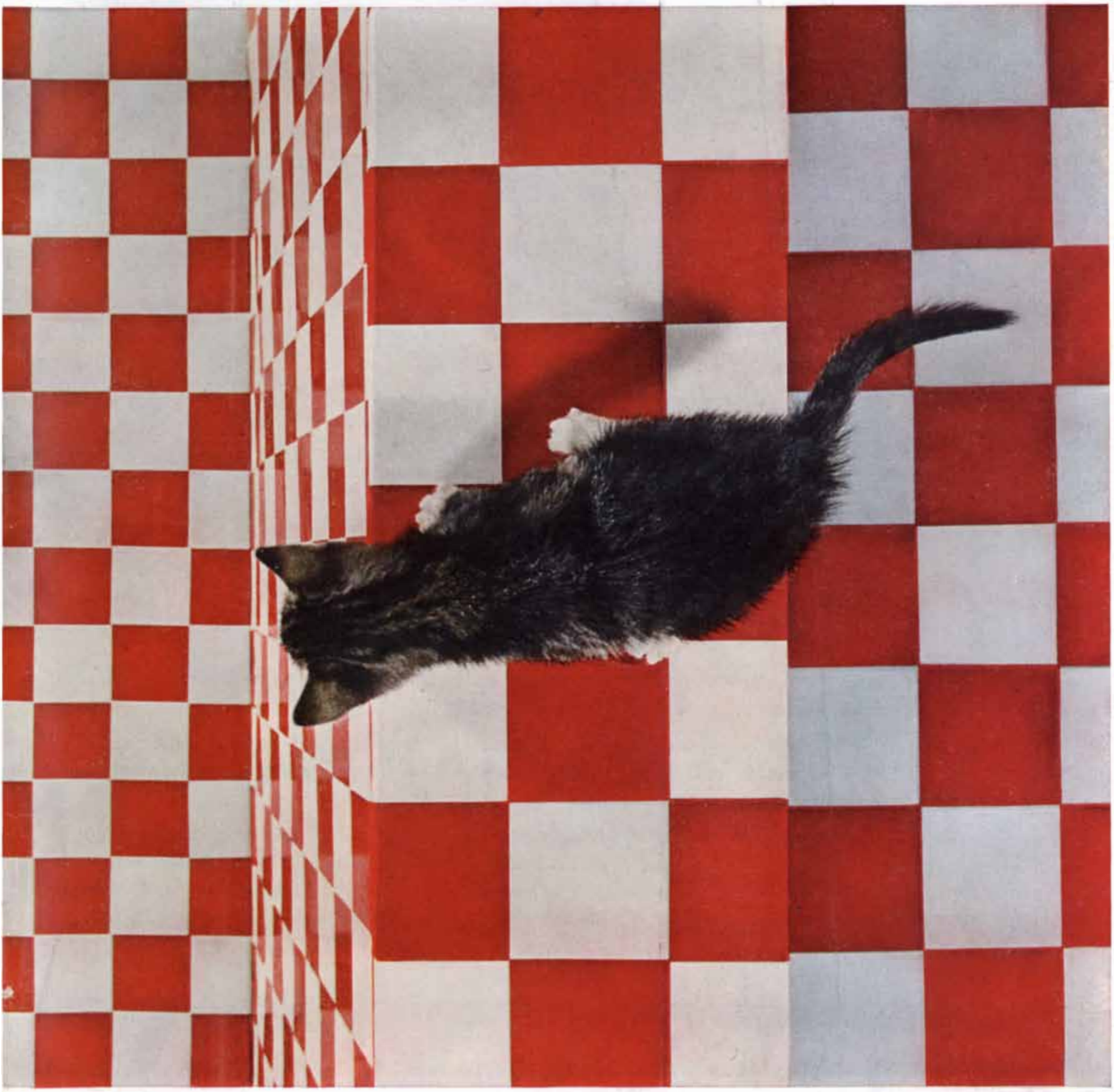
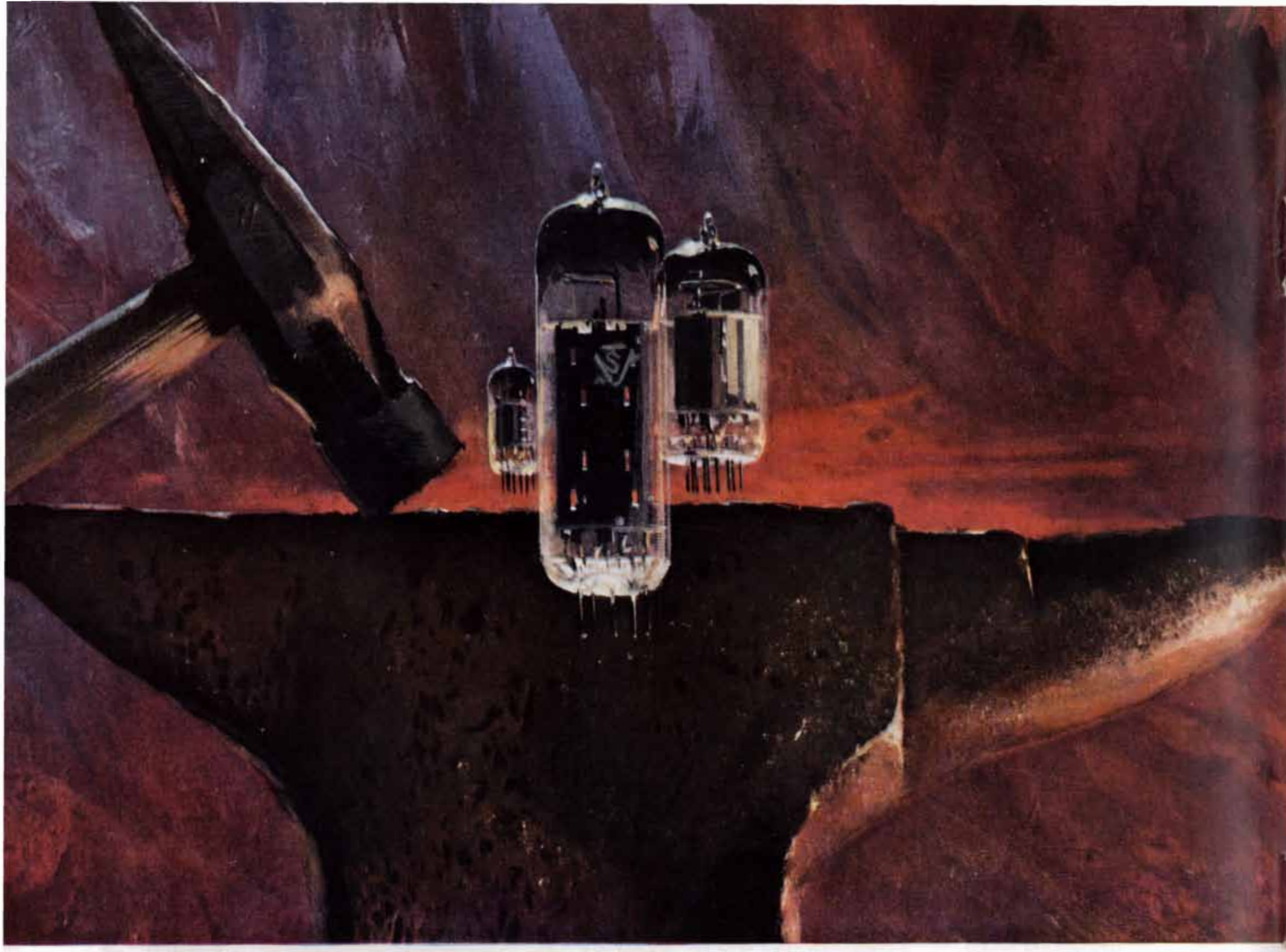
SCIENTIFIC AMERICAN



"VISUAL CLIFF"

FIFTY CENTS

April 1960



Established 1845 **SCIENTIFIC AMERICAN** April, 1960 Volume 202 Number 4

ARTICLES

DEPARTMENTS

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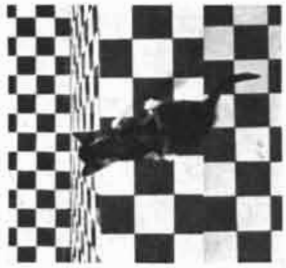

THE COVER

The photograph on the cover shows one version of an apparatus devised to test depth perception in animals and children (*see page 64*). The kitten is standing on a board laid across a sheet of heavy glass set on trestles. The patterned material, which lies directly beneath the glass on the right, is placed several feet below it on the left, giving the appearance of a "cliff." Kittens and other animals normally avoid the cliff, descending from the center board onto the "shallow" rather than the "deep" side. All of the species that have been tested thus far have demonstrated depth perception in this manner as soon as they are old enough to move about, in some cases only one day after birth. Present indications are that depth discrimination is not learned but innate. A "cat's-eye" view of the scene can be obtained by closing one eye and holding the other directly above the kitten's head.

THE ILLUSTRATIONS

Cover photograph by William Vandivert

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170	Courtesy of The Metropolitan Museum of Art, Rogers Fund, 1908
173	David Linton, courtesy of the Metropolitan Museum of Art
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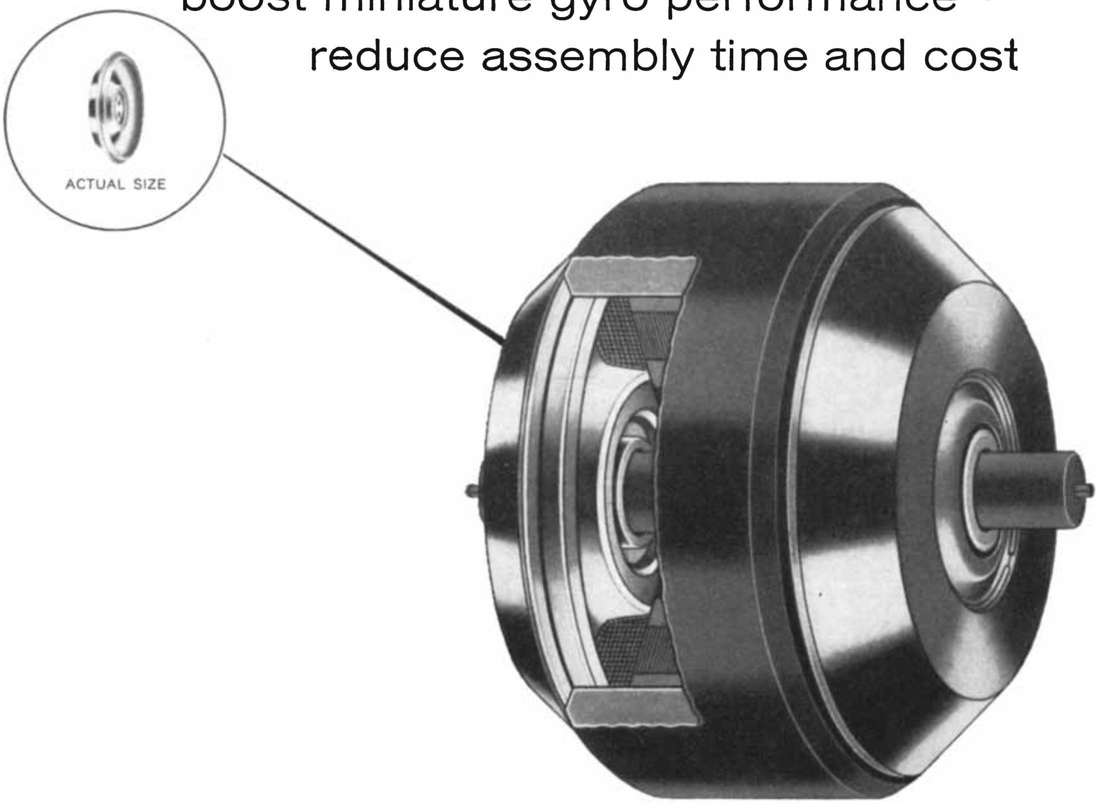
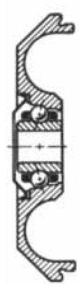
BARDEN end-bell bearings boost miniature gyro performance—reduce assembly time and cost



Integral design simplifies manufacture, reduces mating-part errors



Z155, *above and in main illustration*, is one of several Barden Precision end-bell bearings currently in volume production. Bore sizes range from .0781" to .1250" for through-bored rotor rings from .5751" to .9375" I.D. For complete technical information, write for Engineering Data Sheet Z-1.

Rotor bearings for miniature rate gyros in missile stabilizing systems must meet extremely high performance requirements, yet allow economical production and assembly. To solve this problem, Barden pioneered special configuration, high precision end-bell bearings.

Pressed into opposite sides of the through-bored rim, these bearings become an integral part of the gyro spin mass while serving as end caps for the gyro wheel assembly. This eliminates delicate fitting of very small bearings into conventional end bells . . . reduces mating-part errors and assembly time . . . improves squareness, concentricity, and overall accuracy and reliability.

One gyro manufacturer reports that the use of Barden Precision end-bell bearings in place of conventional flanged bearings reduced noise levels 50% and made it possible to meet unusually stringent life requirements.

Like other Barden advances in design and production, end-bell bearings solve a specific performance problem. Other Barden Precision bearings satisfy such extreme demands as:

- High temperatures (to 575°F.)
- Low torque (to 10 dyne-cm. for 2 lb. load)
- High speeds (to over 300,000 RPM)
- Concentric rotation (to .00005" max. T.I.R.)

Barden is a major supplier of standard bearings in sizes from .0469" bore to over 3" O.D., all manufactured to Barden Precision standards of dimensional accuracy, uniformity and reliability. See Sweet's Product Design File (8h/Ba) for Barden catalog and bearing selection guide.

for reliability . . . specify **BARDEN PRECISION BALL BEARINGS**

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AT RAYTHEON—

Scientific Imagination Focuses on —

MICROCHEMISTRY OF SURFACES

Surface impurities of less than half a monolayer can have a marked effect on semiconductor performance. Because these impurities—residual oxides and adsorbed gases—occur in such minute amounts, highly sophisticated techniques are required to detect their presence. The preparation of optimum semiconductor surfaces requires detailed microchemical data.

To investigate the oxidation and adsorption kinetics of germanium and silicon, Raytheon researchers designed and constructed a vacuum microbalance system. The vacuum microbalance reproducibly detects weight differences of less than three-billionths of an ounce in single crystal oriented samples, 0.002 to 0.004 inch thick, weighing a hundredth of an ounce.

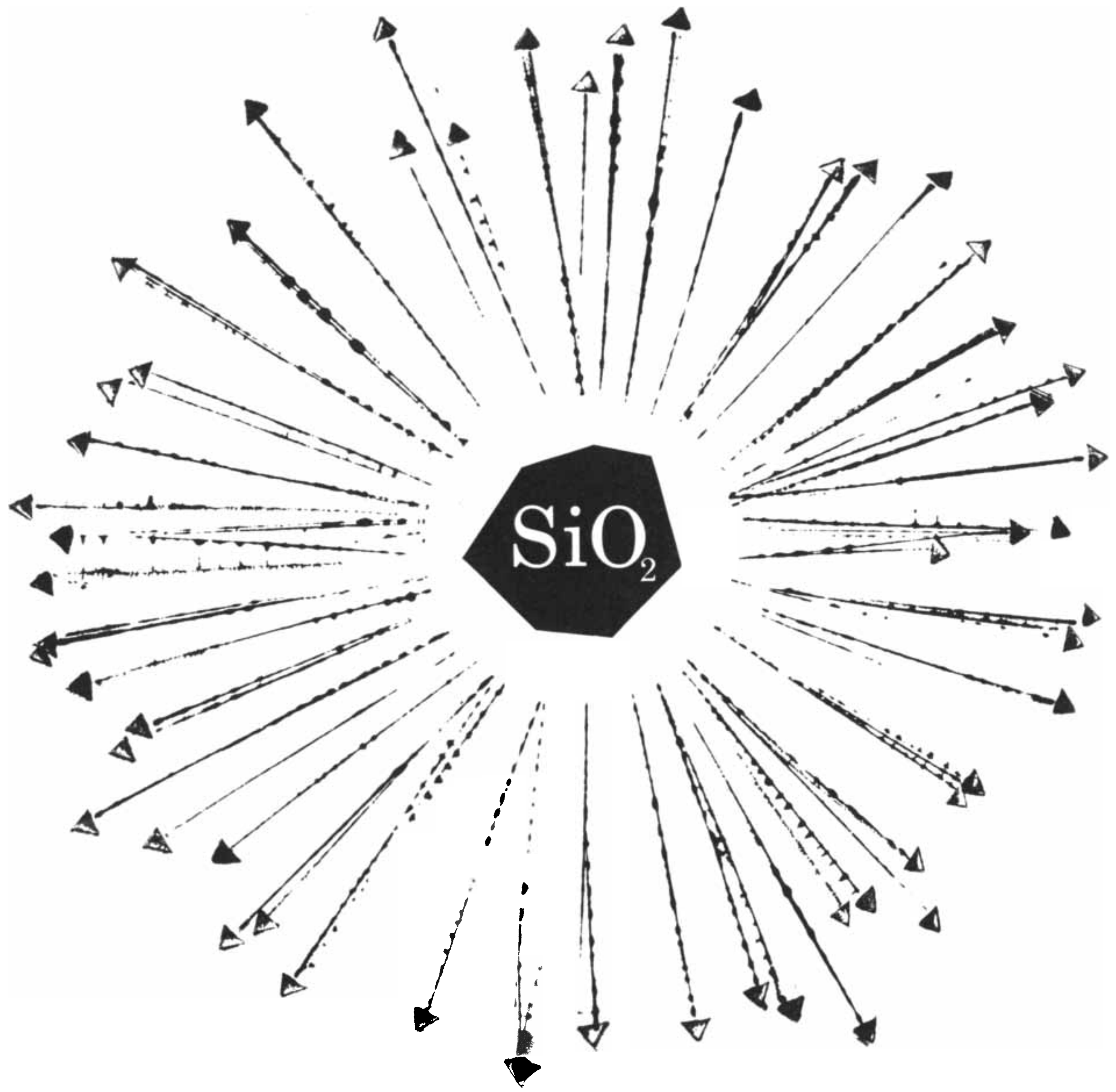
All measurements and analyses are performed in an ultra-high vacuum system in which pressures of 10^{-10} mm Hg are achieved. The initial oxygen concentration is less than one ten-billionth of the gas ambient in the apparatus. Experiments can be performed at temperatures ranging from 1200° C. to -195° C. A combination of an "omegatron" mass spectrometer and the microbalance provides information concerning changes both in the weight of a sample and the composition of the system ambient. Raytheon has made substantial contributions to the development and understanding of the omegatron.

Information obtained from these investigations will guide the development of advanced semiconductor designs. Among the scientists responsible for this unusual research endeavor are Dr. S. P. Wolsky and Dr. E. J. Zdanuk of Raytheon's Research Division.

RAYTHEON COMPANY, Waltham, Mass.

RAYTHEON

Excellence in Electronics



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Silica Gel is a form of silicon dioxide with a porous structure that can adsorb 40% of its weight of water from saturated air. The internal pore surface area of 1 cu. in. of silica gel is calculated to equal 90,000 sq. ft. Its adsorption property is purely physical . . . pore size and shape remain constant on saturation.

This large surface area characteristic is the basis for a number of industrial applications for silica gel. Because surface area, pore size and density can be carefully controlled during production, silica gel has found profitable use in such widely divergent fields as paint, oil and gas, chemical, paper and pharmaceutical. If you have a problem in gas or liquid drying, flatting, anti-blocking, thickening, moisture removal, dehydrated packaging, or catalyst support, write Dept. 5104 for technical assistance and information.

DEPARTMENT 5104

W. R. GRACE & CO.

DAVISON CHEMICAL DIVISION

BALTIMORE 3, MARYLAND

FOR THE COMBAT MARINE

Stromberg-Carlson-San Diego, in cooperation with the U.S. Marine Corps, has developed a revolutionary new tactical communications concept that will instantaneously transmit intelligence from forward observers and present a simultaneous tactical display to command. Known as BASIC (Battle Area Surveillance and Integrated Communications), it works this way:

Forward observers are equipped with small, hand-held digital message generators on which reports are "set up" through a series of switches. After checking the accuracy of his message, the observer sends the entire message in a short burst over his standard field communications equipment. The burst transmission doesn't interfere with simultaneous voice communication over the same radio channel.

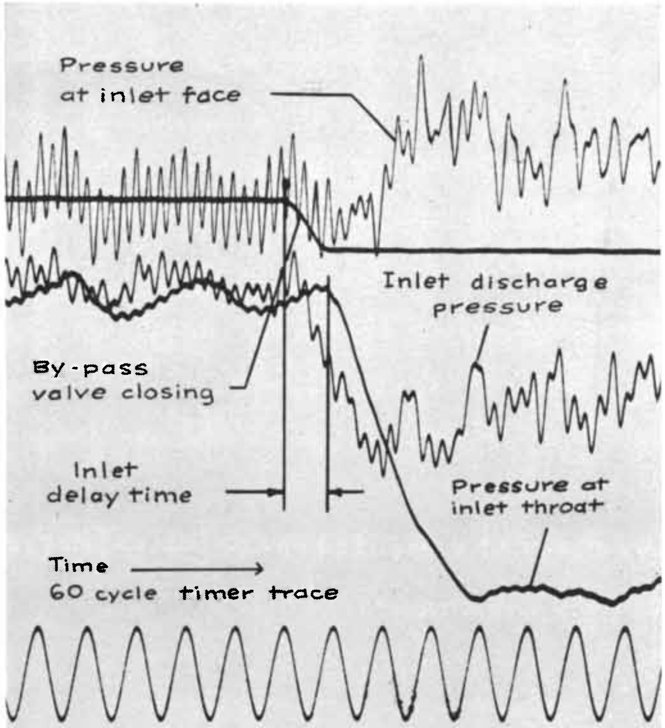
Back at the command post, surveillance information is instantly displayed on a tactical map and simultaneously presented on typewritten cards showing target identity, location and other important information. Data may be fed directly to tactical computers for artillery fire control.

The same techniques and equipment used for the Marine Corps' BASIC concept are readily adaptable to a multitude of other military and commercial communications and display systems. For information about how BASIC techniques can solve your problems, contact Stromberg-Carlson-San Diego, Dept. A-35, 1895 Hancock Street, San Diego 12, California. Telephone CYpress 8-8331.

STROMBERG-CARLSON-SAN DIEGO
A DIVISION OF **GENERAL DYNAMICS CORPORATION**

In research . . .

A Model 906 Honeywell Visicorder wrote this record of pressure fluctuations . . . "buzz" . . . for engineers at the NASA Lewis Flight-Propulsion Laboratory in Cleveland. "Buzz" is an unsteady variation in the pressure and airflow characteristics of a supersonic aircraft or missile inlet. These Visicorder studies defined the buzz-free operating limits of the inlet, and provided the designers with structural load information in case the inlet were inadvertently caused to operate on buzz during flight. This load information is vital, for inlet buzz can result in fluctuating structural loads of the order of 1000 psf . . . loads which could cause structural failure of the inlet and loss of the airplane. Visicorder records such as this have played an important role in the design of inlet control systems.

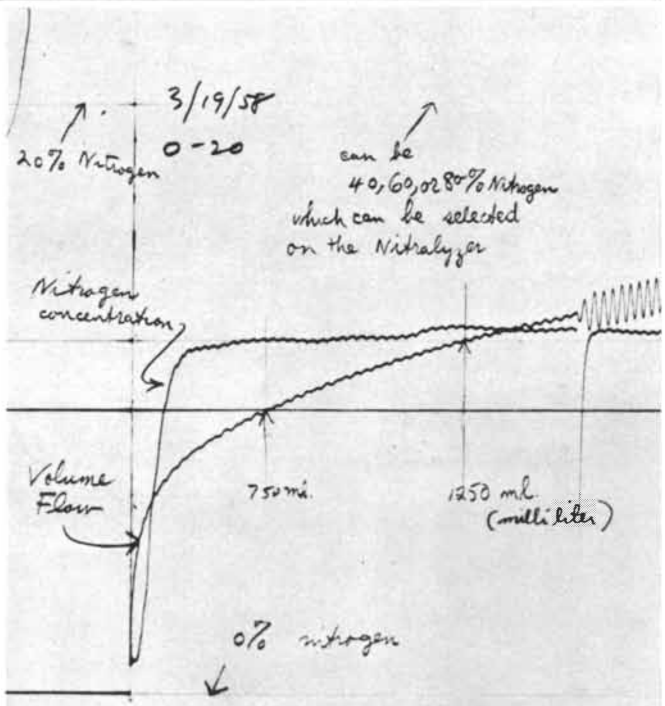


these are records of leadership

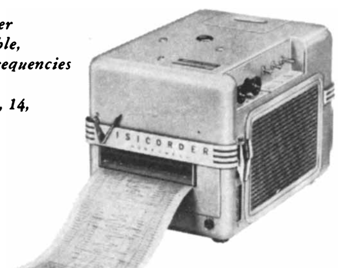
In medicine . . .

This directly-recorded Visicorder chart has told the scientists of the U. S. Public Health Service Occupational Health Program an important story about uneven alveolar ventilation in the human lung during a single breath of oxygen. In these lung function tests, the Visicorder measured anatomic dead space and abnormalities in the distribution of inspired gas in the alveoli of the lungs. The subject, under test, inhaled 100% oxygen to dilute nitrogen in the lungs. The Visicorder recorded the volume and the nitrogen percent of the exhalation. In these and in hundreds of other scientific and industrial applications, Visicorders are bringing about new advances in product design, computing, control, rocketry, nucleonics and production.

For information on applying the unlimited usefulness of the Visicorder to your specific problems, phone your nearest Honeywell Industrial Sales Office.



Visicorder records 2/3 actual size.



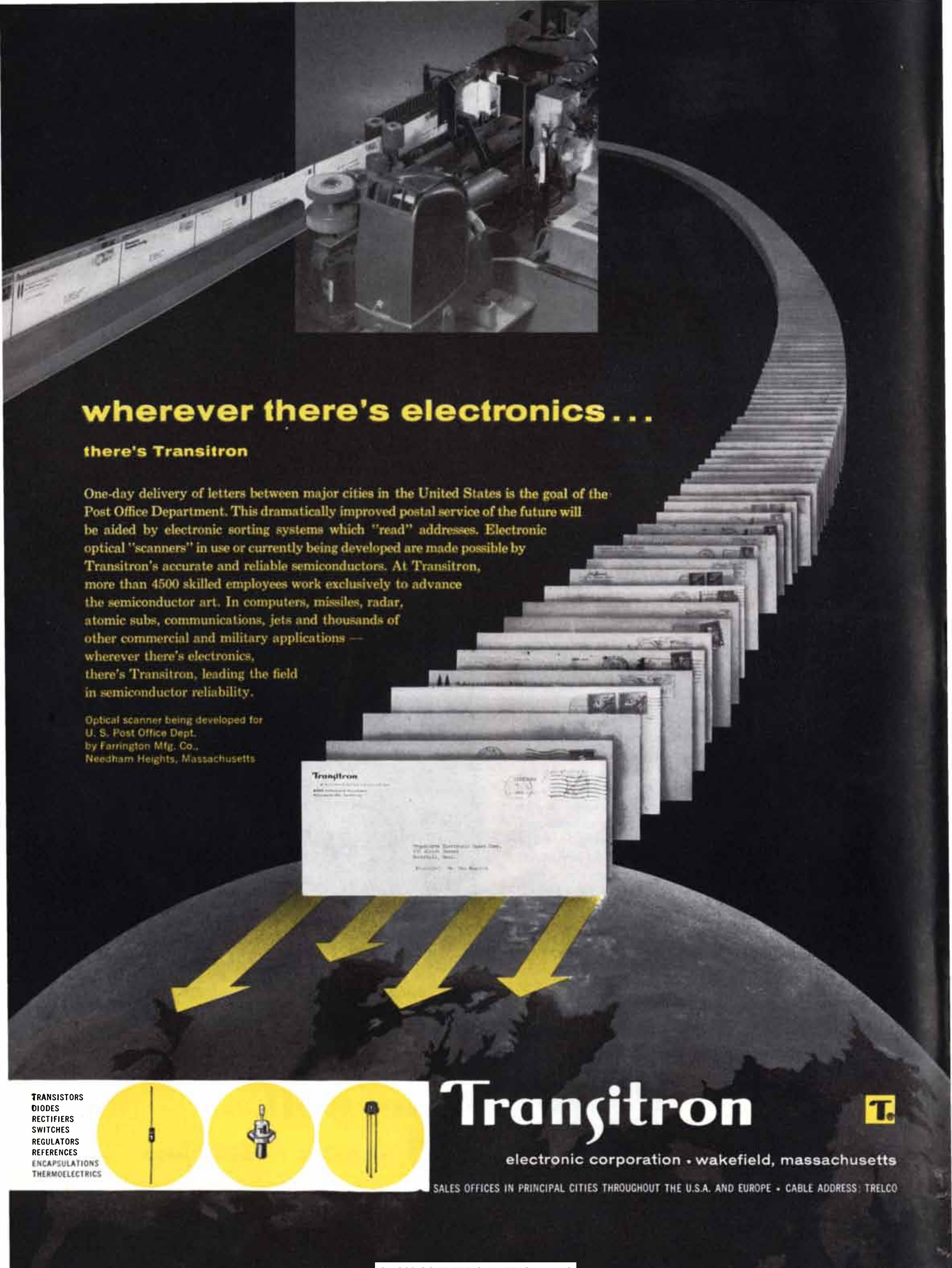
The Honeywell Visicorder provides instantly-readable, high-sensitivity data at frequencies from DC to 5000 CPS. There are models with 8, 14, or 36-channel capacities.

Honeywell

H HONEYWELL *Industrial Products Group*

Reference Data: Write for specifications on Visicorders 906B, 1108 and 1012.

Minneapolis-Honeywell Regulator Co., Industrial Products Group, Heiland Division, 5200 E. Evans Ave., Denver 22, Colorado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One-day delivery of letters between major cities in the United States is the goal of the Post Office Department. This dramatically improved postal service of the future will be aided by electronic sorting systems which "read" addresses. Electronic optical "scanners" in use or currently being developed are made possible by Transitron's accurate and reliable semiconductors. At Transitron, more than 4500 skilled employees work exclusively to advance the semiconductor art. In computers, missiles, radar, atomic subs, communications, jets and thousands of other commercial and military applications — wherever there's electronics, there's Transitron, leading the field in semiconductor reliability.
Optical scanner being developed for U. S. Post Office Dept. by Farrington Mfg. Co., Needham Heights, Massachusetts
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LETTERS

Sirs:

I enjoyed reading Martin Gardner's account of his visit with Dr. Matrix ["Mathematical Games"; SCIENTIFIC AMERICAN, January]. When the doctor was discussing the first chain reaction [obtained by Enrico Fermi in 1942; reversing the 94 gives 1492, the year another Italian made a great discovery], he was certainly on the right track, but because he did not work actively on the Manhattan District project, he missed some important verifications of his conclusions. He would have known, of course, that the only reason the pile was built during the war was to produce plutonium, the 94th element in the periodic system. What Dr. Matrix missed by not having Manhattan District clearance was the fact that the code designation for plutonium, all during the war, was "49." If the good doctor had had this fact available to him, he would also have pointed out that element 94 was discovered in California, the land of the 49'ers.

Since the real test of a new theory is its ability to predict new relationships which the author of the theory could not have foreseen, you have convinced me that numerology is here to stay.

LUIS W. ALVAREZ

Radiation Laboratory
University of California
Berkeley, Calif.

Sirs:

In his article in the January issue of *Scientific American*, "The 600-Foot Radio Telescope," which is in general devoted to looking a few years into the future, Edward F. McClain, Jr., quotes one figure that is a vestige of the past. He says: "Both solid-state devices [masers and parametric amplifiers] have lowered receiver temperatures to around 100 degrees Kelvin."

M. Uenohara and W. M. Sharpless of the Bell Telephone Laboratories have reported a six-kilomegacycle parametric amplifier with a noise temperature of around 20 degrees K. (M. Uenohara and W. M. Sharpless, *Proceedings of the Institute of Radio Engineers*, pages 2055-2148; December, 1959). Masers have exhibited noise temperatures of around 10 degrees K., and R. W. DeGrasse, D. C. Hogg, E. A. Ohm and H. E. D. Scovil, also of the Bell Laboratories, have attained an over-all receiving system noise temperature of around 18 degrees K. (R. W. DeGrasse, D. C. Hogg, E. A. Ohm and H. E. D. Scovil, *Journal of Applied Physics*, Vol. 30, page 2013; December, 1959). This included about three degrees K. due to various circuit losses, and two degrees K. due to reception of radiation from behind and to the side of the antenna, as well as 10 degrees K. due to the maser and three degrees from the sky. It appears that all but the sky noise are amenable to reduction, and we might reasonably expect noise temperatures below 10 degrees within a few years. Thus for the near future McClain's figure seems to be pessimistic by about an order of magnitude.

We should note that so far as signal level (not resolving power) is concerned, a reduction of noise by a factor of 1/10 is equivalent to an increase in antenna diameter of over three times. Other things such as bandwidth enter into the matter, but the point is an important one.

In order to attain low noise-temperature it is of course necessary so to design the antenna and the feed that little radiation is picked up from the hot earth.

J. R. PIERCE

Bell Telephone Laboratories
Murray Hill, N.J.

Sirs:

It is indeed gratifying to hear that workers at Bell Laboratories have

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achieved system noise temperatures in the neighborhood of 20 degrees Kelvin utilizing both masers and parametric amplifiers. I was perhaps being more practical than pessimistic in quoting the system noise temperatures in the neighborhood of 100 degrees K., since temperatures in this order are more nearly in keeping with what we and others have achieved in applying these devices to existing radio telescopes. It was of course impossible to refer to the Bell Laboratories work since it did not appear until December, 1959, well after the deadline for the January, 1960, *Scientific American.*

EDWARD F. MCCLAIN

Head
Radio Astronomy Branch
U. S. Naval Research Laboratory
Washington, D. C.

Sirs:

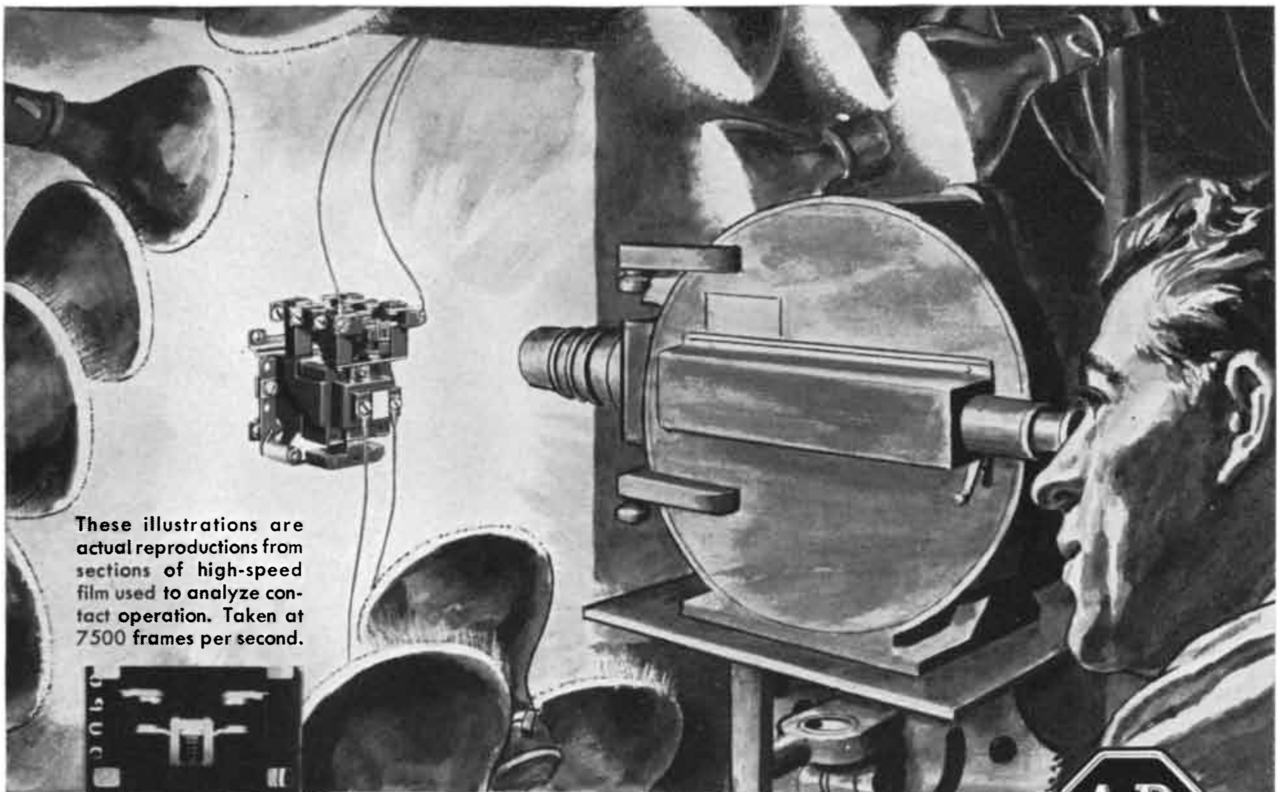
I read the article "The Green Flash" by D. J. K. O'Connell, S.J., in the January *Scientific American* with great interest. It answered many questions about this phenomenon that have been on my mind for several years.

During World War II, I was on duty with the Navy in the Pacific theater. One morning, while I was standing a 0400 to 0800 shipboard lookout watch off the coast of Japan, I began looking at the eastern horizon as the predawn glow gathered. It was a perfectly clear morning; the sky cloudless and the horizon sharply etched against it. I anticipated seeing a beautiful sunrise. But I was not prepared for the startling green flash display which would soon treat my eyes. As the first glimpse of the sun itself appeared, I was shocked to see that it was not its usual rosy sunrise color. Instead it was a brilliant, ghastly, unreal green; like a green fire. And not only the rim appeared green; but the entire visible portion of the sun's disk, amounting to about half of its diameter as it rose higher and higher, was solidly colored a fiery green. I didn't dare blink my eyes. The display lasted at least five seconds, during which the sun appeared to be a perfectly intact, sharply defined green disk. Then, suddenly, the sun became its normal rosy-white color.

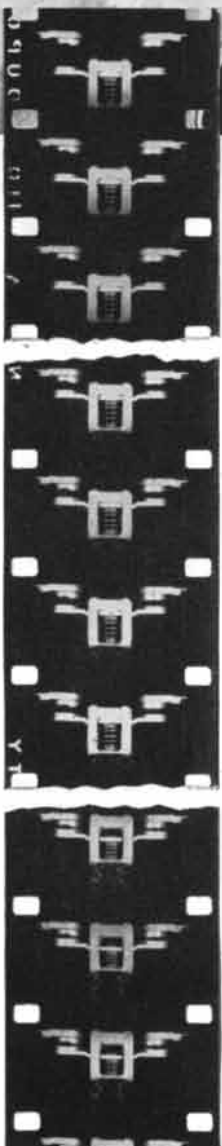
Now I know, at last, that I really saw what I thought I saw.

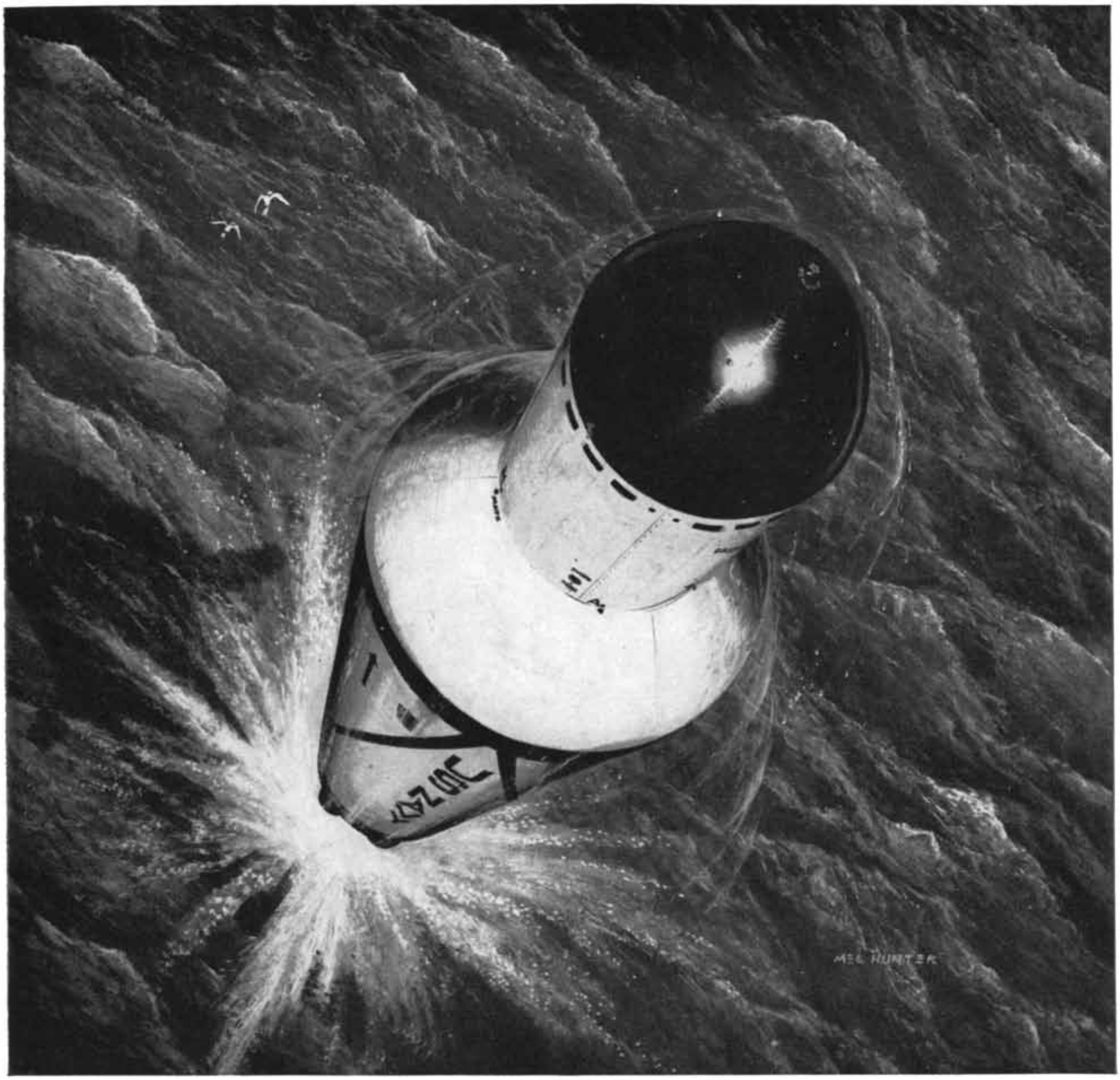
ARNOLD FREIBERGER

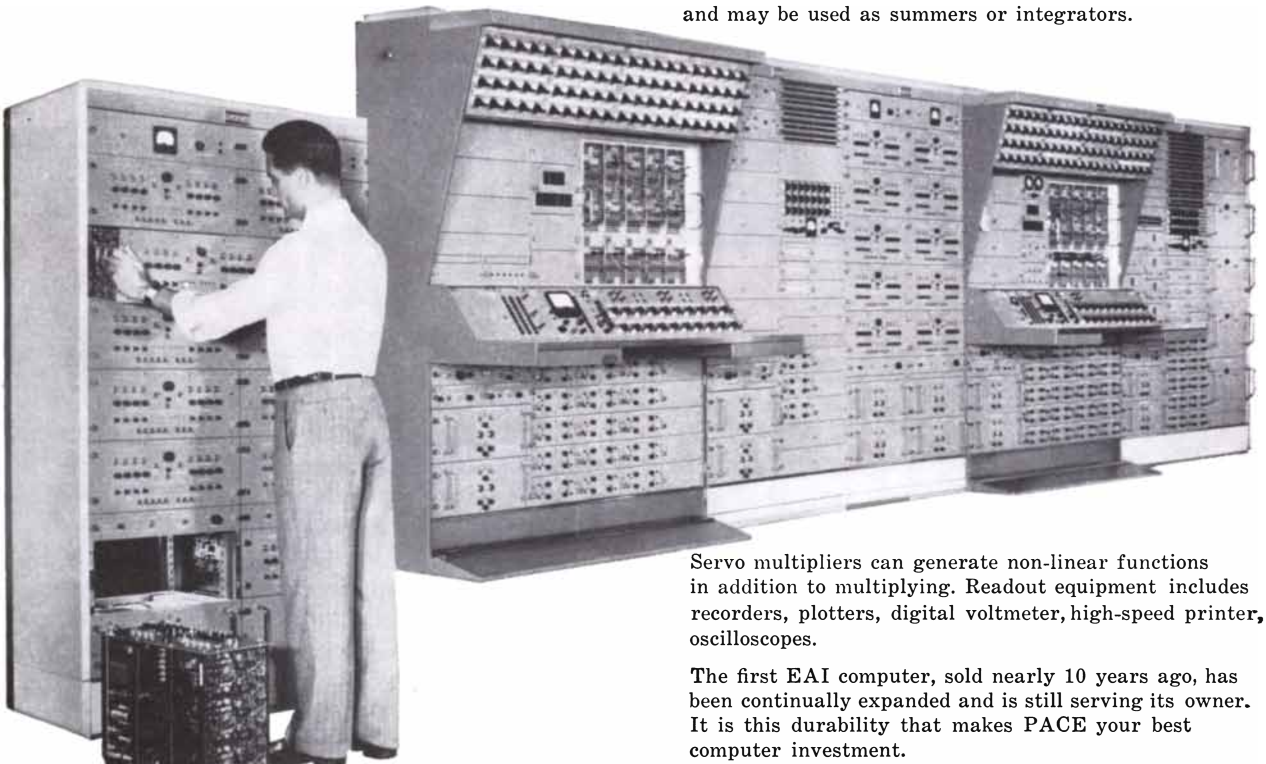
New York, N.Y.

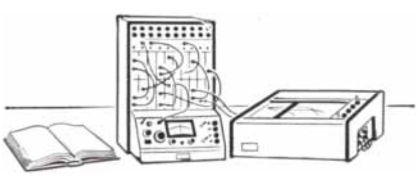


These illustrations are actual reproductions from sections of high-speed film used to analyze contact operation. Taken at 7500 frames per second.

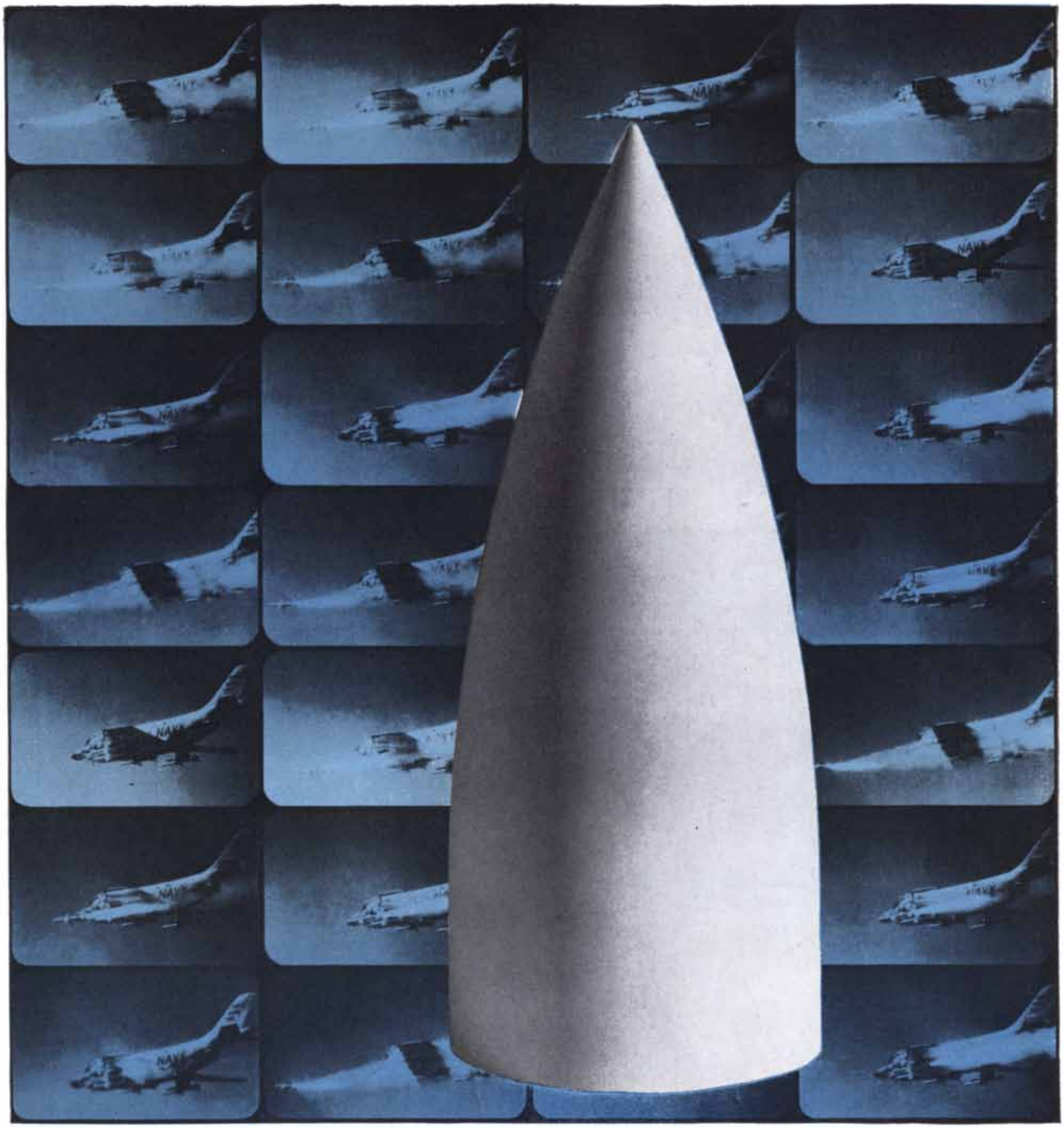



MEL HUNTER





New solid-state computer and desktop X-Y plotter.



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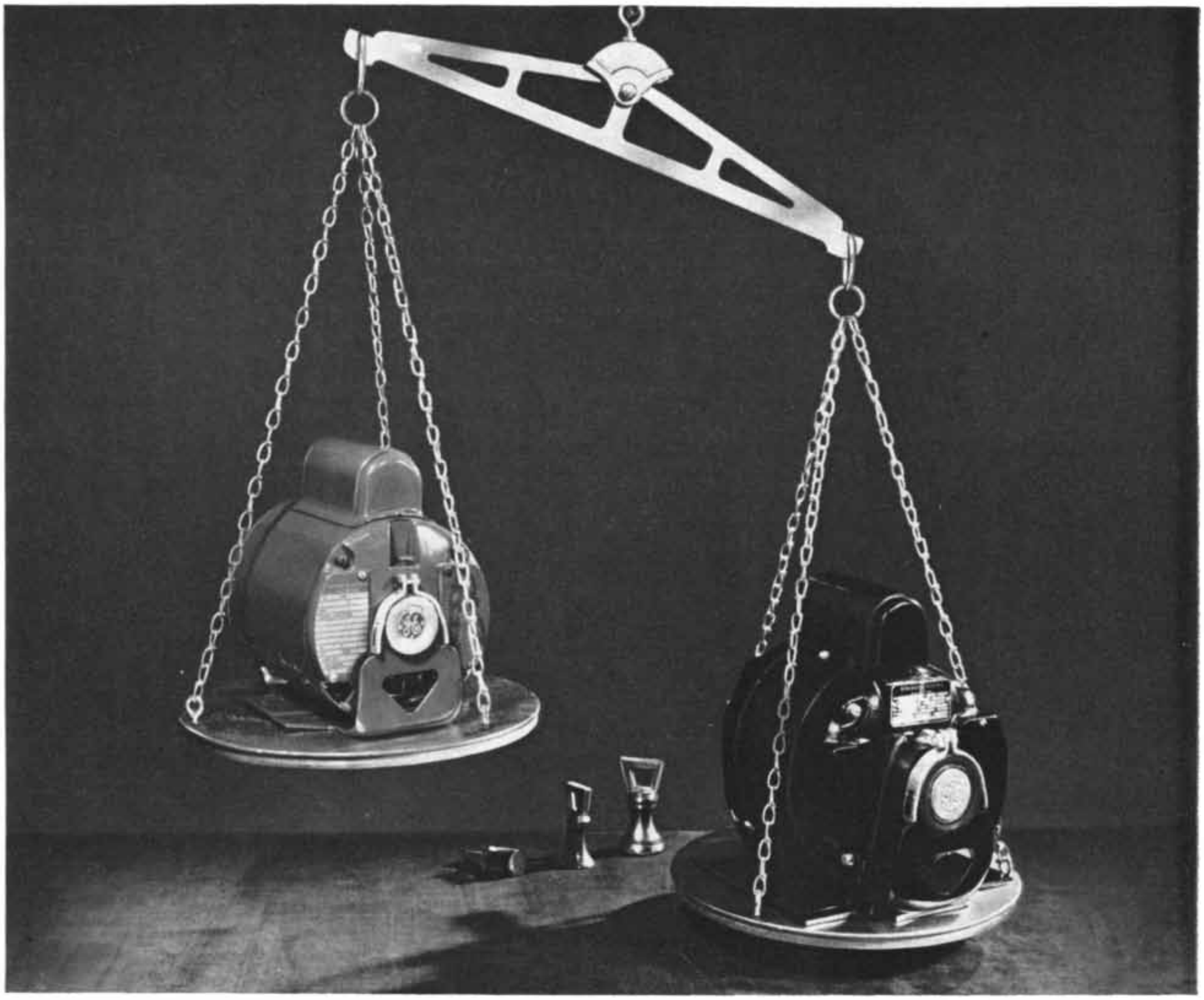
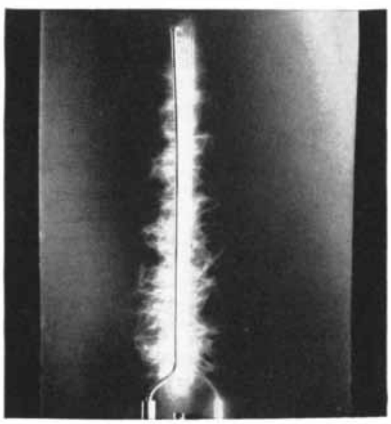


MOTOR MANUFACTURERS REPORT . . .

Tough, thin Du Pont MYLAR® helps cut size . . . improve performance . . . increase life of electric motors



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Manufacturers of electric motors are constantly seeking ways to reduce size and weight while improving motor performance. At the same time, industry demands for cost reductions have been mounting.

Alert motor manufacturers are answering the needs of industry by replacing heavier, conventional insulating materials with Du Pont "Mylar"* polyester film . . . often with *savings in materials costs*. Toughness of "Mylar" in thin gauges permits manufacturers to design lighter, smaller motors . . . stability and moisture resistance of "Mylar" helps extend motor life.

This is but one of the many ways "Mylar" is helping industry improve product performance, develop new products or lower costs. Magnetic recording tape, for example, is tougher and thinner. Drafting film of "Mylar" is more durable, resists rough handling.

For helpful information on how you can improve product performance and lower costs with "Mylar", write today for our new booklet. E. I. du Pont de Nemours & Co. (Inc.), Film Dept., Room SA-4, Wilmington 98, Del.

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

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POLYESTER FILM

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1910: "Again the transatlantic record has been broken, this time by the *Mauretania,* which reduced the long Atlantic course of 2,889 miles by 26 minutes, making the passage from Daunt's Rock to the Ambrose Channel Lightship in 4 days, 15 hours and 29 minutes, at an average speed of 25.91 knots."

"Once again the famous sands of Ormond Beach have been used for making new records with automobiles. During the three days' meet held last week Barney Oldfield once more beat the world's record for speed with his new 200-horsepower Benz racer. This machine, which broke four world's records last fall in England, traveled two miles in 55 87/100 seconds, nearly three seconds better than the record of 58 4/5 made by Demogeot in 1906 with a Darracq car. The rate of speed traveled by Oldfield is 128.89 miles an hour. Oldfield also made new records for the kilometer and the mile. His record for the kilometer (3,280 feet) was 17 4/100 seconds; for the mile, 27 33/100 seconds, a speed of 131.72 miles an hour. In the stock-car races, Oldfield made a new record of 40 35/100 seconds for one mile in a Knox machine. This make of car also won the 10-mile free-for-all in 8 41/100 minutes; a Chalmers 40-horsepower car took second place."

"Whereas biology was until recently chiefly a science of observation, it has now become in a high degree experimental. Gregor Mendel, 40 years ago in his cloister at Brünn by his careful experiments on the crossing of thousands of peas, succeeded in unveiling a law which has profoundly influenced ideas on heredity, not only in plants but in animals. We here have a definite arithmetical relation, which is susceptible to very exact study and confirmation. The method of Mendel, which we may call that of experimental evolution, is now of wide application, and there are laboratories which do nothing else but breed and cross under very exact control. Among one of the large-scale experimenters in this line may be mentioned Mr. Luther Burbank, who, though a master of method and subsidized by the Carnegie Institution, seems to be devoted rather to practical than to scientific results."

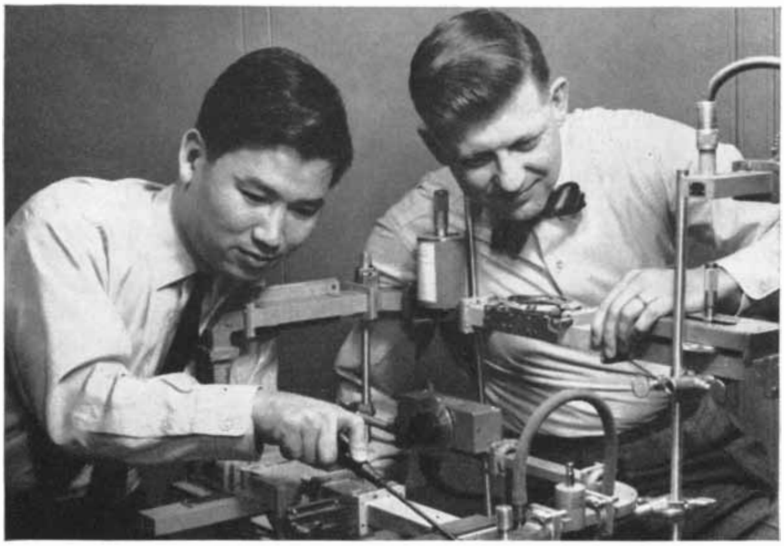
"Credit for producing the first aeroplane to rise from water and fly must apparently be given to M. Henri Fabre, who, according to the French journal *Aéro,* succeeded in getting his combined hydroplane and aeroplane to leave the water and make several flights 1,200 to 1,500 feet in length at heights of from 6 to 10 feet. The experiments were made at the Port de la Mède at Martigues, a city near Marseilles. The first successful flight from water was made on March 31st."

"During recent tests of wireless telegraphy made with apparatus on board the scout cruisers *Salem* and *Birmingham,* which were 1,000 miles from each other, and 1,000 miles from the high-power wireless station at Brant Rock, Mass., there were serious interruptions in the communications between the two ships and the shore station. A fierce storm was raging at the time of the tests, and, in spite of the interruptions, the apparatus was not considered a failure. During the next test the ships will be stationed about 2,000 miles from Brant Rock, one being near Trinidad, and the other 1,000 miles out from the South American coast. The most exhaustive test will be the placing of the ships on the African coast, 3,000 miles from Brant Rock and 1,000 miles apart. If these tests are successful, a tower 100 feet higher than the Washington monument, which is 555 feet in height, will be erected in Washington for communication with ships over a distance of 3,000 miles."

Scientific American.

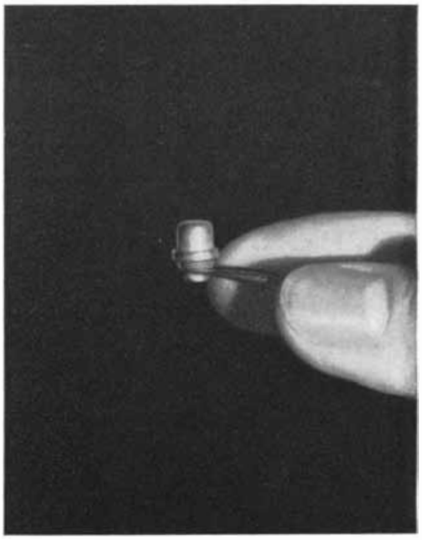
APRIL, 1860: "The Japanese steam corvette *Candinmarruh* arrived at San Francisco on March 17th, 37 days from Jeddo. This corvette is the first native vessel ever permitted to leave the shores of Japan. It brings the information that the Japanese embassy was to leave for the United States, on the *Powhatan,* on February 11th. The corvette is 250 tuns burthen, carries 10 guns, and her crew consists of 57 men. The people of San Francisco are delighted with the arrival

THE IDEA THAT GREW FOR 100 YEARS



At Bell Laboratories, M. Uenohara (left) adjusts his reactance amplifier, assisted by A. E. Bakanowski, who helped develop first suitable diode. Extremely low "noise" is achieved when certain diodes are cooled in liquid nitrogen.

First practical diode for amplifier, shown here held by tweezers, was jointly developed by A. E. Bakanowski and A. Uhlir.



How basic scientific ideas develop in the light of expanding knowledge is strikingly illustrated by the development of Bell Laboratories' new "parametric" or "reactance" amplifier.

Over 100 years ago, scientists experimenting with vibrating strings observed that vibrations could be amplified by giving them a push at strategic moments, using properly synchronized tuning forks. This is done in much the same way a child on a swing "pumps" in new energy by shifting his center of gravity in step with his motion.

At the turn of the century, scientists theorized that *electrical* vibrations, too, could be amplified by synchronously varying the *reactance* of an inductor or capacitor. Later amplifiers were made to work on this principle but none at microwave frequencies.

Then came the middle 50's. Bell Telephone Laboratories scientists, by applying their new transistor technology, developed semiconductor diodes of greatly improved capabilities. They determined theoretically *how* the electrical capacitance of these new diodes could be utilized to amplify at *microwave* frequencies. They created a new microwave amplifier with far less "noise" than conventional amplifiers.

The new reactance amplifier has a busy future in the battle with "noise." At present, it is being developed for applications in tropospheric transmission and radar. But it has many other possible applications, as well. It can be used, for instance, in the reception of signals reflected from satellites. It is still another example of the continuing efforts to improve your Bell System communications.

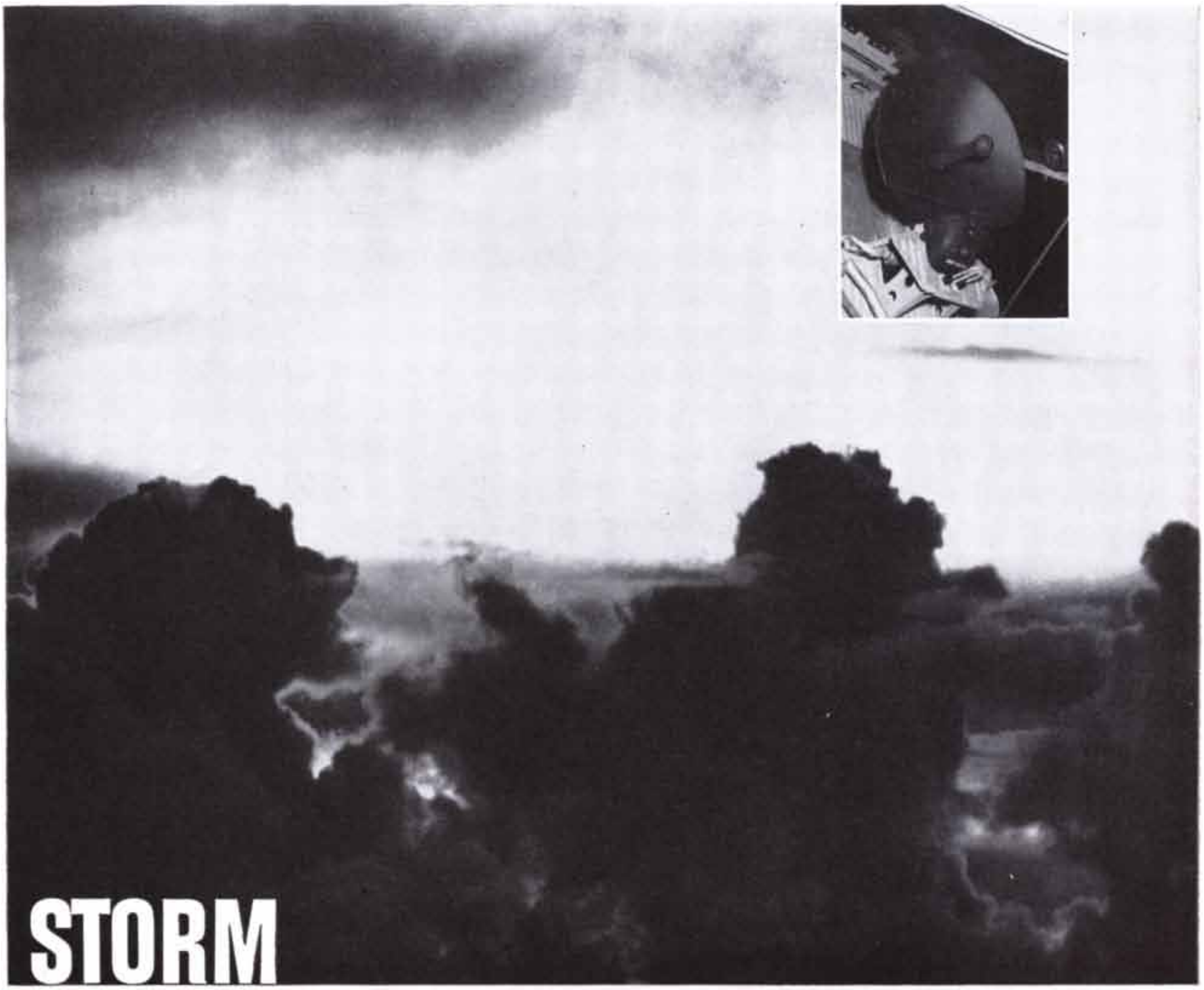
BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT of the Japanese, and are doing everything in their power to entertain their visitors, hoping thereby to stimulate the lucrative trade already commenced with Japan."

"A Paris correspondent of *The New York Daily Times* says that the police of Paris have been for some months engaged in the examination of a variety of falsifications, and among the rest that of perfumery. Several actresses have been suffering from the effects of poison absorbed from the face, without suspecting that their sufferings came from this source. The quantity of corrosive sublimate, arsenic, verdigris, vitriol and other poisonous substances daily absorbed in Paris must in effect be immense, and the reform did not commence too soon. The investigation was instigated by an actress of the Varieties Theater against a perfumer for damages for indisposition attributed to his cosmetics."

"According to the *Annual of Scientific Discovery* for 1860, the researches made in the department of electricity, during the past year, have been most important; Messrs. Faraday and Grove, of England, occupying, as in years past, the most prominent positions as investigators. The results of the experiments instituted by the latter gentleman are exceedingly curious, and must be regarded as all but proving the truth of the modern theory which assumes that electricity is not, in any sense, a material substance, but only an affection (state) or motion of particles of ordinary matter. Thus he shows conclusively, by a great number of carefully instituted experiments, that electricity cannot be transmitted through a vacuum, and that in transmitting electricity through gaseous media, the facility of transmission is increased by a degree of attenuation in the media, but that when a certain point of attenuation is passed, transmission becomes difficult, and finally impossible."

"Samuel Colt, the patentee of the famous six-shooter, has just made application (through Mr. Loomis, a representative in Congress from Connecticut) for a renewal of his patent, known as 'Colt's Rotating Chamber Fire-arms.' Colt has had pretty hard luck heretofore in attempting to get Congress to renew his patent; but he evidently thinks that, by steady perseverance, he may at some time accomplish his object. We recommend to Col. Colt the perusal of the first verse of the 11th chapter of Hebrews."



STORM WARNING... BY RADAR

Atmospheric turbulence has the characteristic of reflecting microwave signals, with the degree of reflection depending on the severity of the turbulence. Returned to the aircraft, this reflected radar warning is displayed in a manner that warns the pilot of the exact location and extent of the turbulence, enabling him to change his course and fly around dangerous storms. Since the radar display also shows him "holes" in storms where there is little or no turbulence, the pilot can choose a course that will result in maximum safety and minimum delay.

Commercial airlines use Varian klystron-equipped weather radar to assure the comfort and safety of passengers and the reduction to a minimum of storm hazards and delays. Photo above shows radar antenna inside the Radome nose of a United Air Lines plane.

In addition to the technical advantages of Varian klystrons to the equipment designer, their rugged mechanical construction and long life are vital benefits to the user. These characteristics are reasons why Varian has become the world's largest manufacturer of klystrons.

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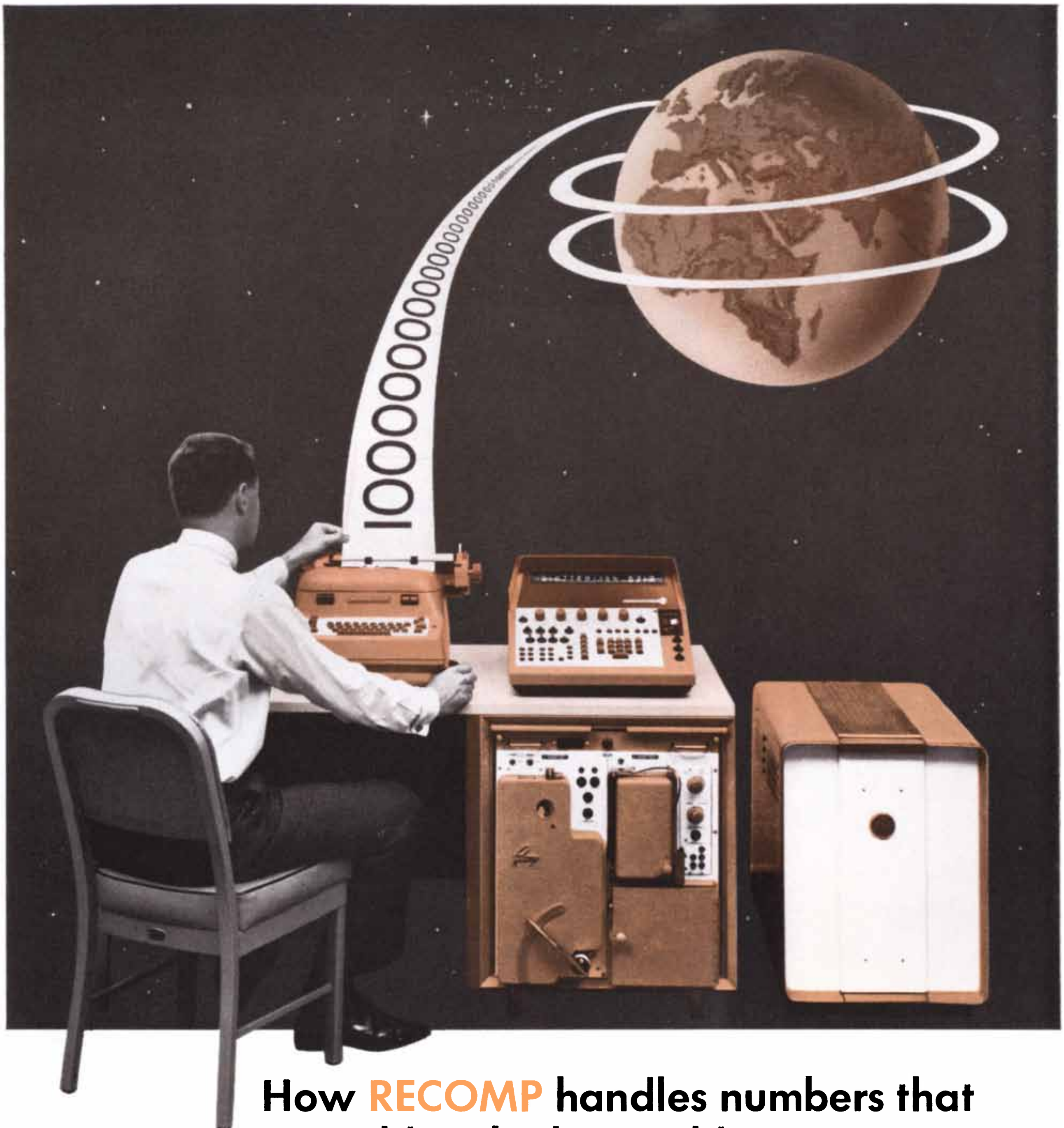


How RECOMP handles numbers that could circle the world 2½ times

RECOMP can handle a floating point number greater than four billion factorial . . . or larger than the figure 1 followed by 41 billion zeros. Typewritten, the number would stretch around the world two-and-one-half times.

RECOMP is a low-cost, general purpose, digital computer—the original solid state computer with *proven reliability*. Its built-in floating point arithmetic and square root instructions come as a standard feature among RECOMP's 49 commands . . . at no extra cost.

Easy to operate, easy to program . . . RECOMP has a storage capacity of over 8000 instructions, simplified coding, fingertip control console with digital readout panel, and a high-speed photoelectric tape reader.

High-powered RECOMP is designed to solve problems of engineering, science, and industry. For information on how RECOMP can solve your special problems, write Autonetics Industrial Products Division, Dept. 104, 3584 Wilshire Boulevard, Los Angeles 5, California.

Digital computers by Autonetics

INDUSTRIAL PRODUCTS

A DIVISION OF NORTH AMERICAN AVIATION, INC. Other offices: Chicago, New York, Washington, D.C.

TARGETS: MOON AND BEYOND. Guidance and control requirements for lunar and planetary travel, and for computers that will operate accurately in space vehicles, are among problems Sperry is studying under current space contracts.

PRECISION FLOATED GYROS for space "platforms" must be as clean as surgical instruments to maintain accuracy through thousands of miles of flight. Assembly is delicate job performed in dust-free laboratories.

ENVIRONMENTAL CHECK FOR HUSTLER BOMB-NAVIGATION SYSTEM. The USAF's supersonic bomber must maintain global capability over a period of years. Here Sperry engineers put the control console of the B-58's rugged, highly accurate bomb-nav system through its paces.

"Sharpshooting" Near and Far Space

New techniques in inertial guidance, space computing, airborne radars are answering the new challenges of space-age navigation.

ONE OF A SERIES:

THE STORY BEHIND THE STORY
of Sperry's Air Armament Division

Inertial is a word in the news more and more, as man ventures farther and farther into space. What it means fundamentally is built-in, independent guidance to a target—whether that target be a hamlet on the map or a plateau on the moon. Inertial navigation success depends greatly upon the absolute accuracy of the individual guidance system and its gyros and accelerometers.

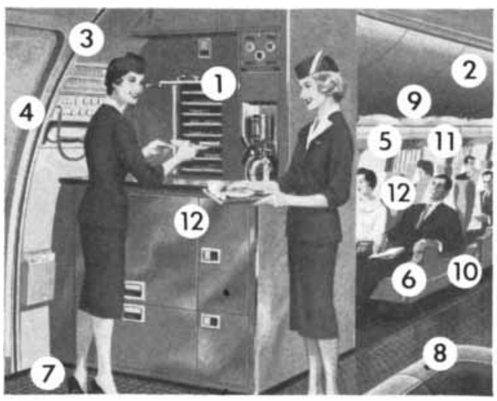
To achieve this accuracy for the Convair B-58 Hustler bomber . . . and for the lunar, planetary and orbiting craft of the future . . . is the major assignment of Sperry's Air Armament Division. The magnitude of this job is seen in the fact that since 1950, 25 million manhours have been expended on inertial guidance by Sperry engineers.

Air Armament has produced or is developing advanced air and space craft equipment such as inertial navigation components for space-exploring vehicles . . . USAF's lightest and smallest search radar . . . Loran C radio navigation system that can pinpoint position up to 1500 miles. And when North American's X-15 takes the first man to the fringes of space and back, an advanced Sperry inertial system will guide him.

Meanwhile, Sperry continues to research and develop still more advanced concepts for ever sharper "shots" in space. Air Armament Division, Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, N. Y.

SPERRY

...made possible with flexible and rigid **stafoam**



Newest jet aircraft use stronger-but-lighter STAFOAM in many forms to provide passenger comfort and protection.

To create home-like comfort at 30,000 feet manufacturers of today's jet passenger liners faced countless new challenges – and solved them in an amazing number of cases with versatile STAFOAM urethane. Whether used for insulating, bonding, padding, or sealing, for transparent windows or foamy chair cushions, the plus-properties of STAFOAM provide the superior service essential to Space Age materials. You, too, will find a new dimension of material technology in miraculous STAFOAM. Take your next product problem to the Freedlander R & D Laboratories, American Latex Products Corp., or its branches.

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Acoustic dampening	Commercial cushioning	Instrument & motor mounts	Crystal clear windows & mtrls.	Instrument & control knobs
Foam core construction	Shock padding (high hysterisis)	Elastomer coupling	Control knobs & accessories	Instrument scope boots
Helmets and liners	Clothing insulation & liners	Oxygen hose and masks	Electronic encasing	Airless wheels & tires
Packaging & flotation	Air & liquid filtering	Window and hatch gasketing	Applicable hardware	Applicable hardware

NEW MINIATURE A.C. MOTOR

high output for commercial use

This a.c. synchronous motor costs you only about half as much as its miniature precision counterpart for military applications. In production quantities it is so economical that you can design it into good quality products that now use induction motors. And because you can put this **bigger** performance motor in **smaller** spaces, it gives you a head start in miniaturizing your design at the same time you improve product quality.

Vital statistics: This Type CMC motor has a starting torque of .7 oz. in. and a continuous duty torque of .7 oz. in. at synchronous speed. It is $1\frac{1}{4}''$ in diameter by $2\frac{5}{8}''$ long, and weighs $6\frac{1}{2}$ oz. The shaft is precision ground stainless steel, supported by ball bearings. The epoxy-sealed design provides good resistance to normal environmental conditions.

If you have hesitated to design with precision miniature motors in the past, now's your chance!

The Globe motor line includes both a.c. and d.c. models. Globe is pleased to work with you to provide the exact motor you need for your commercial, competitive product. Please write for Bulletin CMC. Globe Industries, Inc., 1784 Stanley Avenue, Dayton 4, Ohio. BAldwin 2-3741.

GLOBE INDUSTRIES, INC.

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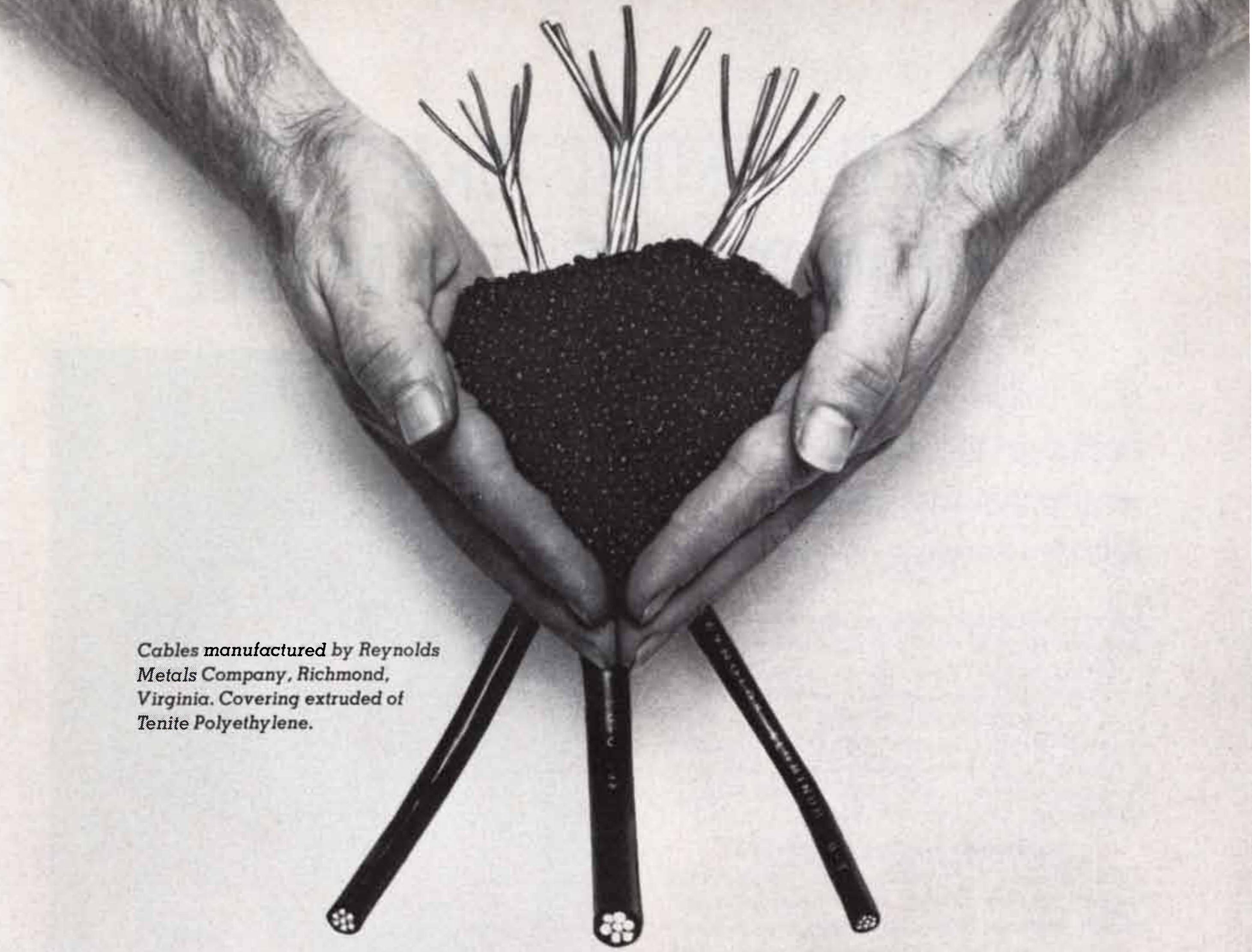


Cables manufactured by Reynolds Metals Company, Richmond, Virginia. Covering extruded of Tenite Polyethylene.

Why Reynolds covers these aluminum conductors with TENITE POLYETHYLENE

To obtain the highest possible performance from their secondary distribution and service line cables, Reynolds Metals Company chooses Tenite Polyethylene as a covering material.

Tenite Polyethylene is manufactured under as rigid a system of quality control as Reynolds' own aluminum conductors, and makes a tough, weatherproof, fast-stripping covering material which offers high dielectric strength and resistance to abrasion, heat, moisture, chemical attack and stress cracking. It remains flexible even at sub-zero temperatures and its light weight permits easy handling and wide spans. Users report that it gives long service life without festooning or splitting.

Tenite Polyethylene is easily extruded as jacketing or insulation for many diverse applications, from coaxials to control cables, from TV lead-ins to telephone wires. For a material with outstanding electrical, physical and chemical properties, specify Tenite Polyethylene. For further information, write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

Both natural and black electrical grade Tenite Polyethylene are available to cable manufacturers in a unique spherical pellet form which flows freely in the extrusion process and in "air-veying" of bulk shipments from truck to bin.

TENITE®
POLYETHYLENE
an Eastman plastic

RCA REPORTS TO YOU:

NEW ELECTRONIC "BRAIN" CELLS FIT IN THE EYE OF A NEEDLE

Basic building block for compact, electronic "thought savers" will serve you in your office, in defense – someday, in your home

● Today, science not only is working on labor-saving devices—but on *thought-saving* devices as well.

These "thought savers" are electronic computers —wonder-workers that free us from tedious mental work and are capable of astoundingly rapid computations. Naturally, the more *compact* these computers can be made, the more applications they can have. Not only in industry, defense and research—but in the office and ultimately in the home.

"Squeezing" exacting components

A big advance has recently been made by RCA research towards making these "thought savers" smaller than ever before, for broader than ever use.

Take, for example, the new "logic" circuit which actually fits in the eye of a needle. It is a new computer component developed by RCA.

