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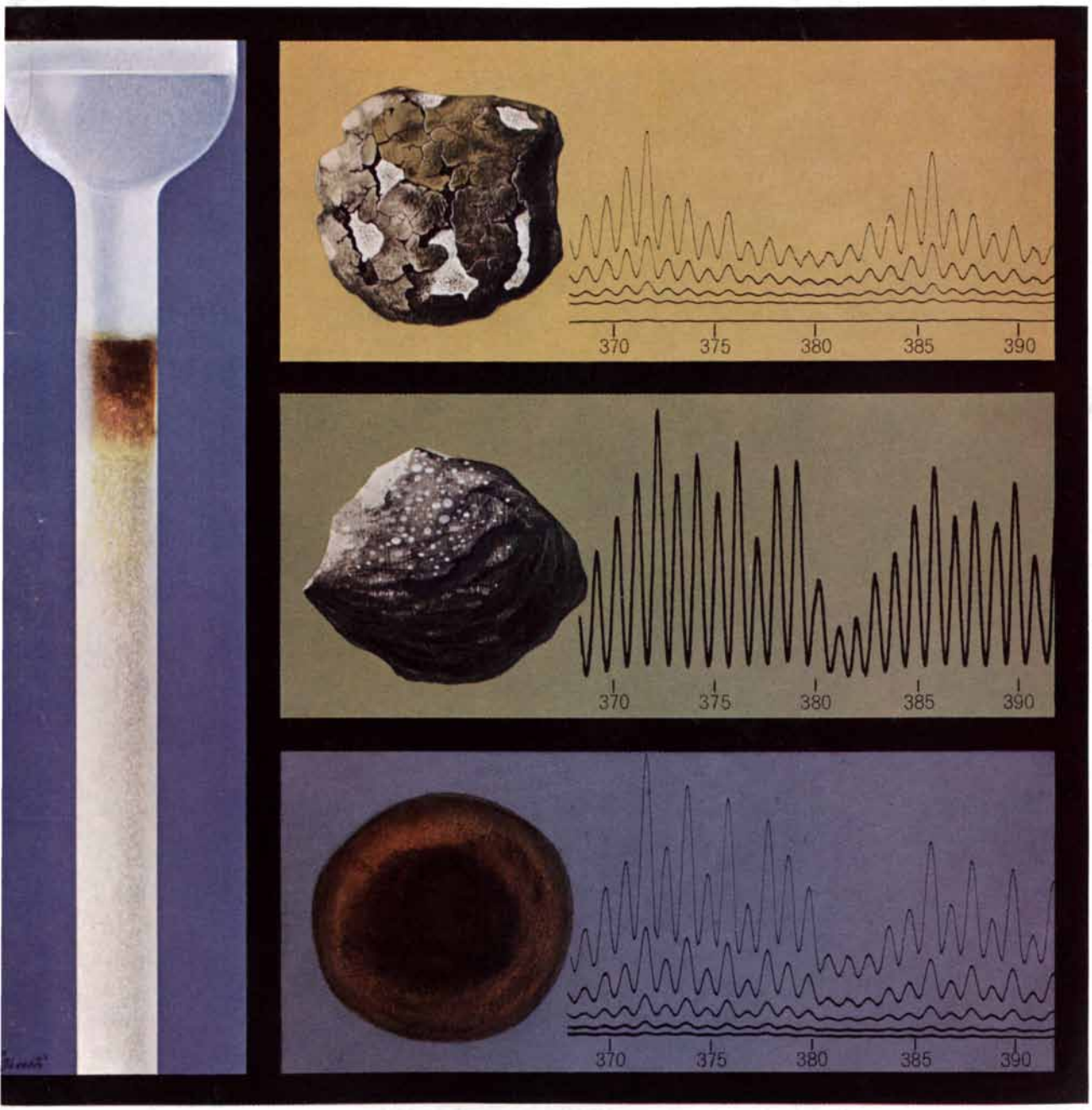
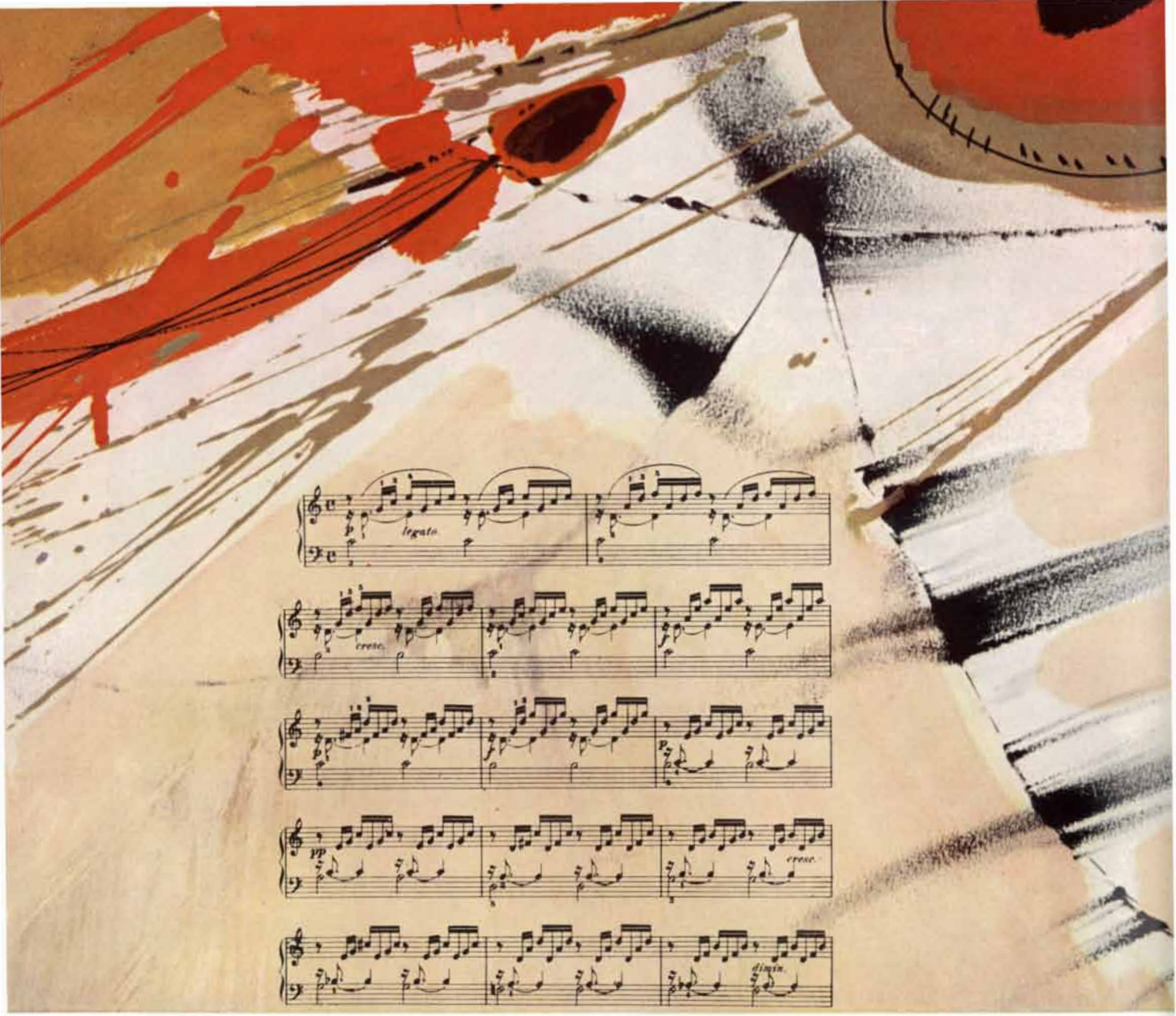


ORGANIC COMPOUNDS FROM SPACE

FIFTY CENTS

March 1963



Art or Science?

The musical staff system is one of the first scientific "graphs" evolved by man. It is essentially a time-frequency-amplitude diagram. The tempered scale which Bach helped develop, actually a logarithmic series with intervals of $\sqrt[12]{2}$, completely revolutionized Western music.

Bach's Preludes and Fugues are beautiful because Bach had the imagination of an artist. They are valid because he employed the disciplines of a scientist.

Imagination and discipline must walk hand in hand if modern technology is to fill the needs of modern markets. And the scope of these needs is limited only by the ability of market research to identify them. We at Celanese regard this task of identifying areas of market opportunity second only to the imagination and discipline necessary to fill the needs thus established. Celanese®

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Centuries ago the critical factor in logistics support was providing basic supplies—food, armaments, raw materials for simple industries. A few decades ago, carrying capacity—sea and land transportation—ruled as the decisive element. Within the last decade, a new critical element in logistics support has emerged. It has been created by the complex, interfacing governmental, industrial and military structure of today. This new factor is up-to-the-minute information—gathered from afar, varied in content, immense in volume.

To help provide and control this flow of information, SDC scientists, and engineers have helped create a new technology: information systems which aid managers in determining the "what, where and when" of logistics support for world-wide and continental activities and forces.

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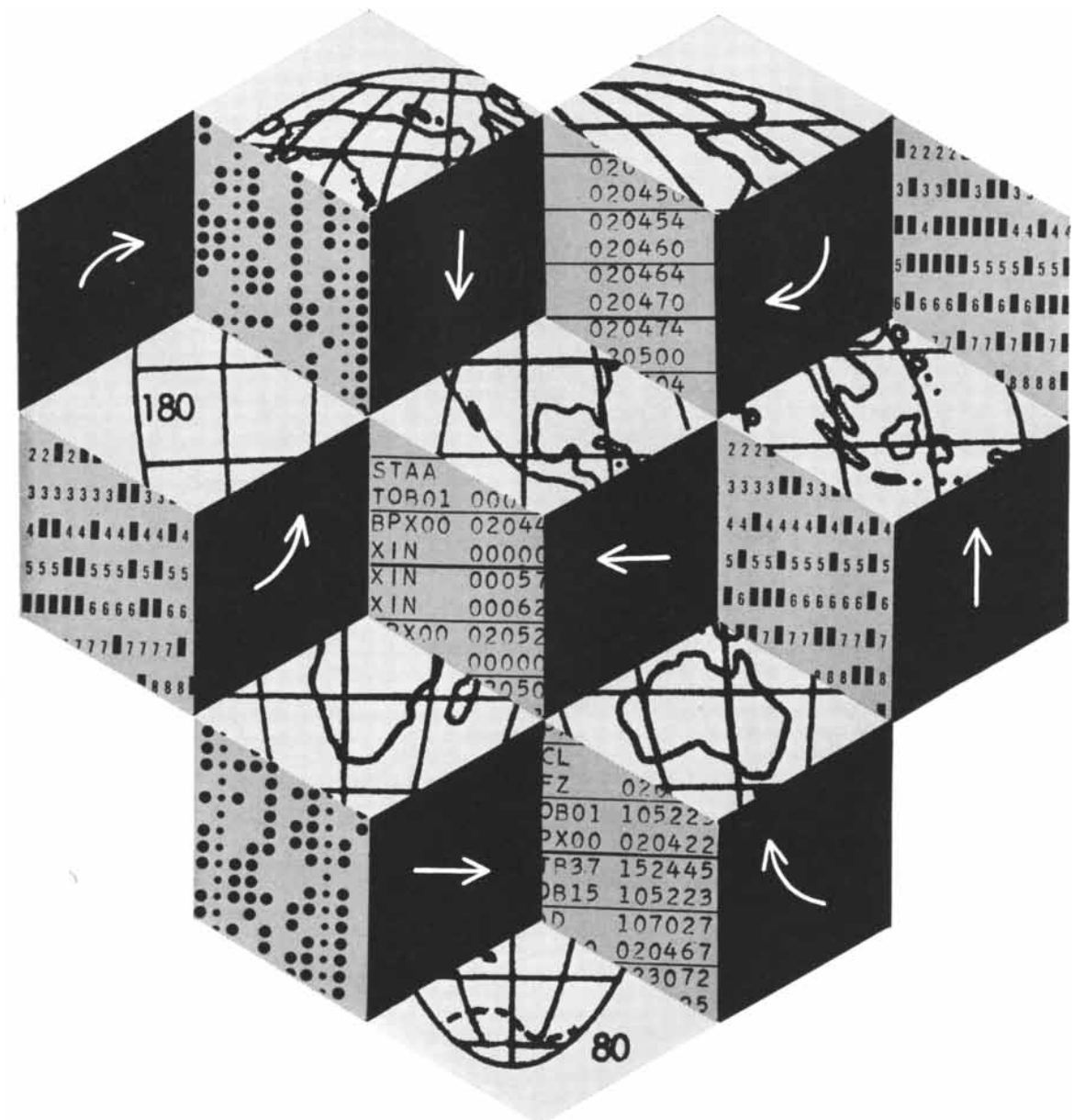

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Established 1845 **SCIENTIFIC AMERICAN** March 1963 Volume 208 Number 3

ARTICLES

DEPARTMENTS

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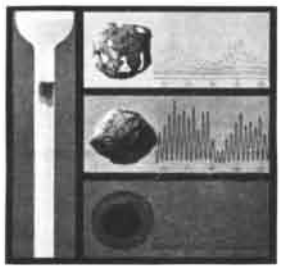

THE COVER

The painting on the cover illustrates one procedure in the study of organic compounds in meteorites (see "Organic Matter from Space," page 43). The three objects in the center are, from top to bottom, a type of meteorite known as a carbonaceous chondrite, a chunk of terrestrial sedimentary rock and a blob of crude oil. Material extracted from each of them is fractionated in a silica-gel chromatographic column, shown at the left. Then the fractions are analyzed on a mass spectrometer, which determines the amount of material present at various molecular weights. The results of the spectrometric analysis, which come in the form of the curves shown at the right, indicate similarities between the meteoritic and terrestrial hydrocarbons.

THE ILLUSTRATIONS

Cover painting by George Giusti

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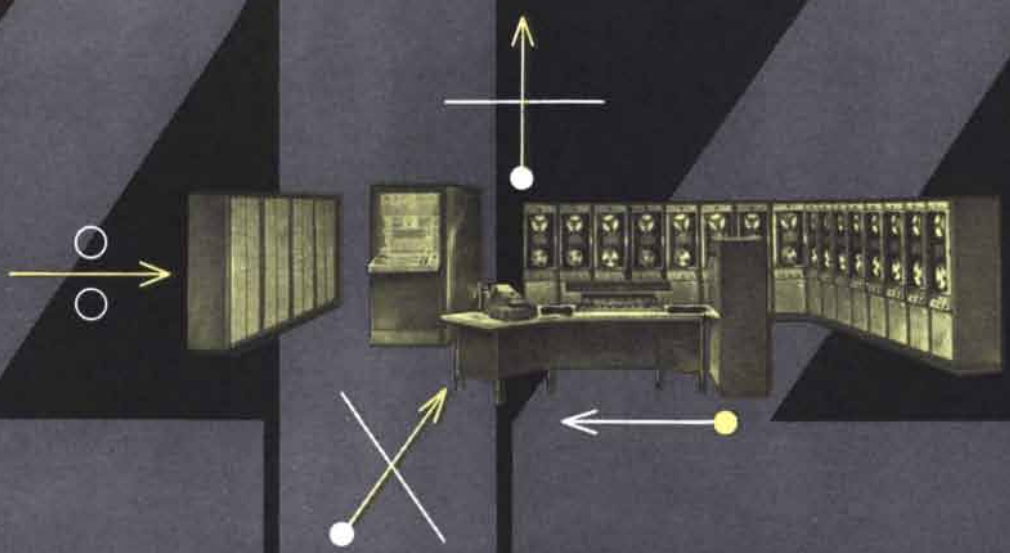

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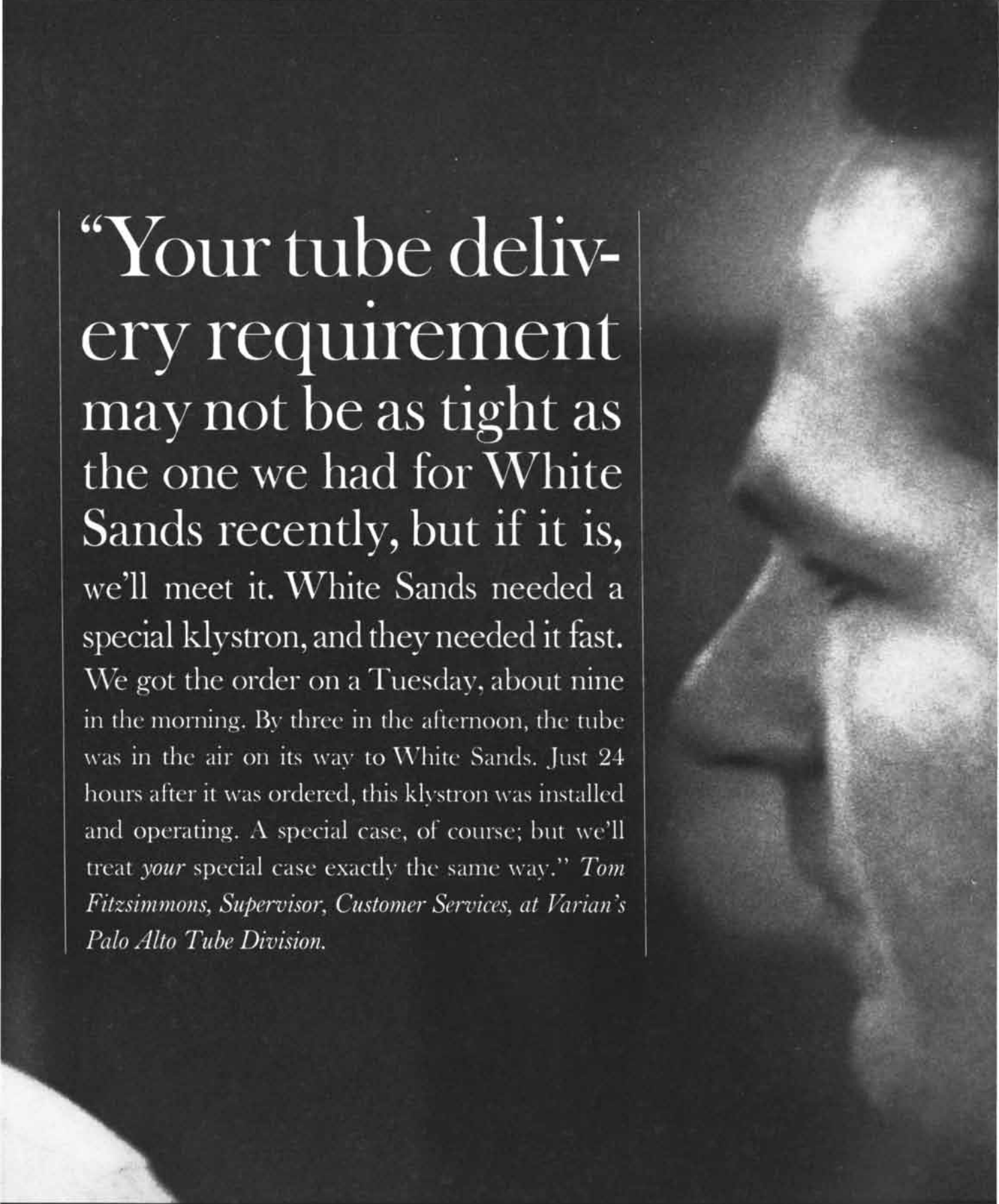

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we'll meet it. White Sands needed a special klystron, and they needed it fast. We got the order on a Tuesday, about nine in the morning. By three in the afternoon, the tube was in the air on its way to White Sands. Just 24 hours after it was ordered, this klystron was installed and operating. A special case, of course; but we'll treat *your* special case exactly the same way." *Tom Fitzsimmons, Supervisor, Customer Services, at Varian's Palo Alto Tube Division.*

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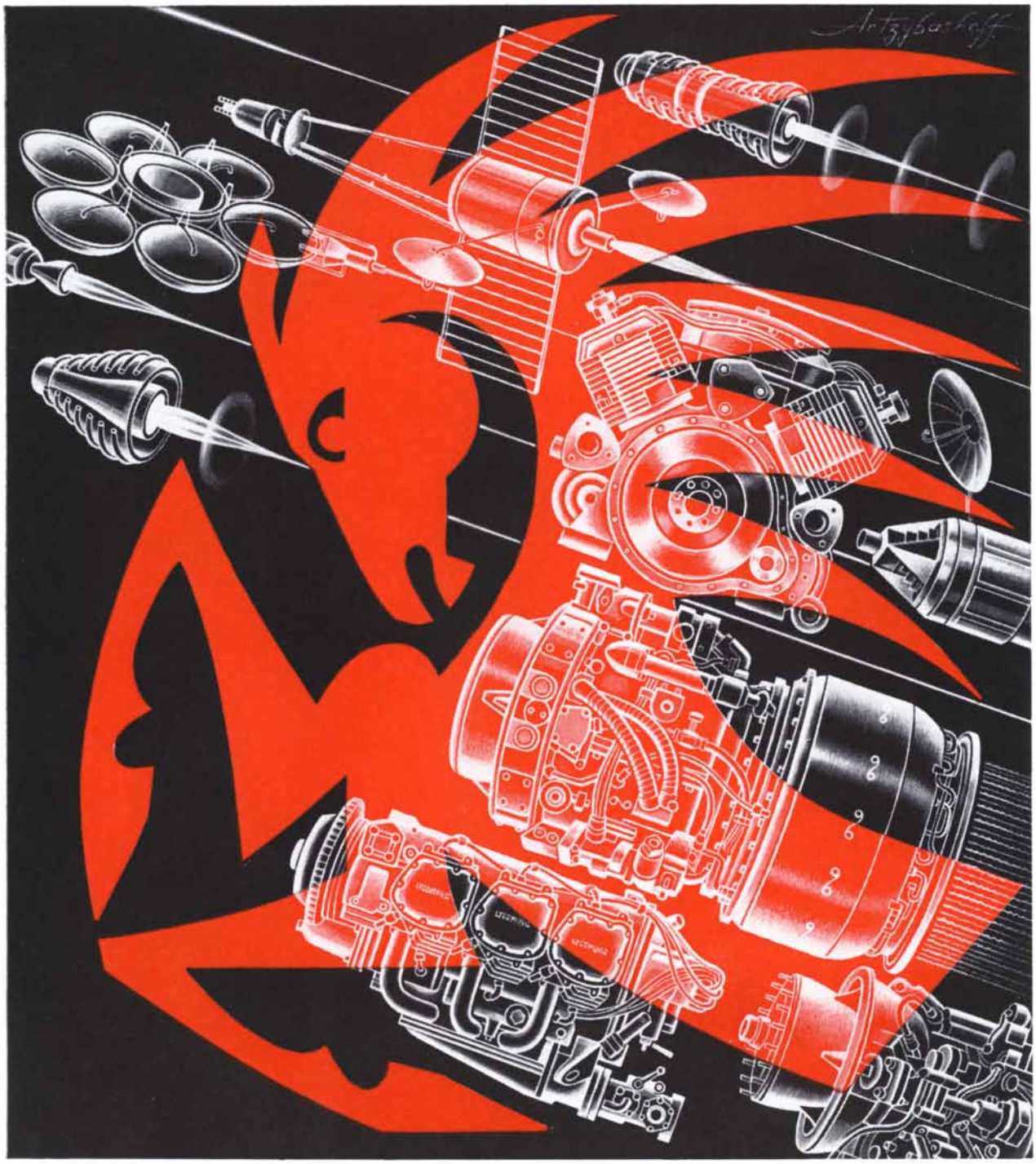

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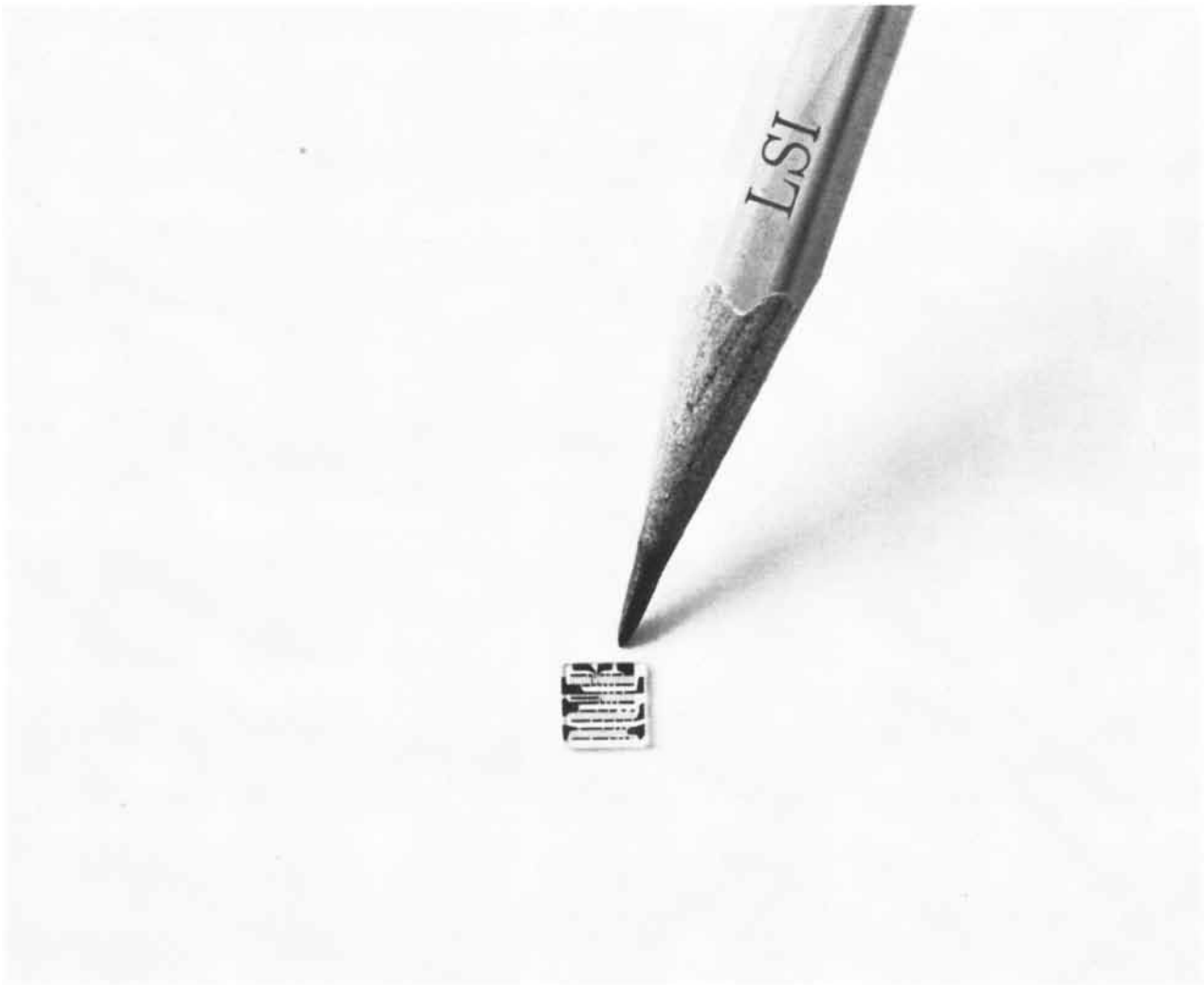

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For applications that range from airborne computers to hearing aids, Lear Siegler is shrinking electronic circuits down to sizes smaller than a quarter-inch square. Reduced interconnections increase reliability. Size and weight are pared up to 50 times. Most important, LSI produces these faster than standard components—*and* cuts costs. ■ These new thin film circuits typify Lear Siegler's ability to move advances out of research laboratories and onto the production line. ■ This kind of better design—along with an outstanding ability to produce—is important in defending America and improving our way of life. Because it has a way of making the future happen faster, LSI may well have the answer to *your* needs in the fields of defense, aerospace and consumer electronics, and research and development.

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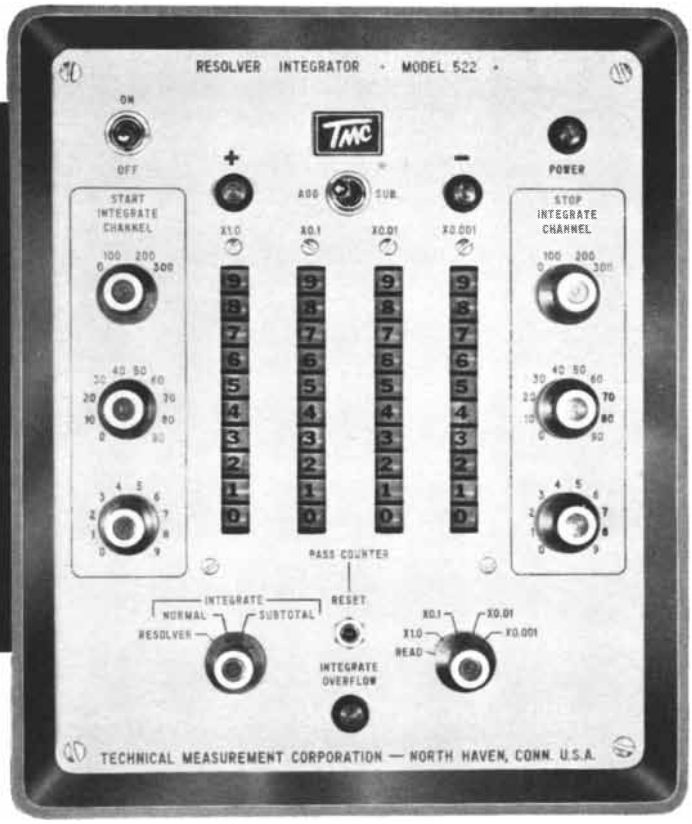


integrates any group (0-399) in one step

This new all-electronic Model 522 Spectrum Resolver/Integrator may be used directly with TMC "400 Series" pulse analyzers to perform resolving and integration functions without the necessity of intermediate tape recording equipment.

As a Resolver the Model 522 takes information directly from any selected quarter or half of the analyzer memory and either adds it to or subtracts it from the data stored in an adjacent quarter or half of the memory. It is possible to remove individual components of a spectrum and leave only the desired elements by adding or subtracting 100%, 10%, 1% or 0.1% increments of reference spectra. The operator has precise control of the resolving process, and has an accurate visual record of the exact percentage removed.

As an Integrator, the Model 522 integrates memory-stored information within any band of channels from 0 to 399 *in one operation*. Two modes of integration are available:

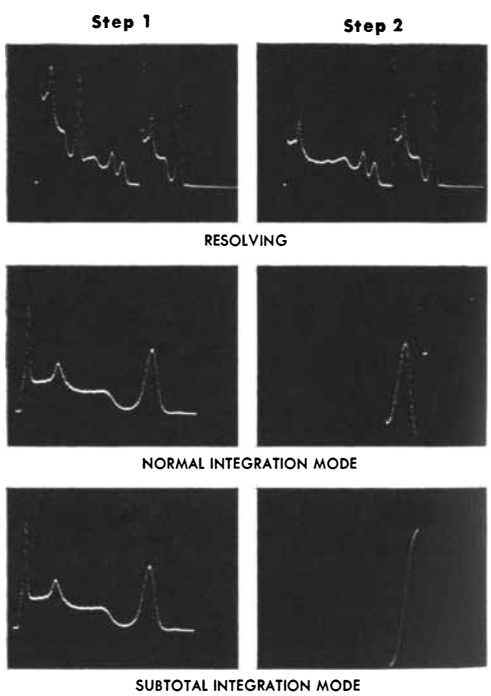
NORMAL mode sums the counts in the preselected band and stores the total in the last channel.

SUBTOTAL mode adds each channel count to the previous one to provide a running subtotal.

With every operation, results are displayed on the analyzer scope and may be printed, recorded or punched out by the readout method of your choice.

Case design of the Model 522 Resolver/Integrator is identical to that of the compatible "400 Series" fully-portable, 400-channel Pulse Height Analyzers.

TYPICAL DISPLAYS



SPECIFICATIONS

Resolving Rate.....0.5 sec. for one add or subtract operation per 100 channels
% Resolved.....100%, 10%, 1% or 0.1%
Integration Rate..... 0.5% sec. per quarter memory
Channel band..... Continuous 1 — 400 channels
Integrating Modes ..... Normal, Subtotal
Blanking..... Only channels to be integrated are visible on Analyzers CRT display
Size.....8⅝" w. x 10¼" h. x 21" d., 28 lbs. (approx.)

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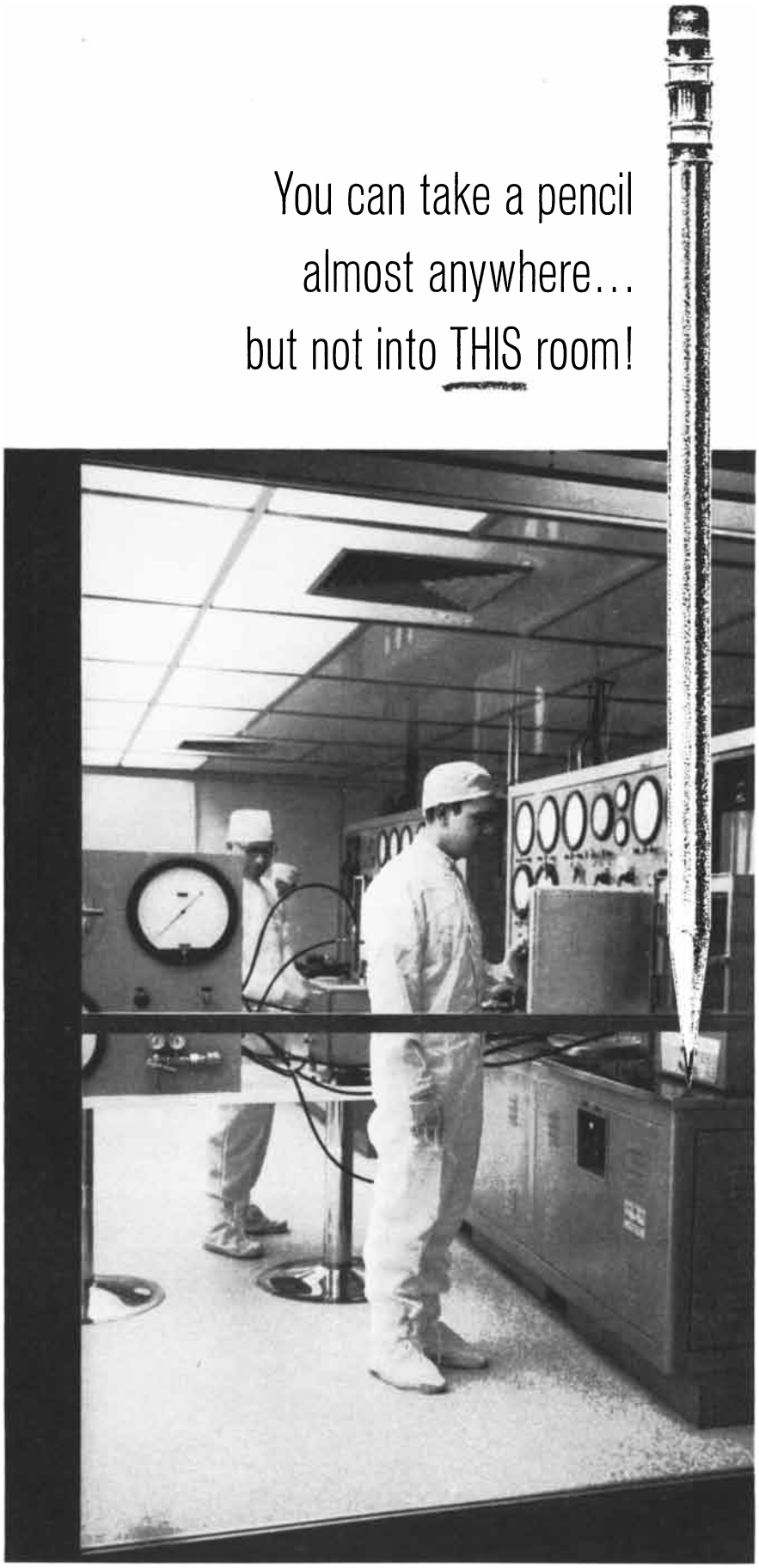
You can take a pencil almost anywhere... but not into THIS room!



When marking, pencils leave tiny deposits of graphite behind them. Particles of matter even **that** small "matter" in the Chandler Evans clean room facility. They represent contamination.

Similarly, ordinary paper contaminates—hence, paper must be "non lint-producing" or coated with polyethylene film. And even then it is thoroughly vacuum cleaned before accompanying its bearer through an air shower into one of three separate clean rooms. Such are the precautions taken in this unusual "laundry" for space hardware.

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LETTERS

Sirs:

Is a wolf called "wolf" because he wolfs his food? Or a fox "fox" because he's foxy?

In the article on hamsters in your January issue it is said that the animal is named from the German verb *hamstern*. *Hamstern* is a colloquial word, analogous to the English "squirrel away." In both cases the word or phrase derives from the characteristics of the animal rather than the other way around.

Actually, it is believed the word hamster (in German *der Hamster*) comes from an Old High German word, *Hamastro,* meaning corn weevil, probably from another of the hamster's propensities—to wit, burrowing.

ARTHUR J. MORGAN

University Research Associates
New York, N.Y.

Sirs:

"The Perception of Neutral Colors," by Hans Wallach [SCIENTIFIC AMERICAN, January] was particularly interesting to me as one of the relatively large group of the color-blind.

The ring-and-disk experiments were anticipated by perhaps 40 years by the poet Charles Wharton Stork, who wrote:

Standards

White is the skimming gull on the somber green of the fir-trees,

Black is the soaring gull on a snowy glimmer of cloud.

CLYDE E. HOLVENSTOT

Assistant Chief Engineer
Ingersoll-Rand Company
Painted Post, N.Y.

Sirs:

In his article "The Thymus Gland" [SCIENTIFIC AMERICAN, November, 1962] Sir Macfarlane Burnet presents interesting immunological concepts. His statement that to a microscopist "the thymus is a rather uninteresting organ" may not reflect the views of many morphologists. Two points deserve special comment:

1. "The" thymus in the human is described as a "two-lobed organ." A paper in 1933 by G. L. Weller, Jr., on the development of the human thymus indicates that there are two separate thymuses, a left thymus and a right thymus, and not two "lobes" of a mid-line organ ("Development of the Thyroid, Parathyroid and Thymus Glands in Man," *Contributions to Embryology,* Carnegie Institution of Washington, Vol. 24, No. 141, pages 93–139; 1933). This is the case in all animals that have thymuses. This distinction may be of fundamental importance in understanding thymic regulatory function because the two glands often behave asynchronously. Studies in our laboratory have indicated that when leukemia develops in some strains of mice, it begins in one thymus, whereas the opposite organ undergoes characteristic pathological changes. The accompanying photograph [*upper illustration on page 14*] shows leukemic enlargement of the right thymus [*rectangle*] of a mouse, whereas the left thymus remains quite small.

2. The histology of the thymus is perhaps more interesting when one considers an important aspect of thymic physiology: the Hassall's corpuscles. These cystic epithelial structures in the medullae of the thymuses are in dynamic activity, constantly forming, enlarging and rupturing. Cells entering these stomach-like cysts are probably dissolved. A cell being *intruded* into the cavity of a Has-

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The appearance of a canoeful of hostile tribesmen or even a strange group on a jungle trail starts the drums talking. This is literally true. The drum beats of the Ngere tribe on Africa's Ivory coast are not a code, but imitations of human speech patterns. This drum language, warning tribe members of the approach of enemies or strangers, may be heard up to twenty miles.

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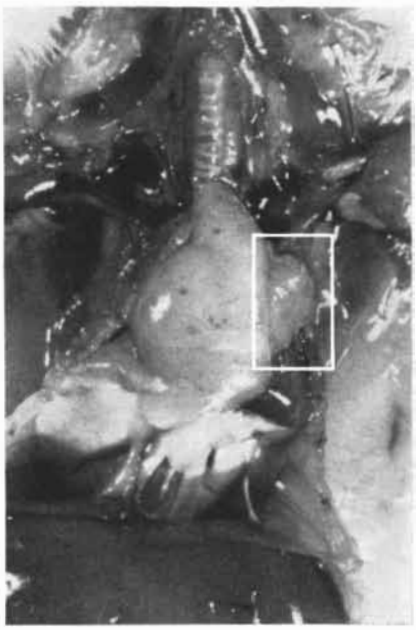
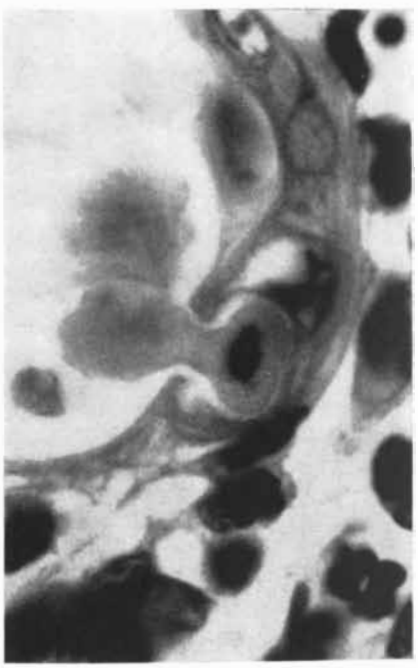
sall's corpuscle is shown in the second photograph [*lower illustration below*]. Since these Hassall's corpuscles are found only in the thymus, they, as well as the lymphocytes of the thymus, may contribute to the biologic uniqueness of these organs.

RICHARD SIEGLER, M.D.

Laboratory of Cancer Research
Albert Einstein Medical Center
Philadelphia, Pa.



Enlarged right thymus of a mouse



Cell intruded into a Hassall's corpuscle

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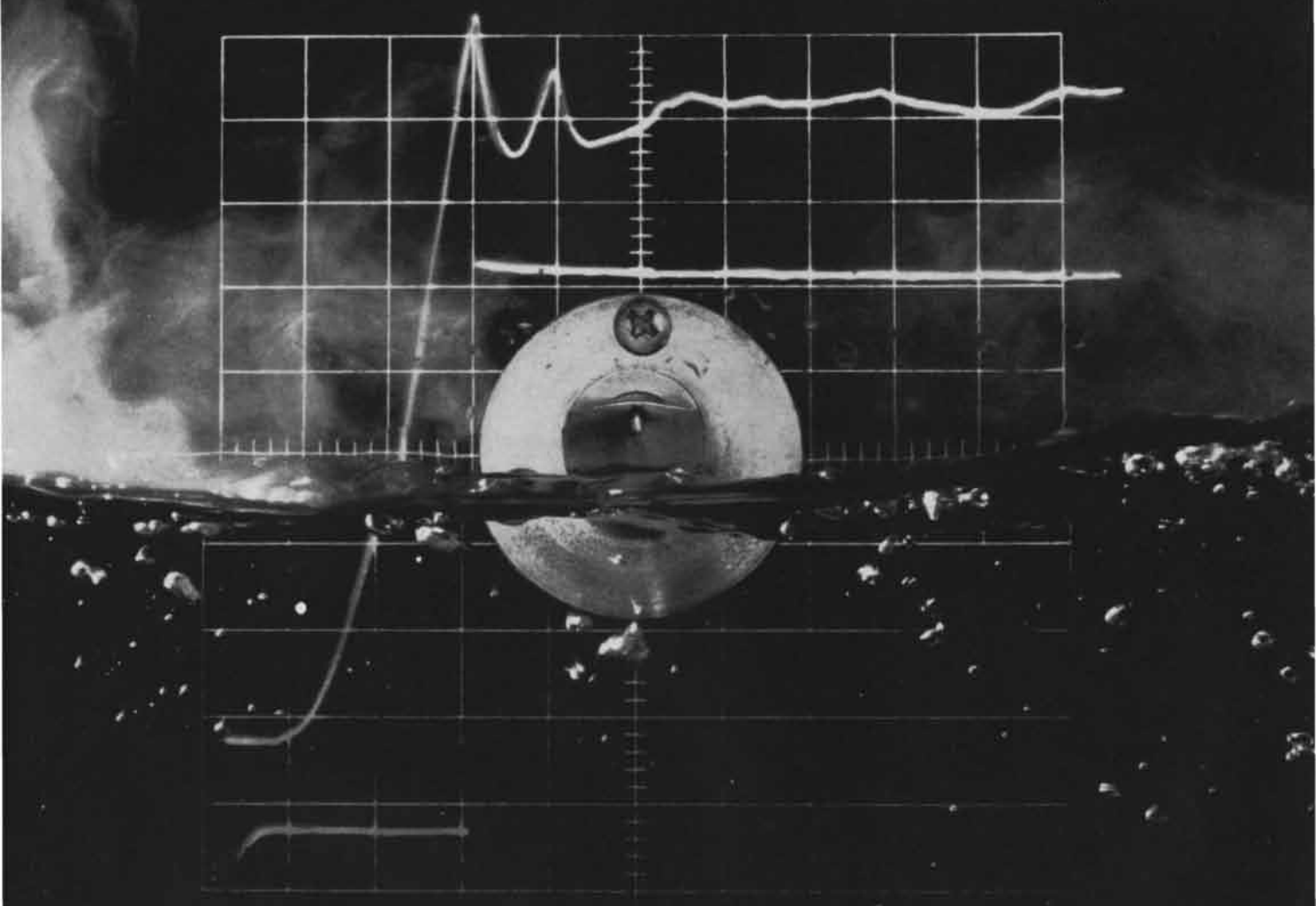

The above photo-reproduction shows UCC's unique Thermal Point Sensor, 1½ times size, in actual testing. The upper trace indicates sensing element position relative to static liquid level (represented by the horizontal center line) at a withdrawal rate of 2-3 fps. The lower trace shows detection of liquid-gas interface. Horizontal time scale is 10 ms/division.

