Jammer points out, there is inadequate understanding of the importance and extent of this change in attitude, representing the culmination of one of the great struggles of intellectual history.

RHYTHMIC AND SYNTHETIC PROCESSES IN GROWTH, edited by Dorothea Rudnick. Princeton University Press ($7.50). Papers from the 15th Symposium for the Study of Development and Growth, dealing with three main topics: tissue-culture methods, cyclic activity, and biochemical evolution. Several of the contributions are unusually stimulating, among them a discussion by Theodore T. Puck of his pioneering experiments on single animal cells treated as microorganisms, a paper by Colin S. Pittendrigh and Victor G. Bruce proposing an ingenious oscillator model for biological clocks, an essay by Hans Gaffron on photosynthesis and the origin of life, B. L. Strehler's "Some Energy Transduction Problems in Photosynthesis."

LIVING REPTILES OF THE WORLD, by Karl P. Schmidt and Robert F. Inger. Doubleday and Company ($10). A lavishly illustrated, ably written book about snakes, lizards and turtles, describing their appearance, habits, geographical distribution and the like. The 266 photographs, of which 145 are in color, are uncommonly good. It should be mentioned that the senior author, the noted herpetologist Karl P. Schmidt, died last September from the effects of a snakebite which he suffered while handling a specimen of *Dispholidus typus*, the "notorious" boomslang. About this reptile the book says: "Ordinarily a mild-tempered snake [which] takes considerable abuse before puffing out its neck in a threatening posture, [the boomslang] should be treated with respect, for several human fatalities have been attributed to [its] bite."

GUNS ON THE EARLY FRONTIERS, by Carl P. Russell. University of California Press ($8.50). A history from Colonial times through the years of the Western fur trade of the guns which soldiers, explorers, trappers, pioneers and Indians used against their wildlife prey and against one another. The author is a naturalist, a museum official of the National Park Service, a former superintendent of Yosemite National Park, a historian and an authority on guns. His book is the fruit of years of loving research on every aspect of the firearms of the period covered: their mechanics, the evolution of the different types, their 17th-century forerunners, their commercial and political aspects. Specialized though it is, this is a diverting survey whose many facets will interest readers other than antiquarians and curators.

Notes

ADVANCES IN GEOPHYSICS: VOL. III, edited by H. E. Landsberg. Academic Press Inc. ($8.80). This book contains papers on Arctic ice-island research, the polarization of light from the sky, subcontinental structure, heat flow through the deep-sea floor, the interior of the earth, hydrology and the use of artificial satellites in geophysical investigations.

THE PROSPECTS OF NUCLEAR POWER AND TECHNOLOGY, by Gerald Wendt. D. Van Nostrand Company, Inc. ($6). A survey for a general audience of the mechanics of atomic power and of its industrial and economic aspects.

NUCLEAR ENGINEERING, edited by Charles F. Bonilla. McGraw-Hill Book Company, Inc. ($12.50). A cooperative volume on the basic engineering principles involved in the design of nuclear-reactor cores and power plants.

AN ESSAY ON THE FOUNDATIONS OF OUR KNOWLEDGE, by Antoine Augustin Cournot. The Liberal Arts Press ($9). The first English translation, by Merritt H. Moore of the University of Tennessee, of a massive work by the noted 19th-century mathematician, economist and philosopher.

JUBILEE OF RELATIVITY THEORY, edited by André Mercier and Michel Kervaire. Birkhäuser Verlag (36 Swiss francs). This volume contains the proceedings of a conference held in Berne, Switzerland, in July, 1955, celebrating the 50th anniversary of Einstein's famous memoir on the special theory of relativity. Among the contributors are Max von Laue, Hermann Bondi, H. P. Robertson, Pascual Jordan, Leopold Infeld, Eugene P. Wigner, Max Born, Wolfgang Pauli and C. Möller.