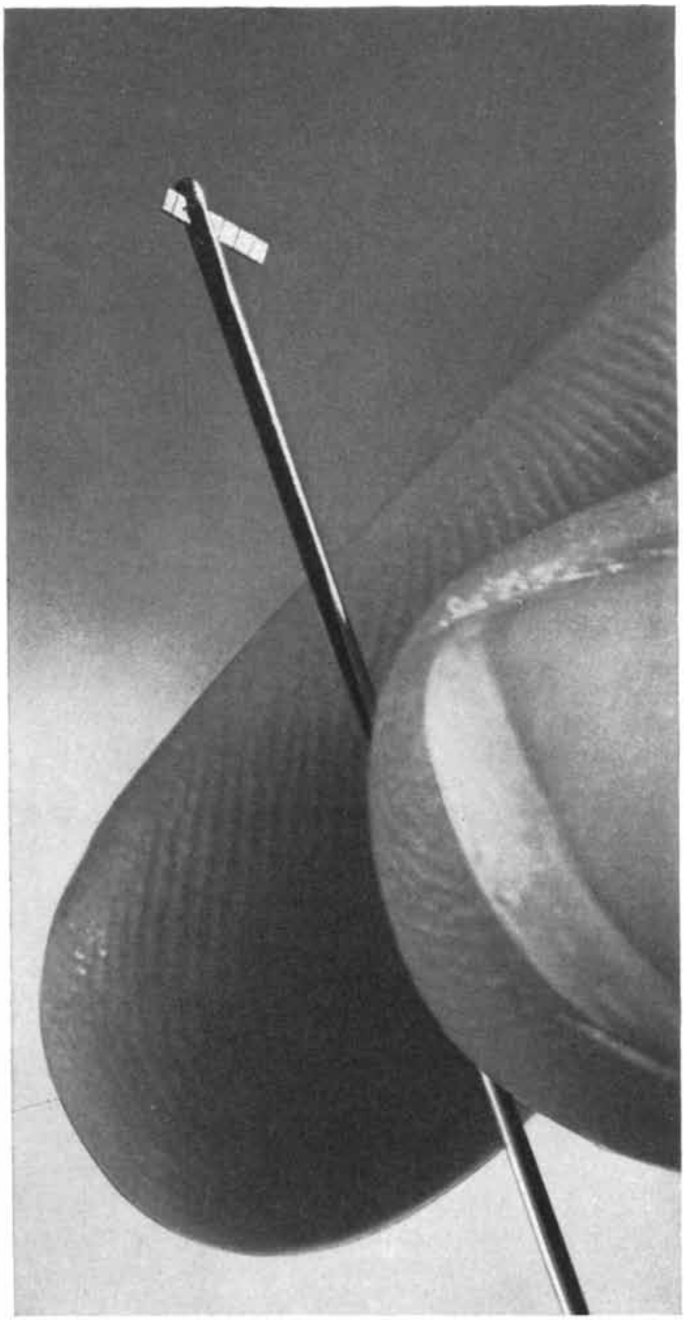
Today, the electronic functions of this micro-miniature device require a whole fistful of wires, resistors, transistors and condensers.

These tiny units will calculate, sort, "remember," and will control the flow of information in tomorrow's computers. Yet they are so small that 100,000,000 of them will fit into one cubic foot!

Cutting computers down to home size

This extreme reduction in size may mean that someday cigar-box-size electronic brains may help you in your home—programming your automatic appliances, and keeping track of household accounts.

Remarkable progress in micro-miniaturization is another step forward by RCA—leader in radio, television, in communications and in all electronics—for home, office, and nation.



Needle's eye holds electronic "brain" cells— Photograph shows how new RCA "logic" element can be contained in the eye of a sewing needle.

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Basic Research at Honeywell
Dr. Finn Larsen
Vice President for Research

Studies in the Magnetic Properties of Thin Metallic Films

Temporary or transient memories of electronic computers consist of small doughnut-shaped ferrite cores hand-assembled into many complex matrices. Bulk, speed of response and costly manufacture create inherent limitations. It now appears possible to overcome these by replacing ferrite cores with tiny spots of magnetic film vapor deposited on a smooth flat surface.

Today's electronic computer has a memory which is part of the brain of the machine. Larger machines commonly have two memories: one for permanent storage of information, the other for temporary storage of more transient information. The temporary memory consists of a collection of ferrite cores, each core shaped like a tiny doughnut and having a number of wires laced between it and other cores forming a matrix or grid. The wires carry either the pulse of electricity which magnetizes the core, or a similar pulse which is the core's response to interrogation.

A series of these pulses, handled in a binary number system, have become the language of the computer. To function binumerically, circuits represent "0" by not conducting current, and represent "1" by conducting. Each memory core can be magnetized in one direction for "0", the opposite direction for "1." To avoid ambiguities, cores are made so they are not readily magnetized in any direction other than these two.

Each small ferrite core can be magnetized or interrogated in about a microsecond (one-millionth second). Unfortunately, the assembly of ferrite cores discourages automation processes, making manufacture slow and costly. In addition, the tremendous bulk of many millions of cores properly assembled prohibits machines requiring considerably larger transient memories.

Current basic research indicates that one of the most promising successors to the ferrite core is a tiny spot of magnetic film about 1,000 Angstroms (four millionths of an inch) thick, deposited on a smooth flat surface. These films have been prepared in Honeywell's Research Laboratories from an alloy of nickel and iron by heating the alloy until it vaporizes in a vacuum. Each freed vapor particle travels until it strikes a cooler surface. There it condenses and stays, if the surface is suitable and immaculately clean.

It might be assumed that the task would be simple. However, as the vapor condenses and becomes solid, it seems to become peculiarly sensitive to the nature of the surface on which it is being deposited. Unless oriented by a magnetic field (created by large coils that encircle the vacuum chamber), the films could be magnetized in a number of directions instead of along the desired single line. When we obtain uniformly bi-stable spots, we are in effect duplicating the action of ferrite cores. We also may use the same cycle by which bits of information are stored and extracted by reversing direction of the magnetic field.

The coercive force necessary to reverse (or "flip") the direction of magnetization within a thin film is very low. Another important advantage stems from the fact that reversal may be accomplished either by employing a rotational mechanism (simultaneous rotation of all atomic magnetic moments) or a wall-motion mechanism (sequential rotation of the atomic magnetic moments in the form of a moving wall). Both may be induced through application of a coercive force as small as one Oersted. Of the two mechanisms, rotational is much the faster; it makes possible the reading and writing of 100,000,000 bits of information per second on a single spot, as compared to about 100,000 for ferrite cores.

Honeywell scientists have consistently produced 256 bit (16x16) matrices uniform to plus or minus 5% of energy. Only this uniformity makes it possible to use the films in circuits, since a given small electrical pulse applied to any film must flip that film.

Uniformity has been achieved in part through study of deposition techniques and experiments both with various types of substrata and with various methods of cleaning them before deposition. It has resulted also, through broader understanding of the mechanisms involved, in causing reversal of the magnetic field. Even more important, however, have been detailed investigations into the factors that lead to non-uniformity, and subsequent development of techniques that tend to eliminate them.

The most difficult task remaining seems to be linking the film spots with printed circuits which will probably replace the wires used with the ferrite cores.

Our research on thin films is both basic and applied. Applied, since our scientists are trying to create better, faster, smaller memory systems for the commercial and military computers our engineers design; and basic, since they are trying to understand and explain all the phenomena described, as well as others that are completely baffling.

If you are engaged in magnetics research and would like to know more about Honeywell's work on thin magnetic films, you're invited to correspond with Dr. Richard Prosen, Honeywell Research Center, Hopkins, Minnesota. Or, if you would like a simplified explanation of the binary number system and how to perform standard mathematical manipulations using this system, write to Honeywell Research, Minneapolis 8, Minnesota.

Honeywell
H HONEYWELL *First in Control* SINCE 1885

PROJECT ASHTRAY

New Hamilton Standard development permits practical utilization of solar energy in space

This object that so closely resembles an ashtray is an experimental solar power generator. Its conception was sparked by one of Hamilton Standard's many continuing studies of the future needs of country and industry—in this case, the need for a lightweight source of continuous electric power in space.

Exploring the unknown through advanced product planning is standard practice at Hamilton Standard. Realistic short and long range predictions of tomorrow's requirements keep products, facilities and capabilities constantly geared to demand.

The company's research in solar power generation is representative of its widely diversified interests and ever-expanding skills. Though long known as the foremost producer of propellers in the world, Hamilton Standard today is a dynamic engineering force in each of these other areas: engine and flight controls, starters, hydraulics, environmental conditioning systems, electronics, ground support equipment and electron beam process equipment.

Sunlight, focused on the tiny metal ball or collector, heats it to 1000°F. A hot junction at the base of the cone and a cold junction just below it comprise a thermocouple. The tremendous temperature differential between these junctions sets up a flow of electrons—useful electrical power for satellites and other space vehicles. ▶

HAMILTON STANDARD

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UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT

THE AUTHORS

SU-SHU HUANG ("Life outside the Solar System") is a physicist at the National Aeronautics and Space Administration's Goddard Space Flight Center in Washington. He was born in Changshu in the Chinese province of Kiangsi in 1915. In high school, he says, he found physics and mathematics the easiest subjects "because they do not demand a good memory, which I lack." He settled on physics because he was more interested in natural phenomena than in abstract thought. He studied at the National Chekiang and Tsing Hua universities and came to the U. S. in 1947 on a fellowship given by the Nationalist Chinese Government. Huang earned his Ph.D. in astrophysics at the University of Chicago in 1949. A Guggenheim fellowship took him to the University of California, where he did research work for eight years. He has published papers in atomic physics, radiative transfer, stellar spectroscopy, celestial mechanics and applied mathematical problems. He states that his interest in the problem of life outside the solar system was aroused through reading various SCIENTIFIC AMERICAN articles concerning the origin and processes of life.

ELEANOR J. GIBSON and RICHARD D. WALK ("The 'Visual Cliff'") are, respectively, research associate at Cornell University and associate professor of psychology at George Washington University. Mrs. Gibson took her B.A. and M.A. at Smith College, and acquired her Ph.D. at Yale University in 1938. Her husband, James J. Gibson, supervised her master's thesis in psychology, and was partly the inspiration for her later studies of the visual cliff; he maintained that their small children could detect a hazardous drop as well as an adult could, while she was not at all sure the children could be trusted on the edges of cliffs and canyons when they were traveling across the country. Mrs. Gibson has taught at Smith and has held her present position at Cornell since 1949, where she has studied perception, learning and their interrelations. She spent the academic year 1955-56 at the University of Oxford, and 1958-59 at the Institute for Advanced Study in Princeton, N.J., where she began a book on perceptual learning and development. Walk graduated from Princeton University in 1942, took his M.A. at the State University of Iowa in 1947 and his Ph.D. at Harvard University in 1951. He was in the Army from 1942 to 1945 and again in 1951 and 1952. He did psychological research with paratroopers at Fort Benning, Ga., where the fear of height is a matter of practical importance. Walk was assistant professor of psychology at Cornell from 1953 to 1959. His work at Fort Benning led to his participation in the investigations of the visual cliff.

SERGIO DE BENEDETTI ("The Mössbauer Effect") is professor of physics at the Carnegie Institute of Technology. A native of Florence, Italy, he holds a doctorate in physics from the University of Florence. He came to the U. S. in 1940 after holding a research fellowship at the Curie Laboratory in Paris, and has been at Carnegie Tech since 1948. In 1956 and 1957 De Benedetti held a Fulbright fellowship in Turin, Italy, where, among other things, he learned to ski, water ski and hunt small fish underwater (he says that big fish are too easy a target). De Benedetti states that he is "a firm believer in the Greek gods and in the humanistic values for which they stand. I went in pious pilgrimage to the Greek temples and worshipped at the Temple of Athena Nike on the sacred slopes of the Acropolis." He was co-author of the article "The Ultimate Atom" in SCIENTIFIC AMERICAN for December, 1954.

PH. H. KUENEN ("Sand") has since 1943 been professor of geology at the University of Groningen in the Netherlands. He was born in 1902 of Dutch parents living in Scotland, where his father was a professor of physics. When he was five, his family moved to Leiden, and at the age of eight he started collecting stones. Kuenen studied geology at the University of Leiden, where he took his doctorate. He was geologist of the Snellius deep-sea expedition to the Moluccas in 1929 and 1930, and served as lecturer in geology at Groningen from 1934 until he became a professor. Kuenen's main field is marine geology, which he has pursued largely by experimental methods. Among the subjects he has studied in the laboratory are pebbles that have been faceted by the wind, the shapes of volcanic cones, tectonic structures, turbidity currents and their deposits and the abrasion of pebbles and sand grains. Trinity College in Dublin has given him an honorary doctorate, and he holds two geological medals.

THEODORE SAVORY ("Spider Webs") is vice-principal of Stafford

House, a tutorial college in Kensington, England. He was born in London and acquired his B.A. at the University of Cambridge in 1918. His special field of study selected him six years before that when a spider fell upon a book he was holding even as he was considering what sort of animal he might devote his time to. A friend, seeing the spider, said: "What about spiders?" To which Savory replied: "Why not?" He has studied them ever since. In 1920 he introduced the teaching of biology into Malvern College, and he remained there for 31 years. From 1951 to 1958 he was senior biology master at the Haberdashers' School in Hampstead. His books include *The Biology of Spiders*, *Spiders and Allied Orders of the British Isles*, *The Spider's Web* and *The Arachnida*. Language is his second interest; he has also written *The Art of Translation*, *Latin and Greek for Biologists* and *The Language of Science*.

ALFRED J. CROWLE ("Delayed Hypersensitivity") heads the division of immunology of the Colorado Foundation for Research in Tuberculosis and is also an assistant professor in the department of microbiology of the University of Colorado Medical Center. The son of British parents, he was born and reared in Mexico City and came to the U. S. in 1947 to attend San Jose State College. In taking his Ph.D. at Stanford University he worked on the isolation and characterization of the immunizing constituents of tubercle bacilli. The close relationship between immunity to tuberculosis and delayed hypersensitivity led him into the study of allergy. While working on mouse tuberculosis, Crowle and his colleagues accidentally discovered that mice could develop delayed hypersensitivity. This opened the way to rapid, incisive experiments with hypersensitivity, and at present he is studying contact dermatitis, the type of allergy that is responsible for poison-ivy reactions in man. This year Crowle holds the James Alexander Miller Fellowship in Medical Research presented by the New York Tuberculosis and Health Association. In his spare time he engages in do-it-yourself activities, camps out with his family, motorcycles and makes photographs to illustrate his papers.

THEODORE T. PUCK ("Radiation and the Human Cell") is professor of biophysics at the University of Colorado Medical Center. A native of Chicago, he studied biophysics at the University of Chicago under the Nobel laureate James Franck, taking his Ph.D. in 1940 at the age of 23. He remained at Chicago until he accepted a fellowship of the American Cancer Society in 1947 to study bacterial viruses with Max Delbrück at the California Institute of Technology. In 1948, when Puck was 31, he was called to organize a department of biophysics at the University of Colorado Medical Center. Struck with the large amount of information that had accumulated about bacterial cells, Puck decided to see if the development of appropriate techniques might not prove illuminating with mammalian cells, and he began intensive studies in this field. His article "Single Human Cells in Vitro" appeared in SCIENTIFIC AMERICAN for August, 1957.

MAX GLUCKMAN ("The Rise of a Zulu Empire") serves as professor of social anthropology at the Victoria University of Manchester, England. He grew up in South Africa, and acquired his B.A. degree at the University of Witwatersrand. He attended the University of Oxford as a Transvaal Rhodes Scholar in 1934, and took his M.A. and Ph.D. at Oxford. He engaged in field research in Zululand from 1936 to 1938 on a grant from the Carnegie Fund of the Union Government Department of Education. In addition to his studies of the Zulus he has done field work among the Barotse, Tonga and Lamba of Northern Rhodesia. Gluckman has been director of the Rhodes-Livingstone Institute in British Central Africa, and has held the post of lecturer in social anthropology at Oxford. He has received two medals from the Royal Anthropological Institute, and has written several books on African tribal life.

GEORGE GAYLORD SIMPSON, who reviews Pierre Teilhard de Chardin's *The Phenomenon of Man* in this issue, is Alexander Agassiz Professor of Vertebrate Paleontology in the Museum of Comparative Zoology at Harvard University. Before assuming his present post in 1959, Simpson was for many years associated with the American Museum of Natural History, and for 15 years had occupied the positions of curator of fossil mammals and birds and chairman of the department of paleontology and geology. He was also professor of vertebrate paleontology at Columbia University. He is the author of numerous books, notably *The Meaning of Evolution*, *Horses*, *Life of the Past*, *The Major Features of Evolution*, *Evolution and Geography* and a textbook entitled *Life*.

Whether Congress would go along with giving the President this authority, however, is not certain.

MAJOR MERGER IN SWITCH INDUSTRY

Controls Company of America Merges Hetherington Div. With Electrosnap Corp. to form New Control Switch Division.

One of the precision switch industry's most complete product lines has come into existence with the announcement by Louis Putze, President of Controls Company of America, Schiller Park, Ill., that its subsidiary Hetherington, Inc., has been merged with Electrosnap Corporation, Chicago. The Electrosnap organization was recently merged with Controls Company of America.

"This merger is important to switch users", Mr. Putze stated, "because it combines two major manufacturers of panel switches, indicator lights and limit switches for military and industrial applications into a single source of supply.

"Now, customers need deal with just one sales engineer instead of two. Three plant locations—Folcroft, Pa., Chicago, Ill. and El Segundo, Calif.—will provide regional engineering and manufacturing facilities to speed up delivery and service.

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C	BLM-022	Tunable	5400-5900	500	TNC
C	BLM-026	Tunable	5400-4900	500	TNC
C	BLM-020	Tunable	5400-5900	700	TNC
C	BL-245	Tunable	5400-5900	900	TNC
C	BL-250	Tunable	5400-5900	150	TNC
X	BLM-003	Tunable	9000-9500	150	TNC
X	BLM-014	Tunable	8500-9000	150	TNC
X	**BLM-012**	Tunable	8900-9400	1000	TNC
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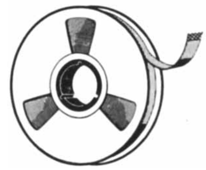

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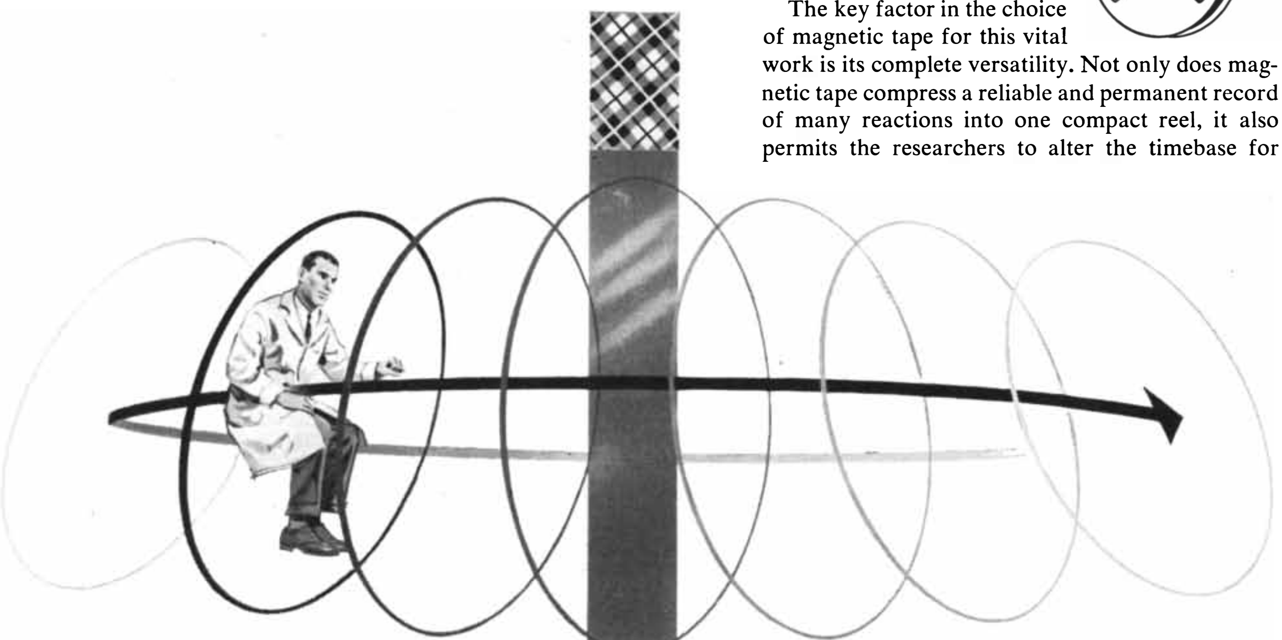

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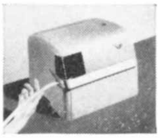

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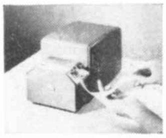

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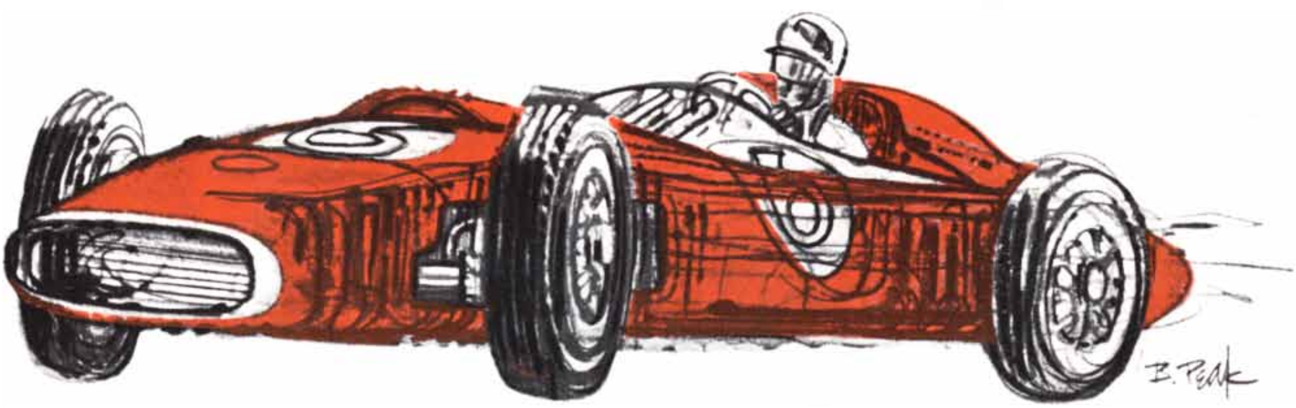

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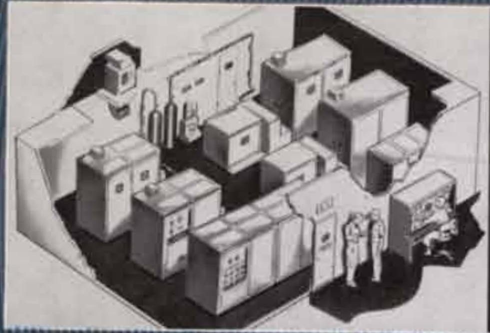

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Pavlov...on the demands of science

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Life outside the Solar System

How many stars in our galaxy may be accompanied by planets capable of supporting intelligent life? The answer requires reflection on the characteristics and life history of stars

by Su-Shu Huang

The evolution of stars and the evolution of living organisms appear to be completely dissimilar processes. The differences between the two can be explained in terms of how the particles of matter are bound together and how energy is exchanged among them. Indeed, the evolution of living organisms represents one outcome of stellar evolution. It was the steady flow of energy from the sun for four or five billion years that brought about the biological developments on earth, culminating in the emergence of intelligent organisms able to contemplate the whole remarkable story. If the sun had had a different history, life would not have appeared in its immediate vicinity.

Astronomical evidence acquired in recent years indicates that what has happened here is probably not unique. Two decades ago it was thought that the solar system might have originated in a near-collision of the sun and another star, which event supposedly pulled away enough matter from the sun to form the planets. Because such encounters must be rare events, they would give rise to few stars with a company of planets. Today most astronomers believe that a star is formed by the condensation of a cloud of dust and gas [see "The Dust Cloud Hypothesis," by Fred L. Whipple; SCIENTIFIC AMERICAN, May, 1948]. This hypothesis much more readily explains the origin of the solar system and is supported by the observation that more than half of the stars in our galaxy are double or multiple systems. In fact, it now appears that most stars are accompanied by other stars or by planets, though the latter must be so small as to escape sure detection by the present instruments of astronomy. Thus the appearance of life—even the appearance of mind—may be far from unusual events in the universe.

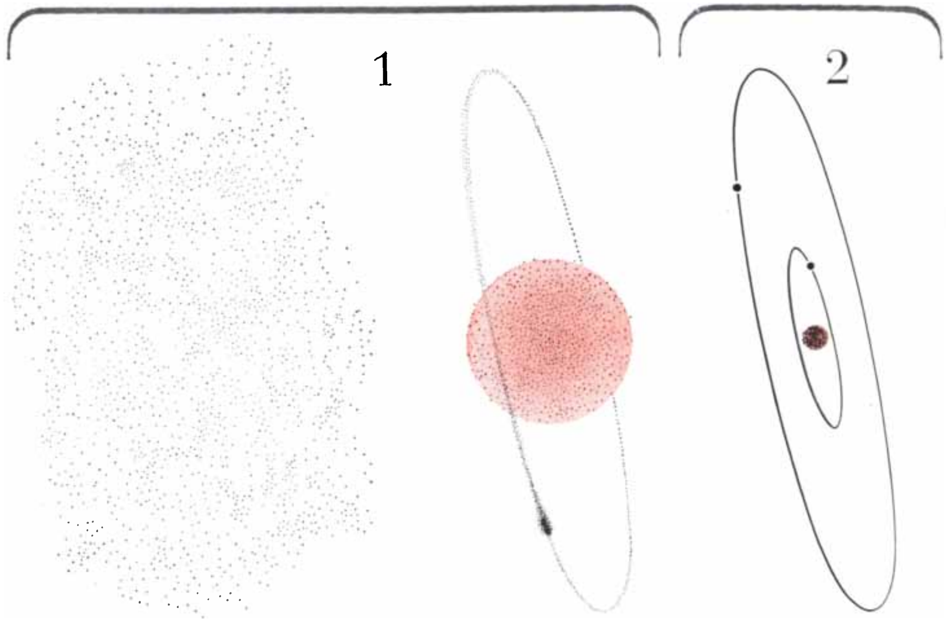
On the other hand, certain critical conditions must be satisfied if life processes are to be initiated and maintained. In the first place the star must shine long enough and steadily enough to permit life to evolve. The star must also be hot enough to warm up a habitable zone deep enough to offer a reasonable chance that a planetary orbit will fall within it. And the planet must ply a stable orbit within this zone. The number of stars that have given rise to life must therefore be considerably smaller than that immediately suggested by the dust-cloud hypothesis.

Taking account of all these factors, what is the probability that man will ever be able to visit the life-bearing planet of another star, or that the earth will receive a visitor from such a planet? Does the possibility justify taking measures now—in advance of a visit—to put existing technology to the task of scanning the sky for signals from intelligent organisms outside the solar system, or for transmitting signals in the hope they may be heard? If so, what sort of signals should be listened for or sent?

A reliable answer to these questions calls for a somewhat closer consideration of the conditions critical for life and an estimate of how often they are likely to be satisfied in the evolution of stars. The first condition is a steady and prolonged flow of energy. How long it takes life to evolve may be judged from the single instance available: Here on earth rational animals evolved from inanimate matter in about three billion years. Biological evolution proceeds by the purely random process of mutation, that is, the unpredictable occurrence of novel chemical processes among the fantastically numerous reactions that constitute life. Since the process is a random one, the laws of probability suggest that the time-scale of evolution on earth should resemble the average time-scale for the development of higher forms of life anywhere. The rate at which mutations occur is of course a variable in the calculation. It is affected by the electromagnetic and corpuscular radiation from the parent star, and the amount of such radiation that reaches the surface of any planet is governed in turn by the magnetic field of the planet, the depth and composition of its atmosphere and other factors. But since mutation itself is a random process, the introduction of a few more variables does not affect the calculation greatly. Furthermore, a higher mutation rate does not necessarily accelerate evolution, because most mutations are harmful. The more frequently they occur, the greater the chance that an individual will suffer an injurious mutation. In order to favor natural selection, mutations should be rare, perhaps as rare as in the evolution of life on earth.

It is somewhat easier to estimate the time-scale of stellar evolution. In contrast to the random nature of biological evolution, stellar evolution is governed by the universal law of gravitation and by a relatively small number of thermonuclear reactions. When a star begins to form in a cloud of dust and gas, gravitational attraction among the gas and dust particles causes the cloud to condense until the pressure raises the temperature within it to the point at which the thermonuclear reactions that convert hydrogen to helium begin. The tremendous quantities of energy liberated by these reactions now set up a counterpressure from the center of the star that exactly balances the force of gravitational contraction. In this state of equilibrium the star shines for a much longer time than that required for its condensation out of dust and gas.

The vast majority of the visible stars are in this phase of their evolution. They are called "main-sequence" stars because their luminosity (energy output per unit of time) plotted on a graph against their surface temperature places them in sequence in a narrow band [*see illustration on page* 59]. What the chart shows is that the hottest stars are also the most luminous. Luminosity depends upon mass, and so the point at which a star appears on the main sequence depends primarily upon the mass of material incorporated in it during condensation. The hottest stars are designated by the

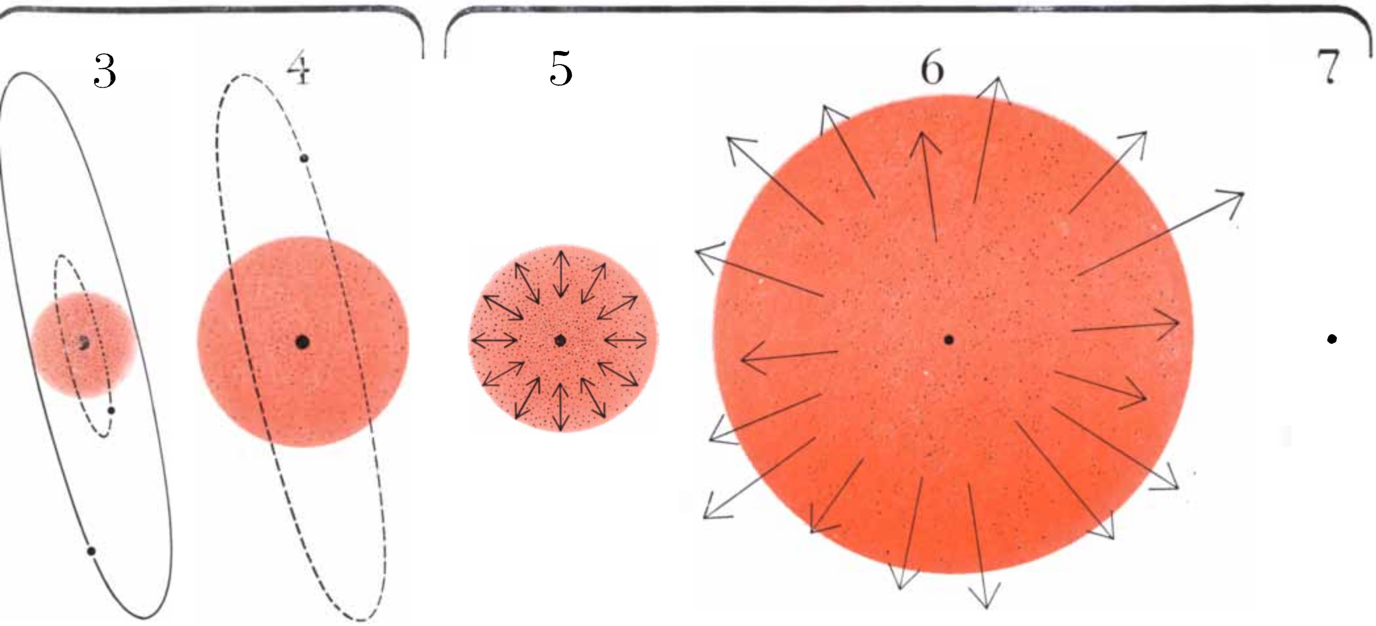


POSSIBLE EVOLUTION OF A STAR **1.2 times the mass of the sun begins with a dust cloud condensing into a star and proto-planets (1), a process taking perhaps 10 million years. Star enters "main sequence" (2) and remains there for approximately eight billion**

letter O, followed in descending order by stars classified B, A, F, G, K and M; these classifications are usually called spectral type. The adjectives "early" and "late," which have nothing to do with the age of the star, are often used before the spectral-type designation to denote further relative temperature differences. An early F-type star is hotter than a late one, which in turn has a higher temperature than an early G-type star such as our sun. The classification is further refined by a number from 0 to 9 written after the letter. Thus the class of early B-type stars includes those from B0 to B4; and the late B-type stars, those from B5 to B9.

The length of time a star remains in the equilibrium state on the main sequence can be calculated from the total mass of hydrogen in its core and the

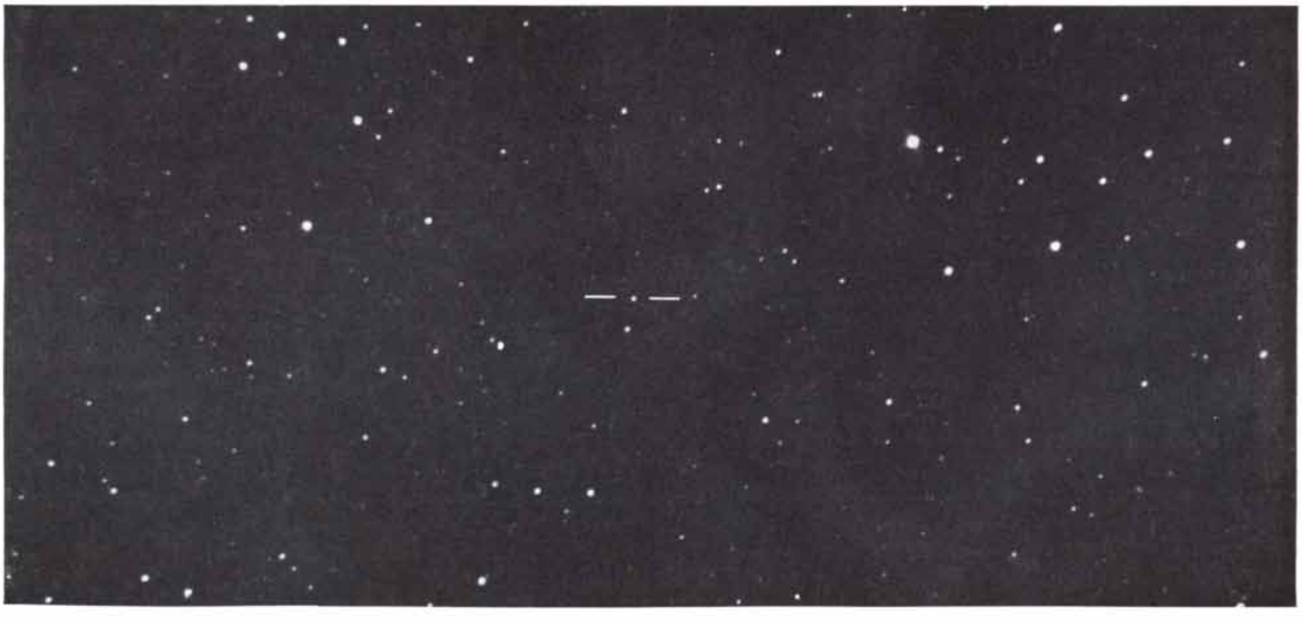
NOVA IN CONSTELLATION CYGNUS, indicated by pair of white lines, blazed up in 1920. This photograph was made at that time with the 100-inch reflecting telescope at Mount Wilson Observatory. Nova may represent a late stage in the life of a star.



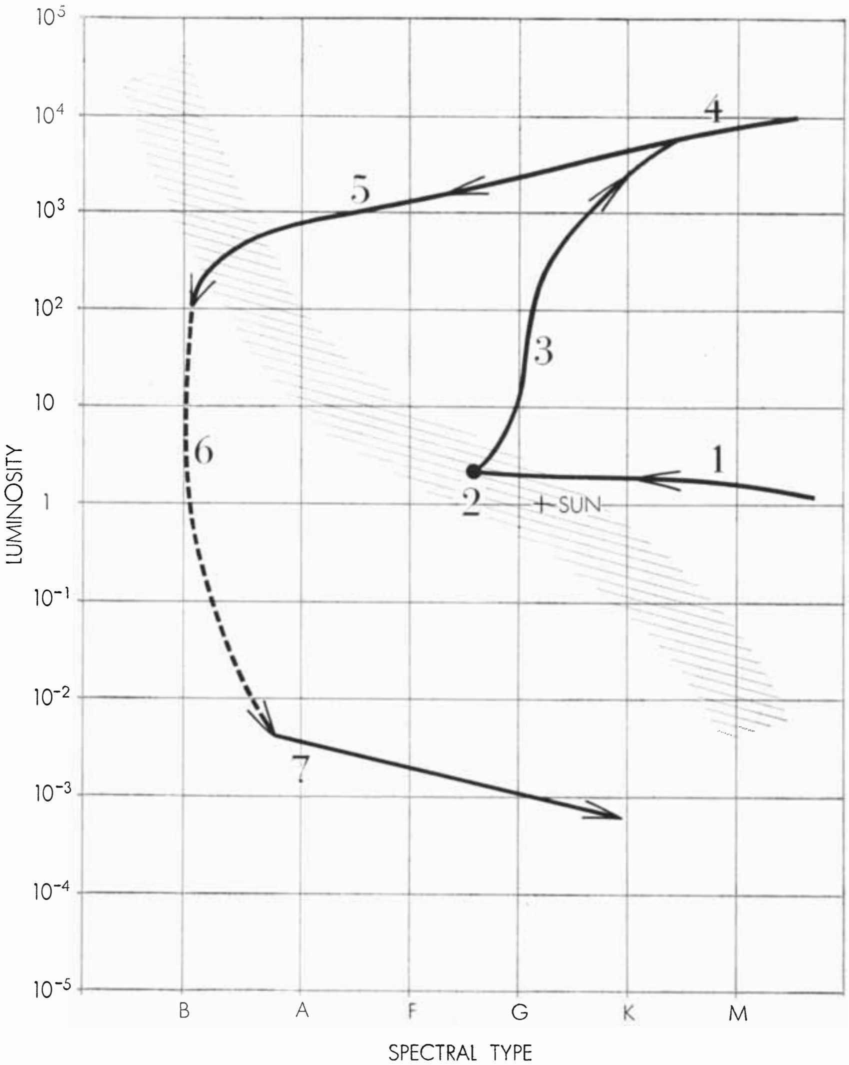
years. Then it expands (3) into red-giant stage (4), first destroying life on its inner planet, then burning up the planets in turn. This period may last about 100 million years. Then star may pulsate in luminosity every few hours (5) for thousands of years, finally exploding into a nova (6) and eventually collapsing into white dwarf (7). Time period for final stages (5, 6 *and* 7) is not known.

rate at which the hydrogen is consumed. Both factors in the calculation are determined by the position of the star on the main sequence. Luminosity, which is an index of the rate of fuel consumption, increases as the fourth power of the star's mass. The most massive stars thus use up their substance most rapidly and so have the shortest lifetimes in the equilibrium state. In general a star will evolve away from the main sequence when the core in which the hydrogen has been consumed has a mass of about 12 per cent of that of the entire star. With the exhaustion of fuel in the central furnace, gravitational contraction takes over again, heating up the interior until the thermonuclear reaction spreads to outer layers. The star now leaves the main sequence and in a comparatively brief period of time evolves into a red giant or supergiant. Its evolution thereafter cannot presently be predicted in detail. But somehow, perhaps through the rapid loss of mass by ejection, it ends up as a hot, faint, dense object known as a white dwarf. A majority of the intrinsic variable stars, of novae and of nova-like objects are apparently in the stage between red giants and white dwarfs.

In leaving the main sequence a star releases so much energy that it would destroy life on any of its planets. Thus



SAME STAR FADED IN 10 YEARS to the faint object visible between the white lines in this photograph made in 1930 with the same telescope. A nova may explode repeatedly before becoming a white dwarf and eventually turning into a cold, dark body.



EVOLUTIONARY PATH OF A STAR with a mass 1.2 times that of the sun is traced. The vertical scale is luminosity (the sun is unity); the horizontal scale, spectral type. The main sequence is outlined by the gray hatching. The numbers on the path correspond to the stages of stellar evolution depicted in the illustration at the top of the preceding two pages. At 1 the star is in the stage of gravitational contraction; at 2 it is on the main sequence; at 3 it is expanding; at 4 it is a red giant; at 5 it pulsates. The broken line (6) indicates uncertainty as to the path the star follows in reaching the white-dwarf stage (7).

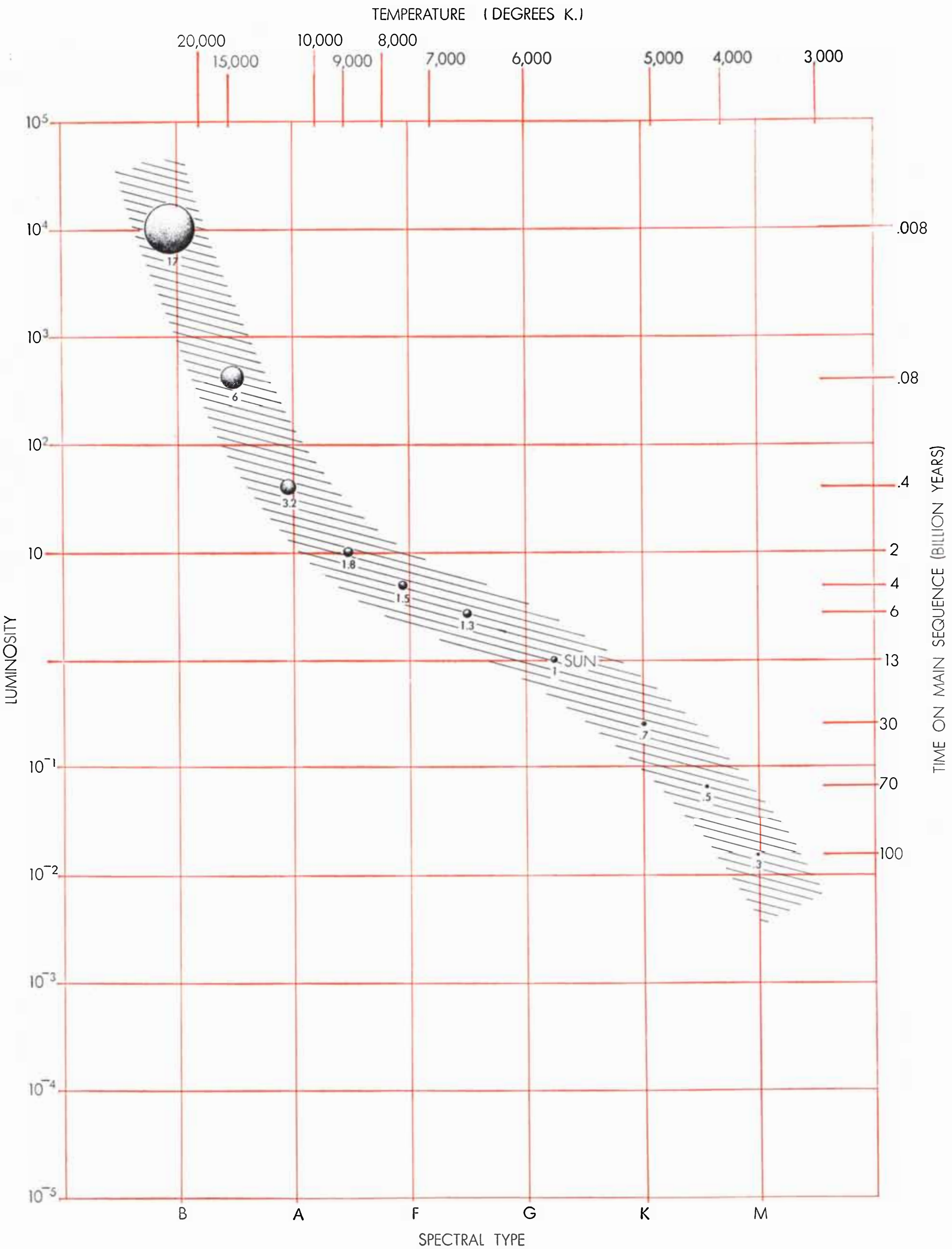
the main-sequence stage of the star's evolution is the only important one so far as life is concerned. The O and early B stars are the most massive, but since they burn much more rapidly than the smaller, less luminous stars, their life on the main sequence lasts only a million to 10 million years. The small M stars, in contrast, remain on the main sequence for more than 100 billion years. None of the early stars in the O, B and A groups has a stable lifetime longer than three billion years; they cannot therefore sustain biological evolution long enough for intelligent organisms to appear on any of their planets. Closer calculation shows that only the stars farther down the sequence than F4 maintain their equilibrium for a sufficient length of time to bring biological evolution to its culmination.

If time were the only critical condition, then the late-K and M stars would stand the greatest chance of having life-bearing planets. But these stars have low luminosity, and the habitable zones in which planets might travel about them must be quite narrow. A more luminous star can obviously warm up a larger space than a less luminous one [*see illustration on page 63*]. It is like a fire in a field on a cold night: the bigger the fire, the wider the zone around it in which the temperature will be neither too hot nor too cold. Thus the chance of finding a planet and intelligent life within the habitable zone of any particular M or even late-K star is quite small. However, since there are 10 times as many M stars as G stars, the total number of life-bearing planets traveling around the M stars may not be negligibly small.

On the basis of their lifetimes and the depth of their habitable zones, stars of the late-F, G and early-K types seem to offer the most favorable environments for life. Approximately 10 per cent of stars fall in these types. Out of the 200 billion stars in the Milky Way, therefore, some 20 billion might foster intelligent life.

This number is reduced considerably upon consideration of the third critical condition: the maintenance of stable planetary orbits. The dust-cloud mechanism that increases the likelihood of planets has also brought most stars into existence as double or multiple systems. It is obvious that the presence of two or more stars in a system will profoundly perturb the orbits of planets in the system. A few double-star systems have members that are so far apart that if they are sufficiently near to us, the stars can be distinguished by a telescope or even by the naked eye. Such systems are called visual binaries. Much more common are the "spectroscopic binaries." In these systems the stars are so close together that even if they are relatively near to us, they cannot be separated by the largest telescope. We can tell that they are double stars only by regular changes in their spectra [*see illustration on page 60*]. These changes also enable us to calculate their orbits.

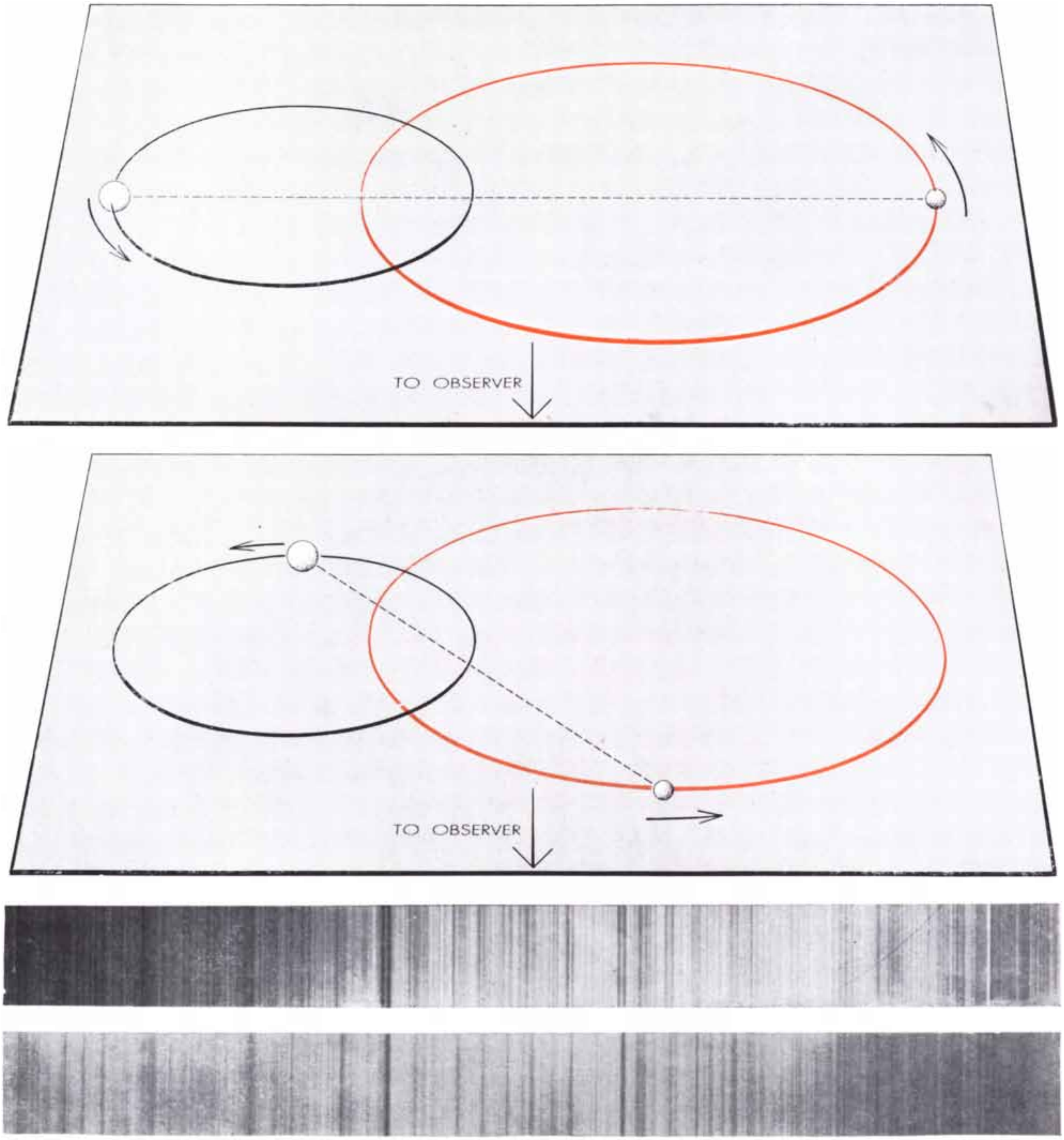
The orbits of planets in such systems are so complicated that astronomers have been able to work them out for only a few idealized cases. A life-bearing planet would have to travel on an orbit close to one of the stars in a widely separated system, or on an orbit at a large distance from the stars in a close system. In the case of a hypothetical binary composed of two stars with the same luminosity as our sun and revolving around a common center in a nearly circular orbit, a planet would find the thermally habitable zone dynamically stable only if the stars were more than 10 astronomical units or less than .05 astronomical unit apart (an astronomical unit is the distance between the earth and the sun). With a separation between the stars of .5 to 2 astronomical units there is no overlapping of the habitable zone and the dynamically stable



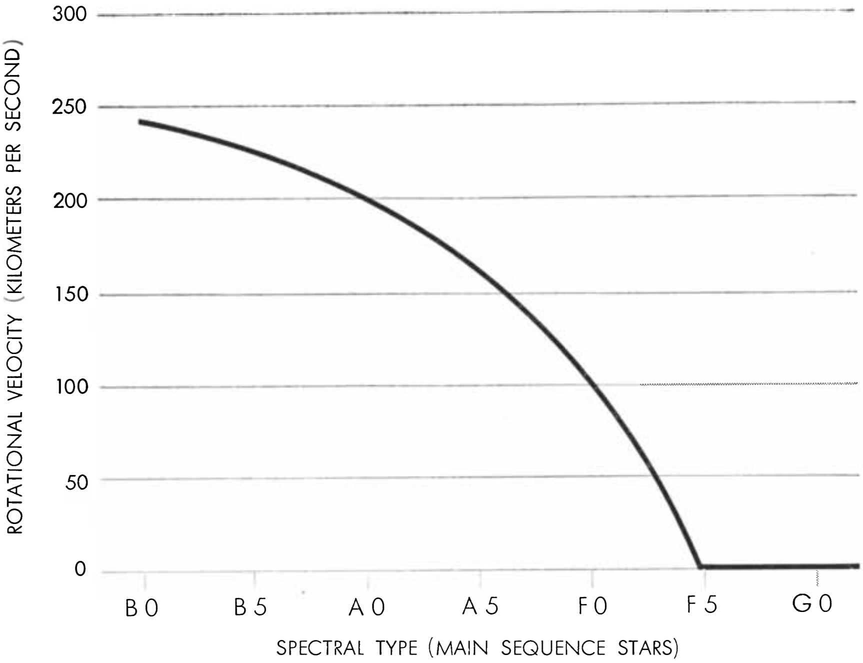
TYPICAL STARS ON THE MAIN SEQUENCE are represented on this diagram. Vertical scale at left indicates luminosity (the sun is unity). Scale at right shows time on the main sequence. The numbers at the top denote temperature in degrees Kelvin; the letters at the bottom, spectral type. Small figures beneath each star give its mass with respect to the mass of the sun.

zone. Therefore no inhabitable planets can exist in such systems. Taking everything into consideration, only 1 to 2 per cent of all double and multiple stars may possess inhabitable planets, and perhaps 3 to 5 per cent of all the stars in our galaxy have such planets.

For the present there is no hope of detecting on a photographic plate the existence of a planet of another star. Such planets as may attend even the nearest star are completely lost to view in the brilliance of the star's light. Someday there may be a telescope on a platform in space, free of the interfering effects of the earth's atmosphere. As has been suggested by Nancy G. Roman of the National Aeronautics and Space Administration, the instrument would produce a sharp star image that could be blocked out so that a planet near the



SPECTROSCOPIC DETECTION OF CLOSE BINARIES is depicted in these diagrams and spectra. At top the stars are orbiting around center of mass, the one at left moving toward the earth, the one at right away from the earth. Spectral lines made by star moving toward earth shift toward violet end of the spectrum, while lines from star moving away shift toward red end, splitting spectral lines as seen in upper spectrum below diagrams. In lower diagram the binaries are moving across line of vision as seen from earth. This gives rise to normal single spectral lines seen in the lower spectrum. Spectroscopic binaries are so close together that no telescope can resolve them into separate bodies, and only their spectra enable us to detect them and to calculate their orbital movements.



ROTATIONAL VELOCITY OF STARS on the main sequence is diagrammed here according to spectral type. Slow spin after Type F5 may indicate that planets are present.

star could be detected by means of a long photographic exposure. Even the subtle methods used to detect spectroscopic binaries are not refined enough to find a planet, because the effect of a planet upon the motion of its parent star is so slight.

There is nonetheless other well-established evidence to support the contention that planets are common. In the first place, no sharp distinction can be drawn between binary or multiple stars and stars with planetary systems. According to Gerard P. Kuiper of the Yerkes Observatory, the mean distance of separation between the components of all binaries so far investigated is about 20 astronomical units. This is of the same order of magnitude as the distance between the sun and its major planets (Jupiter, Saturn, Uranus and Neptune). Kaj Aa. Strand at the U. S. Naval Observatory in Washington has studied small perturbations in the orbital motion of a star called 61 Cygni, which has a companion that is too faint to be directly observed. He has found that the mass of this unseen object is about a hundredth of that of the sun. This mass lies between that of stars and of Jupiter. It is therefore reasonable to believe that the masses of small stars in binary systems grade continuously down to the masses of planets. Since binaries are so common in our galaxy, it would seem that many stars that now appear to be alone actually possess planets.

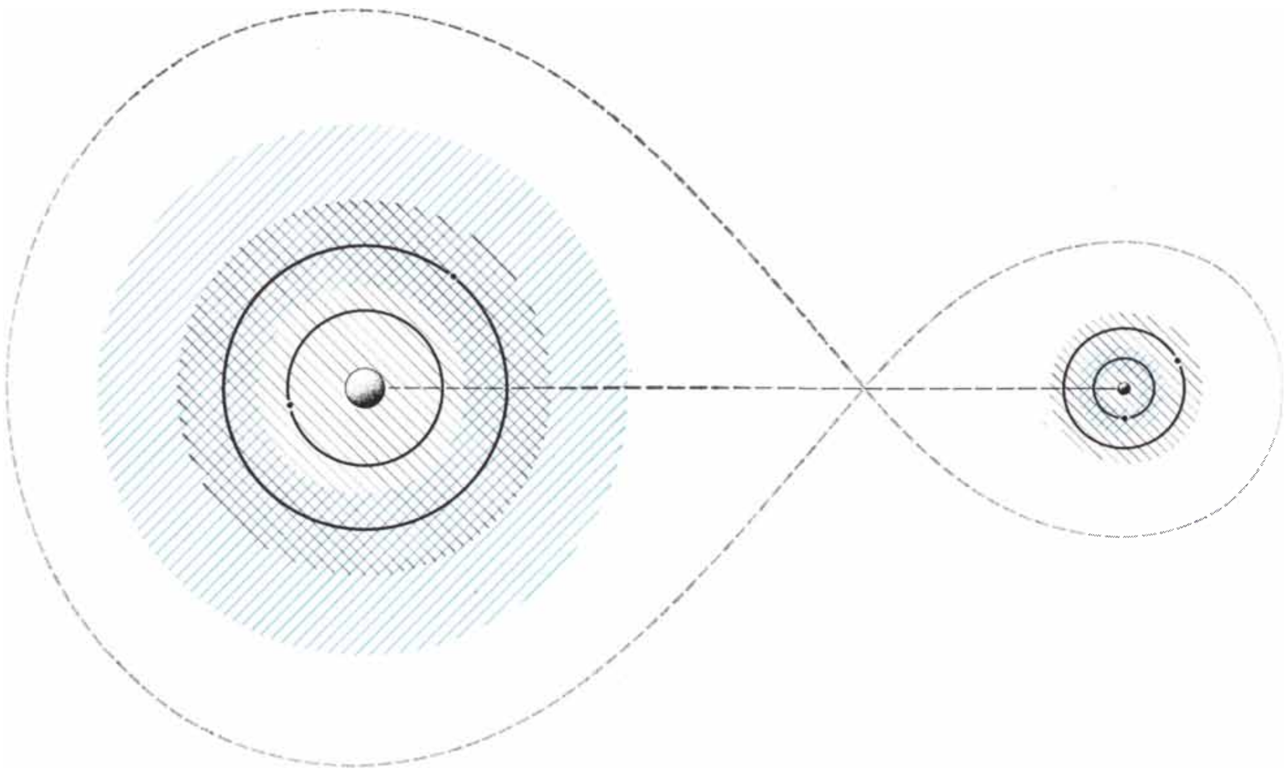
Harold C. Urey of the Scripps Institution of Oceanography has found additional evidence for planets in a certain kind of meteorite. According to Urey, diamonds embedded in these objects show that they must at one time have been under high pressure in a body the size of the moon. Such moonlike objects, known as "prestellar nuclei," would enhance the formation of both stars and planets from a dust cloud. Any irregularity in the motions of a dust cloud should be expected to produce more than one such nucleus, and the formation of planets or multiple stars would follow as a normal consequence.

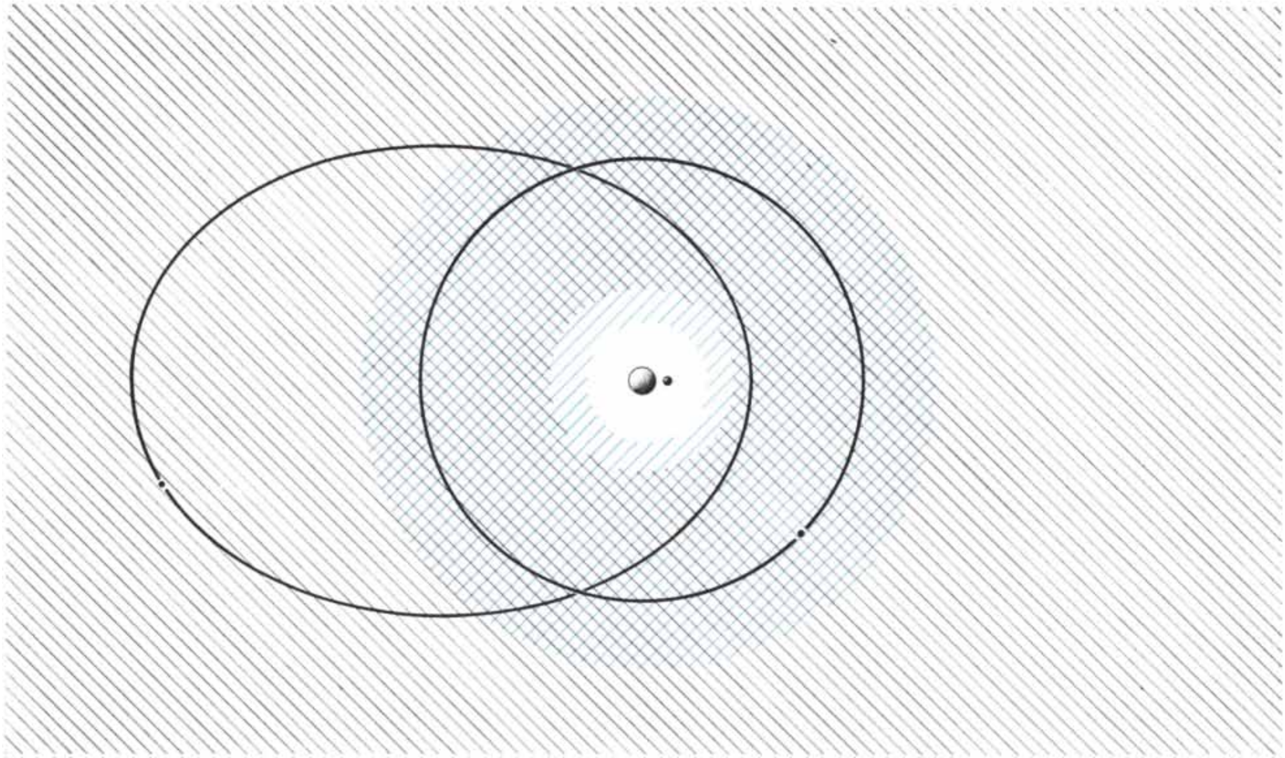
Finally, measurements of the angular momenta of many stars give every indication that planets exist outside the solar system. Otto Struve of the National Radio Astronomy Observatory has pointed out that main-sequence stars more massive than Type F5 usually rotate rapidly, but starting with this type the rotation of stars slows down abruptly. In other words, the average angular momentum per unit mass of the main-sequence stars exhibits a conspicuous break at Type F5 [*see illustration on this page*]. The most reasonable explanation of this strange phenomenon is that unobservable planets have absorbed the angular momentum, just as Jupiter and other planets of the sun carry 98 per cent of the angular momentum of the solar system, leaving the sun with only 2 per cent and a comparatively long period (27 days) of rotation. If planets do indeed account for the slow spin of these otherwise sunlike stars, then planets appear just where life is most likely to flourish.

Thus it seems that intelligent life may be scattered throughout the Milky Way and the universe as a whole. In our immediate neighborhood, however, we may be its only representatives. The sun's nearest neighbor, Alpha Centauri, is only 4.3 light-years away. It is a triple system with two massive components (a G4 star and a K1) revolving around each other about 20 astronomical units apart; at a considerable distance is a small third star. The two larger bodies have highly eccentric orbits, and if there is a stable zone for a planet in this system, it is extremely hard to compute. Moreover, recent investigations indicate that the system may be much younger than the sun, so that higher forms of life might not have had time to evolve even if a habitable planet does exist in it.

Forty other stars are located within five parsecs (16.7 light-years) of the sun. Only two—Epsilon Eridani (a K2 type) and Tau Ceti (G4)—seem to fulfill the conditions for the existence of advanced forms of life, and Epsilon Eridani may not be exactly on the main sequence. Tau Ceti is 10.8 light-years distant, has an apparent visual magnitude of 3.6, is located on the celestial sphere about 16 degrees south of its equator and appears above the horizon in the northern sky only in the winter.

Since intelligent life is probably not a rare phenomenon, and since at least one star in our vicinity meets the specifications of a life-fostering star, it may seem odd that we have had no visitors from other worlds. The idea would have drawn ridicule 20 years ago, but today it deserves consideration. There are, however, several reasons for believing that we have had no visitors from outer space. For one thing, the 10.8 light-years that separate us from Tau Ceti—astronomically a short distance—is an extremely long distance in terms of human experience. Even traveling at the speed of the artificial satellites that man has launched, space voyagers would need hundreds of thousands of years to traverse it. It is possible that organisms from Tau Ceti might have a far longer life-span than man, but this supposition invokes radical assumptions that cannot be supported by present knowledge. Furthermore, if a meeting is to occur,



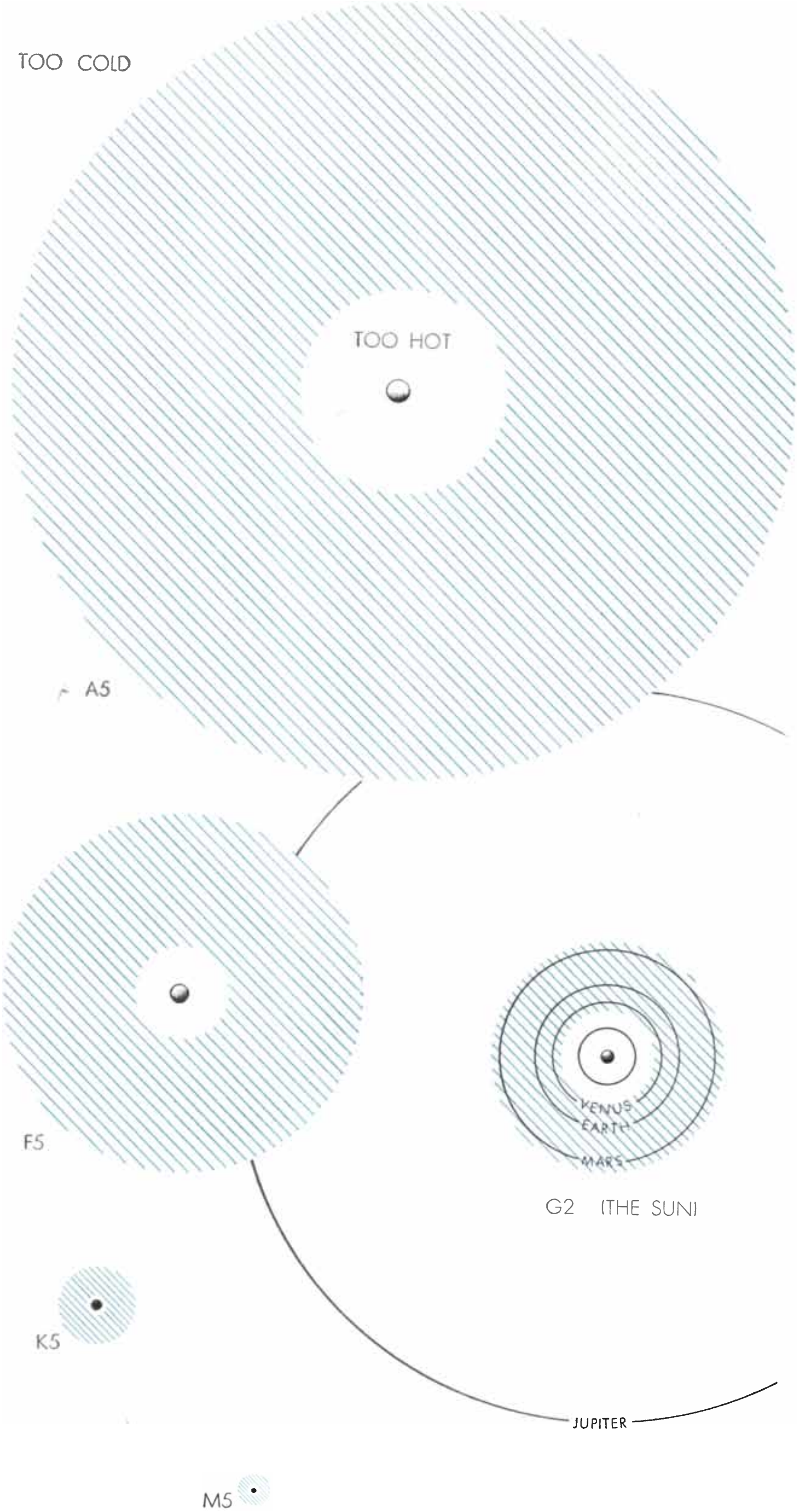


PLANETARY ORBITS AROUND BINARY STARS are depicted here in an idealized manner. The figure eight in the top diagram is simply a mathematical projection from which the dynamically stable planetary orbit is calculated for widely separated binaries. At bottom are close binaries. For a planet to bear life its orbit would have to fall completely within both the dynamically stable zone (*gray hatching*) and the thermally habitable zone (*colored hatching*). At the bottom the highly elliptical planetary orbit is dynamically stable, but it does not fall completely within the thermally habitable zone; the planet therefore could not harbor any life.

our high technological civilization would have to be contemporary with that created by intelligent organisms on other planets. The cultural evolution that brought mankind to its present technical competence began only a few centuries ago. And even if human civilization endures for hundreds of thousands of years, it would be a brief episode in the timescale of biological evolution. Therefore the chance that advanced civilizations might be flourishing at the present time on the planets of one or two nearby stars is excessively small.

Some workers have concluded, however, that the chance is good enough—and certainly intriguing enough—to institute radio surveillance of signals originating outside the solar system. Guiseppe Cocconi and Philip Morrison of Cornell University have pointed out that the most favorable wavelength would be one close to but outside of the 21-centimeter line emitted by hydrogen in space, because in this region of the spectrum the galactic noise and the noise produced in the earth's atmosphere are at a minimum. Moreover, this important wavelength would be of as much interest to astronomers on another planet as to those on earth. Cocconi and Morrison have urged that radiation picked up by the 600-foot radio telescope, now being built by the Navy in West Virginia, be analyzed for the presence of signals. According to them, that telescope will be capable of detecting signals generated 10 light-years away by a technology no more advanced than our own. Meanwhile Frank D. Drake of the National Radio Astronomy Observatory, who makes a more generous estimate of the distance at which signals sent by intelligent organisms could be detected, is in charge of an actual project that is employing a smaller telescope to detect any radio signals transmitted by living beings in other "solar systems."

What kind of signals may we expect to receive or should we send out? Probably the most abstract and the most universal conception that any intelligent organisms anywhere would have devised is the sequence of cardinal numbers: 1, 2, 3, 4 and so on. The most likely signal would be a series of pulses indicating this sequence repeated at regular intervals. Such a signal may upon first consideration appear to be too simple for the sophisticated task of communicating with other beings far away among the stars. It would sound like baby talk. But after all interstellar communication is surely still in the baby-talk stage.



THERMALLY HABITABLE ZONE of various types of star is here represented by hatched area around star. Here the A5 spectral type has largest zone, but star does not remain stable long enough for evolution to take place on a planet near it. Habitable zone of our sun (a G2 type) extends from orbit of Venus to orbit of Mars. Tiny M5 star has the smallest zone.

The "Visual Cliff"

This simple apparatus is used to investigate depth perception in different animals. All species thus far tested seem able to perceive and avoid a sharp drop as soon as they can move about

by Eleanor J. Gibson and Richard D. Walk

Human infants at the creeping and toddling stage are notoriously prone to falls from more or less high places. They must be kept from going over the brink by side panels on their cribs, gates on stairways and the vigilance of adults. As their muscular coordination matures they begin to avoid such accidents on their own. Common sense might suggest that the child learns to recognize falling-off places by experience—that is, by falling and hurting himself. But is experience really the teacher? Or is the ability to perceive and avoid a brink part of the child's original endowment?

Answers to these questions will throw light on the genesis of space perception in general. Height perception is a special case of distance perception: information in the light reaching the eye provides stimuli that can be utilized for the discrimination both of depth and of receding distance on the level. At what stage of development can an animal respond effectively to these stimuli? Does the onset of such response vary with animals of different species and habitats?

At Cornell University we have been investigating these problems by means of a simple experimental setup that we call a visual cliff. The cliff is a simulated one and hence makes it possible not only to control the optical and other stimuli (auditory and tactual, for instance) but also to protect the experimental subjects. It consists of a board laid across a large sheet of heavy glass which is supported a foot or more above the floor. On one side of the board a sheet of patterned material is placed flush against the undersurface of the glass, giving the glass the appearance as well as the substance of solidity. On the other side a sheet of the same material is laid upon the floor; this side of the board thus becomes the visual cliff [*see photograph on cover*].

We tested 36 infants ranging in age from six months to 14 months on the visual cliff. Each child was placed upon the center board, and his mother called him to her from the cliff side and the shallow side successively. All of the 27 infants who moved off the board crawled out on the shallow side at least once; only three of them crept off the brink onto the glass suspended above the pattern on the floor. Many of the infants crawled away from the mother when she called to them from the cliff side; others cried when she stood there, because they could not come to her without crossing an apparent chasm. The experiment thus demonstrated that most human infants can discriminate depth as soon as they can crawl.

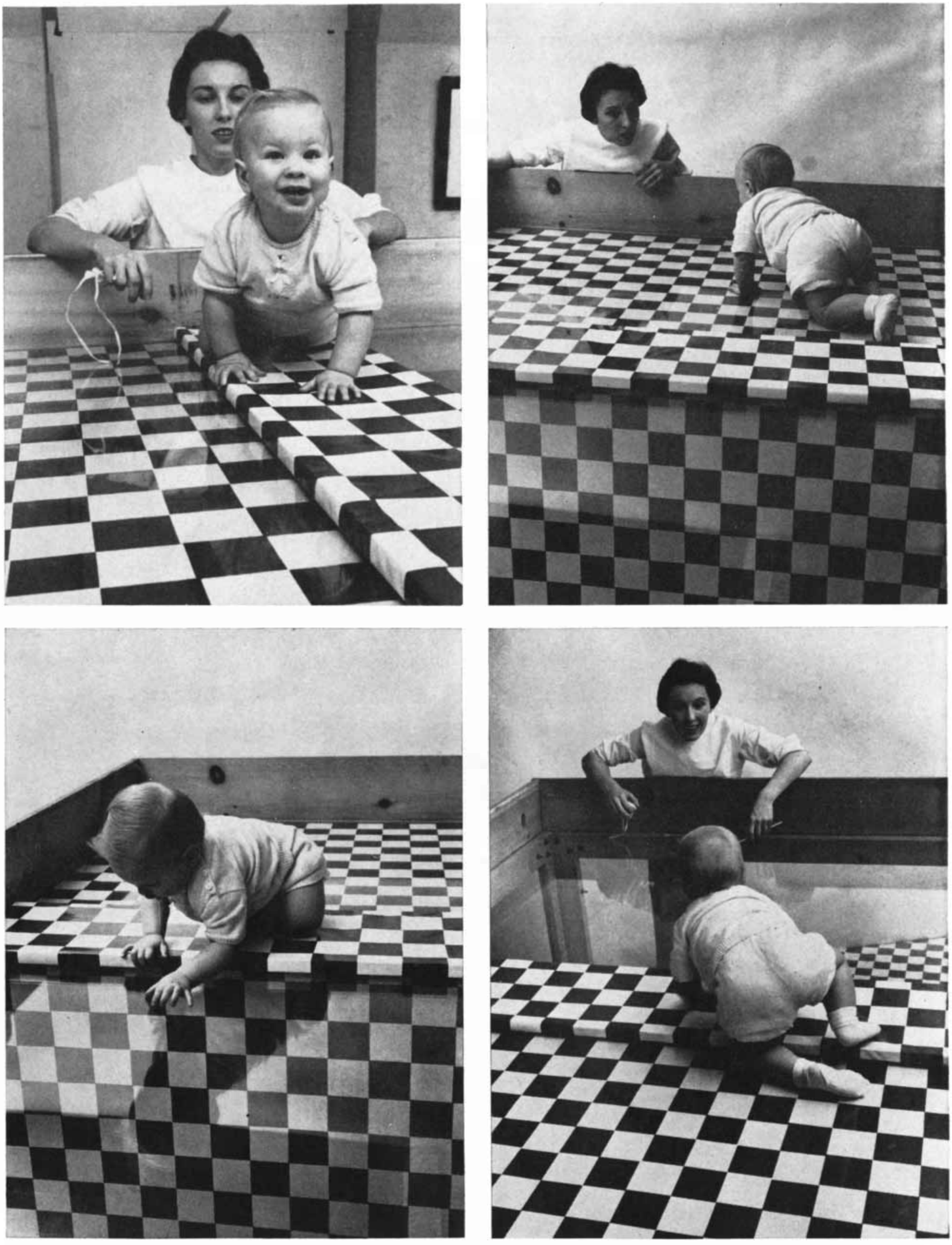
The behavior of the children in this situation gave clear evidence of their dependence on vision. Often they would peer down through the glass on the deep side and then back away. Others would pat the glass with their hands, yet despite this tactual assurance of solidity would refuse to cross. It was equally clear that their perception of depth had matured more rapidly than had their locomotor abilities. Many supported themselves on the glass over the deep side as they maneuvered awkwardly on the board; some even backed out onto the glass as they started toward the mother on the shallow side. Were it not for the glass some of the children would have fallen off the board. Evidently infants should not be left close to a brink, no matter how well they may discriminate depth.

This experiment does not prove that the human infant's perception and avoidance of the cliff are innate. Such an interpretation is supported, however, by the experiments with nonhuman infants. On the visual cliff we have observed the behavior of chicks, turtles, rats, lambs, kids, pigs, kittens and dogs. These animals showed various reactions, each of which proved to be characteristic of their species. In each case the reaction is plainly related to the role of vision in the survival of the species, and the varied patterns of behavior suggest something about the role of vision in evolution.

In the chick, for example, depth perception manifests itself with special rapidity. At an age of less than 24 hours the chick can be tested on the visual cliff. It never makes a "mistake" and always hops off the board on the shallow side. Without doubt this finding is related to the fact that the chick, unlike many other young birds, must scratch for itself a few hours after it is hatched.

Kids and lambs, like chicks, can be tested on the visual cliff as soon as they can stand. The response of these animals is equally predictable. No goat or lamb ever stepped onto the glass of the deep side, even at one day of age. When one of these animals was placed upon the glass on the deep side, it displayed characteristic stereotyped behavior. It would refuse to put its feet down and would back up into a posture of defense, its front legs rigid and its hind legs limp. In this state of immobility it could be pushed forward across the glass until its head and field of vision crossed the edge of the surrounding solid surface, whereupon it would relax and spring forward upon the surface.

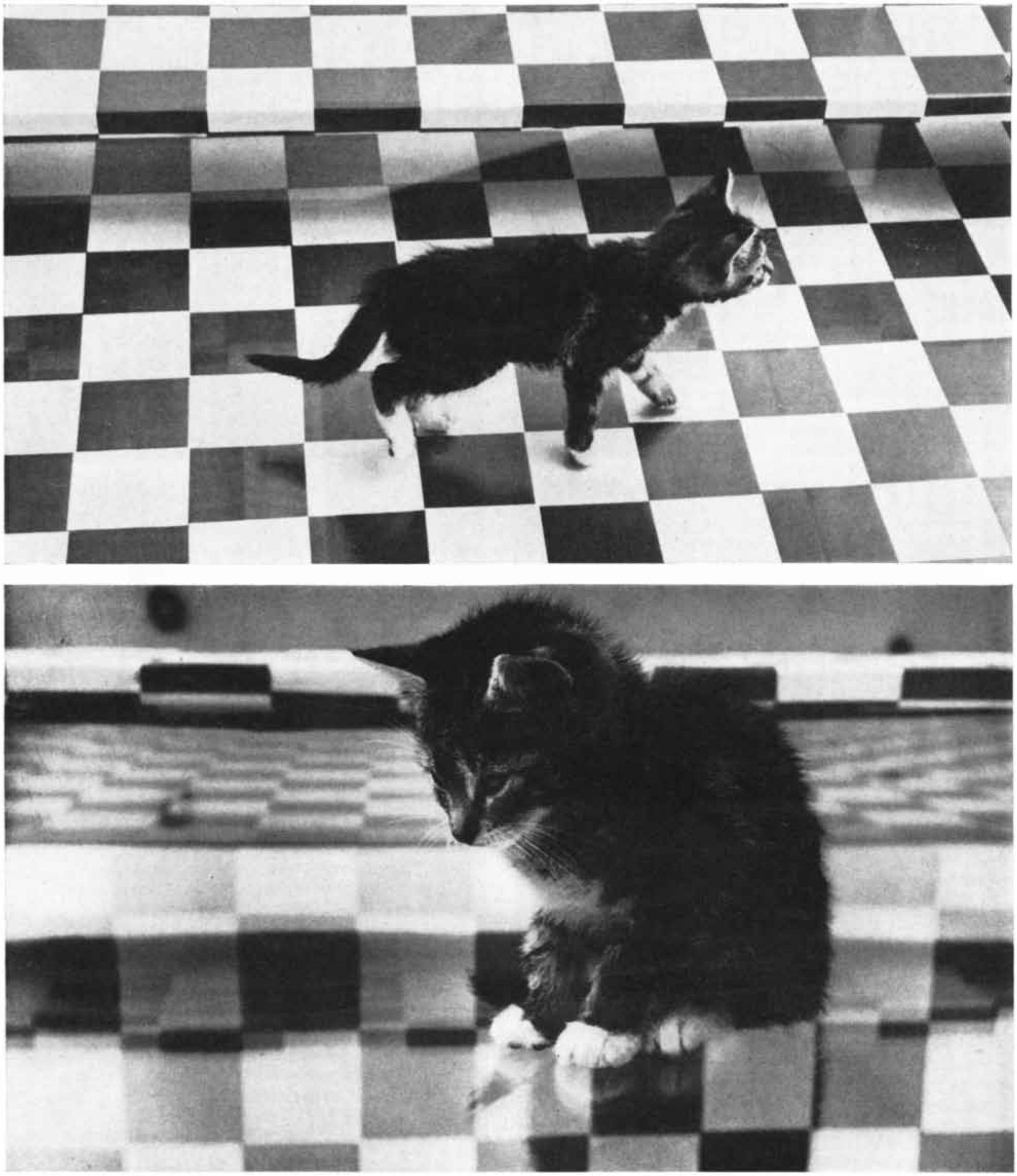
At the Cornell Behavior Farm a group of experimenters has carried these experiments with kids and goats a step further. They fixed the patterned material to a sheet of plywood and were thus able to adjust the "depth" of the deep side. With the pattern held immediately be-



CHILD'S DEPTH PERCEPTION is tested on the visual cliff. The apparatus consists of a board laid across a sheet of heavy glass, with a patterned material directly beneath the glass on one side and several feet below it on the other. Placed on the center board (*top left*), the child crawls to its mother across the "shallow" side (*top right*). Called from the "deep" side, he pats the glass (*bottom left*), but despite this tactual evidence that the "cliff" is in fact a solid surface he refuses to cross over to the mother (*bottom right*).

neath the glass, the animal would move about the glass freely. With the optical floor dropped more than a foot below the glass, the animal would immediately freeze into its defensive posture. Despite repeated experience of the tactual solidity of the glass, the animals never learned to function without optical support. Their sense of security or danger continued to depend upon the visual cues that give them their perception of depth.

The rat, in contrast, does not depend predominantly upon visual cues. Its nocturnal habits lead it to seek food largely by smell, when moving about in the dark, it responds to tactual cues from the stiff whiskers (vibrissae) on its snout. Hooded rats tested on the visual cliff show little preference for the shallow side so long as they can feel the glass with their vibrissae. Placed upon the



KITTEN'S DEPTH PERCEPTION also manifests itself at an early age. Though the animal displays no alarm on the shallow side (*top*), it "freezes" when placed on the glass over the deep side (*bottom*); in some cases it will crawl aimlessly backward in a circle.

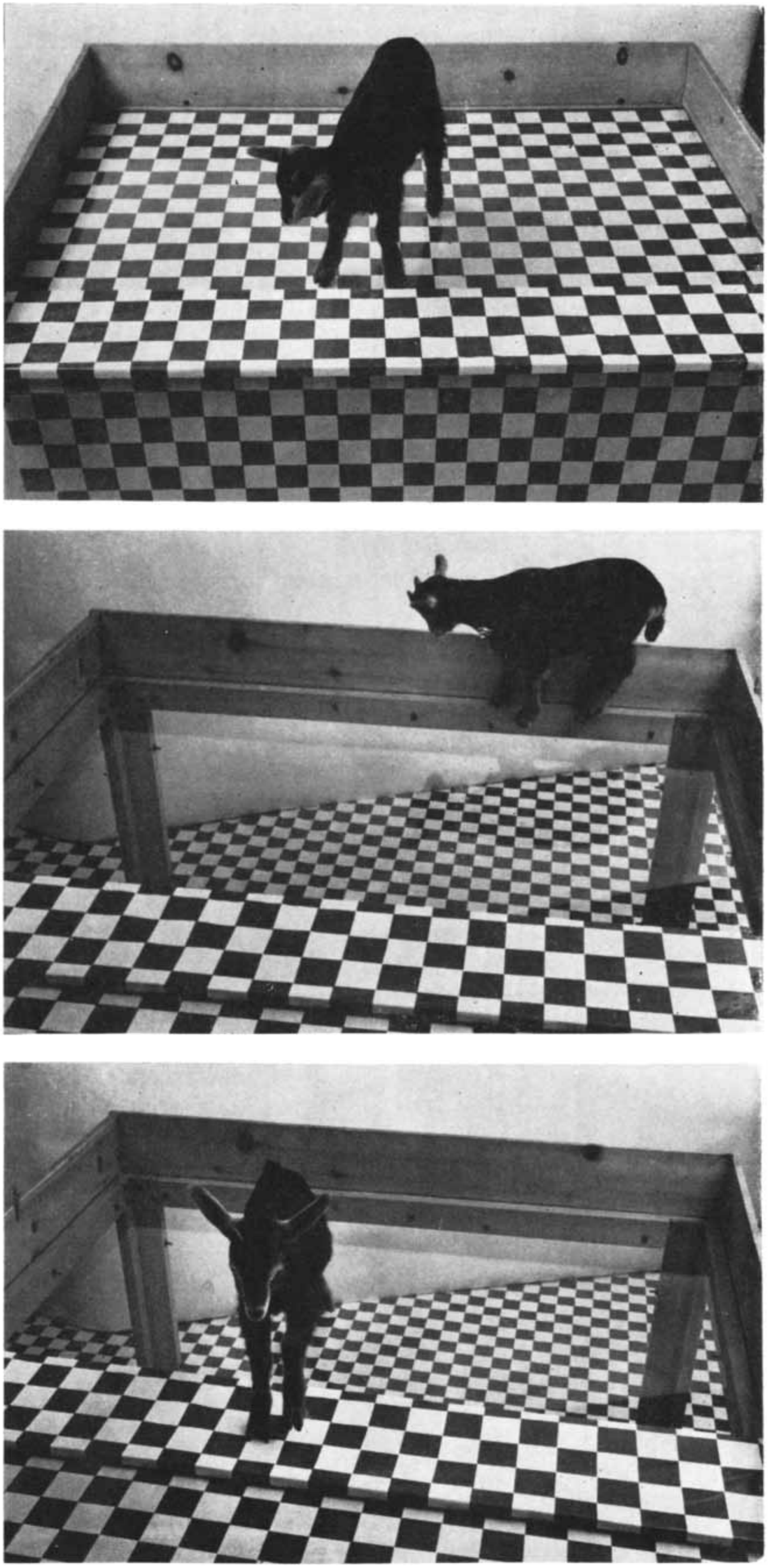
glass over the deep side, they move about normally. But when we raise the center board several inches, so that the glass is out of reach of their whiskers, they evince good visual depth-discrimination: 95 to 100 per cent of them descend on the shallow side.