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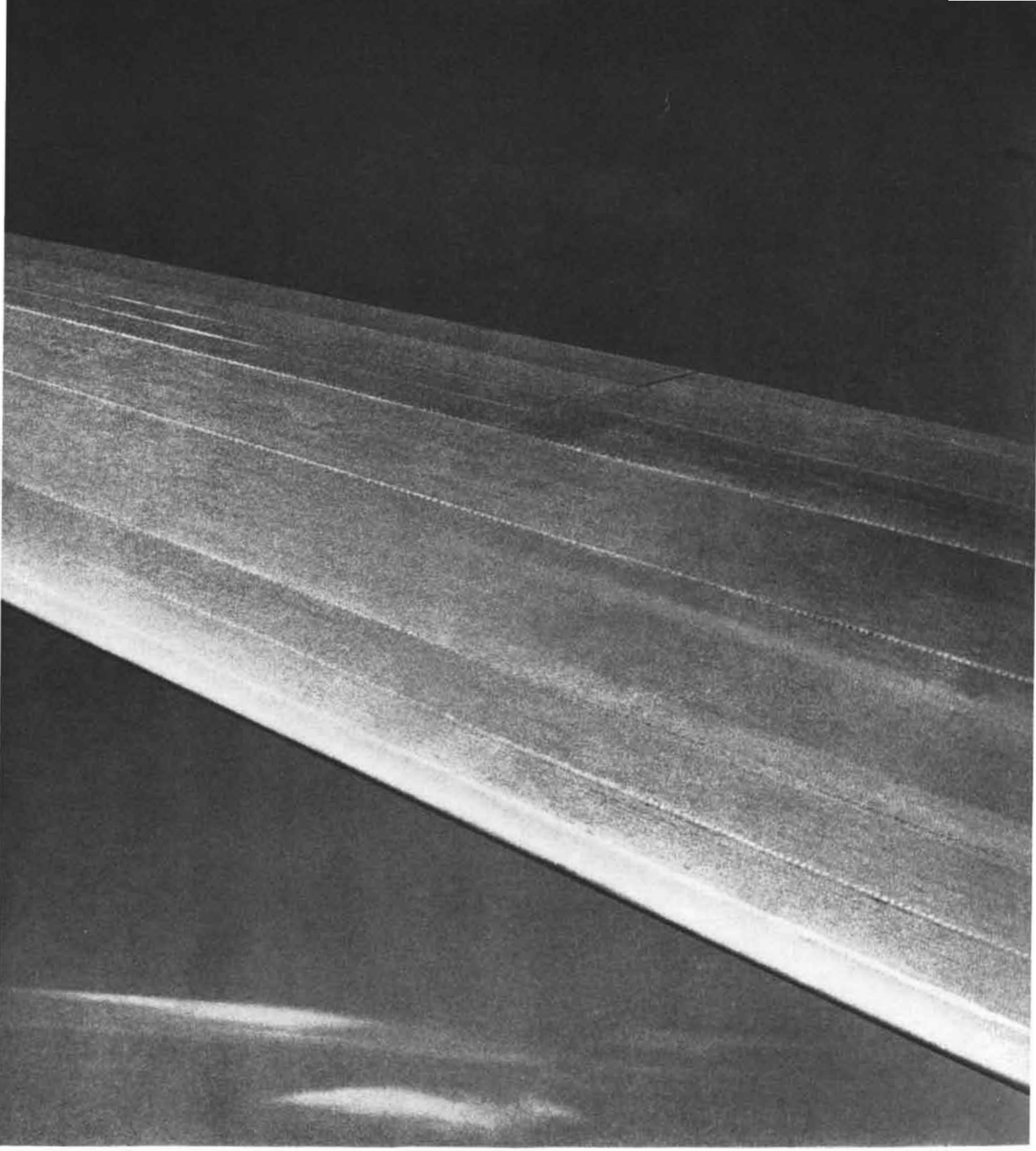
To overcome this problem, Northrop has conducted a 14-year research program, and has developed a system called Laminar Flow Control. Row after row of paper-thin slots are put in the wings of an airplane. At the base of these slots are pinsize holes. A pumping system inhales the boundary



layer air through the slots and holes and expels it to the rear. Swoosh! Eighty percent of the friction drag from boundary turbulence is gone.

Laminar Flow Control will make it possible to extend the range, endurance, or payload of large aircraft by 50% or more — with no increase in fuel consumption. Best of all, perhaps, is that it can be added at very nominal cost. And this initial cost is quickly recovered by economies of operation.

Laminar Flow Control is being applied by Northrop to two U.S. Air Force jet aircraft, which will be designated X-21's. These will be flown in 1963 to demonstrate the new technology. Results of these tests should radically alter the fundamental concepts of large plane design, economics, and missions. **NORTHROP**

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Each of the 1000 printed circuit cards produced daily by Martin can now be given 32 quality tests *in less than 2 minutes* — work which formerly took an experienced electronics technician and inspector 15 to 45 minutes *per card!*

As in the case of Martin, EI *all solid state* Digital Multimeters are *your* answer to greater speed, higher reliability, significant cost savings and a much lower investment.

Whether your interest lies in spacecraft, electronic components or industrial processes, we can demonstrate to you the advantages of EI digital instruments in measuring DC volts, AC volts, DC ratios, resistance, capacitance, inductance and impedance. Let EI *all solid state* Digital Multimeters provide you with swift, accurate, low cost solutions to your measurement and display problems.

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Carle W. Collins, production test engineer, Martin Company's Orlando (Fla.) Division, inserts coded Mylar tape into the reader unit of the Tape Programmed Automatic Tester which he designed.

Electro Instruments, Inc.
8611 Balboa Avenue, San Diego 12, California

ARMY ENGINEERS WANTED MUSCLE AND HUSTLE BOTH IN ONE VEHICLE... CATERPILLAR'S CAPABILITIES CREATED THE 830M

Hustle a convoy-trailer down the highway at 30 mph. Turn off the road and wade into rugged terrain. That's what Army Engineers wanted. That's what Caterpillar delivered . . . and is producing . . . the unique 830M.

Unique Capabilities . . . Unique Vehicles. This machine has road speed and terrain-taming power. The 830M is a 4-wheel drive articulated tractor with hydraulic steering. It took the specialized facilities and deep experience of Caterpillar to create it . . . a typical example of how Caterpillar capabilities can serve military needs.

First Requirement: Mobility. Here's 52,200 pounds that can snap along at 30 mph with a loaded trailer. It can turn in a 40-foot diameter. It fords 3 feet of water, rides a plane or a train (to Berne Scale specifications) and can be operated by any motor-pool driver checked out on trucks.

Second Requirement: Power. The 830M clears sites and cuts roads with a bulldozer and an 18-yard scraper. Bulldozing, it handles more than 100 bank cubic yards an hour. On a 1500-foot haul with the scraper, it moves 348 bank cubic yards an hour.

Third Requirement: Reliability. Preproduction model logged over 800 hours of bruising duty during exhaustive tests at Caterpillar's Peoria Proving Grounds. Caterpillar know-how built the 830M . . . Caterpillar reliability went into every working pound.

Caterpillar Added the Extras. The 830M pushes a freight car without rail damage. It pulls an amphib from the water. It can tow a tank . . . push a snow plow or be equipped with compactor wheels. It performs in punishing climates—from an arctic 25° below zero to a tropical 125° above (F.).

New Military Challenges. If your organization's research plans include special vehicles, components, engines or generator sets, you'll want to know more about Caterpillar's unusual research and development capabilities. Write to Defense Products Department, Caterpillar Tractor Co., Peoria, Ill.

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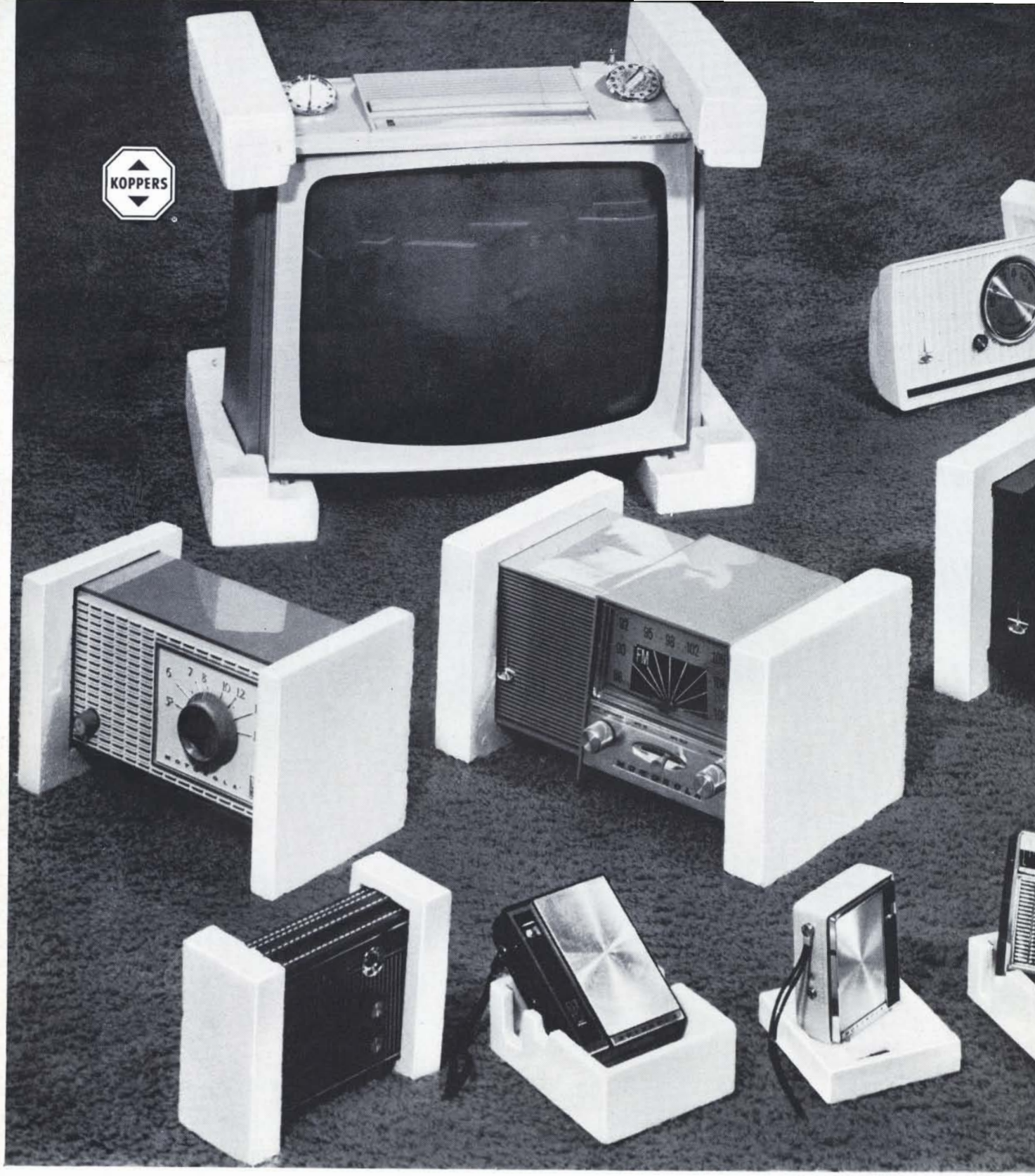
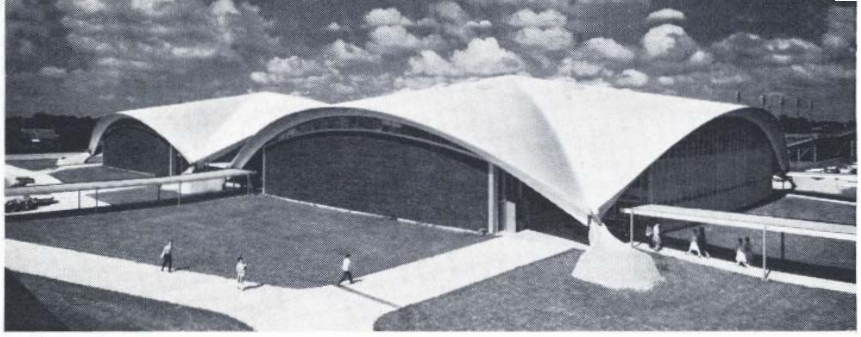


DYLITE® foam plastic cuts packaging costs 20% at Motorola

When packaging engineers at MOTOROLA changed to interior packing made of DYLITE expandable polystyrene, they lowered their packaging costs 20%. This rigid foam plastic protects against shock and abrasion, and reduces shipping damage. MOTOROLA no longer takes time folding, then hand packing bulky pieces of wadding to wedge the products in place. Easy-to-pack corner pads of DYLITE protect clock radios and portable television sets. DYLITE trays and inserts brace transistor radios inside the set-up boxes. This Koppers foam plastic is extremely lightweight and can be molded in almost any size or shape at low cost. Check the coupon for information on how DYLITE can help you cut your packaging cost.

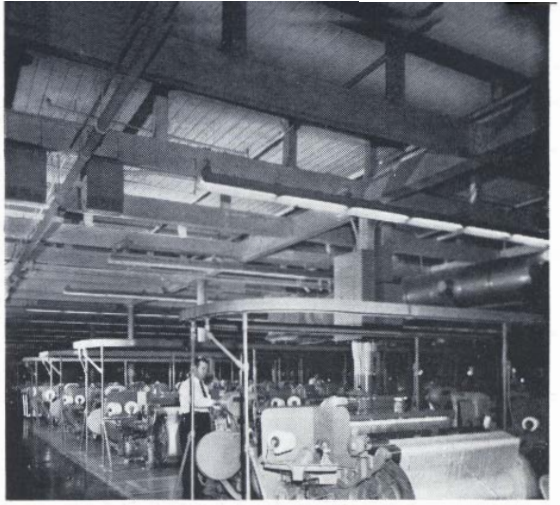


Look what they did in Texas...with glue

Two of the largest open-span buildings in the country are the new gymnasium and auditorium at the THOMAS JEFFERSON HIGH SCHOOL in Port Arthur, Texas. All the arches that support these dramatic spans are laminated from glued-up timbers. The main arches which span 215 feet and the 158-foot-long perimeter arches, which must withstand the most humidity and weathering, are laminated with PENACOLITE® adhesive from Koppers. This waterproof glue makes a bond that is every bit as strong as the wood it joins.

Architects like wood because it's warm and beautiful, easy to work, familiar to construction crews. *Laminated* wood has the extra advantages of great structural strength and low cost, and when laminated with PENACOLITE adhesive, structural timbers give the ultimate resistance to weather, age and strain. Check the coupon.

Architect: CAUDILL, ROWLETT, SCOTT—J. EARLE NEFF, ASSOCIATED ARCHITECTS, *Houston & Port Arthur, Texas*

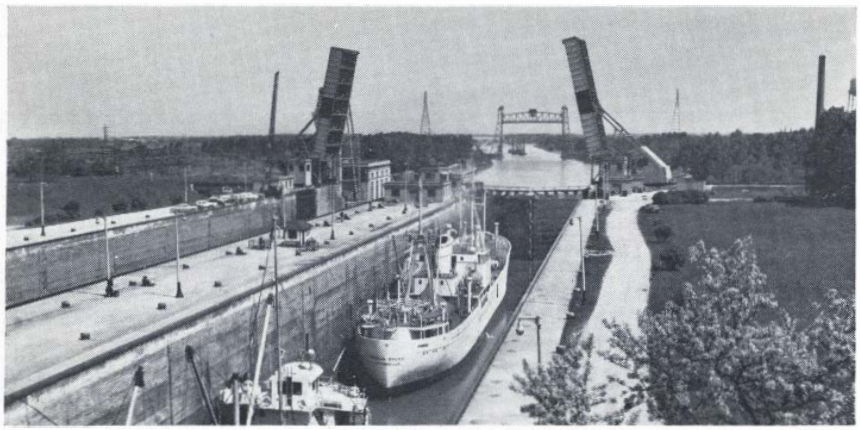


This wood roof deck is always hot and wet—but it won't rot

The weave room at the DAN RIVER MILLS plant in Danville, Va., is kept at 90°F. and 85% relative humidity. These conditions rotted out the old 4-acre wood roof deck, and spot repairs couldn't keep up with the decay. So they built a new roof—again with wood because it is light, a good insulator and easy to erect.

But the new roof isn't ordinary wood. This time they used WOLMANIZED® pressure-treated lumber for the new 3″ deck. WOLMANIZED lumber is *permanently* protected against rot and decay because it is processed in a pressure chamber in which all air is evacuated from the wood cells. Then a solution of WOLMAN® preservative salts is forced into the wood fibers under high pressure. The preservative will not leach out. It has no odor. It will not corrode nails or bolts. The lumber can be painted or glued, and it can be worked like untreated wood. Check the coupon.

Consulting Engineers: LOCKWOOD-GREENE, INC., *Spartanburg, S. C.*



After 30 years, canal engineers still find coal tar coatings best corrosion protection

Oldest man-made link in the St. Lawrence Seaway is the WELLAND SHIP CANAL, completed in 1932 at a cost of some $132 million. The builders made sure they protected this investment by using the best corrosion preventive then known for the many tons of structural steel work that would be in constant contact with water. They specified BITUMASTIC® No. 50 coal tar coating—and they're still specifying it. In fact, the average life of the BITUMASTIC No. 50 on this canal has been eight years, and some of it has lasted fifteen years before requiring touch-up.

BITUMASTIC coatings are coal tar based and the secret of their unequalled corrosion protection lies in the tight benzene ring structure of the coal tar molecule which is impervious to water penetration. BITUMASTIC No. 50 is only one of the many products in the BITUMASTIC line. This is a tough, heavy-duty coating that is five to eight times thicker than conventional paints. Koppers makes a complete line of BITUMASTIC coatings for corrosion protection of steel and concrete surfaces in plants, pipelines, highways, railroads and commercial construction. Check the coupon for information about corrosion protection with coal tar coatings.

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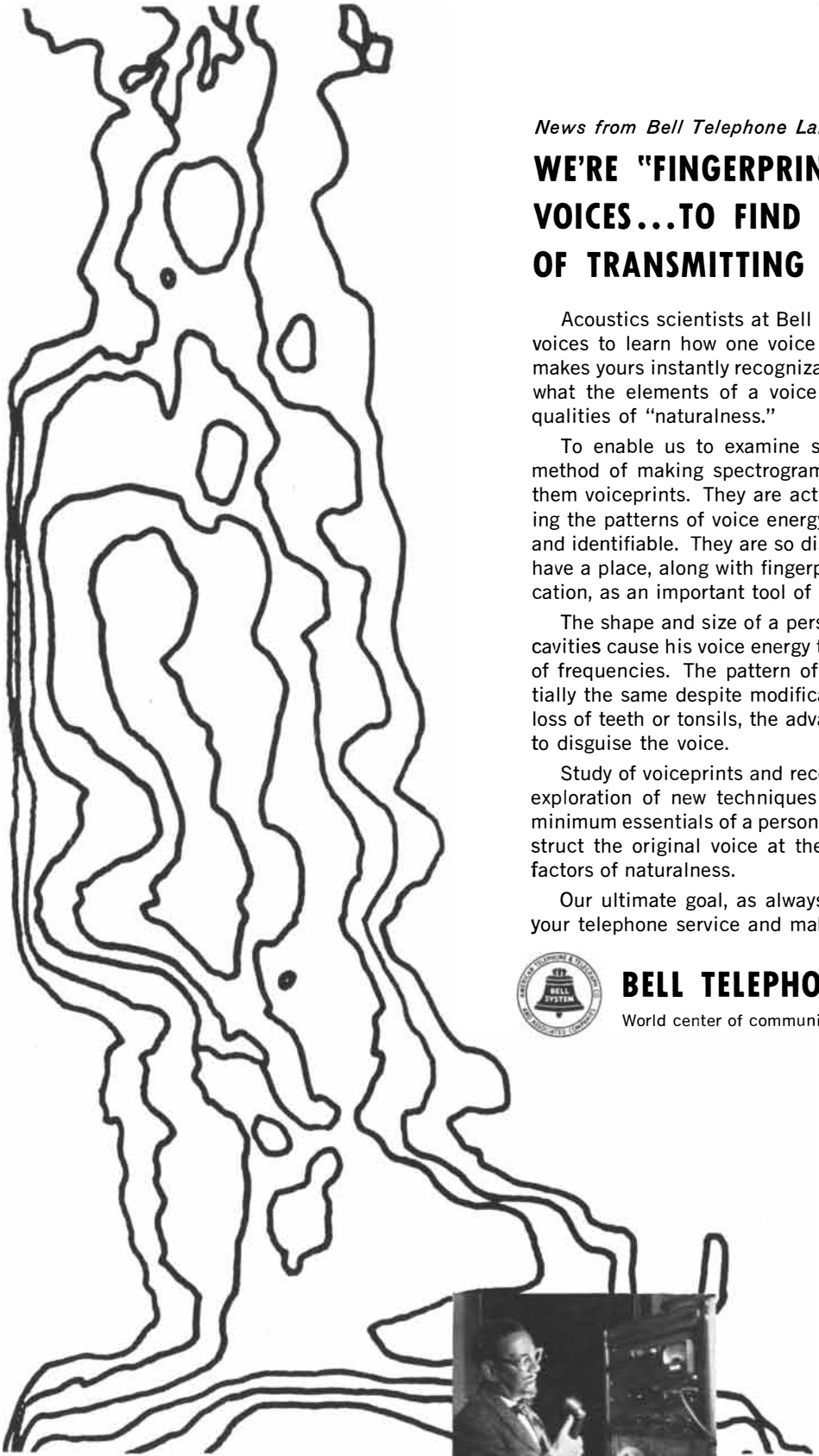
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MARCH, 1913: "On Monday of last week the Edison kinetophone was exhibited for the first time in public on the stages of four prominent vaudeville theaters in New York City. In the first film a man made a speech explaining the perfecting of the talking picture by Edison in the obtaining of absolute synchronism between the pictures and the sounds. Then a pianist played, a bugler sounded the reveille, a young lady sang and some dogs appeared and barked. A second picture showed a minstrel entertainment in which the various members of the troupe performed as naturally as in real life, although there was no mistaking the fact that the talk and music were produced by a phonograph. The intensification of sound necessary in a theater apparently gives to it more of that metallic quality of which it has been successfully deprived in the smaller drawing-room machines. Nevertheless, it is no more disagreeable than the voices of many of the actors who appear on the vaudeville stage. The present talking pictures last about five minutes each."

"Recently reported experiments of a Dutch investigator have gone far to confirm the theory that the electrical resistance of all conductors would be reduced to zero by cooling the conductors to the absolute zero of temperature. By boiling liquid helium in a partial vacuum a temperature of only three degrees above the absolute zero was attained. At this temperature the resistance of mercury was found to be only one ten-millionth as great as at zero centigrade."

"Specifications that have lately been issued for Army aeroplanes are not nearly so rigid and difficult of fulfillment as they doubtless would be if the aeronautic industry in America had kept pace with that abroad. The new machines must be capable of a speed of from 38 to 55 miles per hour. They must carry two persons and a radio-telegraph set weighing about 75 pounds. They must ascend 2,000 feet in 10 minutes when carrying a live load of 450 pounds, and must make a contin-



Word Picture. This is a picture of the spoken word "you." By analyzing the sound with a spectrograph, the Laboratories' Lawrence G. Kersta makes a print of the word in graph form. Graph shows frequency, time taken, and intensity used in making speech sound.

News from Bell Telephone Laboratories

WE'RE "FINGERPRINTING" VOICES...TO FIND BETTER WAYS OF TRANSMITTING THEM

Acoustics scientists at Bell Telephone Laboratories study voices to learn how one voice differs from all others, what makes yours instantly recognizable to friends and family, and what the elements of a voice are that give it the elusive qualities of "naturalness."

To enable us to examine speech closely, we devised a method of making spectrograms of spoken words. We call them voiceprints. They are actual pictures of sound, revealing the patterns of voice energy. Each pattern is distinctive and identifiable. They are so distinctive that voiceprints may have a place, along with fingerprint and handwriting identification, as an important tool of law enforcement.

The shape and size of a person's mouth, throat and nasal cavities cause his voice energy to be concentrated into bands of frequencies. The pattern of these bands remains essentially the same despite modifications which may result from loss of teeth or tonsils, the advancement of age, or attempts to disguise the voice.

Study of voiceprints and recognition factors is part of our exploration of new techniques to extract and transmit the minimum essentials of a person's voice and from these reconstruct the original voice at the receiving end, retaining its factors of naturalness.

Our ultimate goal, as always, is to learn how to improve your telephone service and make it a better value.

BELL TELEPHONE LABORATORIES

World center of communications research and development

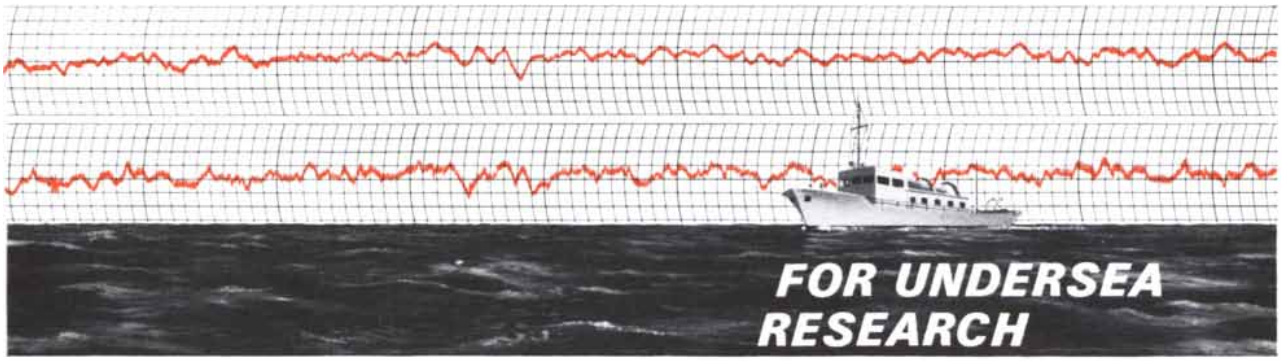
uous flight of four hours' duration during the first part of which a flight of 180 miles across country must be included. All new Army aeroplanes must be capable of rising from or alighting on a harrowed field or a field covered with long grass in not over 100 yards."

"At the age of 85 years and living almost in penury, Charles Tellier, the inventor of the system of cold storage now used all over the world, was decorated recently with the cross of the Legion of Honor and banqueted by the International Cold Storage Association. A subscription of $15,000 was raised for him, so that the remaining years of his life may be passed in comfort. Like many another inventor before him, he sacrificed everything in carrying out a brilliant idea. As early as 1876 he built the ship *La Frigorifique*, which took a cargo of frozen meat from Rouen to La Plata, the first consignment of what has since become an industry of world-wide trade."

Scientific American.

MARCH, 1863: "Ever since the commencement of the potato disease in 1845, if not a little earlier, there has been a very marked diminution in the rate at which population has advanced in western Europe. In France the rate of increase was estimated at .646 per cent per annum from 1801 to 1836, at .445 from 1836 to 1856, and it is now less. In western Germany there has been an extremely slow increase in most parts and an actual diminution in others—Electoral and Grand Ducal Hesse. In Great Britain the population, since the census of 1841, has increased no faster than that of France. That of Ireland has greatly diminished. That of Scotland has scarcely increased at all. The whole increase is in England and Wales, and generally speaking in the towns and manufacturing districts. To take the case of England and Wales alone: these had 18,000,000 inhabitants in 1851, 20,000,000 in 1861; but it must be remembered that England draws constantly increasing supplies of people from other parts; the total 2,000,000, therefore, cannot be set down as the natural increase."

"H. Roper, of Roxbury, Mass., has invented and completed a steam carriage that, according to report, subserves the ends for which it was made. A recent trial of this innovation on the 'old style'



THE VENTURI TURBULENCE SENSOR

A product of extensive studies in hydrodynamics at Aerojet-General®, the Venturi Turbulence Sensor is used for investigating the macrostructure of turbulence in fluid media. ■ Simple in construction, the Venturi Turbulence Sensor has no moving parts. It consists of a venturi hydroframe with a cylindrical piezo-electric transducer element which forms the venturi throat. The transducer is free to expand or constrict radially under differential pressure changes across the throat that result from the turbulent velocity fluctuations in the fluid field sampled. Electrical charges proportional to the resultant stresses produce an e.m.f. which is amplified and recorded on any standard direct-writing oscillograph to indicate the magnitude and frequency of the velocity fluctuations. ■ Applications: investigation of the relationship between turbulence and temperature at any depth; turbulence and diffusion (water pollution studies); turbulence and land erosion; turbulence associated with internal waves; water tunnel analyses; and general oceanographic studies. ■ For complete information on the application of the Venturi-Turbulence Sensor to your needs, write Oceanics Division, Aerojet-General Corporation, P.O. Box 296, Azusa, California.

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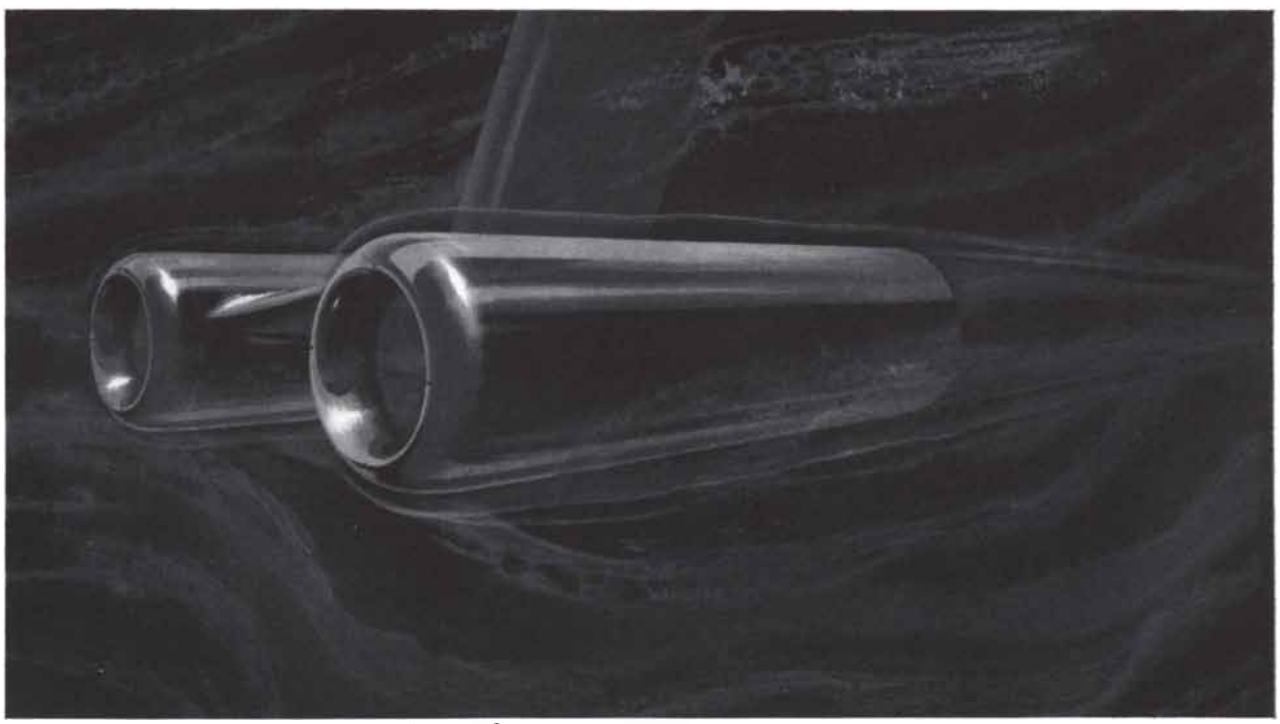

(Venturi Turbulence Sensors illustrated approximately 85% actual size.)

was very successful; it passed through Boston, and, meeting a car on the horse-railroad, turned off the track and went around the car with as much ease as if drawn by a horse. On a smooth road or on the rail, with 60 pounds of steam (the usual amount), the carriage can be run at the rate of 20 miles per hour. The weight of the carriage is 650 pounds."

"Measures are now in progress that to all appearances will lead to the construction and laying of another Atlantic cable at no very distant day. On the fifth instant an influential meeting of capitalists and merchants was held at the Chamber of Commerce, New York City, for forwarding the project of the new Atlantic telegraph. Mr. Peter Cooper stated that the facility such a telegraph would afford to merchants in sending and receiving orders and obtaining the prices ranging in European markets would compensate them for all the cost involved in the undertaking. Such a telegraph would also tend to prevent misunderstandings between Great Britain and the United States. Mr. Cyrus W. Field stated that he wished to correct a wrong impression made on the public mind with respect to ocean cables. It was a common belief here that all such cables hitherto laid had been failures. This was a mistake; and he read a letter from a firm in London engaged in the manufacture of submarine cables, in which it was stated they had already laid 44, the total length of which was 9,000 miles, and all were in good working order."

"According to M. Arago, astronomers and others have failed to arrive at a satisfactory explanation of the twinkling of the stars because of their failure to give an exact definition of the term 'scintillation.' He affirms that, in so far as naked-eye observers of the heavens are concerned, scintillation, or twinkling, consists of very rapid fluctuations in the brightness of the stars. These variations are always accompanied by variations of color and secondary effects, which are the immediate consequences of every increase or diminution of brightness; such as considerable alteration in the apparent magnitude of the stars and in the length of the diverging rays, which appear to issue in different directions from their centers. It has been remarked from a very early age that the phenomenon of twinkling is accompanied by a change of color. It is asserted that the name of Barakish, given by the Arabians to the star Sirius, signifies the star of a thousand colors. M. Arago also asserts that the planets twinkle."

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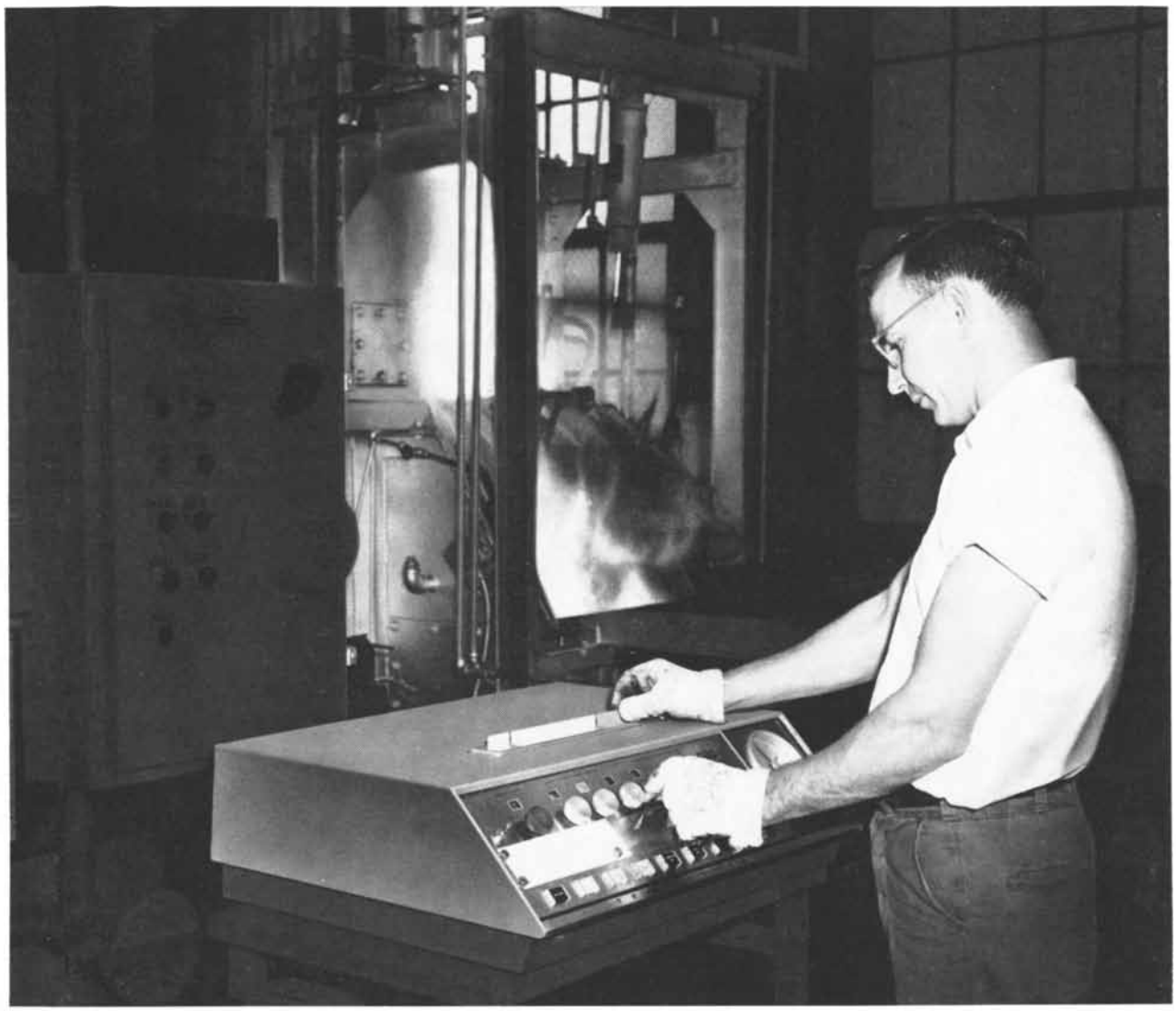

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Basic Research at Honeywell
Research Center
Minneapolis, Minnesota

The Measurement of Surface Roughness by Radioactive Adsorbents

Roughness of surfaces affects several parameters including physical movement, magnetic properties and rate of reaction. Radioactive adsorbents now offer a means of accurate repeatable measurement of roughness on a molecular scale.

Scientists have long known that the degree of surface roughness has a profound effect on the physical movement between surfaces, on the physical and chemical properties of materials and on the rate of reaction with a reacting agent. If the degree of roughness could be accurately and quickly measured, the characteristics of the surface could be predicted.

The problem facing the scientist is similar to the topographer measuring a mountain range but the scientist is dealing with a molecular scale in attempting to measure the true profile of a surface.

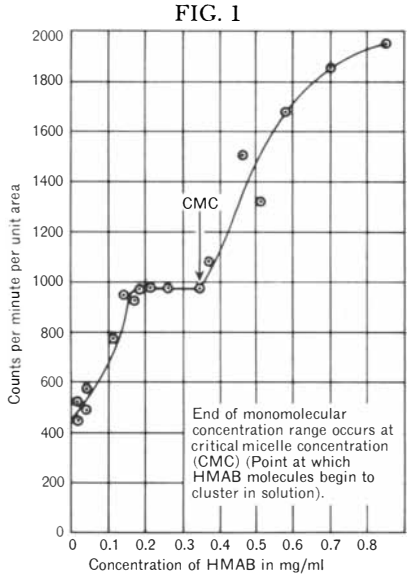
Langmuir, in 1918, discovered that certain gases were adsorbed on a surface in certain cases as a monomolecular layer. In a closed system he would measure the amount of gas adsorbed by the surface. Knowing the area of each gas molecule he could then determine the surface area. The technique was limited in its sensitivity and did not apply to multi-layer adsorption. Langmuir extended his technique to liquids when by dipping a clean glass plate in oleic acid floating on water, he found that the surface was covered with a monomolecular layer of the acid. With diffraction techniques he was able to make a rough measurement of the surface.

Today progress is being made using the new techniques of radioactive tracing.

If a species that would be adsorbed as a monomolecular layer is tagged with a radioactive material of known specific activity (number of counts per unit weight), measurement of the counts on the surface will yield the number of molecules adsorbed. Thus, as with Langmuir's technique, if the area occupied by an adsorbed molecule is known, the total surface area or roughness can be calculated.

Stearic acid was the adsorbent usually used but it would not stick on some surfaces and could not be used on many materials.

FIG. 1



ADSORPTION ISOTHERM OF HMAB ON ALUMINUM AT 25° C.

Honeywell scientists were particularly concerned with measuring the surface roughness of glass and searched for a rapid technique that would work in an aqueous solution. Since detergents are known to coat materials they were considered as a promising group to be tried. They offered wider applications and could be used on plastics, glass and metals. By varying the concentration of detergent it was found that there is a range in water at which the detergent is adsorbed as a monomolecular layer (See Fig. 1.). Hexadecyltrimethylammonium Bromide (HMAB) was chosen and tagged with C^{14}. The radioactivity of the detergent adsorbed on the glass surface was measured and from this the number of molecules on the surface was determined, and thus the area was calculated.

Accurate measurement of surfaces has led to some interesting insights into surface characteristics.

In thin Permalloy films the effect of moderate roughening did not change the coercive force. Upon further roughening, however, there was a sharp rise in coercive force.

When the surface of the substrate was varied by unidirectional scratching a phenomenon known as bi-axial anisotropy (two easy directions of orientation by a magnetic field) was noted for the first time in the material. In addition, aging of the surface was observed as the investigation proceeded.

Measurement of the surface area has also permitted Honeywell scientists to determine the effect of varying roughnesses of glass on the speed of movement of mercury — leading to predictable response in faster-acting mercury switches.

Further understanding of the effect of surface roughness is looked for as the surface area measurement techniques are refined.

If you are actively engaged in work in this field and wish to know more about Honeywell's techniques you are invited to correspond with Dr. Joseph Kivel, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree, you are invited to write Dr. John Dempsey, Director of Research at this same address.

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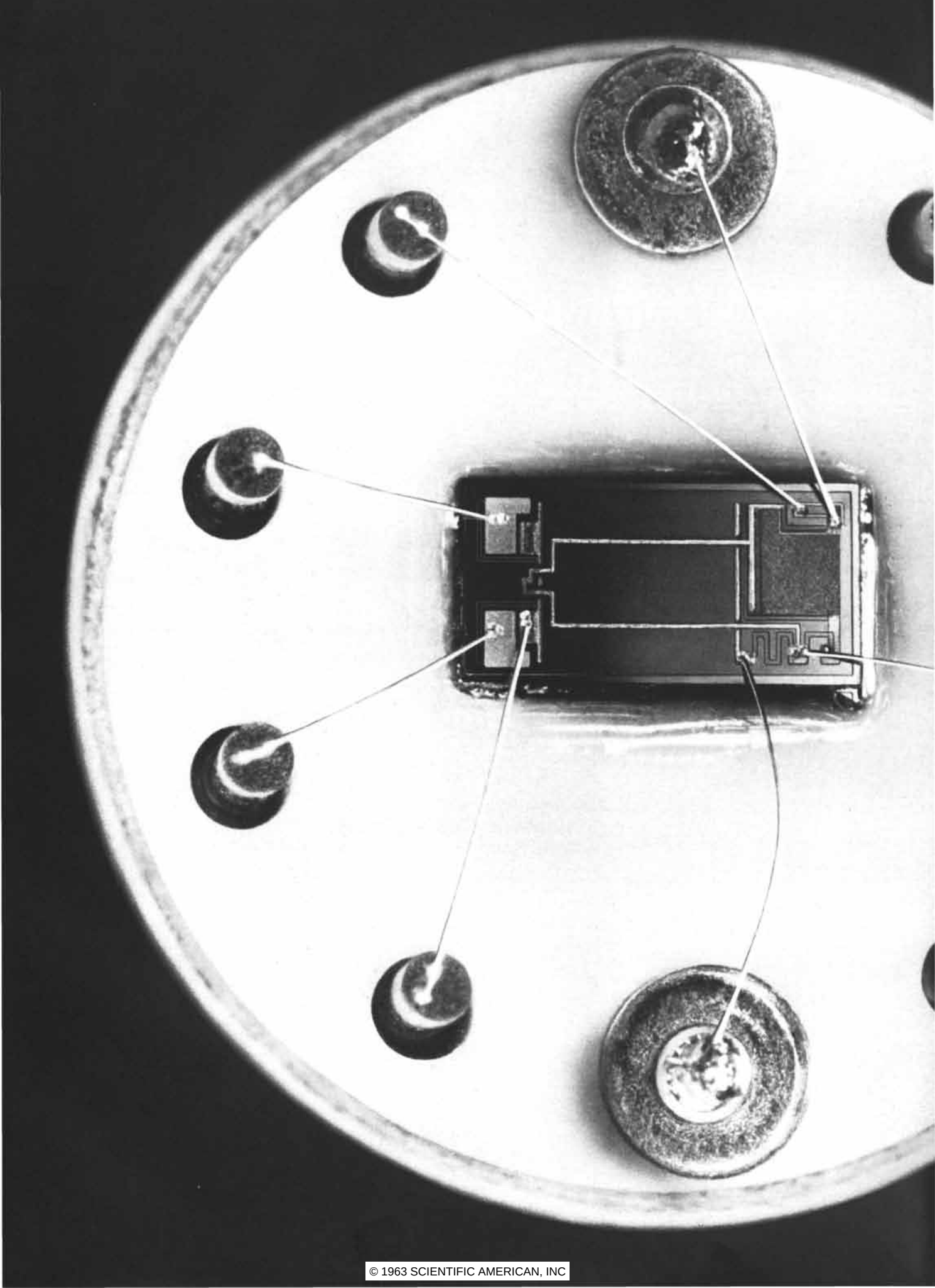

SCIENTISTS AND ENGINEERS: Today's electronic systems for military and space programs demand smaller, lighter weight equipments with lower power consumption and the highest order of reliability. These needs have forced a marriage of the best features of advanced semiconductor and thin film integrated circuit techniques, and resulted in such functional electronic blocks as the tiny compatible circuit shown at left.