A DICTIONARY OF SCIENTIFIC TERMS, by I. F. Henderson and W. D. Henderson. D. Van Nostrand Company, Inc. ($12.50). Sixth edition, revised and enlarged by J. H. Kenneth, of a dictionary of terms in biology, botany, zoology, anatomy, cytology, genetics, embryology, physiology.

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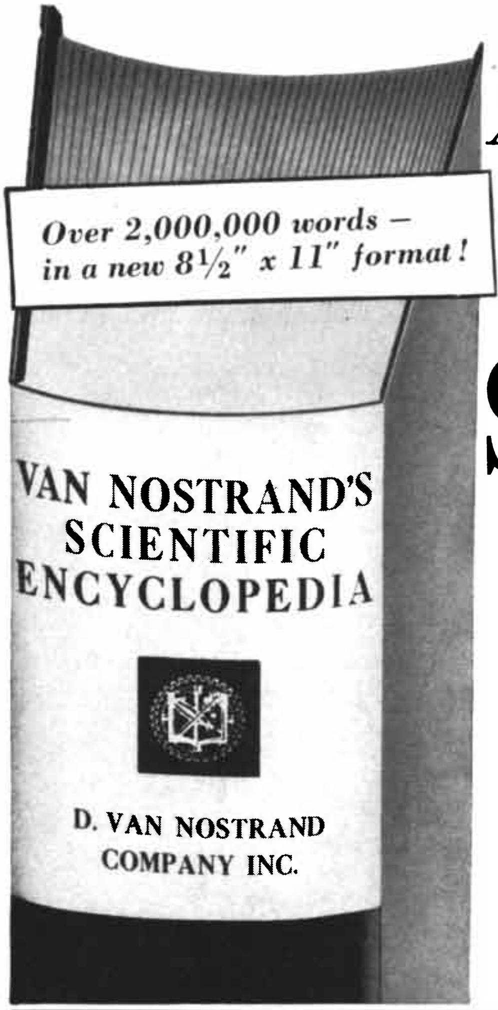

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TRACKING SATELLITES BY RADIO

MINITRACK DETAILS: SATELLITE TRACKING BASED ON PHASE COMPARISON. John T. Mengel in *Aviation Age*, Vol. 27, No. 3, pages 98-105; March, 1957.

MINITRACK SYSTEM DESIGN CRITERIA. J. T. Mengel in *Electrical Engineering*, Vol. 76, No. 8, pages 666-672; August, 1957.

OBSERVATIONS OF SATELLITE I. Fred L. Whipple and J. Allen Hynek in *Scientific American*, Vol. 197, No. 6, pages 37-43; December, 1957.

RADIO SYSTEM WILL TRACK EARTH SATELLITE. John T. Mengel in *SAE Journal*, Vol. 65, No. 5, pages 30-33; April, 1957.

THE SATELLITE PROJECT. Homer E. Newell, Jr., in *Scientific American*, Vol. 193, No. 6, pages 29-33; December, 1955.

THE LEAP OF THE GRASSHOPPER

THE ANATOMY AND INNERVATION OF LOCUST SKELETAL MUSCLE. G. Hoyle in *Proceedings of the Royal Society*, Series B, Vol. 143, No. 911, pages 281-292; January 27, 1955.

GENERAL PHYSIOLOGY. Bradley T. Scheer. John Wiley & Sons, Inc., 1953.

HOW ANIMALS MOVE. James Gray. Cambridge University Press, 1953.

NERVOUS CONTROL OF INSECT MUSCLES. Graham Hoyle in *Recent Advances in Invertebrate Physiology*, pages 73-98; 1957.

NEUROMUSCULAR MECHANISMS OF A LOCUST SKELETAL MUSCLE. G. Hoyle in *Proceedings of the Royal Society*, Series B, Vol. 143, No. 912, pages 343-367; March 15, 1955.

OBSERVATIONS ON GIANT FIBRES OF THE NERVOUS SYSTEM OF LOCUSTA MIGRATORIA. P. M. Cook in *The Quarterly Journal of Microscopical Science*, Vol. 92, Part 3, pages 297-305; September, 1951.