Cats, like rats, are nocturnal animals, sensitive to tactual cues from their vibrissae. But the cat, as a predator, must rely more strongly on its sight. Kittens proved to have excellent depth-discrimination. At four weeks—about the earliest age that a kitten can move about with any facility—they invariably choose the shallow side of the cliff. On the glass over the deep side, they either freeze or circle aimlessly backward until they reach the center board [*see illustrations on opposite page*].

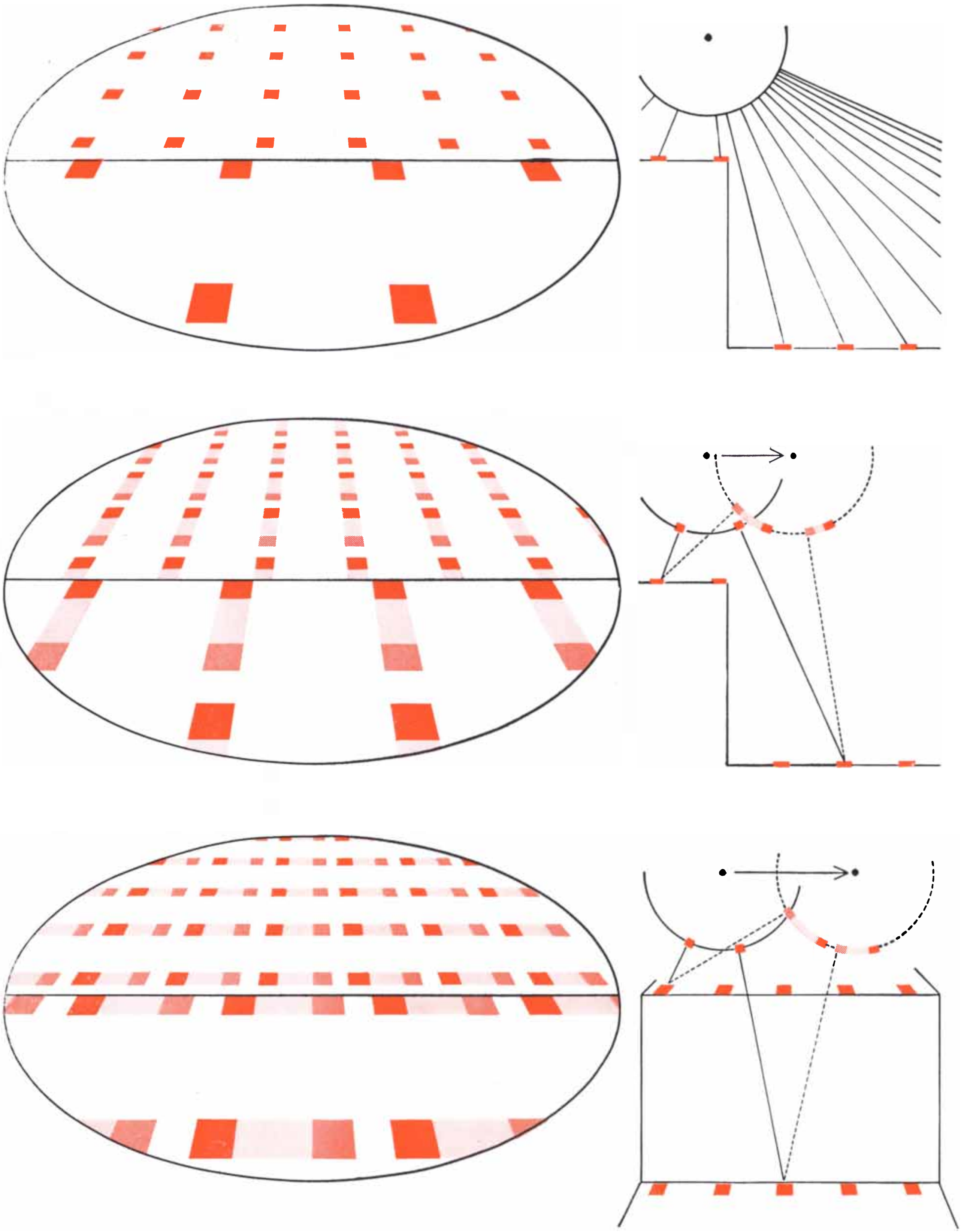
The animals that showed the poorest performance in our series were the turtles. The late Robert M. Yerkes of Harvard University found in 1904 that aquatic turtles have somewhat poorer depth-discrimination than land turtles. On the visual cliff one might expect an aquatic turtle to respond to the reflections from the glass as it might to water and so prefer the deep side. They showed no such preference: 76 per cent of the aquatic turtles crawled off the board on the shallow side. The relatively large minority that choose the deep side suggests either that this turtle has poorer depth-discrimination than other animals, or that its natural habitat gives it less occasion to "fear" a fall.

All of these observations square with what is known about the life history and ecological niche of each of the animals tested. The survival of a species requires that its members develop discrimination of depth by the time they take up independent locomotion, whether at one day (the chick and the goat), three to four weeks (the rat and the cat) or six to 10 months (the human infant). That such a vital capacity does not depend on possibly fatal accidents of learning in the lives of individuals is consistent with evolutionary theory.

To make sure that no hidden bias was concealed in the design of the visual cliff we conducted a number of control experiments. In one of them we eliminated reflections from the glass by lighting the patterned surfaces from below the glass (to accomplish this we dropped the pattern below the glass on both sides, but more on one side than on the other). The animals—hooded rats—still consistently chose the shallow side. As a test of the role of the patterned surface we



GOATS SHOW DEPTH PERCEPTION at an age of only one day. A kid walks freely on the shallow side (*top*); on the deep side (*middle*) it leaps the "chasm" to safety (*bottom*).



TWO TYPES OF VISUAL DEPTH-CUE are diagrammed schematically on this page. Ellipses approximate the visual field of an animal standing near the edge of the cliff and looking toward it; diagrams at right give the geometrical explanation of differences in the fields. The spacing of the pattern elements (*solid color*) decreases sharply beyond the edge of the cliff (*top*). The optical motion (*shaded color*) of the elements as the animal moves forward (*center*) or sideways (*bottom*) shows a similar drop-off.

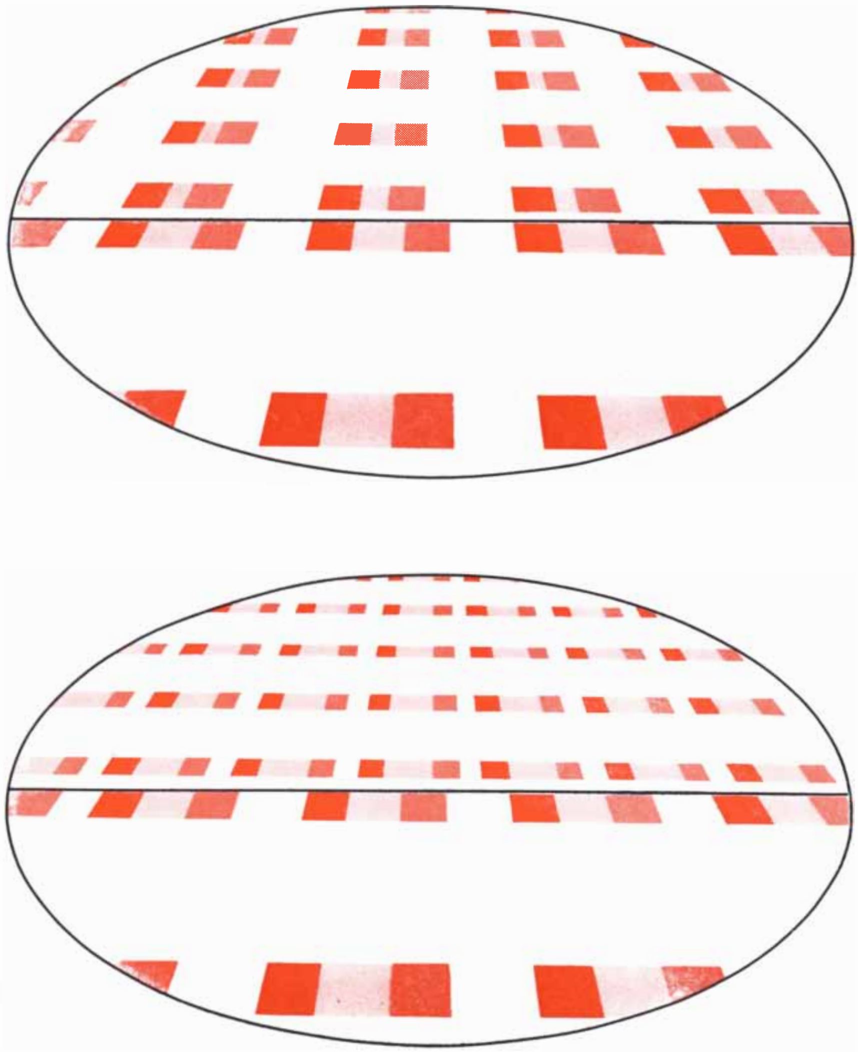
replaced it on either side of the centerboard with a homogeneous gray surface. Confronted with this choice, the rats showed no preference for either the shallow or the deep side. We also eliminated the optical difference between the two sides of the board by placing the patterned surface directly against the undersurface of the glass on each side. The rats then descended without preference to either side. When we lowered the pattern 10 inches below the glass on each side, they stayed on the board.

We set out next to determine which of two visual cues plays the decisive role in depth perception. To an eye above the center board the optical pattern on the two sides differs in at least two important respects. On the deep side distance decreases the size and spacing of the pattern elements projected on the retina. "Motion parallax," on the other hand, causes the pattern elements on the shallow side to move more rapidly across the field of vision when the animal moves its position on the board or moves its head, just as nearby objects seen from a moving car appear to pass by more quickly than distant ones [*see illustration on opposite page*]. To eliminate the potential distance cue provided by pattern density we increased the size and spacing of the pattern elements on the deep side in proportion to its distance from the eye [*see top illustration at right*]. With only the cue of motion parallax to guide them, adult rats still preferred the shallow side, though not so strongly as in the standard experiment. Infant rats chose the shallow side nearly 100 per cent of the time under both conditions, as did day-old chicks. Evidently both species can discriminate depth by differential motion alone, with no aid from texture density and probably little help from other cues. The perception of distance by binocular parallax, which doubtless plays an important part in human behavior, would not seem to have a significant role, for example, in the depth perception of chicks and rats.

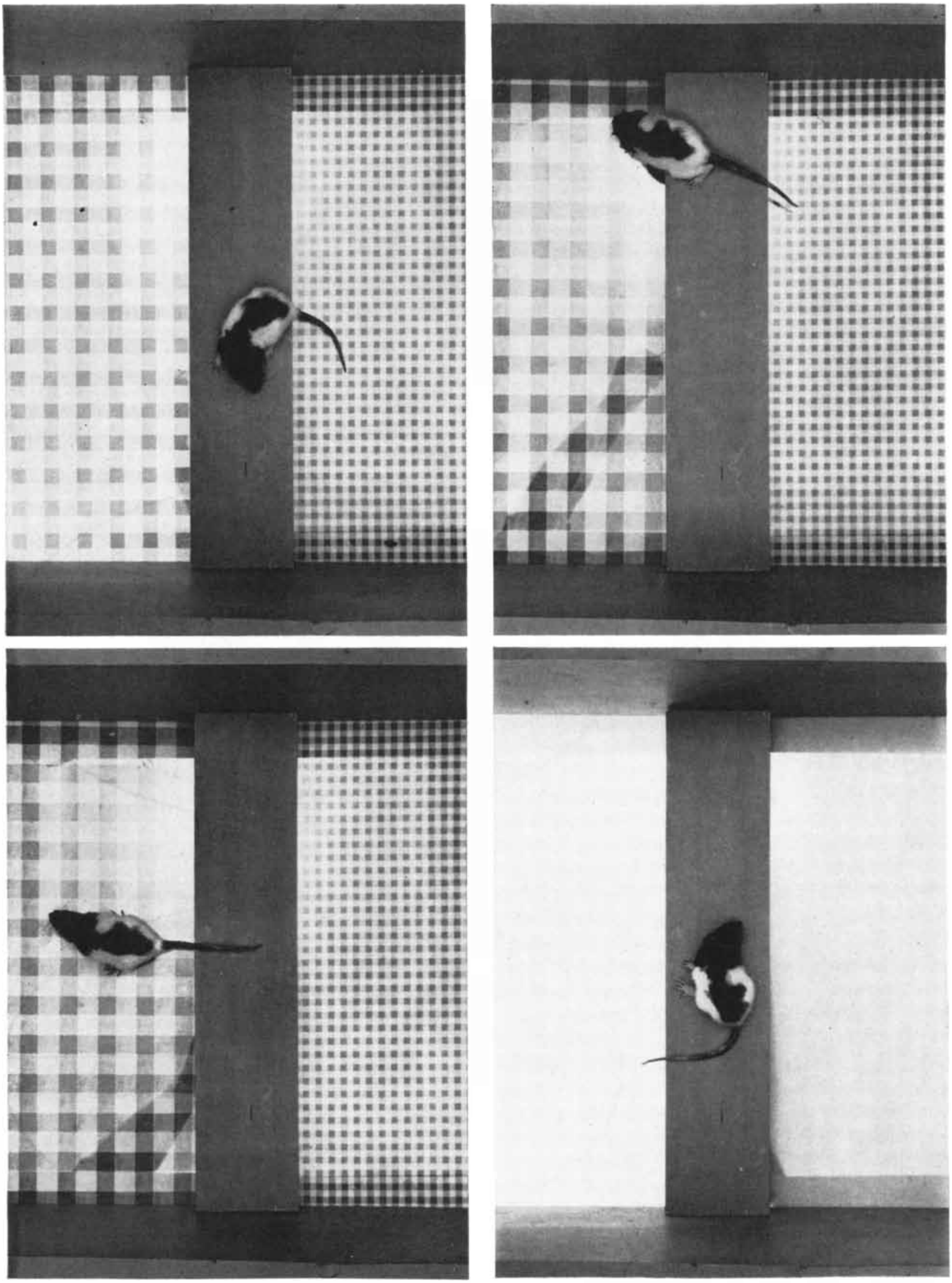
To eliminate the cue of motion parallax we placed the patterned material directly against the glass on either side of the board but used smaller and more densely spaced pattern-elements on the cliff side. Both young and adult hooded rats preferred the side with the larger pattern, which evidently "signified" a nearer surface. Day-old chicks, however, showed no preference for the larger pattern. It may be that learning plays some part in the preference exhibited by the rats, since the young rats were tested at a somewhat older age than the chicks. This supposition is supported by the results of our experiments with animals reared in the dark.

The effects of early experience and of such deprivations as dark-rearing represent important clues to the relative roles of maturation and learning in animal behavior. The first experiments along this line were performed by K. S. Lashley and James T. Russell at the University of Chicago in 1934. They tested light-reared and dark-reared rats on a "jumping stand" from which they induced animals to leap toward a platform placed at varying distances. Upon finding that both groups of animals jumped with a force closely correlated with distance, they concluded that depth perception in rats is innate. Other investigators have pointed out, however, that the dark-reared rats required a certain amount of "pretraining" in the light before they could be made to jump. Since the visual-cliff technique requires no pretraining, we employed it to test groups of light-reared and dark-reared hooded rats. At the age of 90 days both groups showed the same preference for the shallow side of the apparatus, confirming Lashley's and Russell's conclusion.

Recalling our findings in the young rat, we then took up the question of whether the dark-reared rats relied upon motion parallax or upon contrast in texture density to discriminate depth. When the animals were confronted with the visual cliff, cued only by motion parallax, they preferred the shallow side, as had the light-reared animals. When the



SEPARATION OF VISUAL CUES is shown in these diagrams. Pattern density is held constant (*top*) by using a larger pattern on the low side of the cliff; the drop in optical motion (motion parallax) remains. Motion parallax is equalized (*bottom*) by placing patterns at same level; the smaller pattern on one side preserves difference in spacing.

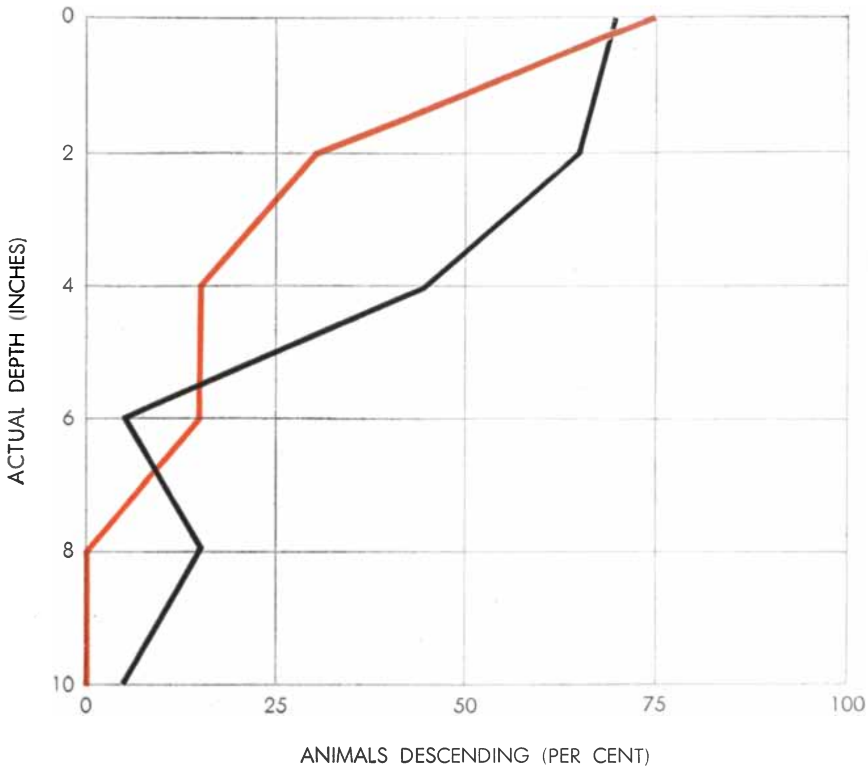


IMPORTANCE OF PATTERN in depth perception is shown in these photographs. Of two patterns set at the same depth, normal rats almost invariably preferred the larger (*top row and bottom left*), presumably because it "signified" a nearer and therefore safer surface. Confronted with two patternless surfaces set at different depths, the animals displayed no preference (*bottom right*).

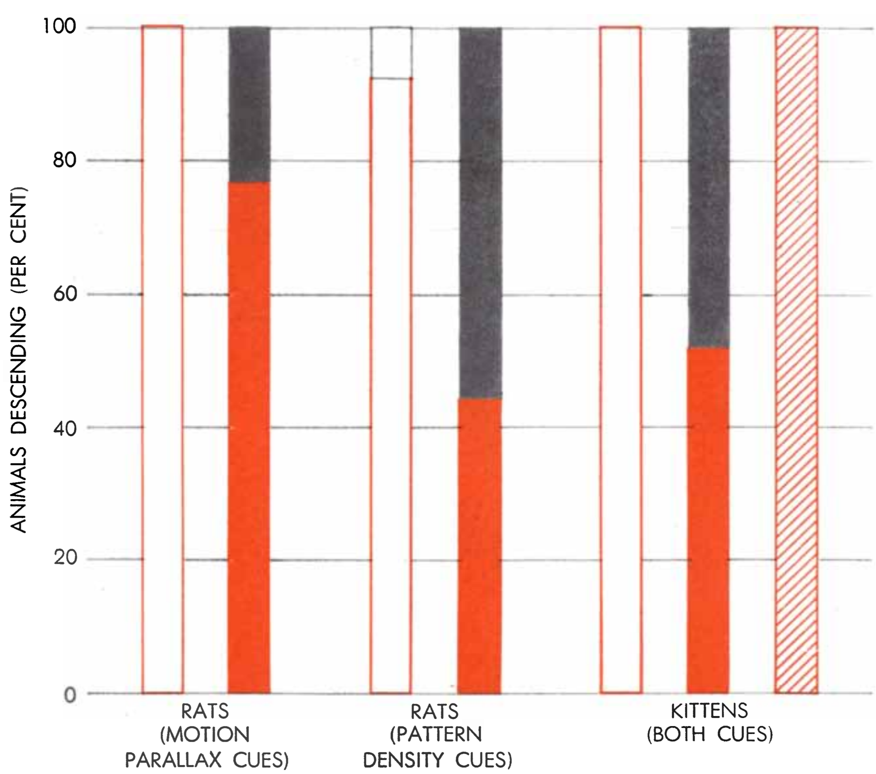
choice was cued by pattern density, however, they departed from the pattern of the normal animals and showed no significant preference [*see bottom illustration at right*]. The behavior of dark-reared rats thus resembles that of the day-old chicks, which also lack visual experience. It seems likely, therefore, that of the two cues only motion parallax is an innate cue for depth discrimination. Responses to differential pattern-density may be learned later.

One cannot automatically extrapolate these results to other species. But experiments with dark-reared kittens indicate that in these animals, too, depth perception matures independently of trial and error learning. In the kitten, however, light is necessary for normal visual maturation. Kittens reared in the dark to the age of 27 days at first crawled or fell off the center board equally often on the deep and shallow sides. Placed upon the glass over the deep side, they did not back in a circle like normal kittens but showed the same behavior that they had exhibited on the shallow side. Other investigators have observed equivalent behavior in dark-reared kittens; they bump into obstacles, lack normal eye movement and appear to "stare" straight ahead. These difficulties pass after a few days in the light. We accordingly tested the kittens every day. By the end of a week they were performing in every respect like normal kittens. They showed the same unanimous preference for the shallow side. Placed upon the glass over the deep side, they balked and circled backward to a visually secure surface. Repeated descents to the deep side, and placement upon the glass during their "blind" period, had not taught them that the deep side was "safe." Instead they avoided it more and more consistently. The initial blindness of dark-reared kittens makes them ideal subjects for studying the maturation of depth perception. With further study it should be possible to determine which cues they respond to first and what kinds of visual experience accelerate or retard the process of maturation.

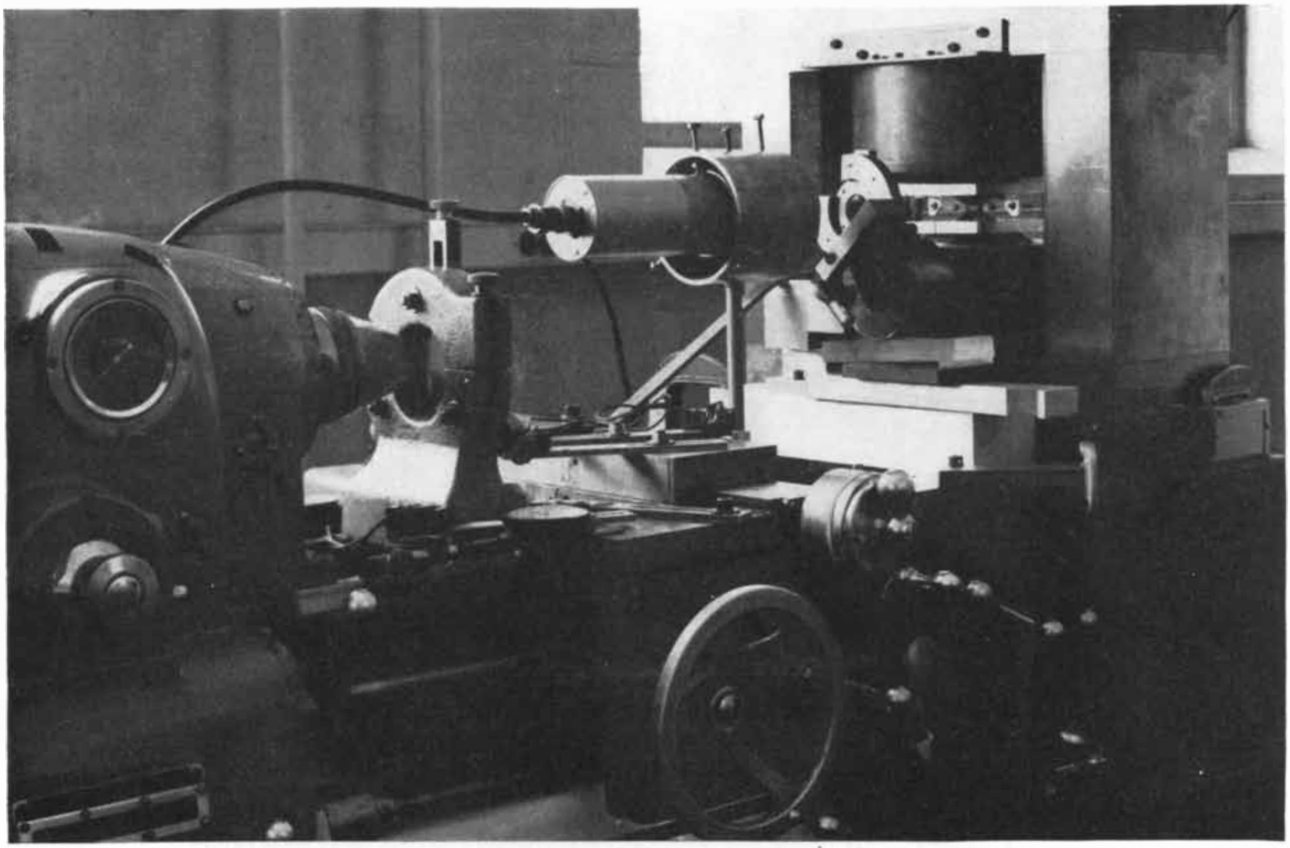
From our first few years of work with the visual cliff we are ready to venture the rather broad conclusion that a seeing animal will be able to discriminate depth when its locomotion is adequate, even when locomotion begins at birth. But many experiments remain to be done, especially on the role of different cues and on the effects of different kinds of early visual experience.

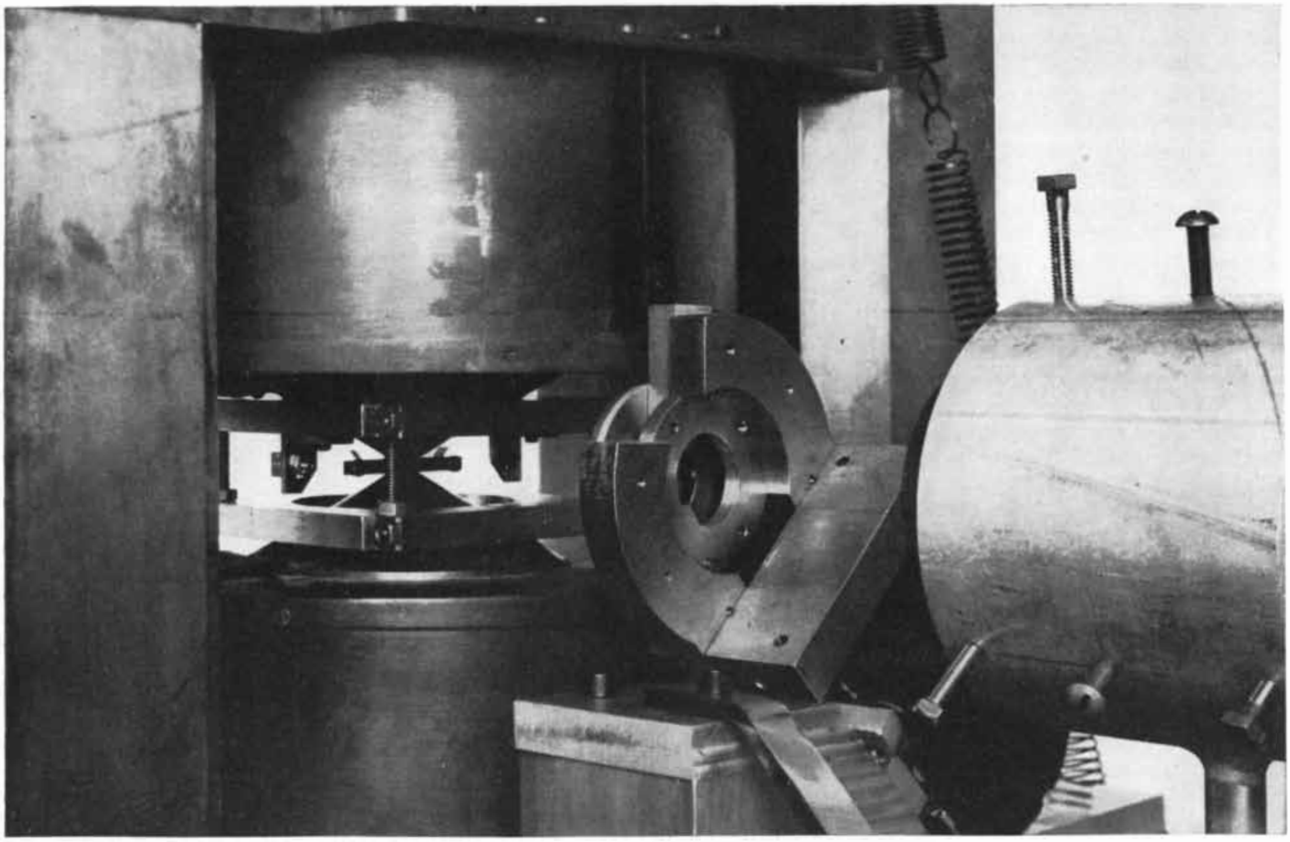


CONTROL EXPERIMENT measured the effect on rats of reflections on the glass of the apparatus. The percentage of animals leaving the center board decreased with increasing depth in much the same way, whether glass was present (*black curve*) or not (*colored curve*).



DARK-REARING EXPERIMENTS reveal the order in which different depth-cues are utilized as animals mature. Animals reared in the light (*open bars*) all strongly preferred the shallow side (*color*) to the deep side (*gray*). Dark-reared rats (*solid bars*), utilizing motion parallax alone, still preferred the shallow side; pattern density alone elicited no preference. Dark-reared kittens also showed no preference, because of temporary blindness. After seven days in the light all of them chose the shallow side (*hatched bar*).





RESONANCE-ABSORPTION EXPERIMENT was photographed at the Argonne National Laboratory. Assembly of iron-57 source of gamma radiation together with absorber and detector can be seen at upper right in top picture, mounted on a lathe that moves the absorber. In the close-up of the assembly (*bottom*) the source is the flat plate between tapering magnetic poles (*left*). Absorber is mounted in circular disk (*center*); detector is in cylinder (*right*). Magnet is used to measure "hyperfine" splitting of absorption line.

The Mössbauer Effect

A German physicist's discovery is the basis of a "nuclear clock" of unprecedented accuracy. Such a device should make possible the first conclusive test of the general theory of relativity

by Sergio De Benedetti

According to a very old and very wise myth, Zeus, the chief deity of Olympus, was the son of Chronos, the god of time. The legend demonstrates the Greeks' deep intuitive understanding of the natural world; they realized that time is the first of all mysteries, the most fundamental of all concepts.

Just recently there has fallen into man's hands an almost unimaginably sensitive technique for measuring time and penetrating some of its long-kept secrets. Thus Chronos is suffering the fate of his Olympian descendants, whose places were usurped by laws of nature as Greek intuition gave way to the quantitative reasoning and experimental methods of our scientific age.

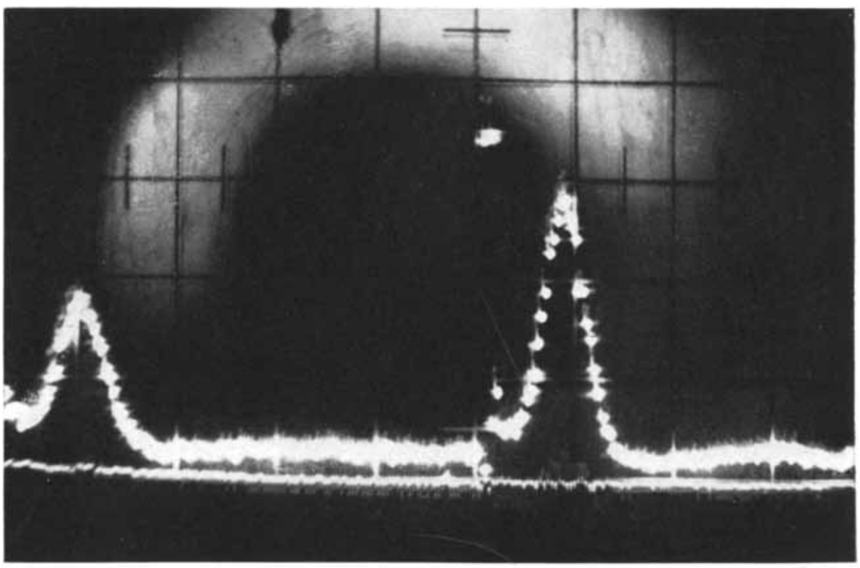
We begin the account of this development in the Attic spirit, with an embellishment of the ancient legend. Imagine that at the first Olympic games, a few hundred years before the time of Christ, Chronos himself awarded a prize to the winner of the marathon. Of course the prize was a watch, but a watch of perfect accuracy such as only the god of time could give. We may well suppose that this matchless timepiece was reverently handed down from father to son. Designed like a modern watch, it ticked away through the centuries exactly five times per second, measuring the absolute and immutable flow of time.

Then came Albert Einstein to proclaim the relativity of time. His special theory of relativity showed that the rate at which clocks run depends on their relative motion. If a fast runner carried Chronos's gift, it would lose time at the rate of about a hundredth of a tick in a million million. Not a very serious loss, but in principle an affront to the dignity of the god. Furthermore, according to the general theory of relativity, the watch would slow down by about the same amount if it were kept on the top floor of a building a few stories high rather than on the ground floor, because of the difference in the gravitational potential energy.

Still, as an anthropomorphic god, Chronos could afford to shrug off relativity. Perhaps subatomic particles, moving at nearly the speed of light, would demonstrate the contraction of time with velocity; perhaps the gravitational effect could be perceived in the red-shift of light from the dense companion of Sirius. But on earth, for distances and speeds on the human scale, the effects would be undetectable. And so they were until a few months ago, when the German physicist R. L. Mössbauer published a paper that opened the way to a measurement of the loss of a hundredth of a tick in a million million!

To understand the significance of Mössbauer's contribution, consider the requirements of an instrument to measure time. First of all, there must be a periodic device—something that undergoes a repetitious, or cyclical, motion always in the same length of time—like a pendulum or a balance wheel. But for extremely accurate studies mere regularity is not enough. There must be a substantial number of repetitions in a reasonable time. The faster the ticking and the greater the number of uninterrupted ticks, the better.

We can see why this is so if we suppose that we really have Chronos's watch, and that its perfect balance-wheel



TRANSMISSION OF GAMMA RAYS in absorption experiment is recorded as vertical deflection on oscilloscope. Peak at left shows transmission when source and absorber are at rest and therefore in resonance. Peak at right shows increased transmission when source and absorber are "detuned" by moving absorber at the rate of 1.17 millimeters per second.

is the fastest pendulum device available to us. All slower processes could be measured in terms of its one-fifth-of-a-second ticks. But what if we made a second watch as closely like it as possible and set out to compare the two? Assume that this second device actually runs slow at the rate of one tick in 10^{12} (a million million). Assume also that we can detect that the two watches are not synchronized when they differ by as little as, say, a 10th of a tick. If they start out exactly together, they must tick 10^{11} times before we can tell that one is running slower. At the rate of five ticks per second this would take about a millennium.

In the past few years physicists have found much more rapid and accurate pendulums. Using the vibrations of certain molecules or atoms, they have built atomic clocks that tick several thousand million times a second [see "Atomic Clocks," by Harold Lyons; SCIENTIFIC AMERICAN, February, 1957]. But nature has provided a still better timekeeper in the nucleus of the atom.

In classical terms (by which is meant not the ancient Greeks and their gods, but simply a description that does not involve quantum ideas) we may think of a nucleus as a spherical body with a uniformly distributed positive electric charge. The sphere is not rigid, but behaves like a liquid drop. If the nucleus is excited, the sphere vibrates like a drop of water or mercury. When it vibrates, the nucleus radiates electromagnetic waves, which we call gamma rays. The emission of the waves requires energy; the amplitude of their vibration gradually decreases in the same way that the vibrations of a violin string die out as their energy is carried away by sound.

In a typical case the frequency of the gamma-ray vibration may be 10^{18} (a million million million) oscillations per second. Since certain nuclei emit energy at a very slow rate, they keep on vibrating for a relatively long time, a time which is measured in seconds, days or even months. These long-lasting excited states of nuclei are called isomeric states, and their duration is usually expressed in terms of a half-life—the time required for the intensity of the emitted radiation to decrease by half.

An excited nucleus with a long half-life is a virtually perfect pendulum. All nuclei of the same kind are exactly alike; this is a great advantage over man-made pendulums, no two of which are ever really identical. Moreover, being protected from external influences by surrounding atomic electrons, a nucleus vibrates at a rate that is not affected by external influences such as temperature or chemical change. Finally, a nuclear pendulum is not damped by unpredictable frictional forces, and thus "ticks" with absolute regularity an enormous number of times without requiring to be pushed again. Even if the half-life is only a millionth of a second, there will be 10^{12} vibrations before the oscillations are considerably damped.

A good pendulum is the heart of a good clock, but it is not the clock itself. There must also be a device, such as a dial with hands, that counts the swings of the pendulum and thus allows us to read the time. We cannot directly count the oscillations of a vibrating nucleus. What we can do, however, is to compare with great accuracy the frequencies of two nuclear pendulums.

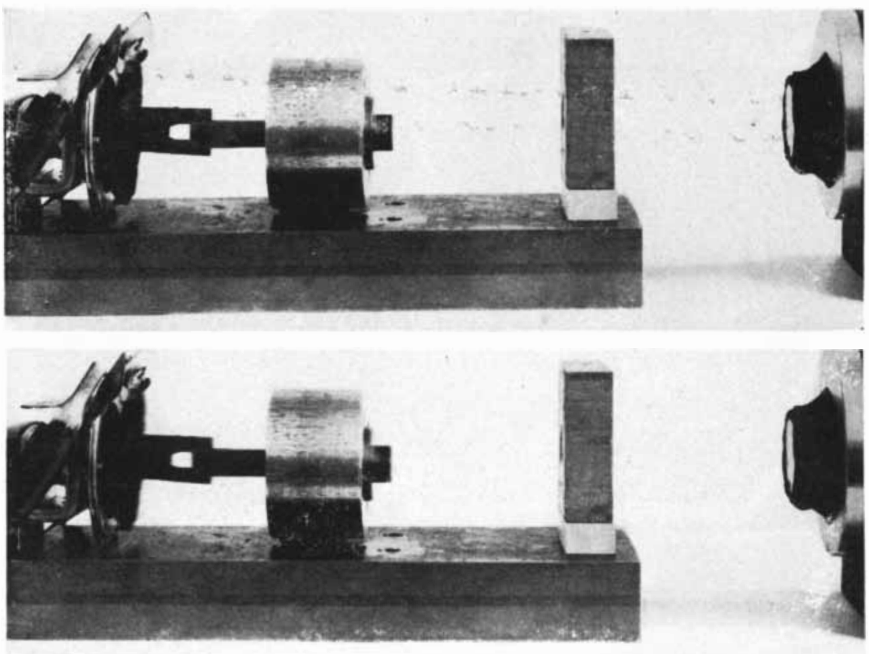
The method is based on the familiar observation that sound waves from a vibrating piano-string induce resonant vibrations in another string, initially at rest but tuned to the same note. In the same manner gamma rays emitted by an oscillating nucleus are absorbed by another nucleus of the same kind, and set it into vibration. When we observe this, we know that the two nuclei must have the same vibration rate, within very narrow limits of error.

What sets the limits? As our earlier example indicated, the accuracy that can be achieved in measuring a frequency increases with the number of oscillations involved. This means that a nucleus with a long half-life has an intrinsically better-defined frequency than a nucleus of short half-life. But resonance excitation requires that the frequencies of emitter and absorber be the same within their intrinsic accuracy. It follows that the "sharpness" of the resonance increases with the half-life of the excitation, which we have already deemed to be related to the quality of the clock.

In our typical case of 10^{12} spontaneous nuclear oscillations the resonance effect disappears if the frequency of the emitting nucleus differs from that of the absorber by as little as one part in 10^{12}. In the language of modern physics we say that the width of the resonance, or the line width, is one part in 10^{12}.

At present the most convenient material to use in resonance experiments is the iron isotope of mass 57. One starts with a radioactive source of the isotope cobalt 57, which is commercially available and has a convenient half-life of 280 days. As the cobalt-57 nuclei decay at this leisurely rate, they change into excited nuclei of iron 57. The iron nuclei vibrate at a frequency of 3×10^{18} oscillations per second, with a half-life of 10^{-7} second (a 10th of a millionth of a second). Thus an iron-57 nucleus emits roughly 10^{12} waves.

In the resonance measurement a narrow beam of the waves is aimed at an-



RELATIVE MOTION of source and absorber can also be produced by linking the source (*thin cylinder*) to a loudspeaker (*left*), which vibrates in response to an audio-frequency signal. Gamma rays pass through absorber (*center*) and into detector (*right*). Source appears sharp when speaker is still (*top*); slightly blurred when it vibrates (*bottom*).

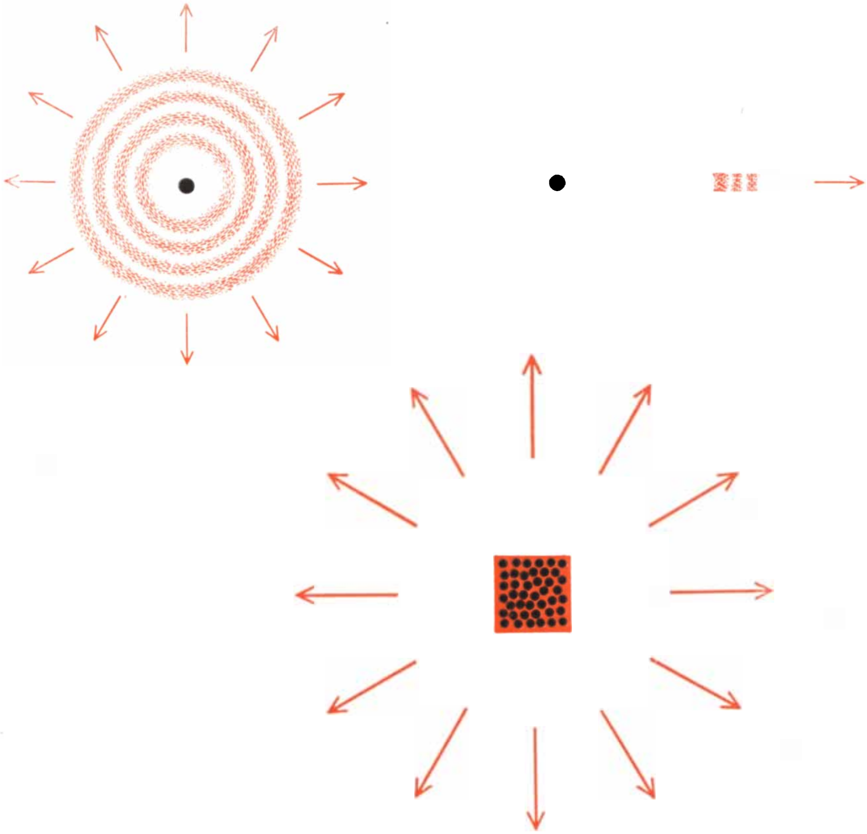
other piece of iron containing stable nuclei of iron 57 [*see bottom illustration on this page*]. At resonance these nuclei strongly absorb energy from the beam and reradiate it in all directions. A scintillation counter set up beyond the absorber in the line of the original beam records a sharp drop when the absorber nuclei are in resonance with the beam. At the same time a counter located near the absorber at right angles to the beam direction shows an increase in energy due to the scattered radiation emitted by the absorber nuclei. The experiment is not at all difficult to perform. If one uses pure iron 57 for the absorber, the difference in the transmitted energy recorded by the first counter at resonance and out of resonance is as large as 50 per cent.

The theory of nuclear resonance goes back several years, and, as we have remarked, the crucial experiment is a comparatively easy one. Why was it not done earlier? The reason is that certain secondary effects made it quite difficult to observe nuclear resonance before the work of Mössbauer.

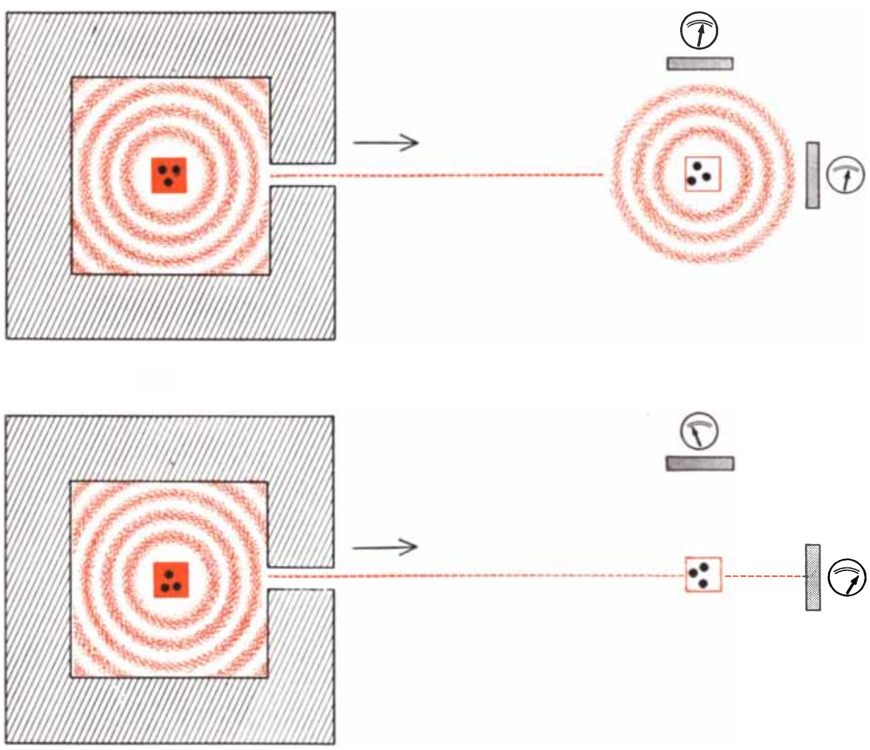
To explain these effects we shall have to abandon the oversimplified, classical picture of nuclear radiation and consider some of its quantum aspects. On this view an excited nucleus does not lose its energy gradually by radiating a continuous wave in all directions. Instead, at an unpredictable moment, it drops abruptly from its excited state to its stable, or "ground," state, emitting a "packet" of radiation in a single, unpredictable direction. This packet, or photon, carries an amount of energy equal to the difference in energy between the excited and ground states of the emitting nucleus. The absorption process is just the reverse. A nucleus in the ground state absorbs a photon and is raised to the excited state. Some time later it reverts to the ground state and reradiates the energy as a new photon.

As Einstein showed many years ago, the energy carried by a photon is proportional to its frequency. Thus in a certain sense the words "energy" and "frequency" can be used interchangeably in quantum-mechanical language. For example, the poor definition in frequency due to a short half-life now becomes a poor definition in energy, and the physicist speaks of the width of an energy line.

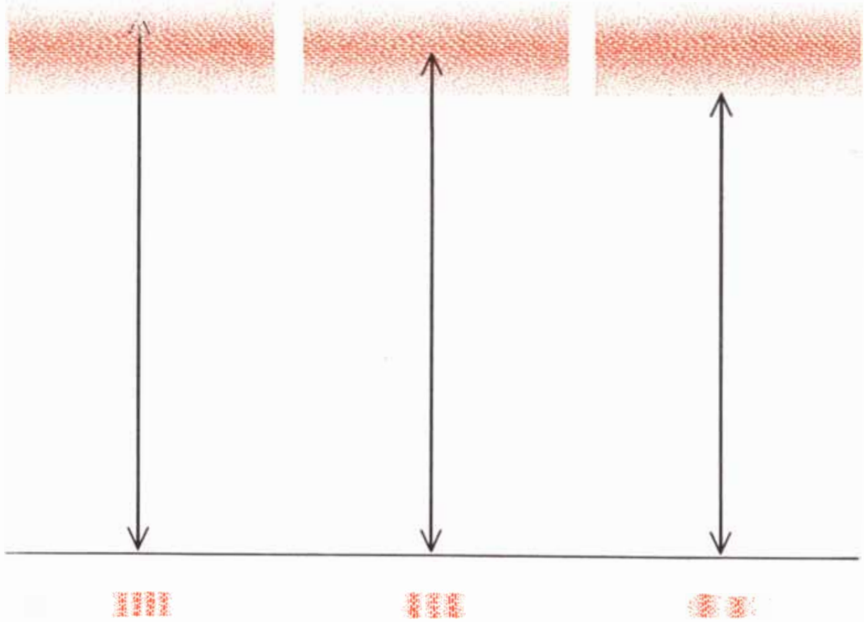
In quantum-mechanical parlance resonance occurs only if the energy lines of the source and absorber overlap within their widths. In the case of iron 57 the photon has an energy of about



NUCLEAR RADIATION is illustrated schematically in "classical" terms (*top left*) and quantum terms (*top right*). Dot represents an isolated nucleus; circles represent spherical waves in cross section. Rectangular wave-packet at right represents a photon. On either picture an assembly of many nuclei would emit radiation equally in all directions (*bottom*).



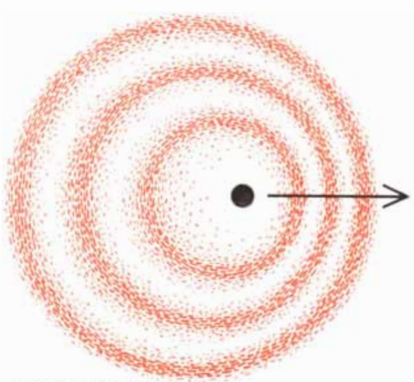
RESONANCE is demonstrated by directing a beam of gamma rays from excited nuclei (*dot at left*) at target nuclei (*dot at right*). Detectors (*rectangles*) in line with beam measure transmission; those at right angles to beam, scattering. Meter dials represent schematically the values of transmission and scattering at resonance (*top*) and out of resonance (*bottom*).



QUANTUM TRANSITIONS between high energy-level (*shaded bands*) of an excited state and low energy-level (*horizontal line*) of the ground state result in emission or absorption of photons (*bottom*). Photons vary slightly in frequency (and spectral lines have finite widths) because of energy spread of excited state. The average value is the most probable.

14,000 electron volts. If we think of this energy as represented by a line in a spectrum of energies, then the width of the line is determined by the half-life of the excited state of iron 57. As we have mentioned, the half-life is about 10^{-7} second, which gives a line width of about 10^{-8} electron volt. This means that the uncertainty or fuzziness in the photons' energy is approximately one part in 10^{12}.

Now when a nucleus emits a photon, the nucleus recoils in the opposite direction, like a gun that has fired a bullet. In both cases the recoiling mass takes up part of the energy produced, and the bullet or gamma ray emerges



DOPPLER EFFECT is a change in frequency of waves emitted by a moving source (*dot*) or received by a moving observer. Waves are crowded in the direction of motion and spread in the opposite direction.

with less than its maximum available energy. On the other hand, a nucleus that absorbs a gamma ray recoils too, and thus requires a photon with somewhat greater energy. As a result both emission and absorption lines are displaced. In the case of iron 57 the recoil energy is about 10^{-3} (one thousandth) electron volt. This is small indeed compared to the energy of a photon, but it is still 100,000 times larger than the line width. Thus the emission and absorption lines are completely separated, and resonance cannot occur.

If we think of the process in terms of frequency rather than energy, then the destruction of resonance can be understood as resulting from the Doppler effect. A moving source of radiation, whether it be the whistle of the proverbial train or an excited nucleus, emits waves that are packed together more tightly in the forward direction and more loosely behind [*see illustration at left*]. Hence the radiation from a recoiling nucleus, which is of course always emitted in the direction opposite to the recoil, has a lower frequency than if the nucleus were standing still.

But if the motion of recoil destroys resonance, an opposite, offsetting motion should re-establish it. And so it does, as P. B. Moon and A. Storruste of the University of Birmingham demonstrated in 1953. They mounted a source of excited mercury-nuclei on the arm of a centrifuge. When the arm was rotated at the right speed, they observed resonance in a stationary mercury absorber. The motion required to offset the nuclear recoil in mercury was of the order of the speed of sound.

Moon showed how to compensate for the recoil. Mössbauer showed how to eliminate it. If we want to keep a gun from recoiling, so that the whole energy of the explosive charge will be imparted to the bullet, we must fasten the gun to the ground or to some heavy object. This is exactly what Mössbauer did to the nuclei; he fastened them to a piece of solid matter.

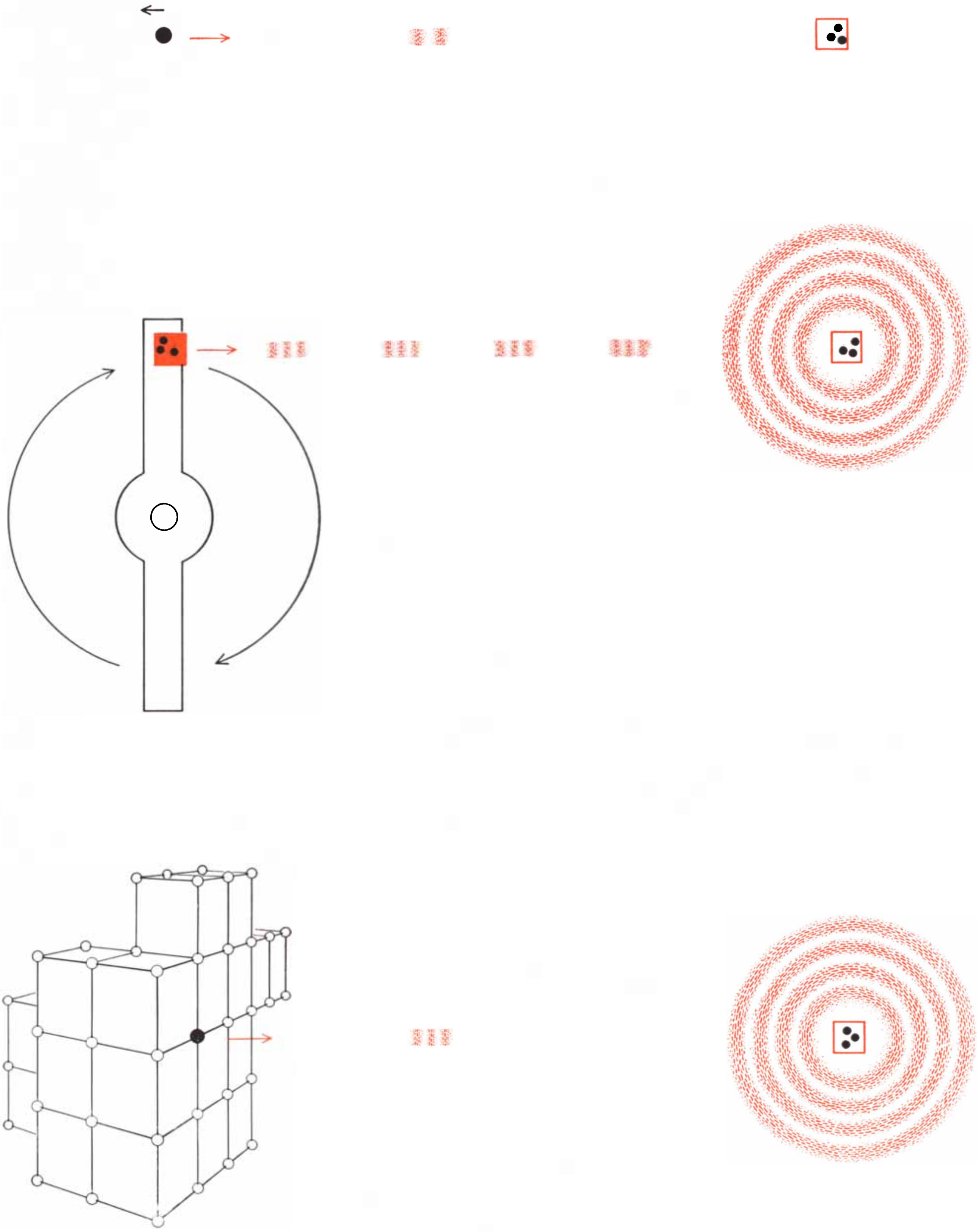
He realized that, under proper conditions, the forces that hold atoms together in a crystal can anchor excited nuclei and prevent them from recoiling when they emit their photons. We will not go into the conditions in detail. One condition has to do with the energy of the photon (which determines the speed of recoil). If the energy is too great, the crystal binding-forces cannot hold any of the emitting nuclei, and they tear loose and recoil.

A second condition concerns oscillations that are always set up in a crystal when a nucleus does recoil. According to quantum theory such oscillations occur more easily at higher temperatures. Hence cooling the crystal reduces its ability to accept the recoil energy, and increases the fraction of nuclei that do not recoil.

In Mössbauer's original studies he used the excited nucleus of iridium 191, whose photon has an energy of 129,000 electron volts. In order to anchor even a few per cent of these nuclei he had to cool the crystal to the temperature of liquid air.

After Mössbauer's work became known in this country, experimenters at Harvard University, the Argonne National Laboratory and elsewhere found several other nuclei that exhibit resonance absorption. The most useful is iron 57. The low energy of its photons (14,000 electron volts) and its relatively long half-life (10^{-7} second) give a sharp resonance of considerable intensity at room temperature.

When recoil is eliminated and resonance is established, a slight motion of the source with respect to the absorber produces enough frequency shift to destroy the resonance again. This provides a means of unparalleled sensitivity for observing the Doppler effect. With older instruments the effect could be observed only for rather high velocities, *i.e.*, velocities of the same order as those of the



RECOILING NUCLEUS (*dot at top left*) emits photons of less than maximum possible frequency, or energy, which are therefore out of resonance with absorbing nuclei (dots at top right). Offsetting the recoil velocity by moving the emitter in the opposite direction (*center*) can restore resonance. In the Mössbauer effect (*bottom*) recoil is prevented by anchoring emitting nucleus in a crystal.

waves involved. Fast trains were needed in order to perceive the acoustical Doppler effect; swift astronomical or atomic motions to detect the optical (electromagnetic) Doppler effect. By means of nuclear resonance, Doppler-frequency changes can be observed for ridiculously small velocities. Mössbauer put his source on the rotating turntable of a record player and the resonance was gone! Still more amazing, with iron 57 the resonance disappears at speeds of the order of a couple of inches per minute.

Moreover, the iron resonance-line is by no means the narrowest known. There are isomers whose half-lives are measured in seconds, or even in months, whose line width must be at least a million times sharper. But will it ever be possible to observe the corresponding resonances? To do so it will be necessary to control the relative speed of source and absorber within a hundred millionth of a centimeter per second or less, and this may present difficulties.

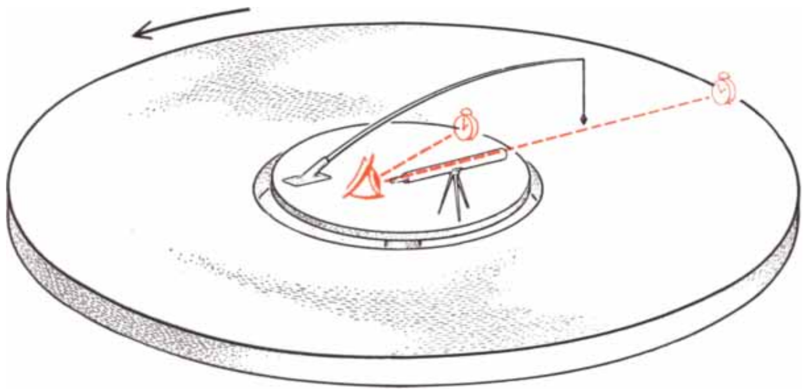
In studying the detailed properties of a nuclear resonance the source is moved toward and away from the absorber at various closely controlled speeds, and the intensity transmitted by the absorber is measured. When the transmission for iron 57 is plotted against velocity, the resulting curve shows a large absorption dip at zero relative speed and some smaller dips on either side [*see illustration on page 80*]. This shape means that the resonance is not actually a single line, but is split into closely spaced lines. The explanation of "hyperfine" splitting, as it is called, is to be found in the magnetic properties of nuclei.

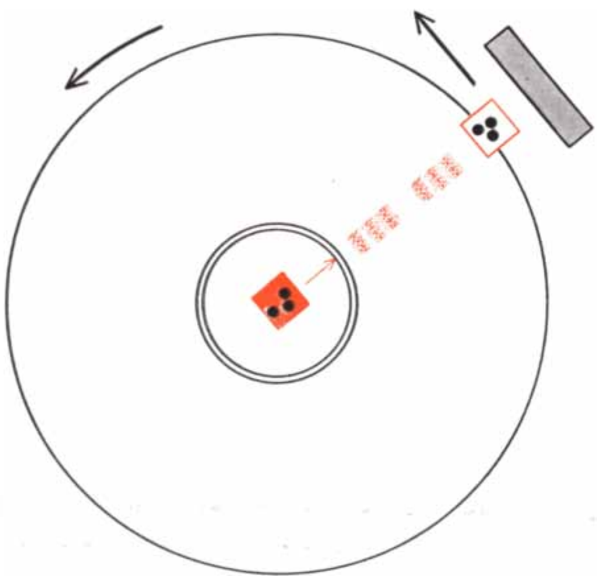
Each nucleus is a small magnet, and the iron-57 nuclei are located in the strong magnetic field of the iron crystal. Quantum theory tells us that the little nuclear magnets can take only certain orientations with respect to the surrounding field; each orientation corresponds to a slightly different energy. Hence every energy level of the nucleus is actually split into several sublevels, corresponding to the various possible orientations in the magnetic field. The transitions between levels, and the emitted photons, have slightly different energies, or frequencies, depending on which sublevels are involved.

The study of hyperfine splitting has just started. The Argonne group has already obtained valuable information about the magnetization of excited nuclei, which is difficult to measure in other ways, as well as about the magnetic fields existing in certain solids. But by far the most fascinating applications of nuclear-resonance absorption are those concerning the essence of time. As we remarked at the outset, two experiments suggest themselves: a test of the contraction of clock time due to velocity, as predicted by the special theory of relativity, and of the similar contraction due to gravitational fields, postulated by the general theory of relativity.

According to special relativity the usual concepts of time and simultaneity are valid only for observers who are not in relative motion. If the watch of a stationmaster and that of a train conductor agree perfectly when the train is in the station, they no longer agree when the train moves: each man will see the other's clock as going too slow. The prediction has been verified in the case of subatomic particles traveling at nearly the speed of light, and the special theory of relativity now rests securely on uncontroversial ground. It is nonetheless of considerable interest to observe the contraction of time in macroscopic bodies moving at comparatively low speeds. Moreover, it should be possible to check one consequence of time contraction that has never been observed with certainty—the transverse Doppler effect.

As we ordinarily think of the Doppler effect, we expect to find a change in frequency in the direction of motion of the radiating source, but not in the direction perpendicular to the motion [*see bottom illustration on page 76*]. However, relativity shows that there must be a small decrease in frequency in the transverse direction, because to a stationary observer the vibrations of the moving source

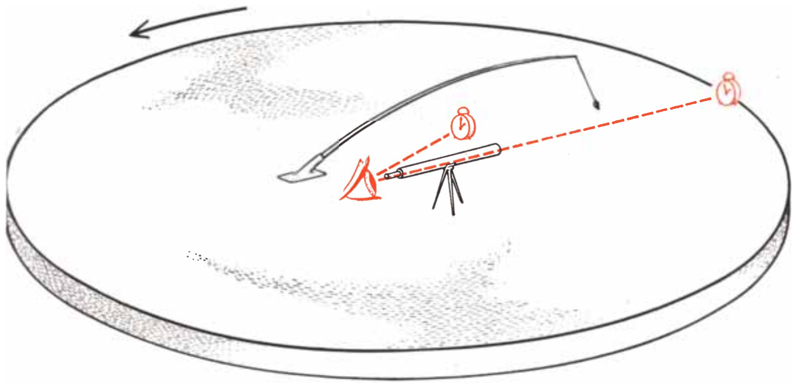


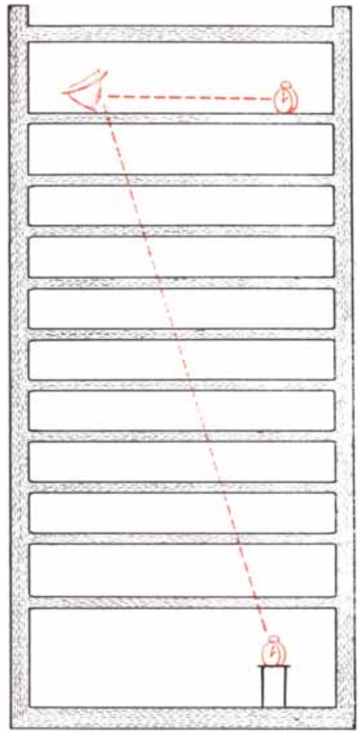


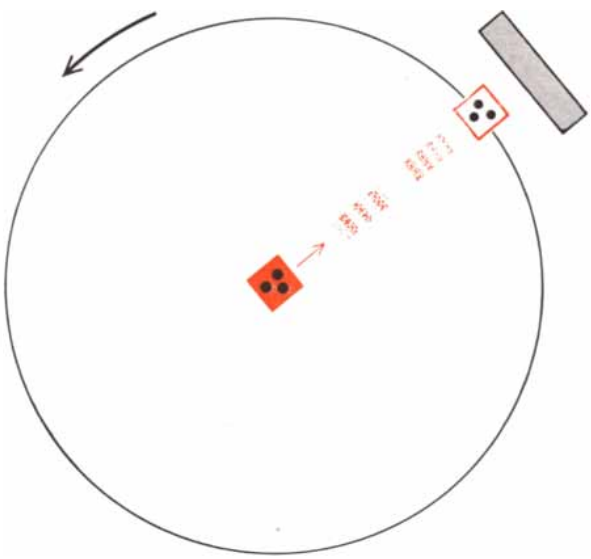
RELATIVISTIC EFFECTS are illustrated schematically in these diagrams. Drawings at top represent imaginary experiments comparing clocks that are in relative motion (*left and*

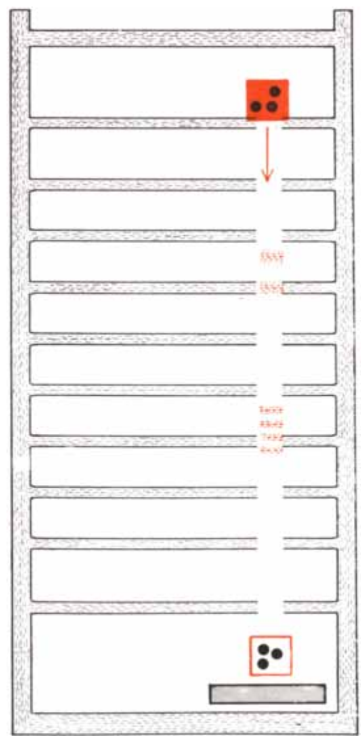
will seem too slow. An experiment to measure the transverse Doppler effect has been conducted in England by H. J. Hay, J. P. Schiffer, T. E. Cranshaw and P. A. Egelstaff. They placed a source of iron-57 nuclei at the center of a rotating disk, put an absorber on the rim and a detector beyond the disk [*see illustrations on these two pages*]. When the disk was rotated at 500 revolutions per second, the counting rate was 4 per cent higher than when it was stationary, indicating that the absorber was out of resonance with the source because of the transverse motion. This is what one expects from time contraction.

Let us look a little more closely at the interpretation of this experiment. The iron nuclei at the center and at the rim of the disk are clocks, or at least pendulums, and we are trying to compare their frequencies of oscillation. To visualize the situation more vividly let us transform the disk into a merry-go-round and put a human observer at the center. With him he has a clock and a fishing rod. On the edge of the merry-go-round is a second clock, identical with the central one. Now suppose that the observer, together with his equipment, is on a platform that does not turn with the merry-go-round. To keep the distant clock in sight he must himself turn around. Thus he knows that the clock is moving, and when he sees it running slower than his local clock, he attributes the difference to the time contraction of special relativity. His fishing line, hanging straight down in the space between his stationary platform and the merry-go-round [*see top illustration on opposite page*] indicates that there is no horizontal force









***center*) or at different gravitational potential energies (*right*). Lower drawings show how nuclear resonance-absorption measurements, as described in the text, make such experiments possible. Turntables test special, and tower general, theory of relativity.**

acting between the two clocks. We shall see the significance of this observation in a moment.

If we replaced the ordinary clocks with "clocks" of iron-57 nuclei, the observer could not actually perceive that one nuclear clock vibrates more slowly than the other. What he would perceive is that the frequency of the photons sent out by the central clock is different from the frequency of the distant clock, or absorber. Since he believes the photon to have the "right" frequency, he says that the absorber frequency is too slow.

Now imagine a slightly different situation. The observer and his clock (or source) are no longer isolated from the merry-go-round, but turn with it. Would we expect a transverse Doppler effect here? The answer is yes, because the linear speed connected with the observer's rotation at the center of the disk is much less than the speed of the absorber on the rim. But in this case an entirely different interpretation is possible.

To return to the man and his fishing rod, he can now stand still and keep the distant clock in sight; it appears stationary to him. But when he looks at his fishing line, he finds it hanging outward, toward the rim of the merry-go-round. Thus he perceives a horizontal force that pushes things from the center to the outside. It is, of course, the inertial (centrifugal) force arising from the fact that the merry-go-round does not move at constant speed in a straight line; in other words, the motion is accelerated. He now attributes the disagreement between clocks (actually, the lack of resonance) to the presence of the force.

He reasons as follows: The photons emitted by the source, in traveling toward the absorber at the rim, must be acted on by the outward force that is revealed by the fishing line. Since the photons are already moving at the maximum possible velocity—the velocity of light—the force cannot speed them up, but it does increase their energy and therefore their frequency. Thus they arrive at the absorber with too high a frequency, and the resonance is destroyed.

Note that in the first case the observer believes that the frequency of the photons is constant and that the frequency of the absorber decreases. In the second case he thinks that the absorber remains at constant frequency while the photon frequency increases. Experimentally there is no way to decide which has happened. They both result in the same detuning from resonance. Furthermore, computation shows that the difference in frequency is the same either way.

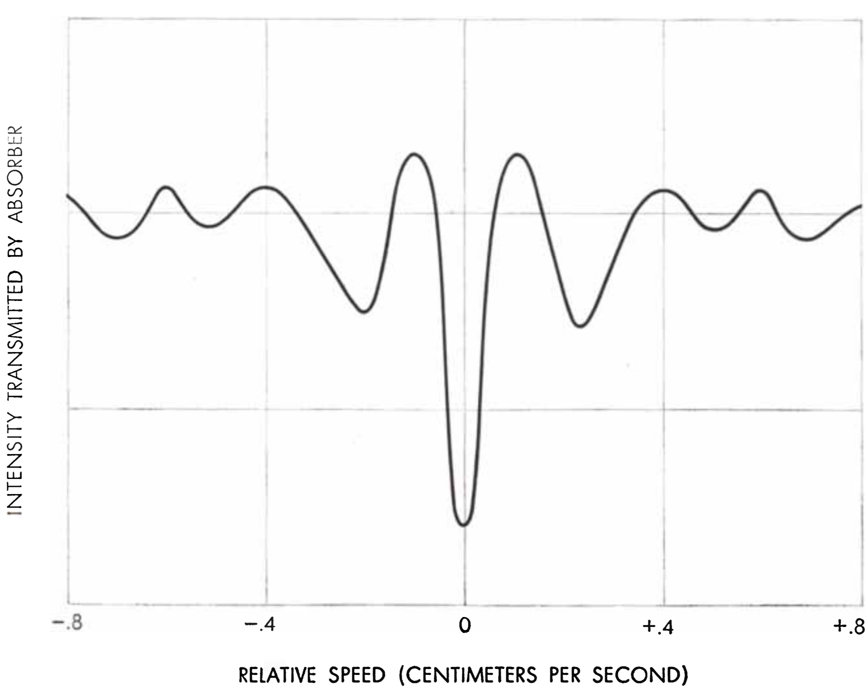
Thus far we have given two equivalent explanations of an effect of special relativity. But now we pass to the next question: Does gravity act on photons in the same way that centrifugal force seems to? The answer is not obvious. For example, electric and magnetic fields do not act on photons at all. How can we decide *a priori* whether gravity will? Einstein answered this question. The fundamental assumption of the theory of general relativity is that gravity acts in exactly the same way as inertial forces that appear in accelerating systems. The assumption is known as the principle of equivalence. It predicts that there will be a lack of synchronization in clocks that is caused by gravitational fields, or, to put it another way, that photons being pushed or pulled by gravitational forces will change in frequency.

Modern physicists are inclined to believe in the validity of general relativity for esthetic reasons, because it is mathematically so elegant and philosophically so satisfying. They use the theory in all speculations on cosmology, including the questions of the curvature of the universe, its size, its beginning, its expansion and its evolution. But although certain experiments seem to check some consequences of the principle of equivalence, according to the experts there is no verification that stands a strict critical analysis.

Presently it seems as though nuclear resonance should provide the long-awaited crucial test. The experiment is very simple in principle. A source of iron 57 is allowed to emit photons vertically, say in the downward direction. Do these photons gain energy, and thus frequency, while traveling down, because of the gravitational attraction of the earth? Is there a detuning, a clock contraction, with an absorber a few stories lower? The expected effect, if general relativity is correct, is small—of the order of one hundredth of the line width. But it should be possible to observe it with available instrumentation.

Schiffer, Cranshaw and A. B. Whitehead, who have performed the experiment at the British Atomic Energy Establishment in Harwell, report that their initial results show an effect about 96 per cent as great as the theory predicts, with an error of 45 per cent. R. V. Pound and Glen A. Rebka, performing the test at Harvard, have not yet announced their findings.

In any case the matter should be definitely settled before very long. And so Chronos is overthrown along with the other gods. Or is he? The writer, an obstinate humanist and classicist, prefers to think that the triumph of physics is just the victory of Athena, the virgin goddess of intellect, over most of her Olympian companions. If only we do not throw away other human values, if we can save Aphrodite, the fertile goddess of beauty and love, all should be well.



RADIATION TRANSMITTED by an absorber moving with respect to a source is plotted against the relative velocity of the bodies toward one another (positive) or away (negative). The multiple dips in the curve represent hyperfine splitting due to nuclear magnetism.

. . . sunshine for the plastics man who worries . . . a little

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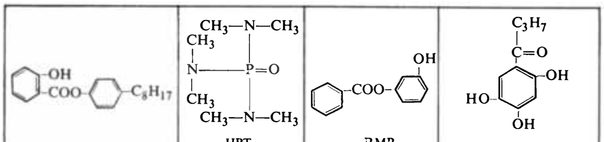
Our involvement in infrared detectors has deepened.

Pictured at the top of this page are, respectively, the simplest kind of *Kodak Ektron Detector* with a rectangular sensitive area of any reasonable dimensions, available either in a 3-pin miniature cable socket or unmounted with resolderable leads; an "immersed" detector with detecting substance deposited on the plano surface of a radiation-collecting lens; a detector mounted in a Dewar for cooling by cryostat. We also deposit detecting substance in separated or intricate configurations as ingenuity, under necessity's goad, may provide.

Since any of these physical forms can now be provided with any of six different kinds of lead sulfide or lead selenide depositions, as governed by spectral sensitivity, response time, temperature, and ambient humidity, the print gets quite fine in a folder we are publishing this month to guide the selection of *Kodak Ektron Detectors.*

A free copy is available from Eastman Kodak Company, Apparatus and Optical Division, Rochester 4, N. Y. It is designed to make the sale with minimum further correspondence. To give you an idea, the off-the-shelf, one-only price scale starts from $14.50.

Corruption can be arrested



OPS will arrest corruption | HPT will arrest corruption | RMB will arrest corruption | THBP will arrest corruption

"You" are assumed to be a producer of compounds for molding or extrusion. This message is strictly private between you and us. As far as your customers, the molders and extruders, will ever know, the reason why your vinyls, cellulosics, polyesters, or polyolefins stand up so well to weathering is the integrity of your name. And as far as *their* customers will ever know, it is *their* integrity that explains why so little cracking, crazing, embrittlement, gumming, or discoloration with the passage of time and sunshine.

The concept of integrity is more readily grasped than is the principle that every C-C bond, every O-H bond, every C-Cl bond, every C=N bond, has its own price—a photon of ultraviolet radiation just right in energy to snap it. Thus corruption of plastics, a chain reaction like other corruptions, begins. A rival substance that grabs off the u-v photons first and degrades their energy will delay the corruption for a long time.

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Obviously, we think we have made a good choice in these new ones:

Eastman Inhibitor OPS (p-Octylphenyl Salicylate), at 1 to 5% levels, a preventive of the photo-oxidation that forms deleterious carbonyl groups in polyethylene and polypropylene.

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Metallography and other matters

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Just issued is a new one, "Photomicrography of Metals." It contains 13 pages on the metallographic microscope (unbiased toward any particular make of instrument, since we are not in that business), 3 pages on illumination, 5 on filters, 3 on photographic materials (which we do make), 5 on exposure determination, and 8 on processing and printing—just enough for thoughtful perusal between the evening paper and the 11 o'clock news. The pages are meaty; the illustrations are there to explain, not just fill space; the author (anonymous) is a photomicrographer, not an ad-writing hack.

Also just published is the 8th edition of one that has taught many thousands of people since 1933 the rock-bottom facts about the photographic emulsion as a scientific device. The title, "Kodak Photographic Films & Plates for Scientific and Technical Use," dissembles a wee bit. In the old days astronomy was regarded as too thin and unworldly a market to justify commercial literature; therefore the title was devised as a shield from the beady eyes of hard-headed accountants. They find it hard to understand that addressing ourselves to the needs of men with their minds inside stars strengthens the capabilities of photographic technology in general. Indeed, this new 8th edition contains some helpful hints from Mount Wilson and Palomar Observatories that could teach an amateur astronomer to think like a pro. The edition reveals some constriction from the sprawling diversity of *Kodak "Spectroscopic" Plates and Films* hitherto offered, and these pages show how the present lineup fills the bill.

Theoretically the purchase of these data books from your Kodak dealer draws him and you closer together. Those willing to forego the personal touch can obtain them from Special Sensitized Products Division, Eastman Kodak Company, Rochester 4, N. Y., which is also the place to address specific questions.

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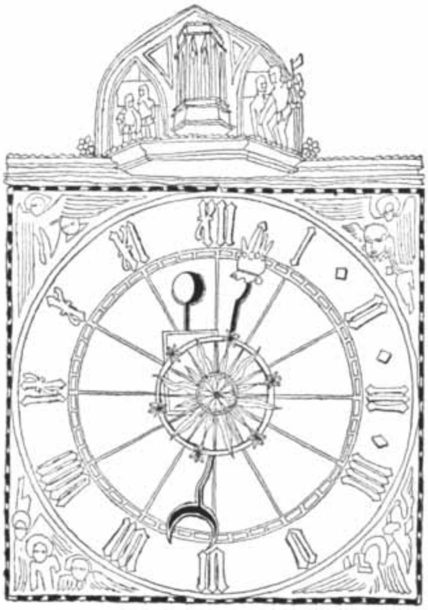

SCIENCE AND

Geneva Conference Resumes

Political representatives of Great Britain, the U.S.S.R. and the U. S. at the Geneva conference on cessation of nuclear-weapons tests have resumed negotiations after a recess of several months. They took up where the technical experts from these countries who met last December left off—debating problems of the detection and inspection of underground tests.

When the conference reconvened, the U. S. proposed a new agreement to cover only "controllable" explosions. This would have included all surface, atmospheric and ocean tests, tests in space out to great distances and all underground explosions "which cause seismic magnitude readings of 4.75 or more." Smaller explosions were to come under the agreement as means of detecting and of distinguishing them from earthquakes improved. The minimum size was expressed in terms of a seismometer reading rather than in kilotons of explosive power because "Soviet and Western scientists are in substantial agreement as to the measurement of signals but not on the equivalent kiloton yields of seismic disturbances." According to U. S. calculations the proposed reading is roughly equivalent to a 20-kiloton explosion.

The U. S. proposal was rejected by Soviet negotiators twice; once unofficially after it had been described (unofficially) in the U. S. press and again when it was formally presented to the conference. Then the U.S.S.R. made a new offer of its own. It would accept criteria suggested by the West for deciding whether a "seismic event" was suspicious enough to merit inspection. Previously the Soviet negotiators and their experts had called for technical criteria limiting much more severely the number of events eligible for inspection. Under the new offer, however, only a few of all the suspicious events could actually be inspected. The quota would be decided on the basis of political negotiations rather than technical considerations. It seemed likely that the two Western nations and the U.S.S.R. would differ widely on an acceptable quota.

A discussion of the experts' conference at Geneva appeared recently in *Bulletin of the Atomic Scientists* together with complete transcripts of the conclusions of the technical groups from the three countries. An article by Jay Orear, a physicist at Cornell University, appraised the disagreement among the experts as being due more to their purposes than to technical uncertainties. The Soviet experts originally put forth inspection criteria that, according to U. S. estimates, would leave less than one natural earthquake per year eligible for inspection. They were trying, says Orear, "to find . . . limitations that would safeguard their country from the thousands of yearly on-site inspections our country was talking about." Although they eventually dropped this demand, the Soviet experts refused to accept the criteria offered by the West, which "made eligible almost any natural disturbances that could be located."

Eugene Rabinowitch, editor of the *Bulletin*, sees some hope that a compromise can be reached on the quota problem. It will require a reduction of Soviet suspicions that inspections would in fact be espionage expeditions, and a willingness on the part of the West to be satisfied with a small chance of catching a violation; "say, one chance in 50." In any case, urges Rabinowitch, there should be more information on the degree of risk represented by clandestine testing. "American public opinion, . . . not to speak of American political leadership, . . . should be given some sober authoritative information on the possible importance of further tests, instead of vague hints that something terrible is likely to follow from clandestine Soviet testing, and something wonderful from our own resumption of tests."

While the conference continued, the

U. S. announced that it is starting to build two experimental seismic stations such as might be incorporated in a control network. One will conform to the specifications recommended for the 180-station network proposed by an earlier conference of experts in 1958. This one is located in "the central part of the U. S." and is expected to be ready this summer. The second, which will take longer to build, will include some of the refinements suggested last year by the U. S. Panel on Seismic Improvement headed by Lloyd V. Berkner.

Cooperative Science

The International Council of Scientific Unions, which cosponsored the International Geophysical Year, has put in motion several new ventures in collaborative research. It has created a Steering Committee for Cooperation in Geophysics and Related Sciences, to be known as CIG (from Comité International de Geophysique), headed by the Soviet geophysicist V. Beloussov. As its first task the committee is organizing a world magnetic survey to measure the intensity and direction of the earth's magnetic field at points over the entire surface of the earth. The survey will be carried out in 1962 and 1963, the next period of minimum solar activity, when there will be least interference from the magnetic storms accompanying eruptions on the surface of the sun.

A second enterprise for 1962 and 1963 will be an investigation of the physical oceanography, marine biology and meteorology of the least known of oceans: the Indian Ocean. The oceanographic study will be directed by another ICSU body, a Special Committee for Oceanographic Research under the chairmanship of Roger Revelle of the Scripps Institution of Oceanography.

A third ICSU-sponsored body, the International Committee on Space Research (COSPAR), is also now ready for business. Disagreement over the composition of its governing body had delayed this committee's formal inauguration. Under a compromise accepted by the ICSU decisions of the space committee will be subject to ratification by a two-thirds vote of an inner group consisting of COSPAR's chairman—currently H. C. van de Hulst of the Netherlands—plus

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three delegates from Western bloc nations and three from the Soviet bloc.

Not with a Bang?

When, where and how were the chemical elements made? Speculation on such questions about the beginning of things necessarily rests on a slender foundation of fact. An important new piece of underpinning has been added recently by John H. Reynolds of the University of California, who discovered that the xenon gas trapped in a certain stony meteorite has an unusually high proportion of the isotope xenon 129 [see "Science and the Citizen," February]. But, as often happens in this field, the same fact may be used to support different theories.

Xenon 129 is the decay product of iodine 129, a radioactive element with a half-life of 17 million years, which has long since disappeared from the solar system. Evidently some of it was still present when the meteorite was formed, and has decayed to xenon in that body. Assuming that the elements in the galaxy were all made simultaneously in one "big bang," and that iodine 129 was originally as abundant as the stable isotope iodine 127, the time between the origin of the elements and the formation of the meteorite can be calculated to have been 350 million years. Other evidence shows that meteorites are about 4.6 billion years old, so on this theory the elements must have been made 4.95 billion years ago, and the solar system must have appeared within the next 350 million years.