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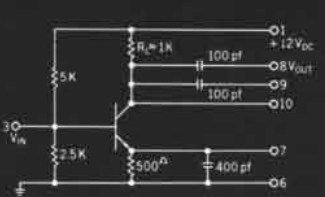
ACTUAL SIZE 120 mc RF high frequency linear amplifier integrated circuit custom built by Motorola's Semiconductor Products Division.



THE AUTHORS

BRIAN MASON ("Organic Matter from Space") is curator of physical geology and mineralogy at the American Museum of Natural History. Born in New Zealand, Mason studied geology and chemistry at the University of New Zealand, which awarded him an M.Sc. in 1937. In 1939 he resigned his job as a geologist for an oil company and went to Norway in order to improve his skiing. While there he enrolled at the University of Oslo and came under the influence of the geochemist Victor Moritz Goldschmidt, who introduced him to the subject of meteorites and their geochemical significance. After the German invasion of Norway in 1940 Mason escaped to Sweden, where he continued his studies at the University of Stockholm, receiving a Ph.D. in mineralogy in 1943. He spent the following year as a scientific liaison officer for the New Zealand Government, was senior lecturer in geology at the University of New Zealand, and from 1947 to 1953 was associate professor of mineralogy at the University of Indiana. Mason took his present job in 1953.

H. W. LISSMANN ("Electric Location by Fishes") is lecturer in the department of zoology at the University of Cambridge. Lissmann, who was born in Russia, studied in Germany, where he obtained a Ph.D. at the University of Hamburg. He received an M.A. from Cambridge in 1947 and became assistant director of research there the same year. Lissmann was elected a Fellow of the Royal Society in 1954. He was made lecturer in zoology at the University of Cambridge the following year and was also elected a Fellow and Lecturer of Trinity College, Cambridge. Lissmann is interested mainly in the behavior of animals, their movements, sense organs and nervous systems. His studies of electric fishes, begun in 1950, are described in his article. Lissmann has found it "useful and illuminating" to collect his own fish in Africa and South America. His work is still frequently hampered by a shortage of experimental subjects, and Lissmann writes that he would be grateful to anyone who could suggest to him a possible source of supply.

LEON M. LEDERMAN ("The Two-Neutrino Experiment") is professor of nuclear physics at Columbia University and director of the university's Nevis

Laboratories. There he has done much of his research on the weak interactions of modern physics, using the facility's 400-million-electron-volt cyclotron. Lederman received a B.S. from the College of the City of New York in 1943. For the next three years he served with the U.S. Army Signal Corps, spending part of that period at the Radiation Laboratory of the Massachusetts Institute of Technology and part in Europe. After the war he studied physics at Columbia under the direction of I. I. Rabi and Gilberto Bernardini, who was visiting professor from the University of Rome at the time. Lederman joined the faculty at Columbia in 1951, having obtained his Ph.D. the same year, and became director of Nevis in 1960.

MARSHALL W. NIRENBERG ("The Genetic Code: II") is head of the Section of Biochemical Genetics at the National Heart Institute, one of the nine National Institutes of Health. Nirenberg took a B.S. at the University of Florida in 1948. After receiving an M.S. in biology from the University of Florida in 1952, Nirenberg went to the department of biological chemistry at the University of Michigan, where he acquired a Ph.D. in 1957. A two-year postdoctoral fellowship from the American Cancer Society brought him to the National Institute of Arthritis and Metabolic Diseases later the same year, where he remained until he took his present post in June of last year.

RAYMOND B. CATTELL ("The Nature and Measurement of Anxiety") is Distinguished Research Professor in Psychology at the University of Illinois. Cattell, who was born in England, studied chemistry and physics at King's College of the University of London, from which he was graduated *magna cum laude* in 1924. He then switched from the physical sciences to psychology in the belief, as he puts it, "that unless our knowledge of the latter began to approach that of the former we should soon be in serious trouble." Cattell obtained a Ph.D. in 1929 and came to the U.S. in 1937 as research associate to Edward Lee Thorndike, who was then teaching psychology at Columbia Teachers College. From 1938 to 1941 he was Hall Professor of Psychology at Clark University. He spent the next three years as lecturer at Harvard University and in 1945 joined the faculty at Illinois.

HAROLD W. LEWIS ("Ball Lightning") is professor of physics at the University of Wisconsin. Lewis acquired an

A.B. from New York University in 1943, served until 1946 in the U.S. Navy and then went to the University of California, where he studied physics under J. Robert Oppenheimer. In 1947 he spent a year at the Institute of Advanced Study in Princeton, N.J. He received a Ph.D. in 1948, returned to the University of California to teach and spent another year at the Institute for Advanced Study before going to the Bell Telephone Laboratories as a member of the technical staff in 1951. He joined the faculty at Wisconsin in 1956.

SELIG ADLER ("The Operation on President McKinley") is Samuel Paul Capen Professor of American History at the State University of New York at Buffalo. Born and raised in Baltimore, Adler attended the University of Buffalo (now the State University), from which he was graduated *summa cum laude* in 1931. After obtaining his M.A. and Ph.D. from the University of Illinois in 1932 and 1934 respectively, Adler returned to take up teaching in the Buffalo high school system. He joined the faculty of the University of Buffalo in 1941. A contributing editor of *Judaism* and the author of *The Isolationist Impulse,* published in 1957, Adler is currently at work on a volume dealing with U.S. diplomatic relations from 1921 to 1941. He first became interested in the subject of his present article a number of years ago when one of his colleagues at Buffalo, Dean Emeritus Julian Park, described to Adler the role played by Park's father in the events following the assassination of President McKinley. A second colleague and the grandson of another participant in the McKinley case, Dean Stockton Kimball, showed Adler a scrapbook that his grandfather had kept of the accounts of the assassination. The scrapbook was lost when Kimball died in 1958 but was found last year.

MARTIN H. ZIMMERMANN ("How Sap Moves in Trees") is a forest physiologist at Harvard University who does his research under the auspices of the Maria Moors Cabot Foundation for Botanical Research. He also holds the title of Lecturer on Forest Physiology at Harvard. Zimmermann, who was born and educated in Switzerland, studied botany at the Swiss Federal Institute of Technology. During that time he became particularly interested in trees as a result of several summers spent as a lumberjack. In 1951 Zimmermann became assistant plant physiologist at the Federal Institute and acquired a D.Sc. in 1953. He went to Harvard the following year.

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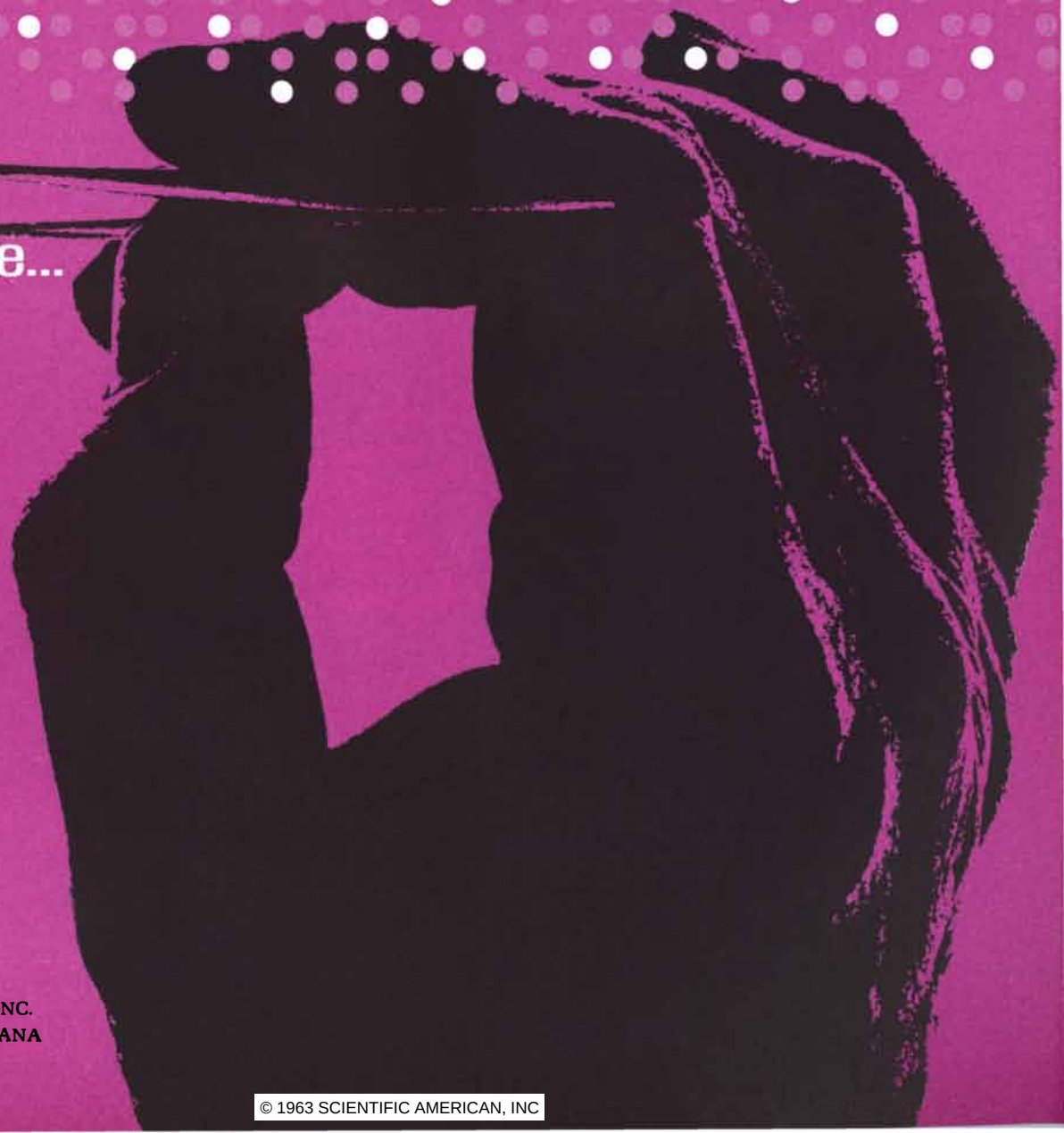

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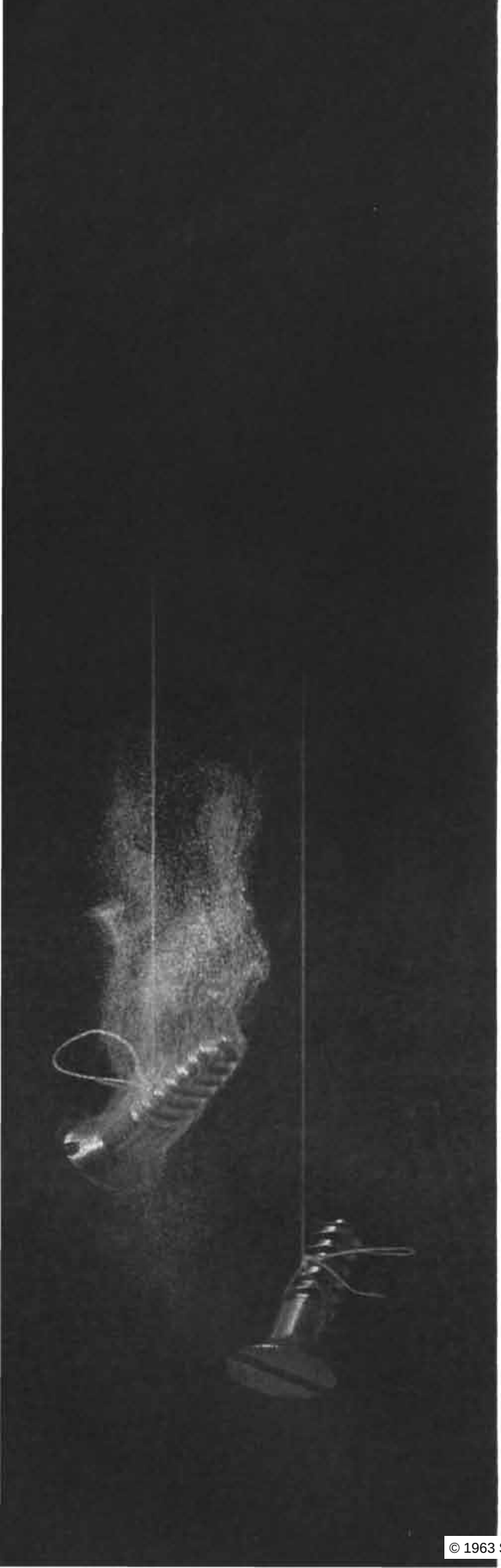

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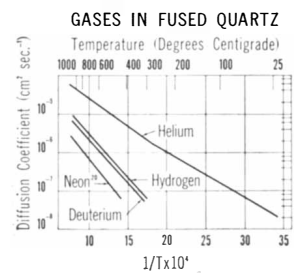

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Screw at left loaded with hydrogen by electrolysis and suspended in a hot oil bath.

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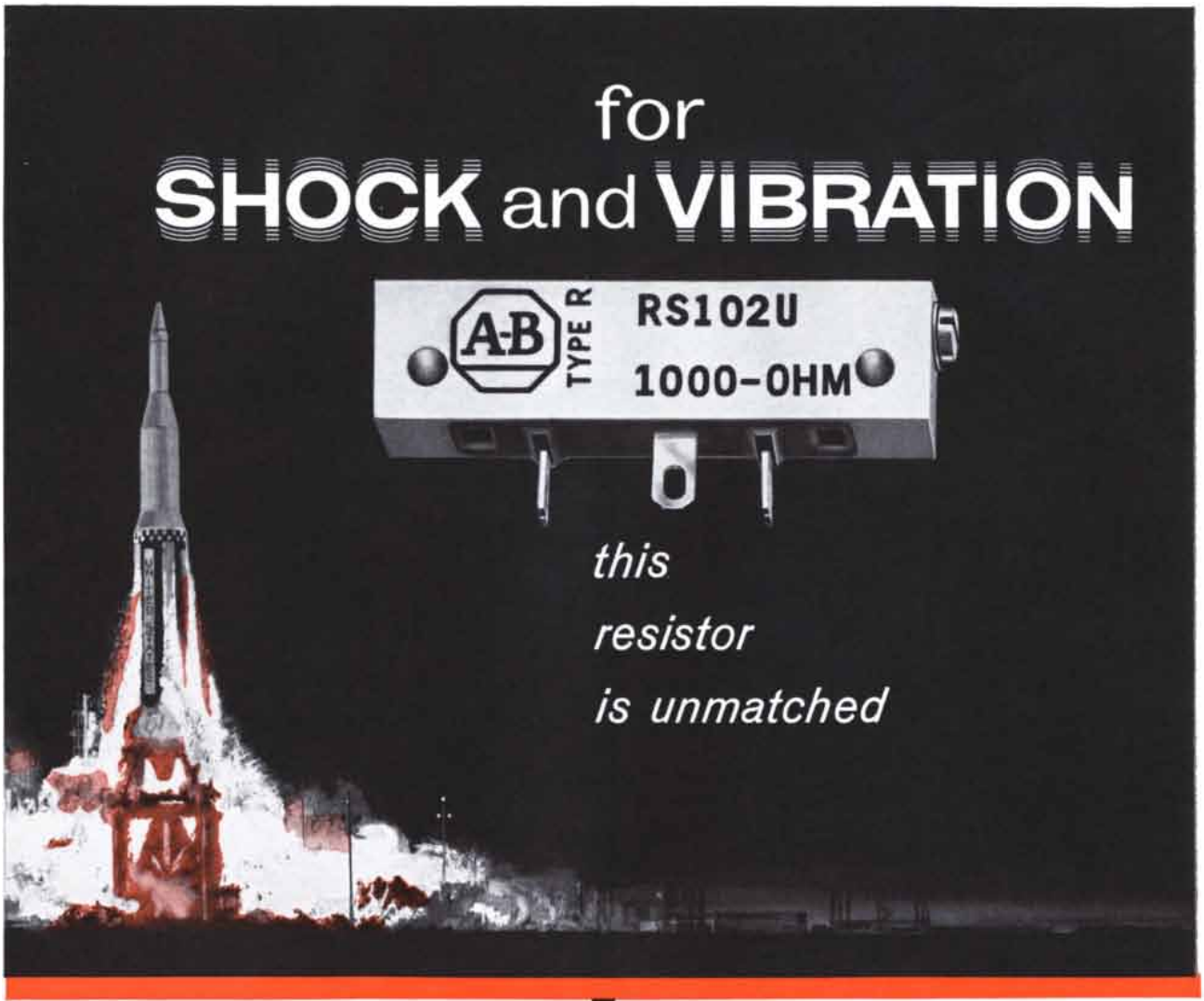

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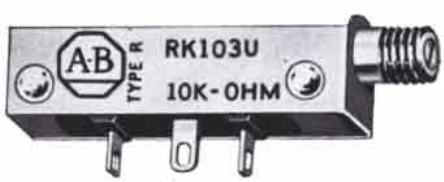

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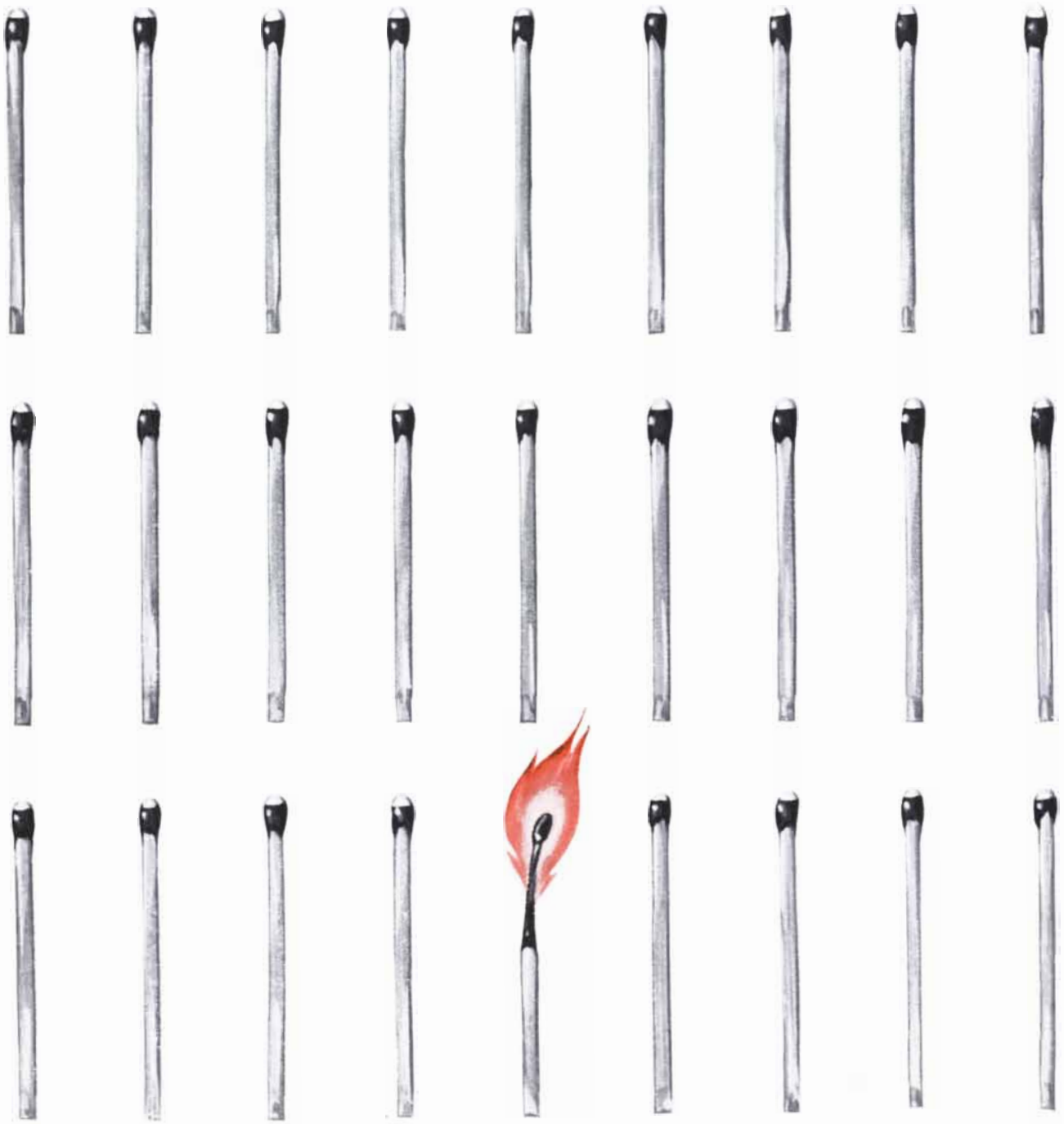

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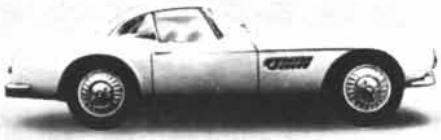

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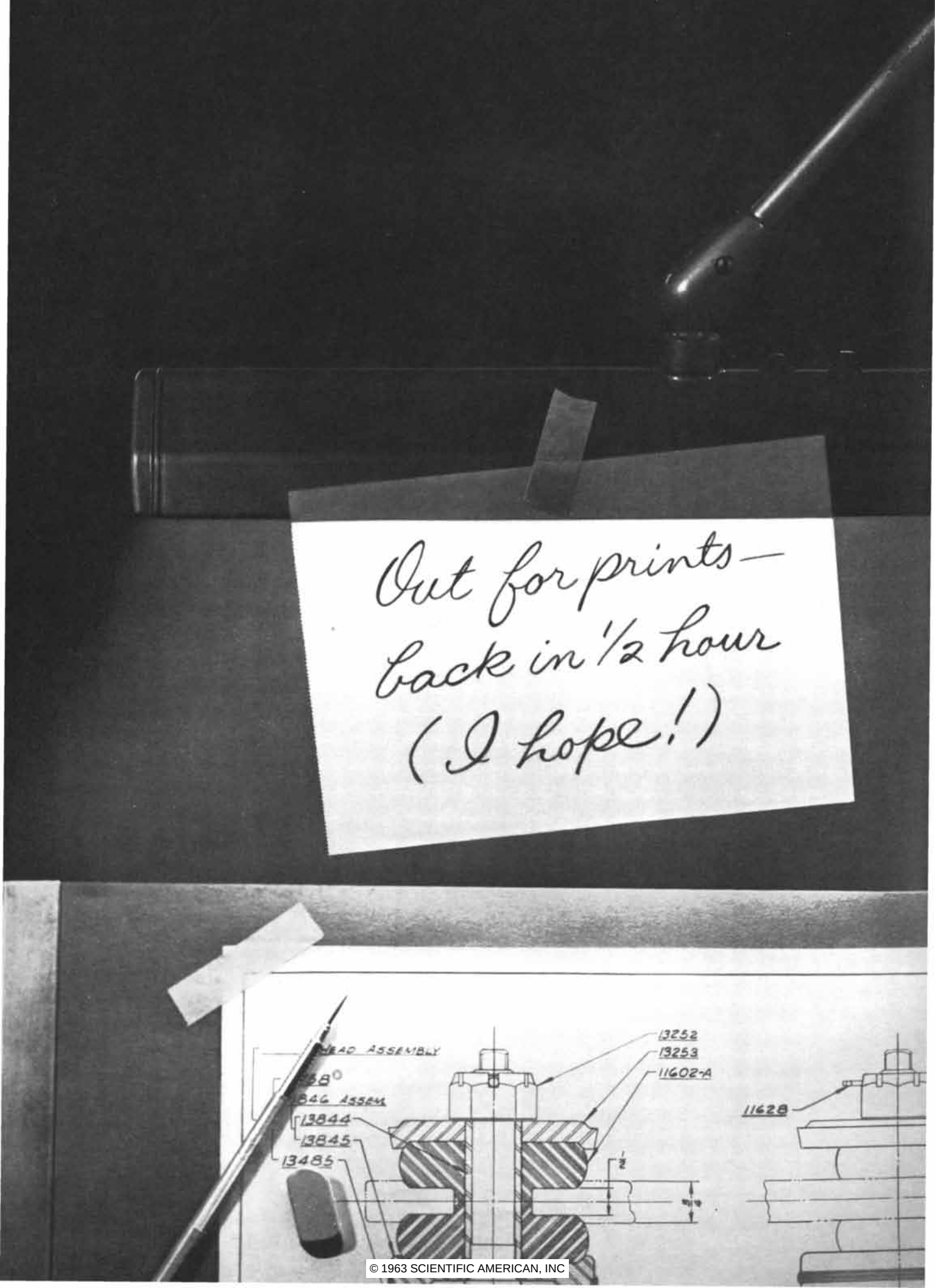

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Organic Matter from Space

Recent studies have found in meteorites "organized elements" and hydrocarbons. Are they remnants of life or perhaps nonbiological carbon compounds formed early in the history of the solar system?

by Brian Mason

In 1834 the great Swedish chemist Jöns Jakob Berzelius analyzed a peculiar meteorite that had fallen near Alais in southern France. He found that it contained carbonaceous material and he wondered: Does it contain humus or traces of other organic compounds? Does it possibly indicate the presence of organisms on extraterrestrial bodies? Berzelius thought not.

The exciting question asked and answered by Berzelius has recently been reopened to investigation, speculation and controversy. In 1961 a group of investigators discovered a variety of complex hydrocarbons in a meteorite of the same type as the one that fell at Alais. They found sufficient resemblance between these compounds and those formed on earth by living things to propose the possibility that the meteorite had arrived bearing products of extraterrestrial life. Within the year there came an announcement of the finding of "organized elements," or fossil "life forms," in this meteoritic material. The implications of these announcements are clearly fundamental and far-reaching. Proof that the organic compounds and organized elements are the residues of living organisms indigenous to the meteorites would be, as Harold C. Urey of the University of California at La Jolla has said, "the most interesting and indeed astounding fact of all scientific study in recent years." Even if the organic compounds are not of biological origin, their presence in meteorites is of great significance for theories of the

METEORITES in which organic compounds and "organized elements" have been discovered include the Orgueil (*left*) and Ivuna (*right*) carbonaceous chondrites. These samples, weighing 40 and 90 grams respectively, are in the collection of the American Museum of Natural History. Carbonaceous chondrites are earthy, crumbly, hard to identify as meteorites and quickly destroyed by weathering.

origin of meteorites, of the planets and of life on the earth.

The Alais meteorite and the others in which organic compounds have been identified are carbonaceous chondrites. These are a subgroup of the large family of stony meteorites known as chondrites because they contain small round bodies, or chondrules, of the magnesium-iron silicates olivine and pyroxene. Sooty, black, friable objects, the carbonaceous chondrites do not look at all like other meteorites. They are characterized by the presence of an appreciable amount of carbonaceous material other than free carbon, and they have been classified into three subgroups, primarily on the basis of their carbon content, the water combined in their minerals and their density [*see illustration below*]. Of the 700 or so meteorites that have been collected after having been seen to fall, only some 20 are carbonaceous chondrites. The true abundance of carbonaceous chondrites may be considerably greater, however, since they are unlikely to be recognized as meteorites by a layman or even by a trained scientist who is not familiar with them. Moreover, they are quickly destroyed by weathering; the ones that have been collected were all seen to fall and were picked up soon afterward.

When I show one of these meteorites to a visitor and explain that it contains complex organic compounds, I am often asked how it survived the fiery passage through the atmosphere. The answer is that although a meteorite does lose material from its surface by ablation, the core of the body survives. A freshly fallen carbonaceous chondrite has a black fusion crust about a millimeter thick, but its interior is quite unaffected, having evidently remained cold throughout—like the ice-cream core of that culinary paradox the baked Alaska. The smallness of the carbonaceous chondrites (the largest one on record is about the size of a man's head; other stony meteorites weigh as much as a ton) is a reflection of the great amount of ablation they have suffered and of the readiness with which they break up. The fireballs accompanying their fall are extremely brilliant even when only a few small stones are recovered.

Studying the Alais meteorite in 1834, Berzelius noted its resemblance to a hardened clay and wrote of its "clayey odor" as it disintegrated in water. He established the presence of carbon compounds by extracting some of them with water and by subliming others out of the sample by heat. The rudimentary state of organic chemistry precluded further analysis, but on the basis of his findings Berzelius decided that the presence of "organic" compounds in the Alais meteorite did not "justify the conclusion that organisms existed in its original locality."

The meteoritic carbon compounds continued to intrigue chemists throughout the 19th century and, as their techniques improved, they made more sophisticated extractions and analyses. Most of the carbon in the carbonaceous chondrites is neither volatile nor soluble; it is present as a fine-grained sooty material that defies precise analysis even with modern techniques. The quantity of

NAME	SITE OF FALL	DATE OF FALL	WEIGHT (KILOGRAMS)	CARBON CONTENT (PER CENT)	H_2O CONTENT (PER CENT)	DENSITY	TYPE
TONK	INDIA	1911	0.01	2.70	21.66	2.20	I
ALAIS	FRANCE	1806	0.26	3.19	19.48	2.23	I
IVUNA	TANGANYIKA	1938	0.70	4.83	18.68	2.23	I
ORGUEIL	FRANCE	1864	11	3.10	19.89	2.24	I
NAWAPALI	INDIA	1890	0.06	2.50	16.41	2.57	II
SANTA CRUZ	MEXICO	1939	0.05	2.54	10.33	2.57	II
COLD BOKKEVELD	SOUTH AFRICA	1838	4	1.30	15.17	2.65	II
NOGOYA	ARGENTINA	1879	2.5	1.62	14.28	2.66	II
ERAKOT	INDIA	1940	0.11	2.14	11.52	2.66	II
MIGHEI	U.S.S.R.	1889	8	2.48	12.86	2.70	II
HARIPURA	INDIA	1921	0.32	4.00	13.70	2.72	II
BORISKINO	U.S.S.R.	1930	1.17	2.06	11.97	2.74	II
CRESCENT	U.S.	1936	0.08	—	—	2.82	II
BELLS	U.S.	1961	0.3	—	—	2.84	II
MURRAY	U.S.	1950	12	2.78	12.42	2.86	II
AL RAIS	SAUDI ARABIA	1957	0.16	2.49	8.49	2.92	II
BALI	CAMEROON	1907	0.01	—	—	3.40	III
KABA	HUNGARY	1857	3	1.99	—	3.40	III
MOKOIA	NEW ZEALAND	1908	4	.47	2.07	3.41	III
VIGARANO	ITALY	1910	16	1.12	2.88	3.42	III
GROSNAJA	U.S.S.R.	1861	3.3	.56	4.02	3.49	III

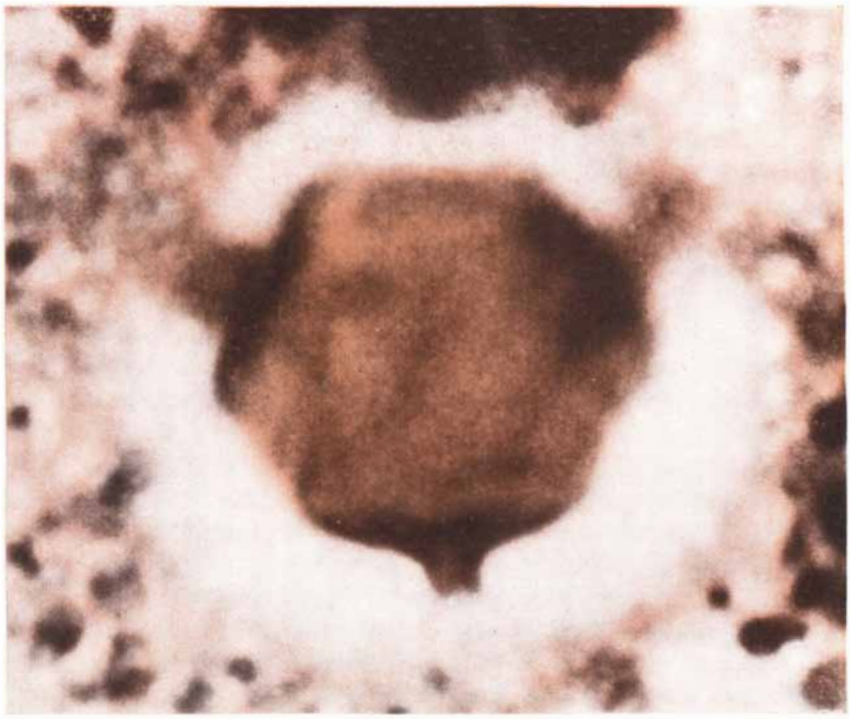
CARBONACEOUS CHONDRITES are listed and classified in three groups. The weights given in the fourth column refer to the total amount of each chondrite preserved in various collections. The fifth column gives the content of carbon in all forms. In the sixth column "H_2O content" includes adsorbed and combined water, hydroxyl groups in minerals and hydrogen in organic compounds.

the extractable compounds is generally small, seldom more than about 1 per cent of the total weight of the sample. The French chemist S. Cloez, who analyzed the Orgueil meteorite immediately after it fell near that town in 1864, was able to show that the insoluble black material is not graphite or amorphous carbon but a complex mixture of compounds of high molecular weight.

For some 60 years, from about 1890 to 1950, little was published on the carbonaceous chondrites and nothing at all on the organic compounds in them. Then a general renewal of interest in meteorites once again focused attention on these remarkable objects. The first modern investigation of the organic compounds was that of George G. Mueller, then at University College London, who in 1953 analyzed the carbonaceous material in the Cold Bokkeveld meteorite from South Africa. With organic solvents he extracted 1.1 per cent of the sample as a resinous material consisting of organic compounds mixed with free sulfur. After separation of the free sulfur the remainder gave the following analysis: carbon, 19.84 per cent; hydrogen, 6.64 per cent; nitrogen, 3.18 per cent; sulfur, 7.18 per cent; chlorine, 4.81 per cent; oxygen and associated elements, 40.02 per cent; ash, 18.33 per cent. A solution of the material in benzene did not rotate the plane of a beam of polarized light. This indication that it contained no optically active compounds was significant, because such compounds are universally present in living organisms. The optical activity of hydrocarbons that have originated with biological material is low, however, and the level of activity could have been less than the sensitivity of Mueller's instrument. The extracted material was insoluble in acids but soluble in alkali; that it was an inhomogeneous mixture of compounds was demonstrated by the varying solubility of its constituents. Mueller deduced that these were complex organic acids with some substituted nitrogen, sulfur and chlorine. Other investigators, applying techniques such as infrared and ultraviolet absorption on extracts from carbonaceous chondrites, demonstrated the presence of a variety of organic compounds including hydrocarbons, but the individual compounds were not identified or isolated.

This was the situation when in March, 1961, Bartholomew S. Nagy and Douglas J. Hennessy of Fordham University and Warren G. Meinschein of the Esso Research and Engineering Company presented the results of their work on a sample of the Orgueil meteorite from the American Museum of Natural History in New York. The mineralogical and chemical investigations were made at Fordham and mass-spectrometric analyses were carried out in the Esso Laboratories. The three authors reported that the volatile fraction of the organic material consisted largely of saturated hydrocarbons, that is, compounds in which all the available bonds on the carbon atoms are occupied by hydrogen atoms. Such compounds are common in ancient terrestrial sediments and petroleum. Mass-spectrometric analysis of solid particles and distillates identified types of compounds, including paraffins and cyclic hydrocarbons, and showed the relative abundance of compounds of different molecular weights in each group. The authors found similarities between these mass spectra and those of the hydrocarbons in butter and in recent terrestrial sediments—that is to say, in material of known biological origin [*see bottom illustration on next two pages*].

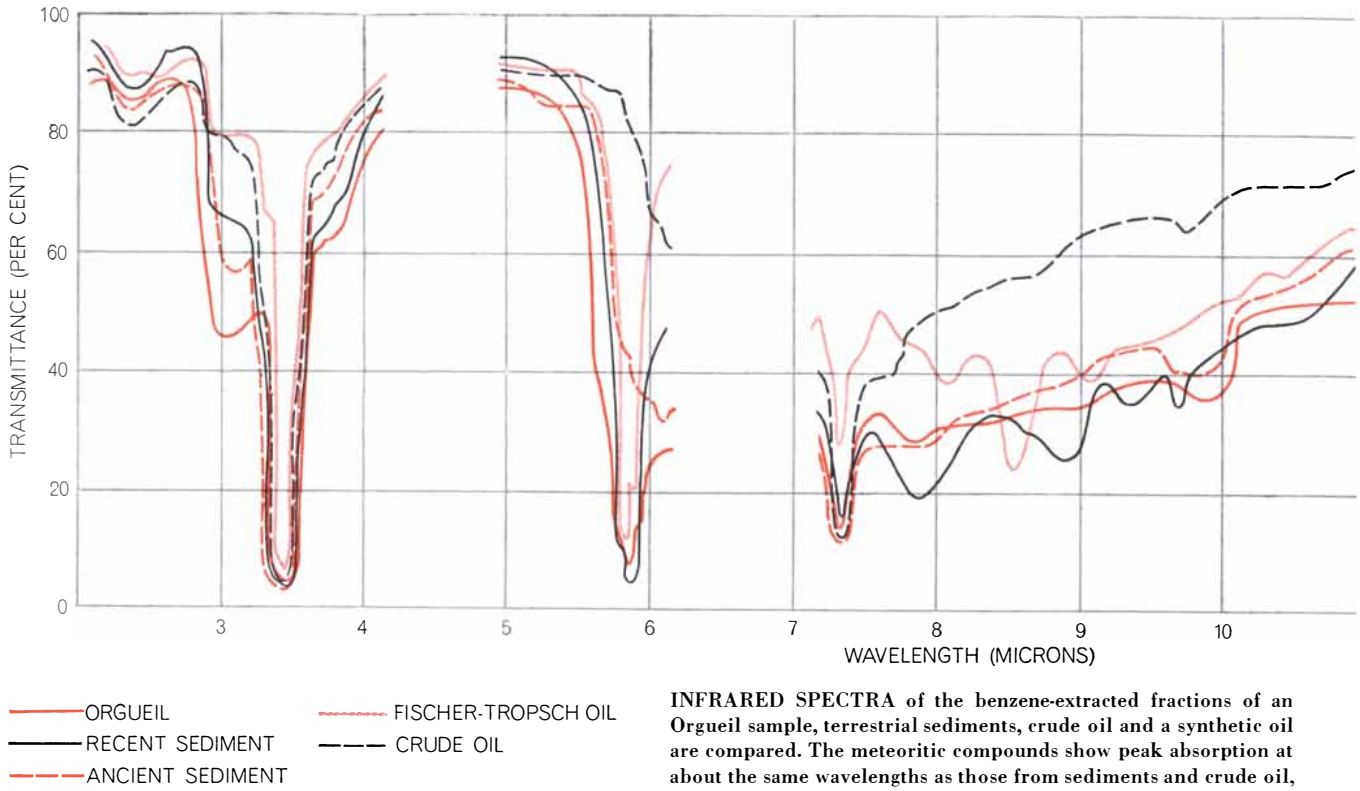
On the basis of these comparisons they wrote: "The mass-spectrometric analyses reveal that hydrocarbons in the Orgueil meteorite resemble in many important aspects the hydrocarbons in the products of living things and sediments on earth. Based on these preliminary studies, the composition of the hydrocarbons in the Orgueil meteorite provides evidence for biogenic activity."



"ORGANIZED ELEMENT" in this photomicrograph made by George Claus of the New York University Medical Center and Bartholomew S. Nagy of Fordham University is enlarged 3,000 diameters. The hexagonal particle has tubular protrusions on alternate sides.

This cautiously worded pronouncement was widely accepted as evidence for life in outer space, specifically on some parent body in the solar system from which the Orgueil meteorite came. The quantities of the hydrocarbons in the meteorite indicate that there can be no reasonable doubt that they were present when it entered the earth's atmosphere and are not the result of terrestrial contamination. They are truly extraterrestrial in origin. It was not the findings of Nagy and his co-workers but their interpretation of these findings that stirred debate: How close is the resemblance between the mass spectra of the Orgueil hydrocarbons and those of known biogenic hydrocarbons, and does this resemblance justify the conclusion that they had similar origins?

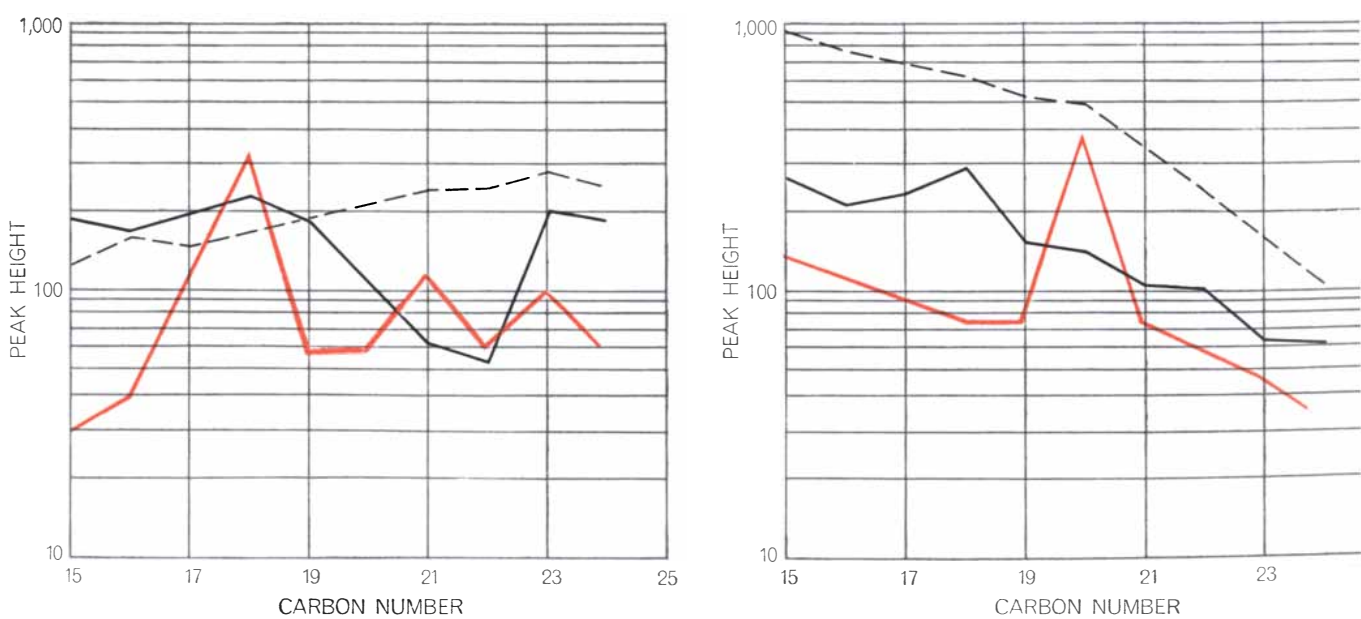
Originally all compounds of carbon were called organic because they were thought to be exclusively the products of life processes. Since Friedrich Wöhler synthesized urea from an inorganic salt in 1828, however, chemists have made almost innumerable organic compounds by nonbiological means. To demonstrate that a compound was formed by an organism requires something more than its identification as, say, a complex hydrocarbon. Dissenters from the view that the Orgueil hydrocarbons provide evidence for biogenic activity



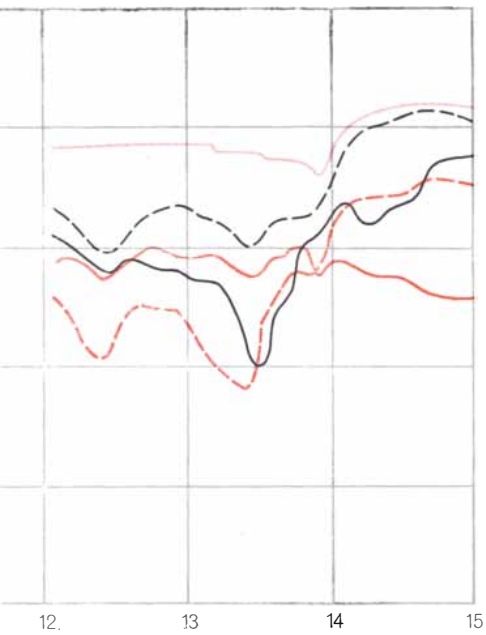
INFRARED SPECTRA of the benzene-extracted fractions of an Orgueil sample, terrestrial sediments, crude oil and a synthetic oil are compared. The meteoritic compounds show peak absorption at about the same wavelengths as those from sediments and crude oil,

have pointed to the vast array of hydrocarbons that can be synthesized by the hydrogenation of carbon monoxide in the Fischer-Tropsch and similar industrial processes. They have recalled also the well-known experiment by Stanley L. Miller, a student of Urey's at the University of Chicago, who in 1953 produced a variety of complex organic compounds, including amino acids, by passing an electric discharge through a mixture of methane, ammonia, water vapor and hydrogen. Might not radiation, acting on the meteoritic material in space, produce the pattern of hydrocarbons observed in the Orgueil meteorite?

In answer to such suggestions Meinschein and his colleagues are reporting more detailed analyses. In benzene extracts of the Orgueil meteorite they have identified compounds containing hydroxy (or amino) and carbonyl groups, and aromatic (ring-structured) as well as saturated and linear hydrocarbon molecules. These extracts and their silica-gel chromatographic fractions absorb infrared and ultraviolet radiation at about the same wavelengths as do comparable extracts and fractions from terrestrial sediments and crude oils. The



MASS-SPECTROMETRIC ANALYSIS of Orgueil material identified hydrocarbons of various types. In the charts here and on the opposite page the Orgueil mass spectra (*solid black lines*) are compared with those of hydrocarbons in butter (*colored lines*) and recent sediments (*broken black lines*). The peaks show the relative abundance of hydrocarbons of different molecular weights in the



but the spectrum for the synthetic Fischer-Tropsch oil is different. The gaps in the record were caused by peaks in the spectrum of the solvent used in the analysis.