ULTRAHIGH-ALTITUDE AERODYNAMICS

THE ATMOSPHERES OF THE EARTH AND PLANETS. Edited by Gerard P. Kuiper. The University of Chicago Press, 1952.

THE EARTH'S ATMOSPHERE. Howard E. Roberts in *Aeronautical Engineering Review*, Vol. 8, No. 10, pages 18-31; October, 1949.

SUPERAERODYNAMICS, MECHANICS OF RAREFIED GASES. Hsue-Shen Tsien in *Journal of the Aeronautical Sciences*, Vol. 13, No. 12, pages 653-665; December, 1946.

THE PRINCIPLE OF UNCERTAINTY

ADVANTAGES AND DISADVANTAGES OF VARIOUS INTERPRETATIONS OF THE QUANTUM THEORY. Henry Margenau in *Physics Today*, Vol. 7, No. 6, pages 6-13; October, 1954.

DISCUSSION WITH EINSTEIN ON EPISTEMOLOGICAL PROBLEMS IN ATOMIC PHYSICS. Niels Bohr in *The Library of Living Philosophers*, Vol. 7, pages 199-241; 1949.

NUCLEAR PHYSICS. W. Heisenberg. Philosophical Library, 1953.

PHYSICS AND MICROPHYSICS. Louis de Broglie. Hutchinson's Scientific and Technical Publications, 1955.

BARBITURATES

THE DISTRIBUTION IN THE BODY AND METABOLIC FATE OF BARBITURATES. J. Raventós in *The Journal of Pharmacy and Pharmacology*, Vol. 6, No. 4, pages 217-235; April, 1954.

REPORT ON BARBITURATES. The New York Academy of Medicine Committee on Public Health, Subcommittee on Barbiturates, in *Bulletin of the New York Academy of Medicine*, Vol. 32, No. 6, pages 456-481; June, 1956.

SYMPOSIUM ON SEDATIVE & HYPNOTIC DRUGS. The Williams & Wilkins Company, 1954.

HOW DO GENES ACT?

THE ABNORMAL HUMAN HEMOGLOBINS. Harvey A. Itano, William R. Bergren and Phillip Sturgeon in *Medicine*, Vol. 35, No. 2, pages 121-159; May, 1956.

THE BIOCHEMISTRY OF GENETICS. J. B. S. Haldane. George Allen & Unwin Ltd., 1954.

A SYMPOSIUM ON THE CHEMICAL BASIS OF HEREDITY. William D. McElroy and Bentley Glass. Johns Hopkins Press, 1957.

EXPERIMENTS IN DISCRIMINATION

A BEHAVIOR SYSTEM: AN INTRODUCTION TO BEHAVIOR THEORY CONCERNING THE INDIVIDUAL ORGANISM. Clark L. Hull. Yale University Press, 1952.

CONDITIONED REFLEXES: AN INVESTIGATION OF THE PHYSIOLOGICAL ACTIVITY OF THE CEREBRAL CORTEX. I. P. Pavlov. Oxford University Press, 1927.

DISCRIMINABILITY AND STIMULUS GENERALIZATION. Norman Guttman and Harry I. Kalish in *Journal of Experimental Psychology*, Vol. 51, No. 1, pages 79-88; January, 1956.

DISCRIMINATION TRAINING EFFECT ON STIMULUS GENERALIZATION GRADIENT FOR SPECTRUM STIMULI. Harley M. Hanson in *Science*, Vol. 125, No. 3,253, pages 888-889; May 3, 1957.

A PRIMARY SOCIAL SCIENCE LAW. Clark L. Hull in *The Scientific Monthly*, Vol. 71, No. 4, pages 221-228; October, 1950.

THE PROBLEM OF PRIMARY STIMULUS GENERALIZATION. Clark L. Hull in *Psychological Review*, Vol. 54, No. 3, pages 120-134; May, 1947.