Another theory holds that the elements in the galaxy were built up gradually by nuclear reactions in stars, over a period of billions of years before the formation of the solar system. G. J. Wasserburg, William A. Fowler and Fred Hoyle of the California Institute of Technology have pointed out in *Physical Review Letters* that the xenon-129 evidence is

INDIVIDUAL ANTIBODY MOLECULES have been made visible for the first time in electron micrographs produced by Cecil E. Hall and his associates at the Massachusetts Institute of Technology. The micrograph reproduced here shows antibodies formed by a rabbit in response to an artificial antigen: a specially treated bovine gamma globulin. The micrograph was made at a magnification of 15,000 diameters and is reproduced at 200,000 diameters. According to the M.I.T. workers, the most striking feature of this and similar electron micrographs is the asymmetry and variation in size of individual antibody molecules of a single immunological type (*i.e.*, that react with a single antigen). Physical and chemical studies had suggested that antibodies of a single type might occur in a range of sizes. Electron microscopy now confirms this. In the preparation of the micrographs the antibody molecules were coated with metal. If allowance is made for the thickness of the metal, the antibody particles have an average length of 250 angstrom units (25 millionths of a millimeter) and an average diameter of 30 angstroms. Other micrographs indicate that antibodies bind antigen predominantly at the ends of the antibody molecules and form short end-to-end chains.

also consistent with this point of view. According to their calculations the abundance of the isotope in the meteorite can be explained by assuming an element-building period of 10 billion years before the solar system condensed out of galactic gas and dust, and a further interval of 200 million years until the formation of the meteorite. Iodine 129 was presumably made during all of the long period, but most of it would have decayed by the time the solar system began to form, and only the amount produced in the preceding 20 million years or so would be represented in the matter that eventually went into the meteorite.

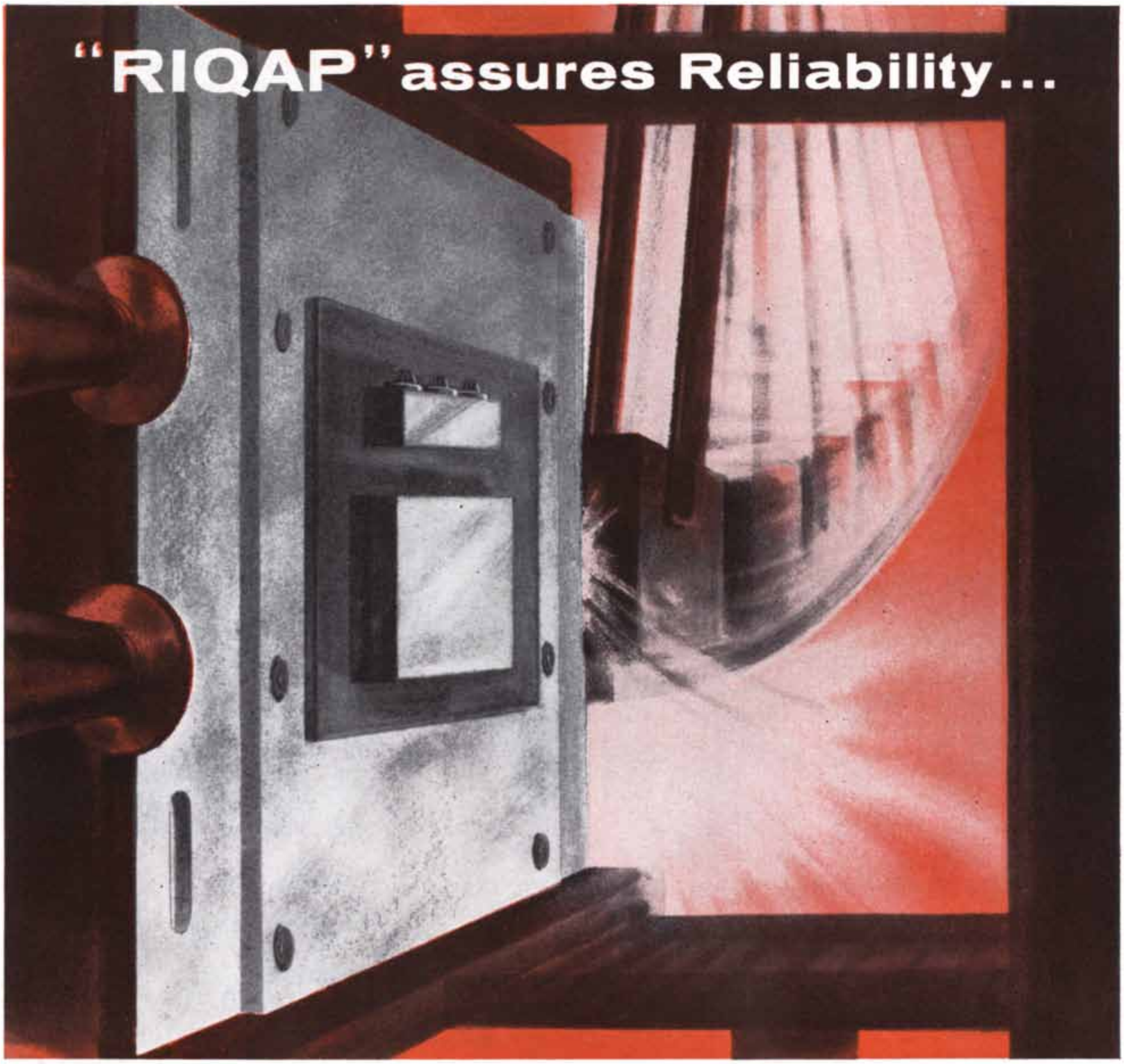
In the light of Reynolds's discovery a big-bang creation of the elements could have occurred no more than about five billion years ago. Yet many objects in the galaxy appear to be substantially older. Hence some cosmologists feel that the xenon-129 measurement delivers the *coup de grâce* to this theory. Whether the universe as a whole was born with a big bang that occurred much earlier and produced only hydrogen and a few other light elements, or whether there was no moment of creation, is still an open question.

Cold Virus at Last?

After 13 years of trying, C. H. Andrewes and his fellow common-cold investigators in Great Britain may have trapped the virus or viruses responsible for the common cold in a tissue-culture tube. If the virus they have isolated is indeed the source of the common cold, then they have also found a means of studying it without need for human volunteers.

Once before, in 1953, the British group succeeded in culturing an agent that induced colds in volunteers. But it soon lost its infective power, and attempts to repeat the experiment failed. The investigators then set out to modify standard tissue-culture procedures. They have now been able to cultivate agents obtained from three individuals with "wild" colds, and the material continues to produce colds in volunteers after as many as eight tissue-culture passages.

In the new technique the cold viruses are grown in embryonic human-kidney tissue at a temperature of 33 degrees centigrade, three or four degrees lower than is usual in virus culture, and in a nutrient medium slightly more acid than customary. The discovery that a more acid medium is helpful came about accidentally, when new batches of nutrient medium, which chanced to contain .09 per cent sodium bicarbonate in place of the .16 per cent of previous lots, were



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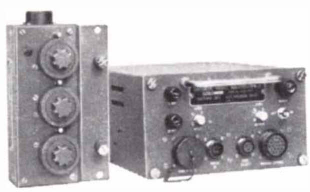

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12333 W. OLYMPIC BLVD. • LOS ANGELES 64, CALIFORNIA • BRadshaw 2-6141 used for the tissue cultures. In this medium the cells of the kidney tissue began to degenerate two to seven days after inoculation with virus. Two strains of the cold virus also exhibited visible cytopathic effects on monkey-kidney tissue. This cell destruction can be utilized to show the presence of virus without recourse to human volunteers.

Andrewes and his colleagues also found that their viruses interfere with the multiplication of a number of other viruses in tissue culture. This interference phenomenon can likewise be used to show the presence of cold virus.

New AEC Commissioner

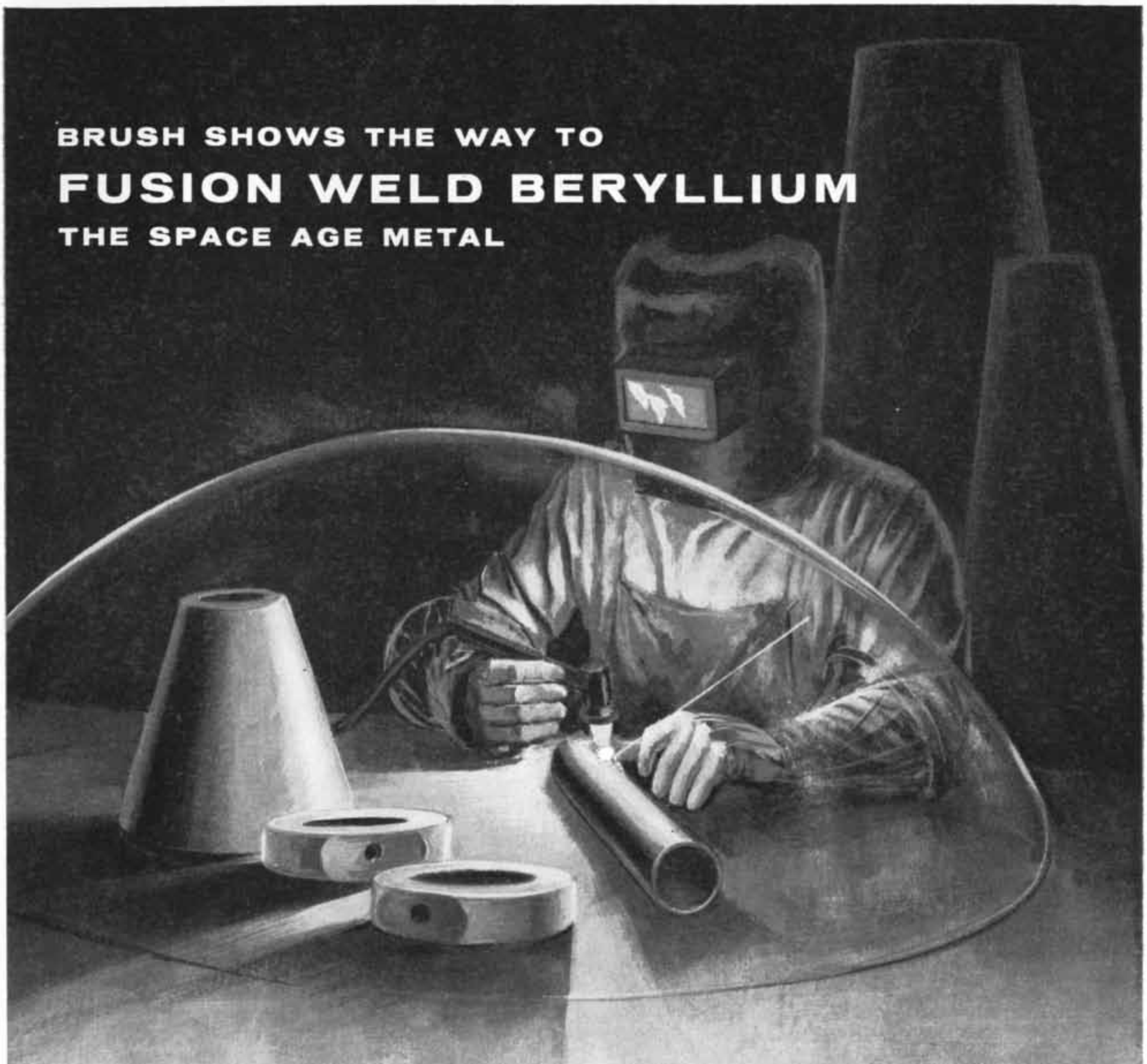
Robert E. Wilson, former chairman of the board of the Standard Oil Company (Indiana), has been nominated to the Atomic Energy Commission to fill the vacancy left by the death last August of Harold S. Vance. If the nomination is confirmed by the Senate, Wilson will serve the four months remaining in Vance's term, plus a five-year term of his own. A member of the AEC's general advisory committee since 1947, Wilson is a chemical engineer by training. The other four commissioners are: John A. McCone (chairman), John S. Graham, John F. Floberg and John H. Williams.

New Radiation Detector

The first solid-state device that measures the number and energy of radiation particles has been produced after several years of work by laboratories in the U. S. and Canada. The new instrument, a modified junction diode or "P-N junction," is small, inexpensive, extremely sensitive and stable and operates on very low power. For many purposes it will replace ionization chambers and other large and far more costly counters. It already counts alpha particles, protons and larger charged particles, and is being refined to work with electrons, neutrons and possibly gamma rays.

One version consists of a thin wafer of pure silicon with some atoms of phosphorus diffused into one surface to provide extra electrons that conduct electricity in an "N" (negative) region. The remainder of the wafer is a "P" (positive) region, in which the conductors are mobile "holes" (missing electrons). A positive voltage applied to the N side attracts the excess electrons, and a negative voltage on the P side attracts holes, so that between the two regions is a "depletion layer" containing neither holes nor excess electrons.

When an energetic particle enters the



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crystal, it creates hole-electron pairs. If these are made in the N or P region, they immediately recombine. But when the particle is absorbed in the depletion layer, the hole-electron pairs are swept apart by the applied voltage, producing an electric current whose strength is a measure of the particle energy.

In the normal P-N junction the P and N regions are relatively thick, and the depletion layer is narrow and deep within the material. The trick in the detector is to make the N region thin enough so that even slow particles can pass through it and reach the depletion layer, and, by means of a high voltage, to make the depletion layer thick enough to absorb the fastest particles.

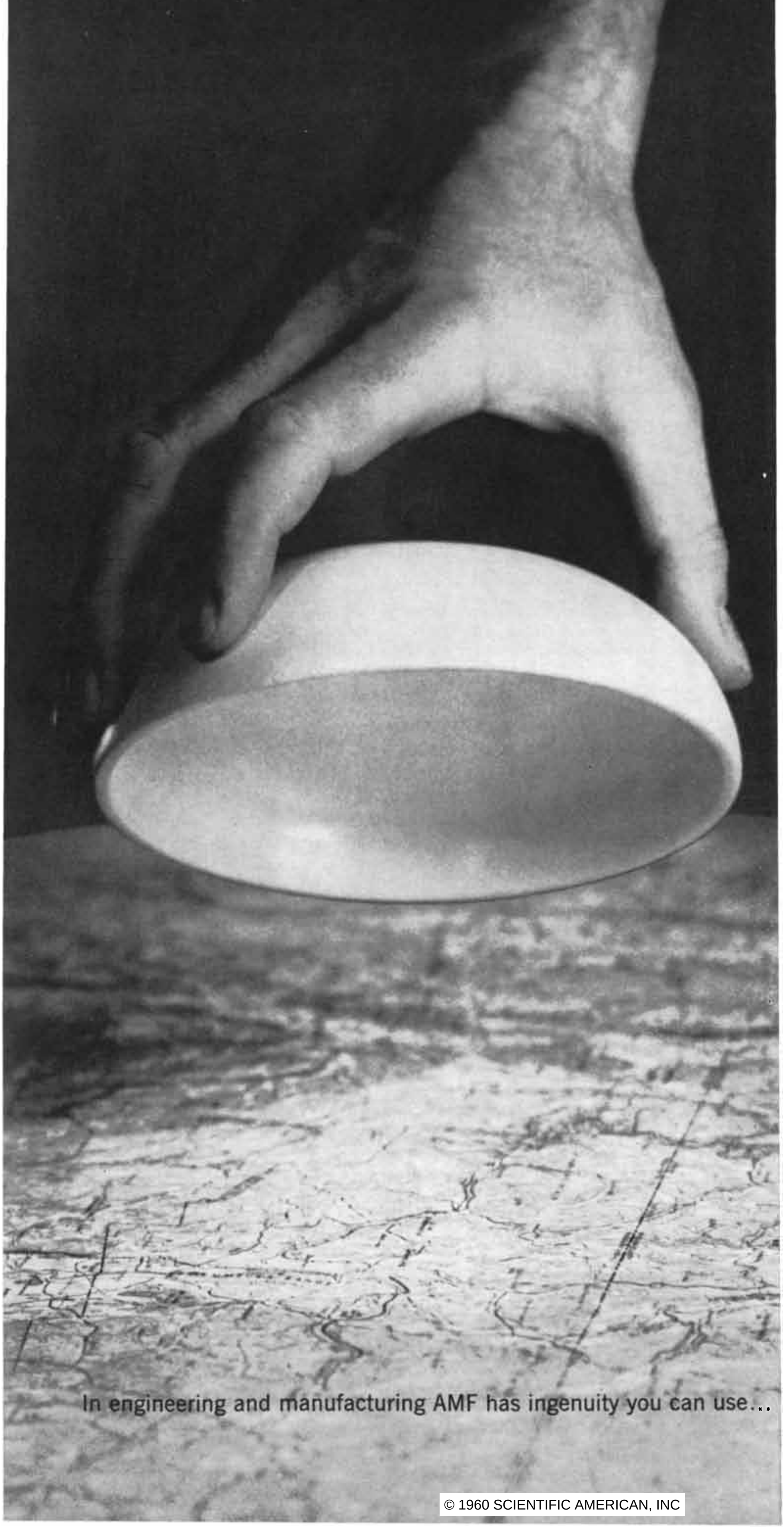
Several versions of the diode detectors are being made on a small scale at the Hughes Aircraft Company of Los Angeles, Oak Ridge National Laboratory, Bell Telephone Laboratories (in collaboration with Brookhaven National Laboratory), the University of California, Atomic Energy of Canada, Ltd. and R.C.A.-Victor of Canada.

Big Press

A hydraulic press of radically new design promises to extend the horizons of ultrahigh-pressure technology. Earlier presses, although capable of generating pressures great enough to convert graphite to diamond (roughly two million pounds per square inch) could not handle a sample much larger than the head of a match. The new device applies equally high pressures to a cylinder three inches long and half an inch in diameter.

Developed by the Engineering Supervision Company of New York, the device uses existing techniques for transmitting extremely high pressure [see "Ultrahigh Pressures," by H. Tracy Hall; SCIENTIFIC AMERICAN, November, 1959]. Four massive "anvils" compress the faces of a soft stone tetrahedron enclosing the specimen to be treated. But instead of driving the anvils together with separate cylinder-and-piston arrangements, the big press employs a hydraulic sphere. The anvils are enclosed in a six-inch-thick rubber ball 25 inches in diameter, which in turn is enclosed in a steel sphere five inches thick and 36 inches in diameter. Fluid pumped into the space between compresses the rubber, exerting a force of 2,500 tons on each of the anvils.

According to its inventors, the most valuable applications of the new design lie in metallurgy, where ultrahigh pressures should produce stronger, more heat-resistant materials. The present machine is big enough to work with metal-



He built the strongest roof in the world

This AMF engineer knows what it takes to shrug off megaton forces. He *had* to know because he designed the prototype atomic bomb shelter at Frenchman Flats, the only building that stood up under the force of the atomic bombs exploded there. Well, not altogether—a flange on the door *was* bent.

In order to design the shelter, he had to calculate the effect of the explosion on materials and structures. He had to know how the shock was transmitted through the earth's crust and what effect it would have on the shelter—from beneath as well as from above. And, after the dust of calculating had settled, he had the very practical problem of expressing the results in steel and concrete. He did so, successfully.

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lurgists' test bars. A scaled-up version, now under development, should be capable of exerting a force of 110,000 tons on a tetrahedron large enough to enclose a gas-turbine blade.

The Sound of Cocktails

A major theory of group-dynamical psychobiophysics has been overthrown. Some months ago William R. MacLean of the Polytechnic Institute of Brooklyn predicted that the noise level at cocktail parties should show a discontinuity at a critical point, when speech at a conversational level is rendered unintelligible by the arrival of additional guests. At that point each speaker would raise his voice, leading to an abrupt increase in noise level. The prediction has now been put to the test by R. F. Legget and T. D. Northwood of the National Research Council of Canada. Their verdict: Not true. Large parties, at least, simply become noisier and noisier, up to a peak of 80 to 85 decibels, a level "not quite high enough to cause permanent impairment of hearing."

Legget and Northwood obtained recordings and other data from eight parties given by professional societies and other organizations. The number of guests at each ranged between 100 and 700. Seven were cocktail parties. The exception was a coffee party. "It was exceptional also," they write in *The Journal of the Acoustical Society of America,* "in that the participants were librarians, *i.e.,* a group dedicated professionally to maintaining quiet. . . . Despite this handicap, they managed to hold their own with the true cocktail party-goers."

Data from one party had to be discarded because of the observer's too liberal interpretation of instructions "not to allow observational work to interfere unduly with other duties." Records from the other seven gatherings revealed a nearly straight-line increase in noise as guests arrived, with no evidence of an abrupt transition. The peak noise-level was reached about 25 minutes after the parties started, and thereafter, in the "mature stage," remained constant.

The two specialists in alcoholic acoustics concede that the MacLean effect might occur at parties with 10 to 50 guests. Such parties, however, are not commonly run by professional societies. The experimenters reluctantly abandoned a scheme to set up artificial parties in this range, because "even assuming that guests and observers would donate their services, there is a residual financial problem that has not yet been solved."

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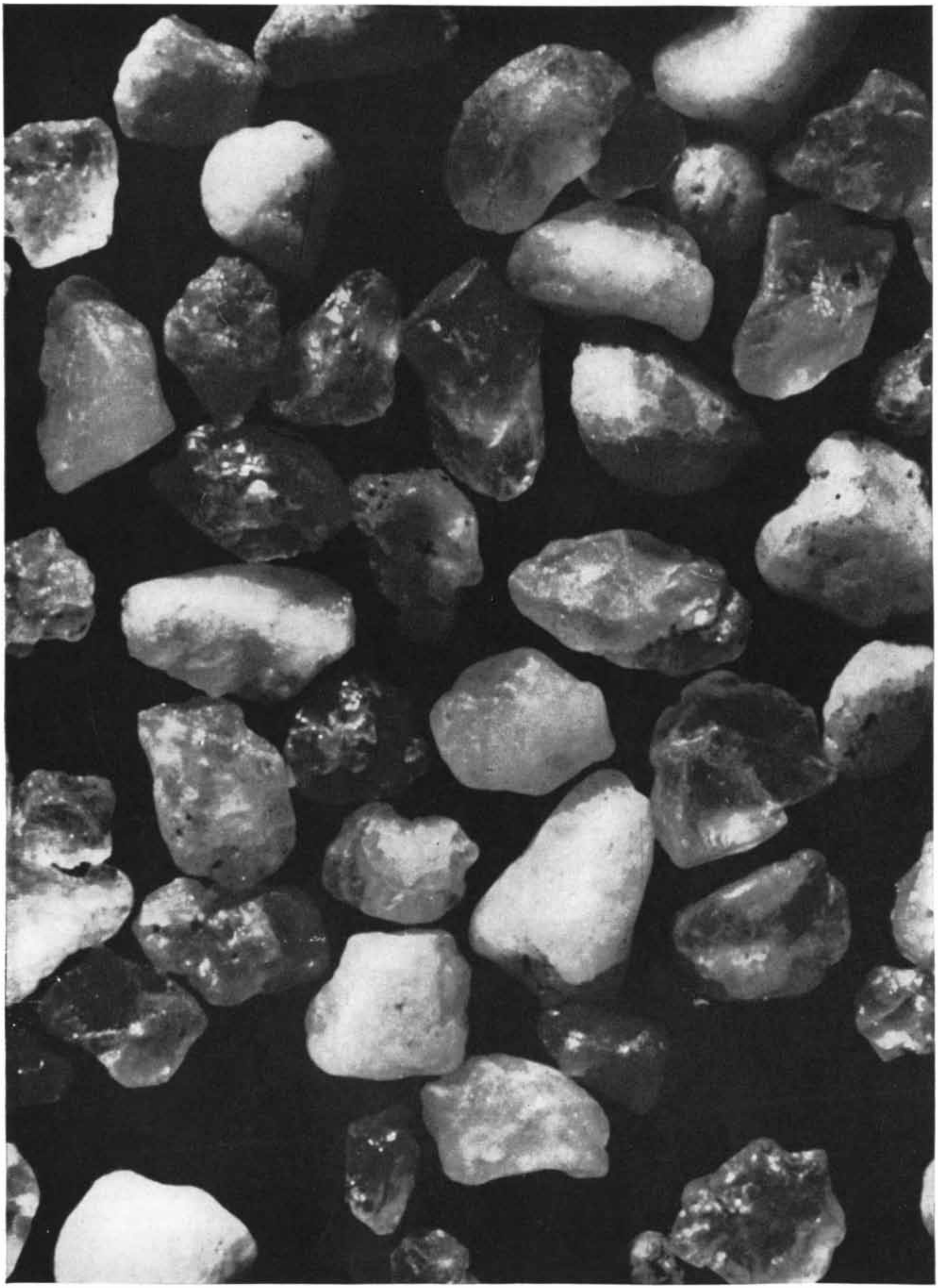


SAMPLE OF SAND from beach at Coney Island in New York City includes old grains that show typical rounding. This sand is principally quartz and originated in granite rock. To develop such a degree of rounding the grains may have been turned over in several cycles of erosion and consolidated more than once in sandstone over a period of some hundreds of millions of years.

SAND

The geologist defines it as particles of rock between .05 and two millimeters in diameter. The shape of sand grains, transported by water and wind, is a clue to their history

by Ph. H. Kuenen

Sand is one of the most common materials on the surface of the continents. Most apparent to the eye on dunes and beaches, it also makes up the bulk of river deposits, although it is often masked by clay or vegetation. Indeed, the prevalence of sand distinguishes the deposits accumulating on the continents from the materials on the ocean bottom. Beds of sand occur here and there on the deep-ocean floor, but clay is the dominant marine sediment. Both sand and clay are end products of the erosion of continental rock. The little grains of sand have been somewhat neglected by geology until recent years, although they have played a mighty role in the history of the continents.

The very abundance of sand has made it so familiar that even geologists did not stop to ask how it came to occupy its place in the landscape and why it tends to accumulate in masses of uniform grain size. Since the vast majority of the ancient sedimentary rocks exposed on the continents are of marine origin, most of them are shales (from clay) and limestones (chiefly from the skeletons of marine organisms); less than 25 per cent are sandstones (from sand). It also happens that sandstones contain fewer fossils than do shales and limestones. Shales and limestones therefore held greater interest in the days when geologists were concerned with general questions of the deformation of sedimentary rocks by mountain-building processes and sought to fix the age of the rocks by study of fossils enclosed in them. Now that the advance into the unknown has broadened, geologists are realizing that sandstones and sands hold the key to many questions still unanswered. The mineral composition of sands can reveal their source; the surface markings and lamination of sandstone beds show how the sediments were laid down and indicate the direction from which the sand came; sand-grain sizes and shapes tell whether the sandstone originated with sand in a river, on a beach or in a dune, and thus yield invaluable information about ancient geography.

Scientific interest in sands and sandstones has been encouraged by powerful economic motives. In glass, concrete, brick and building stone, these materials are the major commodities of the construction industry. Sands in the subsoil are the principal reservoirs of ground water, the supply of which is now so hard-pressed by the needs of urban civilization. Geological inquiry into sand derives its most compelling motivation, however, from the petroleum industry, which has been encountering increasing difficulty in prospecting for new sources of oil and gas.

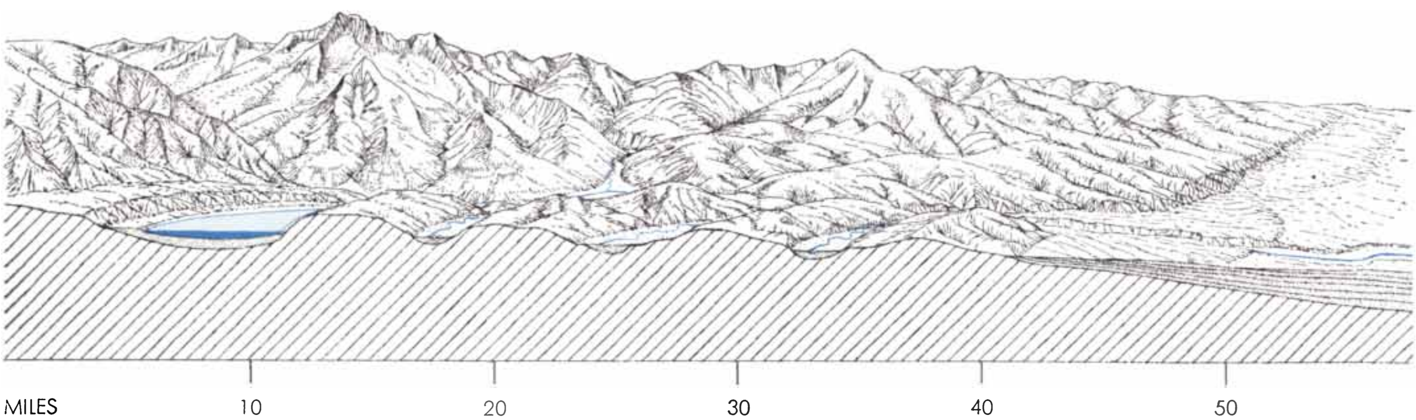
All the obvious places to drill for oil have long ago been drilled. They were indicated by the grander features of geologic structure: domes and major cracks and folds in stratified rock. Geologists are still discovering rich accumulations of oil, but in hoard chambers cunningly secreted by nature—in geologically little-disturbed areas where subterranean sand strata pass laterally into impervious clay-rich beds that keep the oil from escaping. Without the help of disturbed strata, the geologist must attempt to locate sandy channel-bottoms, beach ridges, reefs and similar formations deep underground. The more he can deduce from samples brought up by the first test well, the greater the chance of successfully reconstructing the ancient geographic situation and so of drilling the next well at a productive spot. It is like sitting on a roof with a long drinking straw tipped with a drilling bit and trying to find milk bottles in the building below. In effect the geologist must learn to interpret the various corings of wood, concrete, household utensils and so on in order to find the kitchen and then locate the refrigerator.

The term sand, as geologists use it, means an accumulation of sedimentary particles having a diameter between .05 and two millimeters. Larger grains are classified as gravel and finer ones as silt (.05 to .004 mm.) or as clay (less than .004 mm.). Sands may come from rocks composed of calcium carbonate (limestone), aluminum silicate (feldspar) or silicon dioxide (quartz). Quartz is so much the most abundant mineral occurring in sand grains that the term "sand" is usually taken to mean quartz sand.

The Origin of Sand

Ultimately all sedimentary materials stem from rocks that have formed from the cooling of hot molten matter: either lava or volcanic ash, or rocks such as gneiss and granite that have consolidated at great depths in the earth's crust. Mechanical breakdown produces boulders and pebbles. Chemical breakdown (mainly of feldspar) yields clay; chemical action also puts elements such as calcium and silicon into solution and so carries them over into the life cycles of plants and animals.

What then is the origin of sand? It is common knowledge that boulders and cobbles occur in mountainous areas, that gravels prevail downstream where the rivers descend from the mountains to broader valleys, and that sand and clay comprise the usual water-borne deposits in the lower reaches of the river. The first deduction from these observations is tempting: Mechanical wear during the long journey from source to mouth



SOURCE AND DISTRIBUTION OF SAND are shown in this imaginary landscape. The weathering of rock in the mountains and uplands (*left*) constantly renews the supply of angular grains. These are carried by mountain streams to a river in the lowlands (*center*). The river, in its meandering over the years, distributes the sand broadly over the floor of the valley, where it may be

whittles down pebbles to sand sizes, the "chips" being silt and clay. But quantitative considerations quickly rule out this conclusion. The ratio between the volume of the pebble and that of the grain of sand which is supposed to be whittled out of it is such that to produce a drinking glass full of sand would require a shipload of gravel. The real reason for the downstream decrease in grain size is selective transport. As the river descends to gentler slopes and out onto the valley floor, the gradual slackening of current velocity allows progressively smaller particles to fall by the way, until at the mouth only the finest sand, silt and clay are carried into the sea.

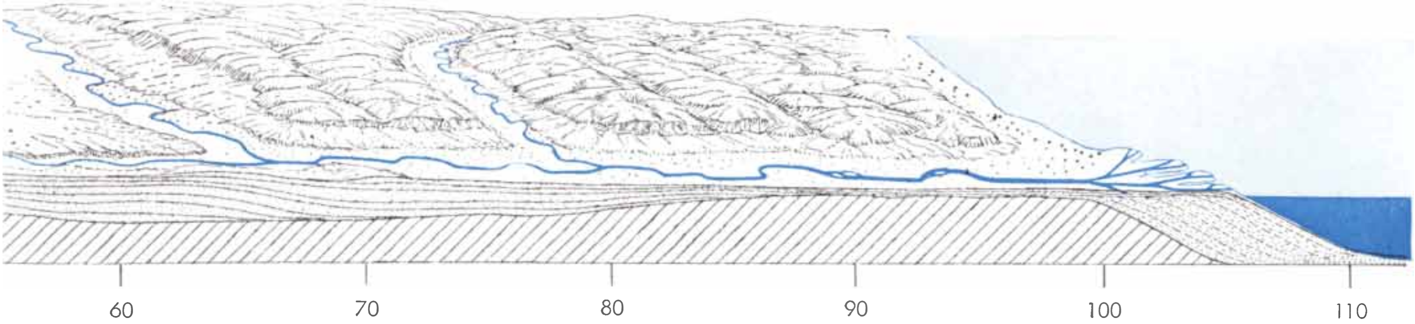
The angularity of most sand grains furnishes additional proof that they are not abraded pebbles. Sand must therefore have a different origin, and the true source is not far to seek. Chemical and mechanical disintegration constantly eat away at gneiss and granite rocks and at the boulders and pebbles of these rocks. In localities where there is strong chemical "weathering," promoted by vegetation and heavy rains, clay and quartz grains are the chief products. Where mechanical disintegration predominates, in deserts and alpine regions, feldspar and quartz grains come to life. Examination of the soil covering mountain uplands and of the screes—the rubble-littered zones—at the foot of steep peaks shows sand particles in abundance.

Transportation by Water

After birth the grains are washed downhill and eventually find their way onto the stream bed. The journey down a mountain stream can happen relatively quickly if the particle is taken into suspension. But this is unusual for a grain of sand. The sand grains tend to roll and bounce along the bottom for a short distance and then to accumulate in an eddying pool or in the lee of a boulder. Years may pass before the next lap in the seaward journey. At last the grain leaves

ANGULAR sand grains are relatively young. In this state the grain breaks free from the parent rock and starts out on its long journey by river, from the mountains to the continental lowlands.

POLISHED sand grains occur in river beds. Chemical action in water



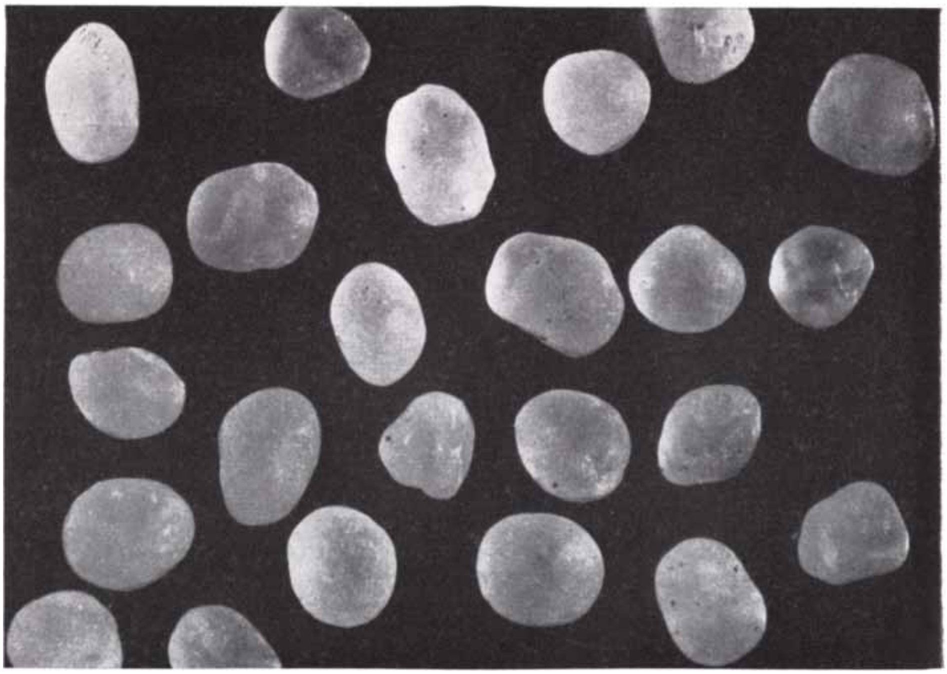
concealed by overlying deposits of silty clays and vegetation. In the process the angular grains begin to be slightly rounded. Where the sand is exposed on deserts, wind abrasion rounds the grains much more completely. Because sand grains are too heavy to be carried by the winds or transported by the rivers beyond tidal estuaries into the sea (*right*), sand accumulates on the continents.

the mountains by way of a river. In the slower-moving water the same spasmodic kind of travel continues, but at a slacker pace. The grain may also be washed over the bank of the river and deposited on its flood plain; in that case a much longer period of rest may ensue. Not until the river alters its course, gradually reworking its own deposits, will it succeed in recapturing such a grain and set it going again on its downstream course. A medium-sized river will take something on the order of a million years to move its sandy deposits a distance of 100 miles downstream.

Few important rivers appear to be carrying sand out into the sea, and only silt and clay reach the oceans in large quantities. A short time ago, geologically speaking, when the glaciers covered the continents, and sea level was some 300 feet lower than it is now, the rivers ran more briskly into the sea. Then they carried some sand offshore. As the ice melted, however, and the sea returned to a more normal level, the slackening of current in the tidal estuaries of most of the world's great rivers caused sand to be deposited well inshore.

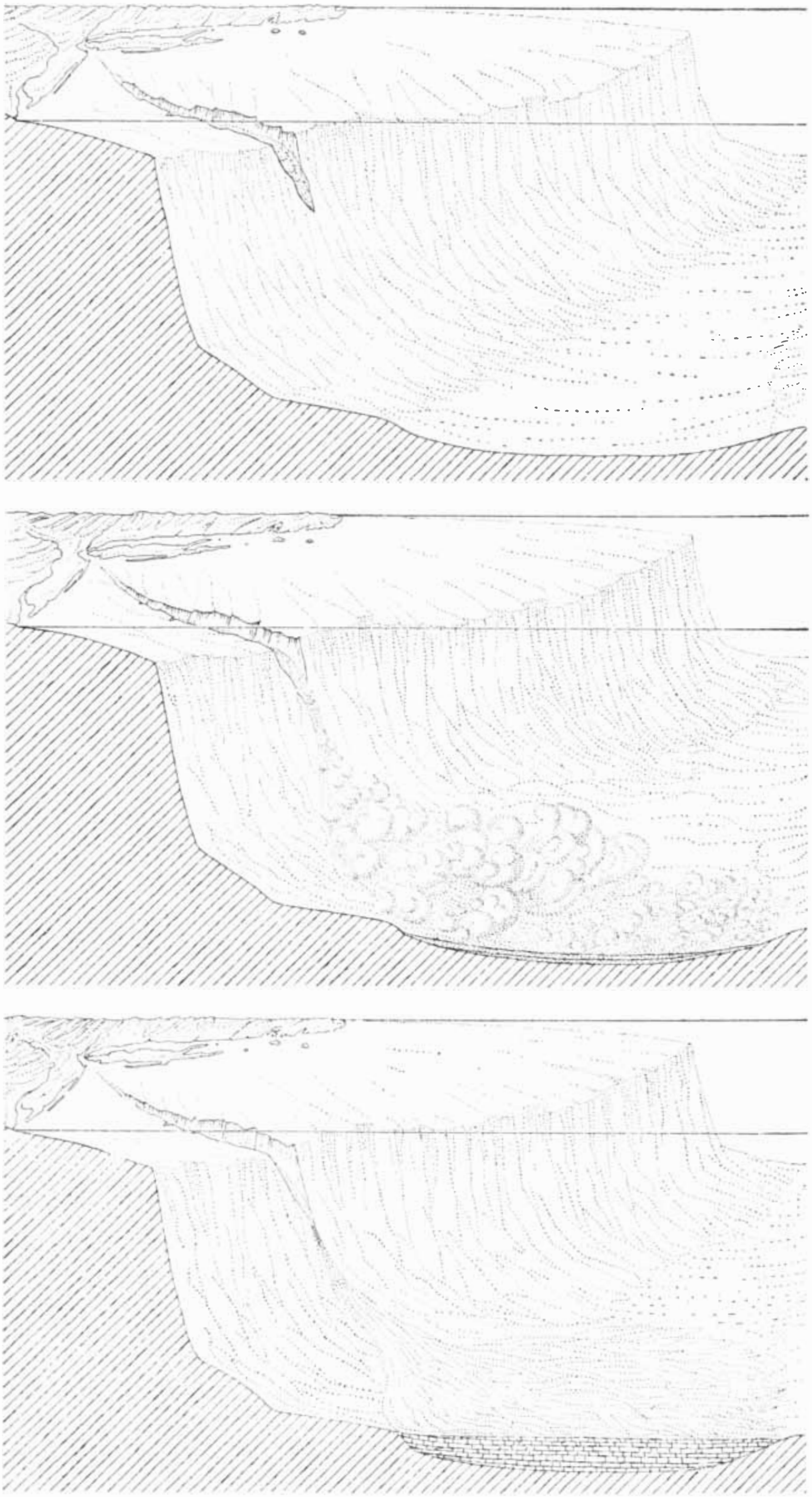
Along the coast and on the continental shelf several processes keep the sand in motion. The inflow and backwash of breakers sweep sand up and down the beach. Where the waves meet the beach at an angle, they carry the grains in a zigzag path downwind, as the water alternately rushes obliquely up the beach and runs back down the slope. Wave commotion dies out rapidly with depth, and even storm waves do not stir a sandy bottom at depths greater than 100 feet. Tidal currents shift the sand back and forth in a more leisurely rhythm. Ocean currents do not usually brush the bottom with sufficient force to carry sand. However, waves frequently join forces with currents, and their combined action may set the grains in motion at depths of 150 feet. There are some sandy areas on the sea floor at greater depths, but only because clay is being washed away from

imparts polish, but grains were probably rounded first by abrasion on land.



FROSTED sand grains are typical of deserts. Grains are rounded by abrasion in wind transport and subsequently frosted by the chemical action that attends wetting by dew and drying by sun.

these areas and not because new sand is being supplied to them. The sand on the deeper stretches of the continental shelf, at a depth of perhaps 300 feet, must have been laid down when the seas were shallower.



TURBIDITY CURRENT explains the occurrence of sand deposits on the deep-sea bottom and the origin of sandstone beds in ancient marine basins now upraised on the surfaces of the continents. In these diagrams the vertical scale is exaggerated about 100 times. Sand and silt accumulating in submarine canyon at the edge of the continental shelf (*top drawing*) become unstable and start to slide. As the material slides, it churns up and creates a layer of water with a higher density than clear ocean water; the momentum of this turbid mass carries the sand long distances across the ocean floor (*middle drawing*). Successive deposits of sand, covered by layers of slowly accumulating silt, consolidate to form sandstone strata separated by layers of clay and shale consolidated from silt (*bottom drawing*).

Turbidity Currents

It is not surprising that geologists came to look upon sandstone beds anywhere among the rocks as indicative of quite shallow waters at the time when the beds were laid down. This axiom led to difficulties, because there are many thick sequences of sedimentary rock in which sand layers alternate with clay. In some cases these sediments contain fossils of animals that lived on the sea bottom in depths up to several thousand feet. This apparent contradiction has been resolved by the discovery of "turbidity currents." Where sand and clay accumulate on steep submarine slopes, the deposit tends to become unstable. It starts to slide and churns up to form a body of turbid water with a density higher than that of the clear ocean. This "heavy water" then accelerates down the submarine slope; with sufficient velocity to keep its load in suspension, it continues flowing out across the ocean floor. Such turbidity currents can carry along many tons of material and run for long distances over favorable stretches of submarine topography. R. A. Daly of Harvard University suggested 25 years ago that this mechanism might explain the excavation of great submarine valleys running down the continental slope. In our laboratory at the University of Groningen in Holland we have conducted experimental investigations that support Daly's hypothesis and show that turbidity currents have remarkable efficiency as agents of erosion. Our experiments have also indicated that the process will lay down sandy beds in which the size of the grains decreases gradually from the bottom of the layer upward, with clay at the top. Oceanographers have since found many sand beds far out in the deep ocean that show this "graded bedding." They have also deduced several contemporary instances of the flow of turbidity currents, recorded by the breaking of submarine telegraph cables [see "The Origin of Submarine Canyons," by Bruce C. Heezen; SCIENTIFIC AMERICAN, August, 1956].

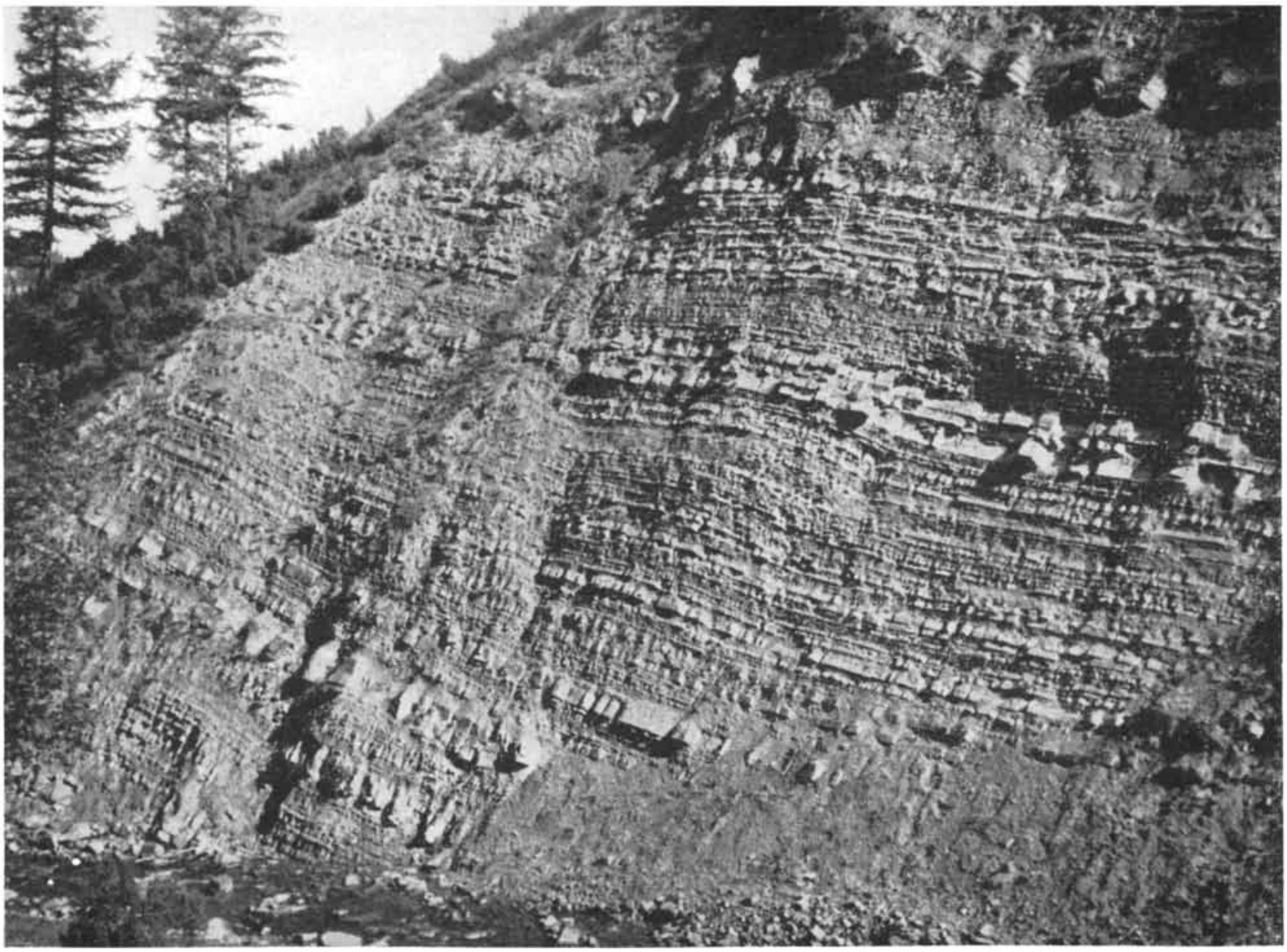
As a turbidity current spreads over the horizontal floor of the ocean, it must lose velocity and begin to deposit its burden. The driving force then disappears and the flow peters out. Examination of ancient rock-series has disclosed many formations built up by graded bedding. The graded sandstone beds alternate with beds of shale, showing that the ancient seas accumulated thick layers of clay and fine silt over the centuries and that once in perhaps 10,000 years a turbidity current came along, leaving a graded bed in its wake. The sandstones record much other evidence of the dynamics of turbidity currents. The churning flow of the current tended to dig out rounded trenches in the bottom mud; where it dragged along sticks and shells it drew grooves in the soft ocean floor. These markings were filled with sand dropping from the current. The resulting casts now stand forth on the lower surface of a sandstone bed from which the underlying shale has been removed. The laminations of the graded sand-grains within the sandstone show undulating patterns that preserve the ripples of the current; here and there the laminations are bent and twisted in a fantastic manner by pressure changes that attended the sudden deposition of the sand.

These and many other features bear testimony to the magnitude of the disturbance that accompanies a turbidity current in its invasion of the quiet ocean depths. Moreover, they record accurately the direction in which the current flowed and hence indicate the direction of the bottom slope. Such information makes it possible to reconstruct the topography of marine basins long since uplifted on the surfaces of the continents. In several cases ancient currents have wended their way for more than 100 miles down the long axis of former deep-sea troughs; recurrent flows have built up alternating sand and clay beds to depths as great as 6,000 feet. The study of such beds is barely 10 years old, but it has thrown interesting and unexpected light on the geography and history of ancient marine basins.

Transportation by Wind

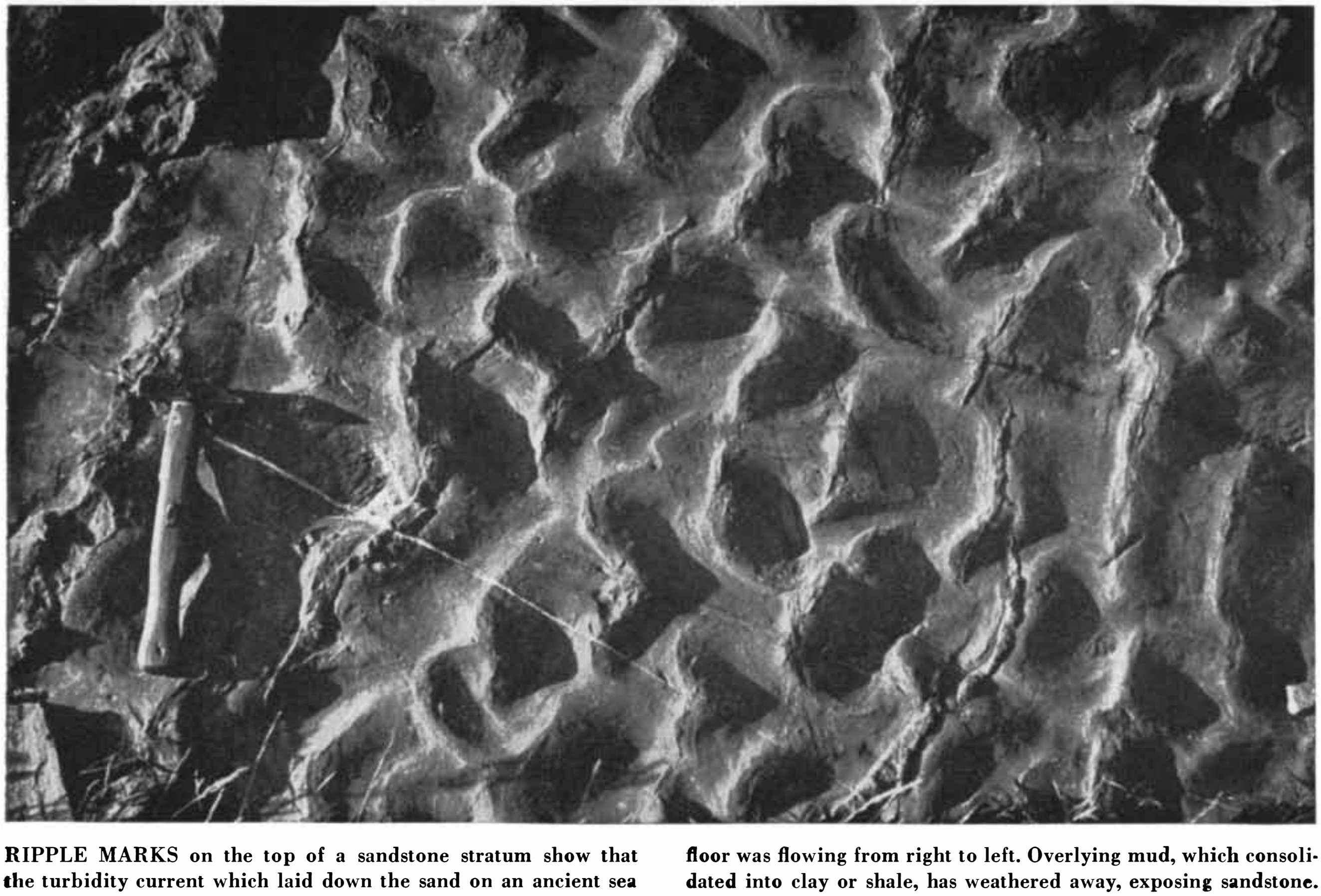
Wind as well as water plays a part in transporting and distributing sand, silt and clay over the earth. Wherever the cover of vegetation is meager or absent, the wind sets sand in motion. The grains bounce and wriggle along, the bulk of them not rising above knee height, but a few are high enough to sting the face if one stands in a strong wind. Silt and clay, on the other hand, will go into suspension in the wind and will travel for long distances above the ground. This explains the occurrence of the silty deposit called loess in the surroundings of certain deserts and formerly glaciated areas. The wind thus serves as an excellent sorting agent, separating silt, sand and pebbles from one another and leaving them at large distances apart. Desert sands, however, tend to have a wide assortment of grain sizes. Rivers sift their sediments more selectively, depositing grains of similar size close together.

The shapes of sand grains have much to tell about their individual biographies. A sand grain in the newborn state is irregular and angular in shape. When viewed with a pocket lens, however, many grains appear smoothly rounded. Roundness here does not mean spheric-



SANDSTONE STRATA alternating with shale reflect the action of turbidity currents (*see drawings on opposite page*) in ancient marine basin. In the centuries between the flow of such currents the silt and clay settling in the deep water laid down the shale.

DEEPLY CONTOURED SANDSTONE records the turbulence that attended the deposition of the sand from a turbidity current in the soft silt and clay on the floor of an ancient sea. Such natural casts are often found to occur on the underside of sandstone strata.



RIPPLE MARKS on the top of a sandstone stratum show that the turbidity current which laid down the sand on an ancient sea floor was flowing from right to left. Overlying mud, which consolidated into clay or shale, has weathered away, exposing sandstone.

ity, but the opposite of angularity; for example, a cylinder with hemispherical ends is said to be rounded. The difference between the young grain and the apparently old one warrants the conclusion that abrasion has taken place in the course of transportation. Here is a clue to whether sand has been carried by wind or by water, an indicator of the age of sand and perhaps a record of the geological revolutions in which it has participated.

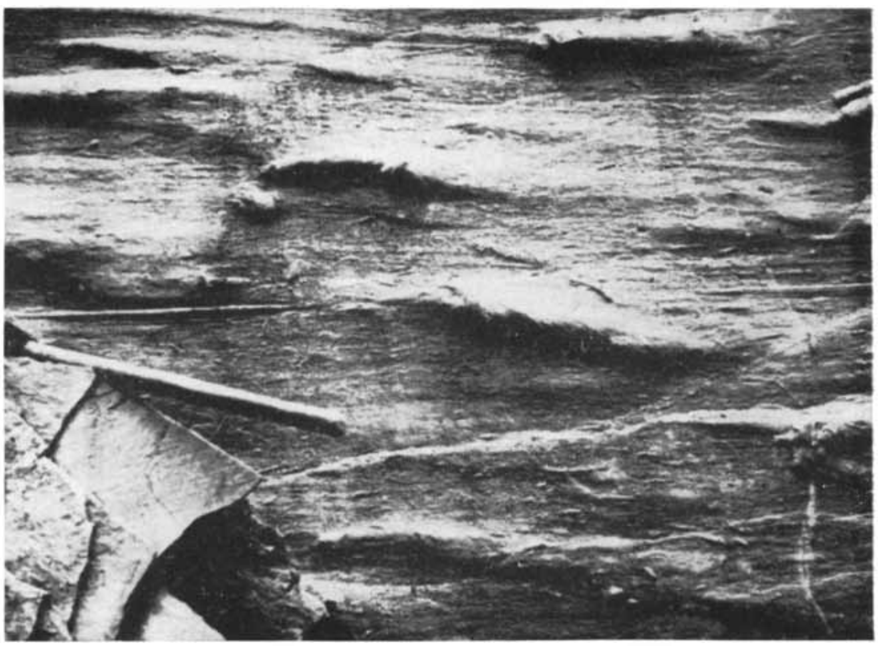
The Rounding of Sand Grains

Since the gravel in a stream bed shows progressive rounding downstream from the source, it has been thought that sand grains also are rounded by transport in running water. Surveys along river courses that showed the roundness of sand grains increasing slightly downstream seemed to support this deduction. Curiously enough, however, a decrease in roundness downstream was detected in some rivers. This could be explained by assuming that the angular grains are picked up more easily and so are carried more swiftly by the water. But it could just as well be argued that the more rounded grains roll more easily and so outstrip their angular competitors in the migration downstream. In either case the influence of selective transport seemed to overshadow any action by abrasion.

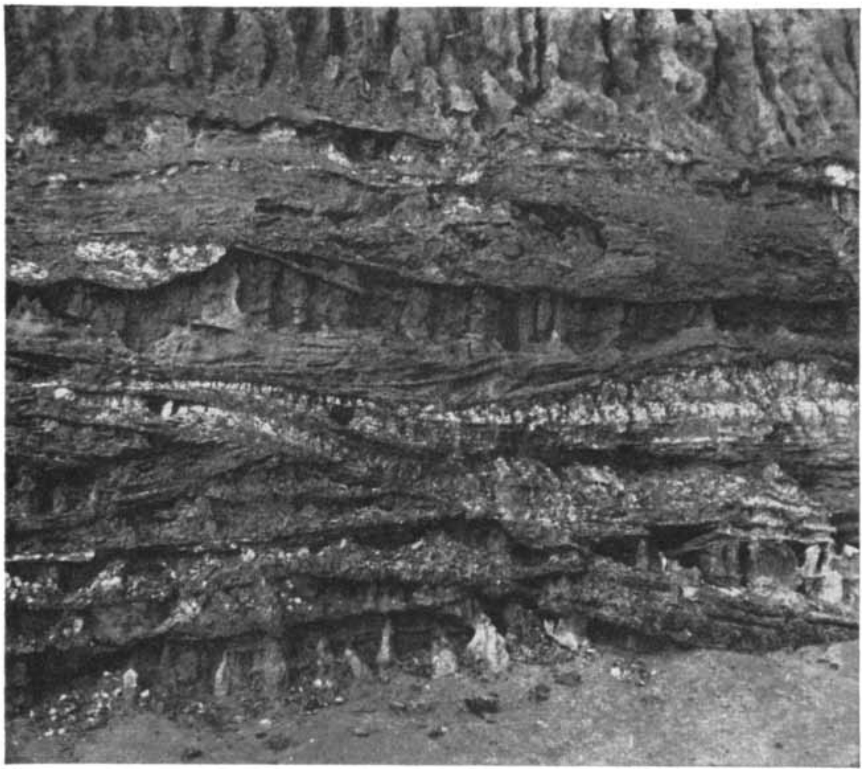
Investigators accordingly turned to experiment. Almost a century ago the French geologist Gabriel Auguste Daubrée put sand and water in a revolving horizontal cylinder and found that the sand lost about .01 per cent of its weight per mile of travel. The grinding motion of a heap of sand churned through and through in this manner poorly imitates the bouncing and rolling movement of the separate grains in a running stream. Nevertheless several authors have repeated Daubrée's experiment with minor variations and have obtained roughly the same measurement.

Recently I have attempted to approximate the natural situation more closely by rolling test grains around a circular moat of concrete in a current propelled by a sort of churn. The concrete, as compared to a loose bed of sand, does increase the rate of abrasion, but only slightly. In order to eliminate the influence of variable shapes I employed specially prepared cubical grains. An extensive series of runs showed that larger grains in a fast current lose about .2 per cent of their mass per 100 miles of travel, and that medium-sized grains lose only

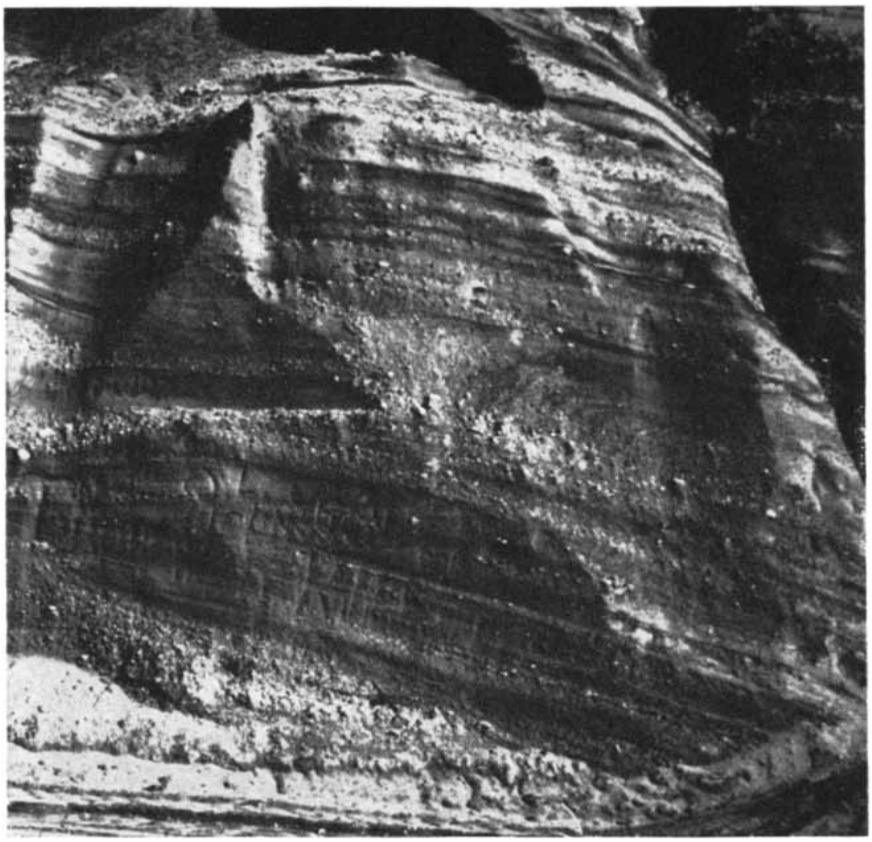
GRADED SANDSTONE-BED reflects the sorting action of the turbidity current as it settled out its burden of sand on the bottom of an ancient sea. The largest and heaviest grains are at the bottom of the bed; the lightest and finest, at the top. Above sandstone is a layer of clay that accumulated over many years following sudden deposition of sand.



GROOVES CUT IN SILT by the flow of a turbidity current across the bottom of an ancient marine basin are preserved in the undersurface of a sandstone stratum. Fine details in the pattern of the grooves show that the current flowed from left to right in this photograph.



SANDY RIVER-DEPOSITS created these sandstone strata. The succession of strata shows that the river departed from and returned many times to the channel in which it laid down the sand. A wandering river thus reworks its deposits, spreading sand over the valley floor.

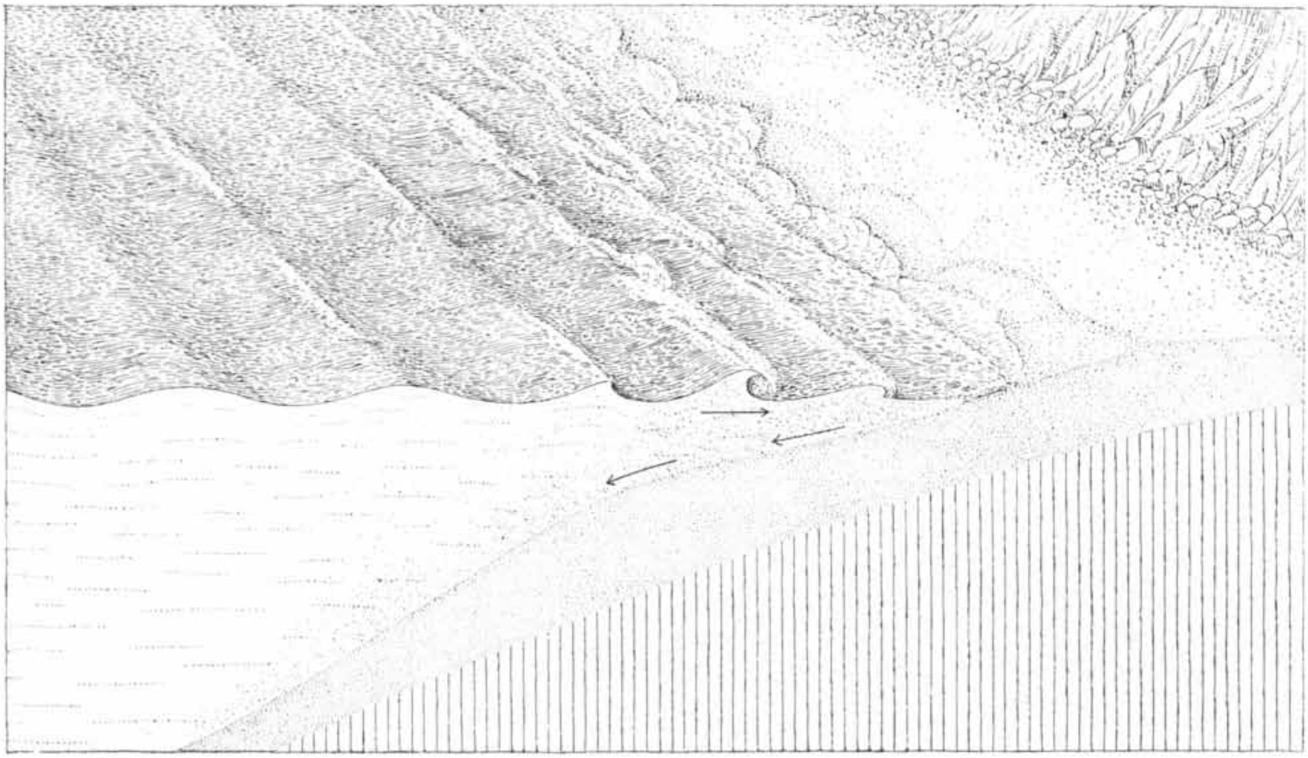


GRAVELLY RIVER-DEPOSIT is preserved in sandstone. The intersection of strata and the varying angles at which they lie show that the river at times scoured away earlier deposits. Differences in texture of the successive strata indicate changes in the rate at which the river flowed and in the character of the material it carried from one period to the next.

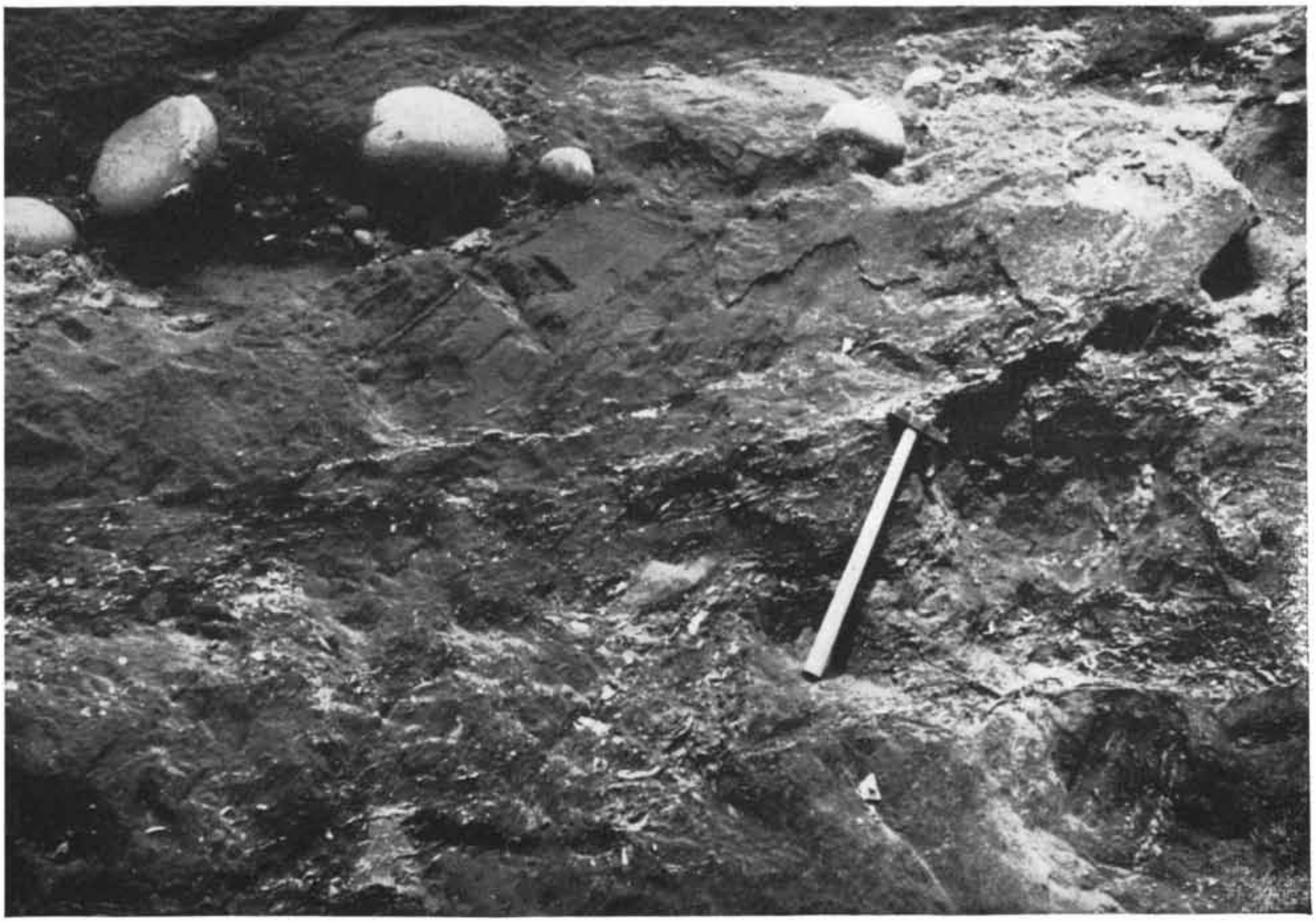
.01 per cent. This means that to round a .5-millimeter cube to a sphere, the particle would have to be rolled 50 times around the Equator. The first dulling of sharp angularity requires a 1- or 2-percent loss and can happen in the first few hundred miles. But thereafter mechanical abrasion of this kind has little effect on quartz sand with medium-sized grains. Experiments with feldspar showed that this mineral also possesses strong resistance to abrasion in water. Even though feldspar is softer than quartz and cleaves more easily, it showed only twice as much loss.

In the past it has often been claimed that the angularity of sand grains in an ancient rock is proof that the sand originated nearby. This contention is not upheld by the results of our experiment. Conversely it has been argued that a well-rounded grain must have had a long history. Abrasion in running water, however, could not in itself account for the roundness of even the most ancient grain of sand.

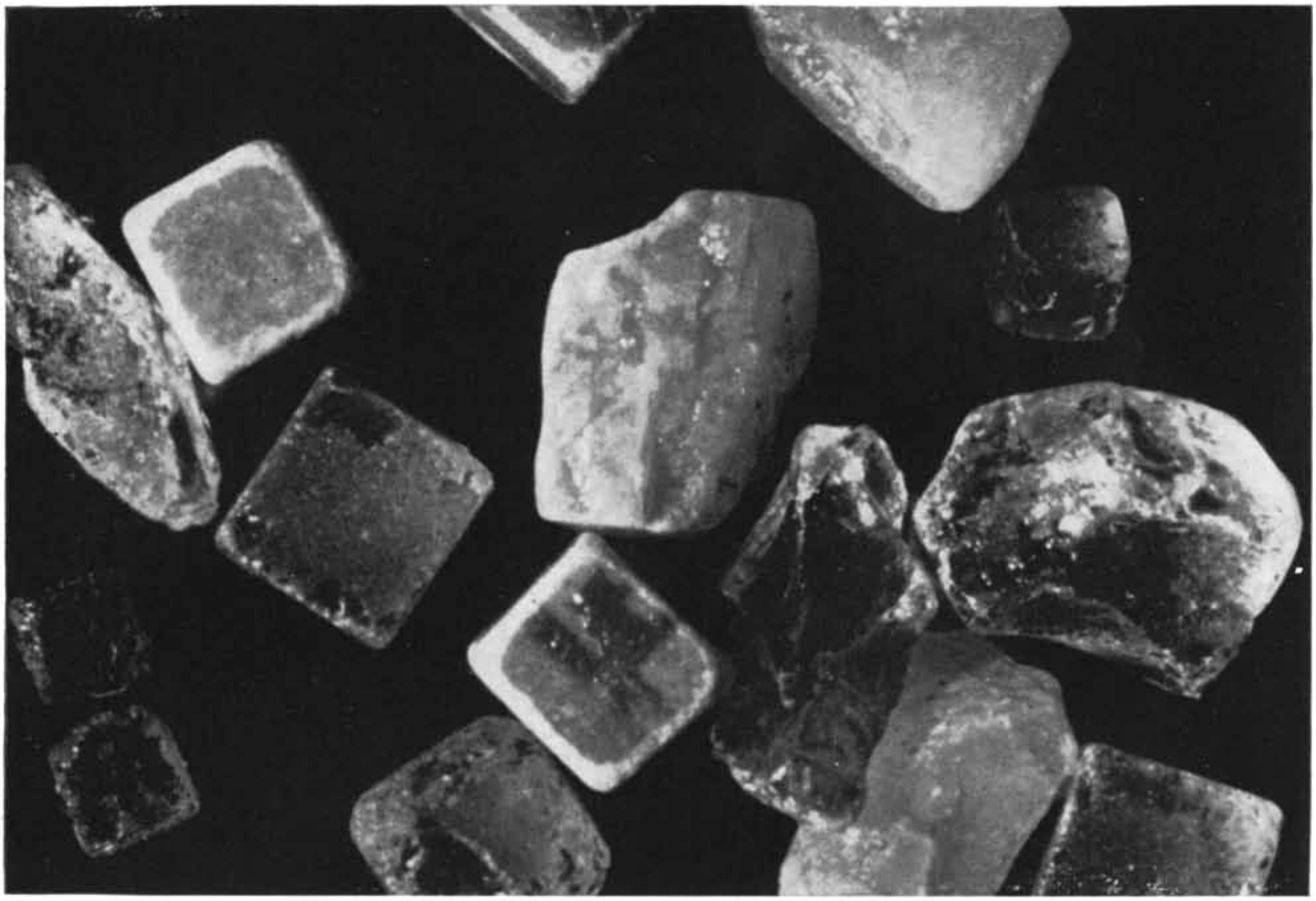
Water has another effect upon the sand grain which must be considered in connection with rounding. While the grains of sand in deserts have opaque, heavily frosted surfaces, many river sands contain grains with glossy, highly polished surfaces. The polishing could not have been accomplished by abrasive action, for the indentations and crevices in a polished grain that are out of reach of abrasion show the same perfect surface. It is possible to impart a polish of sorts to frosted grains by rolling them dry in a bottle, but the indentations in these grains remain opaque. It must therefore be concluded that river sands get their polish by chemical action. A crystal of alum that has been sandpapered can be "polished" by immersion in a saturated solution; precipitation from the solution smooths out the roughened surface. If river waters are sufficiently saturated with silicon dioxide, it will precipitate in the same way on quartz; hence this mechanism can be postulated for the defrosting of sand grains. The opposite action—the dissolution of silicon dioxide from the roughened surface of sand grains in waters that are undersaturated with the oxide—has been suggested as the mechanism for the rounding of sand grains. If such chemical action were significant in rounding, then one would expect to find that the effect is most pronounced on the smallest grains because the surface of such a grain is largest in comparison to its volume. Inspection shows that, on the contrary, in nearly all sands the smaller the grains,



ACTION OF WAVES ON BEACH causes some rounding of sand. Most of the abrasion occurs in the shallower reaches of the waves, where they carry sand up on the beach and wash it back again. At a depth of 50 feet the wave action scarcely disturbs the sand.



BEACH-SAND DEPOSIT contains boulders and also some fragments of shells. Compared to shales and clays, however, sandstones are usually barren of fossils. This deposit formed on the shores of a Pleistocene marine basin, afterward raised above sea level.



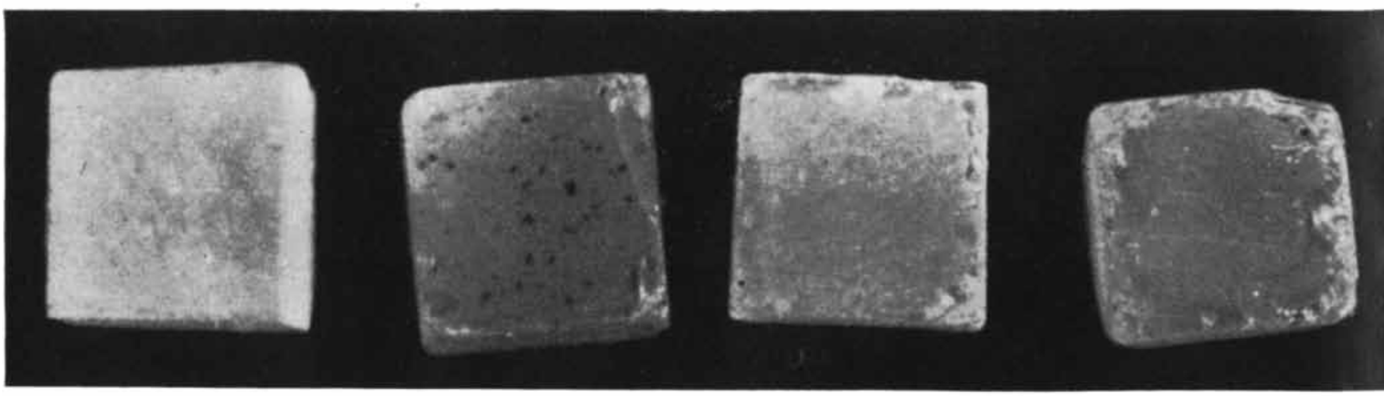
ABRASION OF SAND by wind transport was studied by author in experiments employing cubes of quartz and limestone cut to various dimensions; the cubes are shown here together with natural irregular sand grains. The photographs indicate the abrasion

the sharper their corners. It appears highly improbable that chemical action is the cause of more than a slight dulling of the sharpest angularity of quartz grains.

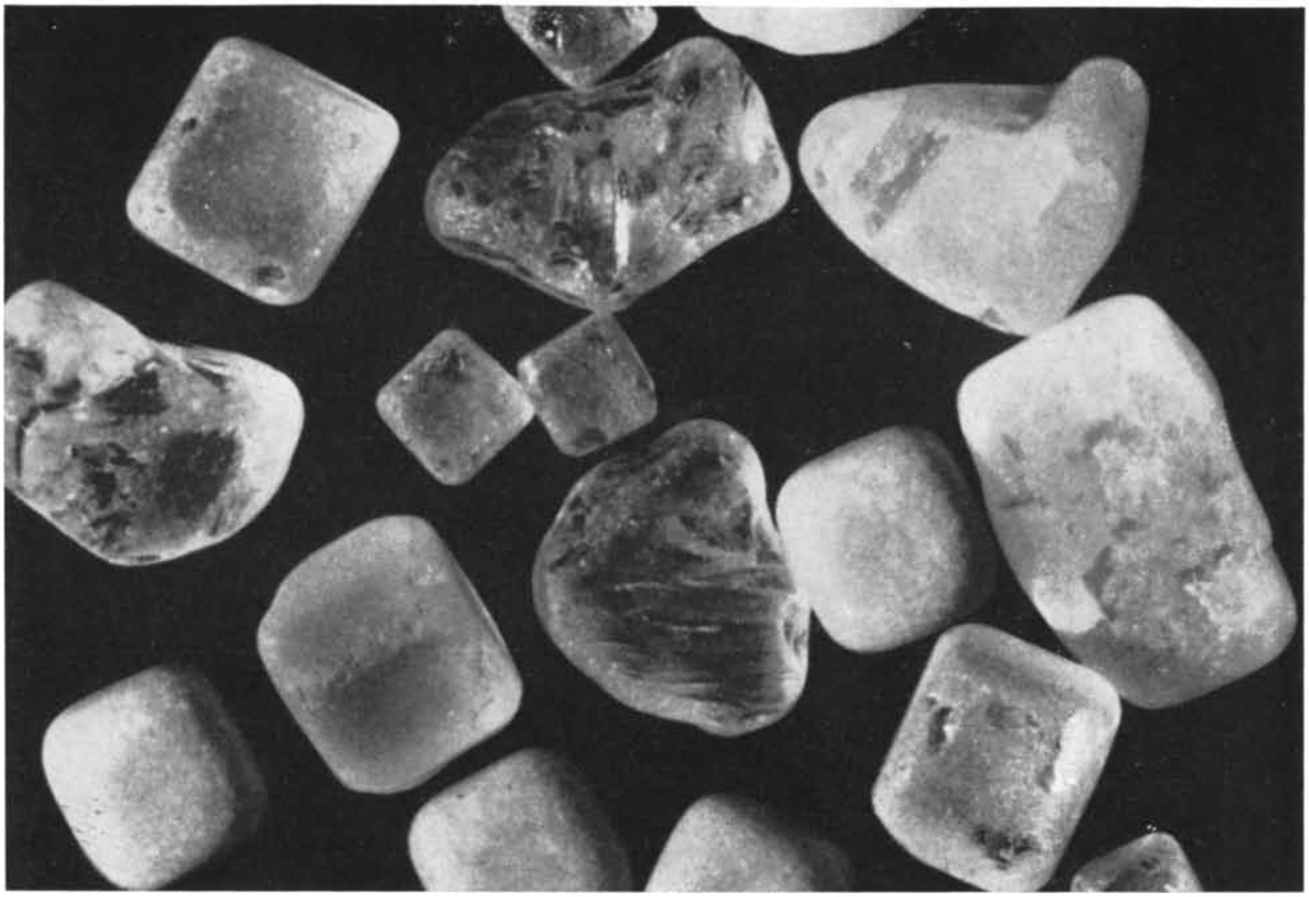
Wind Abrasion

The cause of roundness in sand grains must therefore be sought in some other mechanism. Perhaps the wind is the agent. Well-rounded grains are abundant in deserts and dunes, and geologists have long suspected that transport by wind powerfully abrades the grains. This deduction is open to doubt, however, because it is also observed that the wind selectively sorts the better-rounded grains from beach sands and carries them inland to coastal dunes.