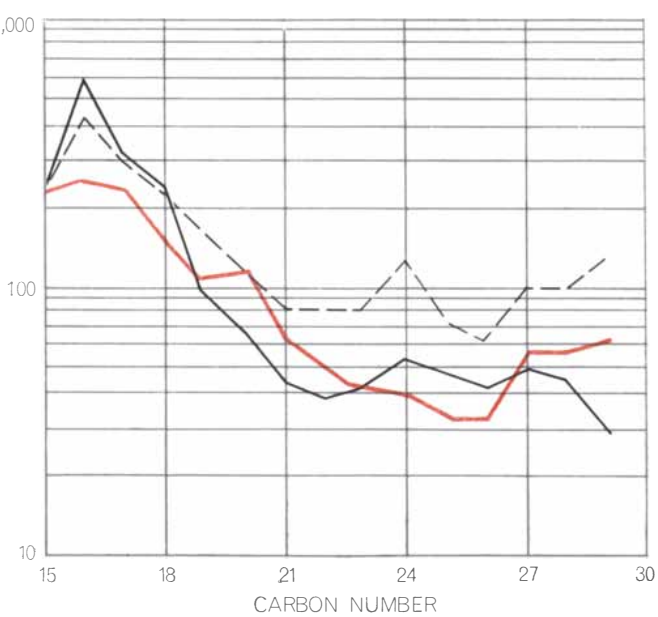
spectra of Fischer-Tropsch products are somewhat different [*see illustration above*]. Among the aromatic hydrocarbons isolated from the meteorite Meinschein has identified phenanthrene, chrysene and pyrene plus the alkyl and cycloalkyl homologues of these aromatics. The same hydrocarbons appear as prominent constituents in aromatic fractions of many recent sediments and some soils. These marked similarities are extremely interesting, but they still do not prove that the compounds were produced by extraterrestrial life. They may rather, as Edward Anders of the Enrico Fermi Institute for Nuclear Studies at the University of Chicago has suggested, have been formed in nonbiological reactions catalyzed by high-energy radiation in space. On earth, according to Anders, such compounds may have anteceded the origin of life; as ready-made molecular constituents for primordial organisms they would have imposed their chemical identity on living matter.

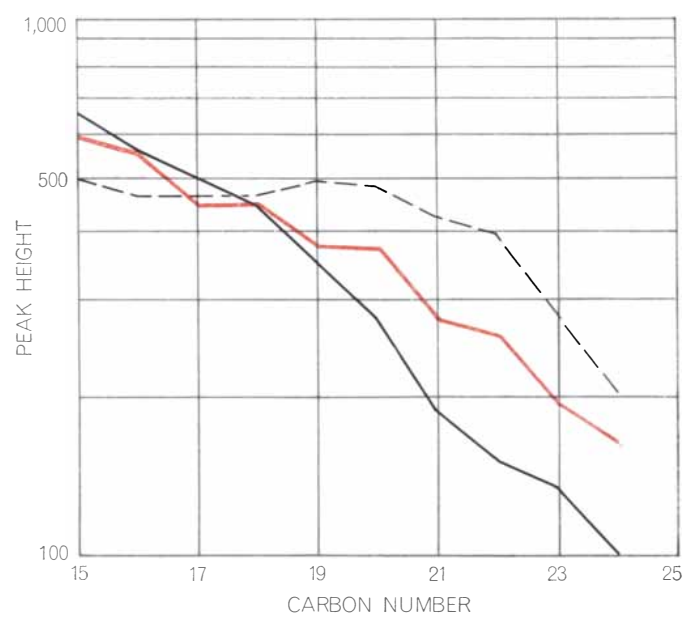
The work on the organic compounds has been rather overshadowed by another kind of evidence. In November, 1961, George Claus of the New York University Medical Center and Nagy announced that they had discovered "microscopic-sized particles, resembling fossil algae, in relatively large quantities within the Orgueil and Ivuna carbonaceous meteorites" [*see illustration on page 45 and at top of page 48*]. This finding, if confirmed—that is, if the particles are in fact the remains of organisms and are clearly not terrestrial contaminants—would certainly be evidence of life in the parent bodies of these meteorites. The announcement by Claus and Nagy aroused a hot controversy that is still far from resolved. In New York last spring interested workers representing several disciplines convened to discuss the identification and interpretation of these "organized elements." They agreed generally that at high magnifications certain regular and in many cases remarkably complex forms can be recognized in the meteoritic material and that these can be concentrated by chemical and physical methods such as acid extraction and centrifugation. But what are they?

The answers fall into three categories: The organized elements are indeed life forms, the vestiges of extraterrestrial organisms; they are merely crystals of organic or inorganic compounds; they are terrestrial contaminants.

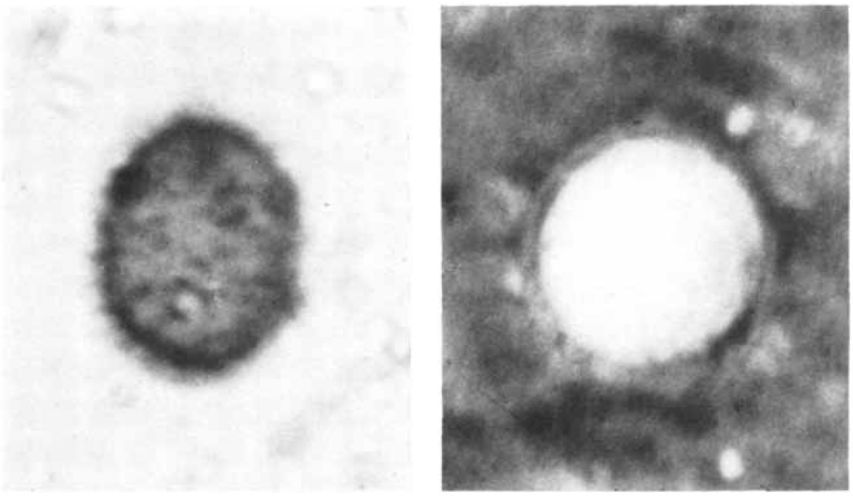
The first possibility, that they are the remains of living things from space, has been argued most strongly from their highly structured morphology and their difference from any known terrestrial organisms. Nagy, Claus and Hennessy have pointed to details in their photomicrographs that look like double membranes, granular particles, vacuoles and spiny surfaces, all of which are characteristic structures of living cells. They note further that some of the elements react to staining with a preparation that, in biological investigation, is considered specific for deoxyribonucleic acid (DNA). The presence of DNA would of course be powerful evidence of biological origin. Conscious of the argument that the particles may be terrestrial contaminants, they have tried to avoid this possibility by examining material from freshly broken surfaces of their samples. And they also argue that the high concentration of the elements makes contamination an unlikely explanation.

Other investigators have found reason

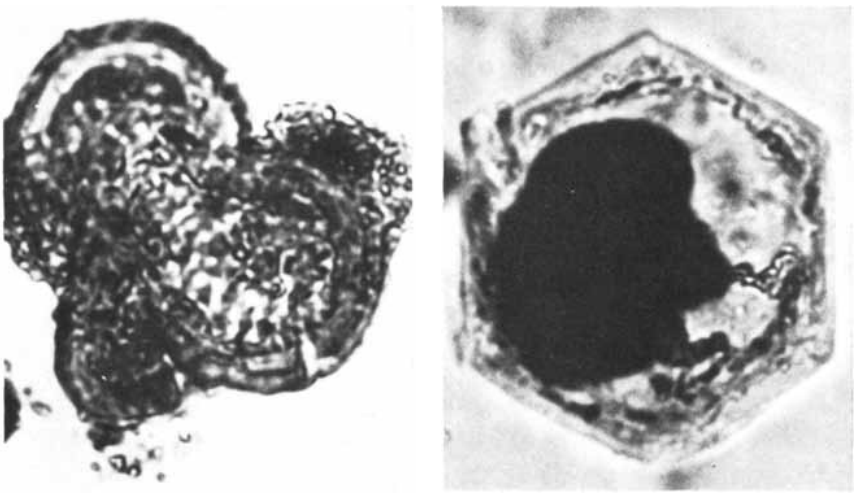




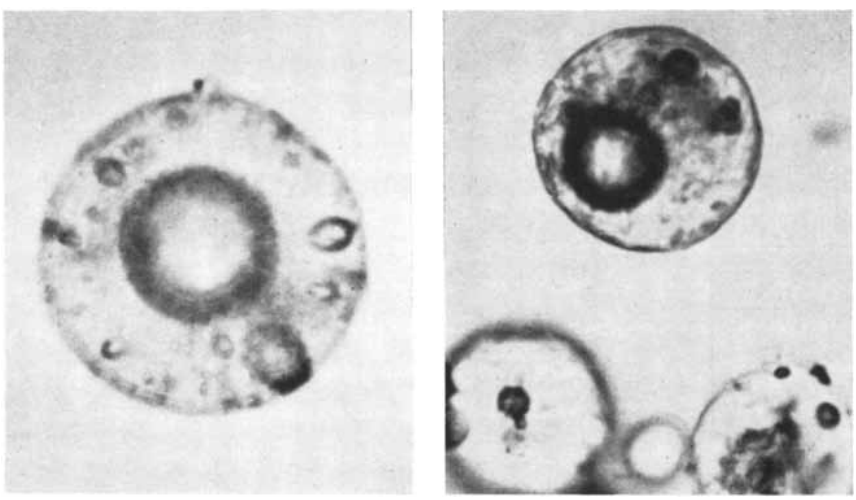
three materials. Each of the charts is for ions with masses equivalent to a different hydrocarbon group. These are designated as (*left to right*) *n*-paraffins, bicycloalkanes, tetracycloalkanes and monocycloalkanes. The similarities between the mass spectra of the Orgueil and the terrestrial hydrocarbons have been interpreted as evidence for the biological origin of the meteoritic compounds.



TYPICAL ELEMENTS of one type found by Claus and Nagy are magnified about 3,000 diameters in these photomicrographs made by them. The one at right survived boiling in hydrofluoric acid, which they consider evidence of organic rather than mineral composition.



"MICROFOSSILS" were identified in an Orgueil sample by Frank L. Staplin of Imperial Oil, Ltd., in Canada. He named the element at the left, enlarged 1,500 diameters, *Clausisphaera fissa* and called the one at the right, here enlarged 2,500 diameters, *Caelestites sexangulatus*.



COMPLEX STRUCTURE of some of the meteoritic elements was paralleled, according to Edward Anders and Frank W. Fitch of the University of Chicago, in some terrestrial contaminants. They compared one of Claus and Nagy's particles (*left*) with furnace ash (*right*).

to support this line of argument. Frank L. Staplin of Imperial Oil, Ltd., in Calgary, Alberta, has identified a number of forms he found in Orgueil material as cellular or tissue-like, and has dignified two of the elements by naming them as new genera and species of uncertain classification, possibly algae [*see middle illustrations at left*]. Frederick D. Sisler of the U.S. Geological Survey cultured samples of the Murray carbonaceous chondrite in a germ-free laboratory and reported that some growth appeared in his culture media after several months, suggesting that the meteorite carried viable microorganisms.

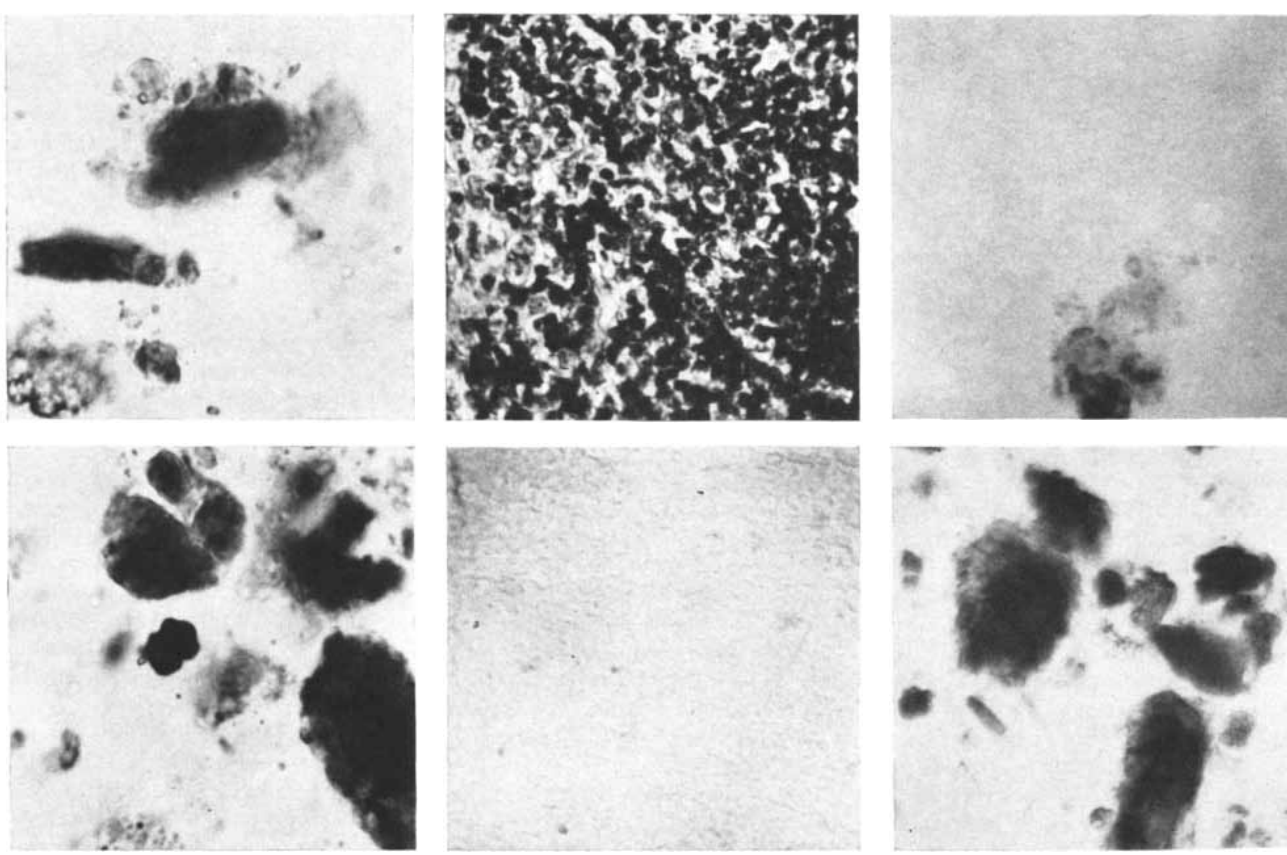
The possibility that most of the organized elements are actually inorganic crystals has been pressed by Anders and his co-workers at the Enrico Fermi Institute. They reported that the Ivuna and Orgueil chondrites contain microscopic hexagonal crystals of troilite (ferrous sulfide) closely resembling the hexagonal elements described by Claus and Nagy. By centrifuging his samples Anders was able to concentrate numerous spherical particles similar to other organized elements listed by the original workers; he identified them as supercooled liquid droplets of sulfur and hydrocarbons rather than "life forms." As for biological staining, Frank W. Fitch and Anders found that kimberlite, a terrestrial rock without biogenic components, reacted to two different stains in much the same way as the meteoritic material does. The stains are indicative not of biogenic material as such but of certain chemical linkages by no means limited to biological material. In view of their diversity and complexity of form, microscopic crystals might certainly simulate the morphology of organisms. One need only recall the intricate ice crystals in snowflakes—a point nicely expressed by Philip Morrison of Cornell University when he suggested that the organized elements are "carbonaceous snowflakes."

As a curator at the American Museum of Natural History I am painfully aware of the many sources of possible contamination of our specimens, so the explanation of at least some of the elements as terrestrial contaminants seems quite sound to me. Many of the carbonaceous chondrites (the Orgueil meteorite in particular) are highly porous. As they entered the atmosphere from the near vacuum of space they must immediately have "breathed in" air and minute floating organisms. They lie on the ground for some time before they are picked up, and they usually undergo a lengthy odyssey and pass through many hands before reaching the apparent security of

a museum collection. Even in museums they have not been kept in sealed containers; they have therefore been subject to contamination not only by local bacteria, spores and pollen but also by exotic organisms carried in with other collections from all over the world. Under these circumstances it would be truly remarkable if one did not find a variety of terrestrial microorganisms in them. Anders and his colleagues think that the few highly structured organized elements that cannot be explained as crystals are pollen grains or other terrestrial contaminants. Such contamination would also account for Sisler's apparent success in culturing bacteria from meteoritic material. Perhaps future falls of carbonaceous chondrites will make it possible to bring the material into the laboratory for immediate preservation and study under sterile conditions.

While the reality of extraterrestrial life or the remains thereof in the carbonaceous meteorites is still in doubt, this should not obscure the great significance of the organic compounds they contain. The fact remains that under certain conditions and in certain regions of outer space rather complex hydrocarbons and other organic substances were produced in considerable amounts and survived for long periods of time. In the first place, the presence of these compounds in the carbonaceous chondrites has a critical bearing on the origin of meteorites. Albert E. Ringwood of the Australian National University and I have independently suggested that these chondrites probably represent the primordial material that aggregated to form the solid objects of the solar system; in other words, we believe they are representative samples of the dust that made up much of the primitive solar nebula. The other types of meteorite could have been derived from large aggregations of this material by heating, reduction, melting and recrystallization, processes that would drive off the volatile elements and their less stable compounds. Urey prefers to regard the carbonaceous chondrites as the products of secondary reactions, produced from the more common chondrites by the infiltration of water, carbonaceous matter and hydrogen sulfide supplied from external sources. Anders suggests that the carbonaceous chondrites are derived from a specific zone in one or more asteroidal bodies formed by the aggregation of dust. Cold at the surface and hot in the interior, these bodies could have had an intermediate zone within which water and organic compounds were stable and could react with silicate minerals to form the material that falls to earth as carbonaceous chondrites. Further study of the organic matter from space may serve to refine and reconcile these conflicting hypotheses.

The discovery in meteorites of complex organic material has still another intriguing implication. An acceptable working hypothesis is that the earth was formed by the accretion of material of meteoritic composition. If this material brought with it complex organic substances, the development on the earth of self-replicating compounds of nucleic acid and protein molecules—which is to say primitive organisms—would be far easier to understand than it has been until now. Perhaps the organic compounds of the carbonaceous chondrites hold the key to the origin of life on this planet.



STAIN-TEST EVIDENCE for the biological origin of the organized elements was also discounted by Anders and Fitch. They applied the Feulgen reaction, which Claus and Nagy had cited as indicating the presence of deoxyribonucleic acid in their particles, to Orgueil material, DNA-rich rat spleen tissue and a terrestrial rock, kimberlite (*top row, left to right*) and found they all stained similarly. When one step of the test was omitted, the meteoritic material and kimberlite still stained (*bottom left and right*) but the spleen tissue did not (*bottom center*), indicating that whatever it is that makes the Orgueil elements and kimberlite stain, it is not DNA.

ELECTRIC LOCATION BY FISHES

It is well known that some fishes generate strong electric fields to stun their prey or discourage predators. *Gymnarchus niloticus* produces a weak field for the purpose of sensing its environment

by H. W. Lissmann

Study of the ingenious adaptations displayed in the anatomy, physiology and behavior of animals leads to the familiar conclusion that each has evolved to suit life in its particular corner of the world. It is well to bear in mind, however, that each animal also inhabits a private subjective world that is not accessible to direct observation. This world is made up of information communicated to the creature from the outside in the form of messages picked up by its sense organs. No adaptation is more crucial to survival; the environment changes from place to place and from moment to moment, and the animal must respond appropriately in every place and at every moment. The sense organs transform energy of various kinds—heat and light, mechanical energy and chemical energy—into nerve impulses. Because the human organism is sensitive to the same kinds of energy, man can to some extent visualize the world as it appears to other living things. It helps in considering the behavior of a dog, for example, to realize that it can see less well than a man but can hear and smell better. There are limits to this procedure; ultimately the dog's sensory messages are projected onto its brain and are there evaluated differently.

Some animals present more serious obstacles to understanding. As I sit writing at my desk I face a large aquarium that contains an elegant fish about 20 inches long. It has no popular name but is known to science as *Gymnarchus niloticus*. This same fish has been facing me for the past 12 years, ever since I brought it from Africa. By observation and experiment I have tried to understand its behavior in response to stimuli from its environment. I am now convinced that *Gymnarchus* lives in a world totally alien to man: its most important sense is an electric one, different from any we possess.

From time to time over the past century investigators have examined and dissected this curious animal. The literature describes its locomotive apparatus, central nervous system, skin and electric organs, its habitat and its family relation to the "elephant-trunk fishes," or mormyrids, of Africa. But the parts have not been fitted together into a functional pattern, comprehending the design of the animal as a whole and the history of its development. In this line of biological research one must resist the temptation to be deflected by details, to follow the fashion of putting the pieces too early under the electron microscope. The magnitude of a scientific revelation is not always paralleled by the degree of magnification employed. It is easier to select the points on which attention should be concentrated once the plan is understood. In the case of *Gymnarchus,* I think, this can now be attempted.

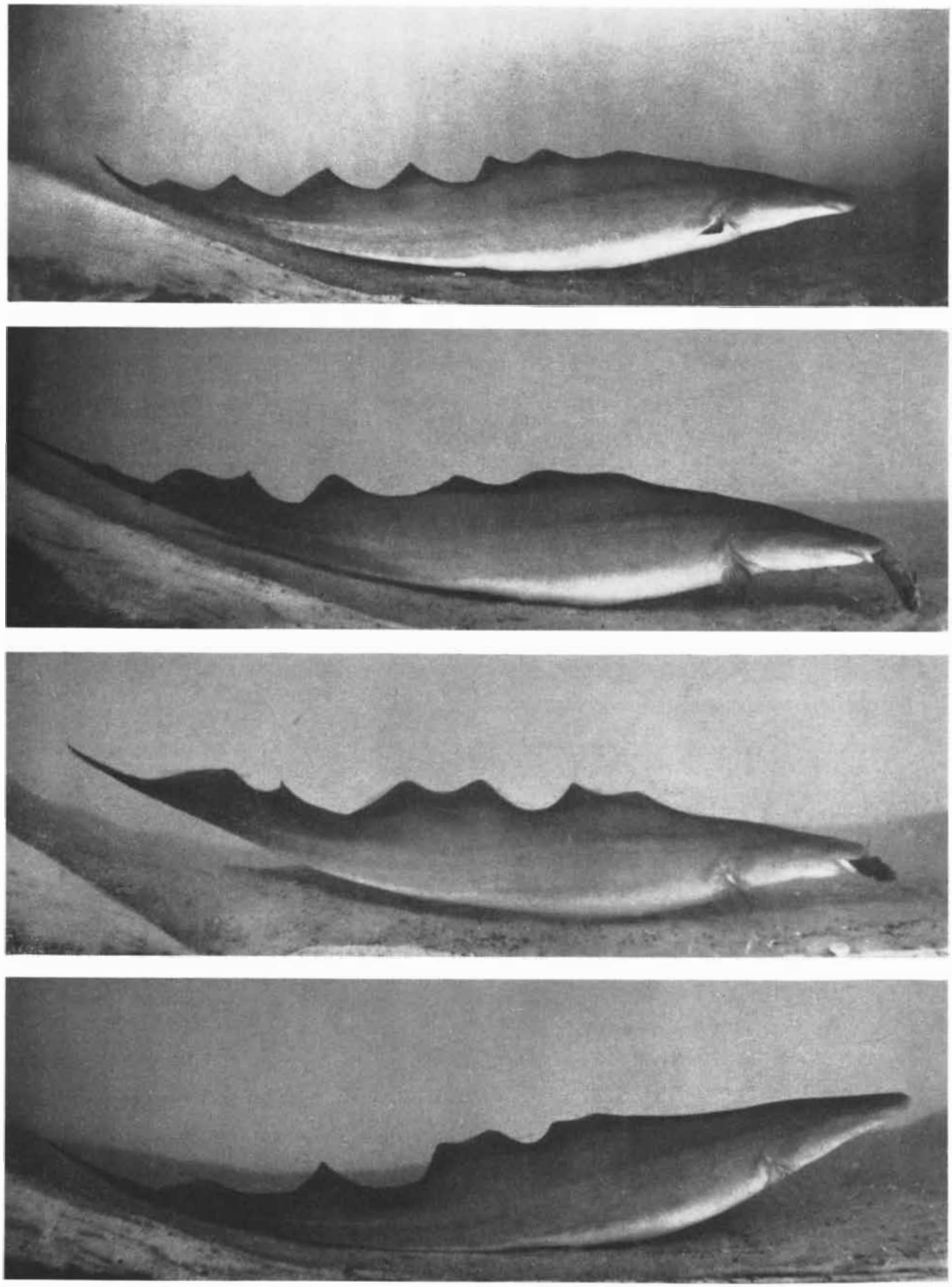
A casual observer is at once impressed by the grace with which *Gymnarchus* swims. It does not lash its tail from side to side, as most other fishes do, but keeps its spine straight. A beautiful undulating fin along its back propels its body through the water—forward or backward with equal ease. *Gymnarchus* can maintain its rigid posture even when turning, with complex wave forms running hither and thither over different regions of the dorsal fin at one and the same time.

Closer observation leaves no doubt that the movements are executed with great precision. When *Gymnarchus* darts after the small fish on which it feeds, it never bumps into the walls of its tank, and it clearly takes evasive action at some distance from obstacles placed in its aquarium. Such maneuvers are not surprising in a fish swimming forward, but *Gymnarchus* performs them equally well swimming backward. As a matter of fact it should be handicapped even when it is moving forward: its rather degenerate eyes seem to react only to excessively bright light.

Still another unusual aspect of this fish and, it turns out, the key to all the puzzles it poses, is its tail, a slender, pointed process bare of any fin ("gymnarchus" means "naked tail"). The tail was first dissected by Michael Pius Erdl of the University of Munich in 1847. He found tissue resembling a small electric organ, consisting of four thin spindles running up each side to somewhere beyond the middle of the body. Electric organs constructed rather differently, once thought to be "pseudoelectric," are also found at the hind end of the related mormyrids.

Such small electric organs have been an enigma for a long time. Like the powerful electric organs of electric eels and some other fishes, they are derived from muscle tissue. Apparently in the course of evolution the tissue lost its power to contract and became specialized in various ways to produce electric discharges [see "Electric Fishes," by Harry Grundfest; SCIENTIFIC AMERICAN, October, 1960]. In the strongly electric fishes this adaptation serves to deter predators and to paralyze prey. But the powerful electric organs must have evolved from weak ones. The original swimming muscles would therefore seem to have possessed or have acquired at some stage a subsidiary electric function that had survival value. Until recently no one had found a function for weak electric organs. This was one of the questions on my mind when I began to study *Gymnarchus.*

I noticed quite early, when I placed a



ELECTRIC FISH *Gymnarchus niloticus,* from Africa, generates weak discharges that enable it to detect objects. In this sequence the fish catches a smaller fish. *Gymnarchus* takes its name, which means "naked tail," from the fact that its pointed tail has no fin.

new object in the aquarium of a well-established *Gymnarchus*, that the fish would approach it with some caution, making what appeared to be exploratory movements with the tip of its tail. It occurred to me that the supposed electric organ in the tail might be a detecting mechanism. Accordingly I put into the water a pair of electrodes, connected to an amplifier and an oscilloscope. The result was a surprise. I had expected to find sporadic discharges co-ordinated with the swimming or exploratory motions of the animal. Instead the apparatus recorded a continuous stream of electric discharges at a constant frequency of about 300 per second, waxing and waning in amplitude as the fish changed position in relation to the stationary electrodes. Even when the fish was completely motionless, the electric activity remained unchanged.

This was the first electric fish found to behave in such a manner. After a brief search I discovered two other kinds that emit an uninterrupted stream of weak discharges. One is a mormyrid relative of *Gymnarchus;* the other is a gymnotid, a small, fresh-water South American relative of the electric eel, belonging to a group of fish rather far removed from *Gymnarchus* and the mormyrids.

It had been known for some time that the electric eel generates not only strong discharges but also irregular series of weaker discharges. Various functions had been ascribed to these weak discharges of the eel. Christopher W. Coates, director of the New York Aquarium, had suggested that they might serve in navigation, postulating that the eel somehow measured the time delay between the output of a pulse and its reflection from an object. This idea was untenable on physical as well as physiological grounds. The eel does not, in the first place, produce electromagnetic waves; if it did, they would travel too fast to be timed at the close range at which such a mechanism might be useful, and in any case they would hardly penetrate water. Electric current, which the eel does produce, is not reflected from objects in the surrounding environment.

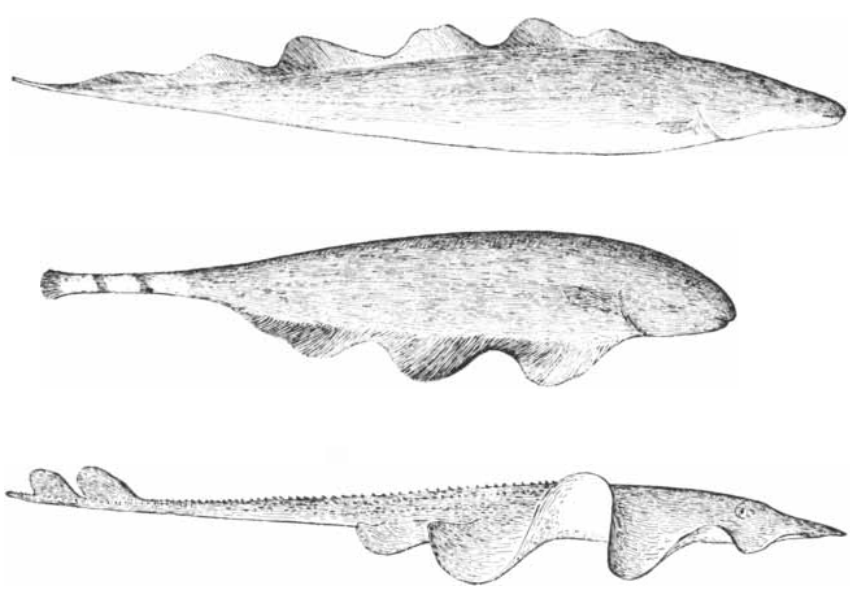
Observation of *Gymnarchus* suggested another mechanism. During each discharge the tip of its tail becomes momentarily negative with respect to the head. The electric current may thus be pictured as spreading out into the surrounding water in the pattern of lines that describes a dipole field [*see illustration on opposite page*]. The exact configuration of this electric field depends on the conductivity of the water and on the distortions introduced in the field by objects with electrical conductivity different from that of the water. In a large volume of water containing no objects the field is symmetrical. When objects are present, the lines of current will converge on those that have better conductivity and diverge from the poor conductors [*see top illustration on page 54*]. Such objects alter the distribution of electric potential over the surface of the fish. If the fish could register these changes, it would have a means of detecting the objects.

Calculations showed that *Gymnarchus* would have to be much more sensitive electrically than any fish was known to be if this mechanism were to work. I had observed, however, that *Gymnarchus* was sensitive to extremely small external electrical disturbances. It responded violently when a small magnet or an electrified insulator (such as a comb that had just been drawn through a person's hair) was moved near the aquarium. The electric fields produced in the water by such objects must be very small indeed, in the range of fractions of a millionth of one volt per centimeter. This crude observation was enough to justify a series of experiments under more stringent conditions.

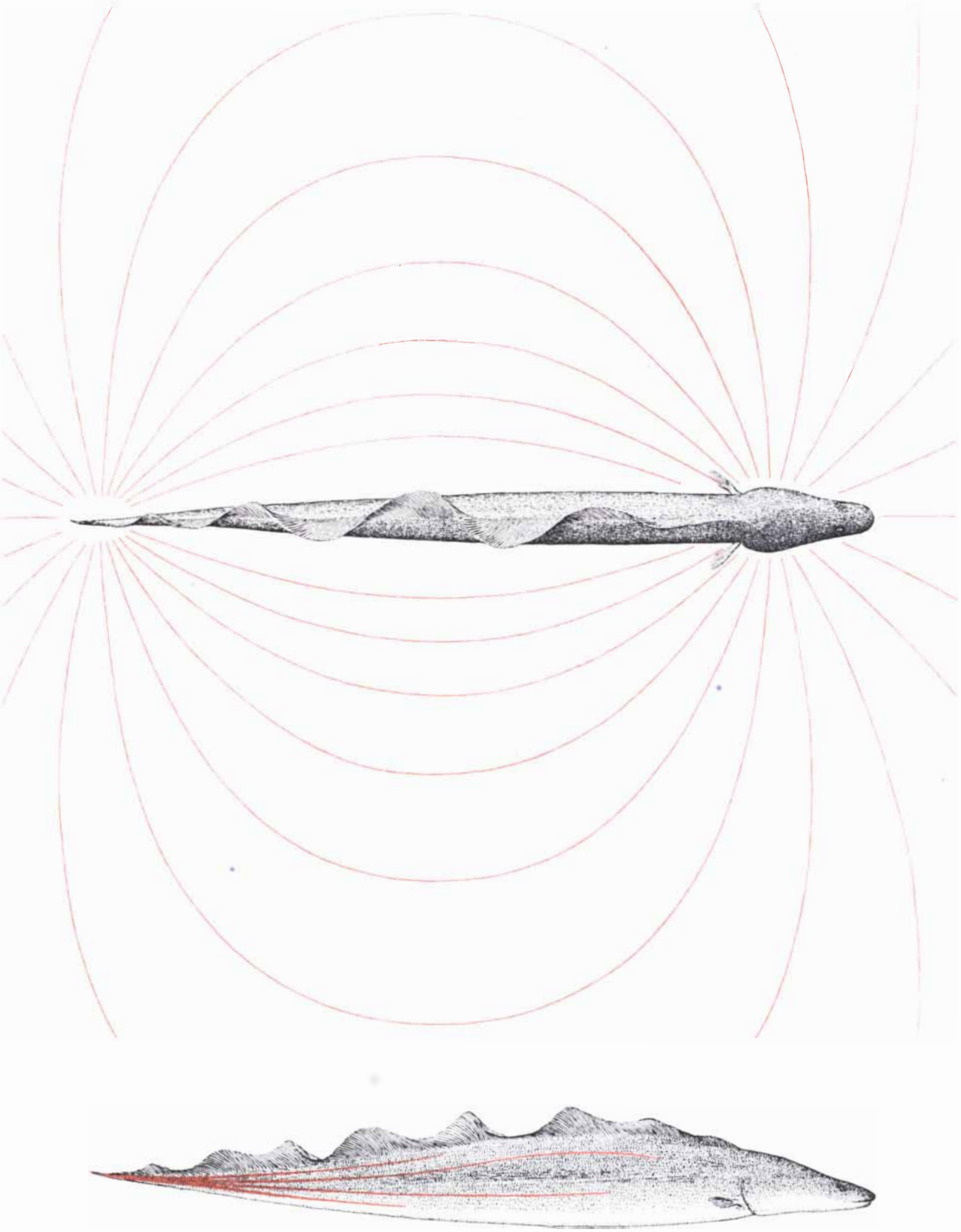
In the most significant of these experiments Kenneth E. Machin and I trained the fish to distinguish between objects that could be recognized only by an electric sense. These were enclosed in porous ceramic pots or tubes with thick walls. When they were soaked in water, the ceramic material alone had little effect on the shape of the electric field. The pots excluded the possibility of discrimination by vision or, because each test lasted only a short time, by a chemical sense such as taste or smell.

The fish quickly learned to choose between two pots when one contained aquarium water or tap water and the other paraffin wax (a nonconductor). After training, the fish came regularly to pick a piece of food from a thread suspended behind a pot filled with aquarium or tap water and ignored the pot filled with wax [*see bottom illustration on page 54*]. Without further conditioning it also avoided pots filled with air, with distilled water, with a close-fitting glass tube or with another nonconductor. On the other hand, when the electrical conductivity of the distilled water was matched to that of tap or aquarium water by the addition of salts or acids, the fish would go to the pot for food.

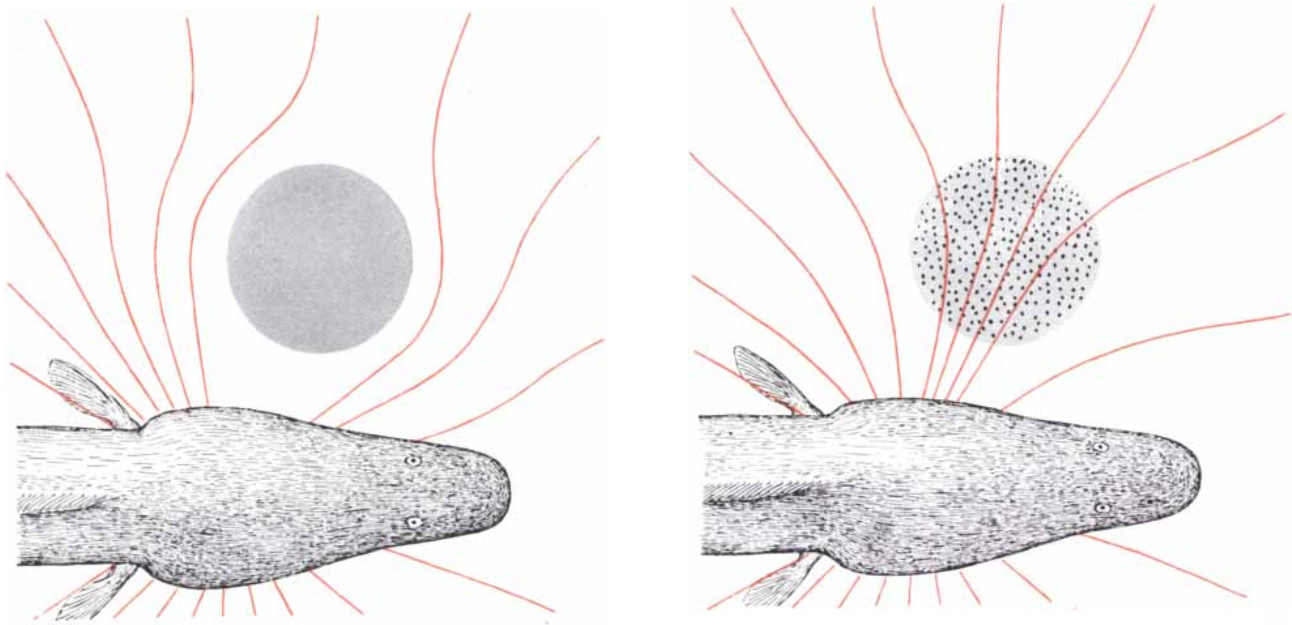
A more prolonged series of trials showed that *Gymnarchus* could distinguish mixtures in different proportions of tap water and distilled water and perform other remarkable feats of discrimination. The limits of this performance can best be illustrated by the fact that the fish could detect the presence of a glass rod two millimeters in diameter and would fail to respond to a glass rod .8 millimeter in diameter, each hidden in a



UNUSUAL FINS characterize *Gymnarchus* (*top*), a gymnotid from South America (*middle*) and sea-dwelling skate (*bottom*). All swim with spine rigid, probably in order to keep electric generating and detecting organs aligned. *Gymnarchus* is propelled by undulating dorsal fin, gymnotid by similar fin underneath and skate by lateral fins resembling wings.



ELECTRIC FIELD of *Gymnarchus* and location of electric generating organs are diagramed. Each electric discharge from organs in rear portion of body (*color in side view*) makes tail negative with respect to head. Most of the electric sensory pores or organs are in head region. Undisturbed electric field resembles a dipole field, as shown, but is more complex. The fish responds to changes in the distribution of electric potential over the surface of its body. The conductivity of objects affects distribution of potential.

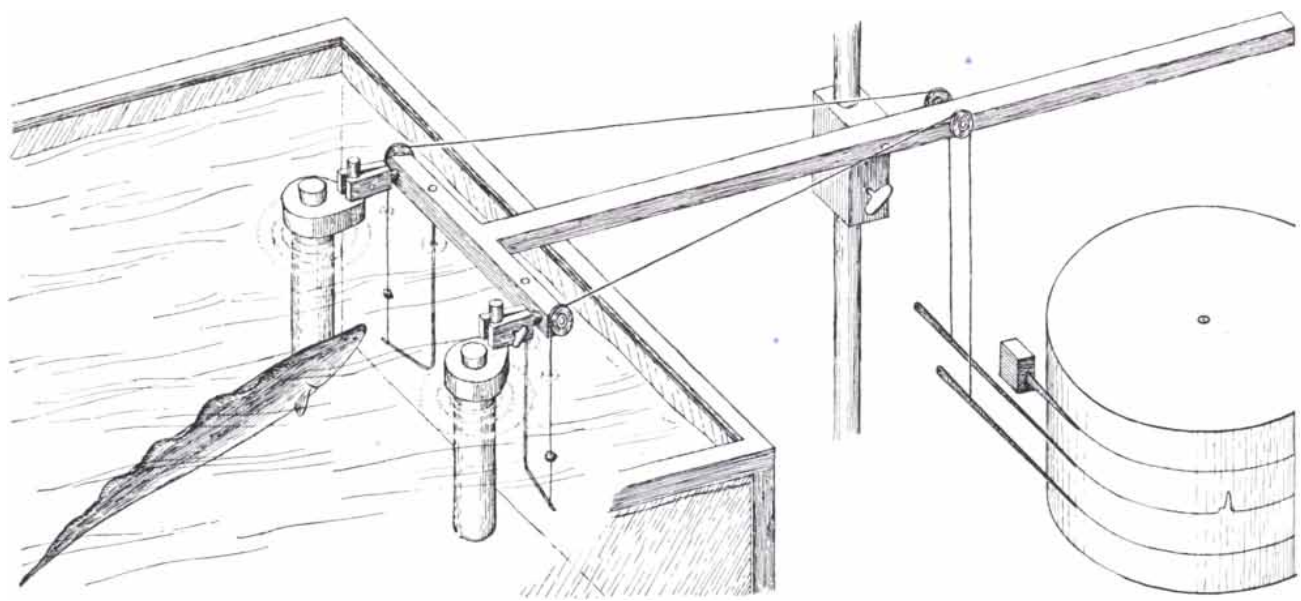


OBJECTS IN ELECTRIC FIELD of *Gymnarchus* **distort the lines of current flow. The lines diverge from a poor conductor** (*left*) **and converge toward a good conductor** (*right*). **Sensory pores in the head region detect the effect and inform the fish about the object.**

pot of the same dimensions. The threshold of its electric sense must lie somewhere between these two values.

These experiments seemed to establish beyond reasonable doubt that *Gymnarchus* detects objects by an electrical mechanism. The next step was to seek the possible channels through which the electrical information may reach the brain. It is generally accepted that the tissues and fluids of a fresh-water fish are relatively good electrical conductors enclosed in a skin that conducts poorly. The skin of *Gymnarchus* and of many mormyrids is exceptionally thick, with layers of platelike cells sometimes arrayed in a remarkable hexagonal pattern [*see top illustration on page 57*]. It can therefore be assumed that natural selection has provided these fishes with better-than-average exterior insulation.

In some places, particularly on and around the head, the skin is closely perforated. The pores lead into tubes often filled with a jelly-like substance or a loose aggregation of cells. If this jelly is a good electrical conductor, the arrangement would suggest that the lines of electric current from the water into the body of the fish are made to converge at these pores, as if focused by a lens. Each jelly-filled tube widens at the base into



EXPERIMENTAL ARRANGEMENT for conditioned-reflex training of *Gymnarchus* **includes two porous pots or tubes and recording mechanism. The fish learns to discriminate between objects of different electrical conductivity placed in the pots and to seek bait tied to string behind the pot holding the object that conducts best.** *Gymnarchus* **displays a remarkable ability to discriminate.**

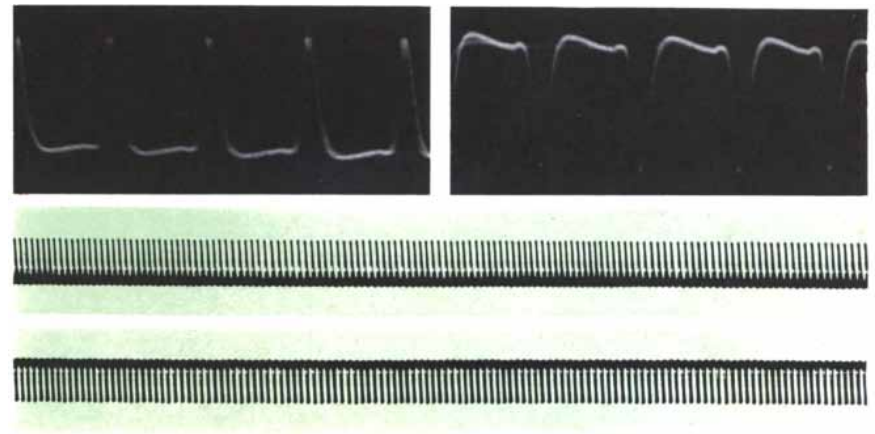
a small round capsule that contains a group of cells long known to histologists by such names as "multicellular glands," "mormyromasts" and "snout organs." These, I believe, are the electric sense organs.

The supporting evidence appears fairly strong: The structures in the capsule at the base of a tube receive sensory nerve fibers that unite to form the stoutest of all the nerves leading into the brain. Electrical recording of the impulse traffic in such nerves has shown that they lead away from organs highly sensitive to electric stimuli. The brain centers into which these nerves run are remarkably large and complex in *Gymnarchus*, and in some mormyrids they completely cover the remaining portions of the brain [*see illustration on next page*].