WHALES, PLANKTON AND MAN

THE BLUE WHALE. Johan T. Ruud in *Scientific American*, Vol. 195, No. 6, pages 46-50; December, 1956.

THE MARINE AND FRESH-WATER PLANKTON. Charles C. Davis. Michigan State University Press, 1955.

THE OPEN SEA. ITS NATURAL HISTORY: THE WORLD OF PLANKTON. Alister C. Hardy. Collins, 1956.

MATHEMATICAL GAMES

MATHEMATICAL RECREATIONS & ESSAYS. W. W. Rouse Ball. Macmillan and Co., Limited, 1939.

MATHEMATICS AND THE IMAGINATION. Edward Kasner and James Newman. Simon and Schuster, 1940.

RIDDLES IN MATHEMATICS: A BOOK OF PARADOXES. Eugène P. Northrop. D. Van Nostrand Company, Inc., 1944.

THE AMATEUR SCIENTIST

AMATEUR TELESCOPE MAKING—ADVANCED. Edited by Albert G. Ingalls. Scientific American, 1952.

THE DISAPPEARANCE OF STEADILY FIXATED VISUAL TEST OBJECTS. Lorin A. Riggs, Floyd Ratliff, Janet C. Cornsweet and Tom N. Cornsweet in *Journal of the Optical Society of America*, Vol. 43, No. 6, pages 495-501, June, 1953.

THE RADIO AMATEUR'S HANDBOOK. Headquarters Staff of the American Radio Relay League. The Rumford Press, 1957.

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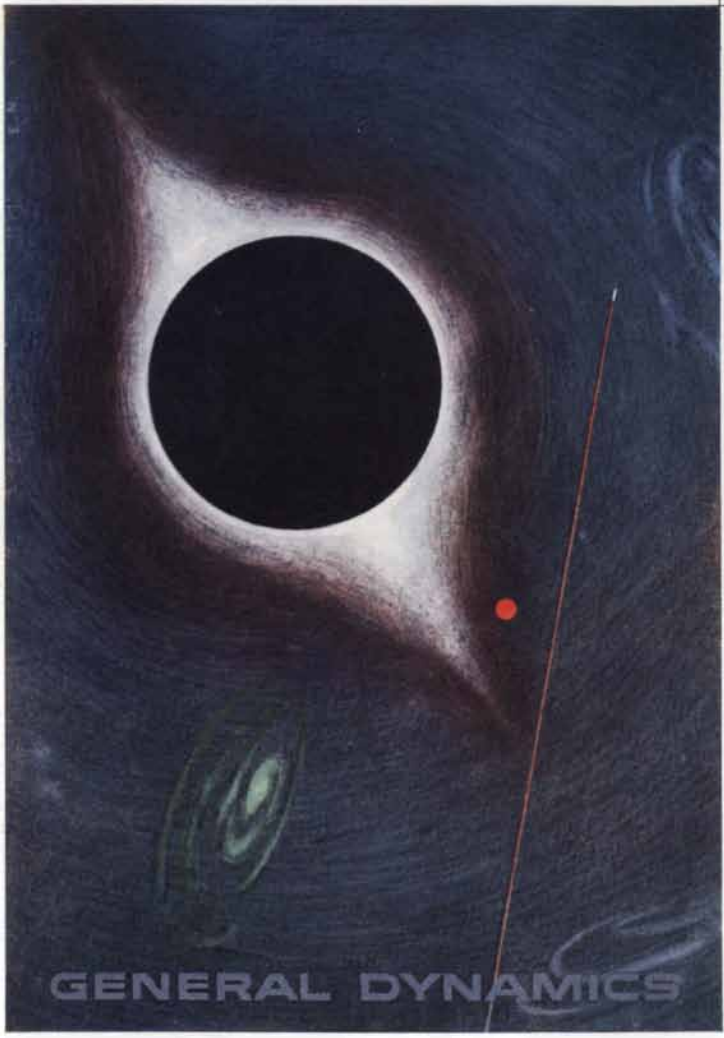

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