In a wind tunnel in our laboratory we have just completed an investigation that seems to offer a reliable answer. The wind picks up the sand grains from a moving belt, redepositing them downwind on the belt for another ride upwind. The movement of the grains as they bounce and roll over the deposit that is traveling up the belt closely approaches their natural behavior, and the distance they travel can be accurately measured. By this means we have made the unexpected finding that transport by wind causes quartz grains to lose 100 to 1,000 times more mass than water transport causes them to lose over



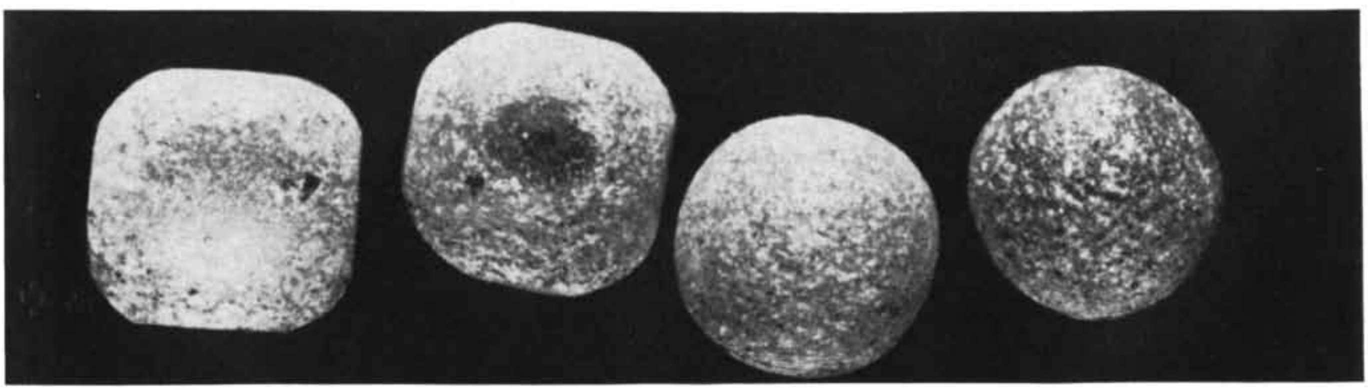
ROUNDING OF A SAND GRAIN is demonstrated by the rounding of an experimental quartz cube to a sphere. The rounding was accomplished in a wind tunnel. In the earlier stages of the process the sharp edges and corners of the cube are roughly chipped. As



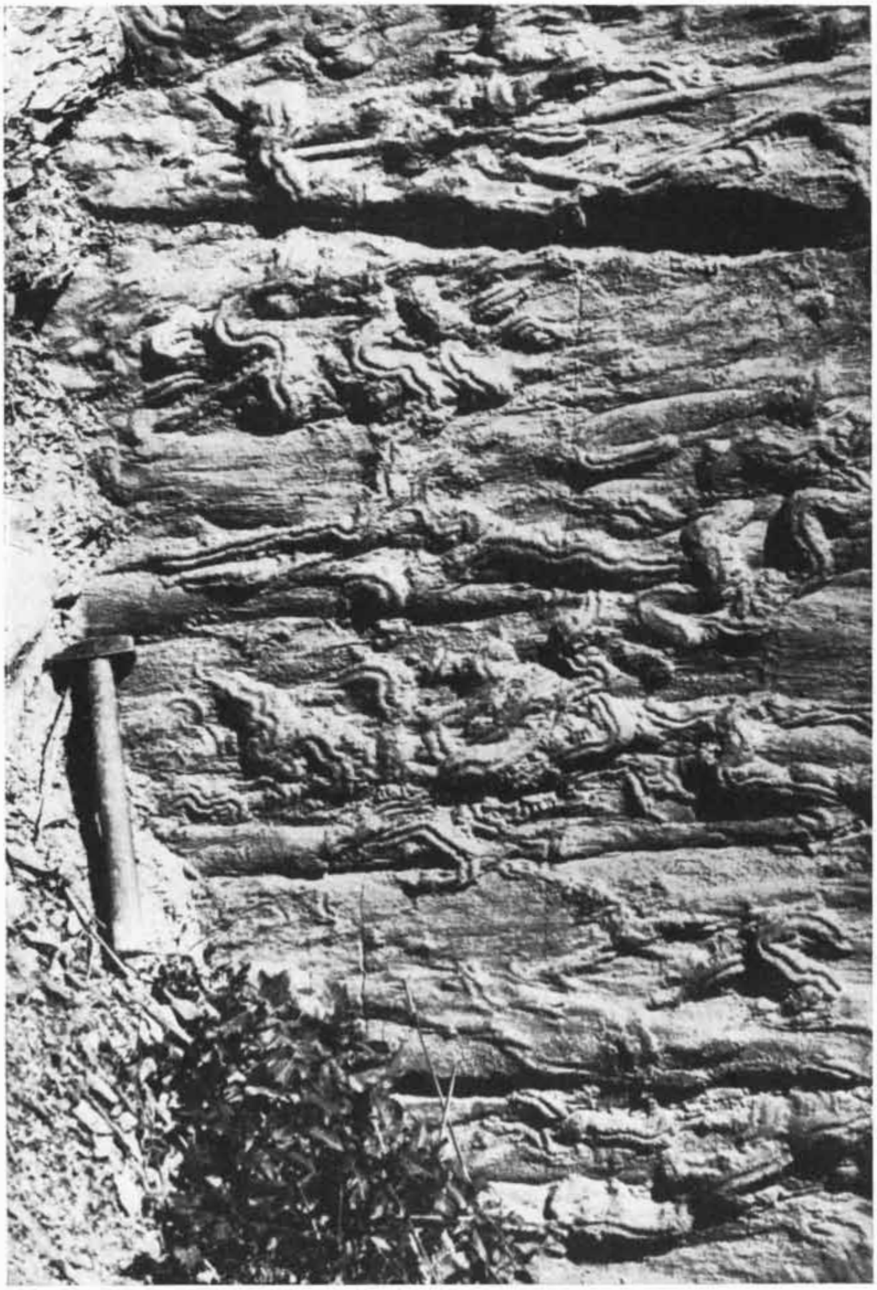
and hence the rounding sustained after 20 miles of experimental transport in a wind tunnel (*left*) and after 40 miles (*right*). Comparison of cubes with natural grains of equivalent roundness at each stage yields estimate of volume lost by the latter to abrasion.

the same distance. Moreover, wind abrasion reduces quartz almost as rapidly as it does feldspar or limestone. Apparently the brittleness of quartz causes it to flake off in the impact of a bouncing grain against a stationary one. On the other hand, we found that well-rounded and polished quartz-grains remain perfectly intact even after prolonged, violent wind action. It must be that they rebound elastically, as billiard balls do. Cubes of quartz change gradually to perfect spheres. This demonstrates that abrasion takes equal effect in all planes of the crystal. The oblong shape of most rounded natural grains may therefore be attributed to the original irregular shape of the particle.

In tests of samples containing a wide assortment of grain sizes we found that the smaller the particle the less abrasion it suffers. Particles with a diameter of .1 mm. or less show no abrasion at all. Apparently these smaller particles cannot hit one another with sufficient momentum to cause a crack in a grain. In mixed samples the minimum size of a grain showing loss goes down to .05 mm.; a larger grain landing on a smaller one can apparently chip a piece from it. But .05 mm. appears to be the bottom limit of the size of particles that show abrasion. The fragments chipped from the grains form an impalpable dust. In nature the wind carries this finer material outside the unvegetated desert and



the cube becomes rounded, however, the rate of abrasion slows down. In its final spherical form (*right*) the cube has lost more than half its mass. Rounding of a cube to a sphere indicates that rounded oblong natural grains started as angular oblong grains.



MARINE-WORM BURROWS are preserved in the undersurface of this sandstone bed. The sandstone also records grooves cut in the soft ocean-bottom by flow of the turbidity current.

dune areas, leaving sand-sized grains behind.

Curiously one does not find the tiny sand chips in the loess laid down by ancient dust storms. The bulk of loess is quartz, but its particles fall outside the size range produced by wind action on sand. This shows that loess must have been formed in some other way, perhaps by the crumbling of cracked grains and the weathering of fine-grained rock.

In the absence of evidence to the contrary it appears that wind is the principal agent in the rounding of sand grains. One way to check this conclusion is to make some round-number estimates involving, first, the average abrasion loss that all sand grains have suffered; second, the current rate of loss occurring in all deserts and sand dunes; and third, the yearly production of new angular grains. Such estimates would incidentally yield a rough measure of the age and hence the durability of sand grains. This in turn relates to the role that sand has played in maintaining the continents against the forces of erosion.

Age and Durability

In a preliminary approach to these estimates we made a chart of 16 shapes observed in cubes of different sizes that had sustained known percentages of

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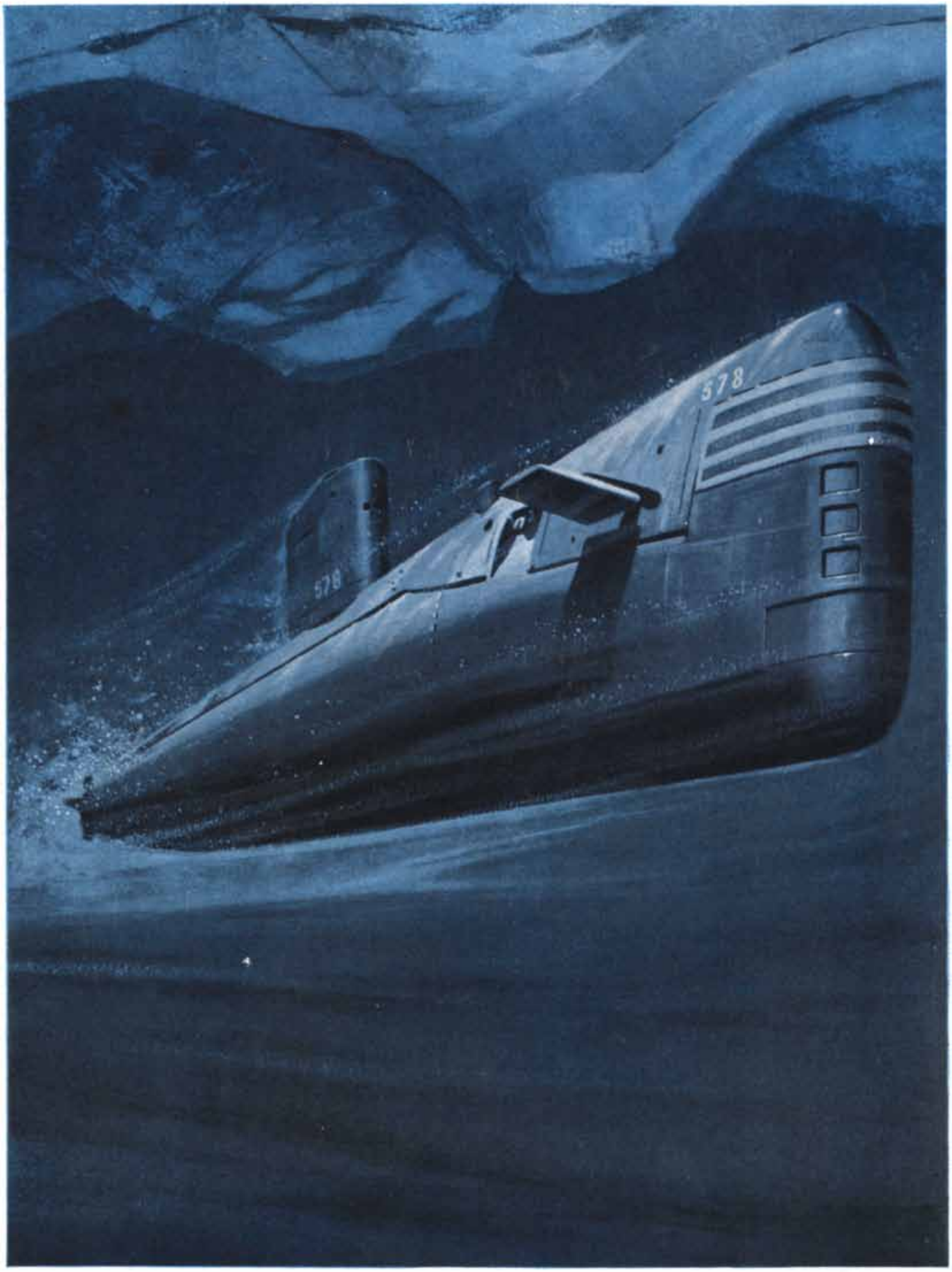

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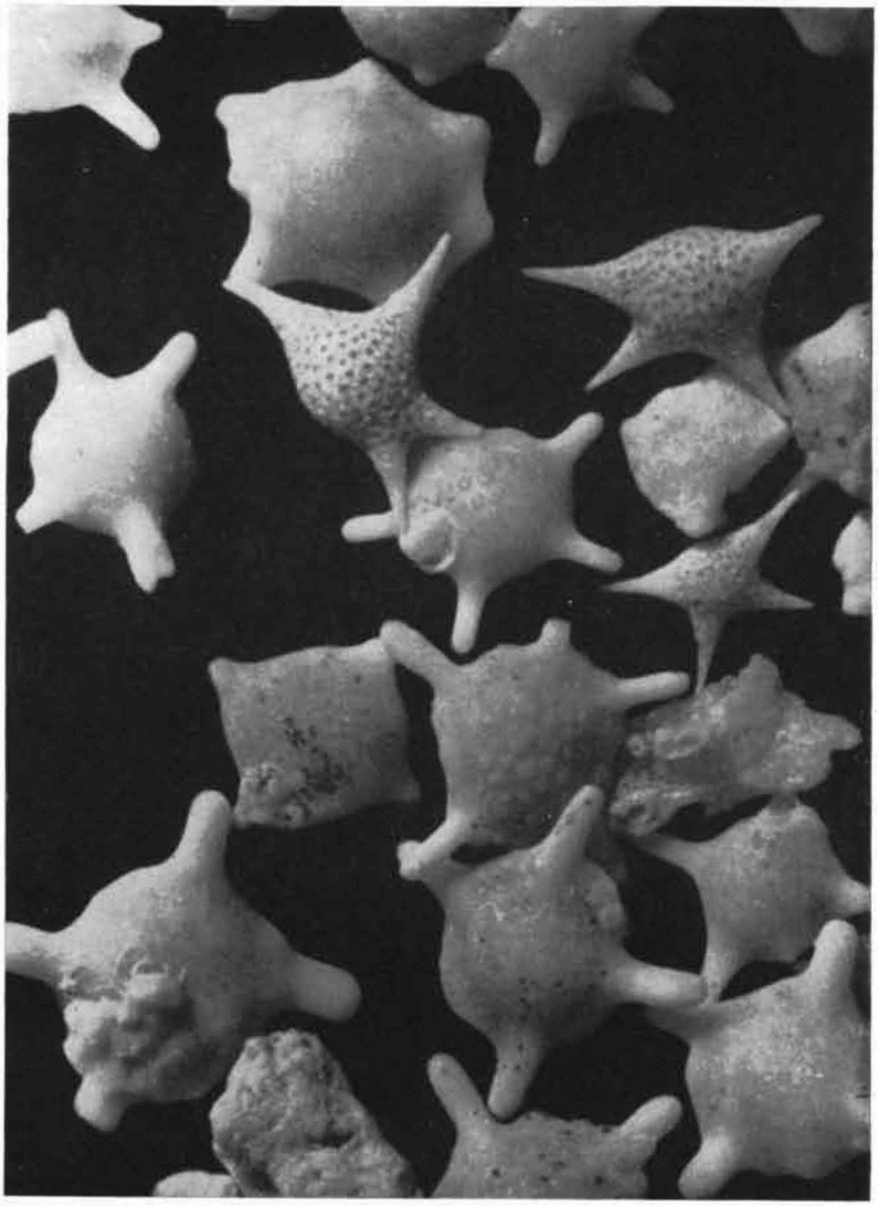


CORAL-REEF SAND is composed of the limy skeletons of minute marine creatures and the debris of coral itself. In comparison to quartz grains these particles are highly fragile.

abrasion loss. By comparing the cubes with natural sand-grains we made a rough appraisal of the losses the natural grains must have sustained. With due allowance for the diminution of roundness with grain size, we found an average loss of about 10 per cent. This serves as the estimate of the average abrasion sustained by all sands. To determine the average current rate of abrasion in desert sands we drew upon our wind-tunnel experiments, plus some values for the average wind-force in deserts, and found that the figure is equivalent to 10 per cent of the weight of 300 cubic yards of sand per square mile per year. The most uncertain estimate is the third: the yearly production of sand grains by weathering of hard rock and the crushing of old grains. The addition of new angular particles to the existing stock of sand would decrease the percentage of rounded grains in the total. To maintain the average abrasion-loss constant at 10 per cent, in accord with our first estimate, the annual loss of all sand must equal 10 per cent of the volume of new grains produced each year. Only a tentative estimate can be made. It would appear that some 200 million cubic yards of sand would have to be undergoing a current abrasion loss of 10 per cent. By combining these results one finds that about 750,000 square miles of desert will do the trick. The present area of sandy deserts is three times as large. This suggests that the average roundness of sand on earth should be increasing. But since the desert area has been much smaller in the past, there is no contradiction in the result. Plainly wind abrasion can more than account for the roundness of the world's sand grains.

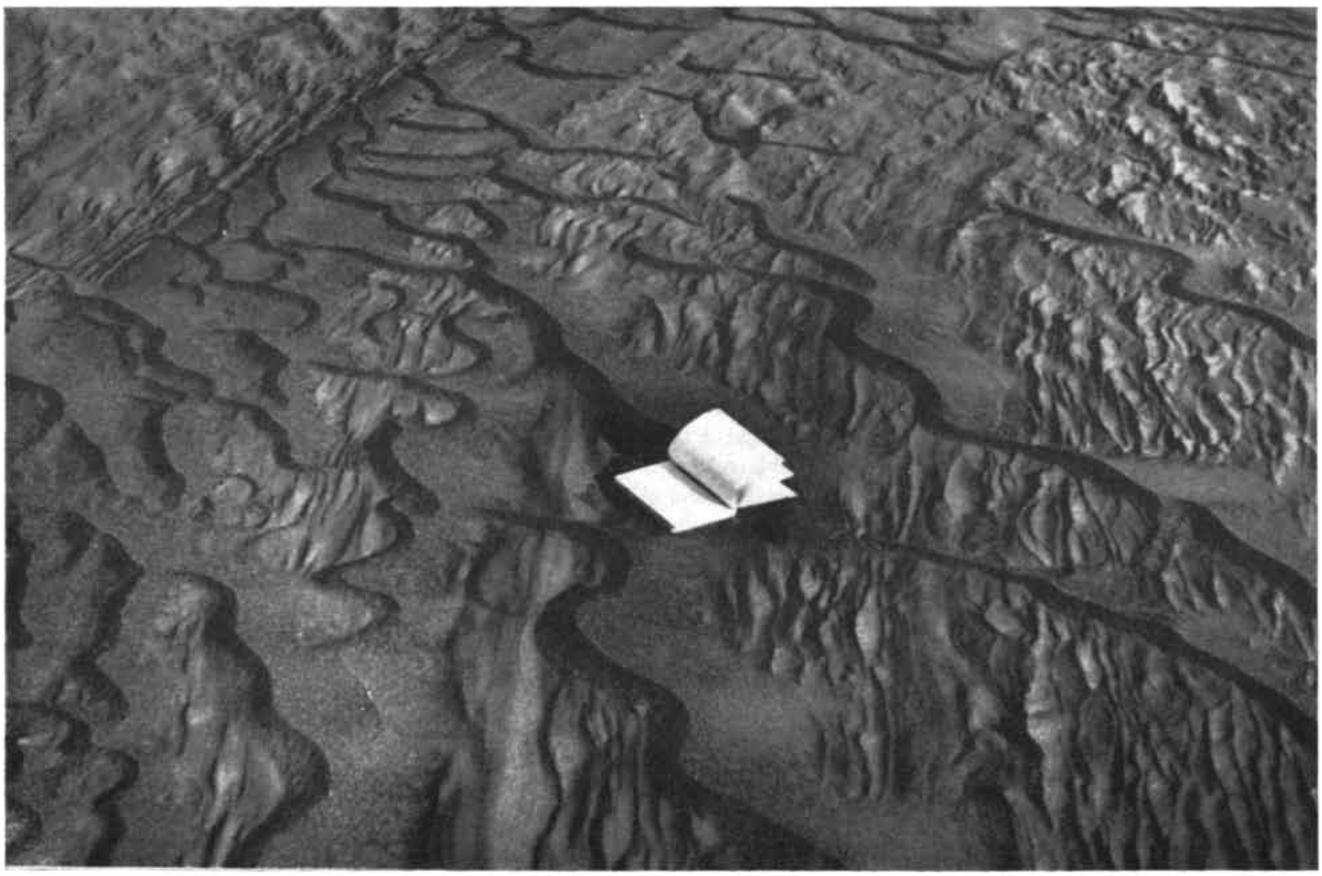
The same calculations confirm the laboratory finding that a sand grain is a durable object. After having been born from some parent rock, it begins the travels that are to wear it down. Its movement is intermittent, and the periods of stagnation vary from a few minutes in a river bed to eons on a flood plain or beach ridge. But ultimately it finds a final resting place where the sand is covered by younger deposits and is no longer disturbed.

No sharp distinction can be made, however, between a temporary halt and the final goal. There is always the possibility that a sleeping grain will be reawakened or that a buried one will become the victim of body-snatching. Deposits on land tend to be disturbed sooner or later by erosion, and not even a cemetery on the floor of a sinking marine basin remains secure for all time. Pressure, temperature and chemical reaction may combine to bond the grains in sandstone. The cement is usually lime, silica or an iron oxide. Yet even when it is sealed in this coffin, a sand grain is no more inviolate than a Pharaoh's mummy is secure from plunderers or archaeologists. It is true that when the grain is part of rock that has been submerged to great depth and subjected to intense heat and pressure, it "returns to dust"; its crystal is disassembled and its molecules recrystallize to form a gneiss or a schist. More likely, however, the sedimentary strata are raised to produce a mountain range. As a result erosion starts to disinter and break down the sandstones and other rocks. In some cases the cement is so strong that pebbles are formed. But usually the breakdown sets the grains free again, with their shape at burial still intact. When this happens, the particles enter a new erosion cycle with the inheritance of the rounding acquired before.

Sand on the Continents

Some investigators hold that more than half the grains partaking in transport and deposition are newly formed, or at least much altered from their former shape. Others maintain that the great majority are held over from former cycles. If the results of our investigations can be relied upon, however, a large proportion of the world's stock of sand grains must have undergone many cycles.

There is another reason for holding that the average age of quartz grains is very high. This is the huge volume of sand now lodged on the continents. Some of it has been lost to the deep-ocean bottom by turbidity currents, but this loss cannot be significant. Abrasion losses amount to only 10 per cent; a certain volume of the fine material thus produced must have been carried from the continents in dust storms and dropped into the deep ocean. Finally, some of the sediment deposited in ancient sea basins now uplifted on the continents has been changed to crystalline schist and gneiss at great depths. The significance of all these losses cannot be assessed, but it is certain that in spite of them quartz has been concentrated in the sandy sediments of the continents to about twice its abundance in the source rocks. This is due to the chemical stability, hardness and comparatively large size of the quartz particles as they are borne from the parent rocks. These properties protect the grains from wear and tear and save them from being wafted into the deep-ocean basins. During geologic time the continents were thus covered with a layer of quartz sand that partly shelters them, in their turn, from the agencies of erosion.



DESERT SAND-DUNE has been eroded by the wind so that its irregular internal structure stands out in ridges. Across these ridges the wind has blown winding ripples of coarser sand. The book in center of photograph shows the scale of distance between ridges.

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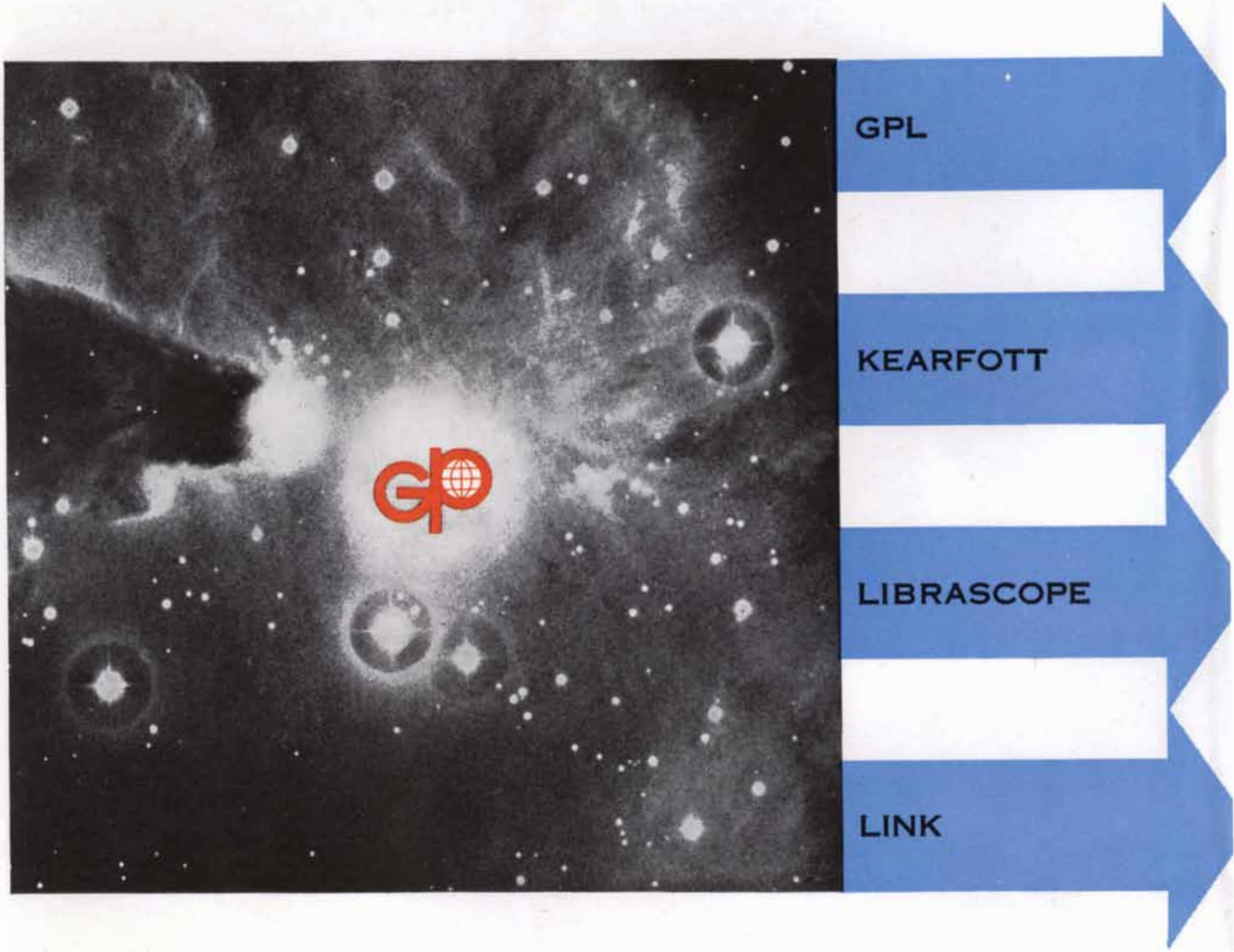
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SHEET WEB of the grass spider *Agelenopsis* is one of the most primitive of spider webs. Insects that blunder into it can find no foothold in its softly yielding tangle of filaments; they become easy prey to the fast-moving spider. Inconspicuous in the spring when it is first spun, the web becomes increasingly visible as the season progresses and the spider adds filaments to it with each excursion.

ORB WEB spun by a spider of the genus *Araneus* represents the acme of web evolution. Spun with greater economy of silk and effort than the sheet web, it holds trapped insects by means of tiny viscid globules that adhere to the threads of the spiral. The web shown here had not yet had its hub spiral added. Both webs in these illustrations were sprayed to make their filaments visible.

SPIDER WEBS

These silken insect traps are spun in many forms, from an apparently careless tangle to a precise geometrical structure. All have evolved from the single thread of silk that all spiders pay out behind them

by Theodore H. Savory

When the young spider leaves its silken cocoon, it swings into the world on a silken thread. It weaves a silken net to snare insects, and binds them with silken cords. When danger threatens, the spider drops to safety on silken ropes, and if it survives the season, it hibernates in a silken chamber. Some spiders line their burrows with silken tubes, and some close them with silken trap doors. In mating, the male spider deposits its semen on a special silken web. When finally a spider dies, it is wrapped (if it has been lucky) in a silken shroud.

Silk is the warp and woof of the spider's life. A few other creatures secrete silk, but none has exploited its possibilities so fully. With their unique mastery of this technology, spiders have colonized the entire habitable world and evolved some 40,000 species. Not all of them spin their silk into webs. The wolf spider, for example, chases its quarry, the jumping spider stalks it, and the crab spider hides and pounces. But most spiders do spin webs, and the success of the spider is only one aspect of the success of the web. The web spiders are alone, or nearly alone, in the practice of setting a trap for their prey. (The only other animal that builds a comparable structure is the water-dwelling larva of one species of caddis fly.) The web is so efficient a device for getting food that the web spider hardly ever responds to sensory stimuli other than those furnished by the motions of its web. So intimately is its sense of touch tied to the web that the web becomes an extension of the spider itself, communicating by the frequencies of its vibration where an insect has been caught, where an enemy lurks or where a mate waits.

Whether it is a hunter or a web-weaver, every spider secretes silk from a battery of spinning organs located at the tip of its abdomen. Like their earliest ancestor, the Archearanead, all spiders lay a dragline of silk behind them as they move, and they fasten it to the ground at frequent intervals. It is this dragline that instinct, environment and chance have fashioned into the webs that spiders weave. The evolution of the web, which is not preserved in the fossil record, may be reconstructed from the behavior of existing species.

Originally the dragline probably served the single purpose of helping the wandering spider find its way back to its crevice—in much the way that Ariadne's thread led Theseus out of the Labyrinth. But a further function must soon have evolved. After constant sallies and returns, the draglines formed a dense pattern radiating from the spider's shelter. Should a passing insect touch one of the lines, its vibrations would carry to the silken mat on which the spider rested, and the slight tremor underfoot would stimulate the spider to rush out and secure its prey. This proto-web, which even today is much more widely distributed than any other design, enabled the early spiders to flourish and diversify.

Early builders of the proto-web climbed up rocks and tree trunks or onto the stems and leaves of small plants, or found their way to brooks and ponds or to the seashore. Wherever they went, these early spiders built their webs, and all the forms of web that were to follow are simply elaborations of the elemental web modified in adaptation to different environments.

The webs spun by those spiders that took to the rocks and tree trunks underwent the first elaboration. Living on slanting surfaces, the spiders must have followed the obvious tendency, when they ran out from a sheltering crevice, to head down the slope rather than upward and to run farther downward than up. The radiating fringes, or bell-mouth, of the proto-web would then no longer be symmetrical, but would spread downward over an increasing area, producing a web like that of Amaurobius or Agelenopsis [*see illustration on next two pages*]. The broadened fringe not only yielded a greater opportunity to catch insects, but also provided a greater measure of warning against enemies. This is the ubiquitous hammock-web that the modern house-spider Tegenaria spins in the corners of little-used rooms and outbuildings. Essentially a silken tube, the lower edge of which stretches out to form a sheet or hammock, it is almost as fundamental a structure as the bell-mouth web.

The simplest form of hammock web is woven on the ground by Agelenopsis. The young Agelena spider does the same, but as it grows older, Agelena seeks refuge from its crawling enemies by climbing high up in bushes. But as they spun their draglines from stem to stem the first aerial spiders found it difficult to maintain a foothold upon the threads. Thus there arose an important new type, the upside-down spider which hangs from the filaments with toothed tarsal claws. Since the spider has no balance mechanism, these species are indifferent to their inverted position.

But for this single difference in the weaver's position, the evolution of the aerial webs paralleled that of the ground webs. The sheet appears as before, except that guy lines support and stabilize the sheet above and below. The superstructure of guy lines brings an unforeseen advantage: flying insects strike the supporting threads and fall down onto the sheet. Soon there are many more guy lines above the sheet than are needed merely for support. The true web is emerging.

As the Agelenidae spin their webs in higher places, where flying quarry are more likely to blunder into them, they retain the silken tube. But the tube is conspicuous to enemies; in the web-building habit of the Linyphiidae it is abandoned. The Linyphiidae are a large family; they make webs of such fine silk that they are visible to human eyes only in the early morning, when beads of dew trace their delicate lines. These are the typical webs of hedges and bushes, the basic design from which, we may suppose, two major variations have come.

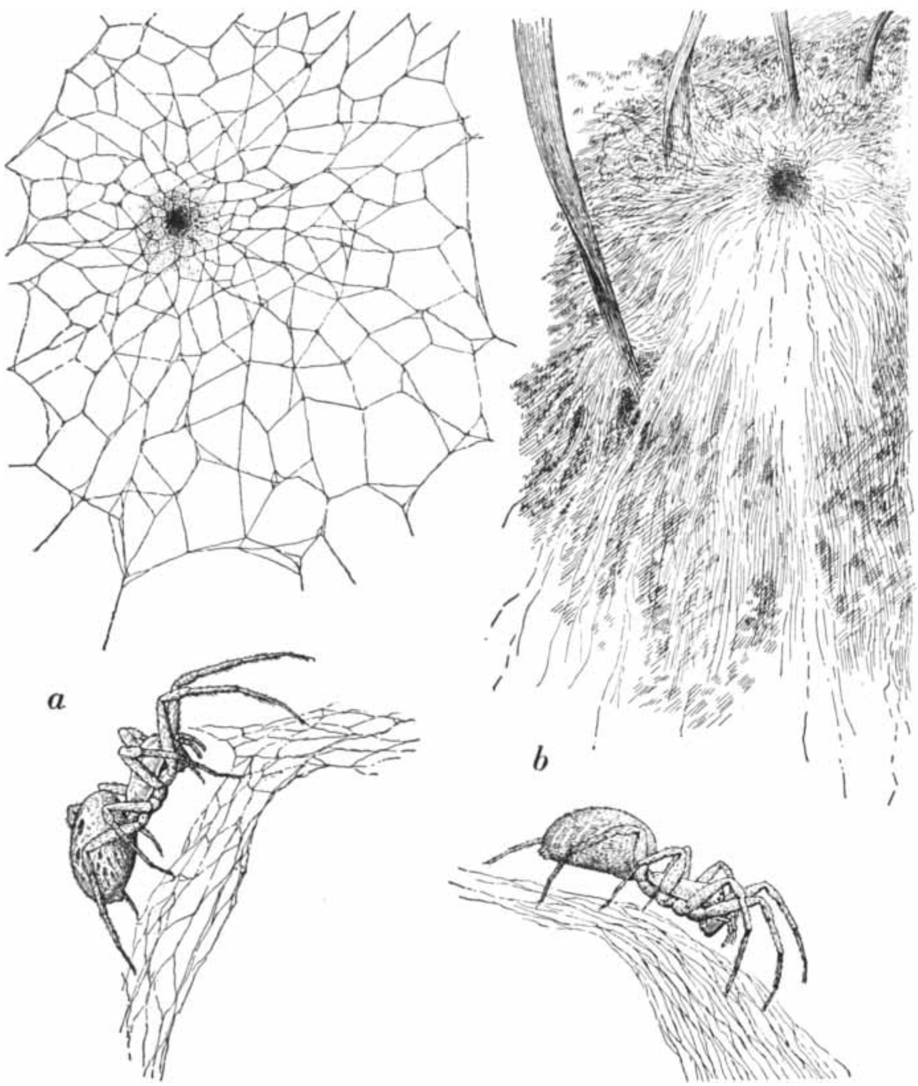
Some members of the Linyphiidae family, the small, black Erigoninae, or "money spiders," underwent a secondary adaptive radiation and returned to the ground. Here the web superstructure was needed neither for structural support nor for trapping flying insects, and so was discarded. Only the sheet was retained, and this the Erigoninae spin close to the ground, suspended from blades of grass and across small depressions in the earth.

A related family, the Theridiidae, remaining aloft in the bushes, followed the opposite line of development. Just as the Erigoninae turned black and merged with the earth colors, so the Theridiidae assumed the colors of the brighter flowered world above. And just as the web superstructure could serve no useful purpose for the ground spider, so the sheet could only advertise the presence of the Theridiidae to their enemies, or at best catch the wind that blew through the bushes. The sheet was thus discarded and the guy lines were retained. The webs of the Theridiidae seem a haphazard tangle of threads, formless and without design. But this lack of organization is only apparent. They are not simple but simplified; they are no less suited to their purpose than are the more orderly webs, and they are far less demanding to construct.

Among the Theridiidae are spiders that spin their webs high in the bushes and others that spin them closer to the ground. The webs of the latter involve a most interesting new adaptation: Stretched above the ground are a few perpendicular threads, and clinging to the lower end of each of them is a string of sticky droplets. The snare is obviously enhanced by the droplets, but far more significant is the fact that just such viscid drops are found on the spiral threads of the orb web.

The orb web, which is spun by members of the families Argiopidae and Uloboridae, is the supreme elaboration of the dragline. It is the symmetry of the orb web that appeals most deeply to the human observer. We are not much impressed by the cobweb, nor by many other webs that we see. We feel that if we were confined in a corner and given the power to produce threads, we might make as good a job of it ourselves. But the orb web, spun as it is in the air, in the dark, and often in a breeze, would defeat us. We gaze at it even as we gaze at St. Paul's Cathedral and Blenheim Palace. From the viewpoint of the spider, however, an "imperfect" orb web is just as good a structure as a "perfect" one. The criterion of symmetry is a human notion. The spider's need is functional, and it requires only that the web should catch enough insects to feed it.

Unlike the spinning of many other kinds of web, which grow gradually from a few threads to thick sheets by the slow accumulation of silk, the building of an orb web is carried out in one continuous operation, taking 30 minutes to an hour. Certain distinct stages may be discerned in this uninterrupted process. But there is little to be said in explanation of it beyond the statement that the web unfolds from the interaction of a ritual of inherited behavior, the spider's anatomy,

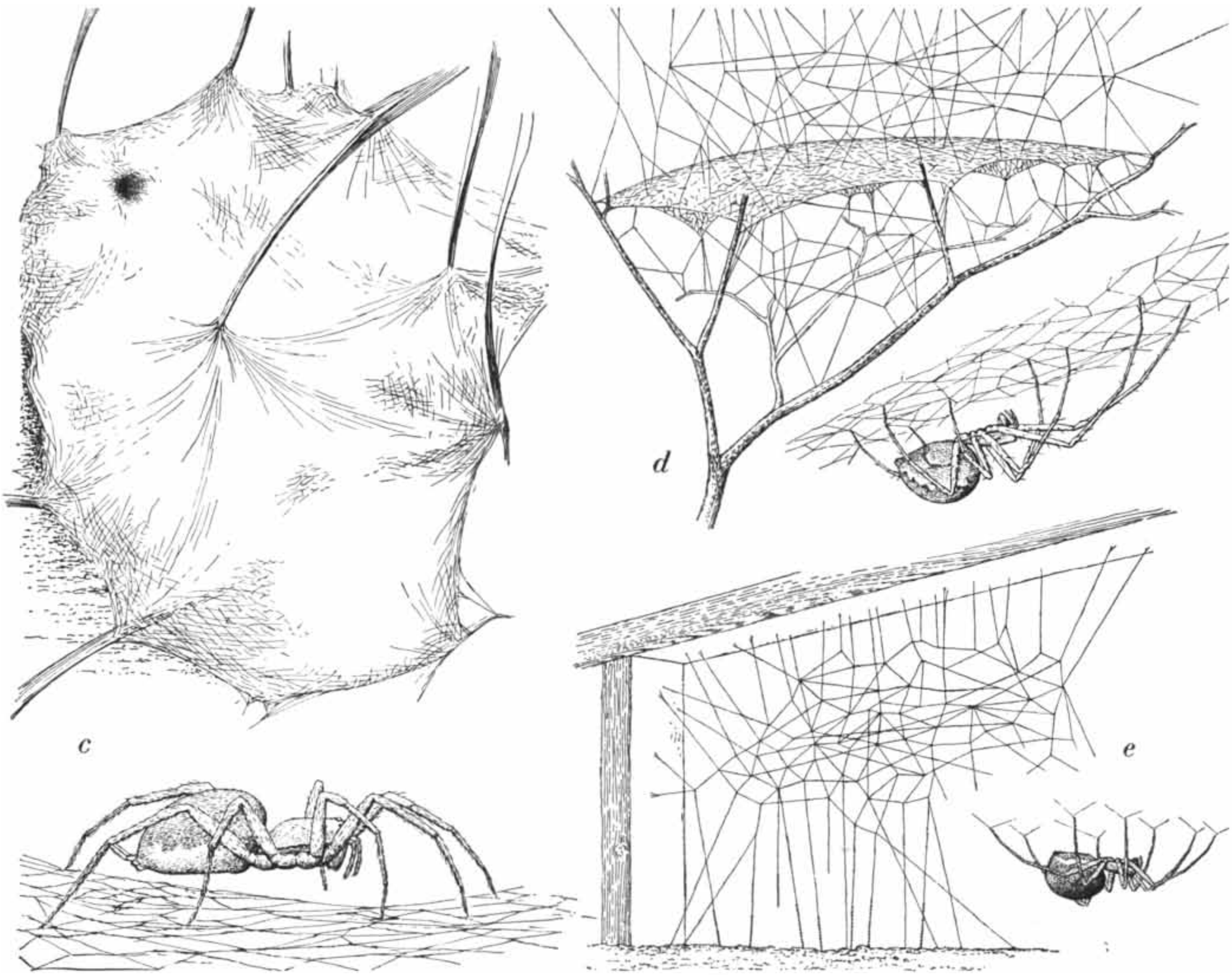


EVOLUTION OF SPIDER WEBS and their diversity are illustrated on these and the following pages. Webs *a*, *b* and *c*, shown with their spiders, *Amaurobius fenestralus, Coelotes terrestris* and *Agelena labyrinthica*, are versions of the proto-web. Amaurobius coats the filaments of its web with sticky globules to trap its prey; Coelotes and Agelena use dry fila-

the setting in which the web is spun and such chance factors as the play of breezes.

The web typically begins with the stringing of the "bridge" line. The spider fixes the line to a starting point and crawls off to another spot, drawing out the silk from the spinnerets as it goes and holding the line free of obstacles with the rear pair of its eight legs. Of course it may find itself located in a place from which it cannot conveniently travel to a second fastening point. In that event chance plays an even more decisive part in the ultimate design of the web. Raising its spinneret-tipped abdomen in the air, the spider extrudes a short length of line often bearing on its end a tuft of silk. The merest breeze draws this line out into a long thin thread. Keeping tension on the airborne thread with its legs, the spider senses the instant it has landed and become securely anchored. Then, fixing a heavier thread to the starting point, it draws itself across the temporary bridge, rolling it up as it goes (and later eating it), paying out the heavier new line of the permanent bridge behind.

It might seem that the next step is to drop perpendicular lines at each end of the bridge, connect these and so start the web inside a rectangular frame. But this is not the spider's way. The typical orb-spinner builds its web outward from a triangular frame. Crawling back across the bridge the spider strings a second line; then it fixes a third line to the approximate center of the second and drops off into space, pulling the threads taut in the shape of a Y [*see illustration on page 120*]. At the fork of the Y the spider starts a fourth thread which it strings along one of the upper arms. It fixes a fifth thread to the midpoint of the fourth, crawls down to the fork and up the other arm, where it pulls the fifth thread taut. The fifth thread and a stretch of the fourth thus form a secondary bridge line which is to frame the top of the web; the fork of the Y is bi-



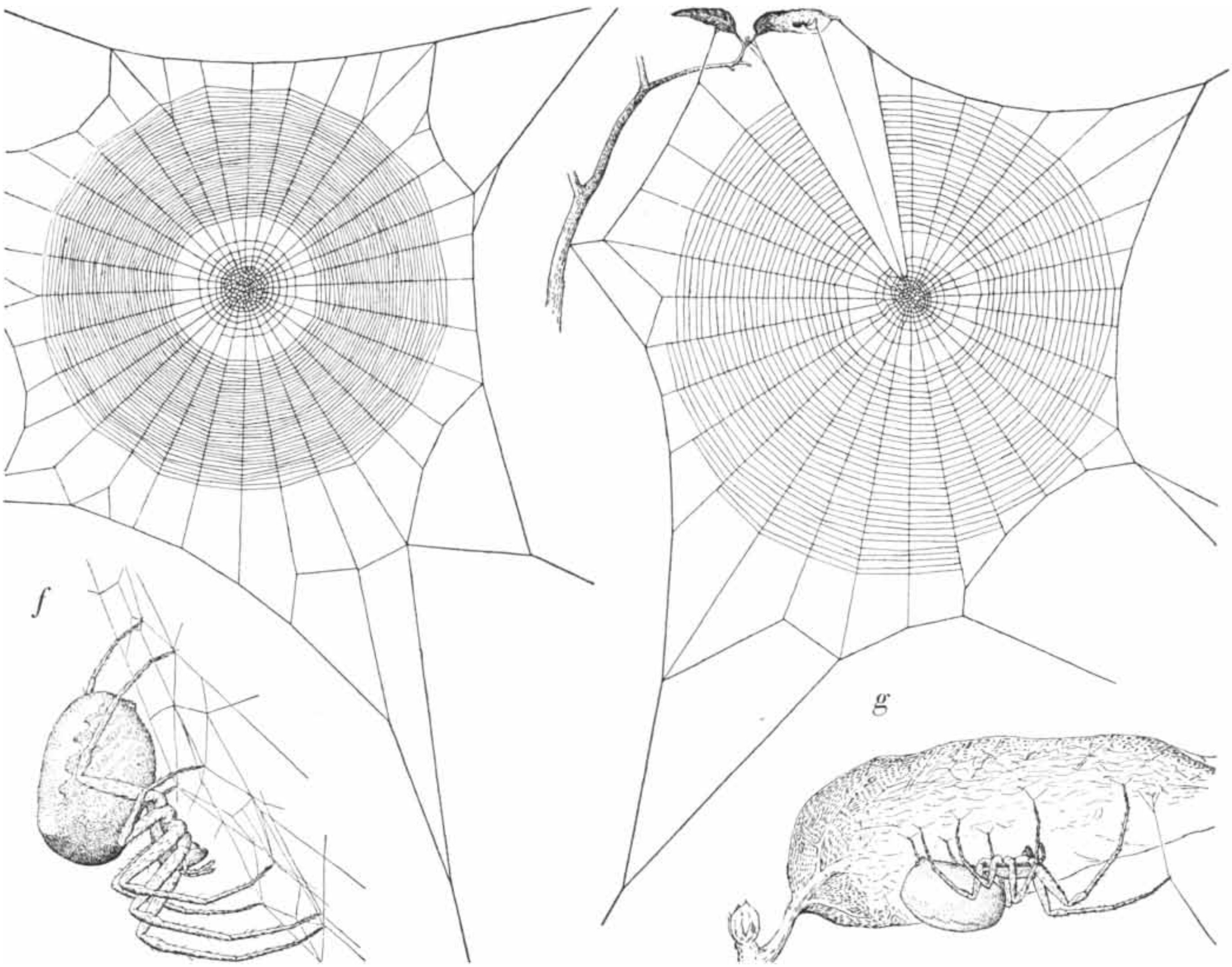
ments that simply impede the flight of insects. *Linyphia triangularis* (*d*) is representative of the first aerial spiders; they hang upside down in their sheet webs, which have stabilizing sub- and superstructures, and depend upon them entirely for food. *Steatoda borealis* (*e*) spins a web that is a variation of that spun by Linyphia; it eliminates the sheet but retains the supporting structure, the ground lines of which it coats with viscid globules, a feature shared by the various orb webs (*see illustration on next two pages*).

sected by the remaining stretch of the fourth line, which forms one of the radii of the web. In the two outside angles formed by the stem and arms of the Y the spider repeats this process.

If this were all, the basic design of the web would remain triangular. But chance contact with points of vantage in the surrounding area furnishes other anchorages for the attachment of radii to the center point, and the frame of the web assumes a polygonal form. With the radii in place, the spider goes to the center of the web and weaves a temporary spiral scaffolding four or five turns outward from the hub.

Until this moment the spider has moved spasmodically and rapidly; now its movements become slow and deliberate. It works inward from the circumference of the web, rolling up the scaffold spiral and laying what is to be the snaring thread in an almost perfect logarithmic spiral. This thread is coated with a viscid, sticky substance by the action of auxiliary spinnerets. As the spider fastens the ensnaring spiral to the radii, it stretches each length of the thread with its legs, drawing it taut and breaking the viscid coating into equally spaced drops. Then, leaving a space within the innermost turn of the viscid spiral, it weaves a small spiral in the center of the web, eats the rolled-up scaffolding and sometimes chews away the crossed radii at the center to create a little empty circle.

To some extent the spider's motion seems dictated by the growing web, which may be considered as a gradually developing field of force. The varying tensions of long and short segments, the distances between intersections, the lengths of filaments and the angles between them—each furnish stimuli to which the instinctively driven spider is compulsorily obedient. For example, when a spider steps upon a slack radius, it often turns about and circles in the opposite direction. If a spiral segment

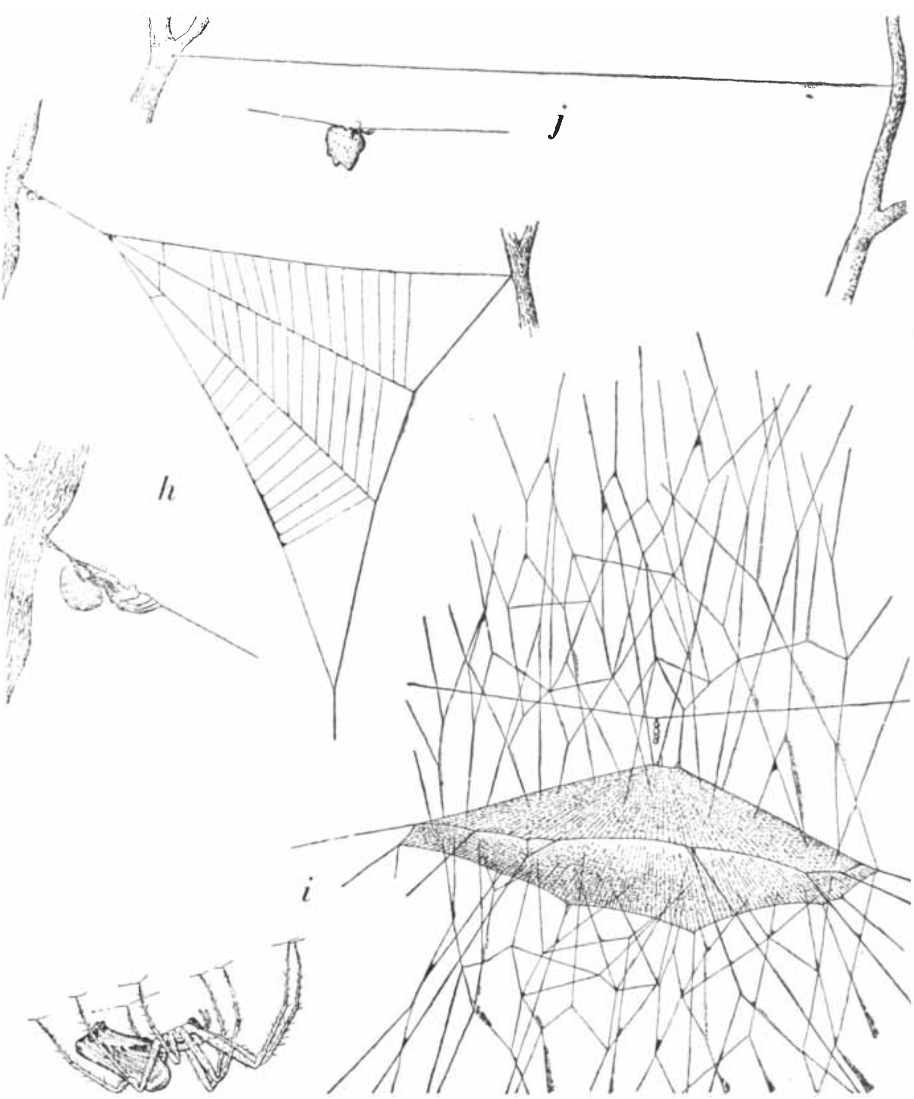


THE ORB WEB spun by *Araneus diadematus* (*f*) is a second and alternative development from the web spun by *Linyphia triangularis,* shown on the preceding page at *d*. More economical of silk and less demanding of effort, the web hangs in open spaces where its effectiveness is enhanced. *Zygiella x-notata* (*g*) leaves a bare radius that extends to its hiding place and transmits to it the flutterings of trapped insects. Hyptiotes (*h*) spins a variation of the orb web: it holds one end of the bridge thread (*see small drawing*),

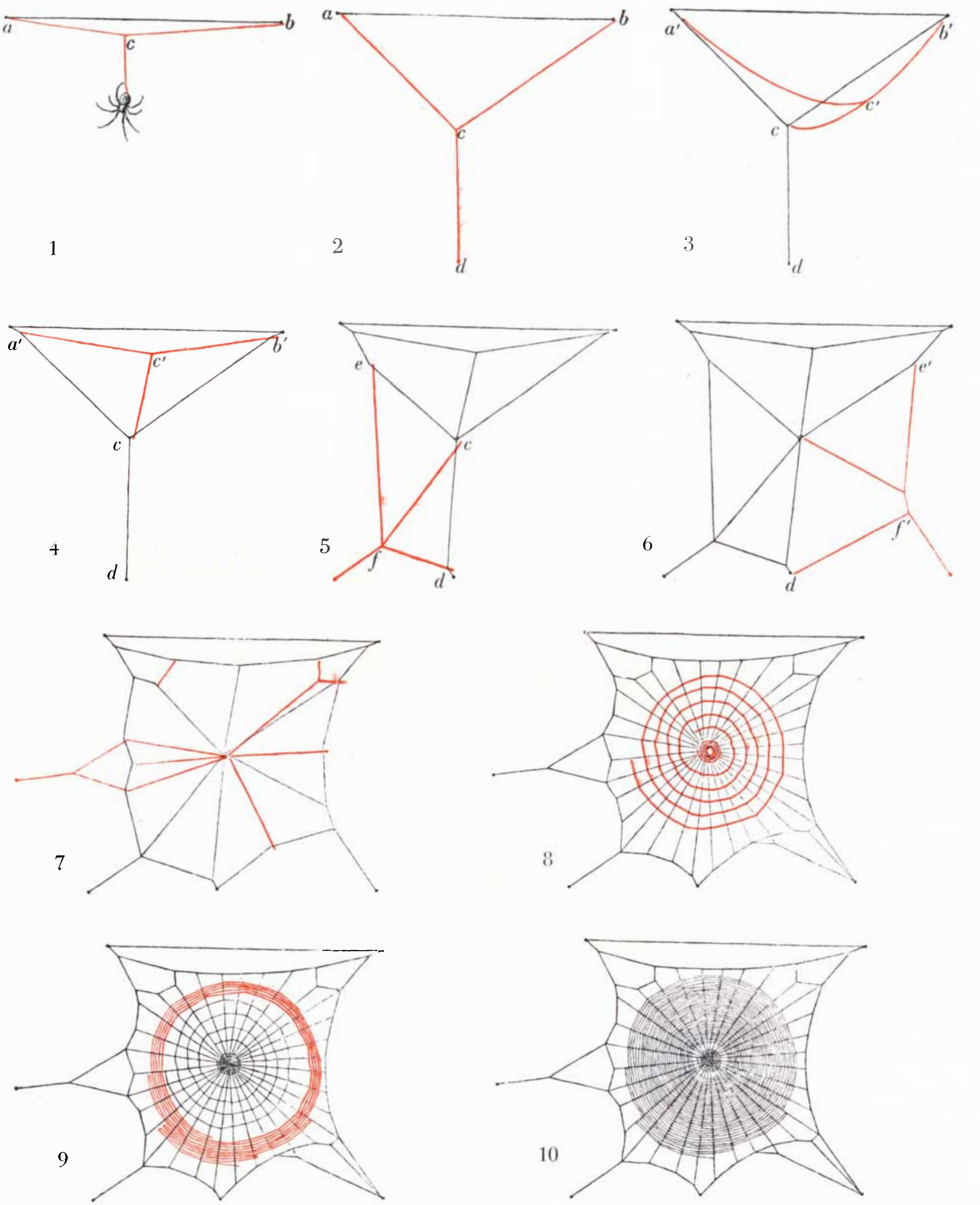
between radii is removed, the spider will stop on its next trip around and palp the lines until it locates the intersection of the nearest intact spiral and will then lay the thread accordingly.

It is no surprise to find an over-all similarity in the webs spun by various species belonging to the same family. If within the limits of a family there is a similarity of spinnerets and legs, there is likely to be a similarity in the results when these organs cooperate in the making of a web. Indeed, there is no reason for expecting anything else. The spider has to spin the kind of web that its limbs dictate; it cannot, for example, put the spiral threads farther apart than they always are, any more than a soldier of ordinary stature can march with paces four feet long.

The inherited nature of the spinning behavior is highlighted by an observation made in 1938 by E. Petrusewiczowa of Poland. She discovered that if common cross-spiders were hatched in small boxes and kept there until they were partly grown, and then were transferred to large cages, they were immediately able to spin perfect webs. In other words, they did not begin their careers by spinning primitive webs or webs of a type from which the full-blown orb web might later evolve. The fact that during their "childhood" they had been



which it relaxes when an insect strikes the web, thus more deeply enmeshing it. *Ulesanis quadratum* (*j*) spins an innocuous-looking single strand upon which many insects unwarily light. *Allepeira lemnistica* (*i*) combines in its web features of both the orb and hammock webs. Safely isolated, a sac containing the eggs of its young dangles over apex of its canopy.



RITUAL OF CONSTRUCTION of a typical orb web follows the establishment of a bridge thread (*ab*). The spider lays a loose thread (*colored line*) coterminous with the bridge, then fastens at *c* a second loose thread (1) which it descends and pulls taut (2), thus establishing *acb*. By a similar procedure (3 *and* 4), it establishes a second bridge (*a′c′b′*) and *cc′*, a radius extension of *cd*; it also spins the frame threads *efd* (5) and *e′f′d* (6). Erection of the remaining radii (7) is followed by the spinning of a temporary scaffolding (8). The spider then lays its viscid spiral (9), rolling up the scaffolding as it goes. Finally it completes the hub (10).

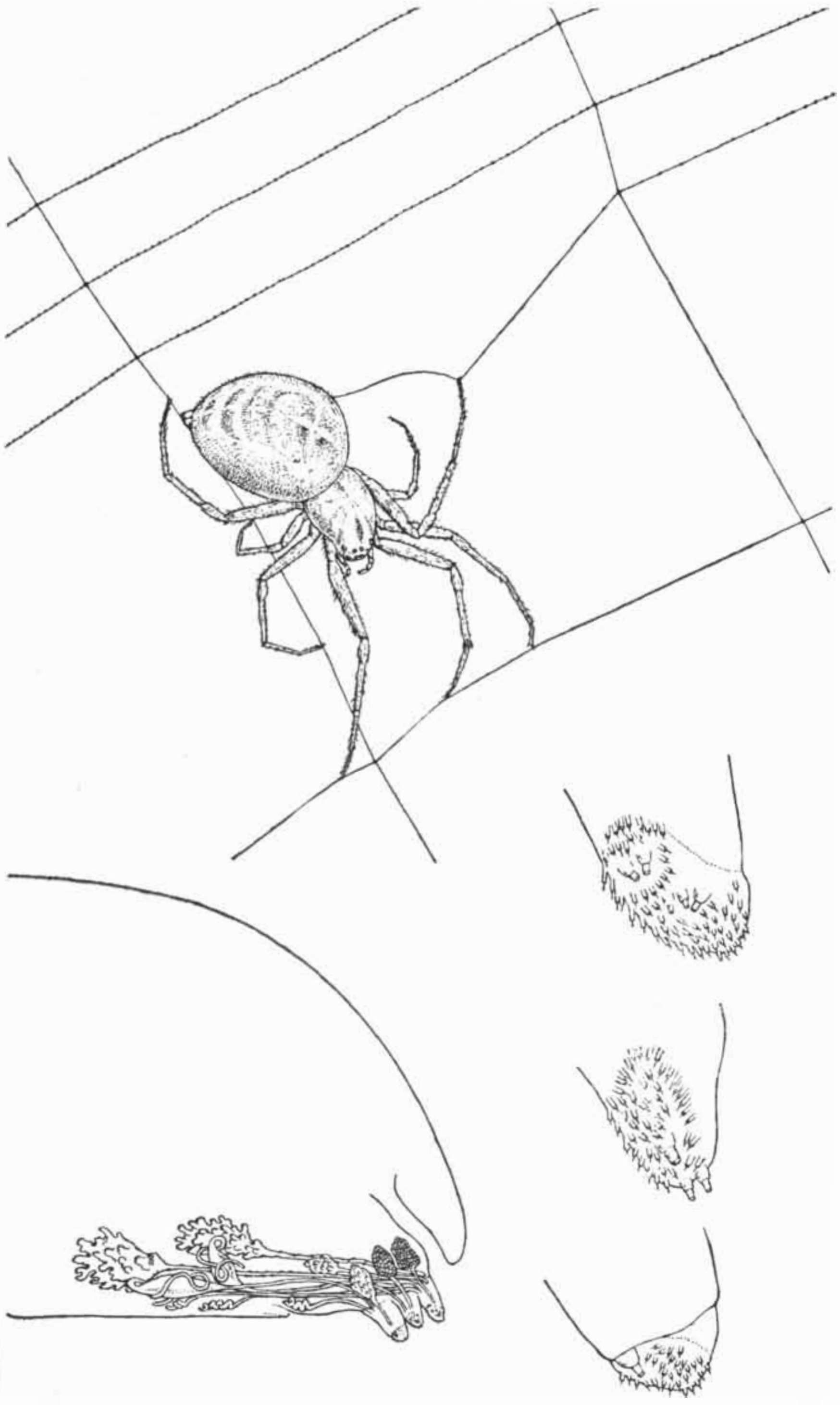
fed by their keeper without any need for spinning had not affected their abilities. At the time of their liberation from the egg membrane, spiders can neither feed nor spin. But after their first molt they can do both of these things. If they belong to a web-spinning family, they can from the first make webs that are in all essentials just like the webs of their elders, though the webs may be smaller. A baby cross-spider may make a web that has a diameter of an inch or so; its mother's web was perhaps six or seven inches in diameter, but was fundamentally the same structure.

A good deal of attention has been given to the webs spun by young members of the orb-spinning species, and often differences in the number of radii or the number of turns of the spiral thread have been remarked upon. But these differences are not basic distinctions: they are differences in degree, not in kind. Variations in the number of radii are always to be found in webs of the same species; in part this variation seems to be fortuitous, in part it is a consequence of age. For example, observation has shown that between June and September the average number of radii in the webs of the cross spider falls from 36.6 to 28.8, while in the webs of the species *Argiope bruennichi* the number of radii increases from 22 to 29 during the spider's lifetime.

Whatever the nature of the inherited plan, webs are often asymmetrical. There is little doubt that this is the result of the more or less fortuitous placing of the first few threads. In other words, the precise shape of any individual web is in part the consequence of the effects of its immediate surroundings on the spinner. This fact is perhaps better shown by house spiders than by orb-spinners. If the small spider *Tegenaria domestica* is kept in a circular glass dish, it makes a normal web, with the characteristic horizontal thread stretching outward from the top of its tube. If *Tegenaria atrica*, a larger species of the same genus, is put into such a dish, it finds itself relatively confined and spins a circular track with a kind of hippodrome effect.

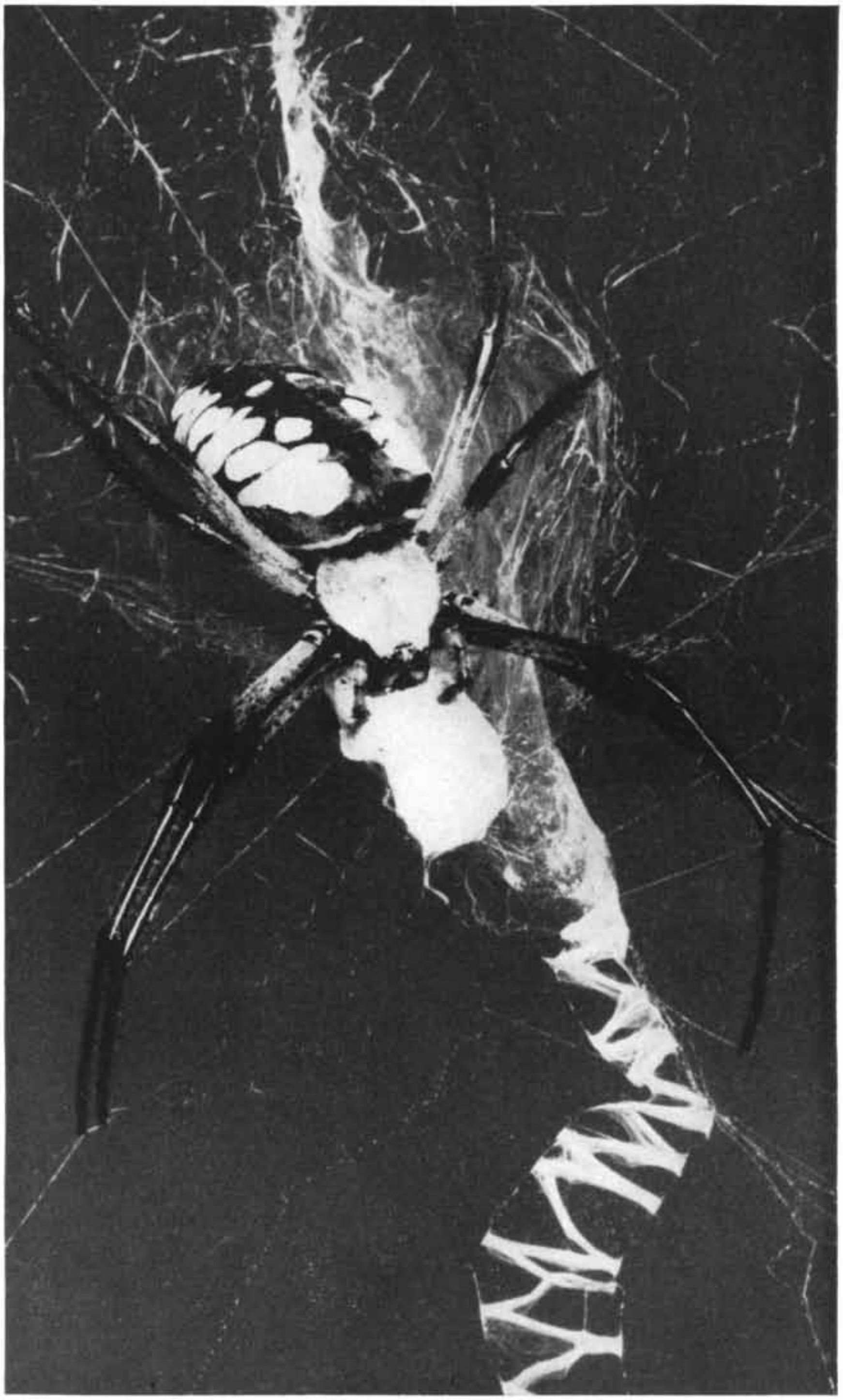
Such observations support the notion that migration into new environments brought into existence those types of web that are often called abnormal or, more accurately, surprising. Much the most familiar of these is that modification of the orb web spun by all members of the genus Zygiella, in which one radius is bare of the spiral thread. The origin of these designs is obscure, and one can only suggest that they have arisen from a combination of anatomical variation in the spider and a change in the circumstances in which it came to live.

Descriptions of other surprising webs still appear from time to time in the writings of those who are fortunate enough to observe the spiders of remote regions. There is, for example, the extraordinary web of the American spider Allepeira, described by Harriet Exline in 1948, which seems to combine the features of an orb web and a hammock web. More remarkable because of its simplicity is the web of *Ulesanis quadratum*, found in New Zealand in 1955 by B. J. Marples. It consists of a single



SILK-PRODUCING MECHANISM of spiders includes the silk glands (*bottom left*), located in the spider's abdomen, which feed liquid silk into the spinnerets, three of which are shown in this longitudinal section. The spinnerets themselves (*bottom right*) carry spigots of various sizes through which the silk issues. The drawing at the top shows how the spider uses its hind legs to draw silk from its spinnerets and place it on the web.

horizontal thread bearing viscid globules so large that they can be seen by the unaided eye. The tiny spider sits on a twig, holding the thread in a raised foreleg. If an insect touches the thread, the spider relaxes, entangling the victim in the slack; the spider thereupon darts forward, rolling up the thread as it goes and laying another behind it. It seems a remarkable way to secure a meal, but one that serves admirably to emphasize the conclusion that the web has played an extraordinarily successful part in the life of spiders. The spider's web is still as full of surprises as it is of problems, and it is a long way from being completely understood by its human observers.



GOLDEN GARDEN SPIDER, *Argiope aurantia*, eats an insect it has subdued by enshrouding it in a silken cocoon. The zigzag structure, formed by a broad ribbon of silk, is called the stabilimentum; it stabilizes the web and, by repeating the pattern on the spider's back, camouflages it when it lies at the center of the web where the stabilimenta cross.

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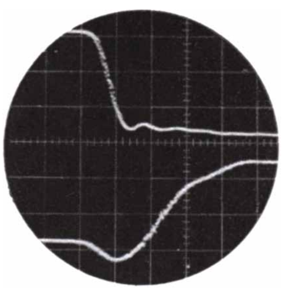

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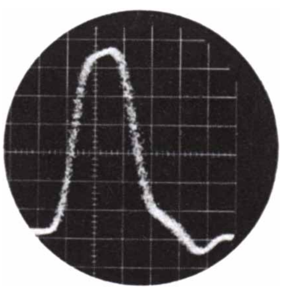

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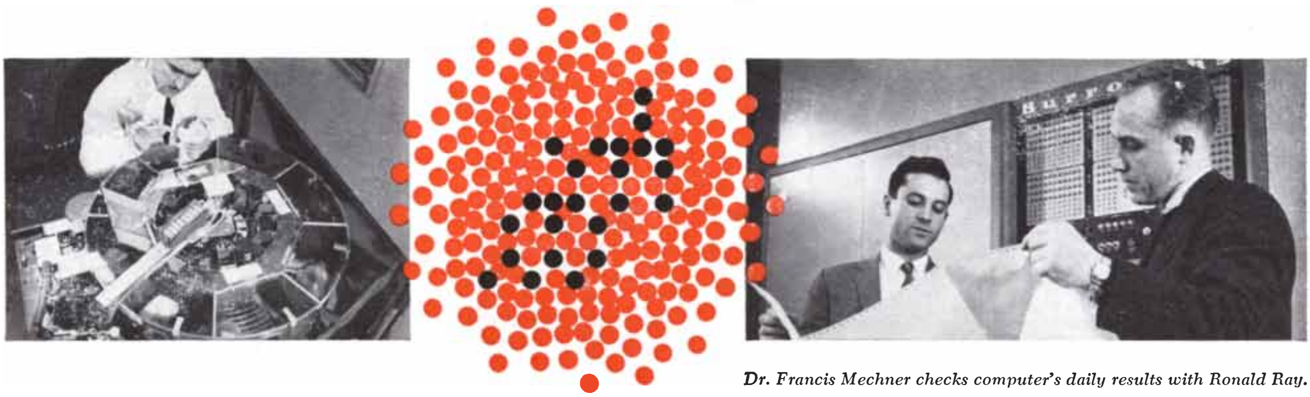

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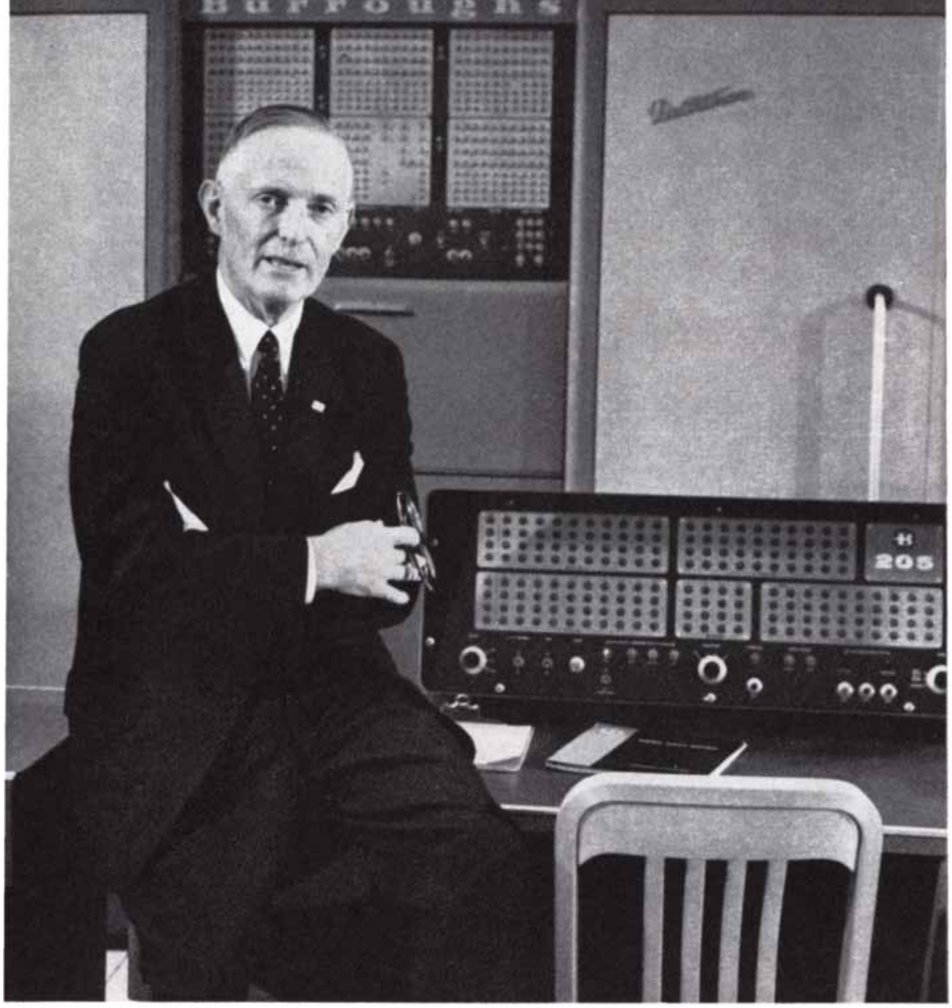

Dr. Bradley Whitman, Director of Research Services, confers with Gordon B. Thomas, Biometrics Manager.

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DELAYED HYPERSENSITIVITY

This type of allergy has been identified as the cause of rash in poison ivy, pains in rheumatoid arthritis, lung cavitation in tuberculosis and nerve degeneration in multiple sclerosis

by Alfred J. Crowle

For some people poison ivy seems to have no poison. While other campers and gardeners must be wary of the paths that they tread and the leaves that they touch, such a person is able to uproot the plant with his bare hands and to suffer no harmful consequences. But the leaves may be touched once too often, and one day, following a brush with poison ivy, that person finds himself afflicted with the skin rash and blisters that make almost everyone else avoid the plant.

Like hay fever, the reaction to poison ivy is an allergy. Just as most people have a hereditary resistance to developing hay fever, so a few people can handle poison ivy with impunity. In either case, however, this impunity may be overwhelmed by repeated exposure to the allergen that proved so innocuous on first exposure. But the hypersensitive reaction that troubles the sufferer from hay fever follows quickly upon his exposure to ragweed or other irritating pollen. The reaction to poison ivy, in contrast, takes more time to develop. Poison-ivy attacks thus are identified with a little-understood group of allergies characterized as "delayed hypersensitivities."

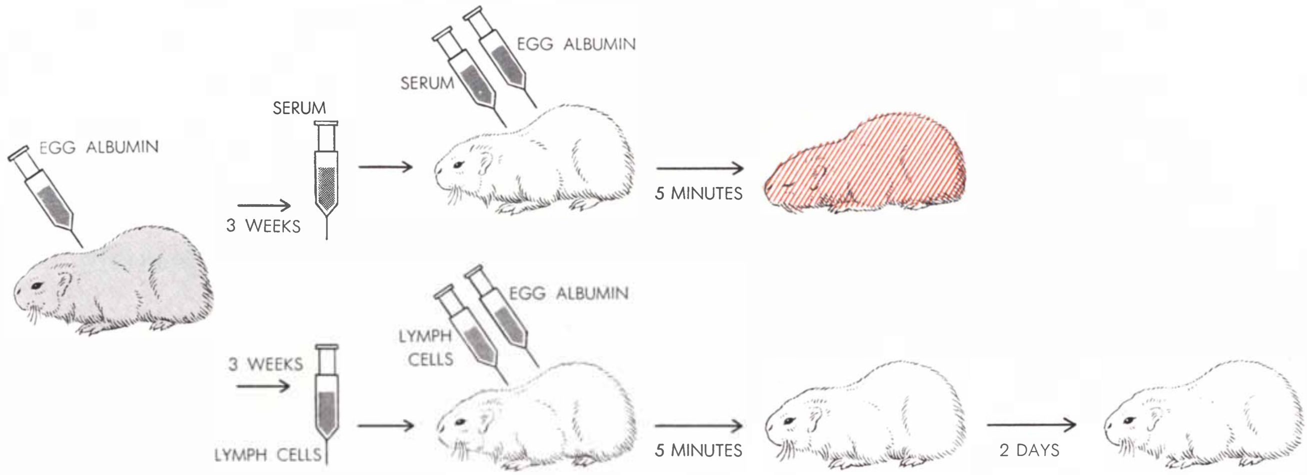
This simple distinction early divided allergic reactions into two main classes. But the underlying reason for the immediacy of the one reaction and the delay of the other was obscured until recently because it was often difficult to provoke delayed hypersensitivity in experimental animals. Techniques developed for this purpose now have begun to expose the mechanisms of delayed hypersensitivity. This understanding in turn has implicated this type of allergy in a wide range of medical problems aside from straightforward allergic conditions: the cavitation of lung tissue in tuberculosis, the rejection of grafted tissue in surgery, the degeneration of nerves in multiple sclerosis, and the stiffening and swelling of joints in rheumatoid arthritis.

The allergic reaction is itself an expression of the body's biochemical integrity. The body reacts to most foreign materials of an organic nature by manufacturing special substances called antibodies. These combine with the foreign material, or antigen, ordinarily without harmful (and often with helpful) results. By this means, for example, the body generates immunity to infectious disease. In allergic reactions, however, the interaction of antigen and antibody does harm to body tissues. For this reason allergies often have been called immunological mistakes. Indeed, such a "mistake" often attends the development of immunity to disease organisms, though there it turns out to be useful. Skin tests based on the allergic reaction are employed by physicians to diagnose diseases such as tuberculosis and undulant fever or to measure the effectiveness of immunization to tuberculosis and smallpox. Epidemiologists sometimes use these tests to trace the spread of an infection in a human population.

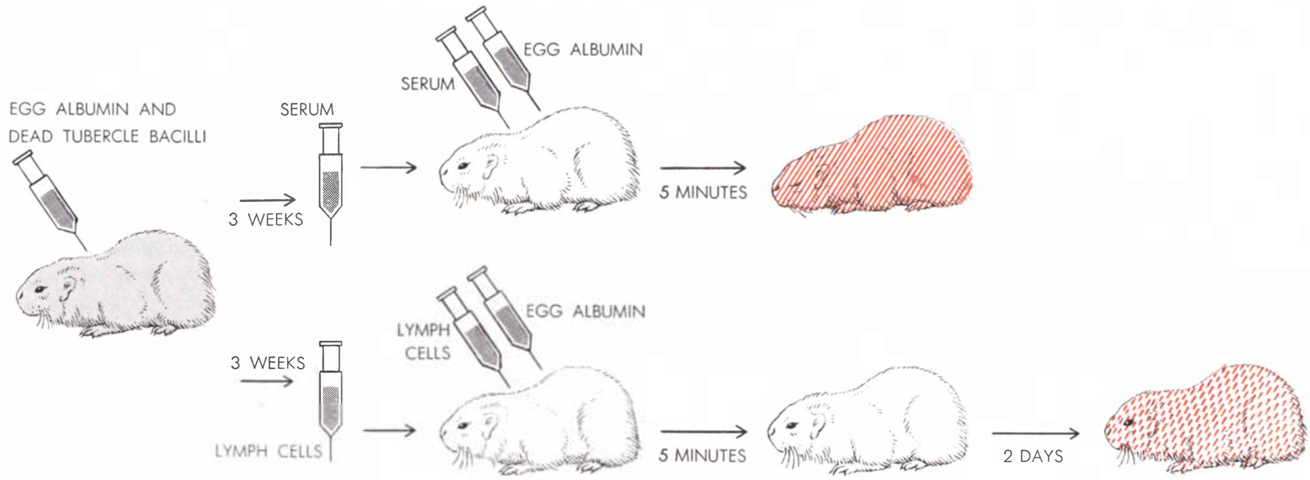
The skin is a sensitive indicator of allergies. In animals hypersensitized to a substance the skin test generally indicates whether the allergy is of the immediate or of the delayed type. The reaction typical of immediate hypersensitivity causes the test area to become hot, red and softly swollen within a few seconds or minutes after the injection. A short while later the skin returns to a normal condition. The skin reaction of delayed hypersensitivity, on the other hand, takes several hours to appear; the affected skin also becomes red and warm, but the swelling this time is firm. The reaction lasts for several days and may kill part of the tissue involved. Of course the differences between immediate and delayed reactions in skin tests are not always clear-cut. For example, a strong immediate hypersensitivity may cause so much local tissue-damage that it appears to be a mixture of immediate and delayed reactions and can be identified only by microscopic examination.

Animal experiments, however, have provided a more significant distinction between the two types of allergy. If blood serum from animals having an allergy of the immediate type is transferred to another animal, the recipient will become temporarily sensitive to the same allergen, and will respond to the skin test with a reaction of the immediate type. This indicates that the antibodies involved in immediate hypersensitivity circulate in the blood serum. In fact, it is possible to isolate these antibodies by precipitating them from the serum in reaction with the antigen that induced their formation. Many of these antibodies have thus been purified and their chemical and physical characteristics described. But the transfer of serum from one animal to another will not carry over delayed hypersensitivity; the antibodies involved in this kind of allergy ordinarily do not circulate in the serum. Delayed hypersensitivity may, however, be passed from an allergic to a normal animal by the injection of cells from the lymphatic system, of related cells from other tissues (reticuloendothelial cells) and of white blood cells. Immediate hypersensitivity is never conveyed passively by such cells.

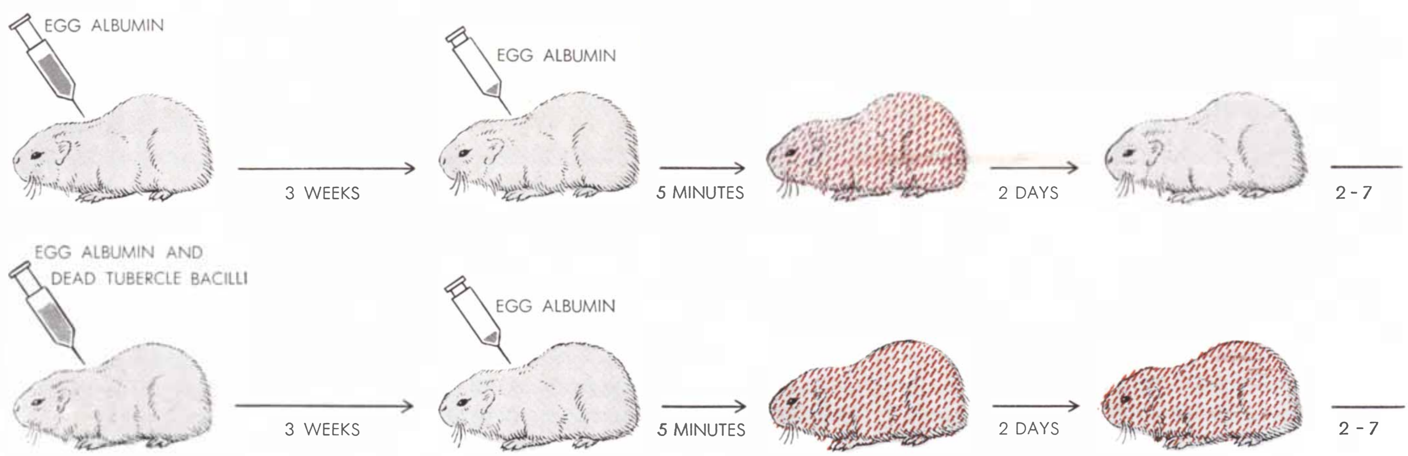
Thus it has become clear that the two types of allergy depend upon two basically different kinds of antibody. One kind circulates freely in the serum; the other is closely bound to living cells. With few exceptions the antibodies of



IMMEDIATE HYPERSENSITIVITY is induced by injecting a guinea pig with the antigen egg albumin (*left*). Serum from this animal can transfer the induced allergy to a second animal (*top row at right*), but lymph cells cannot (*bottom row*). After an injection of antigen, guinea pig given serum dies (*hatching*) from an immediate systemic reaction; the one given cells remains well.



DELAYED HYPERSENSITIVITY to egg albumin is induced along with the immediate type by injecting the antigen and a potentiator, here tubercle bacilli (*left*). Serum from the allergic animal transfers the immediate hypersensitivity to a second animal (*top row at right*); lymph cells transfer the delayed type (*bottom row*). After injection of antigen the animal given serum dies of an immediate systemic reaction; the one given lymph cells later sickens (*broken hatching*) from a delayed type of systemic reaction.



DESENSITIZATION is readily accomplished in immediate hypersensitivity but not in the delayed type. A guinea pig with an immediate hypersensitivity (*top*) is given a small dose of antigen; it becomes sick (*broken hatching*) from an immediate systemic reaction but recovers. The animal then does not react to the antigen. A guinea pig having both immediate and delayed hypersensitivity delayed hypersensitivity lose their activity unless the cells are kept alive and intact. By the same token it has not yet been possible to isolate and identify these antibodies.

For a long time investigators thought that the antigens that induce many kinds of delayed hypersensitivity must be bound equally closely to the living processes of allergenic microorganisms. Infection with certain bacteria will induce both immediate and delayed hypersensitivity in experimental animals. An allergy of the immediate type also can be brought on by extracts of the microorganisms, or indeed by injection of such ordinarily innocuous substances as chicken egg albumin. In early experiments delayed hypersensitivity could be induced only by the living microorganism, so it was often called "infectious allergy." A few years ago, however, various workers found that protein-bearing extracts of killed microorganisms could provoke delayed hypersensitivity if they were injected along with certain lipoidal (fatlike) fractions of these bacteria. Pursuing this lead, they since have succeeded in inducing delayed hypersensitivity to egg albumin and other nonmicrobial proteins by injecting them together with the same type of lipoidal material extracted from bacteria, or simply with the whole killed bacteria.