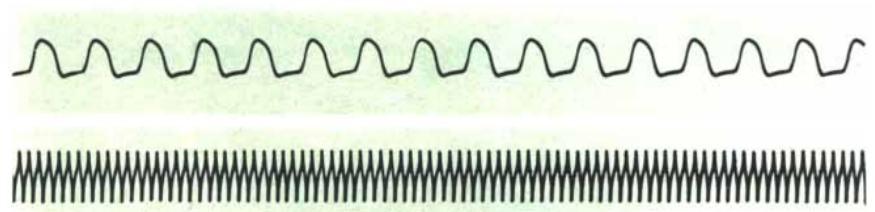
If this evidence for the plan as well as the existence of an electric sense does not seem sufficiently persuasive, corroboration is supplied by other weakly electric fishes. Except for the electric eel, all species of gymnotids investigated so far emit continuous electric pulses. They are also highly sensitive to electric fields. Dissection of these fishes reveals the expected histological counterparts of the structures found in the mormyrids: similar sense organs embedded in a similar skin, and the corresponding regions of the brain much enlarged.

Skates also have a weak electric organ in the tail. They are cartilaginous fishes, not bony fishes, or teleosts, as are the mormyrids and gymnotids. This means that they are far removed on the family line. Moreover, they live in the sea, which conducts electricity much better than fresh water does. It is almost too much to expect structural resemblances to the fresh-water bony fishes, or an electrical mechanism operating along similar lines. Yet skates possess sense organs, known as the ampullae of Lorenzini, that consist of long jelly-filled tubes opening to the water at one end and terminating in a sensory vesicle at the other. Recently Richard W. Murray of the University of Birmingham has found that these organs respond to very delicate electrical stimulation. Unfortunately, either skates are rather uncooperative animals or we have not mastered the trick of training them; we have been unable to repeat with them the experiments in discrimination in which *Gymnarchus* performs so well.

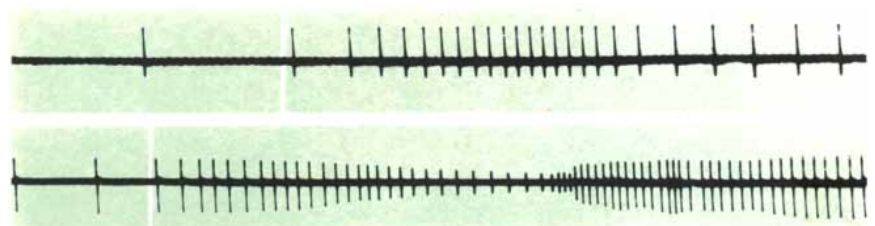
Gymnarchus, the gymnotids and skates all share one obvious feature: they swim in an unusual way. *Gymnarchus* swims with the aid of a fin on its back; the gymnotids have a similar fin on their underside; skates swim with pectoral fins stuck out sideways like wings [*see illustration on page 52*]. They all keep the spine rigid as they move. It would be rash to suggest that such deviations from the basic fish plan could be attributed to an accident of nature. In biology it always seems safer to assume that any redesign has arisen for some reason, even if the reason obstinately eludes the investigator. Since few fishes swim in this way or have electric organs, and since the fishes that combine these features are not related, a mere coincidence would appear most unlikely.



ELECTRIC DISCHARGES of *Gymnarchus* show reversal of polarity when detecting electrodes are rotated 180 degrees (*enlarged records at top*). The discharges, at rate of 300 per second, are remarkably regular even when fish is resting, as seen in lower records.



DISCHARGE RATES DIFFER in different species of gymnotids. *Sternopygus macrurus* (*upper record*) has rate of 55 per second; *Eigenmannia virescens* (*lower*), 300 per second.

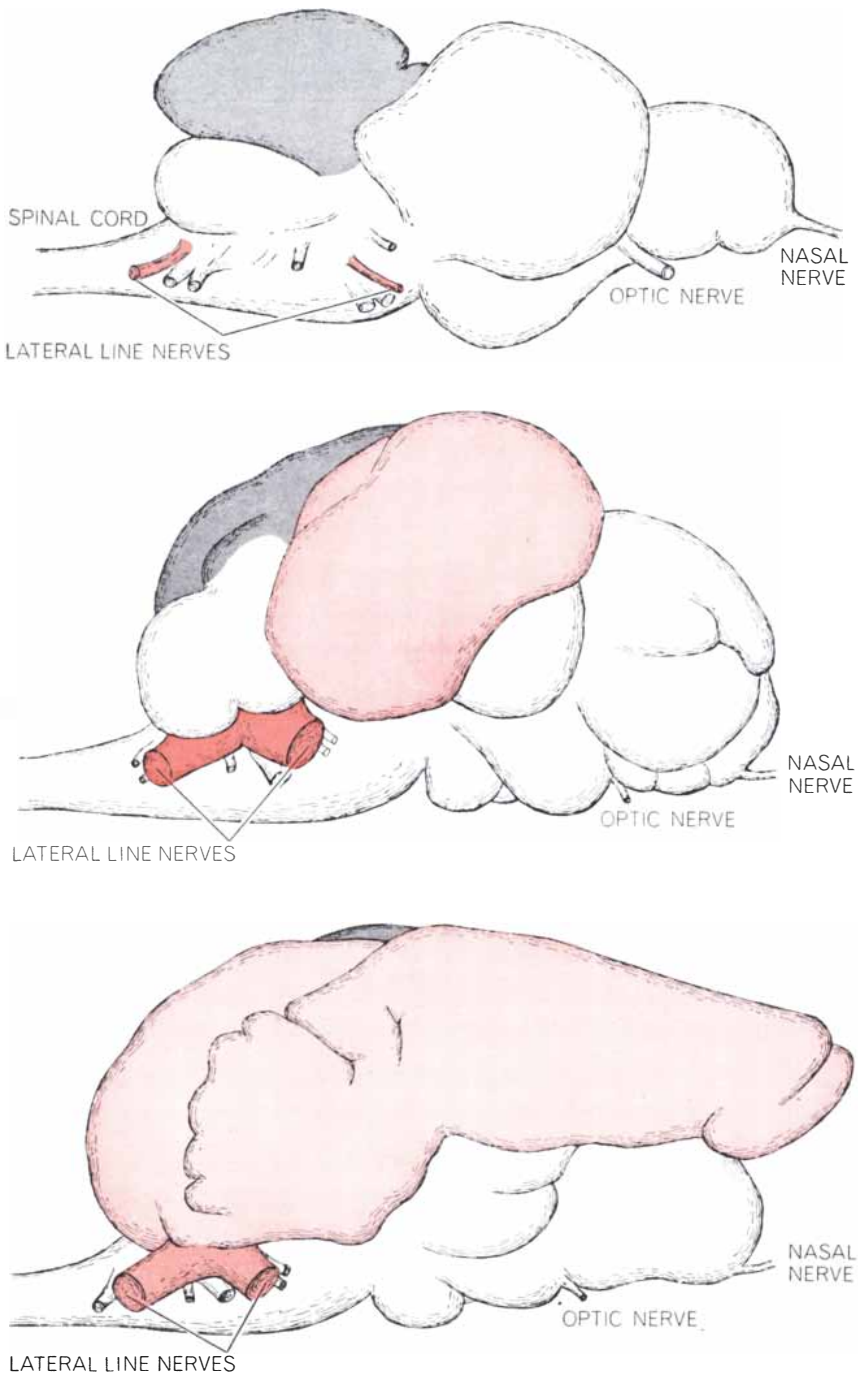


VARIABLE DISCHARGE RATE is seen in some species. Tap on tank (*white line in upper record*) caused mormyrid to increase rate. Tap on fish (*lower record*) had greater effect.

A good reason for the rigid swimming posture emerged when we built a model to simulate the discharge mechanism and the sensory-perception system. We placed a pair of electrodes in a large tank of water; to represent the electric organ they were made to emit repetitive electric pulses. A second pair of electrodes, representing the electric sense organ, was placed some distance away to pick up the pulses. We rotated the second pair of electrodes until they were on a line of equipotential, where they ceased to record signals from the sending electrodes. With all the electrodes clamped in this position, we showed that the introduction of either a conductor or a nonconductor into the electric field could cause sufficient distortion of the field for the signals to reappear in the detectors.

In a prolonged series of readings the

slightest displacement of either pair of electrodes would produce great variations in the received signal. These could be smoothed to some extent by recording not the change of potential but the change in the potential gradient over the "surface" of our model fish. It is probable that the real fish uses this principle, but to make it work the electrode system must be kept more or less constantly aligned. Even though a few cubic centimeters of fish brain may in some respects put many electronic computers in the shade, the fish brain might be unable to obtain any sensible information if the fish's electrodes were to be misaligned by the tail-thrashing that propels an ordinary fish. A mode of swimming that keeps the electric field symmetrical with respect to the body most of the time would therefore offer obvious advantages. It seems logical to assume that *Gymnarchus*, or its ancestors, acquired the rigid mode of swimming along with the electric sensory apparatus and subsequently lost the broad, oarlike tail fin.



BRAIN AND NERVE ADAPTATIONS of electric fish are readily apparent. Brain of typical nonelectric fish (*top*) has prominent cerebellum (*gray*). Regions associated with electric sense (*color*) are quite large in *Gymnarchus* (*middle*) and even larger in the mormyrid (*bottom*). Lateral-line nerves of electric fishes are larger, nerves of nose and eyes smaller.

Our experiments with models also showed that objects could be detected only at a relatively short distance, in spite of high amplification in the receiving system. As an object was moved farther and farther away, a point was soon reached where the signals arriving at the oscilloscope became submerged in the general "noise" inherent in every detector system. Now, it is known that minute amounts of energy can stimulate a sense organ: one quantum of light registers on a visual sense cell; vibrations of subatomic dimensions excite the ear; a single molecule in a chemical sense organ can produce a sensation, and so on. Just how such small external signals can be picked out from the general noise in and around a metabolizing cell represents one of the central questions of sensory physiology. Considered in connection with the electric sense of fishes, this question is complicated further by the high frequency of the discharges from the electric organ that excite the sensory apparatus.

In general, a stimulus from the environment acting on a sense organ produces a sequence of repetitive impulses in the sensory nerve. A decrease in the strength of the stimulus causes a lower frequency of impulses in the nerve. Conversely, as the stimulus grows stronger, the frequency of impulses rises, up to a certain limit. This limit may vary from one sense organ to another, but 500 impulses per second is a common upper limit, although 1,000 per second have been recorded over brief intervals.

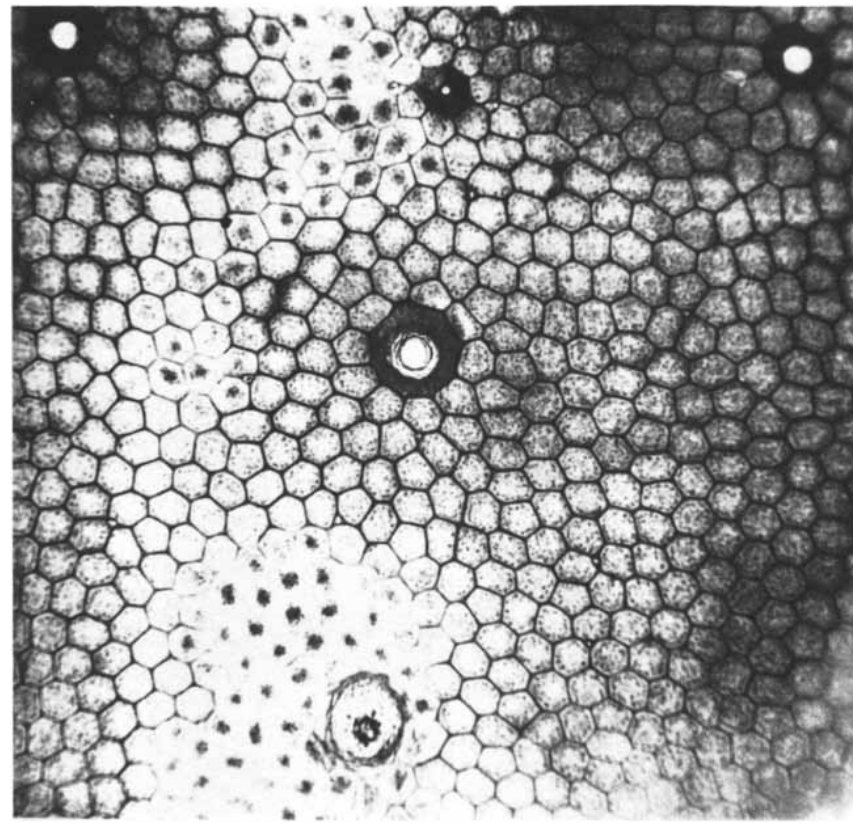
In the case of the electric sense organ of a fish the stimulus energy is provided by the discharges of the animal's electric organ. *Gymnarchus* discharges at the rate of 300 pulses per second. A change in the amplitude—not the rate—of these pulses, caused by the presence of an object in the field, constitutes the effective stimulus at the sense organ. Assuming that the reception of a single discharge of small amplitude excites one impulse in a sensory nerve, a discharge of larger amplitude that excited two impulses would probably reach and exceed the upper limit at which the nerve can generate impulses, since the nerve would now be firing 600 times a second (twice the rate of discharge of the electric organ). This would leave no room

to convey information about gradual changes in the amplitude of incoming stimuli. Moreover, the electric organs of some gymnotids discharge at a much higher rate; 1,600 impulses per second have been recorded. It therefore appears unlikely that each individual discharge is communicated to the sense organs as a discrete stimulus.

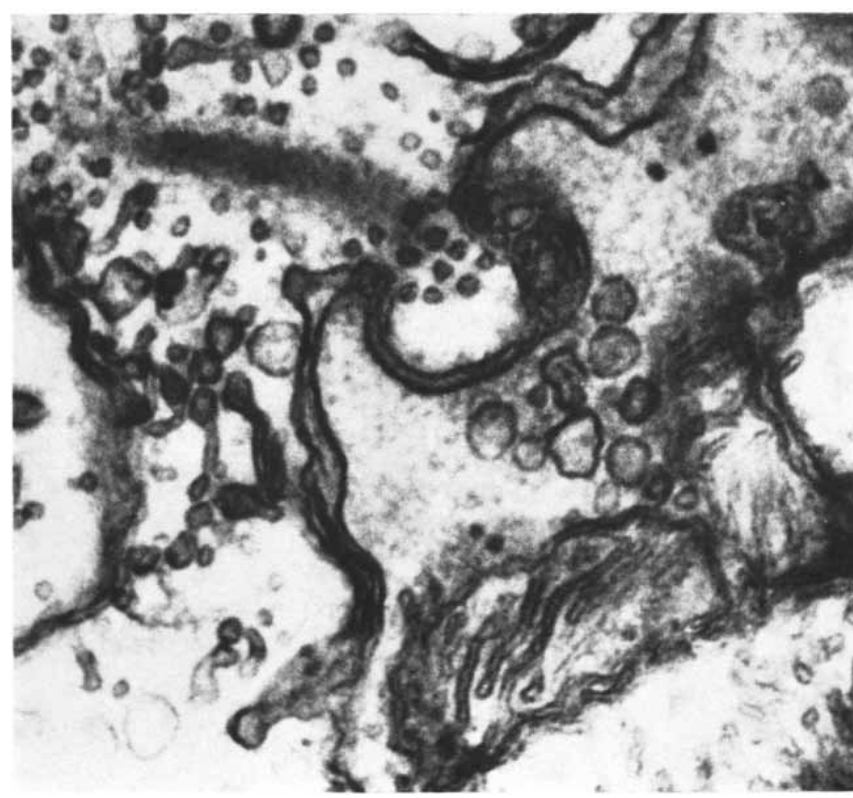
We also hit on the alternative idea that the frequency of impulses from the sensory nerve might be determined by the mean value of electric current transmitted to the sense organ over a unit of time; in other words, that the significant messages from the environment are averaged out and so discriminated from the background of noise. We tested this idea on *Gymnarchus* by applying trains of rectangular electric pulses of varying voltage, duration and frequency across the aquarium. Again using the conditioned-reflex technique, we determined the threshold of perception for the different pulse trains. We found that the fish is in fact as sensitive to high-frequency pulses of short duration as it is to low-frequency pulses of identical voltage but correspondingly longer duration. For any given pulse train, reduction in voltage could be compensated either by an increase in frequency of stimulus or an increase in the duration of the pulse. Conversely, reduction in the frequency required an increase in the voltage or in the duration of the pulse to reach the threshold. The threshold would therefore appear to be determined by the product of voltage times duration times frequency.

Since the frequency and the duration of discharges are fixed by the output of the electric organ, the critical variable at the sensory organ is voltage. Threshold determinations of the fish's response to single pulses, compared with quantitative data on its response to trains of pulses, made it possible to calculate the time over which the fish averages out the necessarily blurred information carried within a single discharge of its own. This time proved to be 25 milliseconds, sufficient for the electric organ to emit seven or eight discharges.

The averaging out of information in this manner is a familiar technique for improving the signal-to-noise ratio; it has been found useful in various branches of technology for dealing with barely perceptible signals. In view of the very low signal energy that *Gymnarchus* can detect, such refinements in information processing, including the ability to average out information picked up by a large number of separate sense organs,



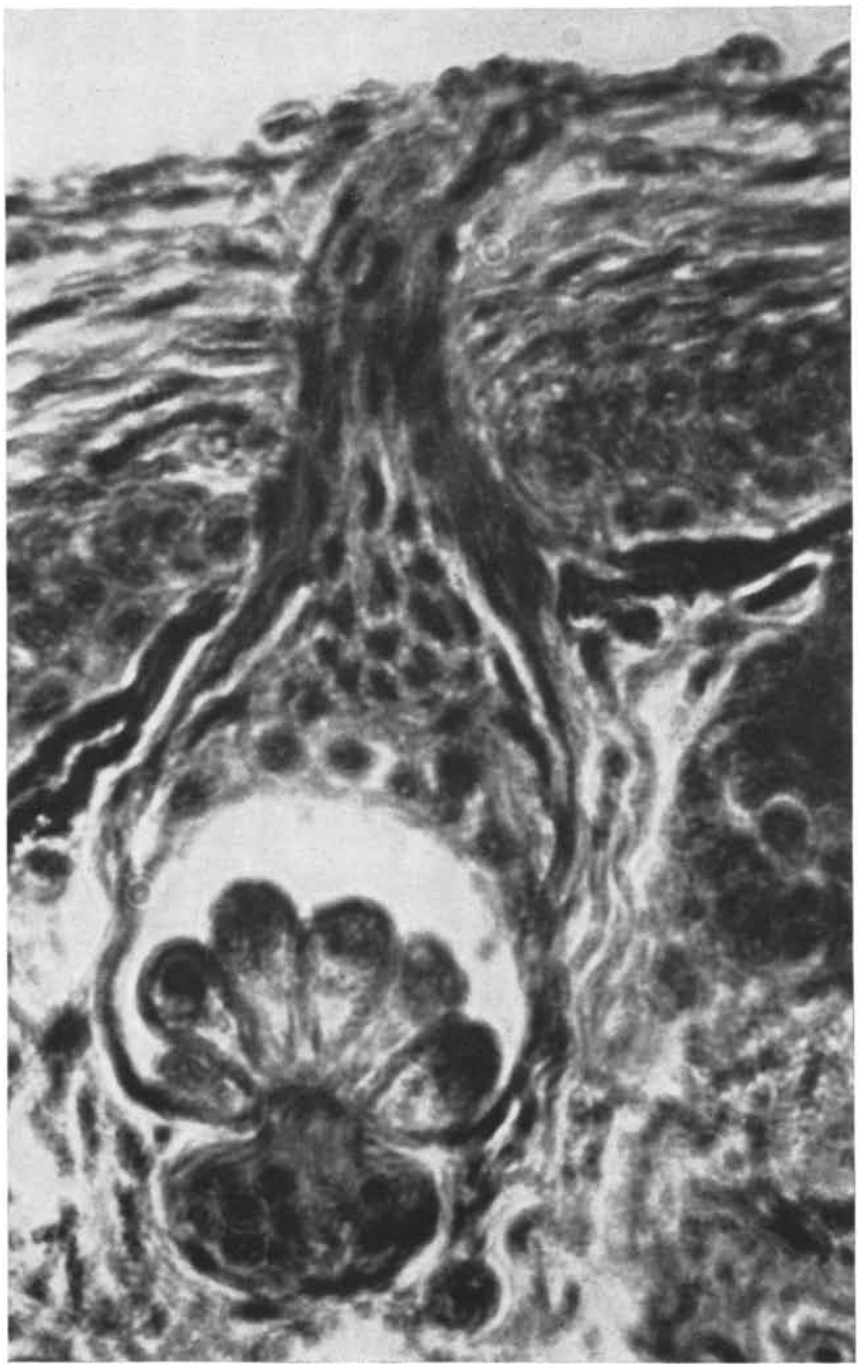
SKIN OF MORMYRID is made up of many layers of platelike cells having remarkable hexagonal structure. The pores contain tubes leading to electric sense organs. This photomicrograph by the author shows a horizontal section through the skin, enlarged 100 diameters.



MEETING POINT of electric sensory cell (*left*) and its nerve (*right*) is enlarged 120,000 diameters in this electron micrograph by the author and Ann M. Mullinger. Bulge of sensory cell into nerve ending displays the characteristic dense streak surrounded by vesicles.

appear to be essential. We have found that *Gymnarchus* can respond to a continuous direct-current electric stimulus of about .15 microvolt per centimeter, a value that agrees reasonably well with the calculated sensitivity required to recognize a glass rod two millimeters in diameter. This means that an individual sense organ should be able to convey information about a current change as small as .003 micromicroampere. Extended over the integration time of 25 milliseconds, this tiny current corresponds to a movement of some 1,000 univalent, or singly charged, ions.

The intimate mechanism of the single sensory cell of these organs is still a complete mystery. In structure the sense organs differ somewhat from species to species and different types are also found in an individual fish. The fine structure of the sensory cells, their nerves and associated elements, which Ann M. Mullinger and I have studied with both the light microscope and the electron microscope, shows many interesting details. Along specialized areas of the boundary between the sensory cell and the nerve fiber there are sites of intimate contact where the sensory cell bulges into the fiber. A dense streak extends from the cell into this bulge, and the vesicles alongside it seem to penetrate the intercellular space. The integrating system of the sensory cell may be here.



VERTICAL SECTION through skin and electric sense organ of a gymnotid shows tube containing jelly-like substance widening at base into a capsule, known as multicellular gland, that holds a group of special cells. Enlargement of this photomicrograph is 1,000 diameters.

These findings, however, apply only to *Gymnarchus* and to about half of the species of gymnotids investigated to date. The electric organs of these fishes emit pulses of constant frequency. In the other gymnotids and all the mormyrids the discharge frequency changes with the state of excitation of the fish. There is therefore no constant mean value of current transmitted in a unit of time; the integration of information in these species may perhaps be carried out in the brain. Nevertheless, it is interesting that both types of sensory system should have evolved independently in the two different families, one in Africa and one in South America.

The experiments with *Gymnarchus,* which indicate that no information is carried by the pulse nature of the discharges, leave us with a still unsolved problem. If the pulses are "smoothed out," it is difficult to see how any one fish can receive information in its own frequency range without interference from its neighbors. In this connection Akira Watanabe and Kimihisa Takeda at the University of Tokyo have made the potentially significant finding that the gymnotids respond to electric oscillations close in frequency to their own by shifting their frequency away from the applied frequency. Two fish might thus react to each other's presence.

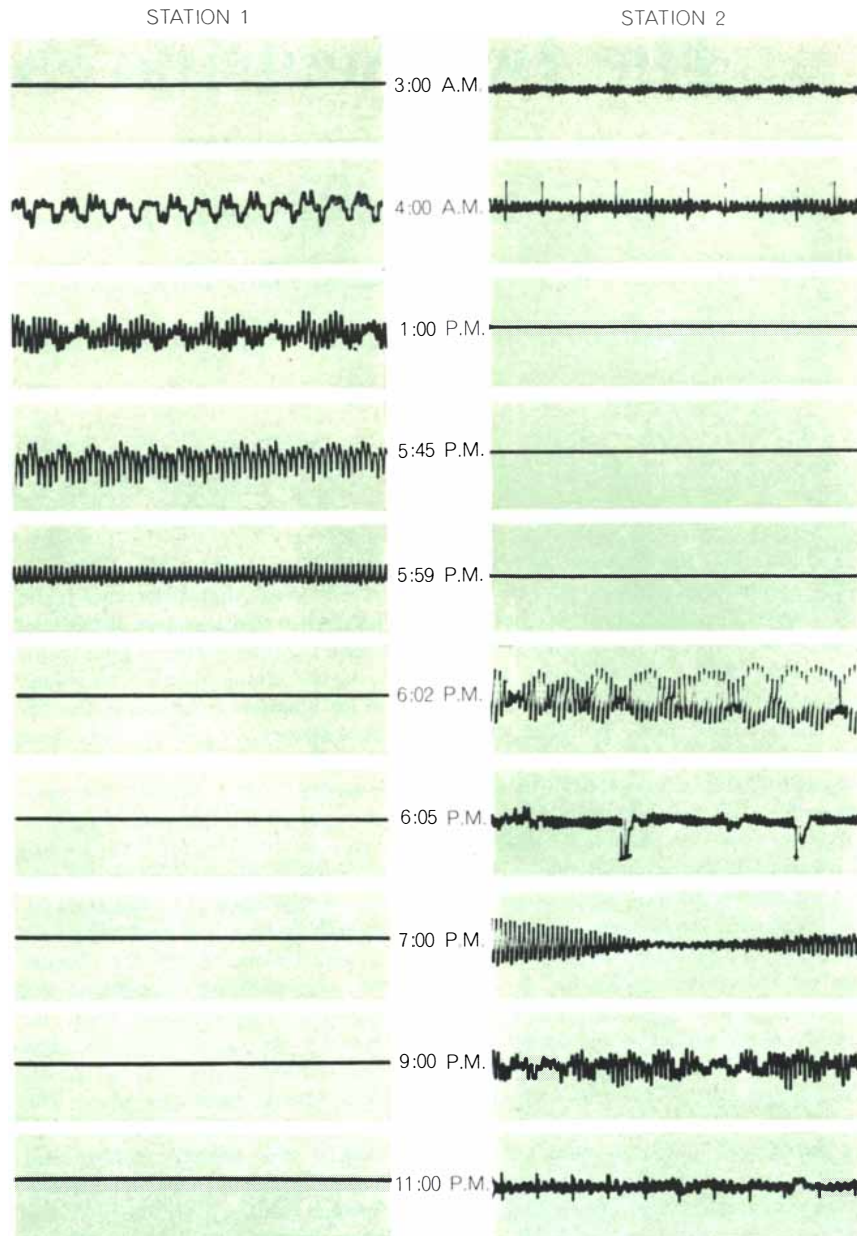
For reasons that are perhaps associated with the evolutionary origin of their electric sense, the electric fishes are elusive subjects for study in the field. I have visited Africa and South America in order to observe them in their natural habitat. Although some respectable specimens were caught, it was only on rare occasions that I actually saw a *Gymnarchus,* a mormyrid or a gymnotid in the turbid waters in which they live. While such waters must have favored the evolution of an electric sense, it could not have been the only factor. The same waters contain a large number of

other fishes that apparently have no electric organs.

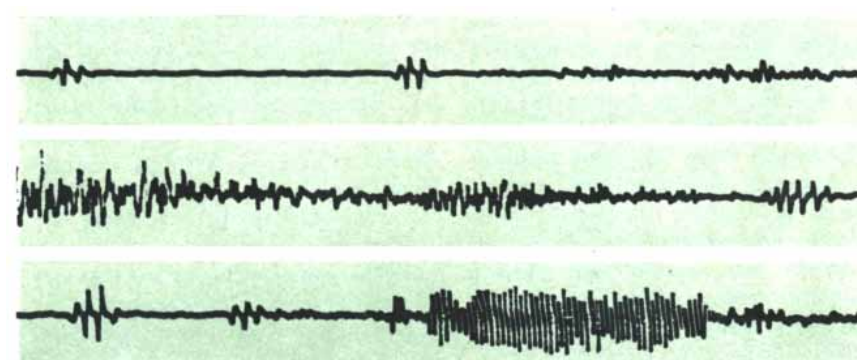
Although electric fishes cannot be seen in their natural habitat, it is still possible to detect and follow them by picking up their discharges from the water. In South America I have found that the gymnotids are all active during the night. Darkness and the turbidity of the water offer good protection to these fishes, which rely on their eyes only for the knowledge that it is day or night. At night most of the predatory fishes, which have well-developed eyes, sleep on the bottom of rivers, ponds and lakes. Early in the morning, before the predators wake up, the gymnotids return from their nightly excursions and occupy inaccessible hiding places, where they often collect in vast numbers. In the rocks and vegetation along the shore the ticking, rattling, humming and whistling can be heard in bewildering profusion when the electrodes are connected to a loudspeaker. With a little practice one can begin to distinguish the various species by these sounds.

When one observes life in this highly competitive environment, it becomes clear what advantages the electric sense confers on these fishes and why they have evolved their curiously specialized sense organs, skin, brain, electric organs and peculiar mode of swimming. Such well-established specialists must have originated, however, from ordinary fishes in which the characteristics of the specialists are found in their primitive state: the electric organs as locomotive muscles and the sense organs as mechanoreceptors along the lateral line of the body that signal displacement of water. Somewhere there must be intermediate forms in which the contraction of a muscle, with its accompanying change in electric potential, interacts with these sense organs. For survival it may be important to be able to distinguish water movements caused by animate or inanimate objects. This may have started the evolutionary trend toward an electric sense.

Already we know some supposedly nonelectric fishes from which, nevertheless, we can pick up signals having many characteristics of the discharges of electric fishes. We know of sense organs that appear to be structurally intermediate between ordinary lateral-line receptors and electroreceptors. Furthermore, fishes that have both of these characteristics are also electrically very sensitive. We may hope one day to piece the whole evolutionary line together and express, at least in physical terms, what it is like to live in an electric world.



TRACKING ELECTRIC FISH in nature involves placing electrodes in water they inhabit. Records at left were made in South American stream near daytime hiding place of gymnotids, those at right out in main channel of stream, where they seek food at night.



AFRICAN CATFISH, supposedly nonelectric, produced the discharges shown here. Normal action potentials of muscles are seen, along with odd regular blips and still other oscillations of higher frequency. Such fish may be evolving an electric sense or may already have one.

The Two-Neutrino Experiment

An account of the heroic experiment, involving a 30-billion-volt accelerator, a 10-ton spark chamber and 45 feet of armor plate, that demonstrated that there is not one kind of neutrino but two

by Leon M. Lederman

These days the discovery of a new elementary particle is scarcely news. Physics has been plagued by what seems to be a surfeit of particles for some time. Within the past year, however, a particle has been discovered that may have solved more problems than it has created. An experiment carried out with the 30-billion-electron-volt accelerator at the Brookhaven National Laboratory has demonstrated that there is not, as had been assumed, one variety of the particle known as the neutrino but two. When the Brookhaven accelerator was being designed 10 years ago, many uses were conceived for it, but no one dreamed that it would ever be employed to make neutrinos for experimental observation. Indeed, 10 years ago many investigators were still concerned with the verification of the neutrino's existence. The proof was ultimately supplied by a long series of detailed experiments, climaxed by the direct observation of neutrino-induced reactions in 1956.

Neutrinos are the most impalpable of particles. They have no electric charge, no mass (or none that has yet been measured) and (if it is assumed that they are massless) they travel with the speed of light. They are produced in huge numbers by nuclear processes inside the sun and other stars. Those that encounter the earth pass right through it with ease. Only about one neutrino in every 10 billion (10^{10}) passing through the center of the earth is likely to react with another particle. Obviously a particle that reacted with nothing whatever could never be detected. It would be a fiction. The neutrino is just barely a fact.

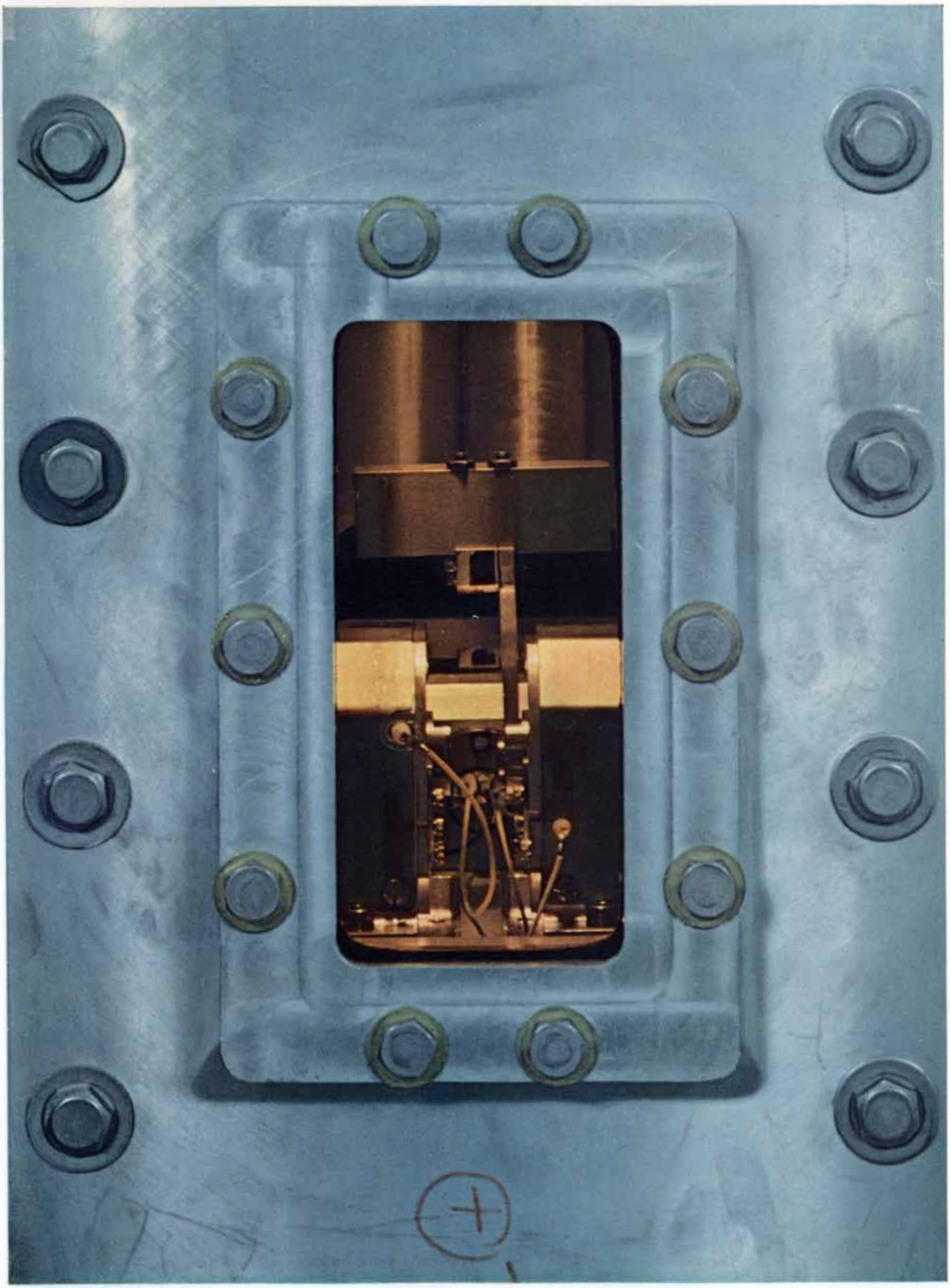
Elementary particles reveal their presence by interacting in various ways. Physicists speak of four fundamental kinds of interaction (the modern term for force), which differ markedly in strength. The weakest is gravitation, which is so weak that it becomes manifest only when vast numbers of particles are bound together to form a ponderable body. In the atomic domain, therefore, it can be ignored. In studying the behavior of elementary particles only three forces need to be considered: "strong," electromagnetic and "weak." The relative strengths of the three are roughly in the ratio of 10^{12} to 10^{10} to 1. The strong force is that which holds the particles in the nucleus of the atom together and which is released in nuclear fission and fusion. It has the further property of generating reactions among strongly interacting particles. These are cataclysmic: no sooner are two such particles within "reach" of the strong force than the reaction takes place. The electromagnetic force is that which binds electrons to the atomic nucleus and which underlies all chemical and electric phenomena. For our purposes it is important to note that fast-moving electrically charged particles are slowed down in matter by their continuous interaction with atomic electrons. Weak forces are responsible for the spontaneous decay of unstable—radioactive—nuclei and of elementary particles. Here again to the force or interaction must be attributed the property of inducing transformations among particles. It is believed that all elementary particles are subject to weak-force interactions, although the effects are often obscured by the strong and electromagnetic forces.

All this can be expressed another way by classifying particles according to the interactions in which they can take part. In the present discussion we shall be concerned only with six particles: the proton, pion, neutron, electron, muon and neutrino [*see illustration on page 62*]. Proton and pion take part in all three interactions: strong, electromagnetic and weak. The neutron, being electrically neutral, has only very subtle electromagnetic properties, but it is involved in both strong and weak interactions. Physicists often refer to the three particles—proton, pion and neutron—as "stronglies." The other three—electron, muon and neutrino—are "weaklies." The neutrino, alone among particles, has only weak force. Each of the six particles has a corresponding antiparticle, with an identical set of forces.

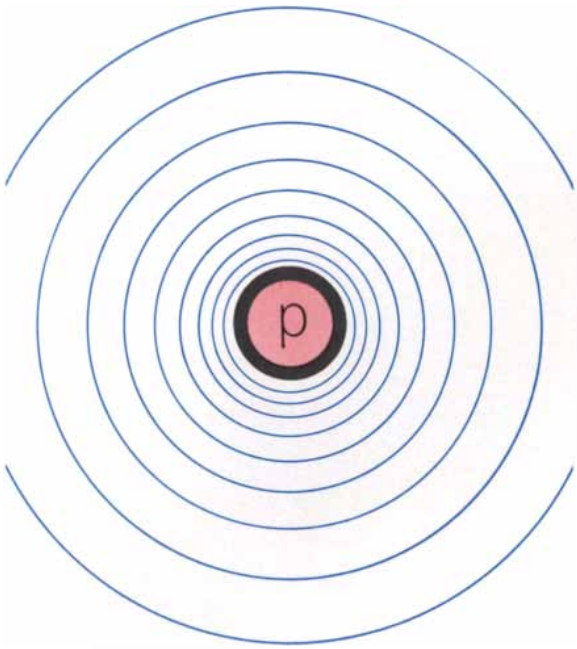
One of the earliest forms of nuclear instability to be investigated was that known as beta decay. This is the spontaneous emission of an electron (or its antiparticle, a positron) from an unstable atomic nucleus. When the energies of the emitted electrons were first measured in the 1920's, the results were baffling. It was expected that all the electrons emitted from one kind of nucleus would have the same energy. Instead they had a wide spectrum of energies, ranging downward from some maximum value. How to account for the missing energy?

With deep insight and considerable daring Wolfgang Pauli of Austria suggested in 1931 that the missing energy was being carried off by an undetected particle. The name "neutrino" was soon supplied by Enrico Fermi. Perceiving that the rate of beta decay was enormously slow compared with the rate of other nuclear reactions, Fermi postulated that it represented a new force and developed a theory to describe it. The simplest beta-decay reaction involves the free neutron. Upon ejection from an atomic nucleus the neutron decays spontaneously, yielding a proton and an electron. Again there was missing energy to be accounted for and it was also assigned to the neutrino, or, to be precise, the antineutrino.

Fermi's theory predicted that it should

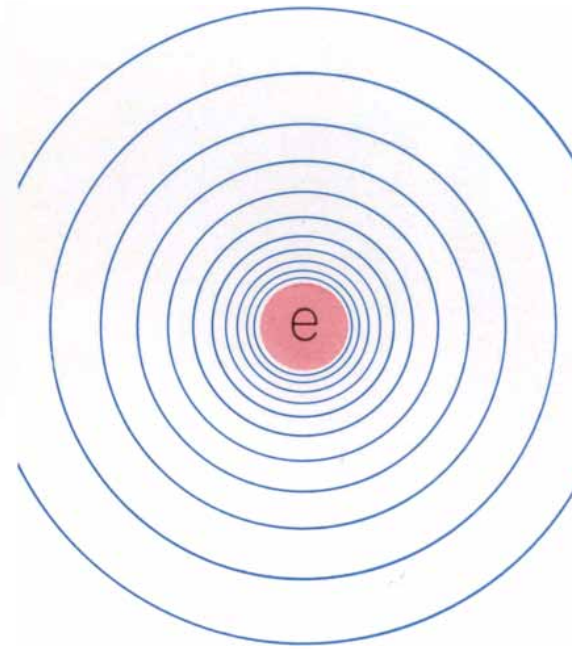


TARGET OF BEAM OF PROTONS that gave rise to one of two kinds of neutrino is the horizontal block above the bright yellow metal parts in the vacuum chamber of the alternating-gradient synchrotron at the Brookhaven National Laboratory. The collision of the protons with atoms in the target results in the production of pions, which decay into the neutrinos required for the experiment described in the text. In this experiment the synchrotron accelerated the protons to 15 billion electron volts, one-half of its energy range.



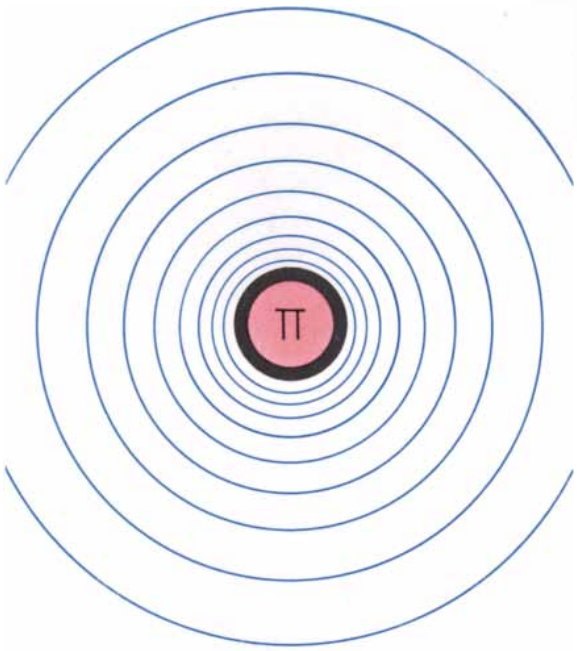
PROTON

STRONG, ELECTROMAGNETIC, WEAK



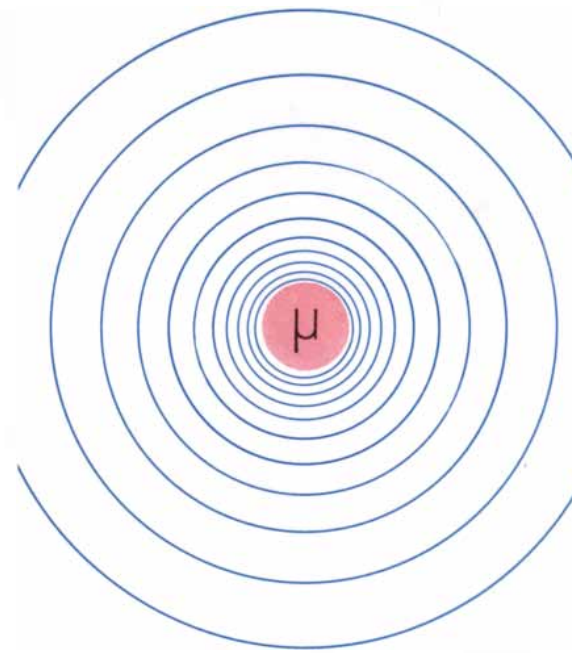
ELECTRON

ELECTROMAGNETIC, WEAK



PION

STRONG, ELECTROMAGNETIC, WEAK



MUON

ELECTROMAGNETIC, WEAK

NEUTRON

STRONG, WEAK

NEUTRINO

WEAK

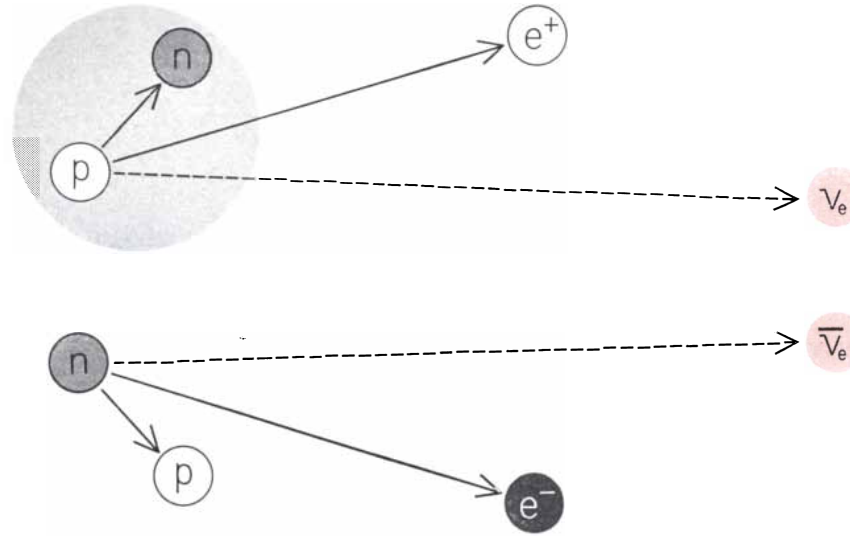
SIX PARTICLES discussed in the text are characterized by three types of "interaction" (the modern term for "force"): strong (*black*), electromagnetic (*blue*) and weak (*pink*). The proton and pion enter into all three types of interaction; the neutron displays only strong and weak forces. The electron and muon have identical properties. Of all the particles, the neutrino alone enters into weak interactions only. In general the three particles at left can be regarded as strong interactors; the three at right, as weak interactors.

be possible for the reaction to go in reverse; that is, that an antineutrino should occasionally react with a proton to produce a neutron and (to balance charges) a positron. This is the reaction that was sought and found in 1956 by Frederick Reines and Clyde L. Cowan, Jr.