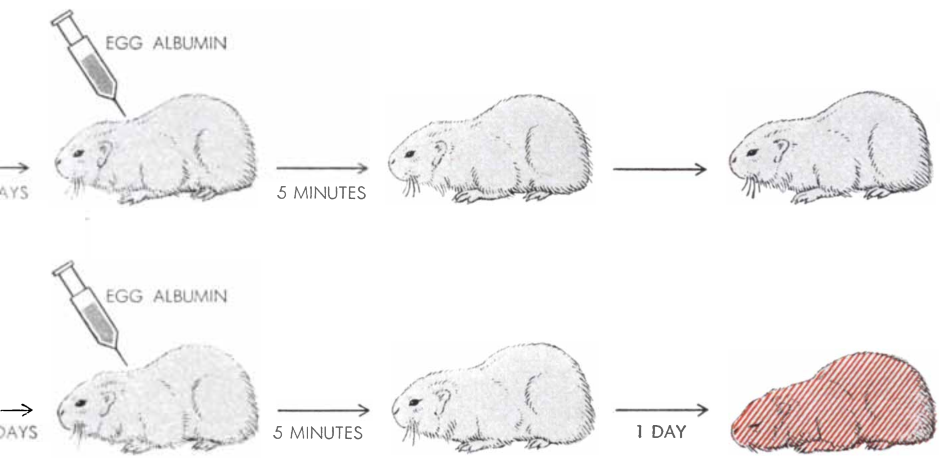
The role of the lipoidal material is not clear. It may serve to modify the physical nature of the antigen, it may make the responsive cells of the injected animal more reactive to the antigen or it may direct the cells into a new and different response. Some experimenters suggest that lipids in the skin of an affected animal may themselves play the same role in potentiating allergy. It is significant in this connection, incidentally, that the oily poison-ivy allergen, or industrial chemicals that cause the same kind of allergy, hypersensitize an animal only if they are rubbed on the skin.

Since fatty materials are not soluble in water, the antigen and the potentiating agent must be dispersed in an emulsion of water in oil to keep them together in the animal after the injection. Not long ago A. M. Pappenheimer, Jr., of the Harvard Medical School succeeded in inducing delayed hypersensitivity by injecting very minute quantities of protein antigens alone, but the allergy induced seems to differ in some respects from the classic type.

With the means to induce delayed hypersensitivity in experimental animals almost at will, investigators have begun to distinguish its mechanisms more clearly from those of immediate hypersensitivity. One of the most striking characteristics of immediate hypersensitivity is the systemic reaction called anaphylactic shock, which follows rapidly upon injection of a relatively large dose of antigen into the bloodstream. A guinea pig that has been sensitized to egg albumin reacts violently to an amount that would be harmless to the normal animal; it goes into violent convulsions, and moments later it dies of suffocation. The animal also may be readily desensitized to an antigen to which it has immediate hypersensitivity. This is accomplished by injecting a smaller dose of antigen, enough to give the animal a severe but not fatal seizure. Upon recovery it will show no reaction at all to any subsequent injection of egg albumin made during the next few hours or days. An injection of many times the quantity of egg albumin that would have killed the guinea pig before now causes it not the least discomfort.

In an animal in which a delayed hypersensitivity has been provoked the reaction to a heavy injection of the antigen follows a different course. Because the sensitizing technique usually induces immediate as well as delayed hypersensitivity, such an animal may be killed by anaphylactic shock. But if it does recover, it will behave normally for only a few hours. Then its fur begins to ruffle; it breathes uneasily, closes its eyes and crouches apparently senseless to its surroundings. Its body temperature drops and it slowly sinks into a coma to die two or three days later, killed by its delayed hypersensitivity. If the challenging dose of antigen is sufficiently reduced, the animal may recover. But it has not thereby become particularly desensitized to the antigen, for a subsequent injection again will induce the delayed type of systemic reaction, almost as strongly as before.

Although the interpretation of these experimental findings still is controversial, the principal mechanism of delayed hypersensitivity is now discernible. The allergy antibodies are manufactured by some of the body's lymphoid cells when they are confronted with an antigen in a certain form and under specific conditions. These antibodies apparently remain within or on the cells and react specifically with the antigen upon future contact. Probably these antibodies accumulate in large numbers; relatively few lymphoid cells containing them can transfer delayed hypersensitivity from one animal to another. Because delayed hypersensitivity, once actively induced, lasts far longer than the life of any single hypersensitized

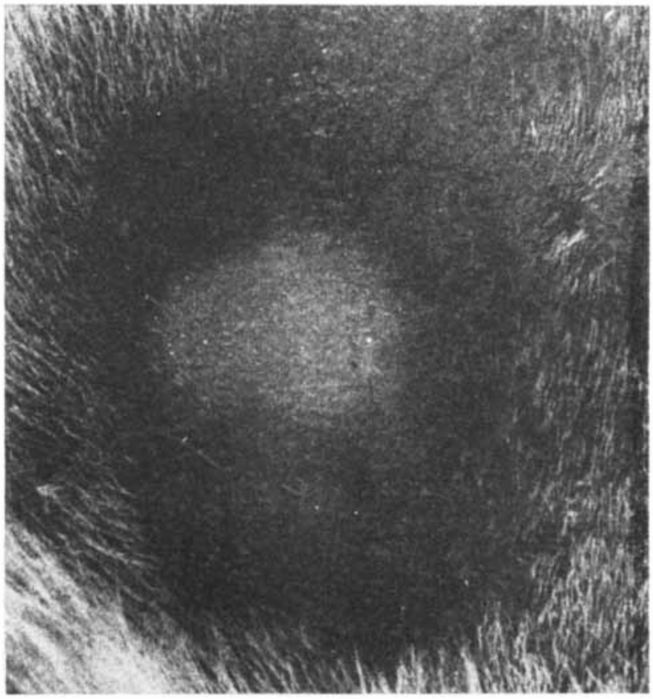


(*bottom row*), on similar treatment, gets nonfatal attacks of both immediate and delayed systemic reactions (*third and fourth steps*). But after the guinea pig recovers, a large dose of the antigen again causes a delayed systemic reaction; the animal then dies (*last step*).

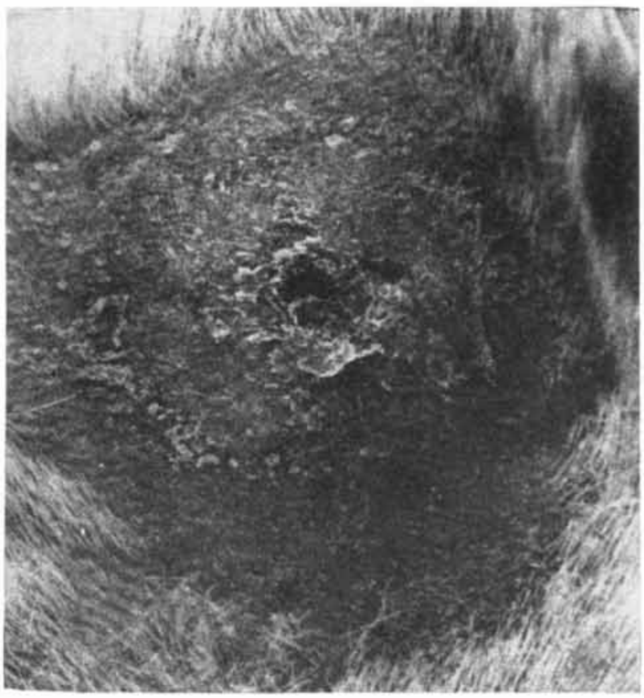
cell, the new cells that replace these either must be freshly sensitized by traces of antigen remaining in the body for a long time, or must inherit the ability to make antibodies through the genetic material of their hypersensitized progenitors. Or the cells may, in some still unknown nonhereditary way, "learn" the art of manufacturing these antibodies from cells already able to do so.

In the delayed allergic reaction the hypersensitive cells seem to be the focus of primary destruction. As the antigen combines with some of the antibodies associated with these cells, it kills the cells. The damaged cells then apparently release uncombined antibodies. The antibodies may be ingested by white blood cells and related phagocytic cells attracted to the site of irritation, and these in turn become hypersensitive and suscep-

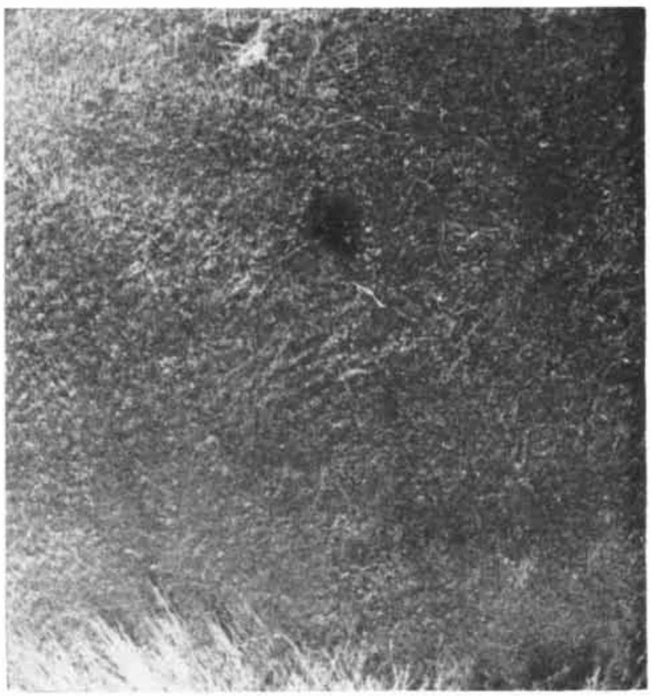
NORMAL MOUSE-SKIN is smooth, and the network of veins is visible through it. In this photograph and the others on this page of mouse-skin tests the areas are enlarged about seven diameters.



SKIN REACTION in immediate hypersensitivity to bovine serum albumin is shown after one and a half hours. Edema is visible as a blanching of the skin and interruption of the normal vein pattern.



CONTACT DERMITITIS, a form of delayed hypersensitivity, is manifested by a firm swelling (*blanched area*) and central necrosis (*dark scaly area*). This part of a hypersensitive mouse had been exposed to a drop of 2,4-dinitrochlorobenzene 48 hours earlier.



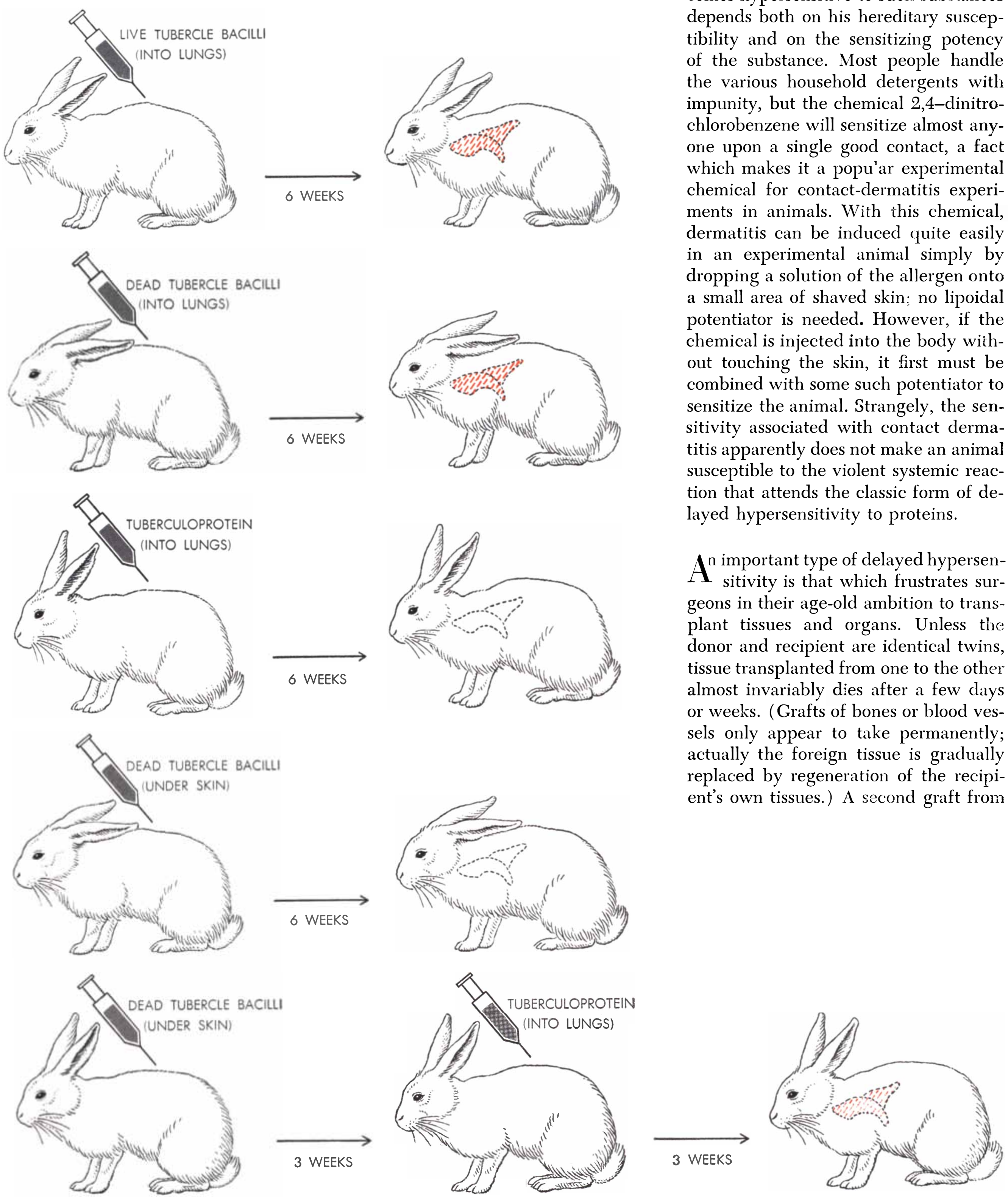
DELAYED SKIN-REACTION persists much longer than the immediate type. Ulceration (*dark spot*) and some swelling are still visible a week after the injection of tuberculoprotein, the antigen to which this mouse had developed a delayed hypersensitivity.

tible to destruction by antigen. This chain reaction evidently continues until antigen or antibody is exhausted. In breaking down, the injured cells release various substances that are toxic to other tissues, thus causing secondary damage that may be more harmful to the body than the primary damage. Secondary effects may account for the death of the skin in a skin test, or for the systemic shock that follows exposure to a large dose of antigen.

The cavities of tuberculosis appear to be formed by delayed-hypersensitivity reactions between protein constituents of the infecting tubercle bacilli and allergic tissue-cells of the lungs, with the secondary toxic products of these reactions causing the destruction of the lung cells. Thus if proteins of tubercle bacilli are injected directly into the lungs of a normal rabbit (in water-oil emulsion to prevent their spread from the site of injection), they cause no cavities to form. But if they are so injected into a rabbit previously hypersensitized by an injection of whole tubercle bacilli elsewhere in the body, they regularly produce cavities. Even a rabbit with delayed hypersensitivity to egg albumin can develop turbercular-like lung cavities if egg albumin is subsequently injected into its lungs.

In many diseases that are chronic enough for delayed hypersensitivity to develop strongly while the body still harbors large or moderate quantities of the infecting agent, it seems likely that gross tissue destruction characteristic of some of them may be traced to the allergic reaction. Recovery from various illnesses caused by bacteria, yeasts, molds and the like thus may depend on how hypersensitive the patient has become to the constituents of the disease germs and on how badly his tissues are injured in allergic reactions with them. Not a little of the itching and sometimes burning irritation of athlete's-foot infection may be due to delayed hypersensitivity to the disease organisms.

Of perhaps less consequence than these manifestations of delayed hypersensitivity is the troublesome and familiar contact dermatitis. This is the itching rash of allergic origin, which can result from repeated exposure of the skin to various nonprotein substances, from the oily constituent of poison-ivy leaves to detergents and industrial chemicals. The substances that cause contact dermatitis seem to have little in common save that they usually combine readily with body proteins; the significance of this tentative finding is not yet completely understood. How readily an individual be-



comes hypersensitive to such substances depends both on his hereditary susceptibility and on the sensitizing potency of the substance. Most people handle the various household detergents with impunity, but the chemical 2,4–dinitrochlorobenzene will sensitize almost anyone upon a single good contact, a fact which makes it a popu'ar experimental chemical for contact-dermatitis experiments in animals. With this chemical, dermatitis can be induced quite easily in an experimental animal simply by dropping a solution of the allergen onto a small area of shaved skin; no lipoidal potentiator is needed. However, if the chemical is injected into the body without touching the skin, it first must be combined with some such potentiator to sensitize the animal. Strangely, the sensitivity associated with contact dermatitis apparently does not make an animal susceptible to the violent systemic reaction that attends the classic form of delayed hypersensitivity to proteins.

An important type of delayed hypersensitivity is that which frustrates surgeons in their age-old ambition to transplant tissues and organs. Unless the donor and recipient are identical twins, tissue transplanted from one to the other almost invariably dies after a few days or weeks. (Grafts of bones or blood vessels only appear to take permanently; actually the foreign tissue is gradually replaced by regeneration of the recipient's own tissues.) A second graft from

LUNG CAVITIES typical of tuberculosis result from delayed hypersensitivity to the protein fraction of tubercle bacilli. The injection of live tubercle bacilli (*top row*) or of whole killed ones (*second row*) directly into the lungs of a rabbit produces lung cavities (*broken hatching*). Killed bacilli injected under the skin do not induce cavities (*fourth row*) because there is then no protein antigen in the lungs. On the other hand, neither does tuberculoprotein, the actual antigen in this case, produce cavities when injected alone into the lungs (*third row*). If the animal has already developed a delayed hypersensitivity to tuberculoprotein as from the injection of whole bacilli under the skin (*fifth row*), cavities develop in the lungs in the area around the injected antigen.

the same donor is rejected more rapidly than the first. Although immediate hypersensitivity cannot yet be entirely excluded, it appears to have little if any significance in the homograft reaction, as this allergic annihilation of transplanted tissue is called. Often no antibodies appear in the blood serum, and the injection of serum from an animal that has rejected a graft does not cause another animal to reject a graft from the same donor any more speedily. On the other hand, the transfer of lymphoid cells makes the recipient animal reject a graft just as quickly as it would if it were sensitized by prior direct exposure to the donor tissue. Both the animal that has rejected a graft and the animal that has received lymphoid cells will show a skin reaction of the delayed type following intracutaneous injection of cells taken from the donor of the graft. Homograft hypersensitivity differs from classic delayed hypersensitivity, however, in that it can be transferred only with lymphoid tissue cells and not with the white blood cells.

Investigation of the homograft reaction has developed an interesting finding that may have wider implications. Extracts of the material from nuclei of the cells of one animal will provoke the hypersensitivity in another animal as effectively as the intact cells themselves. Yet it is not the nuclear material but material from the cytoplasm (that part of the cell which surrounds the nucleus) that enters into the allergic reaction. This cytoplasmic material, on the other hand, does not induce hypersensitivity. The nuclear substance of animal cells presumably directs their synthesis of cytoplasmic proteins; perhaps when it is transferred to another animal it is ingested by that animal's antibody-making cells, enters their nuclei relatively unchanged and directly induces them to begin making antibodies against the cytoplasmic antigens of cells from which it was originally extracted. Thus the animal would become hypersensitive to cytoplasmic material by having been injected with nuclear material. If this idea is verified, it will have considerable bearing upon our understanding of the fundamental mechanisms of antibody formation.

The homograft reaction reflects the capacity of the body, through its immunological system, to "recognize" its own tissues. This capacity apparently develops shortly before or after birth. Mice of one strain become tolerant to tissues from an unrelated strain if they receive injections of cells of the second type before birth, when their immuno-

His Problem:

To boost steel output, improve operators' outlook, with advanced automatic controls

Name of this scientific American:

George Grosvenor,
The Colorado Fuel and Iron Corporation

■ "We find that the further we travel along the road to automatic open hearth operation, the more important becomes the human element." So says George Grosvenor, Superintendent of Steel Production of The Pueblo Plant, Colorado Fuel and Iron Corporation. His comment is of particular interest to management men looking for better production via advanced controls because Grosvenor's well-instrumented open hearth No. 17 is one of the nation's top producers in terms of tons per hour per 1000 square feet of hearth area.

While Grosvenor's emphasis on the human element in automatic operation seems paradoxical at first glance, it makes sense in light of CF&I experience. Ten years ago, the company set out to improve open hearth efficiency using new, automatic controls. CF&I realized, however, that unless operators' skills and interests were considered, results could be less than successful—as indeed they had been previously in many industries where workers saw new controls as a threat to their jobs. As a result, the CF&I program had, in effect, three major objectives:

A. To improve the technical aspects of open hearth operation in terms of output vs. total costs.

B. To improve the human aspects of open hearth operation by letting operators educate themselves to the usefulness and convenience of advanced controls.

C. To keep A and B in step at all times.

A first step in the program was installation of instruments which cleaned up a problem that had long bothered operators. Throwover instruments and components (used to reverse the action of fuel and air atomizers to the opposite end of the hearth) were different on all furnaces (then 16 in number) so that each time melters and first helpers moved from one furnace to the next, they were confronted with a different configuration of valves and levers. Instrument standardization on all furnaces not only cleared up this problem, but gave operators fewer and more consistent procedures—gave the maintenance crew a more compact piping arrangement.

Shortly afterward, high-pressure burners and fuel atomizers became available and were installed on all furnaces. Results were good in terms of output, but because each furnace was of a different design, installation of the new equipment was different in each case. Again, operators were justifiably confused.

This problem was another opportunity in disguise, for it led to redesign and relocation of combustion fluid control systems around new Leeds & Northrup automatic furnace reversal units. Again, the technical problem was solved in a way that helped operators. The new automatic reversals eliminated physical effort in reversing the furnace, and freed operators from the necessity of dropping other work as the time for reversal drew near.

Success of these relatively modest

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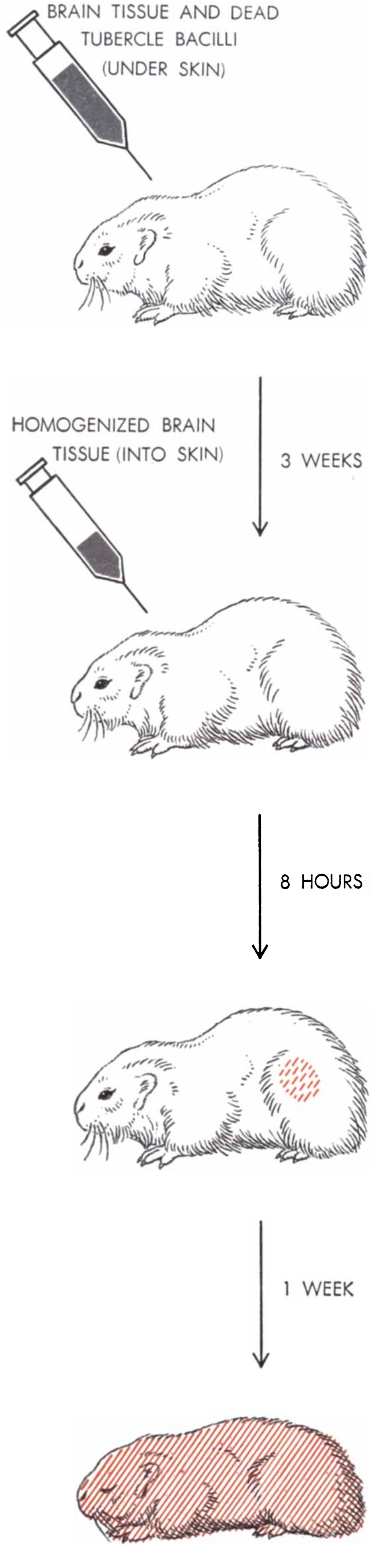
logical system is still immature. Induction of tolerance in infant human beings by this means is scarcely practical. However, recent experiments with kidney transplants indicate that tolerance can be provoked in adults if the immunological system is depressed by chemical or X-ray treatment before foreign tissue is introduced [see "The Transplantation of the Kidney," by John P. Merrill; Scientific American, October, 1959].

Under certain circumstances the body's self-recognition fails. It then develops hypersensitivity to one or another of its own tissues, with consequent injury and destruction to that tissue. Such autosensitization can be of either the immediate or the delayed type. It may be provoked by antigens liberated from the body's own tissue cells. In some instances these antigens may be so well "sheltered," by their usual residence within cells or organs, from the body's antibody-making system that they are genuinely foreign to this system. This seems to be true, for example, of nuclear substances, of physiologically isolated eye substances and of thyroid-gland proteins. On the other hand the tissues may be damaged in such a way as to alter their normal antigenic character by which the body's immunological system recognizes them. Sensitization may also be provoked by antigens of foreign tissues that are similar to but not identical with those of the tissues subsequently affected by the allergy: mammalian tissues upon which viruses for human vaccination are cultured might be a source of such antigens when they are injected inadvertently along with the virus suspension. Thus antibodies directed against antigens closely similar to normal cellular constituents of the body can cross-react with and injure the normal tissues. It is thought that rheumatoid arthritis develops when streptococci, which have a special affinity for joint tissue, remain in the joints long enough for antibodies against the combination of joint tissue and streptococci to form; these antibodies then cross-react with and damage normal joint tissue.

Some types of induced autosensitivity in experimental animals resemble certain diseases in human beings. One of these experimental diseases seems to be closely related to multiple sclerosis and similar degenerative nerve-tissue afflictions in man. In multiple sclerosis portions of the nervous system are destroyed, rendering useless the muscles controlled by those nerves. This grave disease may rapidly reduce someone in



NERVE DEGENERATION disease that mimics multiple sclerosis is produced experimentally by injecting a guinea pig with brain tissue from another guinea pig (*top*). A skin test with the same material (*second from top*) produces an inflammation (*hatched area*) typical of delayed hypersensitivity (*third from top*). The antibodies of the allergy evidently attack the animal's own nerve cells. The animal loses control of its muscles and finally dies (*bottom*).

the prime of life to a veritable vegetable.

The nearest experimental counterpart of this disease, called experimental allergic encephalomyelitis, or EAE, is provoked by injecting a guinea pig with a homogenate of another guinea pig's brain or of a portion of its own brain, along with tubercle bacilli (for the potentiating lipid that they contain) in water-in-oil emulsion. Two or three weeks later the animal begins to lose its ability to balance, and before long its hind legs, and sometimes all four of its legs, become useless hanging appendages. Sometimes slowly, sometimes rapidly, the animal wastes away and dies; occasionally it recovers. Other species can be made to develop the disease, but not always with equal facility.

In many instances antibodies to nerve tissue can be detected in the blood serum, but these antibodies (apparently indicative of an immediate hypersensitivity) are not present in all cases and sometimes show up in measurable quantities in animals that never develop the illness. If serum containing the antibodies is transferred from an afflicted animal to a healthy animal, the recipient is not harmed. If the circulatory systems of a normal and a hypersensitized animal are surgically connected, however, the disease is transmitted to the normal animal. This suggests that it is the white blood cells that carry the damaging antibodies, in accord with the established mechanism of delayed hypersensitivity. Moreover, the animal afflicted with EAE gives a delayed type of reaction to a skin test with nerve tissue.

The damage to nerve tissue in EAE is similar to that in multiple sclerosis. It also closely resembles that seen in the type of encephalomyelitis which sometimes follows vaccination with viruses grown in nerve tissue. If some of the animal nerve tissue is inadvertently injected along with the vaccine, the vaccinated person becomes sensitized to it and, as in EAE, his antibodies may then cross-react with and destroy his own nerve tissue. This has been a particular hazard of immunization against rabies, because the virus used in the vaccine is grown in rabbit spinal-cord or brain.

Unfortunately, despite intensive experimentation on EAE and similar diseases in many laboratories, no way has yet been found to help those people who develop delayed hypersensitivity to their own tissues. A tremendous amount of research still is required to achieve an understanding of, and eventually to control, the phenomenon of delayed hypersensitivity, but the rewards should be almost unimaginably great.

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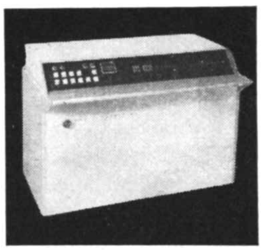

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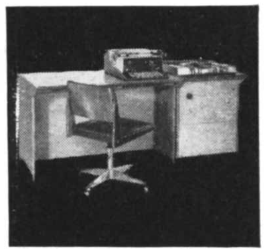

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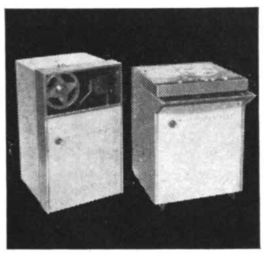

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ROYAL McBEE data processing division, Port Chester, N.Y.

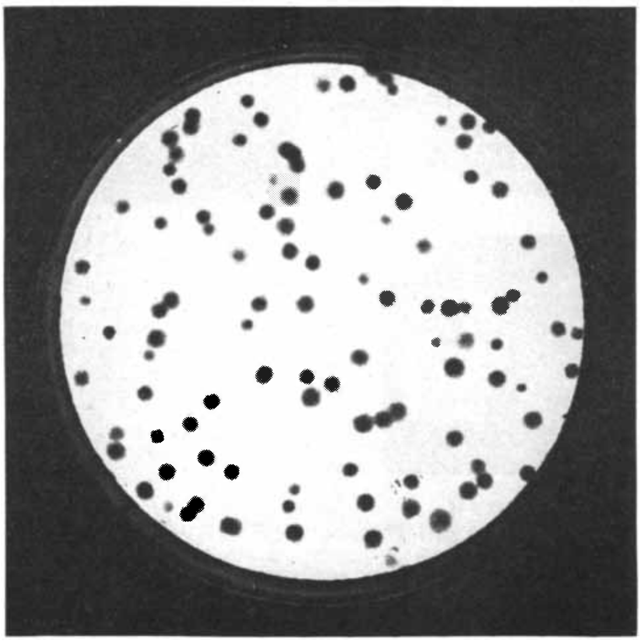
Radiation and the Human Cell

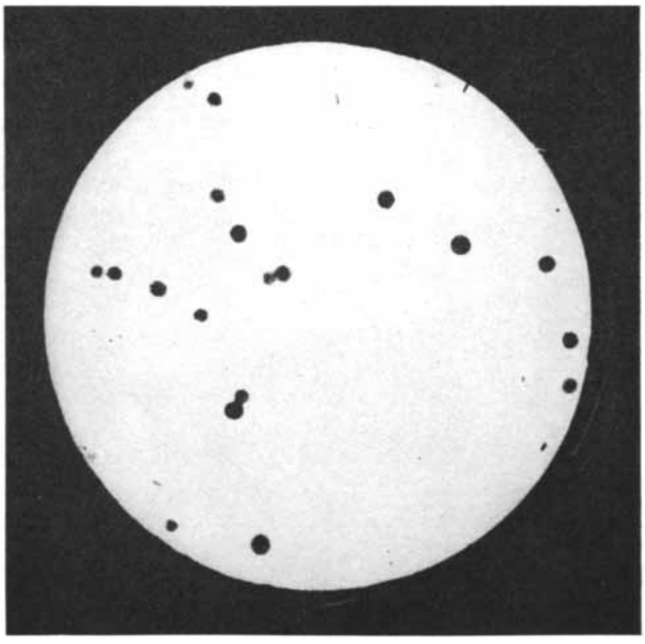
The exposure of single human cells to X-rays indicates that they are far more sensitive to radiation than had been thought. This explains why the relatively small dose of 400 roentgens is lethal to the body

by Theodore T. Puck

Ever since the discovery of X-rays by Wilhelm Konrad Roentgen in 1895, man has been exposed to steadily increasing doses of high-energy radiation. Beyond their well-established functions in medicine, these radiations have been finding progressively wider use in agricultural and industrial research and in industrial processes. But the great energy that makes them so useful also makes them a hazard to living organisms. They are frequently called "ionizing" radiations because they strip electrons from (that is, ionize) atoms and thus break chemical bonds. The large and elaborately structured molecules of the living cell appear to be especially sensitive to damage by radiation. Such damage may find expression in gross harm and death to the organism exposed, or it may be transmitted as a hereditary defect to the offspring. Such a defect may not be revealed until the appropriate mating occurs, an event that may not take place for many generations.

A major objective of investigation into the biological action of ionizing radiation has been to determine the primary site of radiation damage in the cell. In the case of hereditary defects, *i.e.*, those transmitted to the progeny, it seemed logical to look to the genetic structures: the genes and chromosomes and their attendant apparatus, which are localized in the nucleus. But in the case of pathological damage to the irradiated organism itself, the picture was not so clear-cut. Ionizing radiation will disrupt any chemical bond in any molecule of any cell that happens to absorb energy from an incident ray. Injuries as diverse as a drop in the level of white cells in the blood; severe skin damage; ulcerating, nonhealing wounds; loss of hair; gastrointestinal disturbance; internal bleeding due to capillary fragility; cancer; death—all follow as recognized consequences of the exposure of mammalian organisms to large doses of radiation. No readily recognizable target site within the individual cells has been demonstrated to be the seat of all these actions. Some investigators have postulated the nucleus to be the principal sensitive re-

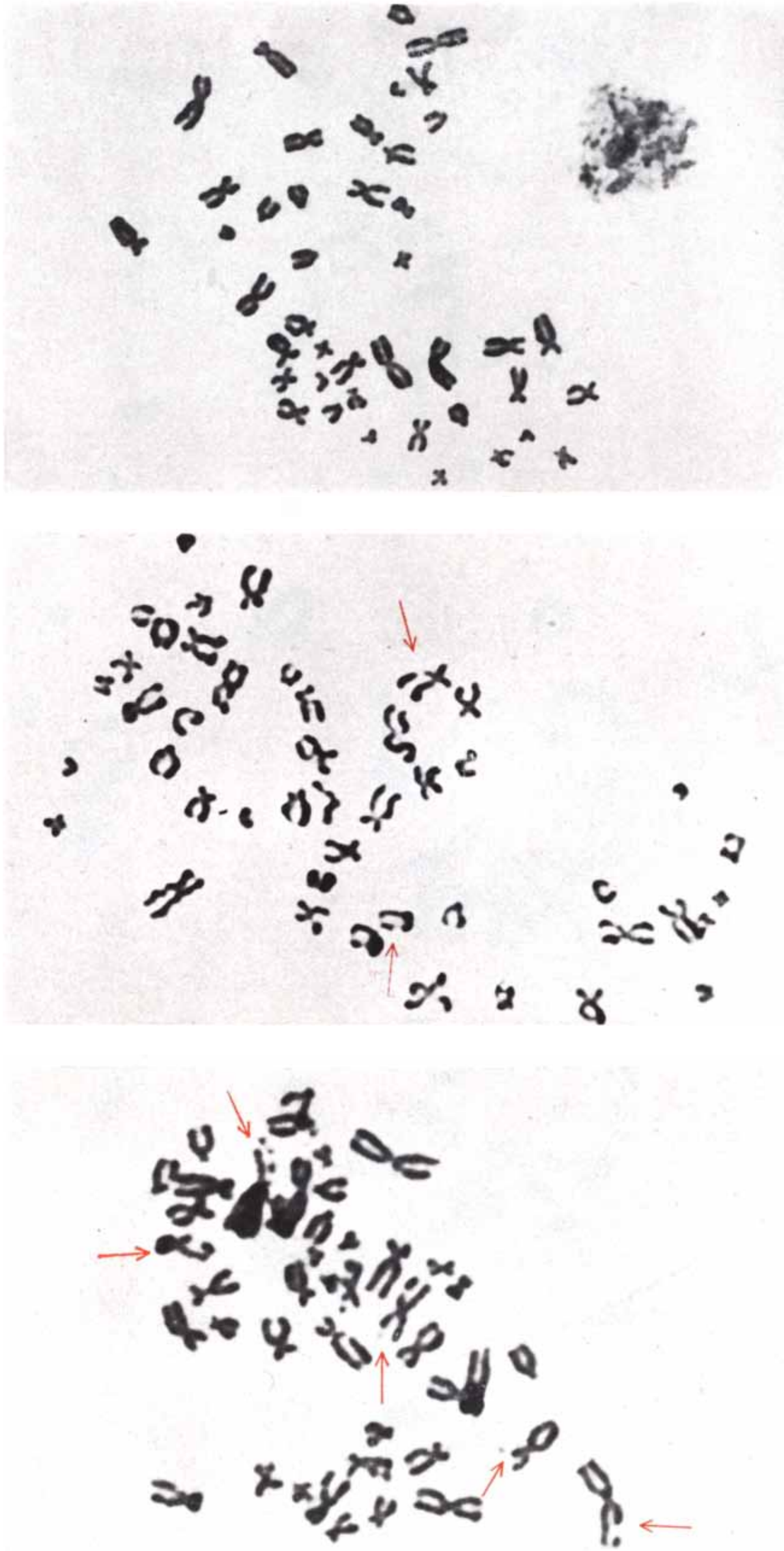




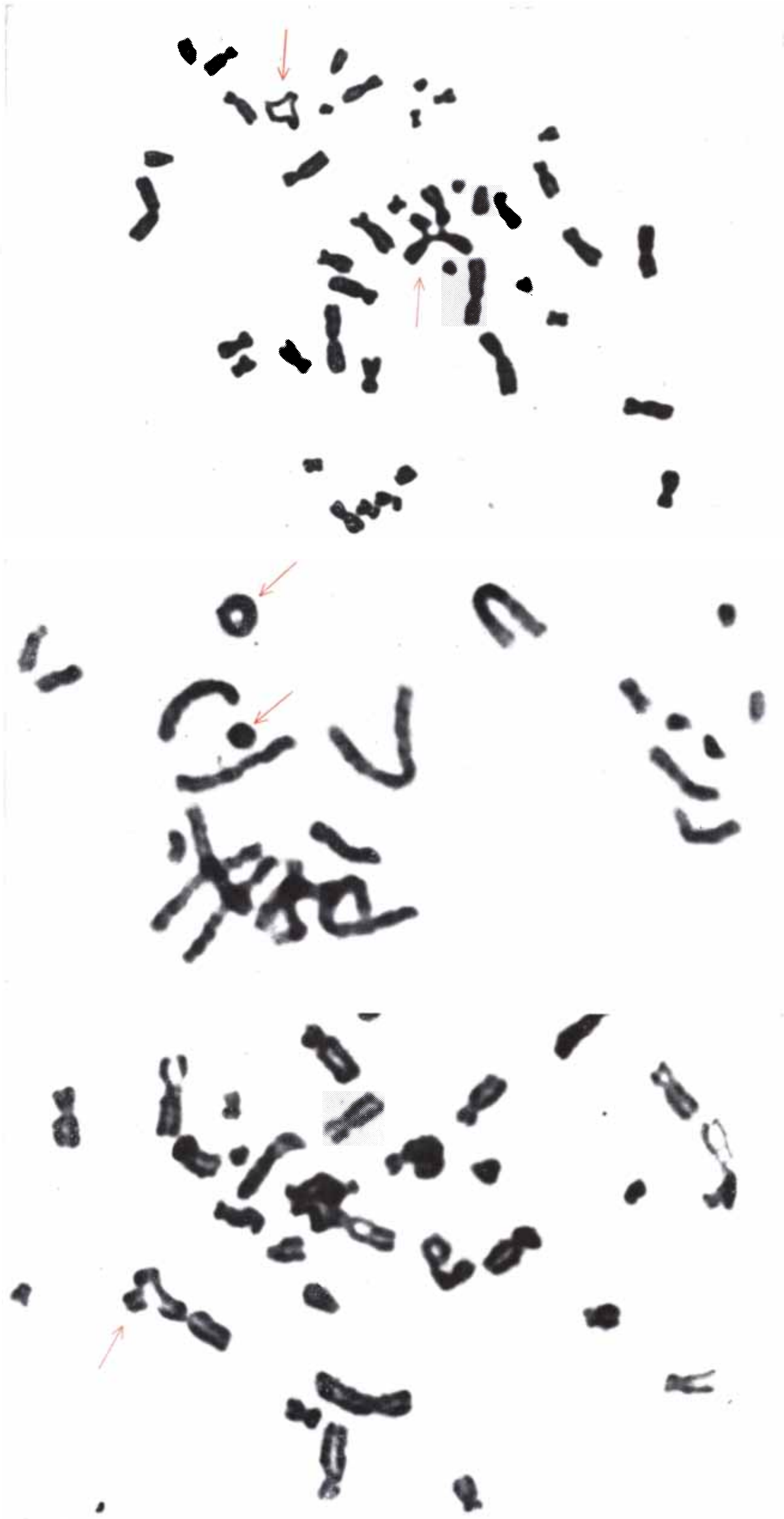
REPRODUCTIVE DEATH in human-tissue cells caused by ionizing radiation is demonstrated by single-cell culture technique. Spots in culture plate at left, shown roughly actual size, are colonies grown from unirradiated control cells. Smaller number of colonies grown from equal number of cells that had been exposed to radiation (*right*) shows how percentage surviving is measured.

gion, while others have held that the basic cellular damage might just as well occur in the structures outside the nucleus, that is, in the cytoplasm, the principal seat of the cell's nonhereditary physiological functions. The issue has been an important one in radiation biology, because a great many other questions have awaited its resolution. A finding that the cell nucleus is an important site of damage would afford new insight into the role of the nucleus in the maintenance of normal function in the body cells of humans and other mammals. It would also indicate the dose range at which genetic damage might be expected to occur.

A ray of high-energy radiation, striking an atom, may knock an electron from a shell of electrons close to the atomic nucleus or from the outermost shell of electrons. The effect on the target atom, however, is the same in the end. Any hole in an inner shell is quickly filled by electrons falling inward from outer shells until the deficiency is transferred to the outermost shell. Since this shell contains the valence electrons that establish the chemical bonds between the atoms in a molecule, the loss of an electron here disrupts the dynamic balance of forces that holds the molecule together. The molecular fragments, produced by the absorption of energy far exceeding that of ordinary chemical bonds, are chemically unsatisfied. They will attack almost any molecule with which they collide in an attempt to regain the lost electron and achieve new stable bonds. The process goes on until all the excited atoms have attained a lower energy-state. In such a simple substance as water the bonds are re-established in the stable configuration H_2O, and all the absorbed energy is converted into heat. Thus there is no permanent change in chemical constitution. A more complex system, such as that represented by a living cell, is not in its lowest possible energy-state initially and possesses countless alternative atomic combinations with similar energy states. These configurations, most of which are incompatible with normal life processes, are usually excluded by the existence of energy barriers. Absorption of high-energy radiation causes these barriers to be surmounted so that the system comes to rest with new chemical bonds established. As a result the chemical constitution of the system is changed by the exposure to radiation; the chemical bonds, broken at random, have been reconstituted in new and bizarre combina-



BREAKS IN CHROMOSOMES of human-tissue cells caused by radiation are marked by arrows in two lower photomicrographs. Chromosomes from an unirradiated control cell (*top*) show no breaks; two breaks are marked in chromosomes from cell irradiated with 50 roentgens (*middle*) and five breaks are marked in chromosomes from cell exposed to 75 roentgens (*bottom*). The photomicrographs on this and next page were made by the author.



ABNORMAL RECOMBINATIONS that result when several chromosomes are simultaneously broken in the same cell indicate random nature of the healing process. Arrows in photomicrograph at top show recombination of several chromosomes (*center of photomicrograph*) and linkage of two chromosomes at two points (*upper left in photomicrograph*). In middle photomicrograph arrows point to rings formed by recombination of broken ends of the same chromosome. In bottom photomicrograph the arrow points to an aberration involving union of two broken arms of one chromosome and of one break in another.

tions. Since the cell is made up to a large degree of giant molecules whose architecture is vital to their function, the rupture of a few bonds may have far-reaching consequences.

The earliest studies of nonmammalian cells had indicated that the nucleus is far more sensitive to radiation than is the cytoplasm. In the cells of the corn plant and the fruit fly, biologists could observe such aberrations as the breakage of chromosomes, the fusion of broken ends of chromosomes that were not previously joined and the deletion of large areas of chromosome structure. Even where no such obvious damage could be seen, the investigators could demonstrate single-gene mutations by appropriate tests of the progeny. Many of these changes result in the ultimate loss of reproductive capacity, even though the cell may multiply for a few generations after irradiation. Investigators also found that the lethality of chromosomal damage depends upon a variety of factors: the total number of chromosomes, the number of duplicate chromosomes, the number of genes essential to reproduction and the degree to which the function of a given gene involves its association with particular neighbors.

Because the same pattern of chromosomal damage and effects upon function was observed in many different kinds of organism, a number of workers, including the distinguished geneticist H. J. Muller, postulated that like processes underlie the action of ionizing radiations upon mammals as well. In their view damage to the reproductive power of individual body-cells would explain many of the pathological symptoms observed in mammals exposed to radiation.

Against this conclusion, however, there stood some significant evidence that at first appeared convincing. The dose of radiation needed to destroy the reproductive capacity of certain cells, such as yeast and the common bacterium *Escherichia coli,* could be accurately measured; it was found to lie in the range of 5,000 to 15,000 roentgens. The paramecium, a protozoon that in many ways resembles human-tissue cells more closely, showed even greater resistance to exposure: radiation in the range from 20,000 to 100,000 roentgens was required to bring about reproductive death. In contrast, the mean lethal dose for whole-body radiation in man is only about 400 roentgens. It did not seem likely that the pathological consequences of radiation exposure in man could be attributed to reproductive death in human-tissue cells, such as that observed in one-celled organisms. Irradiation of human and other mammalian cells seeded in large numbers in tissue cultures seemed to settle the question. These experiments showed that doses in the neighborhood of a few hundred roentgens apparently produced no more than a temporary lag in growth; doses of 10,000 to 100,000 roentgens were required to achieve permanent inhibition of cellular reproduction by these techniques.

Many investigators accordingly turned to other parts of the cellular machinery in the search for the site most sensitive to radiation in mammalian cells. They tested the effect of radiation on many systems of enzymes—the large molecules that catalyze the chemical reactions of the cell—and demonstrated the existence of many new kinds of radiation damage. But none of these easily fitted the specifications of a truly primary site. In summing up the work on the effects of radiation upon the chemical mechanisms of the cell in 1958, the United Nations Subcommittee on the Effects of Atomic Radiation concluded: "The nature of the initial step of radiation damage remains to be determined."

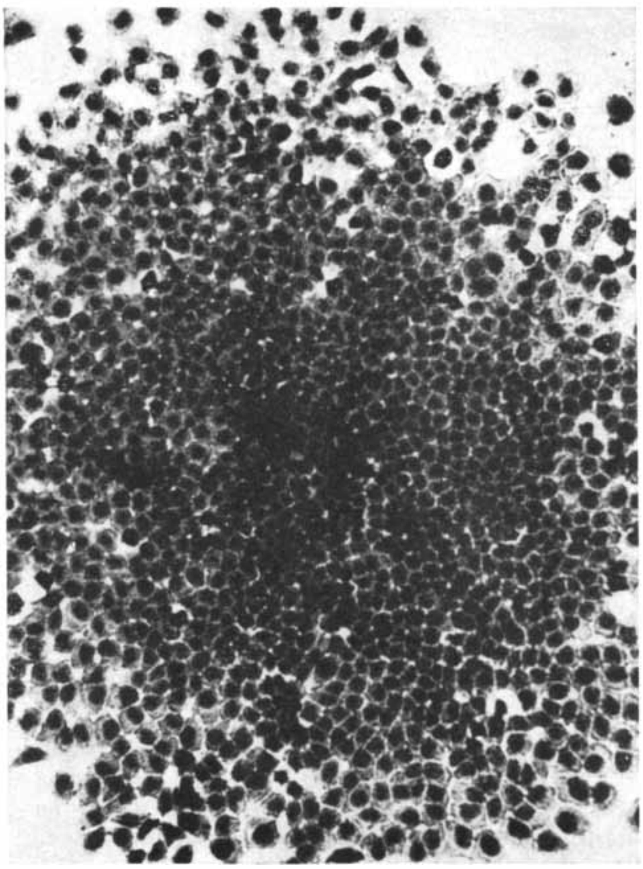
Meanwhile our group in the biophysics laboratory at the University of Colorado was making progress in the development of a new technique for mammalian tissue-culture, a line of investigation we had undertaken in 1955. From each cell in a sample of tissue cells, added to nutrient medium in a glass dish, we learned to culture a large isolated colony of daughter cells that could easily be recognized and counted [see "Single Human Cells in Vitro," by Theodore T. Puck; SCIENTIFIC AMERICAN, August, 1957]. This technique has made it possible to measure with great accuracy the effect of radiation upon the reproductive capacity of a single cell. From a "clone," or colony, of cells cultured from an original single cell we take a sample for irradiation. We then seed the plates with the irradiated cells and with a sample of unirradiated cells as a control. By counting the colonies that grow from the two samples we find the percentage of the cell population that has lost its ability to reproduce.

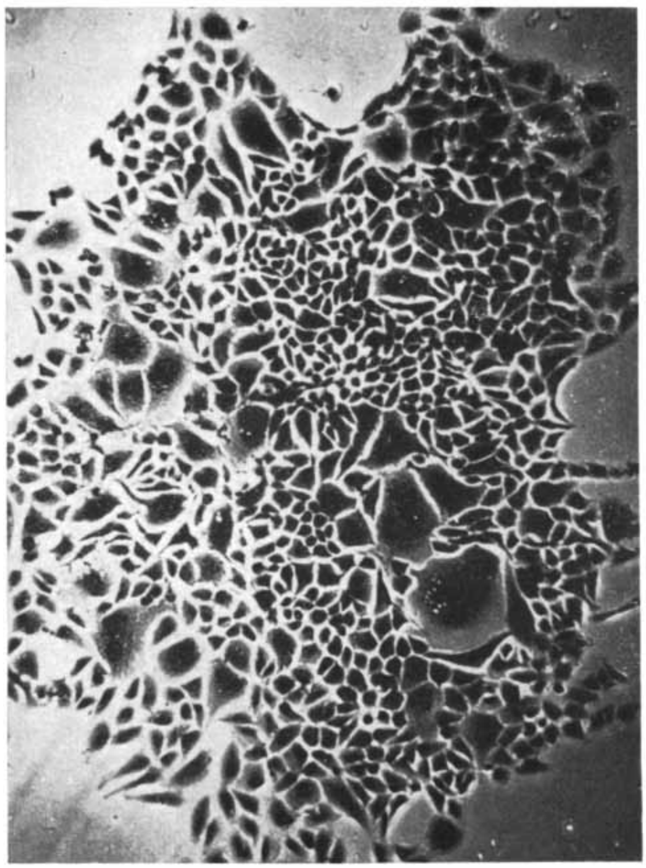
This procedure separates the effect of a lag in the rate of reproduction, which is often induced by radiation, from the irreversible cessation of reproduction in a given cell. In an ordinary tissue-culture containing a mass of cells the two effects cannot be distinguished, and the recovery of reproductive capacity by some cells masks the reproductive death of others. In addition, our technique has made it possible to detect individual mutant cells. We can thus measure the mutation-inducing effect of given doses of radiation upon human and other mammalian cells. Tested in this fashion, human-tissue cells from a wide variety of normal organs have shown survival curves of a simple type.

Determination of many such curves shows that the lethal dose for reproduction in human-tissue cells is only 50 roentgens. This figure is obviously far smaller than those indicated by experiments that measured outgrowth from larger chunks of tissue. What this finding means is that a human cell exposed to X-rays suffers reproductive death when it has absorbed from the X-ray beam an amount of energy equivalent to a temperature rise of less than .001 degree centigrade. Cells with an abnormally large number of chromosomes, such as turn up occasionally in tissue cultures, proved to be about twice as resistant to X-rays, but they were still extremely susceptible to doses hitherto considered quite small [*see illustration on page 150*].

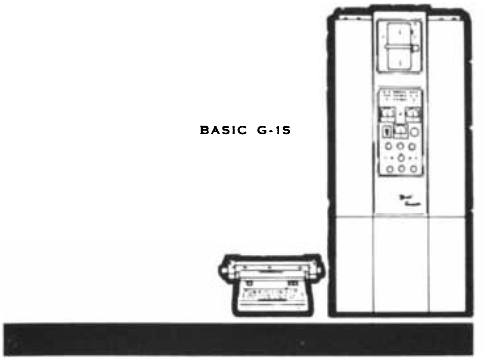
These experiments have also yielded a variety of different lines of evidence indicating that damage to the genetic apparatus, specifically the chromosomes, occurs at sufficiently low doses to account for the destruction of reproductive capacity in the cells. Even the more indirect evidence is persuasive. For example, if the damage is done in the nucleus rather than in the cytoplasm, one would expect the cells that survived exposure to a lethal dose to bear evidence of this experience in the form of mutations. Colonies grown from such survivors frequently do show changes in their appearance and nutritional requirements which are transmitted to succeeding generations like other genetic characteristics. Similarly, except for the few cells actually dividing, chromosome damage should be relatively constant for a given dose of radiation; on the other hand, damage inflicted upon the physiological mechanisms in the cytoplasm might vary greatly, depending on the metabolic activity of the cells. When we cultured cells from colonies that had been irradiated under conditions of maximal growth and of no growth, we found practically identical X-ray survival curves.

In contrast to the great sensitivity of the genetic apparatus of mammalian cells, other cell structures have been found to be much more resistant to radiation. These studies, carried on in many laboratories, have demonstrated radiation damage to a large number of cellular enzyme systems. In every case the necessary X-ray dose was larger than the chromosome-damaging dose, except of course in functions dependent on chromosomal integrity. Cells irradiated with a dose 10 or 100 times that required to destroy their reproductive capacity can still carry on many metabolic functions. They can take in sugars and utilize their stored chemical energy, synthesize specific proteins and nucleic acids, and take up substances from their culture medium in a fashion virtually identical with that of an unirradiated cell. Cells in this condition may become giants, reaching a diameter as great as a millimeter when adhering to a glass plate, and so are readily visible to the naked eye [*top illustration on page 148*]. A reproductively dead, but metabolically alive, cell can be infected with a virus, and it will proceed to synthesize large numbers of virus particles. The production of these intricate particles with their vast number of specific chemical bonds certainly requires the active functioning of a great deal of the cell's chemical machinery. Large regions of the cell's nongenetic





MUTATION OF CELLS, induced by irradiation, is indicated by the appearance of large "monster" cells in colony at right, as compared to cells grown from unirradiated cell in the colony at left. The cells are from a standard HeLa strain of human cancer tissue.



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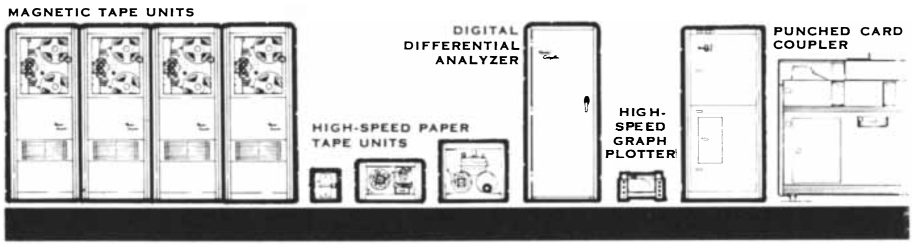

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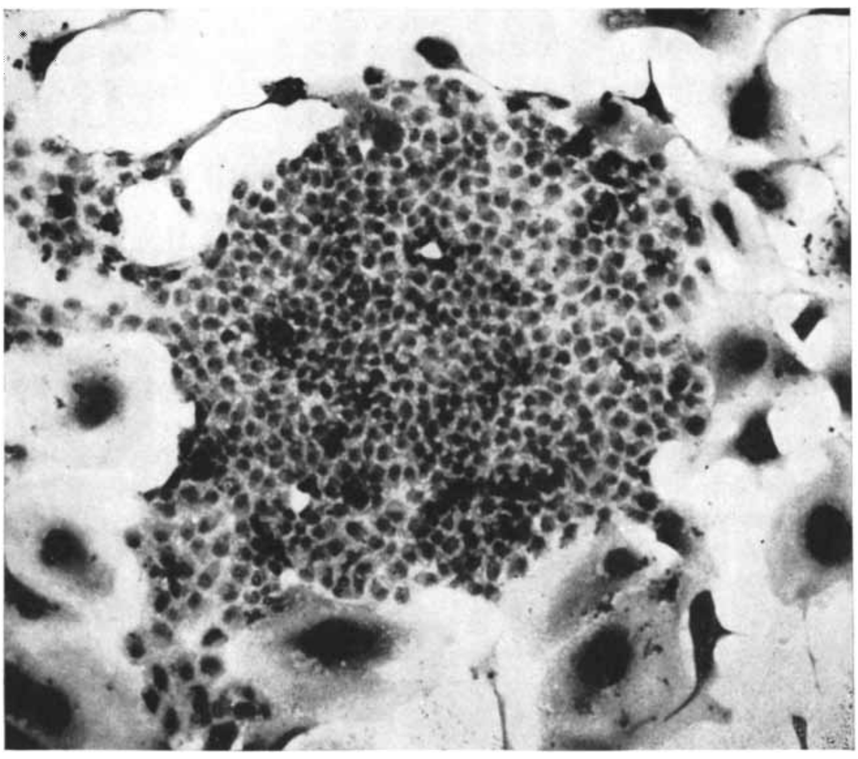
SINGLE GIANT CELLS, shown here at a magnification of only two diameters, demonstrate reproductive death from irradiation. The metabolic processes of the cells continue despite destruction of reproductive capacity; the cells become giants instead of dividing.

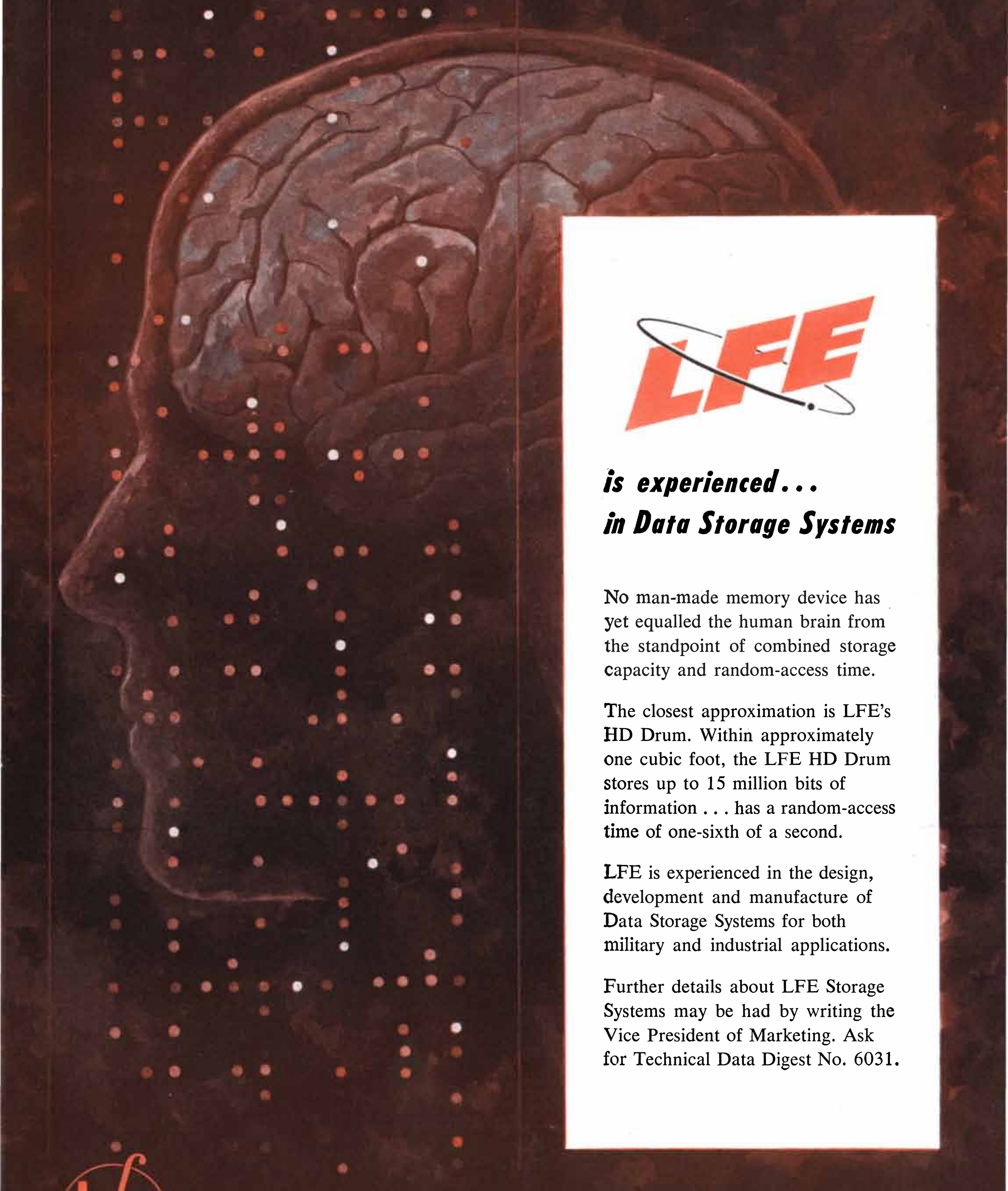


COLONY OF CELLS grown from single-cell survivor of irradiation is here contrasted with radiation-inactivated cells, surrounding the periphery of the colony, which are forming giants. The diameters of some giant cells approach a third the diameter of entire colony.

apparatus must remain in working order.

Until recently it would have been difficult to go beyond this indirect evidence. The numerous small chromosomes in mammalian cells do not lend themselves to inspection so readily as those in other forms of life; thus it was not possible to correlate the effects of radiation with observed damage to these vital structures. New techniques have been contributed by several investigators, including T. C. Hsu of the University of Texas and J. H. Tjio in our laboratory, which have made it possible to delineate the chromosomes of mammalian cells. When the cells are placed in a salt solution whose osmotic pressure is lower than that of the cellular fluid, they swell to many times their normal size, so that the chromosomes become separated from one another and show up handsomely after staining. In cells that have been irradiated by doses in the range of 50 roentgens the chromosomal damage thus made visible appears sufficient to account for their reproductive death. As nearly as present experiments can determine the extent of primary damage observed varies directly with the dosage.

Since the chromosomes possess power of self-repair, the number of breaks observed also depends upon the time interval between the irradiation and the treatment of the cell for inspection of its chromosomes. The mechanism of this exceedingly important restitution process is now being thoroughly explored by a number of workers, particularly by Sheldon Wolff of the Oak Ridge National Laboratory. If the two ends of a broken chromosome rejoin, there may remain no visible evidence of the damage, although a gene at the site of the break conceivably might have suffered mutation. When more than one chromosome is broken, however, the chances are appreciable that the ends of different chromosomes will make connections with one another. Some of these abnormal junctions are recognizable under the microscope. Moreover, some of them may cause reproductive death of the cell. For example, the two centromeres that are supposed to separate the replicated chromosomes from one another during cell division may become joined to the two ends of a single chromosome. They will then pull the two ends to the opposite poles of the cell, producing a chromosomal bridge that prevents completion of the process of division. Even if the reproductive capacity survives, the random nature of the radiation process may introduce muta-



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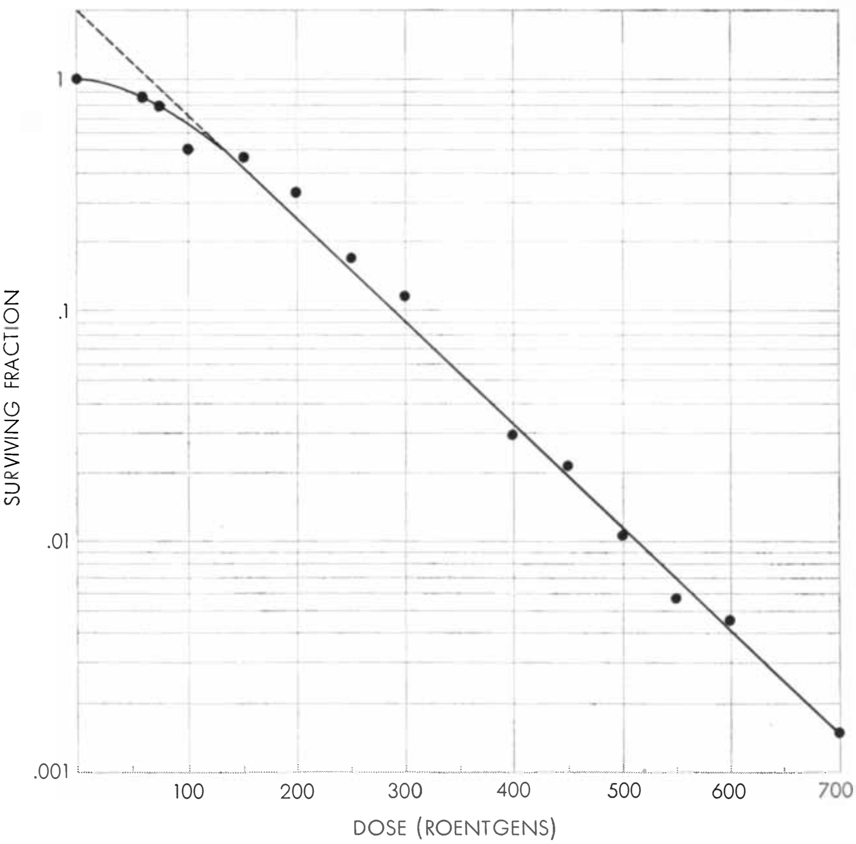
AIRBORNE NAVIGATION • RADAR and SURVEILLANCE • ELECTRONIC DATA PROCESSING • AUTOMATIC CONTROLS • GROUND SUPPORT tions in the genes that happen to be located at the site of the breaks. Still other genetic changes will reflect the subtle working of the so-called position effect, which modifies a gene's potentiality when it becomes juxtaposed to different neighboring genes on the chromosome.

Careful counting of the chromosomal breaks has shown that the dose needed to cause a single break per cell is only about 40 roentgens. This figure, however, includes a discount for the healing of breaks, since the counting is ordinarily done two or three days after irradiation. If the breaks are scored immediately after irradiation, the average dose needed to produce one break per cell falls to 20 to 25 roentgens. This figure shows that significant chromosomal changes follow doses well within the lethal limit.

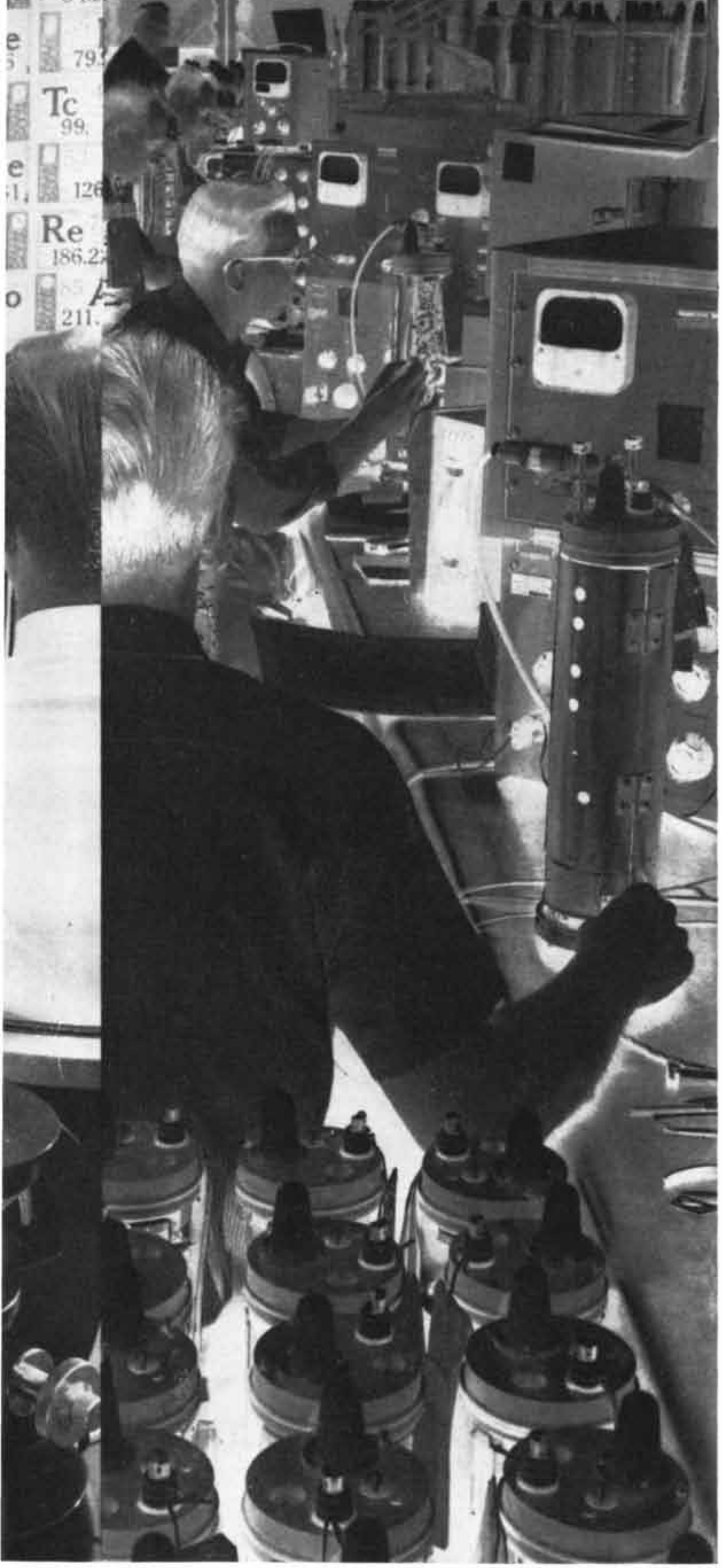
The genetic apparatus thus shows extraordinary sensitivity to radiation. Calculation indicates that the ionization of not more than a few hundred atoms within or around the space occupied by the chromosome may be sufficient to produce a visible break. It seems probable that an even greater number of lesions may occur and remain invisible, either because they are submicroscopic or because they become resealed before they are examined. The biochemical nature of this reaction, resulting from so small an initiating stimulus, will afford a fascinating area of investigation.

How well do these experiments, performed in laboratory glassware, reflect events that occur in intact human tissue under irradiation? Several lines of experimentation indicate that the *in vitro* model is useful for understanding at least some events *in vivo*. H. B. Hewitt and C. W. Wilson of the Westminster Hospital in London have studied the X-ray survival curves of leukemia cells in mice. They irradiate leukemic animals and then test the capacity of cells from these animals to induce leukemia in other mice. This is a reliable test, because a single cell from an unirradiated animal suffices to carry the disease to a new animal. The survival curve for single irradiated cells established by this experiment corresponds closely to the curve for single cells growing in tissue culture.

Perhaps an even more striking demonstration is afforded by the results of



SURVIVAL CURVE for human cells originating from the standard HeLa cancer-cell strain shows correlation between exposure to radiation and reproductive death in the cells. Cells from normal human tissue show same curve but a somewhat higher sensitivity to radiation.



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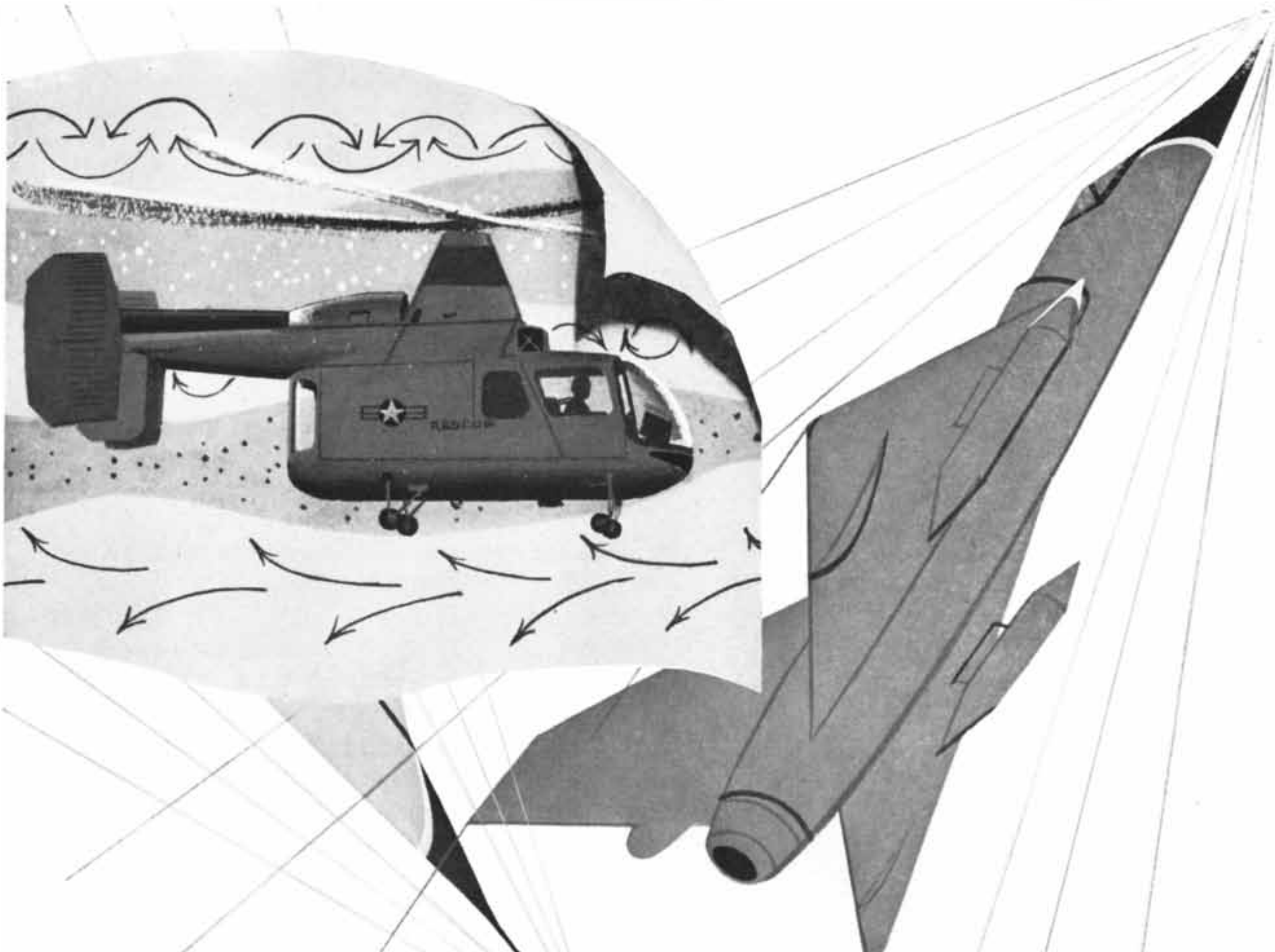

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an experiment involving a situation in the living organism that closely resembles that in the tissue-culture experiments. This is the fertilized egg, a single cell whose history can be readily traced following an episode of irradiation. At the Oak Ridge National Laboratory W. L. Russell and his wife Liane Brauch Russell have exposed female mice to a standard dose of 200 roentgens soon after mating, while the egg is still presumably in the one-celled stage. Only 20 per cent of the embryos survived; this finding agrees well with the figure predicted from experiments with single-cell cultures. When irradiation occurred at later, multicelled stages of development, the survival rate increased, reflecting the capacity of the uninjured cells to replace those destroyed.

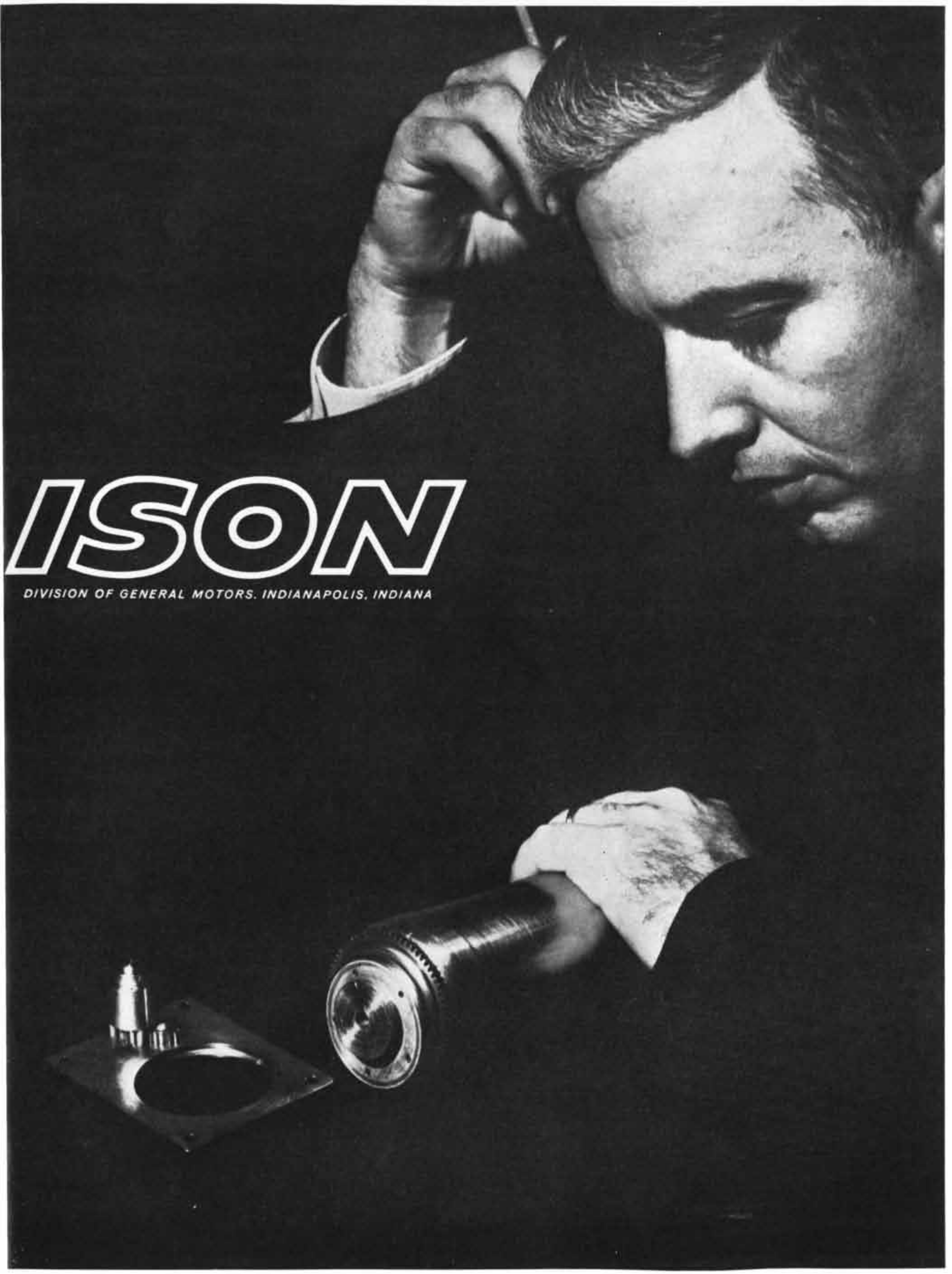
With the new measurement of the mean lethal dose for reproductive function of mammalian cells it is now possible to explain the relatively low mean lethal dose of 400 to 500 roentgens for the entire body. Such a dose leaves only about .5 per cent of the body's reproducing cells still able to multiply. Death, however, will not be immediate. The cells have each absorbed an almost infinitesimal amount of radiation energy. Though they have suffered an appreciable amount of chromosomal damage, their enzymatic machinery is, by and large, still active. Each such cell continues to perform its physiological functions in reasonably normal fashion until the time comes for it to reproduce. But at the next division, or at the next one or two divisions, reproduction will fail. One of the most characteristic features of radiation injury is thus explained: the relatively long lag that usually occurs between even severe irradiation and the development of pathological symptoms.

The same line of reasoning helps explain some aspects of the typical course of radiation disease. One would deduce that the tissue functions first embarrassed are those most dependent upon rapid cell-multiplication. This is indeed the case, as is observed in the well-known generalization that the most rapidly dividing cells of the body are the most sensitive to radiation. Our experiments suggest, however, that exposure to X-rays may distribute chromosomal damage quite impartially among all cell types. The damage merely shows up first in those tissues that multiply most rapidly. Thus genetic damage to cells can cause physiologic damage to the entire organism through failure of functions requiring steady cell-multiplication.

Since the blood-cell-forming tissues of the bone marrow have the highest normal rate of division, the first symptom of whole-body irradiation in the lethal range is usually a depression in the white blood-cell count. Experimental animals that have suffered such exposure can often be saved if new, viable bone-marrow cells are injected into them. The new cells will colonize the bone marrow and restore the necessary rate of cell production. But the dose given may be high enough to stop the reproduction of so many cells in other more slowly reproducing tissues that the survivors may not be able to restore the needed numbers in time to maintain physiological function. The injection of marrow will no longer save the animal.

In experiments with frogs Harvey M. Patt and his associates at the Argonne National Laboratory have found that a reduction in the body temperature of the animals will delay the onset of the symptoms of radiation disease. This is quite understandable in light of present knowledge. At lower temperatures both the rate of cell division and the body's normal dependence upon it are depressed. The damage remains latent even in tissues that multiply rapidly. Upon restoration of normal body temperature the usual sequence of events resumes, and the symptoms of radiation damage manifest themselves.

The new picture of radiation damage thus locates its primary site in the genetic apparatus and shows that the damage consists in the destruction of the capacity to reproduce in some cells and the induction of mutations in others. On this basis a great many otherwise inexplicable phenomena have become understandable. However, much still remains to be learned. The factors that govern the healing of chromosome breaks and the degree to which these may differ in different cell types are still largely unknown; the biochemistry of this process will contribute much to fundamental understanding and to the more effective use of X-rays in the treatment of cancer. The study of the effect of chromosomal damage upon metabolic activities will illuminate many aspects of the complex mechanisms by which the genetic apparatus regulates the physiology of the cell. Single-cell techniques also offer promise in exploration of possible radiation damage to extranuclear cell structures. Finally these techniques permit accurate measurement of mutation rates in body cells, and so should contribute to unraveling the difficult problems involved in setting permissible levels of human exposure to ionizing radiation and other mutagenic agents.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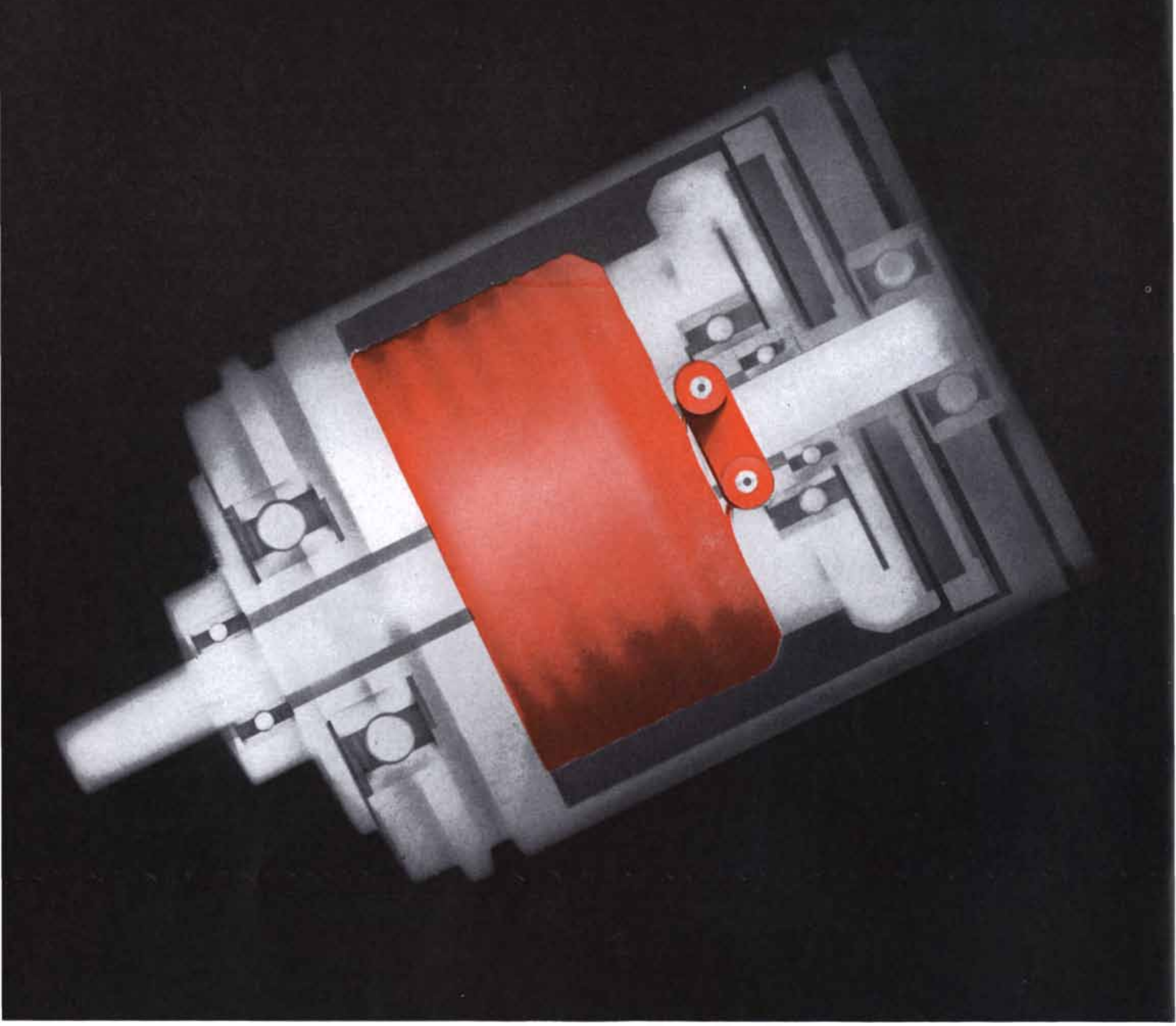

X-ray photograph (here enlarged 3 times) of magnetic clutch manufactured by Dynamic Instrument Corp., Westbury, L. I., N. Y.

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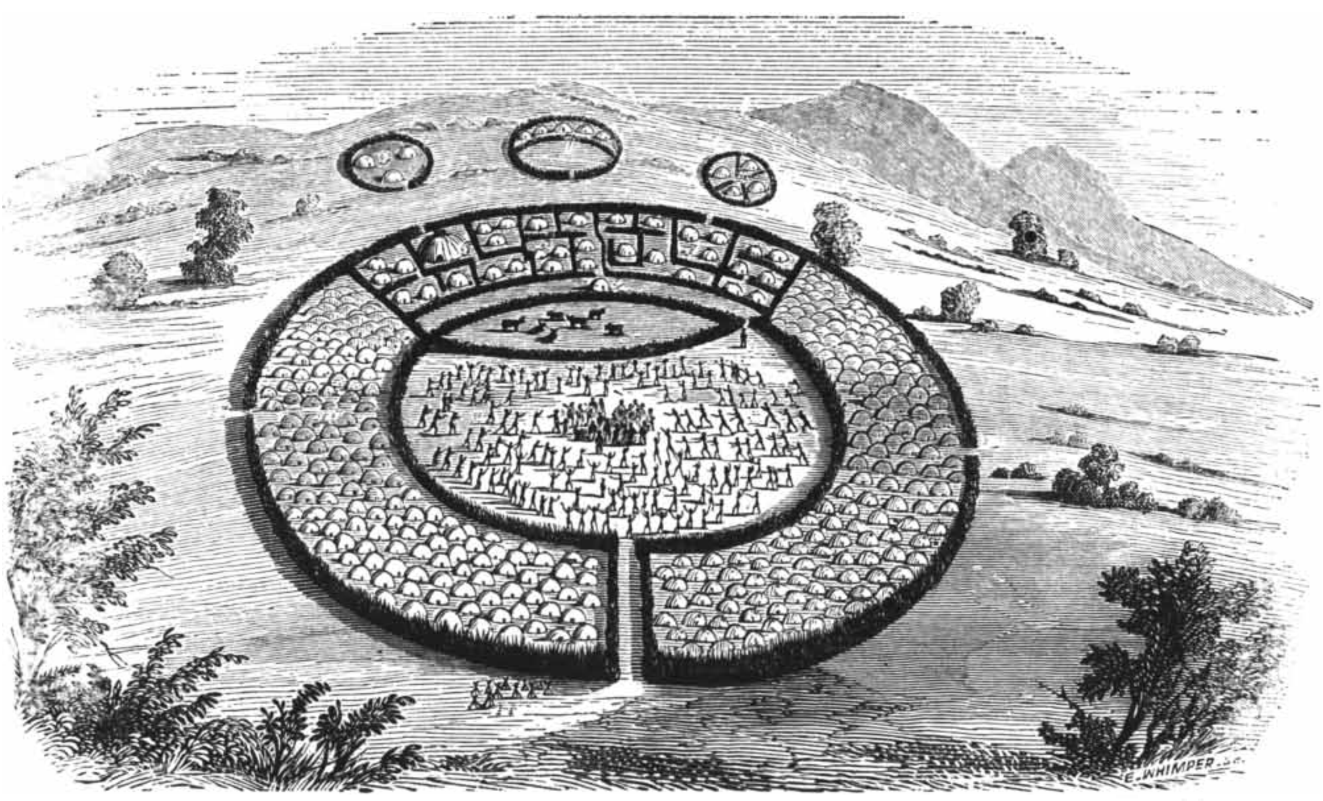
Thou that art vast as the sea!
Thou who growest while others are distracted!

This is a translation of the chant of the Zulus in praise of Shaka, their warrior king. In 1824 a small party of English traders, seeking an audience with Shaka, splashed ashore with their horses and supplies at Port Natal (now Durban) on the east coast of Africa. After his agents had reported them to be friendly, Shaka sent gifts of cattle and ivory and an ambassador to guide them to his capital. They traveled for two days, crossing rivers, acacia-covered grasslands and densely forested hills to reach the royal Bulawayo kraal, a ring of beehive-shaped dwellings built around a central cattle enclosure two miles across [*see illustration below*].

Here is how one of the traders, Henry Fynn, described their reception at Bulawayo: "On entering the great cattle kraal we found drawn up within about 80,000 natives in their war attire." After an exchange of speeches and gifts "Shaka then raised the stick in his hand and after striking with it right and left and springing out from amidst the chiefs, the whole mass broke from their position and formed up into regiments. Portions of these rushed to the river and the surrounding hills, while the remainder, forming themselves into a circle, commenced dancing with Shaka in their midst. It was a most exciting scene, surprising to us, who could not have im-



THE ZULU CAPITAL was the royal kraal, a ring of beehive-shaped thatched huts built around two central enclosures. This 19th-century engraving depicts the kraal of Dingane, Shaka's successor, which was built when the Zulu empire was at its zenith. The chief's hut is at upper left; the smaller huts belong to his many wives. Three kraals belonging to the chief's ministers are in the distance.

agined that a nation termed 'savages' could be so well disciplined. Regiments of girls, headed by officers of their own sex, then entered the center of the arena to the number of 8,000 to 10,000, each holding a slight staff in her hand. They joined in the dance, which continued for about two hours. Shaka now came toward us, evidently seeking our applause."

Fynn and his companions were told that Shaka had built this disciplined nation and army in less than 10 years after he became chief of a small tribe of about 2,000 people. The kingdom he established in Natal became so powerful that long after his death it engaged the British in a major war (the Anglo-Zulu war of 1879). Shaka's armies and the tribes fleeing them cut swaths of devastation through south and south-central Africa, and many of the fugitives were themselves destroyed in their slaughtering flight.

When Shaka defeated his major rival, the Ndwandwe chief Zwide, some of the vanquished Ndwandwes fled to the north and west. One of these tribes established its rule in what is now Mozambique and extorted tribute from the Portuguese trading stations on the Zambezi River. Others went farther inland, conquering and absorbing tribes along the way, and later split into the several Ngoni kingdoms of central Africa. A group of Basuto tribes sought refuge 1,500 miles away along the upper reaches of the Zambezi, where they conquered Barotseland and ruled it for 30 years. Moshesh, chief of another Basuto tribe, gathered broken tribes around him in the mountainous region now known as Basutoland; in this stronghold they formed the powerful Basuto nation, which has recently taken an important step toward self-government. To the north the example set by the Zulus led the Swazis to unite into a kingdom of their own that still survives. Swaziland, like Basutoland, is now a British protectorate, although the Union of South Africa is currently demanding their annexation.

What sort of man was this Shaka, whose conquest disturbed a third of a continent? How was he able to weld hundreds of quarrelsome and fiercely independent small tribes into a mighty nation? A contemporary of Bonaparte, he has been called "the Black Napoleon" and "the African Attila." Even in scholarly works Shaka's exploits have been accounted for in terms of his genius as an organizer and military leader, his ruthless energy and his vision of empire. That is no doubt part of the story. But his rise to power was probably also the result of tides that had been running in the life of the African peoples for two centuries: the rising population in the interior of Africa, the emigration from the interior that was crowding the pasture lands of Natal, and the increasing contacts with European settlers and traders. Shaka's abrupt, brief and bloody appearance in history thus provides significant insights into the all too little-known history of the "Dark Continent."

The evidence from which it is possible to reconstruct his career and its historical setting comes from two sources. The first is native folklore, as recorded by the Englishmen who knew Shaka, and later by other whites. These stories can be cross-checked with those handed down in the folklore of peoples that fled from Natal and first came in contact with whites many decades later. When the traditions of several geographically separated tribes agree, they are likely to be a faithful record of the facts. The other source of information is the journals of seamen shipwrecked on the coast of Natal from 1552 onward; their accounts shed light on the social and historical background of the tribes and provide a further check on the native folklore.

Most historians agree that the Natal region remained relatively untouched throughout the millennium in which commerce with Asia brought flourishing cities into existence on the African coast farther to the north. From the fifth century onward, at ports like Kilwa, Mombasa and Sofala [*see map on page 160*], merchants and traders from Arabia, Persia, India and even China exchanged porcelain, crockery, beads and colored cloth for slaves, gold, silver, nickel, ivory and rhinoceros horns, brought from the interior. This trade fostered the growth of the advanced inland civilizations that built the medieval stone cities of Zimbabwe and Inyanga in Southern Rhodesia. European settlers, reluctant to believe that native Africans could have created these cities, often insist that the great ruins at Zimbabwe are the site of King Solomon's mines. The inhabitants of the region are known to have mined ores to depths of more than 100 feet, and worked iron in large quantities. They irrigated vast hillside terraces and built walls and palaces of granite. In the 16th century their civilizations had already fallen into decline, and the end came when the European powers—principally Portugal—raided the coastal cities and severed the old trade routes across the Indian Ocean.

But the Arab traders who had visited the coastal ports had never ventured farther south than Sofala for fear of contrary winds and currents. Natal was untouched by the outside world until Vasco da Gama opened the sea route to India around the Cape of Good Hope in 1497. Later many European ships were wrecked on the coast of Natal, and the journals of some of the survivors relate their experiences with the local tribes.

The survivors of the Dutch vessel *Stavenisse*, wrecked in 1686 about 60 miles south of the present city of Durban, gave this account of their experiences: "Being now destitute of everything, and the boat being broken in pieces, we consulted how we could best support ourselves, and by what means we could secure ourselves from starvation. The natives, indeed, offered us bread and cattle for sale, but we had nothing wherewith to purchase the one or the other. Nothing is esteemed there but beads and copper rings for the neck or the arms. For nails, bolts, and other ironwork of the wreck, we, indeed, got some bread and corn, but as the natives set to work themselves, and by chopping and burning fully supplied themselves with iron, we not being at first aware that it was so much regarded, nor daring to prevent them for fear of provoking them, as they had sometimes fully a thousand armed men, they had everything in abundance, while we suffered from want." Portuguese castaways used to burn their wrecks to prevent the natives from obtaining a free supply of iron, which was one of the principal items of trade.

The castaways, like many modern students of African history, were inclined to regard the natives as "savages" who would attack and rob strangers unless frightened away. This was surely not the case; the tribes were well-organized societies with elaborate codes of law and ethics. A careful survey of the records has convinced me that the natives did not slaughter and steal only when they felt they were stronger than the shipwrecked party, and trade and parley only when they were afraid; the situation was much more complicated. The natives had a great need for iron, copper and other metals: many of their javelins were made of wood hardened by fire, and in some tribes women cultivated with sticks rather than with iron hoes. They were therefore very eager to get metal, and were ready to trade for it by generous offers of cattle and milk and grain—if they had cattle and milk and grain. If they did not, they attacked

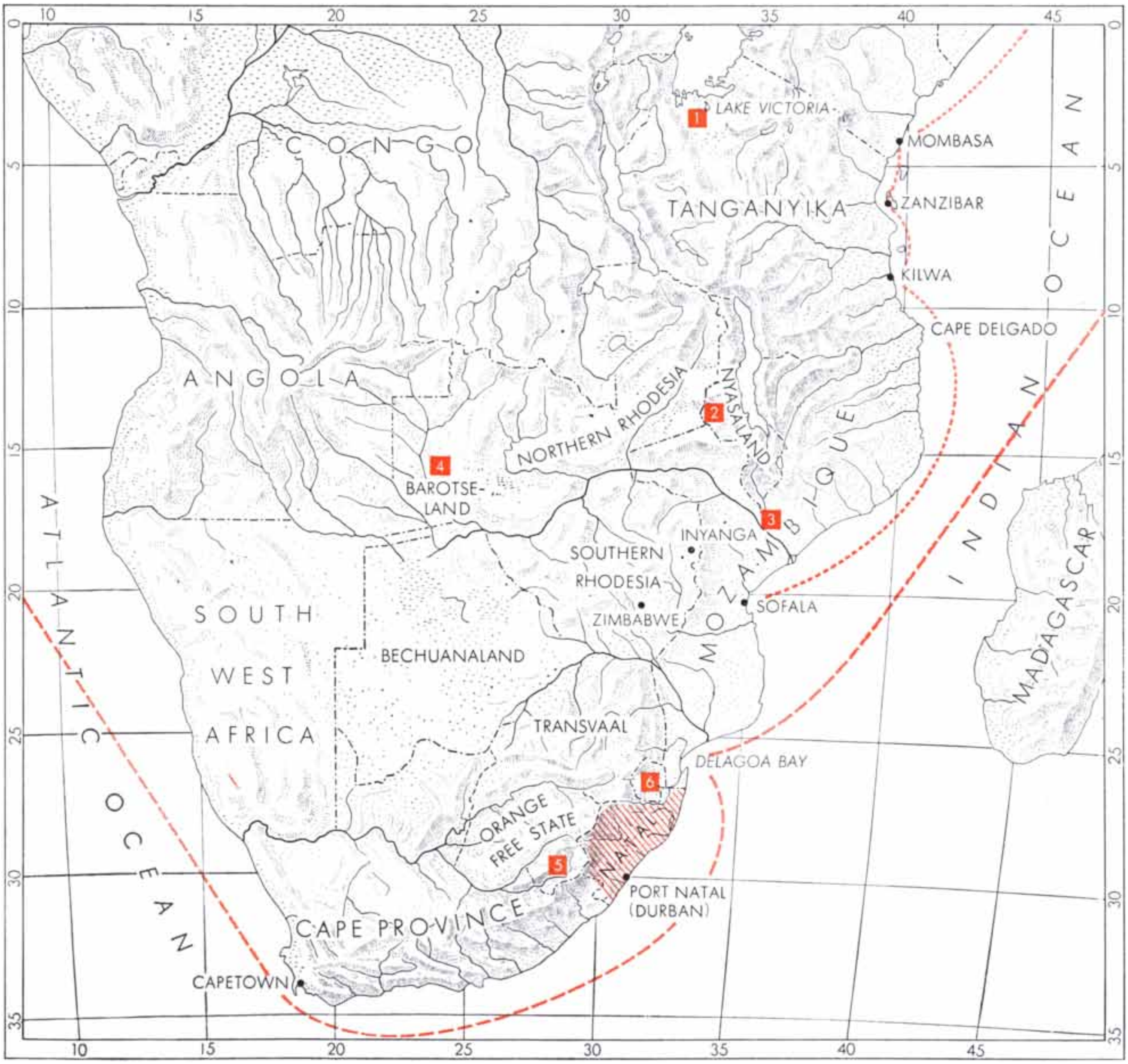
ZULULAND TODAY looks much as it did in Shaka's time. The subsistence farming and pasturing practiced by the Zulus keep their homesteads widely scattered. Each homestead is relatively self-sufficient, and each is the residence of a single family or clan.

WARRIORS DANCE in praise of the Zulu king, who is visiting the kraal of their chief. In Shaka's time warriors on the eve of battle pantomimed in dance the heroic deeds that they intended to perform in combat. They were expected to live up to their boasts.

the castaways and stole their goods. Seven fairly complete journals kept by castaways show that the parties were attacked either in years of widespread drought or after the invasion of locusts, when food was short among the natives; or when they were wrecked just before the harvest and the natives were in want as they waited for the new crops. In good seasons and after the harvest the people came dancing to meet the Portuguese, and freely offered food for the scarce metals.

This analysis is confirmed by the fact that the castaways were attacked even in good years when they encountered individual tribes suffering from want and conversely were welcomed in bad years when they came to isolated tribes enjoying better fortune. Even in bad years, however, castaways who dropped out of the march from weakness were often succored by the very people who had been harassing them. Men from later shipwrecks occasionally met these castaways; often they had been given cattle, wives and land, and had assumed important places among their saviors. The early Natal tribes thus had, like all societies, some rules of compassion and human sympathy. Yet the people were starved for metal and ready to fight for it if necessary.

The journals and the native traditions make it clear that Natal was occupied by a great number of small independent tribes organized around kinship groups. Castaways who traded metal and remnants of cargo for cattle reported that they were able to drive their herds across each chief's territory in a few days. A chief visiting the castaways was escorted by only 50 warriors or so; the force of attackers on less happy oc-

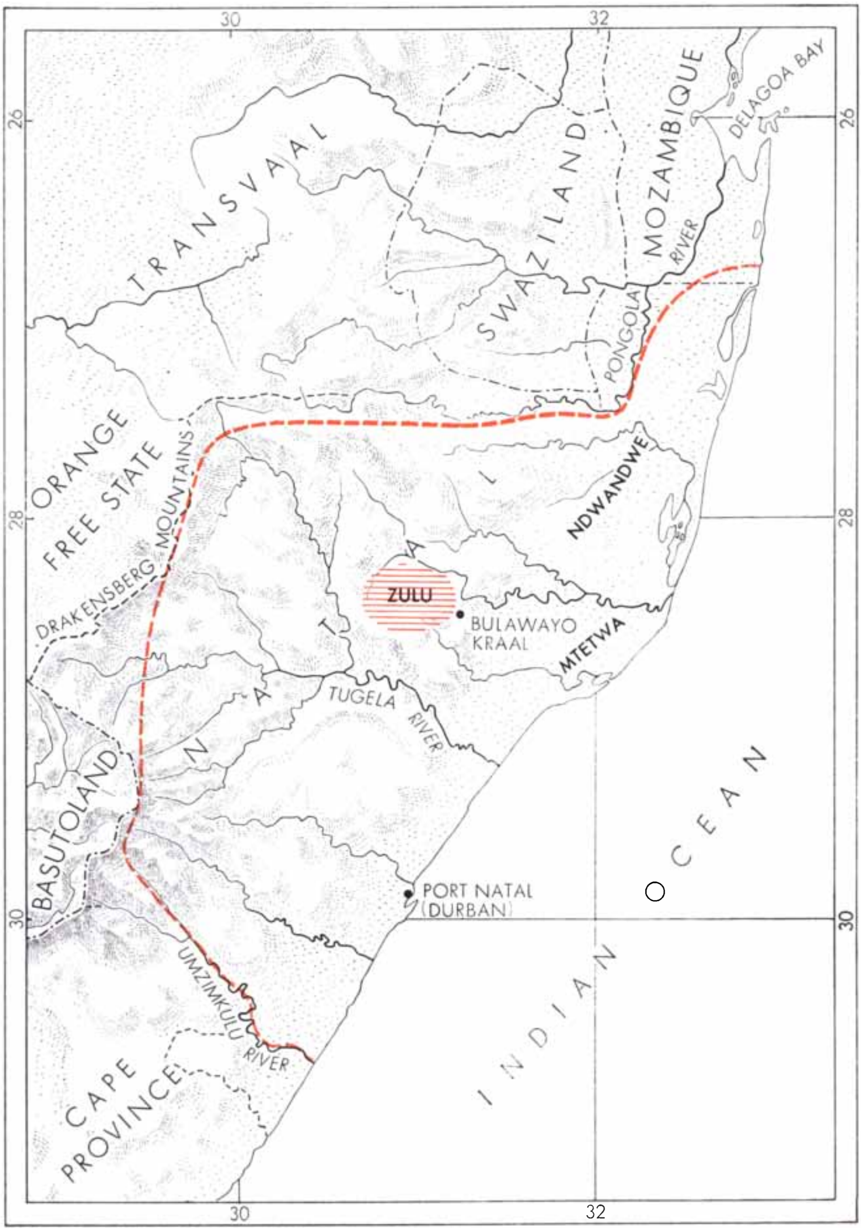


CENTRAL AND SOUTH AFRICA were devastated by Shaka's armies and the terrorized tribes fleeing them. When Shaka defeated the Ndwandwe to become master of Natal (*hatched area*) some of the Ndwandwe tribes fled as far north as Lake Victoria (1); others settled in Nyasaland (2) and still others in Mozambique (3). A fleeing group of Basutos conquered Barotseland (4) and another founded a powerful nation in what is now Basutoland (5). Shaka's example prompted the Swazis to unite into a nation that still survives in Swaziland (6). The heavy broken line indicates Portuguese trade routes; the light broken line, those of the medieval Arabs.

casions was never more than 300. Native folklore indicates that the tribes had come into the region from the north and west in the general population movement attending the expansion of the Bantu peoples that had begun hundreds of years before. Some of the tribes were in flight from Bantu conquerors and some, including the Zulu tribes, were offshoots of the Bantu stock. Together they displaced the indigenous pastoral Bushmen.

As the tribes moved, they often split. A chief had several wives of varying status, and he placed important ones in different parts of his territory and attached followers to them. When the eldest son of an important wife grew up, he thus had an army to support him if he tried to seize the throne after his father's death. According to custom the rightful heir was a son born to a wife married after his father became chief—a son "born in the purple." If a man became chief when he was nearing middle age, this meant that the rightful heir might be a child when his father died, while there were grown-up sons already able to rule. One or more of them might attempt to seize the throne. Sometimes an uncle was appointed regent; when his ward grew up, the regent (as in Europe) might resist giving up power. Often a section of the tribe, ruled by a prince not likely to succeed, moved off to seek independence. A common outcome of a dynastic dispute was thus the splitting of a tribe, and such splitting operated to keep each tribe fairly small.

Without doubt economic forces were at work along with personal ambition in this process of political fission. The tribes obtained their food by farming and by pasturing cattle on the range, so their habitations were necessarily widely dispersed. The success of this way of life is reflected in the growth of the Bantu population, but their rising numbers placed a steadily increasing pressure on the resources of each tribe's territory. Sections of the tribes accordingly moved away to better lands and to independence. The dynastic struggles of the period doubtless arose in part from this competition for dwindling resources. In addition, given the existing techniques of control and administration, it is possible that a chief could not hold a tribe together once its population exceeded a certain size. Sections of the tribe would hive off to take up independent existence in an organization that was in all important respects identical with that from which they had broken away. The tribes did not attempt to subdue one another



SHAKA'S EMPIRE (*broken line*) **occupied an area of 80,000 square miles. Shaka built it after becoming chief of the Zulu tribe, which originally occupied the small hatched area at center. The locations of Bulawayo, and the Mtetwa and Ndwandwe tribes are also indicated.**

by force and extend their domain: tribal wars were brief and occasional, aimed at cattle and ransom. In this restless political equilibrium the tribes existed from at least 1500 until nearly 1800. They must have waxed and waned in size, around some optimum related to their technology, economy and polity.

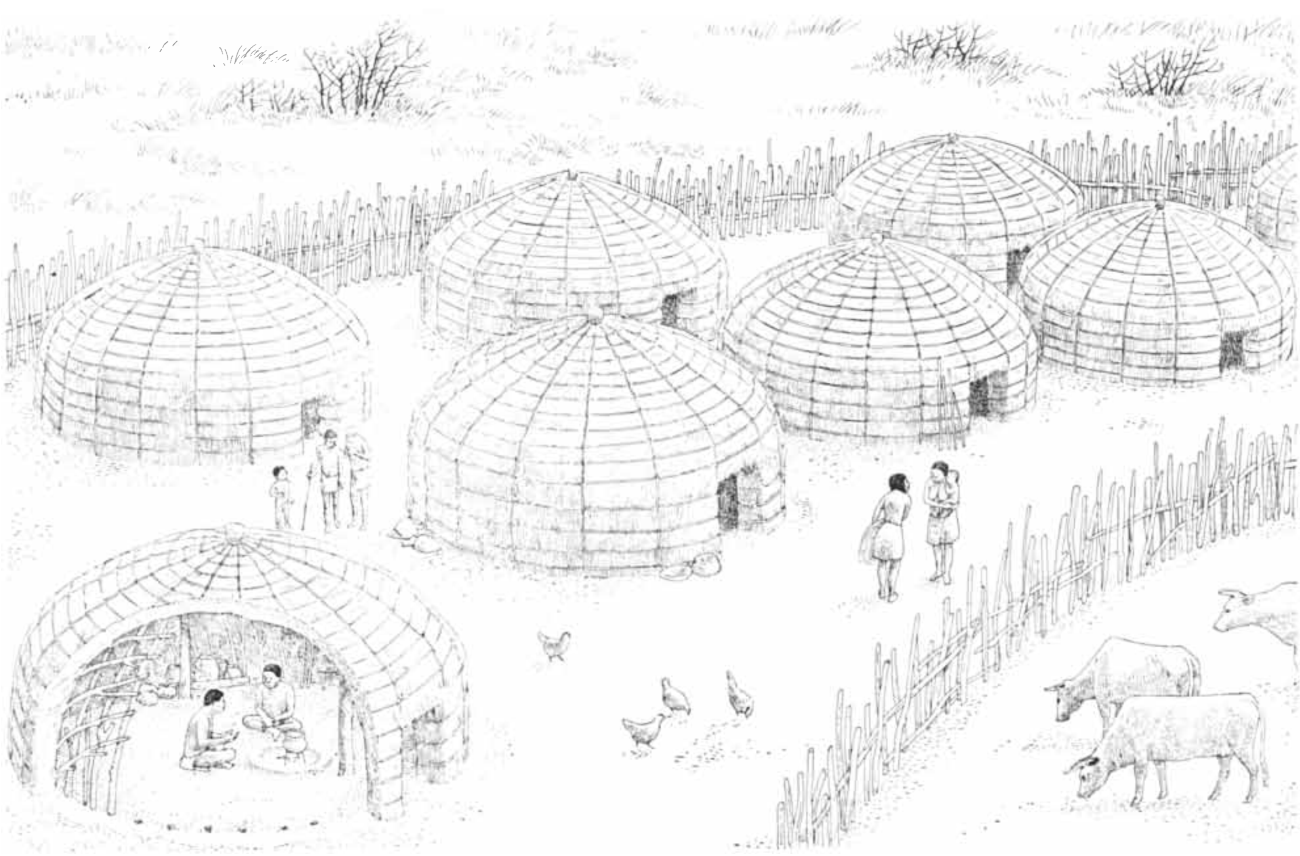
The situation changed radically just after 1800. Then in northern Natal there emerged a chief of the Mtetwa tribe called Dingiswayo. He had fled from his home under the charge of plotting to kill his father, the Mtetwa chief, and there is a legend (which is probably false) that he lived for a time among the whites in the Cape Colony. It does seem true that he was befriended by a white traveler, and that when this man was killed, Dingiswayo took his horse and gun and turned again toward his homeland. He arrived to find his father dead and his brother on the throne. Dingiswayo promptly killed his brother and seized the Mtetwa chieftainship. According to stories told some 16 years later to the English traders who visited Shaka, Dingiswayo declared that the constant fighting among the tribes was against the wish of the Creator, and that he intended to conquer them all and make them live in peace. He proceeded to subdue some 30 tribes. He organized the larger forces that came under his command into regiments and acquired military power unexampled in the previous history of these peoples. But Dingiswayo was temperate in victory. After subduing a tribe with as little slaughter as possible, he left it under its own chiefly family, perhaps choosing from it a favorite of his own to rule, though the young men of the tribe had to serve in his army.

Among the tribes conquered by Dingiswayo was the Zulu, to which Shaka belonged. Shaka was the illegitimate son of the Zulu chief—illegitimate in two senses. He was conceived out of wedlock, and his father and mother were related distantly, but sufficiently closely, to make it unlawful for them to marry. Shaka's mother was hurried into a disgraced marriage with her lover. After Shaka's birth she bore a daughter, but she and her children were ill-treated and not accepted by the tribe, and her husband finally drove her away. She and her children wandered until they found refuge in the land of the Mtetwa, where Shaka became one of Dingiswayo's bravest warriors. He rose to regimental commander and then, still at a youthful age, to commander of the entire Mtetwa army.

It was then that he began to show his martial genius. He decided that it was stupid to use javelins: Why hurl your weapon away and then wait unarmed until you could pick up one of the enemy's? He contrived instead a heavy, short-hafted, broad-bladed, stabbing spear [*see bottom illustration on page 164*]. He trained his men to fight at close quarters and to use their big shields to hook away the shield of the enemy, exposing him to a stab at the heart. Shaka also changed military tactics. In the traditional, somewhat chivalric warfare tribes fought by arranging their champions in broad ranks that stood about 50 yards apart; the warriors threw javelins at each other until one rank yielded. Shaka arranged his warriors in a close-order, shield-to-shield formation with two "horns" designed to encircle the enemy or to feint at his flanks, the main body of troops at the center and the reserves in the rear ready to exploit the opportunities of battle [*see illustration on page 166*]. These innovations revolutionized African warfare, changing it from a skirmish with few deaths to a destructive slaughter.

In 1816, when Shaka's father died, Dingiswayo helped him become chief of the Zulus. With 500 warriors trained to fight with his new weapons and tactics, he surprised and overwhelmed his opponents, who expected to fight the old type of fairly bloodless war. Shaka drafted the survivors into his army, marching them off into Zulu territory and sending Zulu tribesmen to colonize their lands.

Meanwhile Dingiswayo's example had inspired Zwide, chief of the neighboring Ndwandwe tribe, to undertake a career as a conqueror. In 1818 Zwide captured and killed Dingiswayo. Shaka seized the rule of the disintegrating Mtetwa kingdom, and was attacked by Zwide. Skillfully drawing Zwide's more powerful armies after him into territory he had stripped of food, he defeated them, thus clearing the way to establishing his rule over all the region. By 1822 he had made himself master over 80,000 square miles, an area approximately that of the state of Nebraska and a vast ter-



CLOSE-UP OF KRAAL depicts the construction and arrangement of a Zulu hut. To build it, saplings are sharpened and driven into the ground in a 12- to 15-foot circle. A second circle of saplings is placed across the first row at a sharp angle. They are then bent to join at the top, lashed together and covered with thatch. A small hearth is built directly inside the door, which is low and small. Near the back is the most important part of the hut, the *umsamo*, the dwelling place of spirits, where pots and utensils are kept.

THE P-E SPECTRUM

news of advanced systems and instruments from Perkin-Elmer

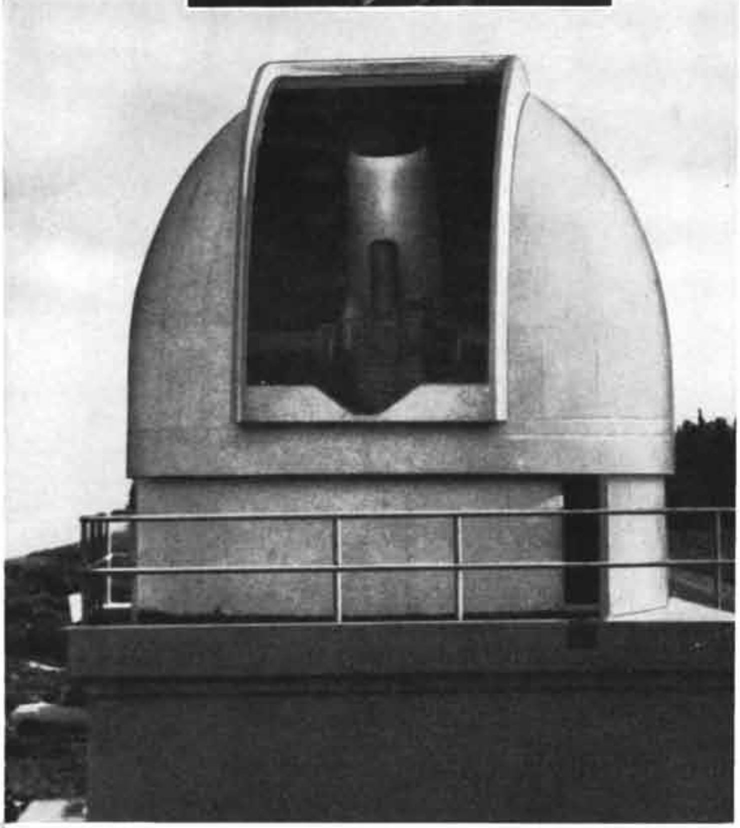
P-E'S TRACKING SYSTEM AND IR RAPID SCAN TEAM UP FOR IN-FLIGHT SPECTRAL STUDIES OF MISSILES

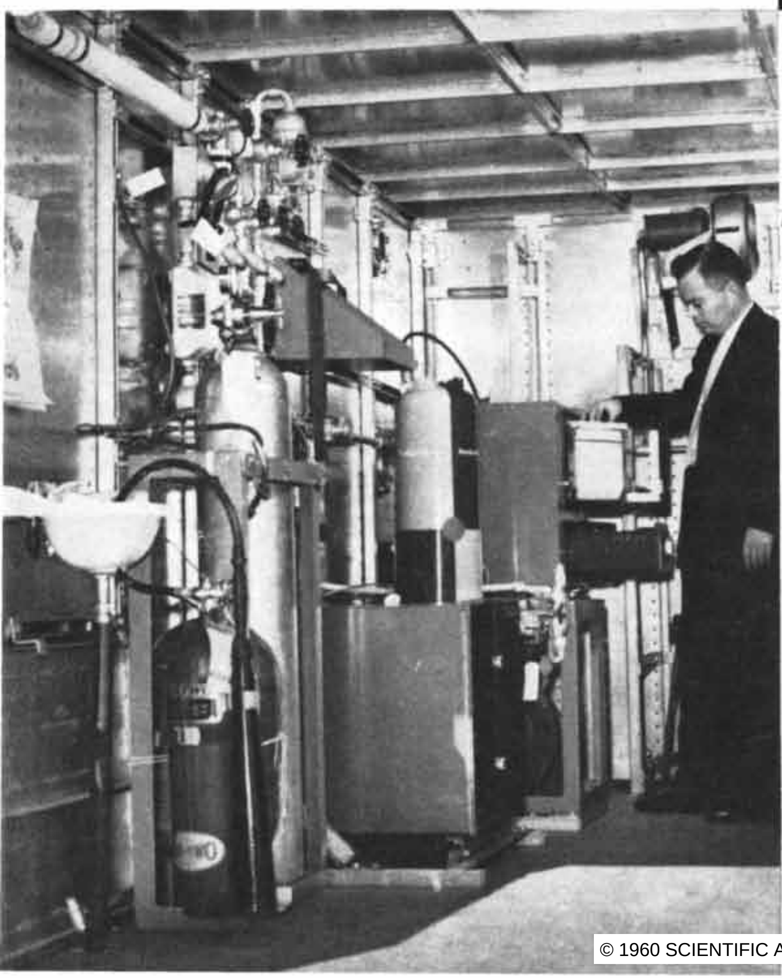
Spectrometric studies of in-flight missile plumes are currently being made on the Atlantic Missile Range by Perkin-Elmer in a project under contract from the Air Force Cambridge Research Center.

Data on the missile flights are obtained with a combination of two P-E systems: A ROTI (Recording Optical Tracking Instrument) tracks and photographs the missile in flight; simultaneously, an IR Rapid Scan System measures the spectral characteristics of the missile's plume. (Both instruments can be seen at right, in place in an observation dome, and in close-up.)

IR Rapid Scan, a new concept developed by P-E over the past several years, has made the present studies possible. Basically it is a spectrometer designed to analyze a particular wavelength region of the spectrum in very short periods of time. With it, progressive spectra of a reaction (such as burning rocket fuel) can be obtained while the reaction is going on, and a record can be obtained of various components throughout the course of the reaction.

While the potential of this method is only just beginning to be recognized, information gained from measurements of this kind could be pertinent to such advances as the development of more efficient fuels and engines, development of homing systems for anti-missile-missiles, improvement of nose cones, and even for the development of characteristic missile "signatures" for detection and identification.





PORTABLE LAB EXPLORES APPLICATIONS FOR CONTINUOUS STREAM ANALYZERS

Taking a cue from Mohammed and his mountain, Esso Research and Engineering Co. has come up with a unique answer to the problem of distance. It has designed a portable laboratory to be shipped to the parent company's refineries for on-the-spot exploration of possible new process analyzer applications.

The new unit, housed in an aluminum truck body, was built by Perkin-Elmer to Esso specification. Heart of the unique lab is a P-E Process Vapor Fractometer, which continually monitors, qualitatively and quantitatively, up to 12 components in a process stream.

At each location, Esso hopes to document the economies of successful analyzer applications as well as establish where analyzers should be installed. This will be done by comparing *before* data with data taken *after* analyzer results have been used for corrective action.

* * * *

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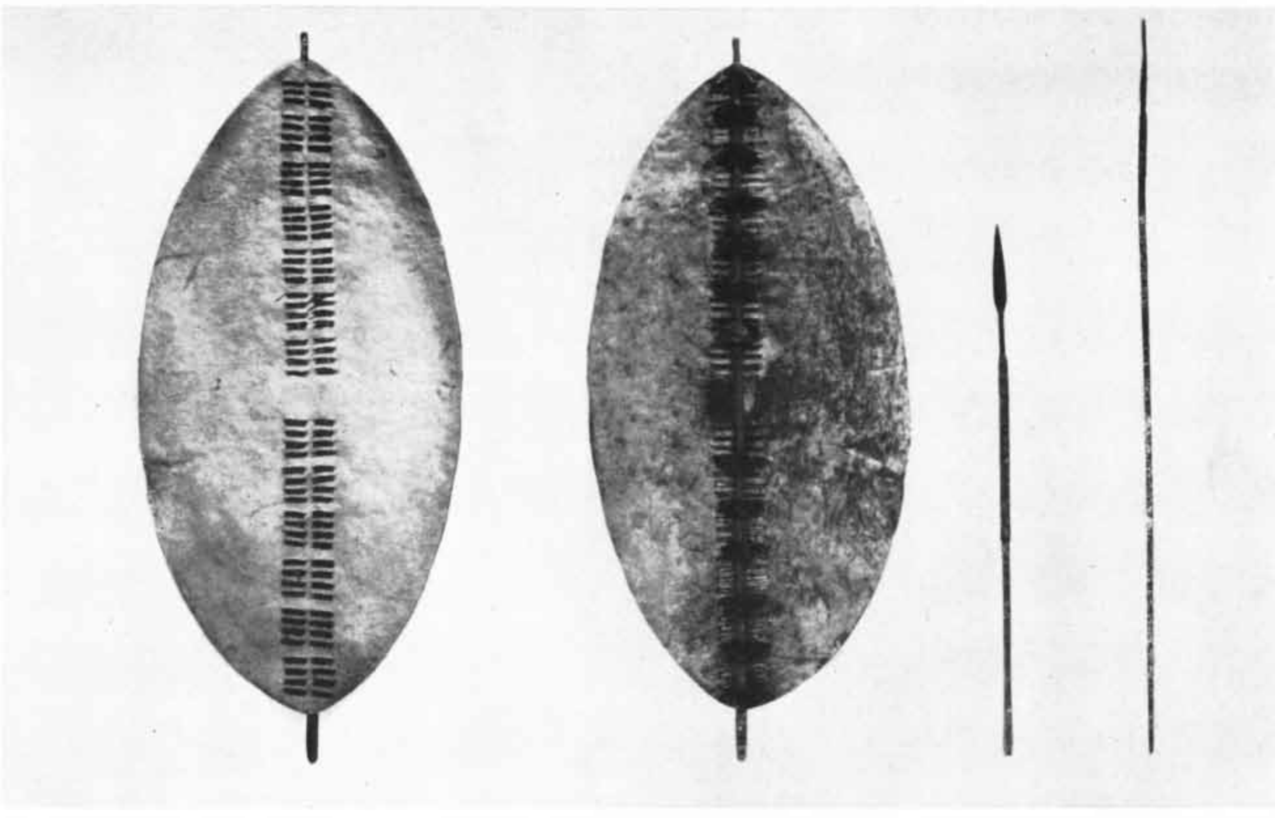
ZULU REGIMENT is halted by its commander during ceremonies in honor of a visit by the Zulu king. The modern Zulus in this photograph are armed with clubs instead of spears, and many of them carry shields smaller than those used by Shaka's troops.



ZULU WEAPONS used by Shaka's troops consisted of a rawhide shield (*shown in front view at left and back view at center*) and a short, broad-bladed stabbing spear (*second from right*) for close combat. Shaka changed war from skirmishing to slaughter by substituting the stabbing spear for the light javelin (*far right*), which was usually hurled at the enemy from a distance of about 50 yards. At this range the javelins could not penetrate the tough five-foot-tall shields, which were hardened by dipping them in water.

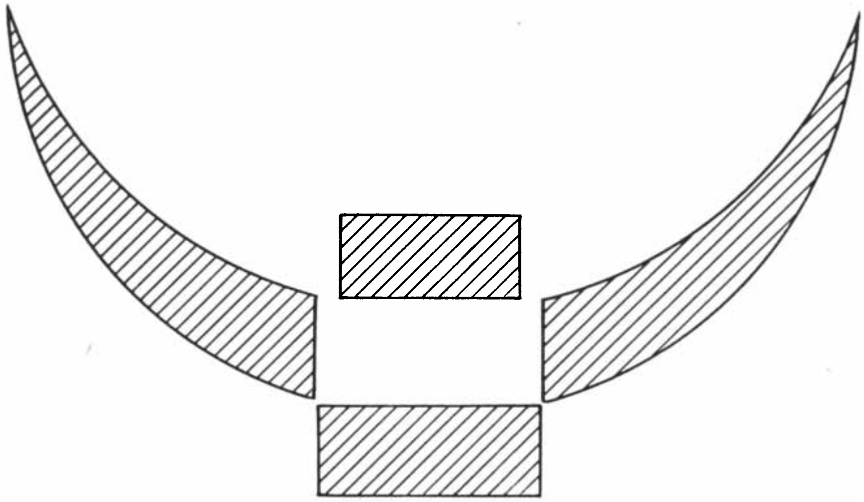
ritory to have mastered only with foot-soldiers armed with spears. His army had grown from 500 men to some tens of thousands.

The slaughter and terror wrought by this army depopulated a vast region surrounding Shaka's kingdom. From 1824 onward his troops had to march across miles of barren lands to seize cattle and to teach distant tribes to fear the name of Shaka.

From the beginning Shaka ruled as a tyrant. He impaled and killed those of his kin who had treated his mother and himself badly in his early years. After each battle troops who had retreated and other alleged cowards were executed. The English traders who visited him described how he would arbitrarily indicate men for death; almost every day men were seized and killed at his whim. His disposition fluctuated from extreme generosity to barbarous cruelty. When his mother died, some 7,000 people were killed in an orgy of mourning. Fynn, who was present when Shaka was told of his mother's death, stated that Shaka stood motionless for about 20 minutes with his head bowed upon his shield. After shedding a few tears, Shaka broke the silence with frantic yells. The tribe took the signal and likewise burst into shouts and wailings that continued through the night and into the next day. Shaka ordered a general massacre of those not displaying sufficient grief. He also ordered that for the next year, upon penalty of death, husbands and wives should abstain from sexual intercourse, that cows should not be milked and that crops should not be planted. Giving his army no rest, he sent it on one distant campaign after another.

The interference with the food supply and the reckless brutality of the year of mourning finally evoked the spirit of mutiny among his subjects. When he sent the army to raid the Portuguese settlement at Delagoa Bay in 1828, two of his brothers, Dingane and Mhlangane, seized the opportunity to assasinate him; Dingane then had Mhlangane killed, and the returning army, reduced by hunger, fatigue and malaria, acclaimed him king.

So ended the reign of the conqueror and tyrant who six years after his accession to a small chieftainship built a nation with a powerful army. He ruled it for only six years more. Yet the Zulu kingdom he had created survived his death and continued under the rule of his family. A half-century later its army was there to fight the British. In 1879 the Zulu army was at last crushed by the British and the nation brought under British sway. Yet despite the weight of



ZULU BATTLE-FORMATION (*hatched areas*) employed by Shaka consisted of four groups of warriors lined up shield-to-shield. The two "horns" were designed to encircle the enemy or to feint at his flanks. Several regiments of seasoned veterans (*center*) did the bulk of the fighting, while the reserves waited in the rear with their backs to the battle.

white overlordship the Zulu nation and the people's adulation of the Zulu royal family still survive.

From this brief chronicle of his life it becomes clear that Shaka was a genius of a kind. But his extraordinary personality does not by itself account for his martial and political triumphs. His life must be seen in the context of the time in which he lived. By the time Shaka reached manhood, Dingiswayo had already upset the pattern of Zulu warfare by waging wars of conquest, and Zwide had followed this example. There is no reason why men so intelligent and energetic as these should not have been born into the tribes during the previous three centuries. Many Portuguese, Dutch and English seamen were adopted by the tribes; any one of them could have inspired a native chieftain to imperial visions on the European scale. In fact it seems odd that none of these castaways attempted to seize and extend power themselves. A possible explanation is that in earlier years there was no point to building up power. The tribal economy was simple and undifferentiated; even in a good year the available technology did not allow a man to produce much beyond his own needs. There was little trade and no luxury, so even a conqueror could not make himself more comfortable than he had been before. One cannot build a palace with grass and mud, and if the only foods are grains, milk and meat, and the only clothes are hides, one cannot live much above the standard of ordinary men.

I believe that the main cause of imperial developments was the shortage of land. The productivity of native African agriculture is low; by the end of the 18th century the population increase had produced a land crisis. The old process of recurrent tribal splitting could no longer solve the problem. Some historians also suggest that increasing traffic with white men may have helped to start the epoch of conquest. It is known that early in his reign Dingiswayo had opened up a trade in ivory and hides with the settlement at Delagoa Bay.

Dingiswayo's attempt at large-scale conquest surely helped to create the social climate that gave Shaka his chance. But why did Shaka succeed where Dingiswayo failed? Undoubtedly here his military genius was decisive, but his personality was also important. Dingiswayo had fought his wars according to the old pattern, with as little slaughter as possible; when he conquered a people, he did not alter their tribal organization. Three times he captured and spared his rival Zwide because Zwide was his brother-in-law; then Zwide captured and killed him. On the other hand, Shaka stated quite clearly that to build a nation he had to destroy the tribal organization. Perhaps he hated that organization because he was doubly illegitimate by its laws and had suffered under it. Shaka explicitly set out to break up the tribes, to mix their peoples and to shatter the chiefly families, which he saw as rivals to his rule.

Yet in this objective not even he could succeed. Because his subjects were widely scattered, he could administer them only by organizing them into counties. He built his kingdom so rapidly that

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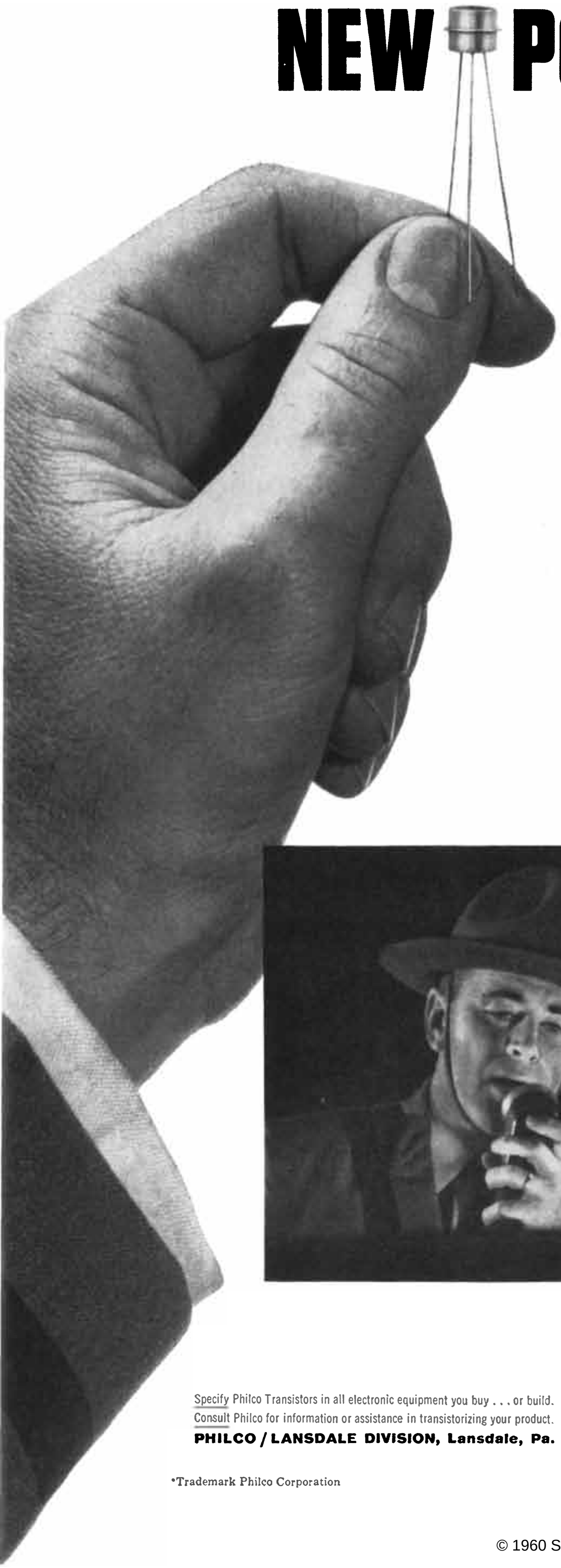

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he had to leave untouched those chiefs who surrendered to him voluntarily. He also had to reward his close supporters, and his only means of doing so was to give them land and followers. They became county chiefs, each with his own army, and the old tribal system thus reasserted itself. When one of the county chiefs died, his son succeeded him. Shaka was aware that his subjects' loyalty to his chieftains was a danger to his own rule and the stability of his empire. In short, without a change in the farming and pasturing methods of his people, without new means of communication, and without an extensive trade to integrate the territorial segments of his kingdom, Shaka was forced to disperse power to people who became the tribal chiefs he had feared. Even in death he was mocked by the tribal rules of the past: When he was killed, no chief opposed the claim of his brothers to the throne. His conquests had validated the title of his family to the throne, according to the Zulu custom.

Shaka himself had had no children. He said that a son would kill him for the throne. He had many concubines but no wives, and any concubine who became pregnant was killed. I believe that this, and other data on his sexual life, show that Shaka was at least a latent homosexual and possibly psychotic. Very likely this motivated another of his military innovations: He forbade his men to marry or have sexual relations with women until he gave them permission to do so in middle age, and he quartered all his men in great barracks, as in any modern army. It is significant that his regimental barracks system was not retained by his successors and imitators, though they used his other inventions.

Shaka became a conqueror because he was born into a system where changes in the ratio of population to land, and perhaps increased trade with Europeans through intermediary lands, were producing a drive toward the emergence of an overlord of the region. Some tribe was bound to achieve that overlordship. Chance, luck and his own energy and genius made Shaka the conqueror. But his emotional outlook, which led him to try to destroy the tribal system and to establish his regiments of highly trained bachelors fighting for the right to marry, was also extremely important.

The Zulu social heritage that he attempted to change reasserted itself in new forms. His story not only shows how a devastating individual can revolutionize his society; it also demonstrates that even a tyrant's power is ultimately restricted by the past he has inherited.

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MATHEMATICAL GAMES

About mathematical games that are played on boards

by Martin Gardner

"Games possess some of the qualities of works of art," Aldous Huxley has written. "With their simple and unequivocal rules, they are like so many islands of order in the vague untidy chaos of experience. When we play games, or even when we watch them being played by others, we pass from the incomprehensible universe of given reality into a neat little man-made world, where everything is clear, purposive and easy to understand. Competition adds to the intrinsic charm of games by making them exciting, while betting and crowd intoxication add, in their turn, to the thrills of competition."

Huxley is speaking of games in general, but his remarks apply with special force to mathematical board-games in which the outcome is determined by pure thought, uncontaminated by physical prowess or the kind of blind luck supplied by dice, cards and other randomizing devices. Such games are as old as civilization and as varied as the wings of butterflies. Fantastic amounts of mental energy have been expended on them, considering the fact that until quite recently they had no value whatever beyond that of relaxing and refreshing the mind. Today they have suddenly become important in computer theory. Chess-playing and checker-playing machines that profit from experience may be the forerunners of electronic minds capable of developing powers as yet unimaginable.

The earliest records of mathematical board-games are found in the art of ancient Egypt, but they convey little information because of the Egyptian convention of showing scenes only in profile [*see illustration below*]. Some games involving boards have been found in Egyptian tombs [*page 173*], but they are not board games in the strict sense because they also involve a chance element. A bit more is known about Greek and Roman board-games, but it was not until the 13th century A.D. that anyone thought it important enough to record the rules of a board game, and it was not until the 17th century that the first books on games were written.

Like biological organisms, games evolve and proliferate new species. A few simple games, such as ticktacktoe, may remain unchanged for centuries; others flourish for a time, then vanish completely. The outstanding example of a dinosaur diversion is rithmomachy. This was an extremely complicated number game played by medieval Europeans on a double chessboard with eight cells on one side and 16 cells on the other, and with pieces in the shapes of circles, squares and triangles. It traces back at least to the 12th century, and as late as the 17th century it was mentioned by Robert Burton, in *The Anatomy of Melancholy*, as a popular English game. Many learned treatises were written about it, but no one plays it today except a few mathematicians and medievalists.

In the U. S. the two most popular mathematical board-games are of course checkers and chess. Both have long and fascinating histories, with unexpected mutations in rules from time to time and place to place. Today the American checkers is identical with the English "draughts," but in other countries there are wide variations. The so-called Polish checkers (actually invented in France)

Relief from a tomb at Sakkara in Egypt shows a board game in profile. Relief dates from 2500 B.C.

Sample cell used at the IBM Watson Laboratory for studies of the self-diffusion of quantum liquids.

Studying Quantum Liquids to Observe Nuclear Theory

Atomic nuclei are dense systems composed of identical particles which obey Fermi-Dirac statistics. Using these statistics, scientists have computed the theoretical behavior of the particles which compose heavy nuclei.

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Experiments on the pure quantum liquid revealed diffusion persisting to the lowest temperatures. However, it was apparent that the diffusion was not thermally activated as in an ordinary liquid, or in a gas. Diffusion persisted for two reasons: (1) because of the zero-point energy of the atoms, and (2), because of the atoms' long wave length as compared with the thickness of the potential barriers which inhibited their motion. The results of the experiments on dilute solutions of He^3 in He^4, in accord with expectations, showed that the He^3 diffusion coefficient increased rapidly with decreasing temperature.

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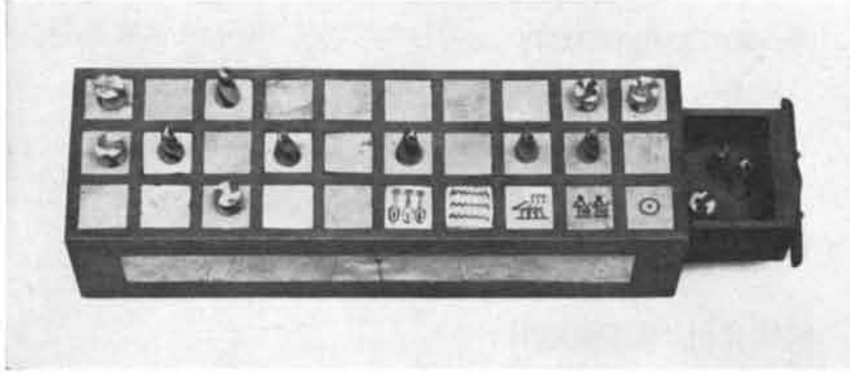


Board game of senet, found in Egyptian tomb of 1400 B.C., also involved throwing sticks

is now the dominant form of the game throughout most of Europe. It is played on a 10-by-10 board, each side having 20 men that capture backward as well as forward. Crowned pieces (called queens instead of kings) move like the bishop in chess, and in making a jump can land on any vacant cell beyond the captured piece. The game is widely played in France (where it is called *dames*) and in Holland, and it is the subject of a large analytical literature. In the French-speaking provinces of Canada, and in parts of India, Polish checkers is played on a 12-by-12 board.

German checkers (*damenspiel*) resembles Polish checkers, but it is usually played on the English eight-by-eight board. A similar form of this "minor Polish" game, as it is sometimes called, is popular in the U.S.S.R., where it is known as *shashki*. Spanish and Italian variants also are closer to the English. Turkish checkers (*dama*) is also played on an eight-by-eight board, but each side has 16 men that occupy the second and third rows at the outset. Pieces move and jump forward and sideways, but not diagonally, and there are other radical departures from both the English and the Polish forms.

Chess likewise has varied enormously in its rules, tracing back ultimately to an unknown origin in India, probably in the sixth century A.D. True, there is today an international chess that is standardized, but there are still many excellent non-European forms of the game that obviously share a common origin with international chess. Japanese chess (*sho-gi*) is played as enthusiastically in modern Japan as *go*, though only the latter game is known in Western countries. *Sho-gi* is played on a nine-by-nine board, with 20 men on each side, arranged at the start on the first three rows. The game is won, as in Western chess, by checkmating a piece that moves exactly like the king. An interesting feature of the game is that captured pieces can be returned to the board to be used by the captor.

Chinese chess (*siang k'i*) also ends with the checkmate of a piece that moves like the king in Western chess, but the rules are quite different from those of Japanese chess, and its eight-by-eight board is divided across the center by a blank horizontal row called "the river." Martian chess ("jetan"), explained by Edgar Rice Burroughs in the appendix to his novel *The Chessmen of Mars*, is a surprisingly well-thought-out variant, played on a 10-by-10 board with unusual pieces and novel rules. For example, the princess (which corresponds roughly to our king) has the privilege of one "escape move" per game that permits her to flee an unlimited distance in any direction.

In addition to these regional variants of chess, modern players, momentarily bored with the orthodox game, have invented a weird assortment of games known as fairy chess. Among the many fairy-chess games that can be played on the standard board are: two-move chess, in which each player plays twice on his turn; a game in which one side plays with no pawns, or with an extra row of pawns instead of a queen; cylindrical chess, in which the left side of the board is considered joined to the right side (if the board is thought of as having a half-twist before the sides are joined, it is called Moebius-strip chess); transportation chess, in which any piece can be moved on top of the rook and carried by the rook to another square. Dozens of strange new pieces have been introduced, such as the chancellor (combining the moves of rook and knight), the centaur (combining bishop and knight) and even neuter pieces (*e.g.*, a blue queen) that can be played by either side. (In Lewis Padgett's science-fiction novel *The Fairy Chessmen* a war is won by a mathematician who makes a hobby of fairy chess. His mind, accustomed to breaking rules, is elastic enough to cope with an equation too bizarre for his more brilliant but more orthodox colleagues.)

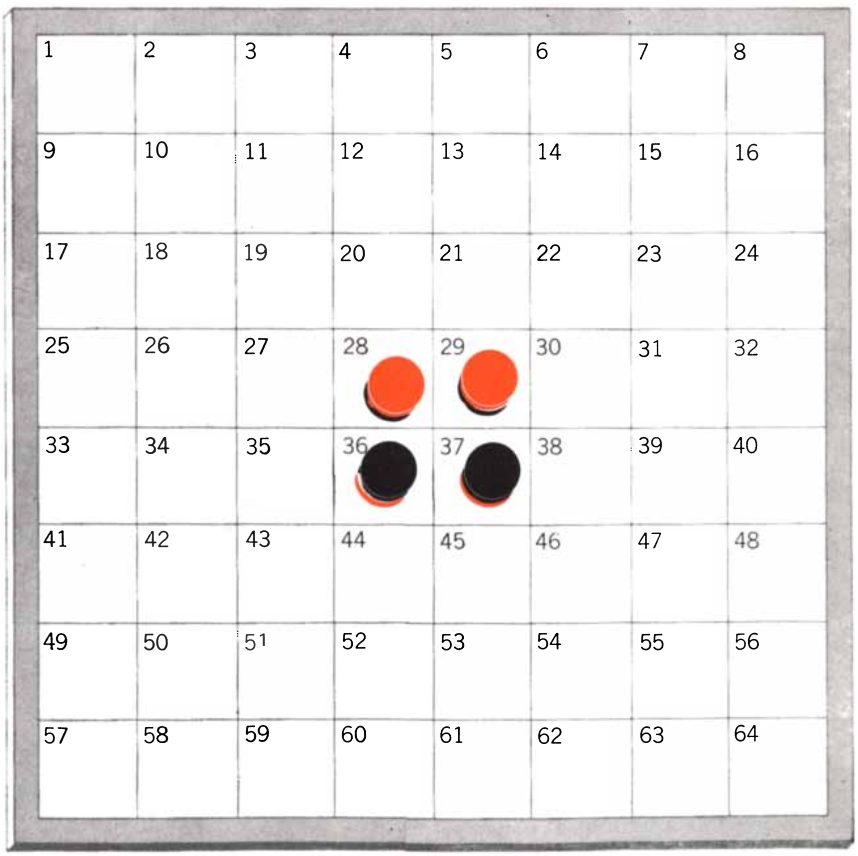
An amusing species of fairy chess that is quite old, but still provides a delightful interlude between more serious games, is played as follows. One player sets up his 16 men in the usual way, but his opponent has only one piece, called the maharajah. A queen may be used for this piece, but its moves combine those of queen and knight. It is placed at the outset on any free square not threatened by a pawn; then the other side makes the first move. The maharajah loses if he is captured, and wins if he checkmates the king. It might be thought that the maharajah has a poor chance of winning, but his mobility is so great that if he moves swiftly and aggressively, he often checkmates early in the game. At other times he can sweep the board clean of pieces and then force the lone king into a corner checkmate.

Hundreds of games have been invented that are played on a standard chessboard but have nothing in common with either chess or checkers. One of the best, in my opinion, is the now-forgotten game of "reversi." It uses 64 counters that have contrasting colors, say red and black, on their opposite sides. A crude set can be made by coloring one side of a sheet of cardboard, then cutting out small circles; a better set can be constructed by buying six boxes of inexpensive checkers and gluing the pieces into red-black pairs. It is worth the trouble, because the game can be an exciting one for every member of the family.

Reversi starts with an empty board. One player has 32 pieces turned red-side up; the other has 32 turned black-side up. Players alternate in placing a single man on the board in conformity with the following rules:

1. The first four men must be placed on the four central squares. Experience has shown that it is better for the first player to place his second man above, below, or to the side of his first piece (an example is shown in the illustration below), rather than diagonally adjacent, but this is not obligatory.

2. After the four central squares are filled, players continue placing single pieces. Each must be placed so that it is adjacent to a hostile piece, orthogonally or diagonally. Moreover, it must also be placed so that it is in direct line with another piece of the same color, and with one or more enemy pieces (and no vacant cells) in between. In other words,



An opening for the board game of reversi. Numbers are for reference only

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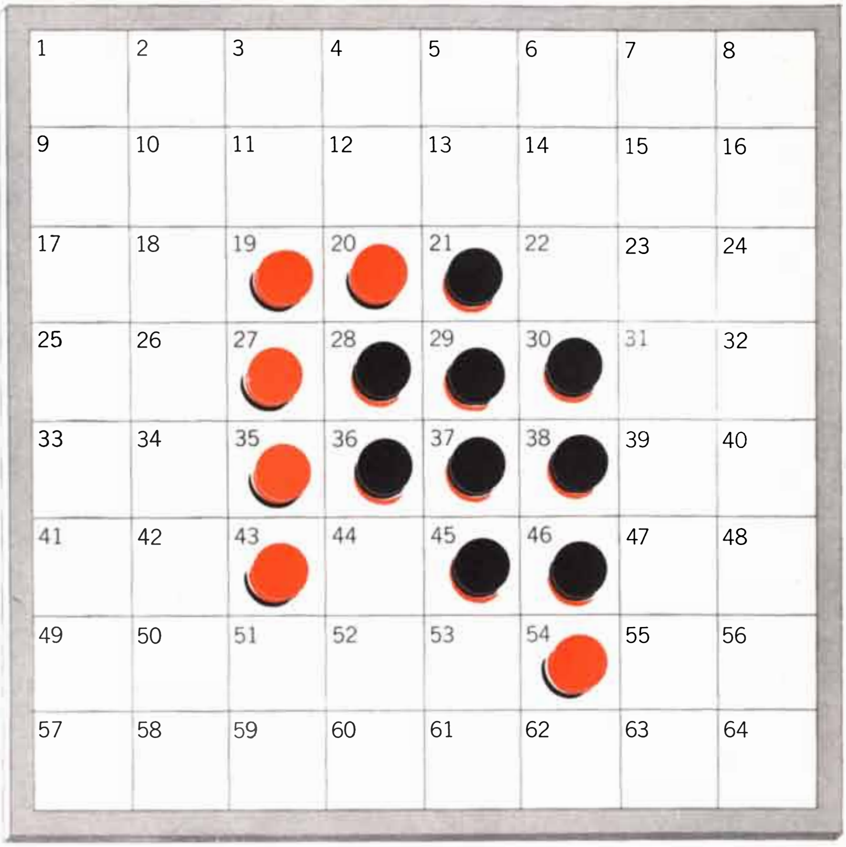

If reversi player with colored pieces makes the next move, he can win six pieces

a piece must always be placed so that it is one of a pair of friendly pieces on opposite sides of an enemy piece or at opposite ends of a chain of enemy pieces. The enemy pieces are considered captured, but instead of being removed they are turned over, or "reversed," so that they become friendly pieces. Pieces remain fixed throughout the game, but may be reversed any number of times.

3. If the placing of a piece simultaneously captures more than one chain of enemy pieces, the pieces in both chains are reversed.

4. Pieces are captured only by the placing of a hostile piece. Chains that become flanked at both ends as a result of other causes are not captured.

5. If a player cannot move, he loses his turn. He continues to lose his turn until a legal move becomes possible for him.

6. The game ends when all 64 squares are filled, or when neither player can move (either because he has no legal move or because his counters are gone). The winner is the person with the most pieces on the board.

Two examples will clarify the rules: In the illustration on page 174 red can play only on cells 43, 44, 45 and 46. In each case he captures and reverses a single piece. In the illustration on this page, if red plays on cell 22 he is compelled to reverse six pieces: 21, 29, 36, 30, 38 and 46. As a result the board, which formerly was mostly black, suddenly becomes mostly red. Dramatic reversals of color are characteristic of this unusual game, and it is often difficult to say who has the better game until the last few plays are made. The player with the fewest pieces frequently has a strong positional advantage.

Some pointers for beginners: If possible, confine early play to the central 16 squares, and try especially to occupy cells 19, 22, 43 and 46. The first player forced outside this area is usually placed at a disadvantage. Outside the central 16 squares, the most valuable cells to occupy are the corners of the board. For this reason it is unwise to play on cells 10, 15, 50 or 55, because this gives your opponent a chance to take the corner cells. Next to the corners, the most desirable cells are those that are next but one to the corners (3, 6, 17, 24, 41, 48, 59 and 62). Avoid giving your opponent a chance to occupy these cells. Deeper rules of strategy will occur to any player who advances beyond the novice stage.

Little in the way of analysis has been published about reversi; it is hard to say

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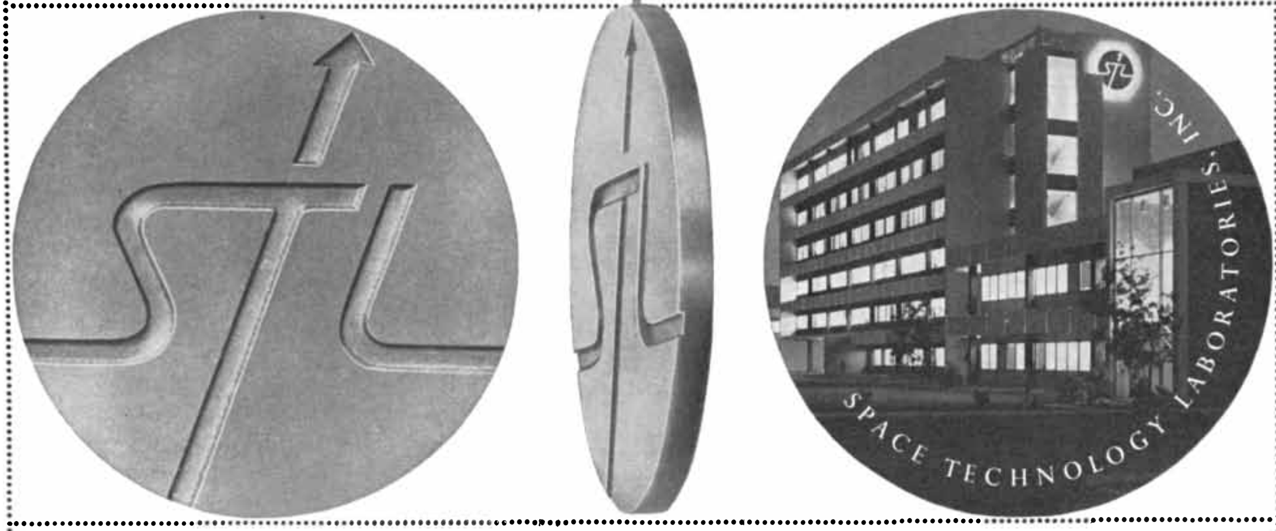

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who, if either player, has the advantage on even a board as small as four-by-four. Here is an interesting problem that some readers may enjoy trying to solve before the answer is given in this department next month. Is it possible for a game to occur in which a player, before his 10th move, wins by removing *all* the enemy pieces from the board?

An amusing thing about the history of reversi is that two Englishmen, Lewis Waterman and John W. Mollett, both claimed to be the sole inventor. Each called the other a fraud. In the late 1880's, when the game was enormously popular in England, rival handbooks and rival firms for the manufacture of equipment were authorized by the two claimants. Regardless of who invented it, reversi is a game that combines complexity of structure with rules of delightful simplicity, and a game that does not deserve oblivion.

The answer in smallest numbers for last month's Lewis Carroll problem of finding three right triangles with integral sides and equal areas is 40, 42 and 58; 24, 70 and 74; and 15, 112 and 113. In each case the area is 840. Had Carroll doubled the size of the two triangles that he found, he would have obtained the first two triangles cited above, from which the step to the third would have been easy. Henry Ernest Dudeney, in the answer to problem 107 in his *Canterbury Puzzles*, gives a formula by which such triangle triplets can be easily found.

Carroll's truth-and-lie problem has only one answer that does not lead to a logical contradiction: A and C lie; B speaks the truth. The problem yields easily to the propositional calculus by taking the word "says" as the logical connective called equivalence. Without drawing on symbolic logic one can simply list the eight possible combinations of lying and truth-telling for the three men, then explore each combination, eliminating those that lead to logical contradictions.

Carroll's solutions to the six doublets are: Grass, crass, cress, tress, trees, frees, freed, greed, green; ape, are, ere, err, ear, mar, man; one, owe, ewe, eye, dye, doe, toe, too, two; blue, glue, glut, gout, pout, port, part, pant, pint, pink; winter, winner, wanner, wander, warder, harder, harper, hamper, damper, damped, dammed, dimmed, dimmer, simmer, summer; rouge, rough, sough, south, sooth, booth, boots, boats, brats, brass, crass, cress, crest, chest, cheat, cheap, cheep, cheek.

The letters *abcdefgi* rearrange to make the hyphenated word *big-faced*.

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How New Landing Systems from Radioplane Meet the Demands of High Altitudes, Increased Bail-out Speeds, and Recovery from Space

by Ed Ewing

Engineering Specialist, Assigned to Project Mercury at Radioplane Division, Northrop Corporation

In high-speed bail outs, the opening process of the standard personnel parachute is a nylon explosion. The fate of the man with his body harness attached to the risers depends mainly on the magnitude of this opening shock and his body position when he receives it. Today's increased speeds and altitudes (where parachutes open even faster) have made opening shock a serious hazard to survival.

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"An Astrovehicle Rendezvous-Guidance Concept" by Norman V. Petersen, Robert Swanson and Leroy Hoover.

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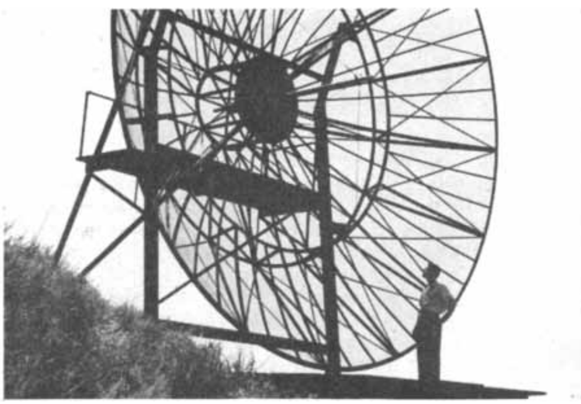

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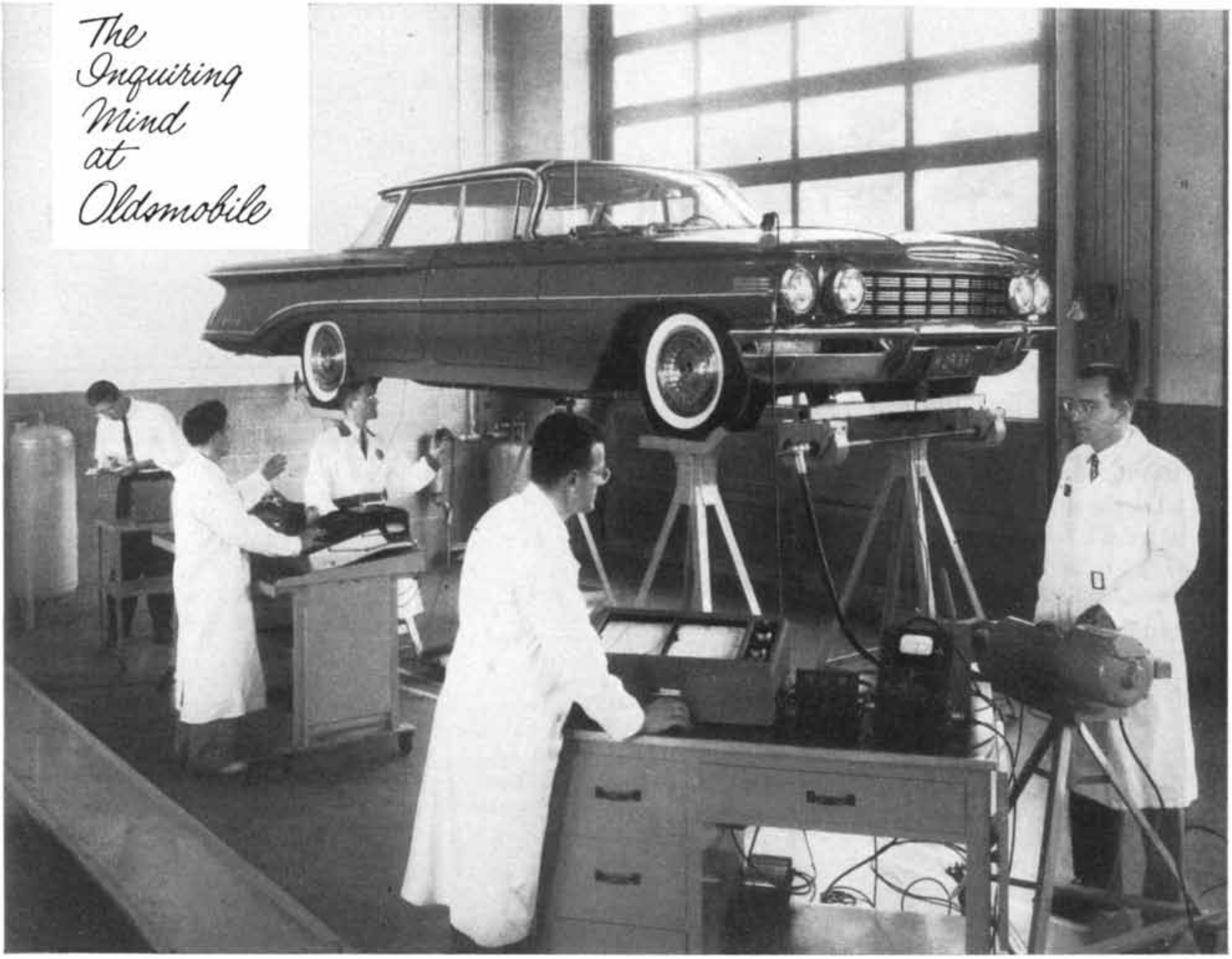

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THE AMATEUR SCIENTIST

Apparatus to demonstrate the Coriolis force, and how to make a kymograph out of a tin can

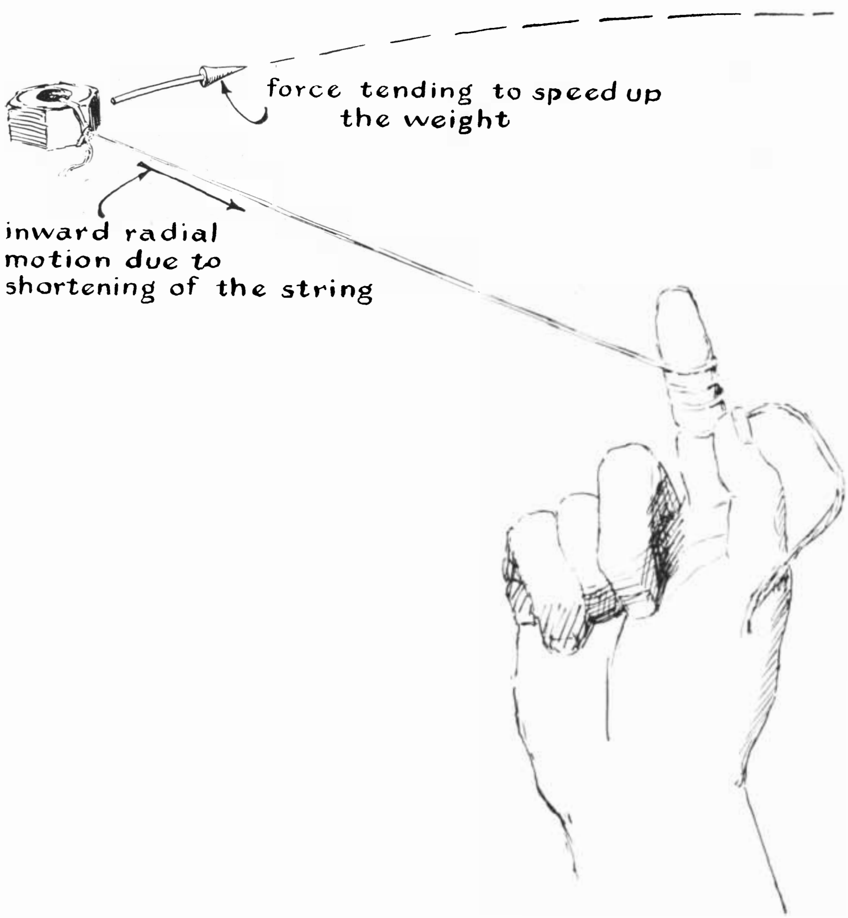
Conducted by C. L. Stong

There was a time not long ago when an amateur who had a keen interest in the physical sciences, and who liked to make things, almost always turned to physical apparatus that has a specific purpose—a telescope, say, or a short-wave transmitter and receiver. Today, with the frontiers of the physical sciences more than ever beyond the reach of the amateur, there is a new trend: the making of apparatus the sole purpose of which is to illuminate a fundamental physical principle. By the construction of such apparatus the amateur can enrich his understanding of, to choose only one example, the motions of an artificial satellite. In this vein Francis W. Niedenfuhr, associate professor of engineering mechanics at Ohio State University, writes:

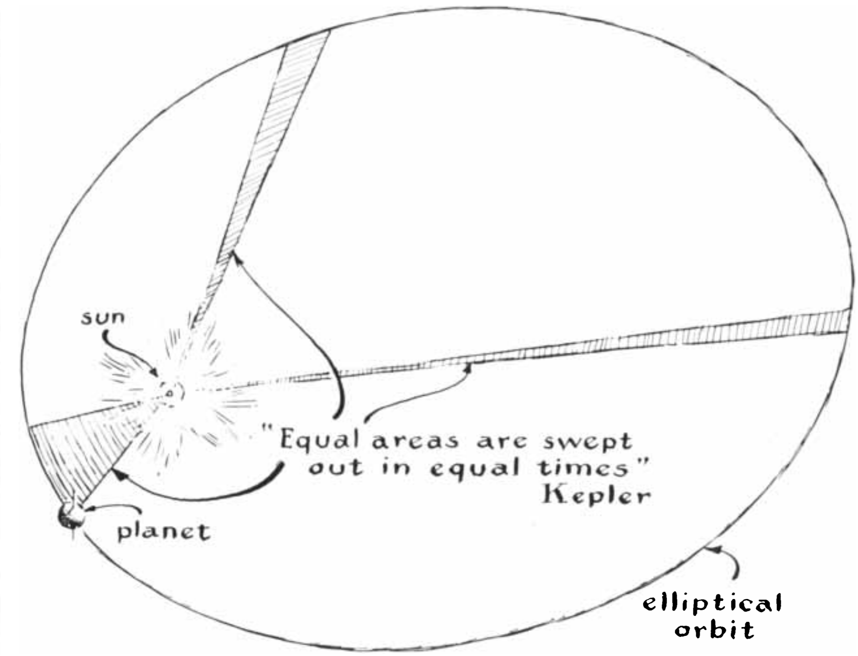
"As an engineering scientist I am always interested in finding seemingly different phenomena that are governed by a single elementary law. When a simple law of physics is well understood in a familiar situation, its application to a new situation is made easier. Moreover, when we understand the application of a law to a variety of situations, we can say that we begin to understand the law itself.

"Some months ago there was a discussion in your department of the speeding-up of an artificial earth-satellite as the radius of its orbit decreases ["The Amateur Scientist"; January, 1958, and April, 1958]. The situation can be visualized as follows. Consider the curious gait of the ticket collector on a moving merry-go-round. The fellow is not drunk; he walks that way because he is responding to a rather complex situation of relative motion. The horses near the outside of the merry-go-round have a greater velocity than those near the inside. When the ticket collector moves from the outer horses toward the inner ones, he takes some of the velocity of the outer horses with him; as he takes each step it appears to him that the floor of the merry-go-round is moving backward. Moreover, the mass of the merry-go-round, which is considerably greater than his own, slows him down and tends to throw him off balance. To be sure, the man also slightly speeds up the merry-go-round. If he weighed much more and the merry-go-round much less, the primary effect would be to speed up the merry-go-round rather than to slow him down. In any case we can observe a relative acceleration arising from the interaction of the radial velocity of the man and the rotational velocity of the platform. Formal mathematical analysis yields the same result, and we find that the acceleration is equal to twice the radial velocity multiplied by the angular velocity.

"The effect can be demonstrated by a primitive experiment that all of us have made at one time or another. Swing a small weight in a circular orbit at the end of a string, and let the string wind up on your finger as depicted in the accompanying illustration [*below*]. The result is always the same. As the length of the string decreases, the speed of the weight increases. It is a law of nature. The string may be likened to a nearly massless merry-go-round, and the weight to a very heavy ticket collector. The



A simple demonstration of the Coriolis force



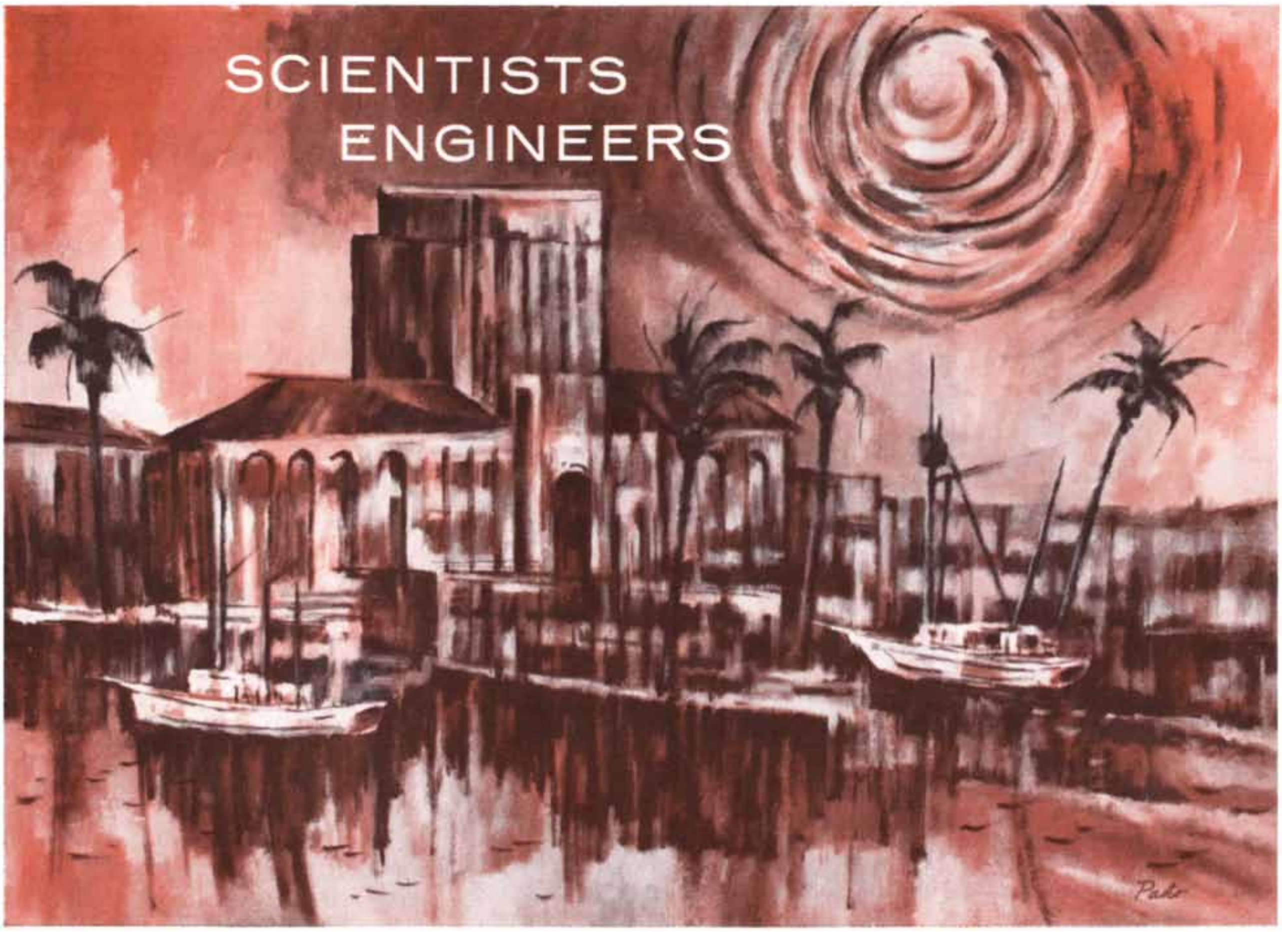
A representation of Kepler's law

weight has a radial velocity toward your finger because of the shortening of the string. The radial velocity interacts with the rotational velocity to produce an acceleration that is tangential to the path of the weight and thus acts to speed up the weight. Students of Newton's laws recall that 'force equals mass times acceleration,' so that it is permissible to think of a force that causes the weight to speed up. The result is quite general. When a body in rotational motion also moves in a radial direction, a force acts to speed up the body if the radial motion is toward the center of rotation (or to slow down the body if the radial motion is away from the center). This force is called the Coriolis force in honor of Gaspard Gustave de Coriolis, a French engineer and mathematician of the early 19th century. Both the speeding-up and the slowing-down effects can be observed with the weight-on-the-string experiment, speeding up as the string winds up on the finger and slowing down as the string unwinds.