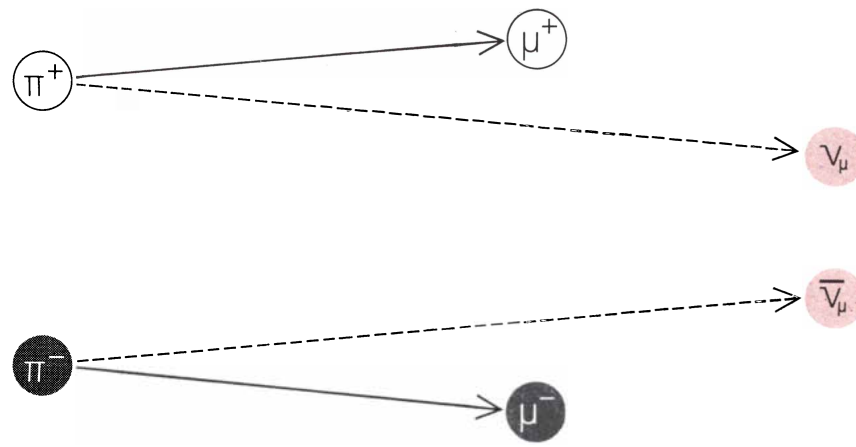
By the time the neutrino was finally observed, physics was deep in new troubles, brought on by the discovery of new particles. They were many, they were unstable and their lifetimes indicated that almost all decayed through weak interactions. A weak-interaction decay is characterized by a lifetime ranging roughly from 10^3 seconds to 10^{-10} second. If strong forces were involved, the decay rate would be 10^{-23} second.

Among the many new particles was one destined to play a central role in the two-neutrino experiment. The particle is the pion, which was discovered in 1947 at Bristol University by C. F. Powell, C. M. G. Lattes and G. P. S. Occhialini. The pion appeared in cosmic ray tracks recorded in photographic emulsions exposed at high altitudes. The pion had been expected by physics since 1935, when the Japanese physicist Hideki Yukawa predicted its existence on theoretical grounds. According to quantum field theory, every force in nature is accompanied by a particle whose assignment is to transmit that force between interacting particles. For example, the electromagnetic force is borne by the photon. Yukawa postulated that a particle with 200 or 300 times the mass of the electron would be needed to conduct the nuclear force field—the strong force—between nuclear particles. The mu meson, or muon, was discovered in 1936 and had about the right mass, but subsequent observations proved that the muon was a weakly. It did not transmit the strong force. In fact, it was the first of the elementary particles for which physical theory was unable to provide a role. The pi meson, or pion, met Yukawa's specifications. The very first emulsion photographs showed that pions reacted violently with atomic nuclei.

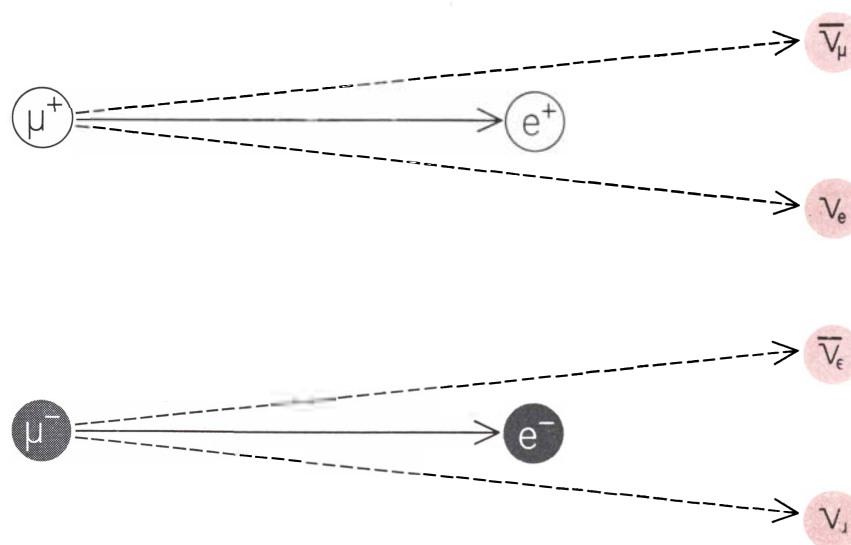
In 2.55×10^{-8} second the positive pion decays into a positive muon and a neutrino. As in beta decay, the neutrino is needed to account for missing energy (and momentum). The first paper analyzing the pion-decay reaction, however, assigned a mass of about 100 electron masses to the invisible particle produced in the decay and dubbed it the "neutretto," to distinguish it from the presumably massless neutrino. Before long the estimated mass was reduced by a



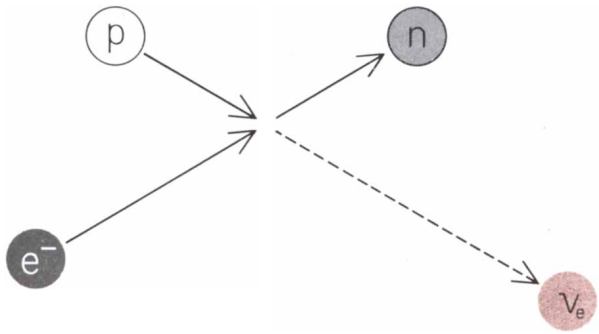
BETA DECAY is a weak interaction involving a proton or neutron. Inside an atomic nucleus, a proton (*top*) can decay into a neutron, positron and neutrino of the electron type. Free neutron (*bottom*) decays into proton, electron and electron-type antineutrino.

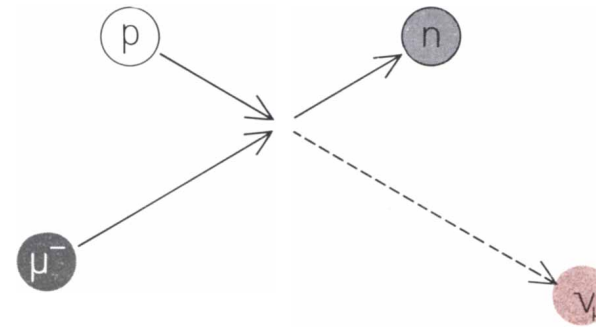


PION DECAY, another weak interaction, yields positive muon and muon-type neutrino (*top*) or negative muon and muon-type antineutrino (*bottom*), according to pion's charge.



MUON DECAY, also weak, yields a positron (*top*) or an electron (*bottom*). Both decays yield a neutrino and an antineutrino, one "belonging" to the muon, the other to the electron.





ELECTRON AND MUON appear to be identical in every respect except mass (and lifetime), the muon having a mass some 200 times greater. This identity extends to the reactions in which they take part. For every reaction involving an electron there is a corresponding reaction involving a muon; for example, the reaction of either particle with a proton produces a neutron and a neutrino.

factor of 10 and the distinction was dropped. The simplest conclusion was that pions decay into muons and neutrinos—the same kind of neutrinos, presumably, as those produced in beta decay. Furthermore, the conservation law known as charge conjugation led to the conclusion that if positive pions produce positive muons and neutrinos, negative pions must produce negative muons and antineutrinos.

The assignment of the neutrino to the positive pion and the antineutrino to the negative pion follows from the idea that "leptons" are conserved. The leptons are the electron, the negative muon and the neutrino; the antileptons are the positron, the positive muon and the antineutrino. The conservation of leptons requires that in any reaction the total number of leptons minus the number of the antileptons is constant.

By 1958 the theory of weak interactions, originally due to Fermi, had been developed in a highly successful manner by a number of workers, most notably by T. D. Lee at Columbia University and C. N. Yang at the Institute for Advanced Study and by Richard P. Feynman and Murray Gell-Mann of the California Institute of Technology. Nevertheless, problems remained.

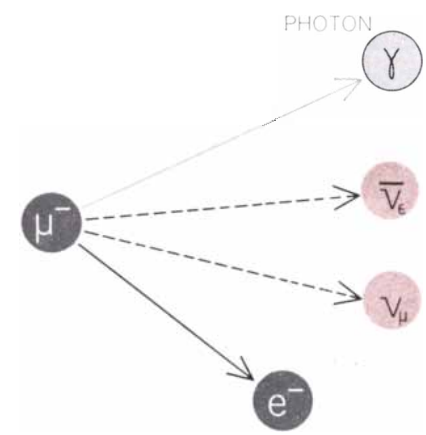
First, there was (and still is) the muon-electron problem. For every reaction known to involve an electron there is a corresponding reaction involving a muon [*see illustration above*]. The similarity of muons and electrons extends also to their intrinsic properties: they have the same quantum characteristic known as spin, and their magnetic and electric properties have been compared to an accuracy of a few per million and found to be the same. Indeed, apart from the fact that the muon is some 200 times heavier than the electron, the two particles seem identical.

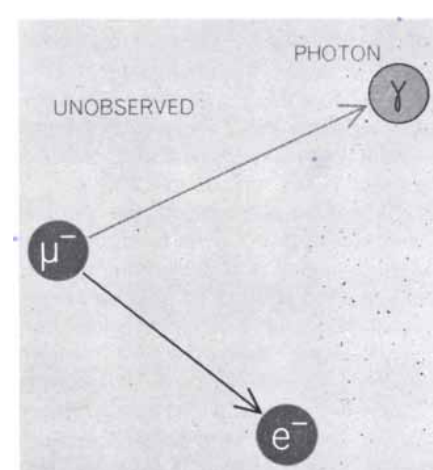
The problem of mass is central to the entire subject of elementary particles. The fact that the large difference in the masses of the muon and the electron does not seem to induce other differences in their properties is one of the most fascinating in contemporary physics. These differences must be sought, however subtle. How can the neutrino help? In beta decay the electron is produced with a neutrino. In pion decay the muon is produced with a neutrino. In neutrino-nuclear collisions electrons and muons should be generated. At high energies this type of experiment would constitute a sensitive probe of muon-electron differences. No one, however, had ever shown that the neutrino born with an electron in beta decay and the neutrino born with a muon in pion decay were identical. If they were different, the difference must obviously be connected with the muon-electron difference. This, then, was one motive for considering a high-energy neutrino experiment.

The fruitfulness of such an experiment was analyzed in detail in late 1959 by Lee and Yang. All knowledge of weak reactions up to the spring of 1962 had been gained from observations at low energies. In no case did the energy transfer exceed 100 million electron volts. Physicists were most anxious to see how the weak force behaved when the energy exchange was increased toward a billion electron volts, and beyond. The traditional result of observing interactions at higher and higher energies is to "see" finer and finer details of structure. Obviously what was needed was a high-energy collision experiment involving a weak interaction. The only collision that would tell anything about the weak force, and that would not be "drowned out" by electromagnetic and strong forces, was a collision in which one of the particles was a neutrino.

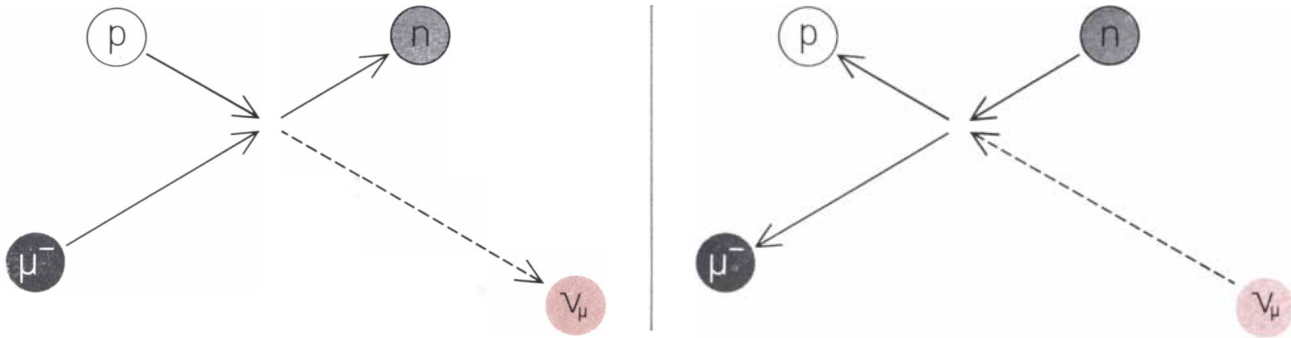
The desire for a high-energy weak-interaction experiment was sharpened by a widely recognized defect of weak-interaction theory. In the summer of 1960 Lee and Yang analyzed this problem at length. Although the theory yielded excellent predictions for low-energy reactions, it led to absurd results for high energies. As a general rule an increase in energy provides an increasing number of ways for a reaction to occur.

In the case of the Fermi theory for weak interactions this led to the prediction that above a certain energy there would be more reactions than particles available to take part in them. Something, therefore, must intervene to damp the reaction rate. What was it?





ANNIHILATION of neutrino and antineutrino (*top*) should yield bottom reaction if there were only one kind of neutrino.



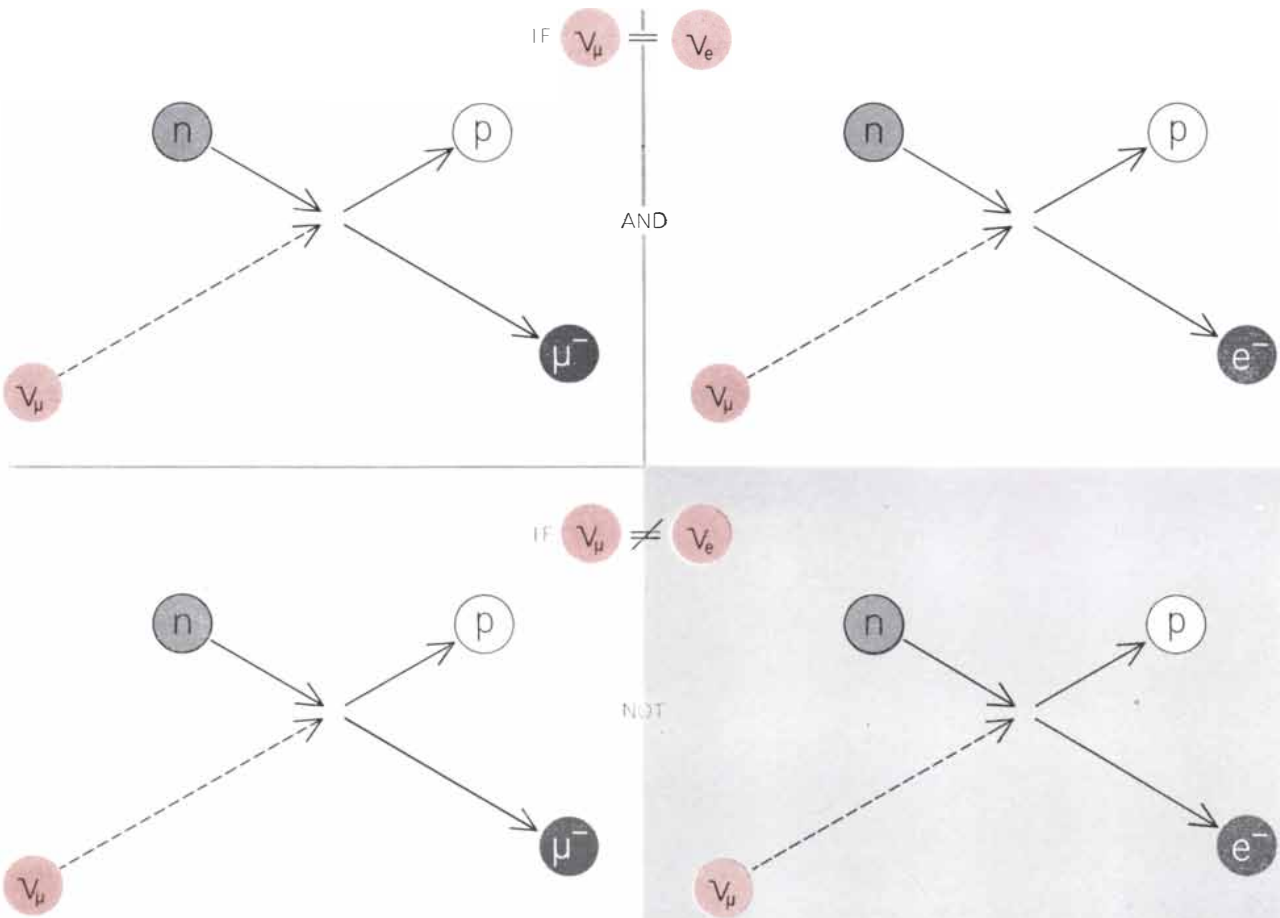
DETECTION OF NEUTRINOS depends on the reversal of a reaction already known to occur. The neutrino leaves no visible tracks in a spark chamber and can only be detected through its interaction with other particles. Since a muon-proton reaction (*left*) produces a neutron and a neutrino, a visible muon (*right*) should occasionally appear when a neutron and a neutrino collide.

One mechanism for damping the weak-reaction rate was the possible existence of an undiscovered particle, about which there had been wide discussion ever since Yukawa's theory of the meson. It had been given the name "intermediate boson" and the symbol "*w*."

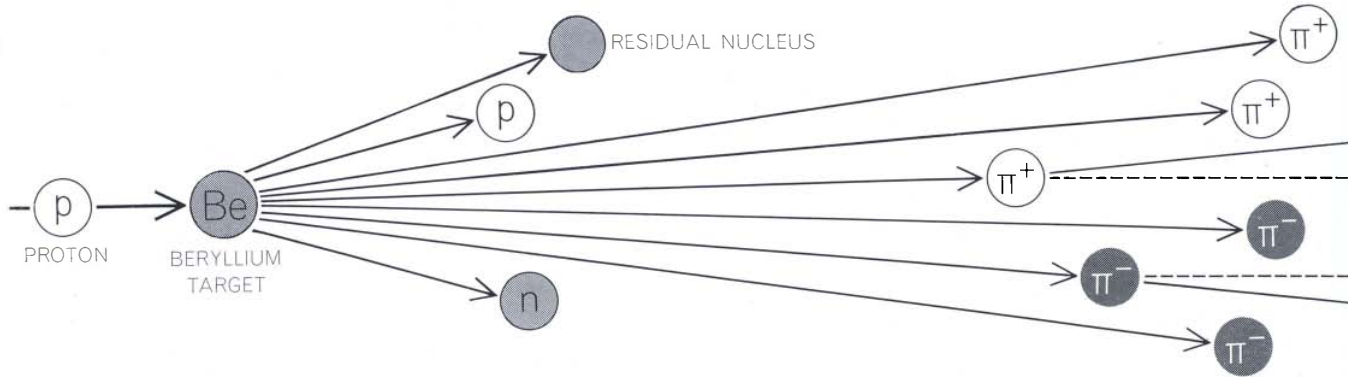
It would serve to carry the weak force in the same way that the photon carries the electromagnetic force and the pion the strong force. It would be the "unglue" that makes a particle break up when it decays. It could not be directly recorded by photographic emulsions, bubble chambers, spark chambers or other devices for making particle tracks visible because its predicted lifetime—about 10^{-17} second—is too short. In this length of time a particle moving at almost the speed of light would travel less than a millionth of a centimeter.

A likely reaction for generating the particle is the collision of a high-energy neutrino with a proton. Out of the collision should come the intermediate boson (if it exists), a proton and a negative muon. Immediately the boson should decay, yielding, some of the time, a positron and a neutrino [*see illustration on page 70*]. With the aid of a suitable detecting device one should be able to see the negative muon and the positron as if they originated at a common point. This would be the boson's "signature." The big advantage of using neutrinos to hunt the boson was that they would produce relatively few background events to obscure its signature.

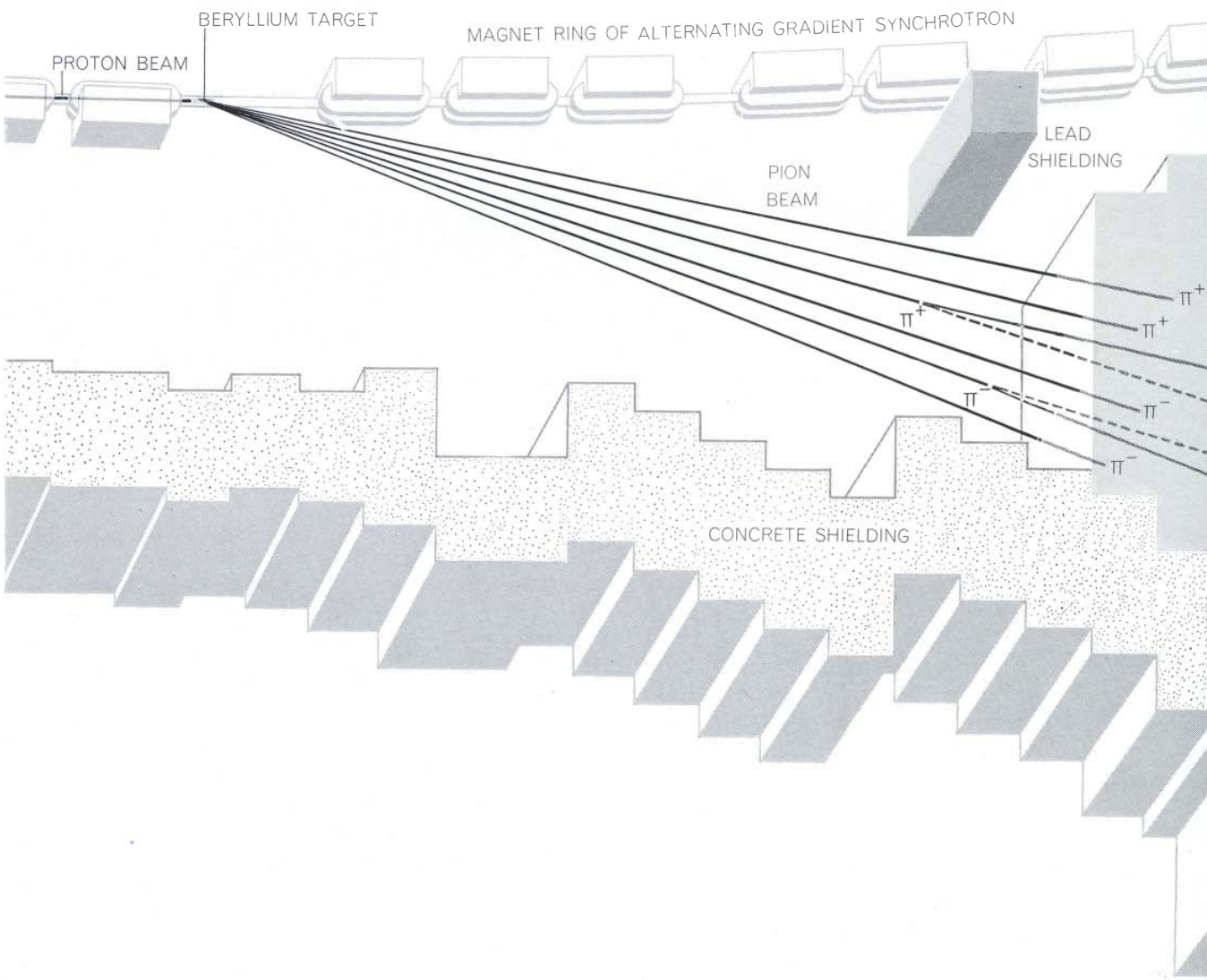
The most compelling motive for wish-



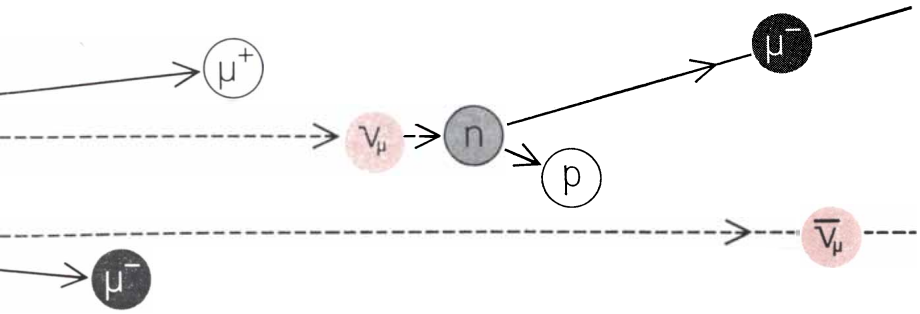
LOGIC OF TWO-NEUTRINO EXPERIMENT depends on the identity (*top*) or nonidentity (*bottom*) of electron-type and muon-type neutrinos. If they are identical, the reaction of muon-type neutrinos (from pion decay) and neutrons should produce muons and electrons in equal numbers. If the two types of neutrino are different, the same reaction should produce muons but not electrons.



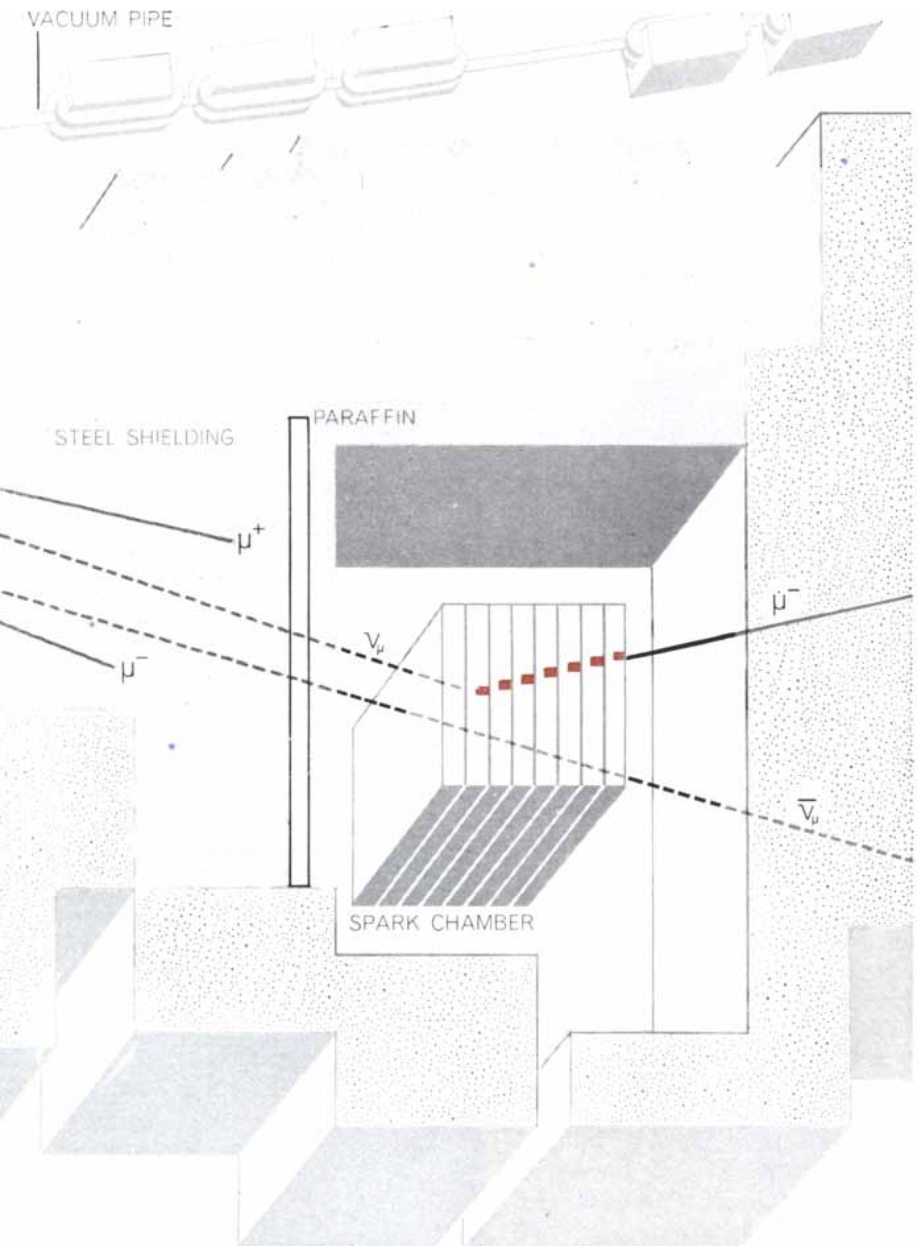
PRODUCTION OF NEUTRINOS for the two-neutrino experiment was achieved by directing a beam of accelerated protons at a target of beryllium atoms (*Be*). The interaction of these protons with the neutrons and protons of the target produces positive and negative



TWO-NEUTRINO EXPERIMENT used the 600-foot-diameter alternating-gradient synchrotron at Brookhaven, only part of which appears in this drawing. A beam of 15-billion-electron-volt protons was allowed to strike a beryllium target, producing an intense beam of pions. About 10 per cent of the pions decayed into muons and neutrinos before smashing into a 13.5-meter wall of armor plate.



pions, which decay into muons and neutrinos and antineutrinos of the muon type. Occasionally a neutrino (or antineutrino) will react with a neutron (or proton), producing a muon.



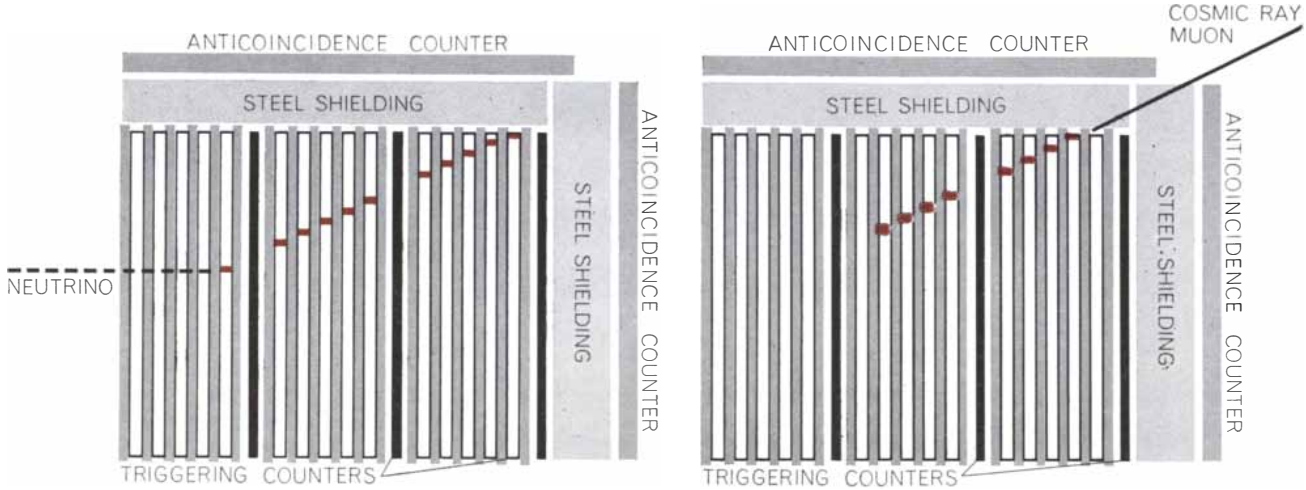
The pions and muons were stopped by the wall; the neutrinos penetrated easily and passed through a spark-chamber detector. At rare intervals the chamber was "triggered" by appearance of a muon (*colored track*) produced by interaction of a neutrino or antineutrino.

ing to examine weak interactions at high energies was the puzzle presented by certain nonobserved reactions. Whenever an electron or a muon appears in a reaction, it is always accompanied by a neutrino. It is possible, however, to write down perfectly good weak reactions for the muon and electron that satisfy all the conservation laws and in which neutrinos do *not* appear. Yet no such reactions had ever been observed. When reactions that could take place are not seen, one must conclude that a basic prohibition law is at work.

One in particular of these evidently prohibited reactions had been sought in many laboratories, with very sensitive techniques. This was the decay of a muon into an electron and a photon. It is well known that a muon sometimes decays into an electron, a photon, a neutrino and an antineutrino [*see bottom illustration on page 64*]. Moreover, particles and their antiparticles annihilate each other when they are in suitable proximity. One can think of the muon's decay into four particles and the annihilation of two of them as being two steps in a "virtual" reaction, virtual meaning that the reaction meets theoretical requirements but cannot be observed. This particular virtual reaction would be stimulated by the presence of the intermediate boson. Under such circumstances the electron and photon would carry off all the energy and momentum of the muon decay. It was this that had never been observed.

Gell-Mann and Gerald Feinberg of Columbia University had independently pointed out that if the intermediate boson, w, existed, the unobserved reaction should "go" at a rate thousands of times faster than the minimum rate experimentally detectable. In fact, the absence of the reaction was often taken as evidence against w. To our experimental group at Columbia the puzzle was converted to a crisis by the further point emphasized to us by Lee (and also contained in the 1960 Lee-Yang paper). *Any* mechanism that would serve to damp the weak-interaction rate at high energies would stimulate the very reaction that no one had been able to observe.

One way to resolve the paradox is to assume that the neutrino and antineutrino of the muon decay cannot annihilate each other because they are of different species. Conceivably one species "belongs" to the disappearing muon and the other to the newly created electron. This hypothesis had the great virtue of preserving all successful features of the existing theory. Clearly a decisive experiment was needed, and this was an-



REAL AND SPURIOUS EVENTS detected by the spark chamber are sometimes indistinguishable. The spurious event (*right*) is produced by a cosmic ray muon, which has slipped into the chamber without triggering "anticoincidence" counters. Ordinarily they would prevent other counters inside the chamber from recording the event. In the actual experiment several hundred cosmic ray events were recorded, but they were identified by the angle of passage. It is estimated, however, that of the 56 events attributed to neutrinos, about five represented cosmic ray muons entering at an angle that made them indistinguishable from a genuine event.

other motive for the Brookhaven neutrino experiment.

Thus there were three urgent reasons for wanting to study weak interactions at high energies: to learn more about the muon and the electron, to observe reaction rates at high energies and to look for a second kind of neutrino. In each case the key to an experiment lay in observing high-energy neutrinos. How could they be obtained?

Late in 1959 Bruno Pontecorvo, working at the high-energy physics laboratory at Dubna, north of Moscow, and Melvin Schwartz of Columbia University independently put forward the feasibility of using accelerators to provide neutrinos of the desired energy. The neutrinos would arise primarily from the decay of pions produced when high-energy protons from an accelerator were allowed to strike a suitable target.

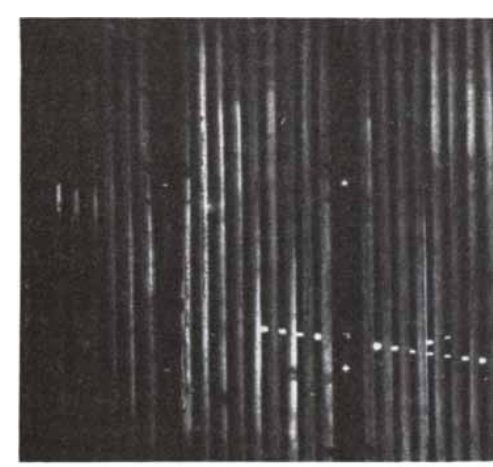
In 1960 Schwartz, Jack Steinberger and I at Columbia calculated that the alternating-gradient synchrotron (AGS) recently completed at Brookhaven might possibly provide high-energy neutrinos in the quantity needed to carry out a search for the second neutrino and to observe the rates of weak interactions at high energies. If the experiment provided evidence for the intermediate boson, so much the better. The proposal was received enthusiastically by the Brookhaven staff and in collaboration our two groups began setting up the experiment with the support of the Atomic Energy Commission. Associated with Schwartz, Steinberger and me in the experiment were Gordon T. Danby of the Brookhaven accelerator department, two Columbia graduate assistants, Konstantin Goulianos and Nariman Mistry, and Jean-Marc Gaillard, a visitor from the French high-energy physics laboratory at Saclay.

The search for the second neutrino was based on the following reasoning. The AGS at Brookhaven produces large numbers of high-energy pions. The neutrinos arising from pion decay would be born with muons; therefore they would be of the muon type, if there were really two types. Only a negligible number of neutrinos of the electron type could be produced. (These would arise from a tiny fraction of pions and K mesons that decay into neutrinos and electrons.) The neutrinos would collide with neutrons (and protons), with two possible consequences. If neutrinos were of only one type, they should react with neutrons to produce *equal numbers* of electrons and negative muons. If there were two kinds of neutrinos, the kind generated in our experiment should be unable to produce electrons and we should observe only muons.

Although the experiment was straightforward, considerable effort was required to obtain a suitable pion beam, to provide shielding that would reduce spurious events to an acceptable level and to design and construct a detector for neutrino collisions. Some 18 months elapsed between the initial planning of the experiment and the first runs with all the apparatus in place.

The great Brookhaven synchrotron is 600 feet in diameter. Protons injected into it require several seconds to reach the full energy of 30 billion electron volts (Bev). At full energy the muons produced in pion decay would be so energetic that they would penetrate more shielding than we could provide and spoil our results. Accordingly we selected for the experiment a beam energy of 15 Bev. When protons of this energy are deflected into a target made of beryllium, they produce pions with a broad distribution of energies peaked at about three Bev. A fraction of these pions fall within a 14-degree cone aimed in the direction of our detecting apparatus.

A three-Bev pion will decay, on the average, after traveling 150 meters. The neutrino arising from the decay will continue in the same general direction as its parent. A simple calculation showed that if we provided a full 150 meters for the pions to decay in, the beam would continue to diverge and we would get fewer neutrinos through our detector than if we placed the detector closer to the target. It turned out, in view of the required shielding, that a flight path of about 20 meters was optimum. In



SINGLE MUON TRACKS were photographed in the 10-ton spark chamber at

this distance about 10 per cent of the pions decay, sending their muons and neutrinos forward. The last, together with the remaining pions, crash into the main shielding wall: 13.5 meters of steel armor plate from an old battleship. The steel wall stops all the particles except the neutrinos, which penetrate the wall as if it were not there. The pions and other strongly interacting particles penetrate only about a foot before being stopped. The muons, which "feel" only the electric force of the electrons in the iron atoms, penetrate farther before all of their energy is removed. The thickness of the shield was actually dictated by the necessity of stopping these highly penetrating particles.

In its early stages the experiment was plagued by leaks, mostly of particles that would pass under or over the steel wall and then be deflected into the detector. Thanks, however, to the zeal of the AGS staff under Kenneth Green, the sources of the background were eventually located and suppressed. This involved stacking hundreds of tons of rusty armor plate within inches of one of the world's most delicately aligned mechanisms.

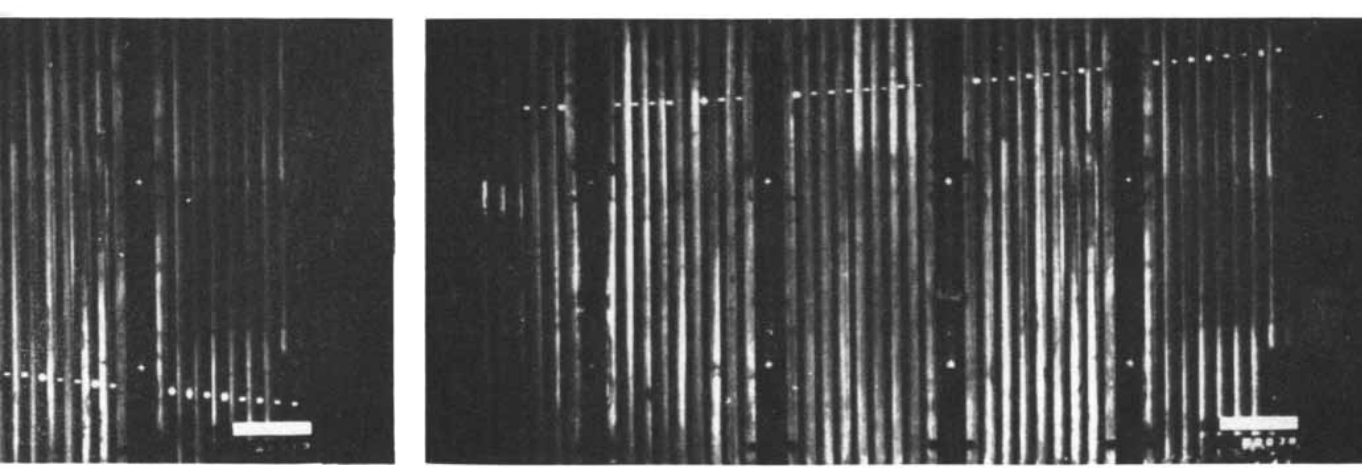
The detector used in our experiment is called a spark chamber, which is quite new to particle physics [see "The Spark Chamber," by Gerard K. O'Neill; SCIENTIFIC AMERICAN, August, 1962]. It is the only detector yet developed that could supply the 10 tons of protons and neutrons required to induce a reasonable number of neutrinos to react. In other words, the number of neutrino events we could hope to observe depended on the number of protons and neutrons that could be packed within the detector itself. Our spark chamber consisted of 90 aluminum plates, each an inch thick and four feet square, arranged in 10 modules of nine plates each. The plates were held three-eighths of an inch apart by spacers made of transparent plastic. The space between the plates was filled with neon gas.

When a charged particle passes through the spark chamber, it leaves in the gas a wake of free electrons, which stay put for many millionths of a second. This period, although brief, is crucial because it allows one to record only selected events. Scintillation counters located both inside and outside the chamber detect the passage of the charged particles. The output of these counters provides information about the events taking place within the chamber. Only if the event is "interesting" is the recording process set in motion. This is done by placing a high voltage on the plates of the chamber. Where particles have left a wake of free electrons, a spark jumps through the neon gas. Cameras photograph the spark tracks through the clear plastic walls, thereby providing a stereoscopic view of the paths taken by charged particles less than a millionth of a second earlier.

In our experiment we were interested in events produced by charged particles that had more than 100 million electron volts (Mev) of energy and that were created *within* the chamber. It was impractical to provide enough shielding to block all cosmic ray muons entering the chamber from the outside. These, of course, were able to activate the triggering counters, arranged as vertical slabs between the 10 modules of the chamber. We established that several hundred cosmic ray muons entered the chamber every second. To avoid photographing so many useless events we placed "anticoincidence" counters on the front, back and roof of the chamber. If any of these counters recorded the passage of a particle immediately before it was sensed by the triggering counters inside the chamber, the command to fire was canceled. Since the bottom and side faces of the chamber could not be monitored in this way, however, the cosmic ray muon count still came to about 80 per second.

The problem was managed by making the durations of the synchrotron-produced radiation as short as possible. The Brookhaven experts were able to generate pulses of radiation that were only three-millionths of a second long. Pulses were repeated at intervals of 1.2 seconds. Most of the cosmic ray background could therefore be eliminated simply by requiring that the synchrotron be "on" when a particle was detected. The entire experiment, which stretched over eight months, consisted of just under two million pulses. This meant the machine was on for only six seconds all told. At a rate of 80 counts per second only about 480 cosmic ray events were recorded in this period, and it was usually easy to establish from the position of the tracks in the photographs which of them had been produced by cosmic rays. Nevertheless, we estimated that about five cosmic rays entered the chamber at such an angle that they were indistinguishable from genuine events. The number of such events that could simulate neutrino collisions was carefully determined by long runs on weekends when the synchrotron was in fact off.

The experiment was run intermittently from September, 1961, until June, 1962. When the synchrotron was well behaved, 10 million neutrinos passed through the spark chamber on each pulse. In a good hour the machine delivered 3,000 pulses, and a good day had 20 good hours. The experiment ran for 25 good days, during which time nearly 10^{14}, or 100 trillion, high-energy neutrinos traveled through the spark cham-



Brookhaven during the two-neutrino experiment. They provide visible evidence of the occurrence of reactions between individual neutrinos and neutrons (or antineutrinos and protons). Electron tracks (*see text*) would have a distinctly different appearance.

ber. This is about the number of low-energy neutrinos from the sun that pass through our bodies every second, producing, perhaps, one reaction in a human lifetime. We had estimated that 10^{14} high-energy neutrinos would yield about 25 reactions.

The counters triggered the chamber about 10 times an hour—about five times the rate anticipated—providing us with some 5,000 photographs. More than half of the pictures were blank; we have never figured out why. We found the expected number of cosmic ray tracks (about 480) and a surprising number of tracks made by muons from the accelerator beam, which had slipped past the anticoincidence guard to trigger the system. When all such nonsignificant events were thrown out, we were left with 51 events that we could attribute to neutrino collisions. Of these, 29 showed the tracks of single muons and 22 showed the tracks of a muon together with one or more tracks produced by a pion or something else.

How could we be sure that the tracks had been produced by muons and not half by muons and half by electrons? Certainty on this point was essential to a decision whether there are two neutrinos or only one. Fortunately electron tracks are readily distinguished from muon tracks. We established the character of electron tracks by exposing two modules of our spark chamber to an electron beam produced by another accelerator. A muon almost always produces a strong track that follows a straight path. An electron track is usually erratic, wandering slightly from side to side. Often the path is marked by several weak sparks, and frequently there are gaps in the track. The neutrino experiment produced only six photographs that might be interpreted as electron showers. All were obtained in the first part of the run, when some neutrons were almost certainly leaking into the spark chamber. It is probable that some of the six events are small "stars" produced by neutrons. One or two could, in fact, be muons. Finally, a few electron events could be expected from electron-type neutrinos created in the decay of K mesons known to be in the pion beam. In short, there was nothing approximating equal production of muons and electrons, as predicted by the "one neutrino" theory.