"So much for fingers, strings and weights. In the case of an artificial satellite the string is replaced by the force of gravity. When the orbit of the satellite dips closer to the earth so that the radius of curvature of its path decreases, the satellite must speed up. This effect, when observed in celestial bodies, is usually explained in terms of Kepler's law, which states that the straight line joining a planet to the sun sweeps out equal areas in any two equal intervals of time [*see illustration above*].

"The Coriolis force operates in many earth-bound ways, not the least interesting of which is the 'gyrotron.' This device is simply a tuning fork that is made to rotate on its long axis as its tines vibrate at right angles to the axis [*see illustration on page 186*]. As the weighted tines move toward the center of rotation, the Coriolis force acts to speed up the rotation of the fork in perfect analogy with the weight on a string. As the tines move away from the center of rotation, the force reverses and so acts to slow down the rotation. The effect here is just the same as the one we observed with the weight on a string, except that in this case the law gives rise to an alternating torque: a torque because the changing force tends to twist the tuning fork on its axis; alternating because the force changes with the oscillation of the tines. The tines of a tuning fork pitched at middle C oscillate 256 times per second. In consequence the alternating torque also oscillates 256 times per second.

"An important property of this alternating torque is that it grows in magnitude in direct proportion to the rate of rotation of the tuning fork. This means that if a way could be found to measure the magnitude of the torque, we would have an instrument sensitive to rates of rotation, just as a gyroscope is. This instrument would have a number of advantages over the gyroscope: it would have no continuously spinning parts or complex gimbal rings (hence nothing to wear out), and it would not need an erecting system. The puzzle of how to



San Diego Civic Center, an original painting by Sammy Pasto, Convair/San Diego artist

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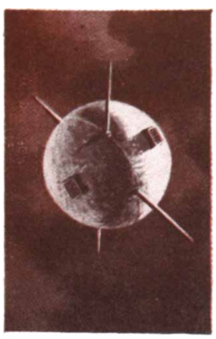
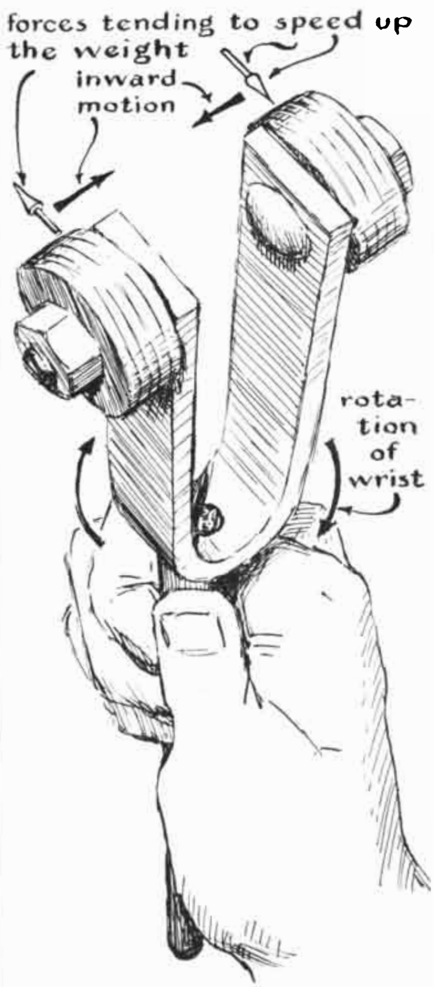


CONVAIR DIVISION OF GENERAL DYNAMICS

measure the alternating torque has been solved. One of the effects of the alternating torque is to twist the shaft or shank of the tuning fork and thus to set up a torsional vibration there. This vibration strains the material of which the shank is made, and the strain can be measured very accurately by electrical strain-gauges.

"Incidentally, electrical strain-gauges are interesting in their own right. They consist essentially of fine wires glued to the surface of the shaft. As the shaft is strained, the wires are stretched a minute amount that alters their electrical resistance in proportion. The change of resistance controls the voltage output of a constant-current power-supply. The effect can be displayed by a voltmeter calibrated to measure the strain.

"A model of the gyrotron which demonstrates the effect in terms of sound is easy to make. A conventional tuning fork of the type sold by music shops is mounted on a wooden base by means of a heavy metal bar [*see illustration on page 188*]. A lever attached to the shank



Tuning-fork demonstration of Coriolis force

Flames swept across the open plains as the Mongol hordes ran in terror from the "arrows of flying fire". When the smoke had cleared the Chinese had won the battle of Pienking with the first rocket.

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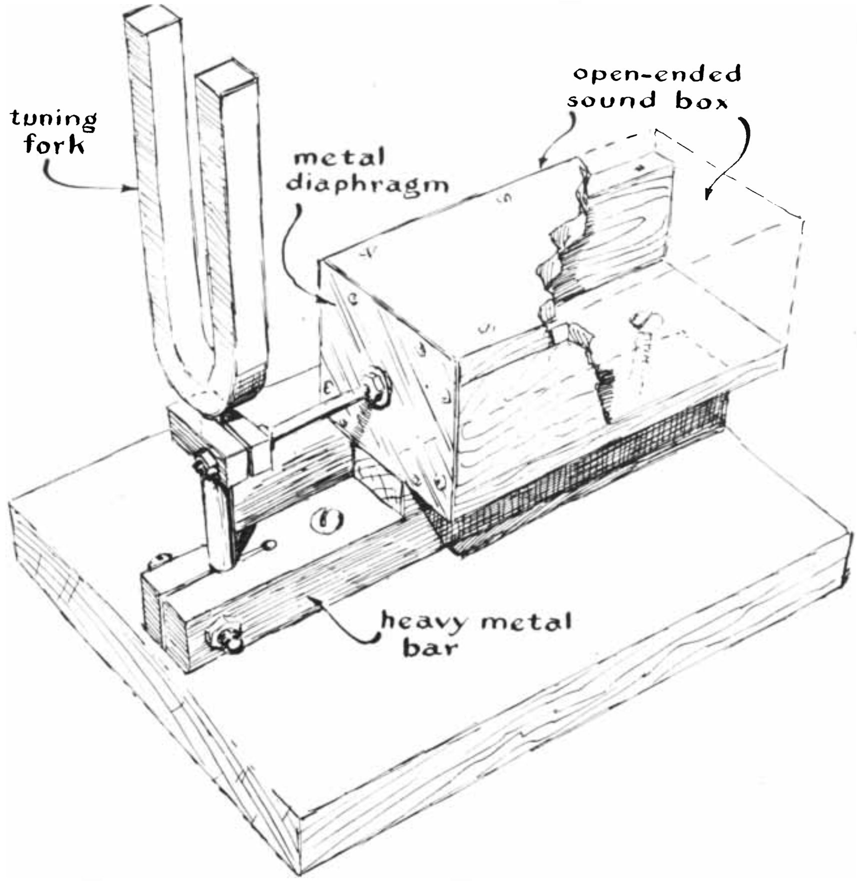
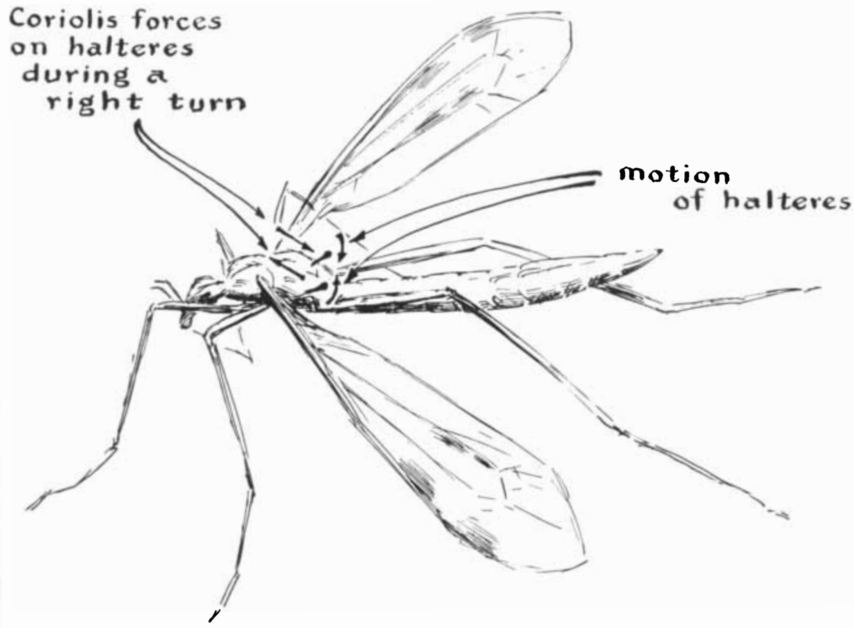


Gyrotron apparatus for sensing rate of turn

where it joins the fork communicates vibration through a steel rod to the closed end of a box. This end acts as an oscillating diaphragm. The opposite end is open. The box can therefore operate as a cavity resonator, just as an organ pipe does. If the tines of the fork are set in motion and the whole apparatus is turned about its vertical axis, the Coriolis force will set the upper end of the shank into torsional vibration. (The bottom end is restrained by the heavy metal bar.) It will be found that the volume of sound emitted by the cavity varies according to the rate at which the apparatus is turned. The best results will be obtained when the respective parts of the apparatus are tuned to the same frequency, that is, when the tines of the fork, the torsional vibration of the shank and the resonator all respond to the same pitch. These responses can be calculated, but beginners will have more fun if they cut and try until the best result is achieved. When this happy state is reached, the gyrotron will give forth a satisfying 'oowah' when given a turn.

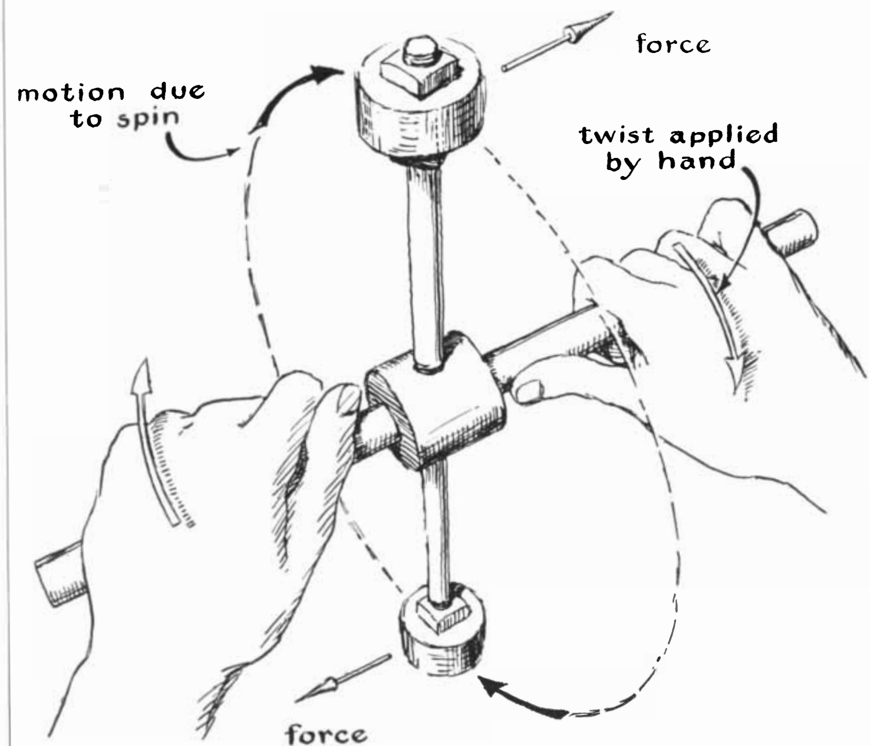
"Long before I had heard of the gyrotron, J. W. S. Pringle published in *Philosophical Transactions of the Royal Society* (Series B, 1948) a most interesting paper entitled: 'The Gyroscopic Mechanism of the Halteres of Diptera.' (Diptera are insects that have two wings.) This proved to be a discussion of the mechanism that informs the insect of changes in its flight path. All the two-winged insects, including the housefly and the mosquito, have instead of an extra pair of wings (most insects have four wings) a pair of small, club-shaped organs called halteres (singular: halter). As the insect flies about, it moves the halteres up and down in much the same way as it beats its wings. Upon making a turn, the halteres exert an alternating torque on the body of the insect. The forces and motions at one instant of a right turn are indicated by the arrows in the accompanying illustration [*top of page 190*]. Pringle's work showed conclusively that the halteres act as a 'rate of turn' sensor. The torques generated by the halteres are picked up by nerve endings at the base of each halter, transformed into an electrochemical signal and transmitted to the insect's brain. This nerve impulse tells the insect not only that it is turning but also how fast. When the halteres are removed, the insect cannot control its flight.

"The halteres can best be seen on

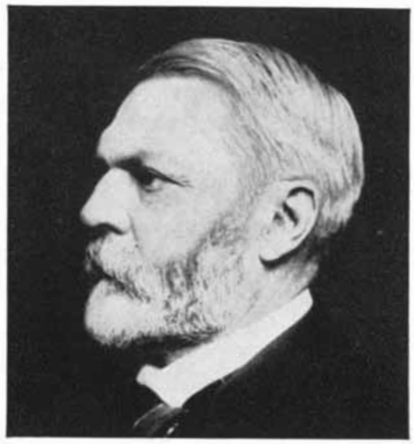


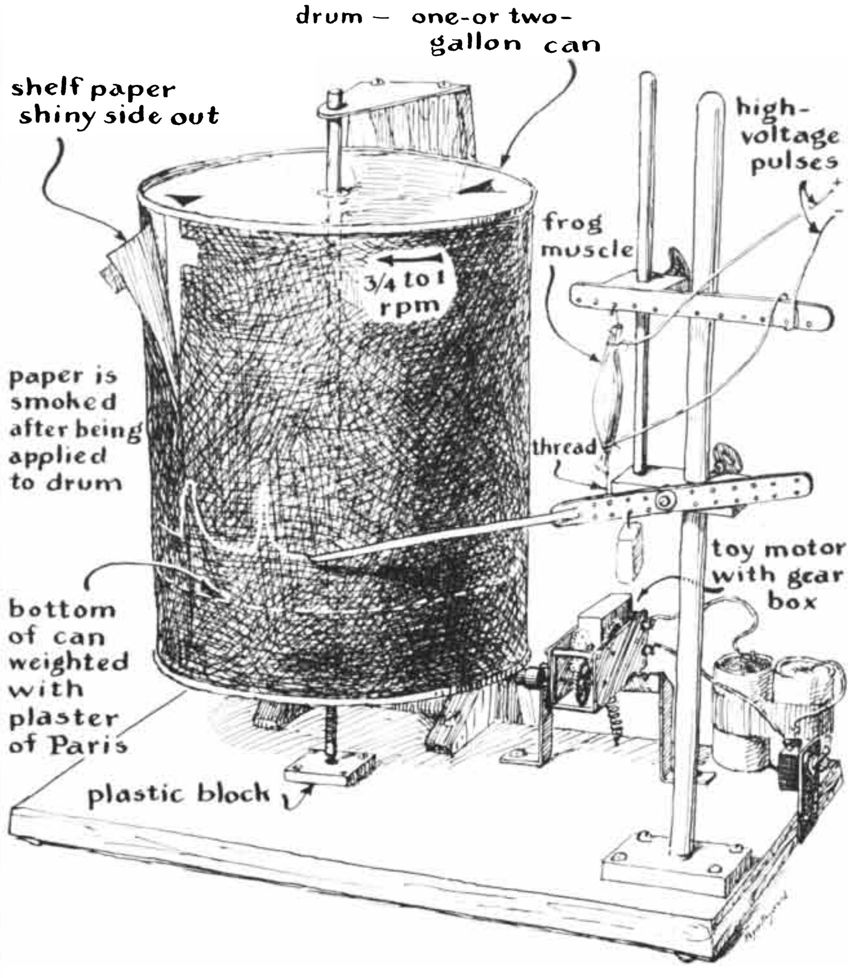
How a mosquito applies the principle of the gyrotron

some of the large species of Diptera. The crane fly is easy to catch in the garden on a late-summer day because he is a large fellow, measuring an inch or more in length. His halteres are nearly a quarter of an inch long and clearly visible to the unaided eye. If he is not pinched too vigorously when he is caught, he will oblige the amateur observer by alternately shaking and resting his halteres, thereby giving a splendid exhibition of how they operate. A mosquito is built in much the same way, but of course on a smaller scale. The observer thus needs a light touch to capture one without damaging it, and a hand glass to see the halteres in action. The housefly is easier to catch, but harder to observe. Its halteres are hidden away from the slipstream in a cavity between its thorax and its abdomen, and are protected by a pair of tiny plates called squamae. The



A simple gyroscope for demonstrating a basic law of dynamics





The tin-can kymograph set up to record the contractions of a frog muscle

squamae are located just behind the wings and cover the joint between the thorax and the abdomen. The plates must be lifted to see the halteres, and again a good magnifying glass will be needed.

"Since it is so well established that the halteres of the two-winged insects act as a turn-rate sensing device, it would be interesting to know whether the four-winged insects use their wings for the same purpose. The dynamic forces exerted on a wing are the same as those on a halter; all that is necessary is a nervous system adapted to pick up the signal. Perhaps amateurs who enjoy experiments in both mechanics and zoology will wish to explore this problem.

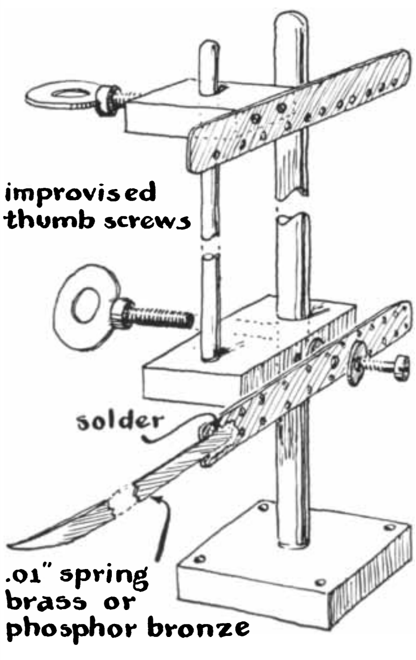
"I have mentioned gyroscopes. The combination of linear motion and turning motion in this apparatus gives rise, as always, to the Coriolis force. In the case of the gyroscope the linear motion is found in the spinning mass. Being unidirectional, this action produces a continuous—not alternating—set of Coriolis forces. A steady torque is accordingly generated by rotating the gyroscope as shown in the accompanying illustration [*bottom of page 190*]. In this gyro the mass is shown as a pair of weights corresponding to the tines of a tuning fork or the halteres of a fly. The conventional gyro uses a wheel, of course, rather than a pair of weights. The effect of the Coriolis force acting on a wheel can be obtained by adding up the effects of such forces on the elementary parts of the wheel. This is a mathematical problem called integration that I have discussed in 'The Amateur Scientist' [August, 1958]. When the necessary mathematical steps are taken, the whole set of phenomena called gyroscopic action is readily explained."

On one occasion or another most experimenters and science teachers have need for a recording apparatus that can automatically plot the movement of a pen or a stylus against time. They usually find some alternative, because the price of commercial recorders begins at $100 and has a fast rate of climb. Norman D. Weis, an instructor at Casper College in Casper, Wyo., was confronted

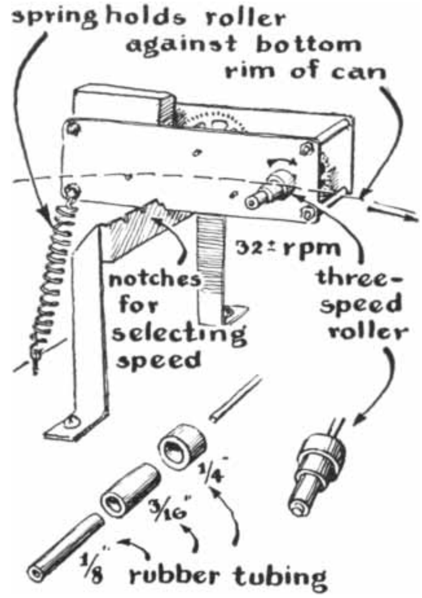
by the problem last year while he was doing graduate work at the University of Colorado, and he decided to meet it head-on. He calls the result the tin-can kymograph. Basically Weis's instrument consists of a motor-driven drum mounted vertically on a thrust bearing and fitted with a sheet of smoked paper on which the graph is traced by a mechanically actuated stylus.

"The cost of this apparatus," writes Weis, "will vary from nothing to as much as $10, depending upon the builder's talents for adapting and scrounging. The secret of the low cost is found in the method of driving the drum that transports the record sheet. Instead of coupling a motor to the axle of the drum by means of gears, as is done in conventional designs, my drum is driven at its edge by frictional contact with an extension of the motor shaft. Moreover, when the apparatus is used to chart the respiration of a human subject, the stylus is actuated by a length of thread anchored by a book instead of the expensive chest-expansion tube and tambour-needle assembly familiar to students of biology. The original model of my apparatus, which is depicted in the accompanying illustration [*page 192*], is currently employed at Casper High School.

"The stylus assembly can be moved up and down the drum as desired, thus providing for several recordings on one sheet of paper. The number of recordings per sheet is limited only by the amplitude of the stylus excursions. Although normally actuated by a mechanical link



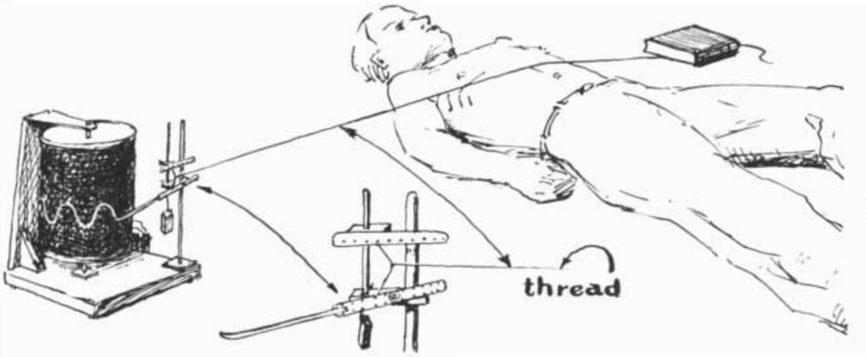
Detail of stylus for kymograph



Detail of drive for kymograph

in biological observations, the stylus may be coupled to any desired sensing device and driven pneumatically, electrically or otherwise.

"A gallon can of the kind used for shipping fruit juice or syrup serves as the drum. The can is weighted with about an inch of plaster of Paris. An accurately centered hole 1/4 inch in diameter is drilled through the top and bottom. One or more additional small holes in the top equalize the air pressure inside the can with that of the atmosphere. The drum turns on a shaft made of 1/4-inch drill rod, or other straight material, inserted through the centered holes of the can and soldered in place. The ends of the shaft extend beyond the can two inches at the top and 1½ inches at the bottom. The bottom of the shaft should be cut square and smoothed with a fine stone. The drum assembly is supported by a thrust bearing: a piece of plastic 1/2 inch thick drilled with a centered hole 3/8 inch deep. A steel ball 1/4 inch in diameter is placed in the bottom of the hole. The shaft turns on this ball. The upper end of the shaft is supported laterally by a simple journal-bearing: a hole through a piece of 16-gauge sheet metal screwed to a solidly braced column of plywood. The base to which the column, thrust bearing and other components are screwed, is a piece of plywood 3/4 inch thick, 12 inches wide and 16 inches long, finished with shellac. It rests on four rubber buttons of the kind used on the bottom of chair legs. The drum assembly is removed from the instrument simply by lifting it from the thrust bearing, swinging the



How the kymograph is used to chart respiration

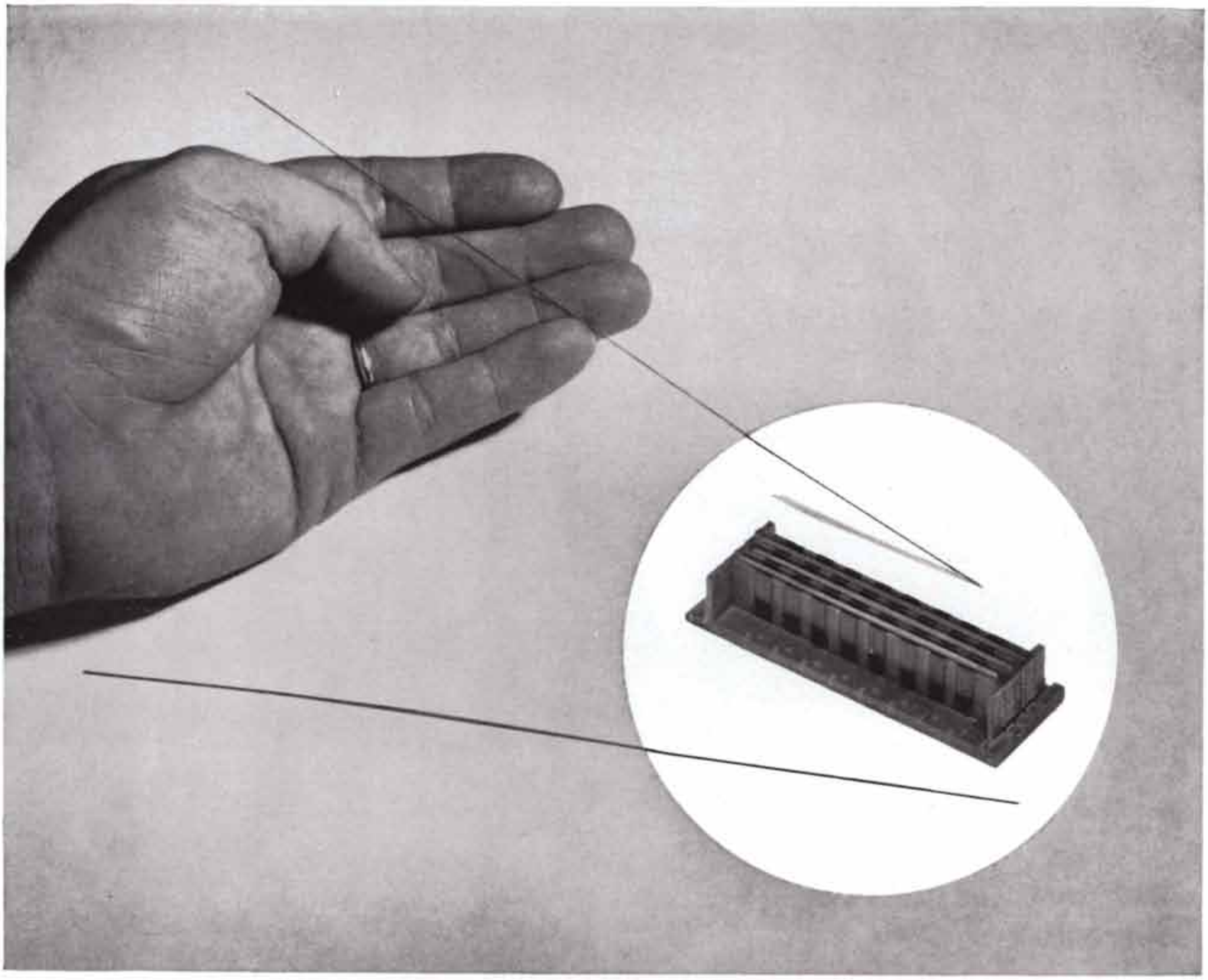
shaft to one side and sliding it out of the upper bearing.

"Any small motor will serve for the drive, but construction is simplified by using a motor with built-in reduction gears. Mine was taken from a mechanical toy that operated from a two-cell battery. Similar motors are sold by hobby shops and toy stores for use with model-construction kits. The drive shaft should turn at a rate of about 30 revolutions per minute. The shaft is fitted with a series of frictional rollers of increasing diameter. These are made of rubber tubing; a relatively long piece that makes a snug fit with the shaft is first pushed over the shaft. Progressively shorter lengths of increasing diameter are then telescoped over the first length. My rollers were made from three sizes of tubing: 1/8, 3/16 and 1/4 inch, as shown in the accompanying illustration [*top of page 194*].

"The active components of the stylus assembly include the stylus and its supporting lever arm together with a secondary fixture that is electrically insulated from the remainder of the apparatus [*bottom illustration on page 194*]. These parts are supported by a movable block that rides on and clamps to a vertical post attached to the base by a flange. The post may be made of drill rod 3/8 inch in diameter. Any handy material, such as steel or plastic, may be used for the block. The lever arm of the stylus assembly is drilled in the middle and mounted on the block by a screw and washers. It must turn freely. The edges of the lever arm are drilled with holes 3/32 inch in diameter spaced at 1/4-inch intervals. These make it possible to balance the stylus by hooking a small weight to the bottom of the arm, and to attach specimens or apparatus to the top of the arm. A secondary post of 1/4-inch stock extends from and above the movable block. This supports a second block made of insulating plastic, to which a metal strip is attached that will hold the upper end of a specimen. The lower edge of this strip is drilled with a set of holes to match those in the upper edge of the lever arm. The blocks are secured to their respective posts by thumbscrews. This arrangement permits the entire stylus assembly to be shifted vertically merely by loosening the thumbscrew that clamps the lower block.

"I find that recordings made on highly calendered (slick) shelf paper are quite sharp and easy to read. A 25-cent roll of paper lasts for months. The paper is cut to match the depth of the cylinder and long enough to wrap around it with 1/4-inch overlap. The direction of the wrap should be chosen so that the stylus slides off the top of the overlap—otherwise it may catch and tear the edge of the paper. The overlap is stuck together by bits of Scotch tape. The paper may be smoked over almost any flame deficient in oxygen: a Bunsen burner with the air supply closed, a candle or a kerosene lamp.

"Graphs of respiration are made by stretching a thread over the chest of the subject, tying one end to the lever arm and anchoring the other under a book. (If the subject should sit up suddenly, the thread slides from beneath the book and spares the apparatus.) Variations in respiration can be observed by having the subject rest for a few minutes prior to starting an experimental run or, conversely, by having him exercise vigorously immediately prior to the run. Muscle contraction is recorded by attaching a bit of muscle from a frog or some other experimental animal between the lever arm of the stylus and the insulated fixture. Contraction is stimulated by applying a pulse of high voltage across the ends of the muscle. Warning: Do not take the pulse from a high-current source such as a 110-volt power line. To do so invites accidental shock and possible injury. Small 'B' batteries of the kind used in portable radio sets are safe and completely adequate."



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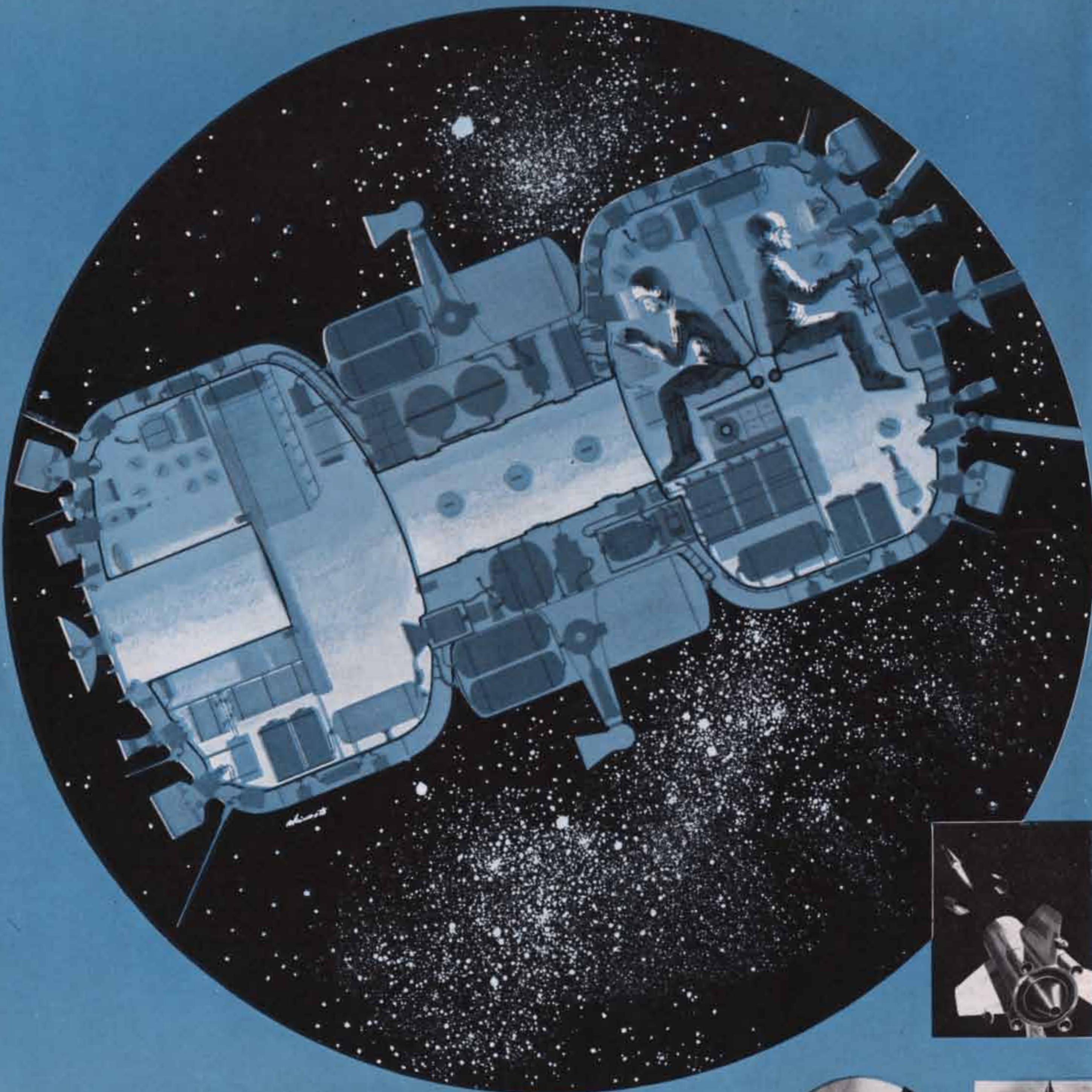
EXPANDING THE FRONTIERS OF SPACE TECHNOLOGY



THE ASTROTUG

Tugboat for Space: Spaceborne scientific laboratories and platforms for further exploration into space are an accepted concept based on established engineering techniques. Components would be fired as individual units into space, on precalculated orbits, and there assembled. To solve the major problems of how men are to live and work in space during the assembly process, Lockheed has prepared a detailed engineering design of an astrotug—a manned vehicle housing a crew of two or three. Missile-launched, the astrotug will be capable of supporting its crew for a number of days in an environment of suitable atmosphere, artificial gravity, and with provisions for exercise, relaxation, bathing facilities, medical care, illumination and adequate food and water.

The Lockheed astrotug is a completely independent working vehicle. Personnel need not leave it in space suits in order to work on the project of assembling the space station components. As shown in the diagram, the tug consists of two double-walled pressure vessels approximately 20 feet long overall and 9 feet in inside diameter. Swivelling rocket nozzles are arranged for maneuvering. On the forward end, extending out are four mechanical manipulator arms with interchangeable "hands" for such specialized functions as gripping, welding, hammering, cutting, running screws, etc. "Hands" can be changed by remote control from inside. Viewing ports provide uninterrupted observation. Radar antennas, searchlights, and other equipment necessary to the tug's work are mounted externally. Main controls and instruments including radar, radio, infrared, computers and navigation consoles are duplicated in each of the two major compartments as a safety measure.

Men working in single units afloat in space suits would have little applicable force and could work for very limited periods of time. With the Lockheed astrotug, personnel could carry on the work in relative safety and comfort with maximum efficiency. A special reentry vehicle, separate from the astrotug, has been conceived for ferrying to and from earth. Tugs themselves would remain floating in orbit indefinitely, being reprovisioned and refurbished as fresh crews arrive in relief.

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BOOKS

On the remarkable testament of the Jesuit paleontologist Pierre Teilhard de Chardin

by George Gaylord Simpson

THE PHENOMENON OF MAN, by Pierre Teilhard de Chardin. Harper & Brothers ($5).

Father Pierre Teilhard de Chardin, S. J., author of *The Phenomenon of Man,* was himself a phenomenal man. He uniquely combined in one well-integrated personality a religious mystic and a scientist. He synthesized these radically disparate approaches into a metaphysics suggestive of a new personal religion, although he always insisted that his "vision" (the word, often repeated, was his) not only was compatible with but also was the true interpretation of Roman Catholic Christianity. *The Phenomenon of Man* now makes an expression of the Teilhardian ontology generally available in English for the first time. As the French editors and commentators have rightly insisted, it cannot be fully understood or fairly judged without further knowledge of Teilhard's life and of voluminous writings not available in English and only now being published in any language.

Born in Auvergne in 1881, Teilhard attended a Jesuit college and entered the Society of Jesus at the age of 18. (He was ordained in 1912.) He continued studies of science, philosophy and theology on the island of Jersey and in Sussex and taught physical sciences briefly in Egypt before returning to France, where he took up vertebrate paleontology under Professor Marcellin Boule in Paris. He established a reputation as a paleontologist with two monographs that are still basic in their fields: one on some early Oligocene carnivores (published in 1914) and the other, still more extensive, on late Paleocene and early Eocene mammals in France (1921). During this period he taught at the Institut Catholique, and he took his doctorate at the Sorbonne in 1922. In 1923, in company with another Jesuit, Father E. Licent, he went to China on a geological expedition for the Muséum d'Histoire Naturelle.

At that time Teilhard was already developing the evolutionary *mystique* that was the obsession of the rest of his life. His ecclesiastical superiors found some of these views unorthodox, and when he returned to France he was forbidden to teach. After an unhappy period of constraint, he returned to China in 1926 and there lived as an exile for 20 years. It is ironic that his being disciplined for his attitude toward human evolution indirectly caused his being brought into further contact with the subject and becoming increasingly engrossed with it. Peking man (so-called *Sinanthropus*) was discovered soon after his return to Peking. Teilhard was not personally involved in the description of those remains, but he was closely associated with their describers, Davidson Black and Franz Weidenreich. With the Chinese paleontologists C. C. Young and W. C. Pei he studied some of the mammalian fossils and artifacts found with Peking man. In addition he was very active in geological field studies, especially in western China and central Asia, and (usually in collaboration) he completed several important monographs on the late Cenozoic mammals of China.

Just before World War II Teilhard planned to return to a research post in Paris, but the war prolonged his exile until 1946. The war years of relative physical inactivity and isolation were a period of profound soul-searching and spiritual development for Teilhard. It was then that he wrote not only *Le Phénomène Humain* but also numerous other metaphysical and mystical manuscripts, most of them destined to remain unpublished during his lifetime. Back in Paris, he was still forbidden to publish on philosophical subjects or to teach, although an eminent professorship would otherwise have been open to him. He optimistically prepared a briefer and, as he hoped, less theologically objectionable version of some of the ideas of *Le Phénomène Humain,* but permission to publish this manuscript (*Le Groupe Zoologique Humain*) was also refused in Rome. In 1951 he finally gave up the long dream of working and teaching in France and moved definitively to New York where, except for brief excursions, he spent the rest of his life as the guest of a research foundation. His death in 1955 occurred, with a certain macabre appropriateness, on Easter Sunday.

Besides being an accomplished theologian and scientist, Teilhard was an extraordinarily likable man. His wanderings took him over much of the world, and almost everyone he met, of whatever creed or race, became a lifelong friend. He carried the *mystique* of love into all his personal relationships, and he had an indescribably warm and sparkling personality combined with an attractive humility on every subject but one. The memory of his charm and the attempts to suppress so much of his work have helped to produce a legend and something approaching a cult. He would have approved of the cult, provided it gave more attention to his ideas than to his personality, but he would have disapproved of the legend.

Teilhard observed his vow of obedience to the extent of limiting open publication of his views, but he did disseminate them widely in person, in letters and even in what amounted to private publication. He also left a great mass of manuscripts in such a way as to assure their eventual publication. He was hardly in his grave when both *Le Groupe Zoologique Humain* and *Le Phénomène Humain* were sent to the printer, the latter as the first volume of a proposed set of collected works that has now reached five volumes without including any of his technically scientific work. Two volumes of letters have also been published posthumously and an inspirational "*cahier*" with text in French, English, German, Russian and Arabic.

The Phenomenon of Man is a generally excellent translation of *Le Phénomène Humain,* differing from the French edition (Editions du Seuil, 1955) only by the substitution of an introduction by Julian Huxley for a shorter "*avant-propos*" by N. M. Wildiers, a theologian. The new introduction naturally reflects

Huxley's own interests and also the warm sympathy for Teilhard felt by everyone who knew him. It may not be quite so adequate in evaluating the broader intent and nature of Teilhard's thought. That becomes fully evident only in the light of this fact: Teilhard was *primarily* a Christian mystic and only secondarily, although importantly, a scientist.

One of Teilhard's fundamental propositions is that all phenomena must be considered as developing dynamically, that is, in an evolutionary manner, in space-time. "It [*i.e.*, evolution] is a general condition to which all theories, all hypotheses, all systems must bow and which they must satisfy henceforward if they are to be thinkable and true." On this basis, unimpeachable in itself, he reviews briefly the evolution of the cosmos and at greater length that of organisms and of man. He is not concerned with details but with the broadest features of the story as it moves onward. These are traced in a style often delightfully poetic but sometimes syntactically overcomplex and often obscurely metaphorical. The whole process, from dissociated atoms to man, is seen as a gradual progress with two revolutionary turning-points among others of less importance: first, and early, the achievement of cellular organization; second, and late, the emergence of true man. Much of the intervening story is envisioned in terms of the succession and frequently the replacement of what Teilhard usually called *nappes*, a term difficult to translate that is here rendered as "layers" or "grades." The "*nappe*" phenomenon involves the expansion or radiation of groups that had reached new structural and adaptive levels, and it has been extensively discussed by other evolutionists in those or similar terms.

Teilhard's book is not, however, strictly or even mainly concerned with describing the factual course of evolution. That is "the *without*" of things, and the author is here concerned rather with "the *within*." The within is another term for consciousness (the French *conscience*, another word without a really precise English equivalent), which in turn implies spontaneity and includes every kind of "psychism." Consciousness, in this sense, is stated to be a completely general characteristic of matter, whether in an individual atom or in man, although in the atom it is less organized and less evident. The origin of the cell was critical because it involved a "psychic mutation" introducing a change in the nature of the state of universal consciousness. The origin of man was again critical because at this stage consciousness became self-consciousness, reflection or thought. Now this as yet highest stage of consciousness begins a concentration or involution that will eventually bring it into complete unity, although without loss of personality in that collective hyper-personal. Then the consciousness of the universe, which will have evolved through man, will become eternally concentrated at the "Omega point," free from the perishable planets and material trammels. The whole process is intended; it is the *purpose* of evolution, planned by the God Who is also the Omega into which consciousness is finally to be concentrated. Mystical Christianity is to be the path or the vehicle to ecstatic union with Omega.

Teilhard's first sentence is as follows: "If this book is to be properly understood, it must be read not as a work on metaphysics, still less as a sort of theological essay, but purely and simply as a scientific treatise."

In the last chapter (before the epilogue, the postscript and the appendix) he wrote:

"Man will only continue to work and to research so long as he is prompted by a passionate interest. Now this interest is entirely dependent on the conviction, strictly undemonstrable to science, that the universe has a direction and that it could—indeed, if we are faithful, it *should*—result in some sort of irreversible perfection. Hence comes belief in progress."

But the direction of evolution toward an irreversible perfection is the whole theme, and not merely a philosophical appendage, of the book. Hence we have a book submitted purely as a scientific treatise and yet devoted to a thesis admittedly undemonstrable scientifically. (The word here translated as "belief" is *foi*, and the context makes it unmistakable that religious faith is meant.) The anomaly is partly explained by the fact that in this particular manuscript Teilhard did avoid explicit discussion of certain points in dogmatic theology. The origin and fate of the individual soul, Adam and Eve and original sin, and the divinity of Christ, for instance, are all alluded to or allowed for, but only briefly and in veiled terms. In addition the discussion begins as a sort of mystical science and only gradually, almost imperceptibly, becomes mystical religion. Identification of Omega with God is evident from the beginning to anyone already familiar with Teilhard's thought, but in this book it is not made explicit until the epilogue.

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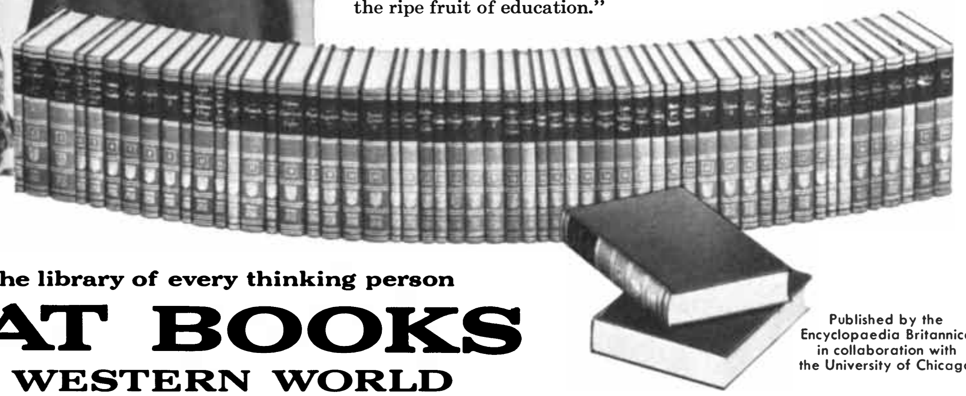

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and not alone his theology, must be called mystical may be illustrated from an early passage (in Chapter II) that introduces concepts crucially used throughout all that follows. First he makes a distinction between material energy and spiritual energy, and points out that material energy, for instance that derived from bread, is not closely correlated either in intensity or in variety with spiritual energy, for instance that exhibited by human thought. But surely both of these can be described and at least conceivably may be explained in material terms. A reasonable mechanical analogy is provided by a television set, in which the activity and multiplicity of the pictures are not well correlated with the intensity and uniformity of the power in wires and tubes. One could speak of "picture energy" as distinct from "electron energy," but it would be evident that "energy" is not even roughly comparable in the two senses and that the metaphorical terminology obscures rather than promotes understanding of the phenomena. And surely it is further obfuscation when Teilhard goes on to explain:

"We shall assume that, essentially, all energy [*i.e.*, both material and spiritual energy] is physical in nature; but add that in each particular element this fundamental energy is divided into two distinct components: a *tangential energy* which links the element with all others of the same order (that is to say of the same complexity and the same centricity) as itself in the universe; and a *radial energy* which draws it towards ever greater complexity and centricity—in other words forwards."

As to the mechanism of evolution, obviously a, or indeed *the*, crucial point of the scientific part of the inquiry, Teilhard accepted both Darwinism and neo-Lamarckism as partial factors. He called Darwinism evolution by chance (although natural selection is the only objectively established anti-chance evolutionary factor) and therefore considered the non-chance neo-Lamarckian factors more important (although, as he knew, most biologists consider them not merely unimportant but nonexistent). However, he maintained that these and all proposed material mechanisms of evolution are related only to various details of the process. The basic over-all pattern and also the essentially directional elements in its various lineages he ascribed to orthogenesis.

Orthogenesis was variously defined by Teilhard as the "law of controlled complication," which acts "in a pre-determined direction," as "the manifest property of living matter to form a system in which 'terms *succeed each other* experimentally, following the constantly increasing values of centro-complexity,' " or as "*directed* transformation (to whatever degree and under whatever influence 'the direction' may be manifested)." The last definition, which is not from this book but from a brief manuscript written just before Teilhard's death, is broad enough to include the effects of natural selection; but that was certainly not intended, because Teilhard repeatedly contrasted selection with orthogenesis and indeed usually treated them as complete opposites. Similar imprecision or contradiction in definition is one of the constant problems in the study of the Teilhard canon.

Indeed these and other usages of the term orthogenesis in Teilhard's work seem at first sight to have no explanatory meaning whatever but to be tautological or circular. History is inherently unrepeatable, so that any segment of a historical sequence (such as that of organic evolution) begins with one state and ends with another. It therefore necessarily has a direction of change, and if orthogenesis is merely that direction, it explains nothing and only applies a Greek term to what is obvious without the term. However, when Teilhard says that the direction is "pre-determined" and that there is only one direction—toward greater "centro-complexity," toward Omega, ultimately toward God—then the statement may not be much more clearly explanatory, but it is no longer trivial.

Now it is easy enough to show that, although evolution is directional as a historical process must always be, it is multidirectional; when all directions are taken into account, it is erratic and opportunistic. Obviously, since man exists, from primordial cell to man was one of the directions, or rather a variety of them in succession, for there was no such sequence *in a straight line* and therefore literally orthogenetic. Teilhard was well aware of the consensus to that effect, but he brushed it aside and refused to grapple with it in terms of the detailed evidence.

Here we come to the real crux of the whole problem: Which are the premises and which the conclusions? One may start from material evidence and from interpretive probabilities established by tests of hypotheses, that is, from science. Despite the objections of some philosophers and theologians, it is then legitimate to proceed logically from these premises to conclusions regarding the nature of man, of life or of the universe,

even if these conclusions go beyond the realm of science in the strictest sense, and that is not only legitimate but also necessary if science is to have value beyond serving as a base for technology. On the other hand, one may start from premises of pure faith, nonmaterial and nontestable, therefore nonscientific, and proceed to conclusions in the same field of the nature of the material cosmos. It cannot be argued that this approach from metaphysical or religious premises is *ipso facto* illegitimate. It is, however, proper to insist that its conclusions should not be presented as scientific, and that when they are materially testable they should be submitted to that scientific discipline. Gradual recognition of that necessity has been evident in the historical change in the relationships between science and religions.

Teilhard's major premises are in fact religious and, except for the conclusion that evolution has indeed occurred, most of his conclusions about evolution derive from those and not from scientific premises. One cannot object to the piety or mysticism of his book, but one can object to its initial claim to be a scientific treatise and to the arrangement that puts its real premises briefly, in part obscurely, as a sort of appendage after the conclusions drawn from them. That this really is an inversion of the logic involved is evident from the whole body of Teilhard's philosophical writings and also from the statements, or admissions, made toward the end of this book. A passage indicating that the main thesis of the book is a matter of faith and not scientifically demonstrable has already been quoted. Elsewhere in Teilhard's work there is abundant testimony that his main premises were always in Christian faith and especially in his own mystical vision.

That is evident, too, in the complex concept of Omega that is the key to Teilhard's personal religious system and to his purpose in writing this book. He explained on various occasions that the concept is necessary in order to keep mankind on its job of self-improvement and in order to evade distasteful thoughts of aimlessness and eventual death—worthy but certainly not scientific premises. The following passage from another of his manuscripts may additionally represent this contribution of Teilhard's, also essential in *The Phenomenon of Man*, but there perhaps even less clear:

"In order to resolve the internal conflict that opposes the innate evanescence of the planets against the necessary irreversibility developed on their surface by planetized life, it is not enough to draw a veil or to recoil. It is a case for radical exorcism of the specter of Death from our horizon.

"Very well, is it not that which permits us to form the idea (a corollary, as we have seen, of the mechanism of planetization) that there exists ahead of, or rather at the heart of, the universe, extrapolated along its axis of complexity, a divine center of convergence. Let us call it, to prejudge nothing and to emphasize its synthesizing and personalizing function, the *Omega point.* Let us suppose that from this universal center, this Omega point, there are continuously emitted rays perceptible only, up to now, by those whom we call 'mystic souls.' Let us further imagine that as mystical sensitivity or permeability increases with planetization, the perception of Omega comes to be more widespread, so that the earth is heated psychically while growing colder physically. Then does it not become conceivable that humanity at the end of its involution and totalization within itself may reach a critical point of maturation at the end of which, leaving behind earth and stars to return slowly to the vanishing mass of primordial energy, it will detach itself psychically from the planet in order to rejoin the Omega point, the only irreversible essence of things?"

This book provides a fascinating glimpse into the mind of a great soul, a kindly man and a subtle mystic. It may prove to be psychologically and historically important if, as is quite possible, it eventuates in a new religious cult of mystical evolutionism. It may do good (but could also conceivably do harm) in forcing theologians to face the fact of evolution more squarely. Despite its own claims and those of some of its sponsors and reviewers, it should not be taken either as a scientific treatise on evolution or as a derivation of religious conclusions from scientific premises.

Short Reviews

THE OPEN SEA: ITS NATURAL HISTORY; PART II, FISH AND FISHERIES, by Sir Alister Hardy. Houghton Mifflin Company ($7.50). This work, so brilliantly begun in the first volume on the world of plankton, is now completed in a no less delightful survey of the natural history of fishes and of the fishing industry. The emphasis is on the fish of the British Isles, but no matter; the marine population is well represented. Sir Alister Hardy knows his subject—every corner of it; he loves it and is a superb teacher. He can make the ciliary mechanism of a mollusk as engrossing as the nucleus of the atom. Once on his line or in his net, one neither can nor wants to get away. He deals with the fish of pelagic and demersal habit; the herring, the plaice, the haddock, the hake and the cod; the benthonic invertebrates of the ocean floor; hags, hounds, sharks and skates; the incredible world of marine parasites; whales and walruses; sea serpents, real and imaginary; different methods of commercial fishing. All is fascinating, from the love life of the herring to the mathematical equations of overfishing. At the time of the full moon in mid-October and mid-November there is a special "shoaling excitement," part of a courtship behavior, which leads herring gathering to spawn in the English Channel to swim more often or in greater numbers into the nets: thus the East Anglian fishermen speak of a "herring moon." (Other herring, curiously enough, are not susceptible to this nuptial frenzy.) Herring have fine rings on their scales, formed like tree rings, which enable students to determine the individual fish's age. The oarfish, *Regalecus glesne*, the largest of the so-called ribbonfish, may be as much as 50 feet long; it sometimes swims with undulating movements near the surface of the sea. This is probably the answer to the sea-serpent riddle. Tunnies (we call them tunas) are unique among fish in having a body temperature three or four degrees above that of the surrounding water. *Leptocephalus brevirostris* is a little eel whose remarkable history was discovered by the great Danish oceanographer Johannes Schmidt. He first caught specimens of *Leptocephalus* to the west of the Faroe Islands. He decided to hunt further to find the source of these frail little fish, and in a series of expeditions went farther and farther west until he found the smallest 600 miles southeast of Bermuda, over the deep water of the Sargasso Sea. It is to this place that mature "freshwater" eels, after spending some five to seven years in the rivers, canals and backwaters of Europe, set out in old age on a pilgrimage to lay their floating eggs some thousand fathoms deep in the ocean more than 2,000 miles away. From the eggs the transparent larvae hatch out and drift to the coast of Europe growing as they do so. Now they undergo a striking metamorphosis, becoming narrower, rounder and pigmented—changing into little black elvers. They enter fresh water, swim against the current and enter the rivers. Again, when they are grown, their return migration takes them from Norway, Spain and the Mediterranean to this spot in the Sargasso Sea. *Carapus* *dentatus*, a pearlfish, has the unusual habit of entering the body of a large sea cucumber by slipping tail first and with great rapidity into its anus, where it feeds for a time upon its host's gonads; later it emerges and maintains only an intermittent association with the sea cucumber. These are samples of the material in Hardy's lovely book. It contains poetic passages of description of complex anatomical mechanisms that remind one of the writings of Sir Charles Sherrington. The illustrations, all by the author, include many enchanting water colors and some fine photographs. If you never buy another book about nature, don't miss this one.

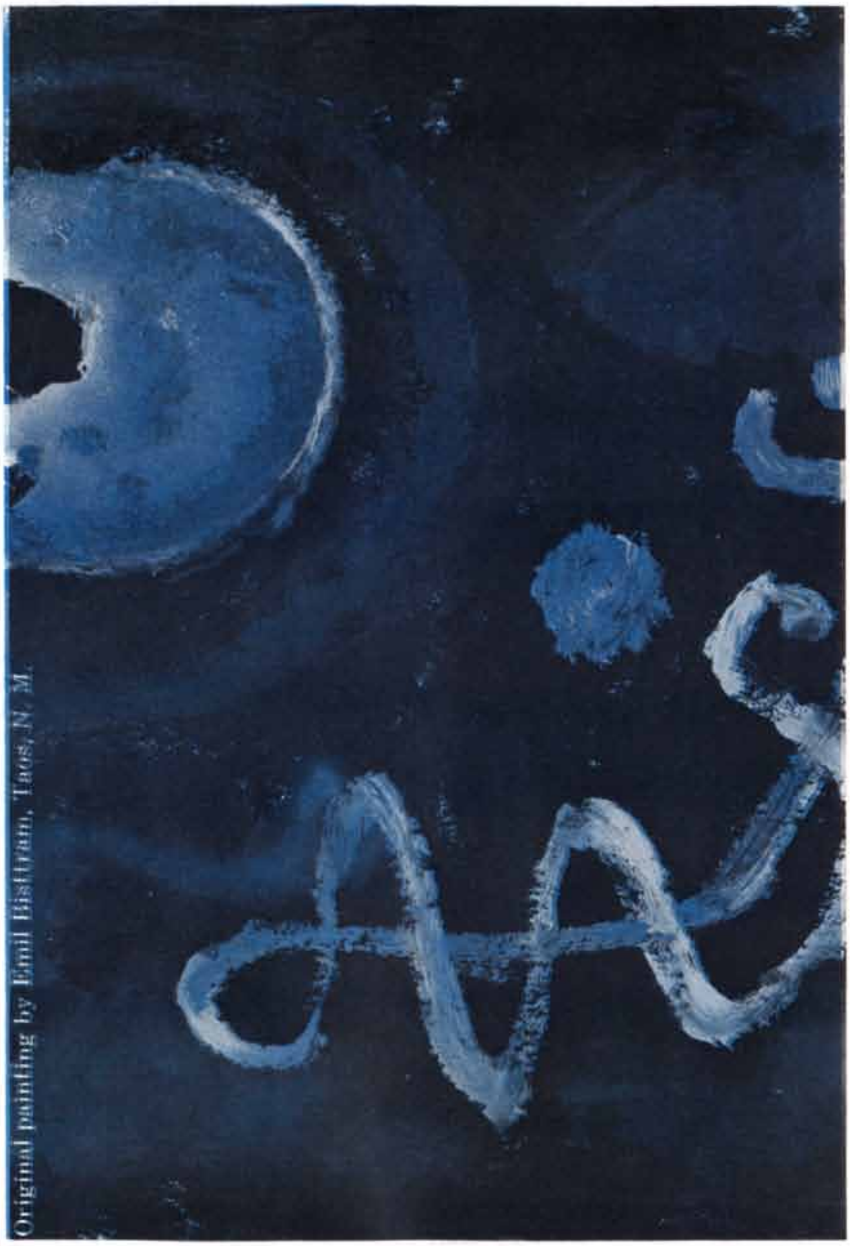
VIRUS HUNTERS, by Greer Williams. Alfred A. Knopf ($5.95). Man's search for the tiny things that cause disease makes an absorbing story, which began with Jenner and Pasteur and is still far from ended. Years ago Paul de Kruif wrote a dramatic popularization of this branch of research that introduced the subject to an entire generation of readers. His book had serious faults, but it would be unjust to dismiss it; despite its shortcomings it afforded millions entertainment as well as instruction. Williams has written a sounder book; there is less jazz in it and more of sober fact, yet it is not a bit less palatable. He explains the achievements of the leading virologists and sketches their personalities. Among those whose work is described are: Martinus Beijerinck, the Dutch bacteriologist who discovered a filterable virus in tobacco plants sick with tobacco-mosaic disease; George M. Sternberg, Surgeon-General of the Army under Grover Cleveland, who suggested that antibodies neutralized viruses, and that a fine way to look for the criminal was to look for his captor; Gilbert Dalldorf, who discovered the first of the Coxsackie viruses (Coxsackie is a Hudson River Valley village where an outbreak of a "pseudo-polio" disease led to identification of the virus); Ernest Goodpasture, who with Alice Woodruff invented the invaluable chick-embryo technique of virus cultivation; Wendell M. Stanley, the first man to crystallize a virus; Robley C. Williams, the astronomer turned biophysicist who metal-plated viruses so that they would pose brightly for electron microscope portraits; John F. Enders (and his associates Frederick C. Robbins and Thomas H. Weller) who got a Nobel prize for developing a test-tube method of cultivating polio virus; Max Theiler of the Rockefeller Institute, whose 17D yellow-fever vaccine has been administered to tens of millions of persons, with the result that the disease has practically disappeared from the territories in which vaccination was performed; Jonas Salk, who deserves almost as much credit for his admirable behavior during the great Public Health Service-polio flap as for his researches; Heinz Fraenkel-Conrat, who has done for viruses what couldn't be done for Humpty Dumpty—taken them apart and put them together again. One of the advantages of reading a connected account of this long line of scientific inquiry is that one comes to realize what a large part of research consists of patience, perseverance and manual skill. The dazzling flights of imagination popularly associated with research play a larger role in cosmology or mathematical physics, say, than in virus hunting; to recognize this fact is not to elevate one pursuit over the other, but to come to a more mature understanding of the character and variety of scientific labor.

LAROUSSE ENCYCLOPEDIA OF ASTRONOMY, by Lucien Rudaux and G. de Vaucouleurs. Prometheus Press ($15). A clearly written, very fully illustrated, large-format, 500-page book that is by far the best general survey of its kind for anyone who has graduated from the ordinary popularizations and wants a taste of the real business of astronomy. The authors explain such matters as the orbits of the planets, Kepler's laws, astronomical distance, the role of the atmosphere in astronomical observation, Foucault's pendulum, the ecliptic, precession, nutation, equinoxes and solstices, the Zodiac, the earth as a planet, terrestrial magnetism and electricity, the earth's crust, earthquakes, the moon and its phases, eclipses, occultations, tides, the atmosphere of Venus, the canals and the polar caps of Mars, the minor planets, the satellites of Saturn, comets, meteors and meteorites, the constitution of the sun, double and variable stars, stellar atmospheres and interiors, nuclear reactions in the sun and stars, the galaxy, the expansion of the universe, cosmological theories, astronomical instruments and methods of measurement, spectroscopic analysis and its astronomical applications. The lucid and interesting text is supported by a most effective and intelligently planned collection of diagrams, photographs and charts; the pictures may not always be cleanly executed and handsome, but they are always easy to follow, always answer the question and elucidate the complex motions and relations of the heavenly bodies that everyone but the professional astronomer finds it almost impossible to visualize. This is an achievement of a high order, and the price is very low for what you get.

FOLKWAYS, by William Graham Sumner. Dover Publications, Inc. ($2.49). A paper-back reprint of a classic survey by a Yale scholar who died in 1910. It is primarily concerned with the sociological importance of usages, manners, customs, mores and morals. Why do Arab women veil their faces? Why do the Chinese regard the naked foot as indecent? Why in some societies is a mere cover over the navel regarded as an adequate costume? Why do the Chinese give their children repulsive names? Why do Kaffirs hold that our form of marriage degrades a woman to the level of a cat—"the only creature among them that has no value"? These are among the thousands of beliefs and customs treated in Sumner's study.

PICTORIAL HISTORY OF PHILOSOPHY, by Dagobert D. Runes. Philosophical Library, Inc. ($15). This book, except for a few photographs of modern philosophers that are not easy to find elsewhere and that satisfy curiosity, is a pretentious piece of goods. The writing is pompous; the organization by nationalities and schools is wayward and confusing. As for the illustrations, the editor deems it appropriate in tracing the growth of philosophy to exhibit views and portraits of the Globe Theater in London, John Brown's last moments, Ben Franklin's bifocals, Napoleon's projected scheme for a balloon invasion of England, Marat stabbed in his tub, favored positions in Yoga meditation, Leninists massacring "Democratic Socialists," Adolf Hitler in a top hat, and Joseph Stalin (in connection with Runes's characterization of Bertrand Russell as one who "advocates a general acceptance of Soviet Russian world domination.") Unmixed tripe.

PIRATES AND PREDATORS, by Colonel R. Meinertzhagen. Oliver & Boyd (70 shillings). This is a book about the piratical and predatory habits of birds—vultures, eagles, hawks, falcons, kites, owls and others. Meinertzhagen has mixed in with his observations and his reminiscences of 70 years of bird study an astonishing collection of scraps and oddments—political and social commentary, terms used in falconry, information on whales and sea snakes and crocodiles, the underwater speed of penguins, homilies on the invigorating qualities of war. Not the least of the author's charms is the self-assurance with which



he contradicts himself. An amusing volume with some fine pictures.

STANDARD HANDBOOK OF TELESCOPE MAKING, by N. E. Howard. Thomas Y. Crowell Company ($5.95). HANDBOOK FOR OBSERVING THE SATELLITES, by N. E. Howard. Thomas Y. Crowell Company ($2.50). For amateur astronomers who are eager and reasonably handy. The author has had many years of experience teaching teen-age boys to build and use telescopes. He gives clear directions for grinding, polishing, aluminizing and testing mirrors, for constructing the eyepiece, telescope tube, mounting and observatory and for making astronomical photographs. There are instructive illustrations. In the satellite guide he presents a general introduction to the subject, and then explains methods of observation, the use of binoculars and telescopes, the world-wide Moonwatch program, methods of photographing the satellites. The scientific knowledge to be gained from outer-space explorations—as to air density, temperature, meteorites, cosmic rays, the ionosphere, solar radiations, the earth's magnetic field, weather, relativity paradoxes—is succinctly described.

THE EARLIEST GEOLOGICAL TREATISE (1667), by Nicolaus Steno. St. Martin's Press ($3.25). In 1669 the Danish anatomist Nicolaus Steno (Niels Stensen) published in Florence the treatise *De Solido* ("concerning a solid body enclosed by process of nature within a solid"), which, it is said, marks him as the founder of geology as an exact science. Two years earlier, however, he had published another Latin treatise that dealt primarily with the anatomy of muscles, but which incorporated as a "digression" an appendix on geology. The appendix, *Canis Carchariae Dissectum Caput* (*Dissection of a Shark's Head*), is presented in this little book in Latin, together with an English translation, introduction and notes by Axel Garboe. This, then, rather than *De Solido*, may be regarded as the earliest geological treatise, and its interest lies not only in Steno's observations and ingenious conjectures, but also in the way the digression itself came about. When Steno arrived in Italy for the first time in 1666, a gigantic shark was caught in the Mediterranean off Livorno, and the Grand Duke of Tuscany ordered its head to be sent to Florence for Steno's anatomical studies. Examining its teeth, Steno was led to consider their relation to the *Glossopetrae*, or "tongue stones," which are common in the Mediterranean region. The question was: Were these stones produced in the rocks by inanimate forces that accidentally in their action duplicated shapes like teeth and other parts of animals, or were the *Glossopetrae* in reality fossilized shark's teeth? Steno favored the latter view, and to find support for it turned to the study of the formation of the earth's crust. An "image of its evolution began to take shape in his mind": he concluded that the strata are sediments originally deposited in water, which later harden; that disturbances cause the strata to move from their original horizontal position; that "juices"—aqueous solutions—circulate in the strata and bring changes; that chemical and physical processes, like those known in the laboratory, affect the earth's crust. He hesitated to publish these radical views, but finally—and fortunately—tucked them modestly away in his book on muscles. A nice historical tidbit.

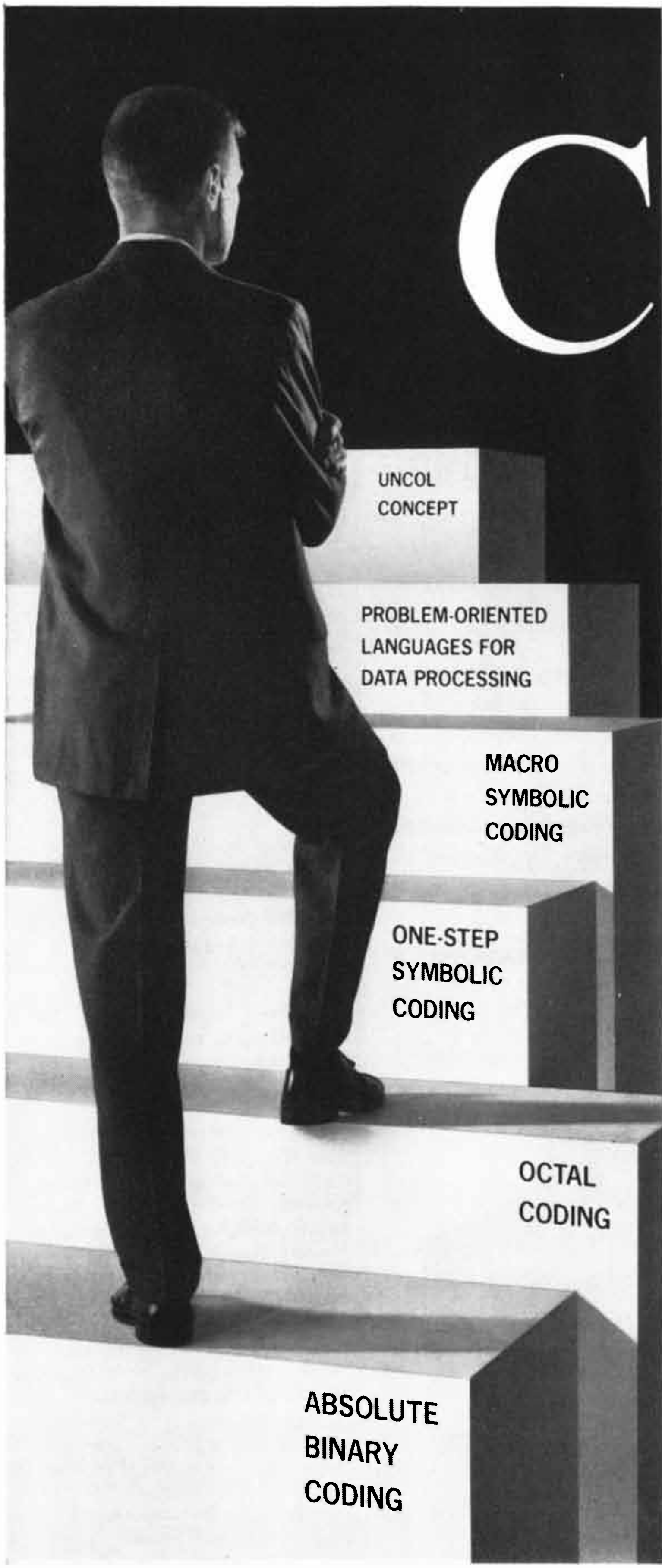
WILDLIFE IN AMERICA, by Peter Matthiessen. The Viking Press ($10). A history of American wildlife from the time of the white man's arrival to the present day; altogether a melancholy chronicle of depredation and destruction. There are many books about what man has done to the birds, the bears, the buffalo and other creatures of this continent, both by slaughter and by laying waste the land which was their home and source of sustenance; here, however, is the first attempt to give the whole story. An intelligent, well-written, persuasive job; many illustrations, a useful bibliography and appendices on rare, declining and extinct vertebrate species, and on conservation legislation.

BABIES BY CHOICE OR BY CHANCE, by Alan F. Guttmacher. Doubleday & Company, Inc. ($3.95). "This," says Guttmacher, "is an indignant book. I am indignant that the liberal side of the socio-medical issues we discuss is rarely, if ever, portrayed to the American reader by a physician. I am indignant that organized American medicine is more interested in its own economic security than in the social health of those it serves. I am indignant that the Church wields such stultifying power in certain areas of medical care." He has put his indignation to a good cause. He presents the best general up-to-date account of the problems of contraception, sterilization, abortion and artificial insemination. Guttmacher is a highly regarded physician, director of the department of obstetrics and gynecology at a large New York hospital, and clinical professor of medicine at the Columbia University College of Physicians and Surgeons. For 30 years he has studied eugenics and planned parenthood and has taken a vigorous part in bringing about better understanding of birth control and more rational official policies. He has had his hands full; it has been a bitter fight all the way, and it is still a bitter fight, but there have been notable gains. When is contraception advisable from the physician's standpoint? Must he be bound in his advice by medical circumstances alone, or shall he consider social and economic factors? What are the best birth-control methods? What is the area of legitimate concern for clergymen, judges and legislators? When is sterilization the proper course? What are the issues involved in artificial insemination? What are the dimensions of the abortion problem and how can the honest, responsible doctor meet the dilemma raised by the jumble of absurd and pernicious state statutes covering legal abortion? These are the major questions that Guttmacher treats frankly, fairly and fully. His little jokes are, like most medical jokes, not very funny; he might have spared us some anecdotes. But these are minor blemishes on an admirable tract. Birth control is too serious a business to be left to lawyers or preachers. Ignorance, self-righteousness, hypocrisy, cruelty and blind prejudice have long prevailed in the councils that have dealt with the subject. Guttmacher offers an enlightened and courageous challenge to these backward forces.

PAUL EHRENFEST, COLLECTED SCIENTIFIC PAPERS, edited by Martin J. Klein. North-Holland Publishing Company, Interscience Publishers, Inc. ($13.75). The scientific papers, previously unpublished doctoral dissertation, Leiden inaugural speech, article on statistical mechanics from the *Encyklopädie der Mathematischen Wissenschaften,* and published lectures and addresses of the famous Viennese-born physicist, known especially for his work in statistical mechanics and its relations with quantum mechanics, who in 1912 succeeded to H. A. Lorentz's chair of theoretical physics at the University of Leiden. Except for a skimpy introduction by H. B. G. Casimir, this volume, which will be treasured by Ehrenfest's many pupils, contains no biographical memoir, a regrettable deficiency.

Notes

MATHÉMATIQUES ET MATHÉMATICIENS, by Pierre Dedron and Jean Itard.



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Magnard (1,980 francs). An attractively illustrated survey of mathematical thought from antiquity to the age of Newton and Leibnitz.

Africa, by George Peter Murdock. McGraw-Hill Book Company, Inc. ($11.75). An introductory guidebook based on the ethnographic literature, dealing with food-producing activities, the division of labor by sex, housing and settlement patterns, kinship and marriage, the forms of social and political organizations and several related topics. Maps, a large fold-out chart and photographs.

Ward and Whipple's Fresh-Water Biology, edited by W. T. Edmondson. John Wiley & Sons, Inc. ($34.50). Second edition of this concise (1,200 pages), authoritative guide to the North American freshwater fauna and flora. Thousands of illustrations.

The Special Theory of Relativity, by J. Aharoni. Oxford University Press ($7.20). This book deals with both tensors and spinors (the latter being needed because of quantum mechanics) in simple mathematical terms—which is to say only elementary knowledge of group theory is required—and uses this approach to explain the theory of relativity.

Studies in Ancient Technology, Vol. VI, by R. J. Forbes. W. S. Heinman ($6.50). The sixth volume of this series of studies gives our present knowledge of the ancient means of producing heat, cold and light. Illustrations and tables.

Principia Ethica, by G. E. Moore. Cambridge University Press ($1.95). A paper-back reissue of Moore's most influential book.

Logical Positivism, edited by A. J. Ayer. The Free Press ($6.75). An anthology of classical papers on the logical positivist movement by its founders: Moritz Schlick, Rudolf Carnap, Otto Neurath, Hans Hahn. The book also contains, among others, Bertrand Russell's essay on logical atomism (which was a forerunner of the development of the movement), a section on analytical philosophy and an invaluable 60-page bibliography of logical positivism.

A History of Science, Technology and Philosophy in the 16th and 17th Centuries, by A. Wolf. Harper and Brothers (two volumes, $1.95 each). Reprint in soft covers of a clearly writ-

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INTRODUCTION TO THE MECHANICS OF THE SOLAR SYSTEM, by Rudolf Kurth. Pergamon Press, Inc. ($6.50). The fundamental methods of the astronomical part of celestial mechanics in a succinct and relatively elementary presentation.

THE COMMON SENSE OF SCIENCE, by J. Bronowski. Random House (95 cents). A Modern Library paper-back reissue of an edifying little book.

DESIGN AND PERFORMANCE OF GAS TURBINE POWER PLANTS, edited by W. R. Hawthorne and W. T. Olson. Princeton University Press ($15). This volume (Vol. XI) and its companion (Vol. X) in the High Speed Aerodynamics and Jet Propulsion Series treat the major engine components of aircraft gas-turbine power plants, describing and explaining the basic phenomena underlying their design and operation.

HANDBOOK OF PHYSIOLOGY; SECTION I, NEUROPHYSIOLOGY; VOL. II, edited by John Field, H. W. Magoun and Victor E. Hall. The Williams & Wilkins Company ($20). The second volume of this critical and comprehensive survey contains some 27 articles on such topics as the pyramidal tract, autonomic mechanisms, posture and locomotion, control of eye movements, respiration, the cardiovascular system, digestive function, body temperature, the cerebellum, the reticular formation, the hippocampus.

LIGHT FROM THE ANCIENT PAST, by Jack Finegan. Princeton University Press ($10). Revised edition of an excellent survey of the archaeological background of Judaism and Christianity, incorporating the results of many new excavations and further studies. Fresh illustrations have been added. A first-class job that nonspecialists as well as scholars can appreciate.

THE AVIAN EMBRYO, by Alexis L. Romanoff. The Macmillan Company ($35). This massive and exhaustive monograph is a complementary and companion volume to the author's *The Avian Egg*, published in 1949, and seeks to bring together all the known facts about the structural and functional development of the embryos of birds. The book is based upon a study of more than 7,000 original publications, of which about 2,700 are cited in the text; it contains an 80-page bibliography.

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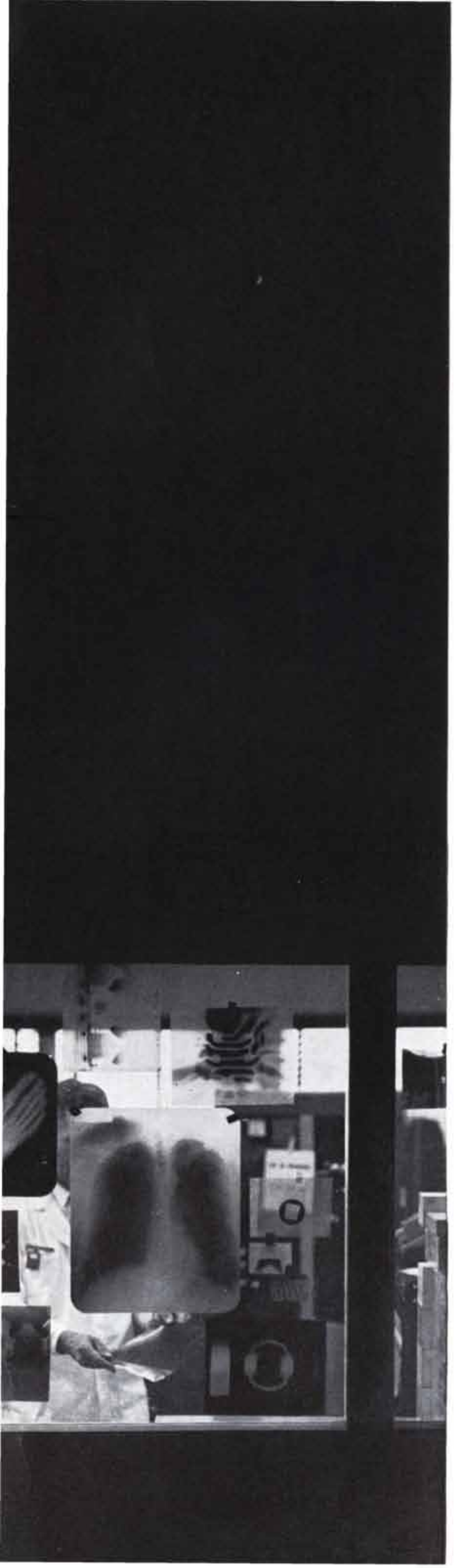

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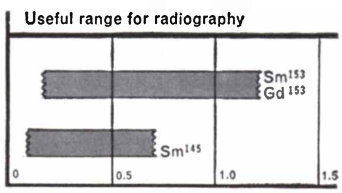
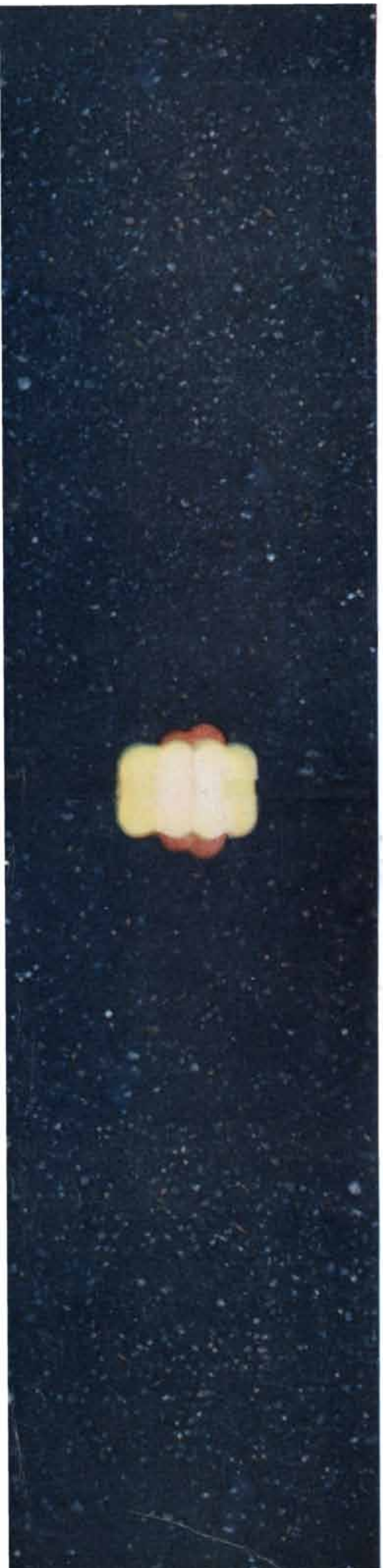
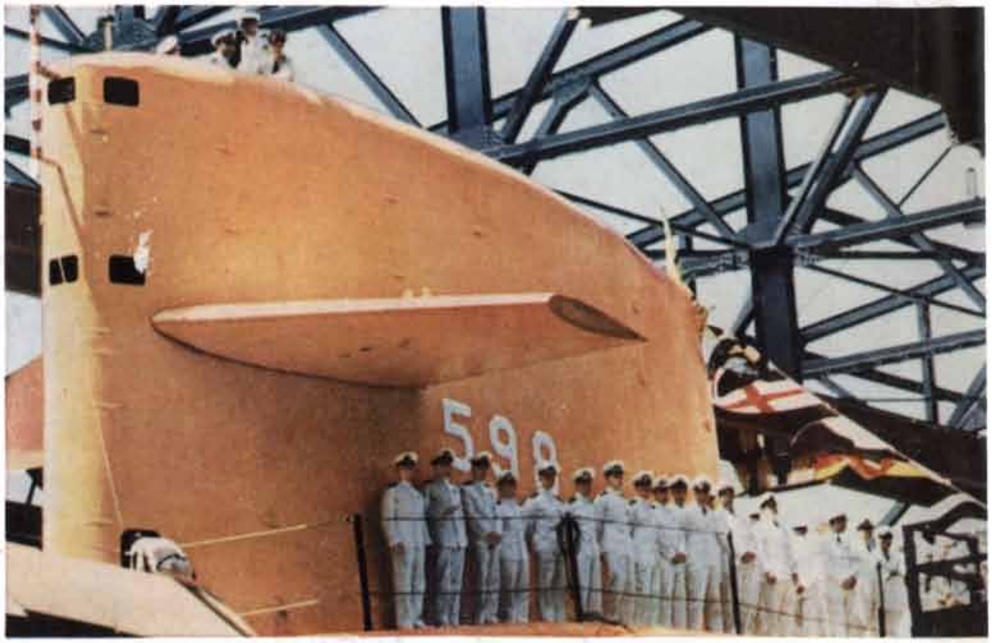


Aluminum thickness (inches)


Sm^{153} exposure unit.





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