The conclusion, we think, is quite clear. There are two kinds of neutrino. Those produced by the decay of pions in our experiment are of the muon type and cannot produce electrons by interacting with neutrons. To produce electrons by this reaction one would need neutrinos of the electron type.

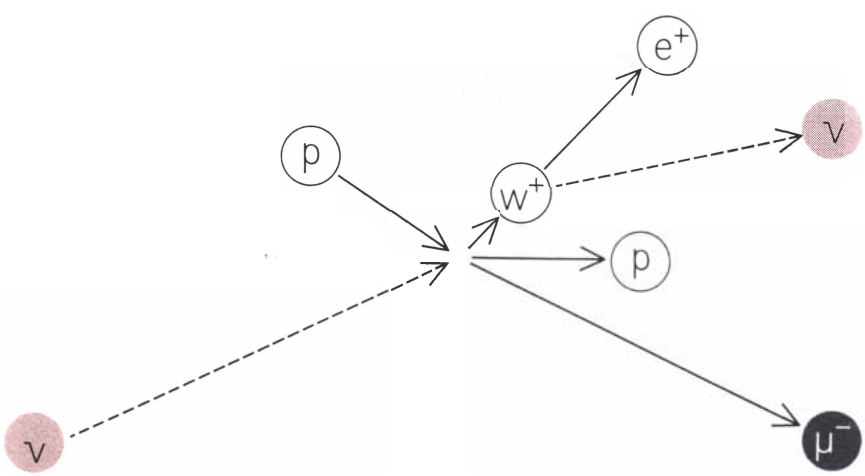
Over and above this particular finding, the Brookhaven experiment proved the feasibility of high-energy neutrino experiments using accelerators of 15 Bev or more. The only accelerators now capable of such experiments are the Brookhaven synchrotron and the similar machine at the European Organization for Nuclear Research (CERN) in Geneva. Investigators at both laboratories (as well as at the Argonne National Laboratory, where a 12-Bev machine is nearing completion) are preparing experiments in which the proton beam will be extracted from the machines to obtain intense pion beams.

The Brookhaven experiment failed to indicate any deviation from the weak-interaction rate predicted by theory. This is probably because our average neutrino energy was still well below that at which the theory predicts a steep rise. The next experiments should be done with particles of considerably higher energy. My associates and I are preparing a new experiment that may reveal whether or not the intermediate boson exists. We plan to look for its signature this fall.

Meanwhile theorists have two neutrinos to play with. The first clear gain of this finding is that a long list of prohibited reactions can now be understood. Neutrinos born with muons are in some way different from neutrinos born with electrons. This difference can be labeled with a new "quantum number"—say M, for muon-ness—which must be conserved. For the positive muon and its neutrino M equals 1. For the negative muon and the antineutrino M equals -1. For all other particles M equals 0. The new quantum number must be conserved in reactions, and this is nothing but a standard way of "explaining" why the unobserved reactions do not occur. The electron and its neutrino have a corresponding quantum number, say N, which must also be conserved.

Until recently physicists asked the question: Why does nature need two particles, the muon and the electron, that are alike in everything but mass? One must now add: Why does nature need a muon-neutrino and an electron-neutrino that may not even have a mass difference? The electron-neutrino's mass is now known to be less than a thousandth the mass of the electron, and it is generally assumed to be zero. Less is known about the muon-neutrino's mass. The best measurements indicate a mass less than seven times the mass of the electron. Should it turn out to be different from zero, the original name "neutretto" would be most appropriate for it.

The puzzle of the two particles may be resolved in two quite different ways. It may turn out that muon-ness conceals a complex inner structure to which present-day experiments are not sensitive. Another possibility, suggested by Lee, is that muon-ness and electron-ness are analogous to the situation presented by electric and magnetic fields. In the 19th century the two fields were regarded as similar but not identical. Albert Einstein's special theory of relativity, presented in 1905, revealed the intimate relation of the two and explained how electric and magnetic fields can be transformed into each other. The theory that will explain how muon-ness transforms into electron-ness may provide another deep clarification of physical thought



"INTERMEDIATE BOSON," if it exists, should be created by the collision of a high-energy neutrino and a proton. Almost instantly it should decay into a positron and a neutrino, although other decay modes are possible. The decay is so rapid that in a spark-chamber photograph the positron should seem to arise at the same point as the negative muon.

Kodak reports on:

movies without entertainment . . . the value of a dollar . . . a big one with a low threshold

Brig. Gen. Webb's assignment

You sway in the Sea Beach Express under Manhattan and note how deeply engrossed is the young woman across the aisle in reading about movie stars. You walk down a side street in a Kansas town in the evening and note how every family in every house sits transfixed before the blue bottle. The motion picture camera has held the people in thrall for a long time now. You have your opinions and impressions of how most professional motion picture cameras are employed. You could be wrong.

Not long ago we announced a new 16mm professional motion picture camera, the KODAK Reflex Special. Embodies 10 years' research and design, we told the movie-makers. They bought. Then we took a look at exactly who they might be. Not entirely the crowd that the careless observer might have guessed—

Cineangioradiographers who make clinical x-ray movies of the great vessels and valves of the heart.

Psychiatrists.

Petroleum engineers.

Sociologists, professional ones.

Surgeons.

Aerospace medical people.

A biologist who shoots 5,000 feet per month of time-lapse motion pictures of tissue cultures, mostly through the oil-immersion microscope objective, and who has opened up dynamic morphology by photographing the mechanism of neoplasia, the functioning of organoids within the living cell, and the structural changes by which it answers physical and chemical changes in its environment.

A physicist, a mathematician, and a few others talked one night at Woods Hole till dawn about the motion picture as a research tool and means of communication between scientists, quite apart from science teaching. They moved the National Academy of Sciences, the National Research Council, and the National Science Foundation. These imposing bodies have correlated their complex functions to seek out the scholar bending a movie camera to his will in some ignored nook of the campus. Their survey has turned up two or three hundred of him.

NSF has granted funds to the National Academy of Sciences to start the American Science Film Association. Brig. Gen. Willard Webb has left the Library of Congress to become administrative director of ASFA. The isolated researcher with a movie camera and the scientifically dead-serious businessman with priceless studies of whales copulating can look to ASFA. It will be able to tell one how others have solved problems he is still struggling with and to help him make contact with colleagues in various parts of the world who want to see *his* footage. He ought to make sure that his name and his interests are on file with American Science Film Association, 704 Seventeenth St. N. W., Washington 6, D. C.

Neither ASFA, NSF, NRC, nor NAS endorses any particular brand name, but we do. In doing so we can answer many pertinent questions about cameras, projectors, film, processing services, and auxiliary equipment for anybody who asks them of Eastman Kodak Company, Motion Picture Film Department, Rochester 4, N. Y.

An interest in silver

To avoid crippling confusion in motivation, one stoutly reaffirms the belief of ages past that one is in business for the money. Today, however, other motivators exhibit their power, and though we still pursue the almighty dollar fiercely, once we have caught it we give little thought to the promise printed on it under President Washington's portrait. It promises silver.

Our house is founded on this truly unique gem of the periodic table. The marvelous behavior of the crystal lattice that it forms with bromine, when properly studded with impurities, makes photography possible; the importance of photography in both the serious and the gay is a major component of the force that attracted over 10^9 almighty dollars into the till last year. (Figuratively. Physically they are only a configuration of magnetized domains on a strip of iron oxide in some vault. Wonderful is the mind of man.)

Silver is drawn from the vault (a different vault) and made into pure $AgNO_3$. The vast bulk of this gets converted to silver halides and moves out on photographic goods. A very few parts per million find their way into bottles carrying the EASTMAN Organic Chemicals label.

Silver Nitrate itself, a fixture of the chemical laboratory since long before the invention of the test tube, still makes news. Only last spring it was revealed that silica impregnated with $AgNO_3$ displays highly selective adsorption with respect to the geometry and number of C=C's in related unsaturated lipids, as detailed for chromatographic practice in *Chemistry and Industry*, June 16 and July 7, 1962. Last year also $AgNO_3$-Dichromate spray reagent was proposed for mercapturic acids and S-phenylcysteines (*J.C.S., 1962*, 608). $AgNO_3$ paper detects and fixes volatile As and Sb hydrides (*Chim. Anal.*, 43, 441). $AgNO_3$ is needed in the complexometric titration of K, Li, and Rb (*Mikrochim. Acta, 1961*, 644, 729, 732).

We also offer Silver Nitrite, Silver Arsenate, Silver Carbonate, Acetic Acid Silver Salt (*aren't we silly in our nomenclature!*), Silver Cyanate, p-Toluenesulfonic Acid Silver Salt, *numerous reagents* for *silver, and an invitation to all chemists interested in silver to keep in touch with* EASTMAN *Organic Chemicals Department, Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).*

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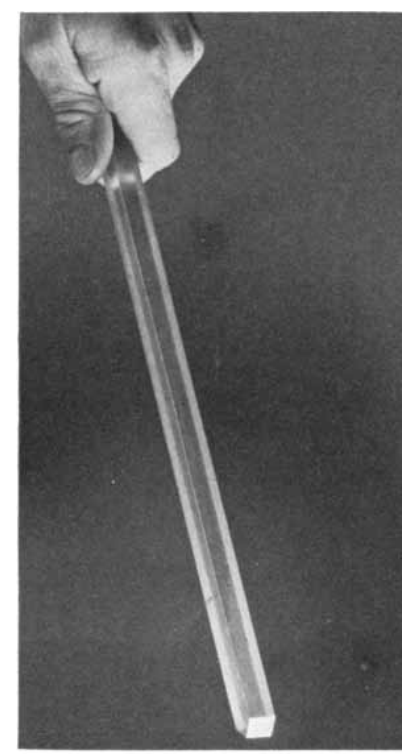
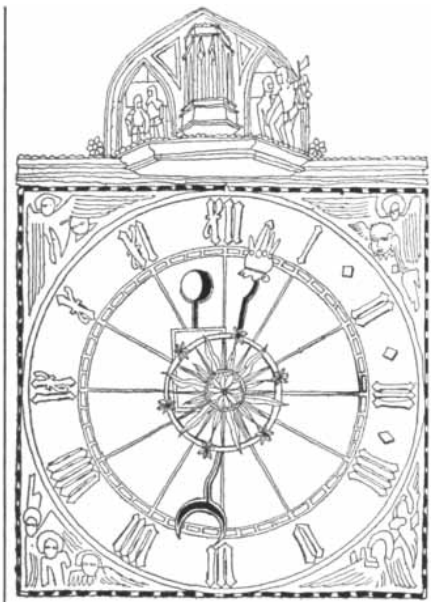


We can make laser rods big because we make them out of glass. A big piece of homogeneous glass is far more likely than a big homogeneous crystal. Homogeneity and long experience in precision prism-polishing help keep beam divergence small. The problem with glass has been threshold. Fortunately, with non-silicate glass it's no problem. Low, low, low. Inquiries about KODAK Neodymium Glass Laser Rods welcomed by Eastman Kodak Company, Apparatus and Optical Division, Rochester 4, N. Y. (Phone 716-562-6000, Ext. 5166).

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



SCIENCE AND

Nuclear Politics

A new note of hope was injected into the nuclear testing negotiations in January by Soviet acceptance of the principle of on-site inspection. But the concession failed to bring quick agreement, and no early break in the long impasse seemed likely. At the same time both the U.S. and the U.S.S.R. were troubled by nuclear-weapons controversies within their respective alliances; the nuclear ambitions of France and Communist China were likely to complicate any progress at Geneva toward a ban on nuclear testing.

Ever since the beginning of the negotiations in 1958 the U.S. and Great Britain have insisted on inspection of suspicious seismic events to guard against the possibility of secret underground testing. At first the U.S.S.R. agreed, but since November, 1961, Soviet representatives have refused to discuss the issue, arguing that inspection was merely an excuse for espionage. Last December, during a recess in the Geneva disarmament talks, Premier Khrushchev conceded the point. In a letter to President Kennedy he said the U.S.S.R. would allow two or three inspections a year. He also confirmed the Soviet offer, made at Geneva last fall, to permit the installation of three automatic seismic stations ("black boxes") in regions of the U.S.S.R. where earthquakes occur frequently. These would be inspected periodically by an international commission for evidence of testing.

President Kennedy welcomed Premier Khrushchev's proposals but said that three inspections would not be enough. He added, however, that although the U.S. had originally demanded between 12 and 20 a year, it might now settle for eight to 10. There was a feeling of optimism as representatives of the U.S., Great Britain and the U.S.S.R. met in New York and Washington in January to pursue the matter. President Kennedy ordered a temporary suspension of underground testing and there were hints that a compromise should be possible between three and eight inspections.

Early in February, however, the Soviet representatives broke off the meetings, because, *Pravda* reported, the U.S. and Great Britain had "no intention" of ending tests. The Russians apparently objected to U.S. insistence on discussing details of the inspection system before agreeing to a specific number of inspections. The U.S. resumed underground testing and the issue was returned to the 18-nation disarmament conference at Geneva, where the U.S.S.R. expected that its concession on inspection would attract neutral support and bring pressure on the Anglo-U.S. delegates.

Nuclear power-politics was being played within each of the two great blocs as well as between them. The U.S., having got Great Britain to accept the submarine-based Polaris missile system instead of the Skybolt air-to-ground missile, hopes to make the Polaris the basis of an eventual NATO nuclear force that will forestall the development of more national nuclear forces. Turkey and Italy appeared to be willing to accept Polaris submarines in the Mediterranean Sea as a substitute for U.S. intermediate-range missiles now based on their territory. But France turned down Polaris and announced it would have its own nuclear striking force by the end of the year. On the Communist side, Moscow was reported to have withdrawn from China the Soviet technicians who had been helping to develop nuclear weapons. China was nonetheless expected to have its first atomic devices ready for testing within the year.

Oldest Solids

A small collection of pea-sized stony bodies called chondrules, separated from a meteorite that fell in Canada in 1960, may be a sample of the oldest solid matter in the solar system. Tests

performed by Craig M. Merrihue, a graduate student at the University of California at Berkeley, suggest that the chondrules materialized before the earth and the other planets and only some 35 million years after the formation of the elements that make up the solar system.

According to the current theory of the origin of the solar system, the sun and the solid bodies that orbit it formed from a gaseous mixture of hydrogen and heavier elements. Radioactive-dating studies indicate that stony meteorites, the earth and presumably the other planets all materialized at about the same time: some 4.6 billion years ago. Obviously the mixture of elements came into existence earlier. The theory holds that the heavier elements were made by the "cooking" of hydrogen in the interior of stars; the primordial cloud that gave rise to the solar system consisted of hydrogen and heavier elements spewed out by exploding stars. In 1960 John H. Reynolds of the University of California at Berkeley found a way to go back beyond the formation of the solar system to date the birth of its elements.

Reynolds' "clock" was iodine 129, a radioactive isotope formed with the other elements but no longer present in nature because of its short half life of 17 million years. Iodine 129 decays into xenon 129, an isotope of the noble gas. Until the meteorites formed, the xenon 129 produced by the decay of iodine 129 was dissipated in space, but any iodine 129 that was still around when the meteorites materialized would have been trapped in their minerals. The iodine 129 would reveal itself as an excess of xenon 129 over the normal ratio of this isotope to the other xenon isotopes. Reynolds measured the content in meteorites of xenon 129 and thereby learned how much iodine 129 had been incorporated in the meteorites. He measured the content of stable iodine 127 and learned how much iodine 129 must have been formed in the stars. Calculations based on these quantities and on iodine 129's half life told him how much the iodine clock had "run down" between element formation and meteorite formation. Reynolds concluded that this "formation interval" was about 100 million years. The elements, in other words, must have been formed about 4.7 billion years ago.

Merrihue, a student of Reynolds', un-

dertook to examine this 100-million-year interval. In a study described in the *Journal of Geophysical Research* he investigated the occurrence of xenon 129 in the Canadian meteorite, called Bruderheim. He determined a formation interval, based on the meteorite as a whole, of about 35 million years—substantially less than in the case of other meteorites. Then he discovered that the chondrules contained considerably more xenon 129 than the rest of the meteorite. This implies that they were formed at a time when there was considerably more iodine 129 available than when the other meteoritic minerals materialized. It conflicts with the prevalent view that chondrules are the result of volcanic activity within the meteorites' parent bodies. Merrihue is now trying to determine specific formation intervals for the chondrules and for other minerals in Bruderheim in an effort to understand the sequence of events during its formation. His preliminary findings suggest that chondrules, which are found in most stony meteorites, may have been the first solid objects to materialize in the primordial cloud from which the solar system evolved.

Upper-Air Pollution

Large quantities of exhaust gases spewed into the upper atmosphere by the giant space rockets of the future may have a deleterious effect on long-range radio communications and even on global weather patterns. This note of warning was sounded recently in a report prepared for the Department of Defense by the Geophysics Corporation of America. The Bedford, Mass., research firm has spent most of the past year studying the changes that might occur in the upper atmosphere as a result of the large-scale deposition of rocket-exhaust substances.

The study was prompted by the imminent appearance on the scene of the new superbooster rockets currently being developed for manned exploration of the solar system. The 12-million-pound-thrust Nova rocket, which will take off carrying more than 2,000 tons of fuel, will release upward of several hundred tons of exhaust substances in the upper atmosphere. According to the latest estimate of the "holdup time" of radioactive fallout in the upper atmosphere, the exhaust substances of a Nova rocket can be expected to remain aloft for a considerable period.

The problem is magnified by the fact that the commonest exhaust products of liquid-fuel rockets—hydrogen, water and carbon monoxide—are extremely rare in the upper atmosphere. The addition of a mere 25,000 tons of hydrogen could filter out much of the sun's ultraviolet radiation, thereby decreasing the electron density of the lower ionosphere enough to interfere with the radio signals regularly bounced off this layer.

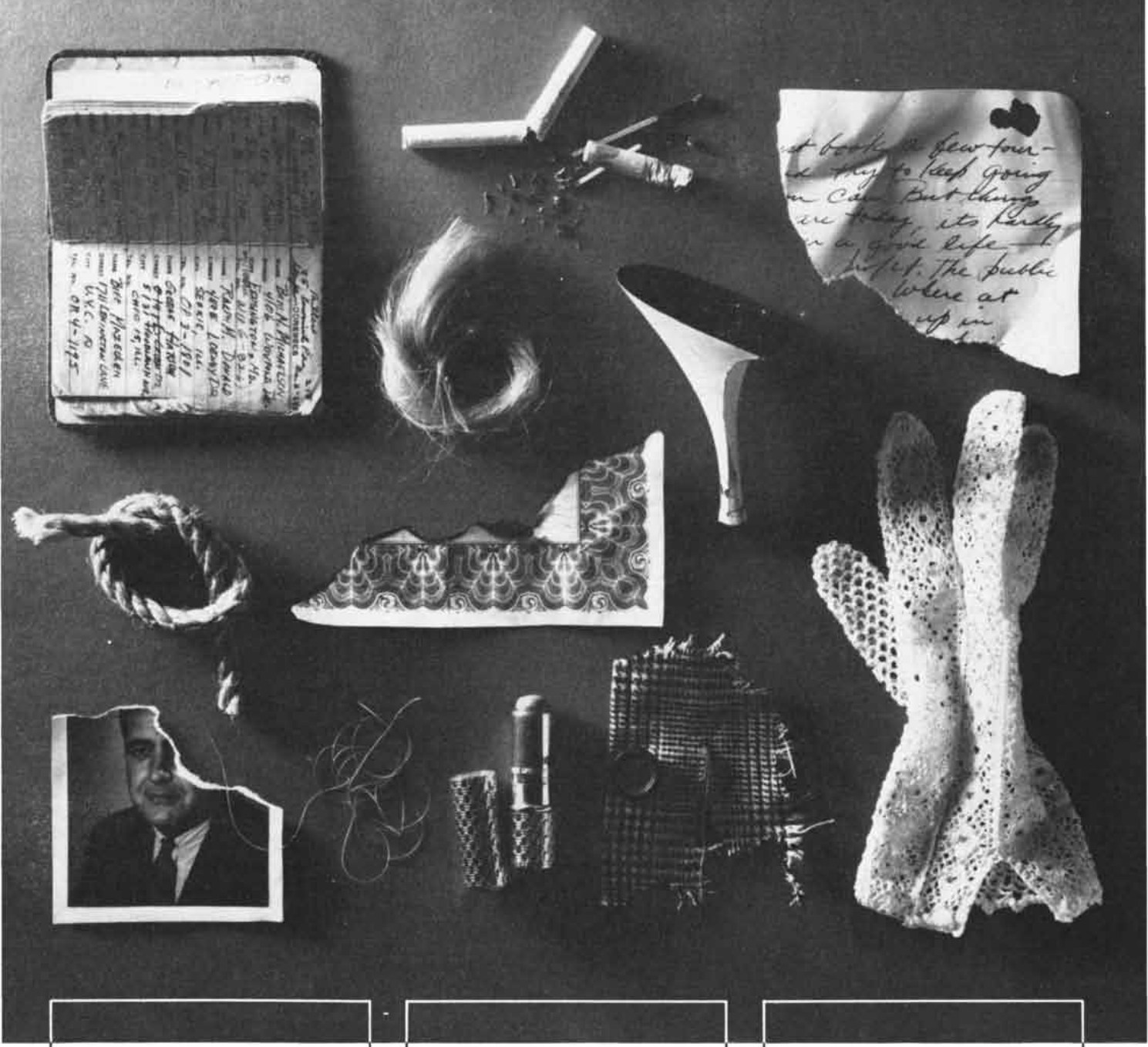
Other effects specified in the report include changes in the composition, structure and temperature of the upper atmosphere—all of which could materially alter the earth's climate. In addition, chemical contaminants could cause the night skies to glow with the brightness of a faint aurora.

The increased use of solid-fuel rockets and the development of new exotic fuel combinations may pose even more troublesome contamination problems in the more distant future. Small amounts of aluminum, zirconium and other metals used as additives in solid-fuel rockets may, in the words of the report, "be able to cause strong perturbations" in the upper atmosphere.

Polarized Protons

A high percentage of polarization—alignment of proton spin axes—has been achieved for the first time in a target suitable for use with a high-energy particle accelerator. Together with a polarized beam of particles from the accelerator, this makes possible a number of important experiments that could not be done before. The new trick was turned by Owen Chamberlain and a group of colleagues at the Lawrence Radiation Laboratory of the University of California at Berkeley, who reported their work at the January meeting of the American Physical Society in New York City.

Previous attempts to line up protons in targets had failed because the proton is weakly magnetized and easily thrown out of line by thermal vibrations. Brute-force methods—cooling the material to within 1 degree of absolute zero and placing it in magnetic fields as strong as 20,000 oersteds—produced only about one-tenth of 1 per cent polarization. Chamberlain's group adopted a method invented by Carson D. Jeffries of the University of California at Berkeley and applied by him to very small samples. Jeffries used rare-earth ions that are 700 times more strongly magnetic than protons. They become highly polarized in available magnetic fields at 1 degree above absolute zero. By making rare-earth crystals that incorporated a good deal of water he placed the protons and ions in close proximity. Then he fed in radio microwaves that transferred



MATERIAL WITNESSES FOR THE PROSECUTION

A piece of cloth becomes an informer, a blot of ink a formidable witness for the state. Paper, paint, plastics, materials of all kinds become hard-to-discredit evidence when analyzed by spectrometry. Through infrared analysis, for example, the geographic origin of narcotics can be pinpointed by analyzing trace impurities in the parts per million range. Perkin-Elmer has developed highly precise electronic-optical systems that measure and record radiations as they interact with different levels of electron energy. The data recorded leads to extremely accurate qualitative, elemental, functional and structural analyses. Infrared and ultraviolet spectrophotometers are examples of Perkin-Elmer's dedication to the development of techniques and instruments for precise measurement for industry, science and defense. The Perkin-Elmer Corporation, Norwalk, Connecticut.

PERKIN-ELMER

the ions' polarization to the protons.

The Berkeley physicists have found a way to scale up Jeffries' 200-milligram experiment to samples weighing an ounce and large enough to scatter a significant fraction of an accelerator beam. In doing so they had to increase the cooling and microwave power more than 100-fold. Polarization of 20 per cent has already been accomplished, and refinements in the technique are expected to push the figure even higher. (Twenty per cent polarization means that 60 per cent of the protons are pointing in one direction and 40 per cent in the opposite direction.)

In some of the first experiments on polarized targets the Lawrence Laboratory group will subject them to beams of particles polarized parallel and antiparallel to the target material and measure the scattering of the particles. Beams of pi mesons and protons will be used. Such experiments will bring out the effects of spin on the attractive force between mesons and protons and between protons and protons. Later the polarized targets will help in measuring intrinsic properties, such as angular momentum and parity, of short-lived nuclear particles.

Source of the Third RNA

The site of manufacture of all three forms of RNA (ribonucleic acid) essential to the synthesis of proteins has now been established. As Marshall W. Nirenberg explains in his article beginning on page 80, the three forms are messenger RNA, ribosomal RNA and transfer RNA. The first provides a direct transcription of the genetic code in the hereditary material DNA (deoxyribonucleic acid), so that its site of synthesis has been known since its discovery in 1960. The second form is a component of ribosomes, the particles that provide a support for messenger RNA during protein synthesis. It was shown last year that DNA is also the primary site for the manufacture of this form of RNA. Now Howard M. Goodman and Alexander Rich of the Massachusetts Institute of Technology have established that the third form, transfer RNA, similarly arises from DNA. There are at least 20 different kinds of transfer RNA molecule, each capable of "recognizing" and conveying to the ribosome one of the 20 kinds of amino acid from which proteins are synthesized.

It can be shown that RNA molecules will hybridize, or bond together, with DNA molecules if the bases, or coding units, in the two molecular species have a complementary sequence. Working with transfer RNA and DNA obtained from several kinds of bacteria, the M.I.T. investigators showed that about .025 per cent of the DNA will hybridize with transfer RNA molecules. This implies that a sequence of coding units representing a single gene in the DNA molecule will provide sites for the synthesis of about 40 transfer RNA molecules, each different. This is twice the minimum number required for recognizing the 20 amino acids. Presumably each of the 40 transfer RNA's responds to a different code word in the messenger RNA that directs the placement of amino acids in a protein chain. Such an assumption is consistent with the finding, reported in the article by Nirenberg, that many of the amino acids are represented by more than one code word. A simple analogy would be to imagine a restaurant that served 20 different dishes, each listed on the menu in several languages. If a dish were ordered in French, it would be served by a French waiter; if ordered in Italian, by an Italian waiter, and so on. Why the cell needs a variety of "waiters" to serve amino acids to the ribosome is still to be discovered.

The Start of the Pleistocene

Cores from the bottom of the Atlantic and Indian oceans have provided the first tangible evidence of the end of the Pliocene epoch and the beginning of the Pleistocene. The boundary is marked by an abrupt change in fossil fauna from warm-water to cold-water species and apparently records the onset of the first ice age of the Pleistocene, according to a report in *Science* by David B. Ericson, Maurice Ewing and Goesta Wollin of Columbia University's Lamont Geological Observatory. They point out that geologists and anthropologists have long sought a way to measure the duration of the Pleistocene, the epoch during which man evolved from some lower primate, but continental deposits have provided only a discontinuous and garbled record. In attacking the problem by taking cores of oceanic sediments, geologists have been hampered by the fact that cores providing a continuous record have not reached as deep as the beginning of the Pleistocene; other cores, while penetrating much deeper, have done so only because upper layers, including the Pleistocene, have slumped away in submarine landslides. The problem has been to find cores taken in areas where only the uppermost layers of sediment have

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slumped away and the cores can bring up a clear record including the beginning of the Pleistocene.

Among the 3,000 cores collected by Lamont the authors finally found eight containing a nearly identical series of changes in layers dating from about the same age. The changes included the disappearance of all discoasters, tiny star-shaped shells probably secreted by an extinct order of algae. Among the Foraminifera, marine protozoa whose shells constitute much of the sediments in wide areas of the ocean bottom, one conspicuous species disappeared completely and a species prominent throughout the Pleistocene appeared for the first time. Below the boundary 95 per cent of the spiral shells of one foraminifer, *Globorotalia menardii,* coil to the right; above the boundary 95 per cent coil to the left.

These sudden breaks in the evolutionary record are confined to sediment layers representing the passage of no more than 6,000 years and therefore reflect an abrupt and massive change in the marine environment. The Lamont workers believe that this was the same climatic change that brought the first continental ice sheets of the Pleistocene. The beginning of the Pleistocene has previously been estimated at anywhere from millions of years ago to as recently as 300,000 years. Judging by known rates of accumulation of Pleistocene sediments based on radiocarbon dating, the Lamont investigators now place the date of their boundary—and the age of the Pleistocene—at not less than 800,000 years ago. Because of the world-wide distribution of the fossils that mark the boundary, they expect that further research on new cores will eventually pin down the date more closely.

Supersupernova

According to a new hypothesis, the vast amount of energy radiated into space by "radio galaxies" may originate in gravitational energy released by the collapse and explosion of stars having one million to 10 million times the mass of the sun. The idea, conceived by William A. Fowler and Fred Hoyle at the California Institute of Technology, was presented at the January meeting of the American Physical Society.

As "seen" by radio telescopes, many radio galaxies form a pair of intensely "bright" radio images, between which is sandwiched an optically visible galaxy consisting of billions of stars. The visible galaxy is often separated from the radio-emitting regions by 100,000 light-years or more. Hoyle estimated that to supply the radio energy emitted by a pair of such regions would require the entire thermonuclear output of all the stars in the central galaxy. Obviously the radio regions must be fed energy from another source.

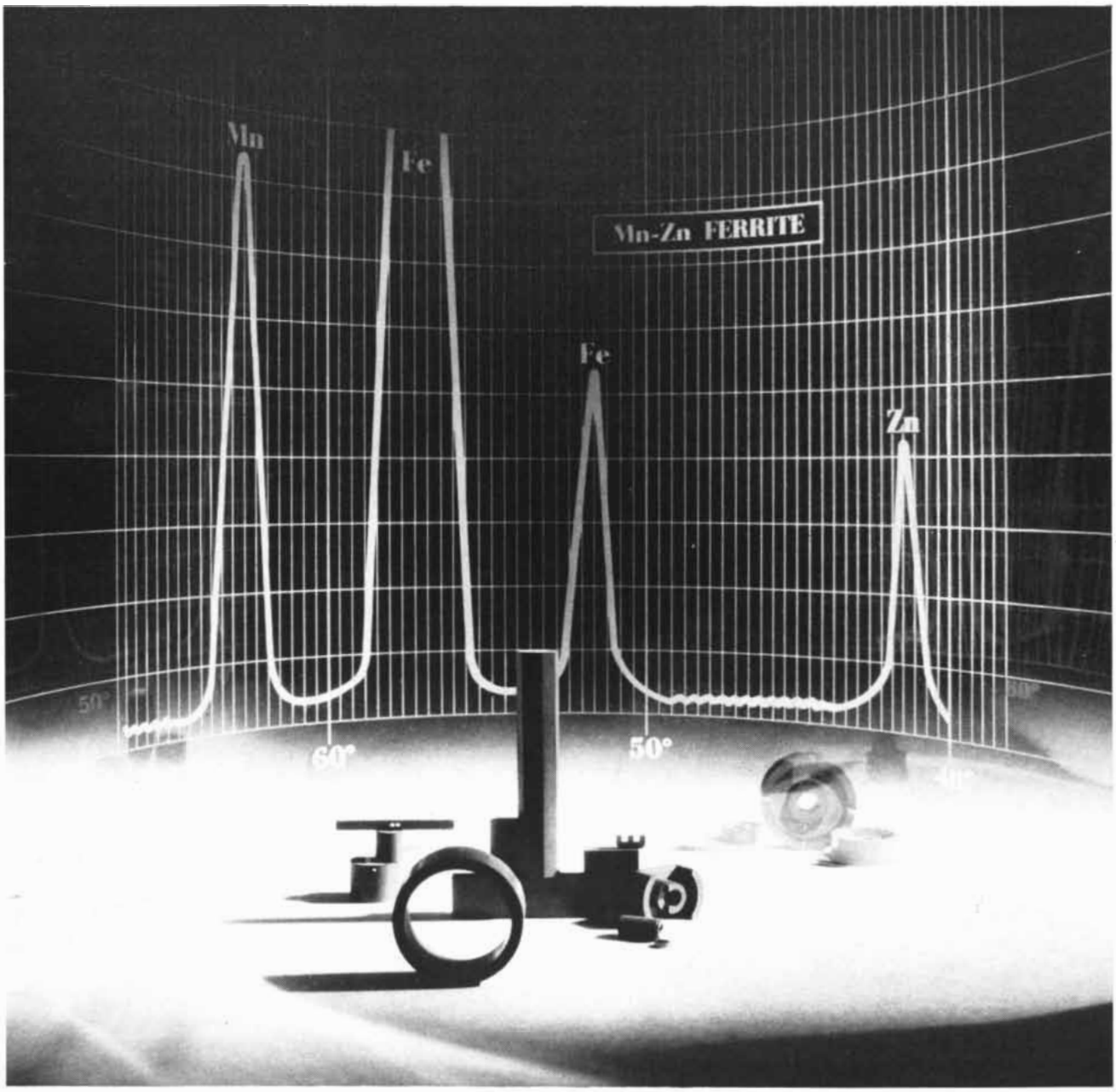
Fowler and Hoyle propose that the gravitational energy of a star far larger than any yet observed could yield the energy required. Such a superstar might form in the spherical nucleus of a galaxy, where vast clouds of gas are available. The star would be so massive that it would collapse with a titanic explosion, comparable to that of a supernova but many times greater. The "supersupernova" would eject astronomical numbers of electrons beyond the edge of the galaxy and into extragalactic space. There they would finally be checked by the magnetic field of the galaxy. Thus trapped they would travel with nearly the speed of light, emitting the enormous volume of radio energy observed as a radio galaxy.

X Rays and the Time of Day

An animal's susceptibility to X rays varies dramatically with the time of day of its exposure, according to a report by three radiologists at the Bowman Gray School of Medicine in Winston-Salem, N.C. They found that rats were very differently affected by the same large dose depending on whether the dose was administered in the morning or at night.

The discovery came during a study of protection against whole-body radiation. The experiment required that test rats be irradiated both in the morning and at night; as a control, a fresh group of rats was also exposed at each X-ray session. The radiologists were surprised to note that the control animals exposed at night died but those exposed in the morning survived. To investigate this phenomenon further, they selected a group of female rats of about the same size, fed them similarly and kept them in a room that was artificially illuminated from 7:00 a.m. until 4:00 p.m. and dark the rest of the day. On each of four occasions five of the rats were given a 900-roentgen dose of X radiation at 9:00 a.m. Another five were irradiated with the same dose at 9:00 p.m. All 20 of the "morning" rats were alive and healthy after 130 days; none of the 20 "evening" rats lived more than 13 days. Donald J. Pizzarello, Richard L. Witcofski and E. Ann Lyons reported in *Science* that they are conducting further experiments in the hope of establishing the mechanism of the effect.

QUALITY. As manufacturing member of the Bell System, Western Electric must produce communications products which meet the highest quality standards. An example is manganese-zinc ferrites (ceramic-like iron compounds) for coils, inductors, and transformers for Bell System and U. S. Government use. Since each ferrite application requires unique chemical composition and magnetic properties, W. E. engineers must analyze and test the ferrite powder to an extremely high degree of precision. X-ray spectrographic analysis is one of the many procedures used. With it, the ferrite material is subjected to X-rays, and the refracted secondary X-rays produce "X-ray fingerprints" or graphs, like the one below. Thus, exact composition can be quickly determined and the mix altered for optimum gain capability and permeability. Just one of the many quality tests employed in the manufacture of ferrites virtually unmatched in industry for reliability of performance. **WESTERN ELECTRIC**



THE GENETIC CODE: II

A sequel to F. H. C. Crick's article of last October, which discussed how the hereditary material embodies the code for the manufacture of proteins. The nature of the code has now been further elucidated

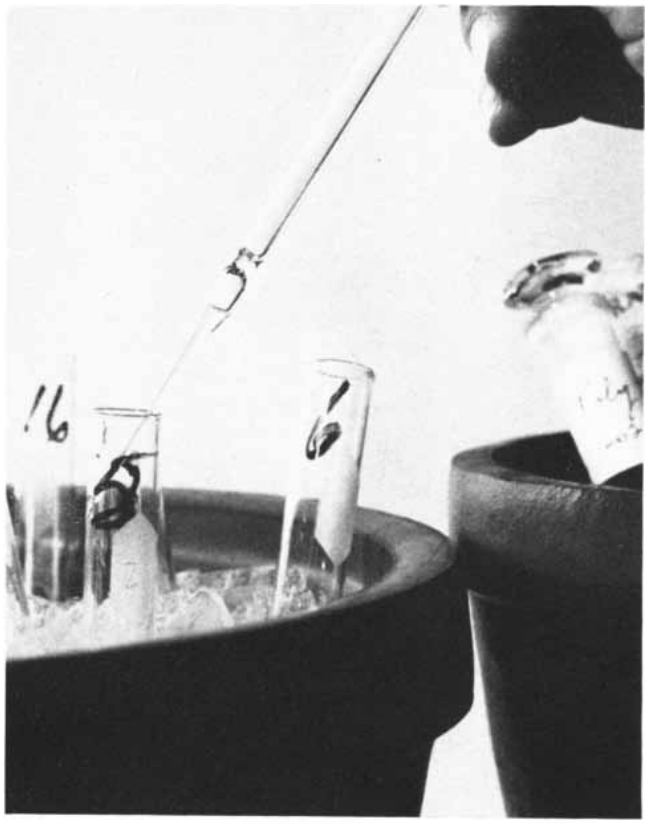
by Marshall W. Nirenberg

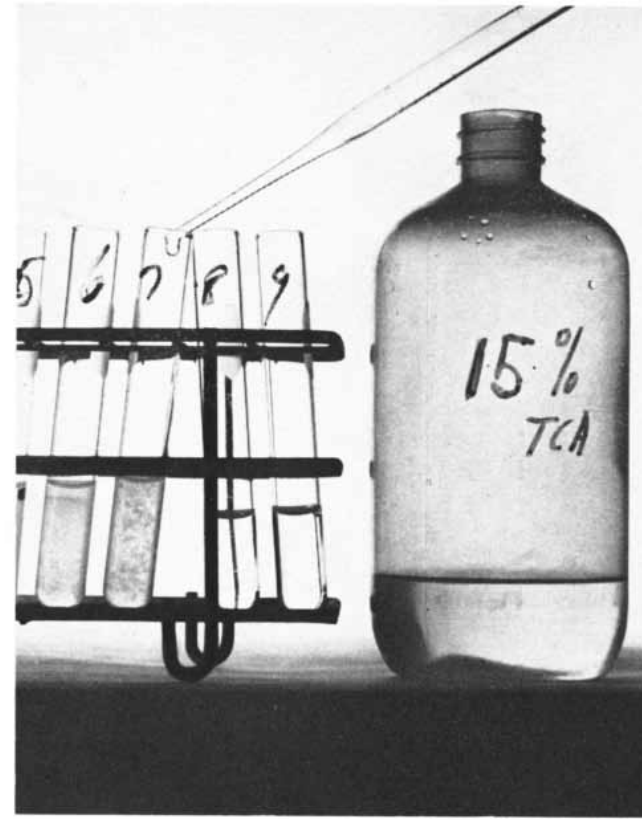
Just 10 years ago James D. Watson and Francis H. C. Crick proposed the now familiar model for the structure of DNA (deoxyribonucleic acid), for which they, together with Maurice H. F. Wilkins, received a Nobel prize last year. DNA is the giant helical molecule that embodies the genetic code of all living organisms. In the October 1962 issue of *Scientific American* Crick described the general nature of this code. By ingenious experiments with bacterial viruses he and his colleagues established that the "letters" in the code are read off in simple sequence and that "words" in the code most probably consist of groups of three letters. The code letters in the DNA molecule are the four bases, or chemical subunits, adenine, guanine, cytosine and thymine, respectively denoted A, G, C and T.

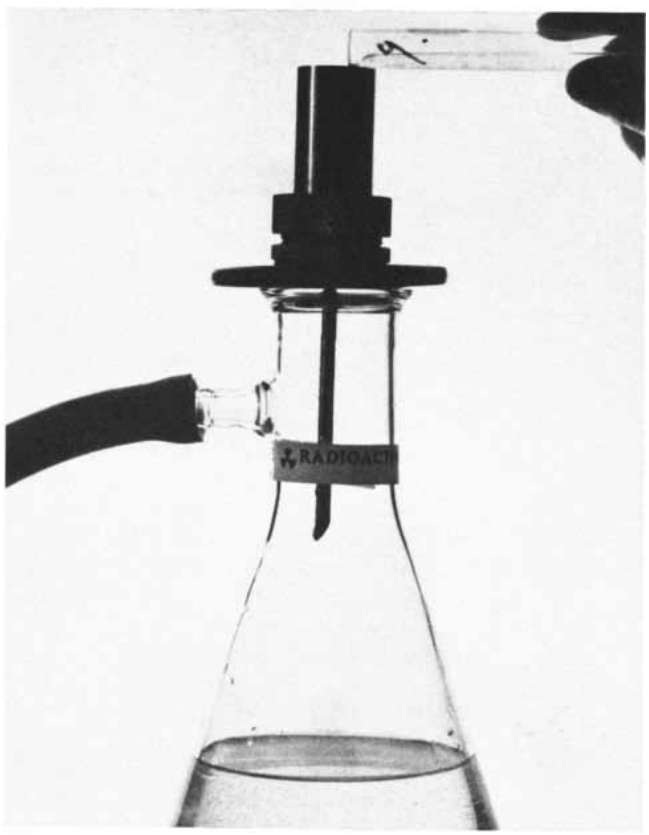
This article describes how various combinations of these bases, or code letters, provide the specific biochemical information used by the cell in the construction of proteins: giant molecules assembled from 20 common kinds of amino acids. Each amino acid subunit is directed to its proper site in the protein chain by a sequence of code letters in the DNA molecule (or molecules) that each organism inherits from its ancestors. It is this DNA that is shaped by evolution. Organisms compete with each other for survival; occasional random changes in their information content, carried by DNA, are sometimes advantageous in this competition. In this way organisms slowly become enriched with instructions facilitating their survival.

EXPERIMENT BEGINS when cells of the colon bacillus are ground in a mortar with finely divided aluminum oxide. "Sap" released from ruptured cells still synthesizes protein.

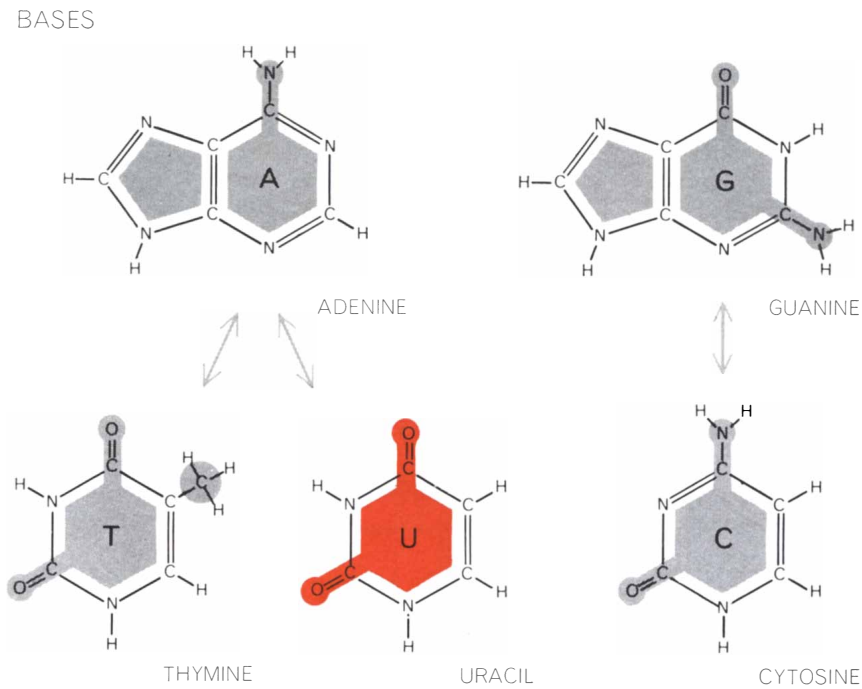
The exact number of proteins required for the functioning of a typical living cell is not known, but it runs to many hundreds. The great majority, if not all, of the proteins act as enzymes, or biological catalysts, which direct the hundreds of different chemical reactions that go on simultaneously within each cell. A typical protein is a molecular chain containing about 200 amino acid subunits linked together in a specific sequence. Each protein usually contains all or most of the 20 different kinds of amino acids. The code for each protein is carried by a single gene, which in turn is a particular region on the linear DNA molecule. To describe a protein containing 200 amino acid subunits a gene must contain at least 200 code words, represented by a sequence of perhaps 600 bases. No one yet knows the complete base sequence for a single gene. Viruses, the smallest structures containing the blueprints for their own replication, may contain from a few to several hundred genes. Bacteria may contain 1,000 genes; a human cell may contain a million. The human genes are not strung together in

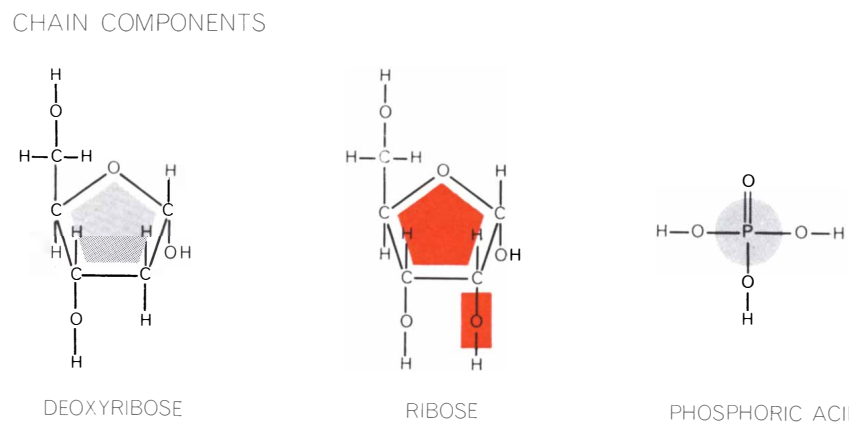




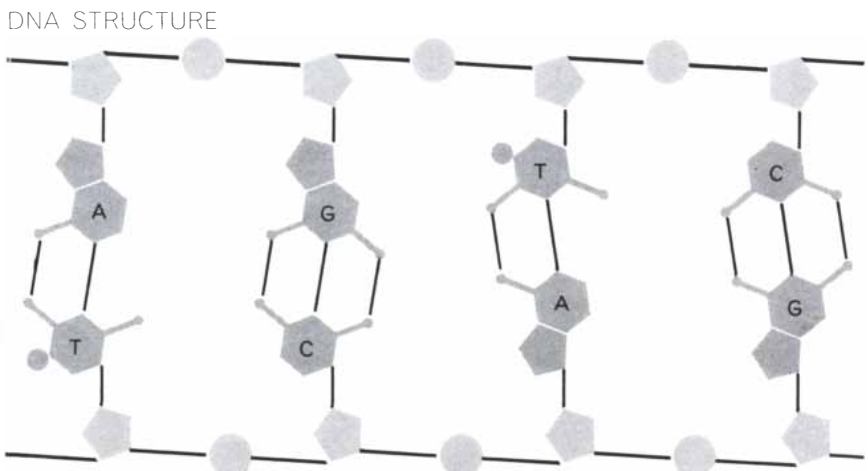


STEPS IN CODE BREAKING are shown in this sequence of photographs taken in the author's laboratory at the National Institutes of Health in Bethesda, Md. The open test tubes at upper left contain samples of the cell-free bacterial system capable of synthesizing protein when properly stimulated. The photograph shows stimulants being added. They include synthetic "messenger RNA" (ribonucleic acid) and amino acids, one of which is radioactive. The protein is produced when the samples are incubated 10 to 90 minutes. At upper right the protein is precipitated by the addition of trichloroacetic acid (TCA). At lower left the precipitate is transferred to filter-paper disks, which will be placed in carriers called planchettes. At lower right the planchettes are stacked in a radiation counting unit. Radiation measurement indicates how well a given sample of messenger RNA has directed amino acids into protein.





COMPONENTS OF DNA (deoxyribonucleic acid) are four bases adenine, guanine, thymine and cytosine (symbolized A, G, T, C), which act as code letters. Other components, deoxyribose and phosphoric acid, form chains to which bases attach (*see below*). In closely related RNA, uracil (U) replaces thymine and ribose replaces deoxyribose.



DNA MOLECULE resembles a chain ladder (actually twisted into a helix) in which pairs of bases join two linear chains constructed from deoxyribose and phosphate subunits. The bases invariably pair so that A links to T and G to C. The genetic code is the sequence of bases as read down one side of the ladder. The deoxyribose-phosphate linkages in the two linear chains run in opposite directions. DNA molecules contain thousands of base pairs.

one long chain but must be divided among at least 46 DNA molecules. The minimum number is set by the number of human chromosomes (46), which collectively carry the hereditary material. In fact, each chromosome apparently carries not one or two but several copies of the same genetic message. If it were possible to assemble the DNA in a single human cell into one continuous thread, it would be about a yard long. This three-foot set of instructions for each individual is produced by the fusion of egg and sperm at conception and must be precisely replicated billions of times as the embryo develops.

The bottom illustration at left shows how the bases in DNA form the cross links connecting two helical strands composed of alternating units of deoxyribose (a simple sugar) and phosphate. The bases are attached to the sugar units and always occur in complementary pairs: A joined to T, and G joined to C. As a result one strand of the DNA molecule, with its associated bases, can serve as the template for creating a second strand that has a complementary set of bases. The faithful replication of genes during cell division evidently depends on such a copying mechanism.

The coding problem centers around the question: How can a four-letter alphabet (the bases A, G, C and T) specify a 20-word dictionary corresponding to the 20 amino acids? In 1954 the theoretical physicist George Gamow, now at the University of Colorado, pointed out that the code words in such a dictionary would have to contain at least three bases. It is obvious that only four code words can be formed if the words are only one letter in length. With two letters 4×4, or 16, code words can be formed. And with three letters $4 \times 4 \times 4$, or 64, code words become available—more than enough to handle the 20-word amino acid dictionary [*see top illustration on page 90*]. Subsequently many suggestions were made as to the nature of the genetic code, but extensive experimental knowledge of the code has been obtained only within the past 18 months.

The Genetic Messenger

It was recognized soon after the formulation of the Watson-Crick model of DNA that DNA itself might not be directly involved in the synthesis of protein, and that a template of RNA (ribonucleic acid) might be an intermediate in the process. Protein synthesis is conducted by cellular particles called ribosomes, which are about half protein and

half RNA (ribosomal RNA). Several years ago Jacques Monod and François Jacob of the Pasteur Institute in Paris coined the term "messenger RNA" to describe the template RNA that carried genetic messages from DNA to the ribosomes.

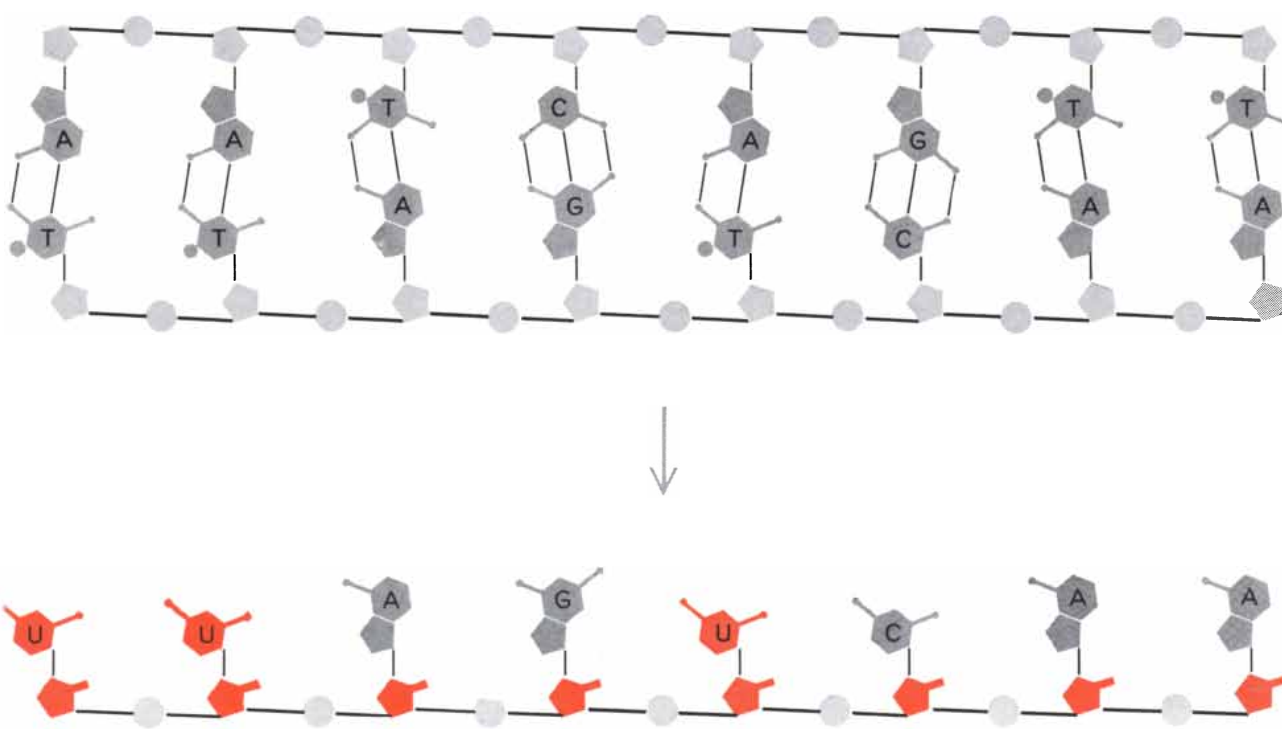
A few years ago evidence for the enzymatic synthesis of RNA complementary to DNA was found by Jerard Hurwitz of the New York University School of Medicine, by Samuel Weiss of the University of Chicago, by Audrey Stevens of St. Louis University and their respective collaborators [see "Messenger RNA," by Jerard Hurwitz and J. J. Furth; SCIENTIFIC AMERICAN, February, 1962]. These groups, and others, showed that an enzyme, RNA polymerase, catalyzes the synthesis of strands of RNA on the pattern of strands of DNA.

RNA is similar to DNA except that RNA contains the sugar ribose instead of deoxyribose and the base uracil instead of thymine. When RNA is being formed on a DNA template, uracil appears in the RNA chain wherever adenine appears at the complementary site on the DNA chain. One fraction of the RNA formed by this process is messenger RNA; it directs the synthesis of protein. Messenger RNA leaves the nucleus of the cell and attaches to the ribosomes. The sequence of bases in the messenger RNA specifies the amino acid sequence in the protein to be synthesized.

The amino acids are transported to the proper sites on the messenger RNA by still another form of RNA called transfer RNA. Each cell contains a specific activating enzyme that attaches a specific amino acid to its particular transfer RNA. Moreover, cells evidently contain more than one kind of transfer RNA capable of recognizing a given amino acid. The significance of this fact will become apparent later. Although direct recognition of messenger RNA code words by transfer RNA molecules has not been demonstrated, it is clear that these molecules perform at least part of the job of placing amino acids in the proper position in the protein chain. When the amino acids arrive at the proper site in the chain, they are linked to each other by enzymic processes that are only partly understood. The linking is accomplished by the formation of a peptide bond: a chemical bond created when a molecule of water is removed from two adjacent molecules of amino acid. The process requires a transfer enzyme, at least one other enzyme and a cofactor: guanosine triphosphate. It appears that amino acid subunits are bonded into the growing protein chain one at a time, starting at the end of the chain carrying an amino group (NH_2) and proceeding toward the end that terminates with a carboxyl group (COOH).

The process of protein synthesis can be studied conveniently in cell-free extracts of the colon bacillus (*Escherichia coli*). The bacteria grow rapidly in suitable nutrients and are harvested by sedimenting them out of suspension with a centrifuge. The cells are gently broken open by grinding them with finely powdered alumina [*see illustration on page 80*]; this releases the cell sap, containing DNA, messenger RNA, ribosomes, enzymes and other components. Such extracts are called cell-free systems, and when they are fortified with energy-rich substances (chiefly adenosine triphosphate), they readily incorporate amino acids into protein. The incorporation process can be followed by using amino acids containing carbon 14, a radioactive isotope of carbon.

Optimal conditions for protein synthesis in bacterial cell-free systems were determined by workers in many laboratories, notably Alfred Tissières of Harvard University, Marvin Lamborg and Paul C. Zamecnik of the Massachusetts General Hospital, G. David Novelli of the Oak Ridge National Laboratory and Sol Spiegelman of the University of Illinois. When we began our work at the National Institutes of Health, our

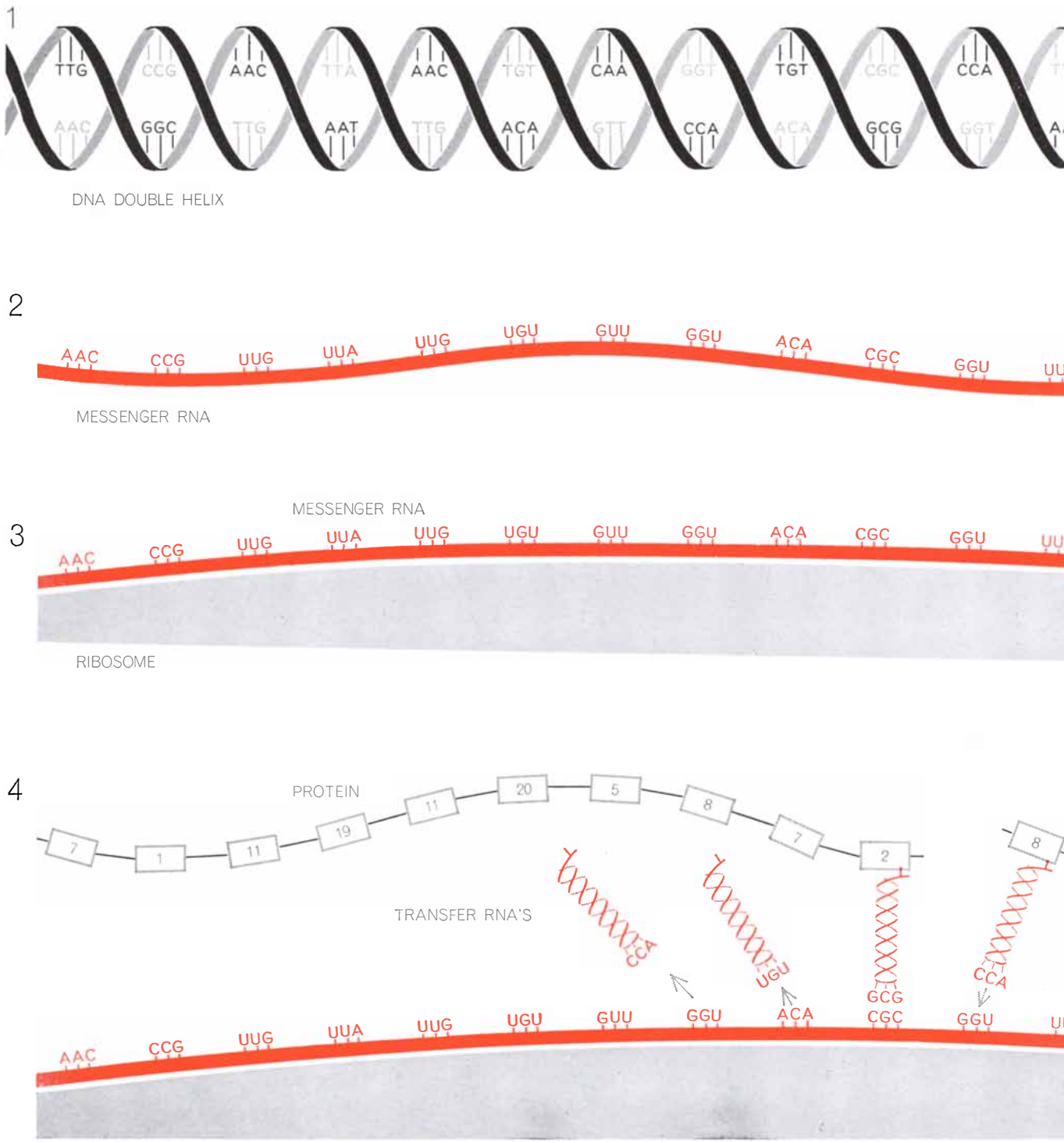


MESSENGER RNA is the molecular agent that transcribes the genetic code from DNA and carries it to the sites in the cell (the ribosomes) where protein synthesis takes place. The letters in messenger RNA are complementary to those in one strand of the DNA molecule. In this example UUAGUCAA is complementary to AATCAGTT. The exact mechanism of transcription is not known.

progress was slow because we had to prepare fresh enzyme extracts for each experiment. Later my colleague J. Heinrich Matthaei and I found a way to stabilize the extracts so that they could be stored for many weeks without appreciable loss of activity.

Normally the proteins produced in such extracts are those specified by the cell's own DNA. If one could establish the base sequence in one of the cell's genes—or part of a gene—and correlate it with the amino acid sequence in the protein coded by that gene, one would be able to translate the genetic code. Although the amino acid sequence is known for a number of proteins, no one has yet determined the base sequence of a gene, hence the correlation cannot be performed.

The study of cell-free protein syn-



SYNTHESIS OF PROTEIN begins with the genetic code embodied in DNA (*1*). The code is transcribed into messenger RNA (*2*). In the diagram it is assumed that the message has been derived from the DNA strand bearing dark letters. The messenger RNA finds its way to a ribosome (*3*), the site of protein synthesis. Amino acids, indicated by numbered rectangles, are carried to proper sites on the messenger RNA by molecules of transfer RNA (*see illustration on opposite page*). Bases are actually equidistant, not

thesis provided an indirect approach to the coding problem. Tissières, Novelli and Bernard Nisman, then at the Pasteur Institute, had reported that protein synthesis could be halted in cell-free extracts by adding deoxyribonuclease, or DNAase, an enzyme that specifically destroys DNA. Matthaei and I also observed this effect and studied its characteristics. It seemed probable that protein synthesis stopped after the messenger RNA had been depleted. When we added crude fractions of messenger RNA to such extracts, we found that they stimulated protein synthesis. The development of this cell-free assay for messenger RNA provided the rationale for all our subsequent work.

We obtained RNA fractions from various natural sources, including viruses, and found that many of them were highly active in directing protein synthesis in the cell-free system of the colon bacillus. The ribosomes of the colon bacillus were found to accept RNA "blueprints" obtained from foreign organisms, including viruses. It should be emphasized that only minute amounts of protein were synthesized in these experiments.

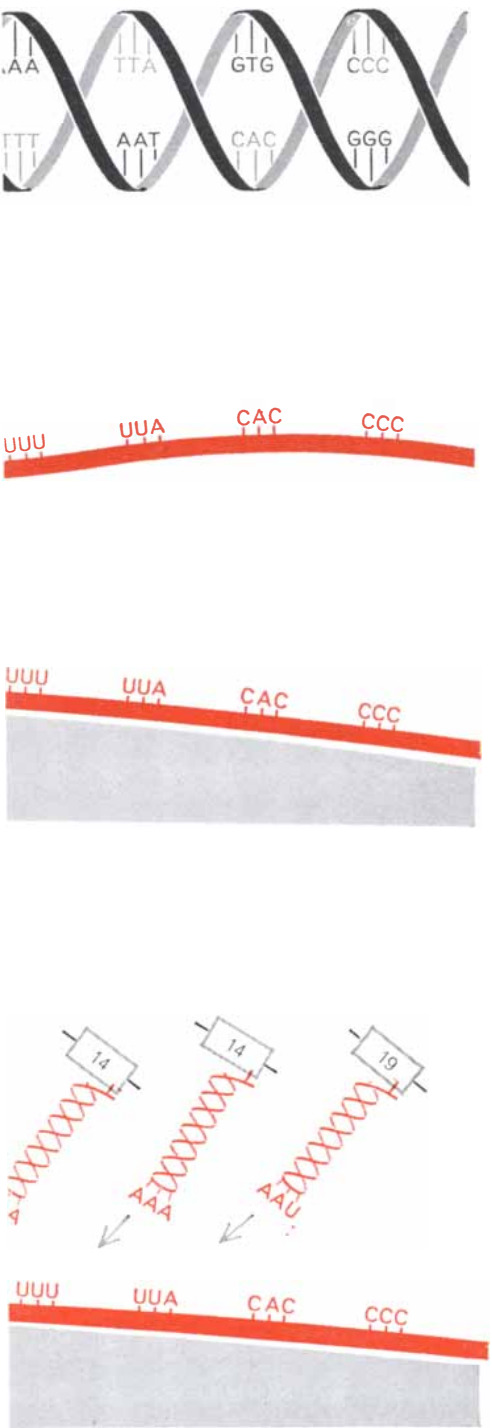
It occurred to us that synthetic RNA containing only one or two bases might direct the synthesis of simple proteins containing only a few amino acids. Synthetic RNA molecules can be prepared with the aid of an enzyme, polynucleotide phosphorylase, found in 1955 by Marianne Grunberg-Manago and Severo Ochoa of the New York University School of Medicine. Unlike RNA polymerase, this enzyme does not follow the pattern of DNA. Instead it forms RNA polymers by linking bases together in random order.

A synthetic RNA polymer containing only uracil (called polyuridylic acid, or poly-U) was prepared and added to the active cell-free system together with mixtures of the 20 amino acids. In each mixture one of the amino acids contained radioactive carbon 14; the other 19 amino acids were nonradioactive. In this way one could determine the particular amino acid directed into protein by poly-U.

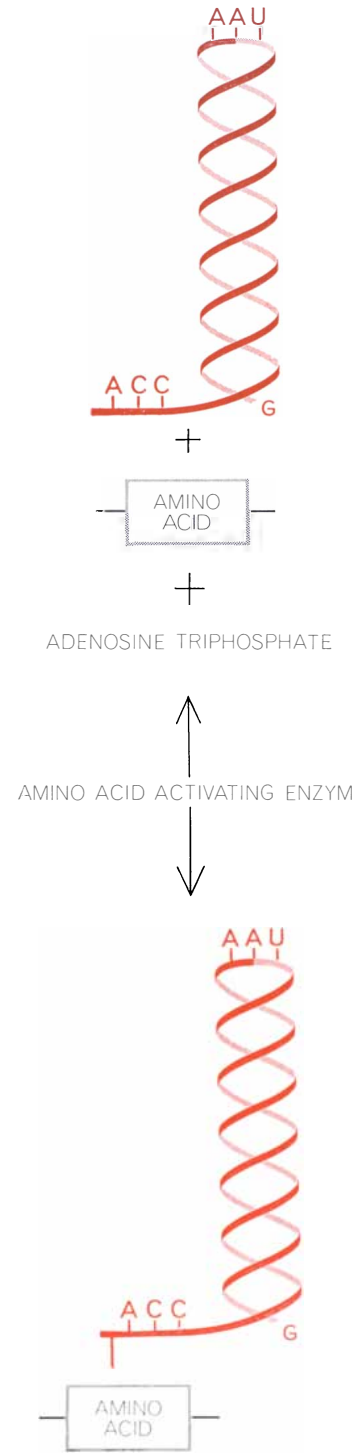
It proved to be the amino acid phenylalanine. This provided evidence that the RNA code word for phenylalanine was a sequence of U's contained in poly-U. The code word for another amino acid, proline, was found to be a sequence of C's in polycytidylic acid, or poly-C. Thus a cell-free system capable of synthesizing protein under the direction of chemically defined preparations of RNA provided a simple means for translating the genetic code.

The Code-Word Dictionary

Ochoa and his collaborators and our group at the National Institutes of



grouped in triplets, and mechanism of recognition between transfer RNA and messenger RNA is hypothetical. Linkage of amino acid subunits creates a protein molecule.



TRANSFER RNA is a special helical form of RNA that transports amino acids to their proper site in the protein chain. There is at least one transfer RNA for each of the 20 common amino acids. All, however, seem to carry the bases ACC where the amino acids attach and G at the opposite end. The attachment requires a specific enzyme and energy supplied by adenosine triphosphate. Unpaired bases in transfer RNA (AAU in the example) may provide the means by which the transfer RNA "recognizes" the place to deposit its amino acid package.

RNA STRUCTURE can take various forms. Transfer RNA (*top*) seems to be a fairly short double helix (probably less perfect than shown) that is closed at one end. Some RNA molecules contain a mixture of coiled and uncoiled regions (*bottom*).

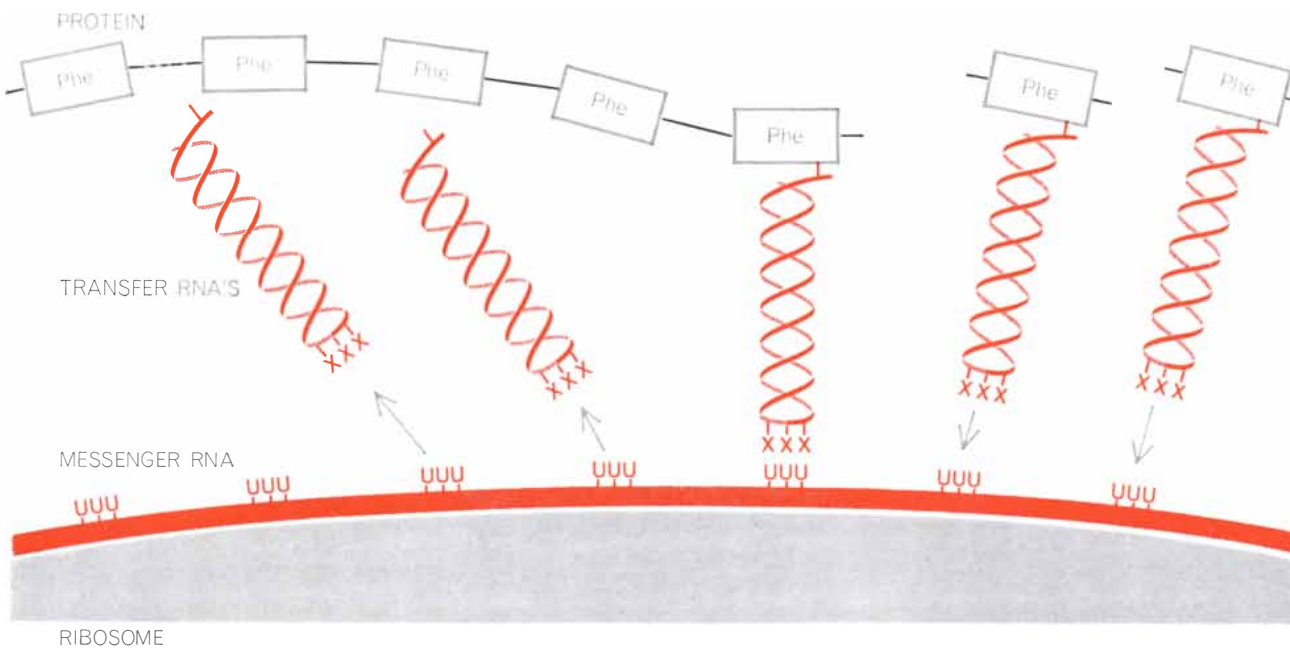
Health, working independently, have now synthesized and tested polymers containing all possible combinations of the four RNA bases A, G, C and U. In the initial experiments only RNA polymers containing U were assayed, but recently many non-U polymers with high template activity have been found by M. Bretscher and Grunberg-Manago of the University of Cambridge, and also by Oliver W. Jones and me. All the results so far are summarized in the table at the bottom of pages 90 and 91. It lists the RNA polymers containing the minimum number of bases capable of stimulating protein formation. The inclusion of another base in a polymer usually enables it to code for additional amino acids.

With only two kinds of base it is possible to make six varieties of RNA polymer: poly-AC, poly-AG, poly-AU, poly-CG, poly-CU and poly-GU. If the ratio of the bases is adjusted with care, each variety can be shown to code with great specificity for different sets of amino acids. The relative amount of one amino acid directed into protein compared with another depends on the ratio of bases in the RNA. Assuming a random sequence of bases in the RNA, the theoretical probabilities of finding particular sequences of two, three or more bases can be calculated easily if the base ratio is known. For example, if poly-UC contains 70 per cent U and 30 per cent C, the probability of the occurrence of the triplet sequence UUU is $.7 \times .7 \times .7$, or .34. That is, 34 per cent of the triplets in the polymer are expected to be UUU. The probability of obtaining the sequence UUC is $.7 \times .7 \times .3$, or .147. Thus 14.7 per cent of the triplets in such a polymer are probably UUC. This type of calculation, however, assumes randomness, and it is not certain that all the actual polymers are truly random.

It had been predicted by Gamow, Crick and others that for each amino acid there might be more than one code word, since there are 64 possible triplets and only 20 amino acids. A code with multiple words for each object coded is termed degenerate. Our experiments show that the genetic code is indeed degenerate. Leucine, for example, is coded by RNA polymers containing U alone, or U and A, or U and C, or U and G.

It must be emphasized that degeneracy of this sort does not imply lack of specificity in the construction of proteins. It means, rather, that a specific amino acid can be directed to the proper site in a protein chain by more than one code word. Presumably this flexibility of coding is advantageous to the cell in ways not yet fully understood.

A molecular explanation of degeneracy has been provided recently in a striking manner. It has been known that some organisms contain more than one species of transfer RNA capable of recognizing a given amino acid. The colon bacillus, for example, contains two readily distinguishable species that transfer leucine. Bernard Weisblum and Seymour Benzer of Purdue University and Robert W. Holley of Cornell University separated the two leucine-transfer species and tested them in cell-free systems. They found that one of the species recognizes poly-UC but not poly-UG. The other species recognizes poly-UG but not poly-UC [*see top illustration on page 89*]. Although the number of transfer RNA species per cell is unknown, it is possible



FIRST BREAK IN GENETIC CODE was the discovery that a synthetic messenger RNA containing only uracil (poly-U) directed the manufacture of a synthetic protein containing only one amino acid, phenylalanine (*Phe*). The finding was made by the author and J. Heinrich Matthaei. The X's in transfer RNA signify that the bases that respond to code words in messenger RNA are not known.

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Did you know that only one in every 140 uranium atoms found in nature can be split to produce usable nuclear energy? It takes fantastically intricate equipment to capture these elusive atoms. The people of Union Carbide are doing it in a plant at Oak Ridge, Tennessee, large enough to hold 35 football fields. ▶ Many people thought the uranium separation process too complex to work. For example, pumps had to be developed that run faster than the speed of sound . . . filters made with holes only two-millionths of an inch across. Union Carbide scientists and engineers not only helped design such a plant and made it work, 20 years ago, but they have been operating it ever since. Union Carbide also operates other vital nuclear energy installations for the U.S. Atomic Energy Commission. One is Oak Ridge National Laboratory, the largest nuclear research center in the country. ▶ To handle such big research and production jobs requires big, experienced industrial companies. It is only because of their extensive resources and skills that it is possible to take the giant steps needed to bring laboratory developments to full-scale production quickly and successfully.

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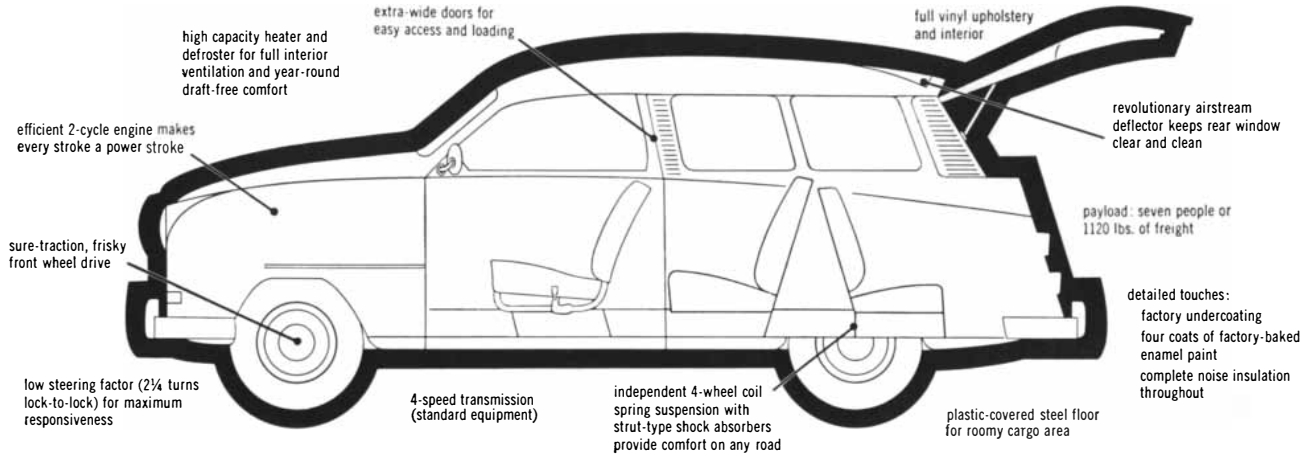

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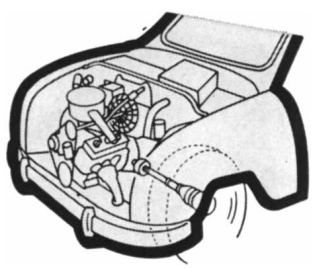

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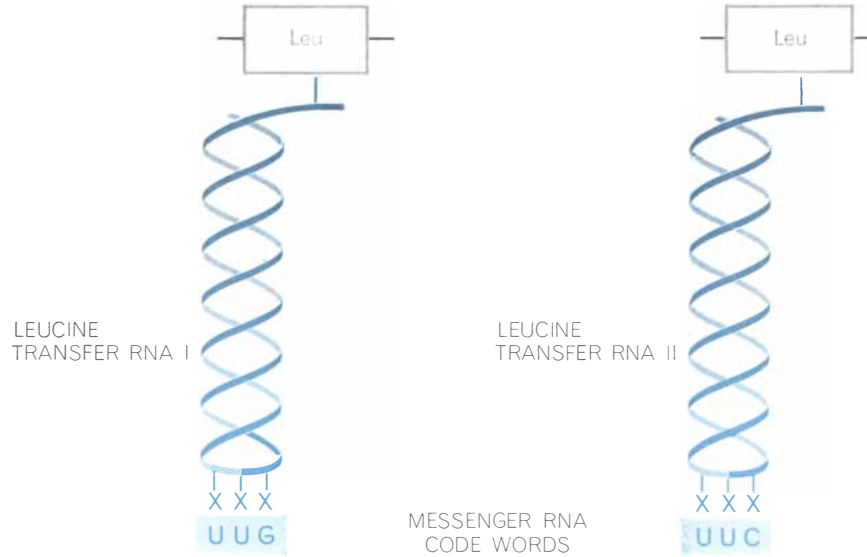
that each species corresponds to a different code word.

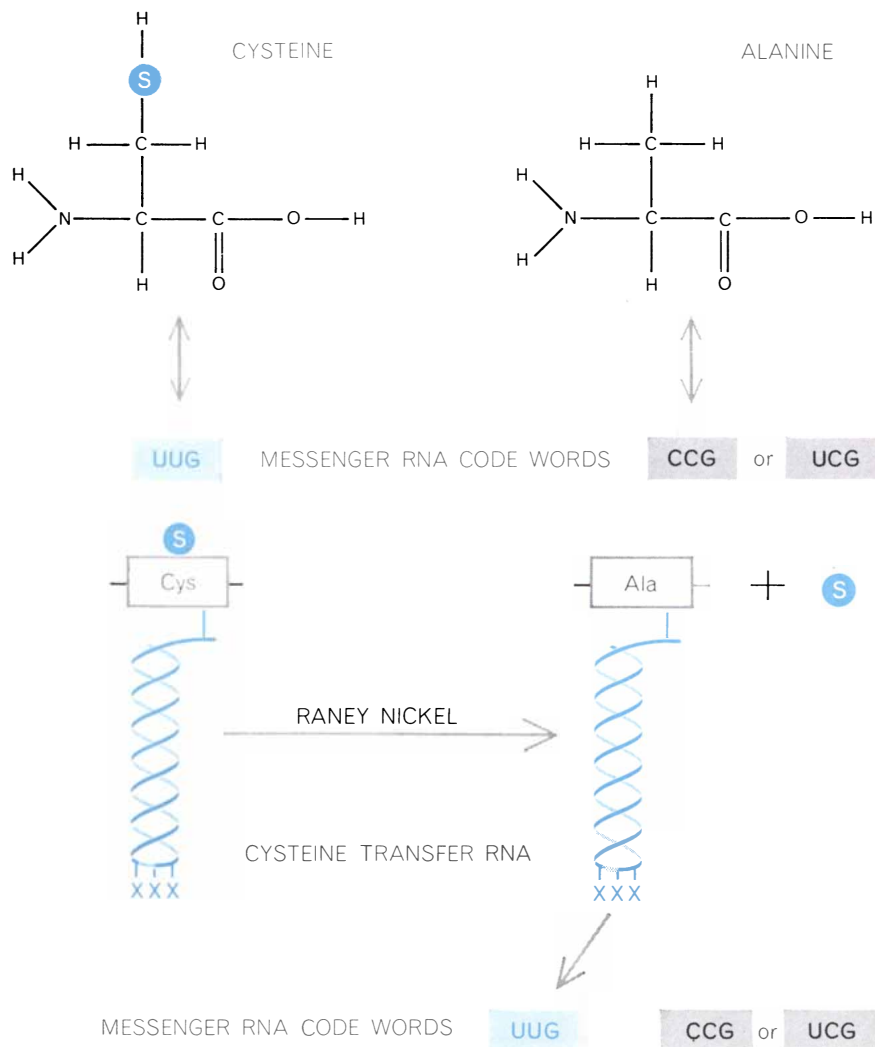
There is, however, the possibility of real ambiguity in protein synthesis. This would occur if one code word were to direct two or more kinds of amino acid into protein. So far only one such ambiguity has been found. Poly-U directs small amounts of leucine as well as phenylalanine into protein. The ratio of the two amino acids incorporated is about 20 or 30 molecules of phenylalanine to one of leucine. In the absence of phenylalanine, poly-U codes for leucine about half as well as it does for phenylalanine. The molecular basis of this ambiguity is not known. Nor is it known if the dual coding occurs in living systems as well as in cell-free systems.

Base sequences that do not encode for any amino acid are termed "nonsense words." This term may be misleading, for such sequences, if they exist, might have meaning to the cell. For example, they might indicate the beginning or end of a portion of the genetic message. An indirect estimate of the frequency of nonsense words can be obtained by comparing the efficiency of random RNA preparations with that of natural messenger RNA. We have found that many of the synthetic polymers containing four, three or two kinds of base are as efficient in stimulating protein synthesis as natural polymers are. This high efficiency, together with high coding specificity, suggests that relatively few base sequences are nonsense words.

In his recent article in *Scientific American* Crick presented arguments for believing that the coding ratio is either three or a multiple of three. Recently we have determined the relative amounts of different amino acids directed into protein by synthetic RNA preparations of known base ratios, and the evidence suggests that some code words almost surely contain three bases. Yet, as the table at the bottom of the next two pages shows, 18 of the 20 amino acids can be coded by words containing only two different bases. The exceptions are aspartic acid and methionine, which seem to require some combination of U, G and A. (Some uncertainty still exists about the code words for these amino acids, because even poly-UGA directs very little aspartic acid or methionine into protein.) If the entire code indeed consists of triplets, it is possible that correct coding is achieved, in some instances, when only two out of the three bases read are recognized. Such imperfect recognition might occur more often with synthetic RNA polymers containing



TWO KINDS OF TRANSFER RNA have been found, each capable of transporting leucine (*Leu*). One kind (*left*) recognizes the code word UUG; the other (*right*) recognizes UUC.



INGENIOUS EXPERIMENT showed that code-word recognition depends on the specificity of transfer RNA, not on the structure of the amino acid being transported. Cysteine is coded by UUG, alanine by CCG or UCG. Cysteine was hooked to its specific transfer RNA and sulfur was removed by a catalyst (Raney nickel). With sulfur removed from the molecule, cysteine became alanine. It was still directed into protein, however, as if it were cysteine.

SINGLET CODE (4 WORDS)	DOUBLET CODE (16 WORDS)				TRIPLET CODE (64 WORDS)			
A	AA	AG	AC	AU	AAA	AAG	AAC	AAU
G	GA	GG	GC	GU	AGA	AGG	AGC	AGU
C	CA	CG	CC	CU	ACA	ACG	ACC	ACU
U	UA	UG	UC	UU	AUA	AUG	AUC	AUU
					GAA	GAG	GAC	GAU
					GGA	GGG	GGC	GGU
					GCA	GCG	GCC	GCU
					GUA	GUG	GUC	GUU
					CAA	CAG	CAC	CAU
					CGA	CGG	CGC	CGU
					CCA	CCG	CCC	CCU
					CUA	CUG	CUC	CUU
					UAA	UAG	UAC	UAU
					UGA	UGG	UGC	UGU
					UCA	UCG	UCC	UCU
					UUA	UUG	UUC	UUU

CODE-LETTER COMBINATIONS increase sharply with the length of the code word. Since at least 20 code words are needed to identify the 20 common amino acids, the minimum code length is a sequence of three letters, assuming that all words are the same length.

only one or two bases than it does with natural messenger RNA, which always contains a mixture of all four. The results obtained with synthetic RNA may demonstrate the coding potential of the cell; that is, it may reveal code words that function routinely in the living cell and potential words that would be recognized if appropriate mutations were to occur in the cellular DNA. The table on page 93 summarizes the code-word dictionary on the assumption that all code words are triplets.

The Universality of the Code

Does each plant or animal species have its own genetic code, or is the same genetic language used by all species on this planet? Preliminary evidence suggests that the code is essentially universal and that even species at opposite ends of the evolutionary scale use much the same code. For instance, a number of laboratories in the U.S. and England have recently reported that synthetic RNA polymers code the same way in mammalian cell-free systems as they do in the bacterial system. The base compositions of mammalian code words corresponding to about six amino acids have been determined so far. It nevertheless seems probable that some differences may be found in the future. Since certain amino acids are coded by multiple words, it is not unlikely that one species may use one word and another species a different one.

An indirect check on the validity of code words obtained in cell-free systems can be made by studying natural proteins that differ in amino acid composition at only one point in the protein chain. For example, the hemoglobin of an individual suffering from "sickle cell" anemia differs from normal hemoglobin in that it has valine at one point in the chain instead of glutamic acid. Another abnormal hemoglobin has lysine at the same point. One might be able to show, by examining the code-word dictionary, that these three amino acids—glutamic acid, valine and lysine—have similar code words. One could then infer that the two abnormal hemoglobins came into being as a result of a mutation that substituted a single base for another in the gene that controls the production of hemoglobin. As a matter of fact, the code-word dictionary shows that the code words are similar enough for this to have happened. One of the code groups for glutamic acid is AGU. Substitution of a U for A produces UGU, the code group for valine. Substitution of an A for a U yields AGA, one of the code groups for lysine. Similar analyses have been made for other proteins in which amino acid substitutions are known, and in most cases the substitutions can be explained by alteration of a single base in code-word triplets. Presumably more code words will be found in the future and the correlation between genetic base sequences and amino acid sequences can be made with greater assurance.

The Nature of Messenger RNA

Does each molecule of messenger RNA function only once or many times in directing the synthesis of protein? The question has proved difficult because most of the poly-U in the experimental system is degraded before it is able to function as a messenger. We have found, nevertheless, that only about 1.5 U's in poly-U are required to direct the incorporation of one molecule of phenylalanine into protein. And George Spyrides and Fritz A. Lipmann of the Rockefeller Institute have reported that only about .75 U's are required per molecule of amino acid in their studies. If the coding is done by triplets, three U's would be

AMINO ACIDS CODED	U	A	C	G
	PHENYLALANINE	LYSINE	PROLINE●	
	LEUCINE■			

■ POLY U CODES PREFERENTIALLY FOR PHENYLALANINE
● REPORTED BY ONLY ONE LABORATORY; STILL TO BE CONFIRMED
▲ REQUIRES ONLY FIRST OF TWO BASES LISTED
▵ REQUIRES ONLY SECOND OF TWO BASES LISTED

SPECIFICITY OF CODING is shown in this table, which lists 18 amino acids that can be coded by synthetic RNA polymers containing no more than one or two kinds of base. The only amino acids that seem to require more than two bases for coding are aspartic acid and methionine, which need U, A and G. The relative amounts of amino acids directed into pro-

required if the messenger functioned only once. Evidently each poly-U molecule directs the synthesis of more than one long-chain molecule of polyphenylalanine. Similar results have been obtained in intact cells. Cyrus Levinthal and his associates at the Massachusetts Institute of Technology inhibited messenger RNA synthesis in living bacteria with the antibiotic actinomycin and found that each messenger RNA molecule present at the time messenger synthesis was turned off directed the synthesis of 10 to 20 molecules of protein.

We have observed that two factors in addition to base sequence have a profound effect on the activity of messenger RNA: the length of the RNA chain and its over-all structure. Poly-U molecules that contain more than 100 U's are much more active than molecules with fewer than 50. Robert G. Martin and Bruce Ames of the National Institutes of Health have found that chains of poly-U containing 450 to 700 U's are optimal for directing protein synthesis.

There is still much to be learned about the effect of structure on RNA function. Unlike DNA, RNA molecules are usually single-stranded. Frequently, however, one part of the RNA molecule loops back and forms hydrogen bonds with another portion of the same molecule. The extent of such internal pairing is influenced by the base sequence in the molecule. When poly-U is in solution, it usually has little secondary structure; that is, it consists of a simple chain with few, if any, loops or knots. Other types of RNA molecules display a considerable amount of secondary structure [*see top illustration on page 86*].

We have found that such a secondary structure interferes with the activity of messenger RNA. When solutions of poly-U and poly-A are mixed, they form double-strand (U-A) and triple-strand (U-A-U) helices, which are completely inactive in directing the synthesis of polyphenylalanine. In collaboration with Maxine F. Singer of the National Institutes of Health we have shown that poly-UG containing a high degree of ordered secondary structure (possibly due to G-G hydrogen-bonding) is unable to code for amino acids.

It is conceivable that natural messenger RNA contains at intervals short regions of secondary structure resembling knots in a rope. These regions might signify the beginning or the end of a protein. Alternative hypotheses suggest that the beginning and end are indicated by particular base sequences in the genetic message. In any case it seems probable that the secondary structure assumed by different types of RNA will be found to have great influence on their biological function.

The Reading Mechanism

Still not completely understood is the manner in which a given amino acid finds its way to the proper site in a protein chain. Although transfer RNA was found to be required for the synthesis of polyphenylalanine, the possibility remained that the amino acid rather than the transfer RNA recognized the code word embodied in the poly-U messenger RNA.

To distinguish between these alternative possibilities, a brilliant experiment was performed jointly by François Chapeville and Lipmann of the Rockefeller Institute, Günter von Ehrenstein of Johns Hopkins University and three Purdue workers: Benzer, Weisblum and William J. Ray, Jr. One amino acid, cysteine, is directed into protein by poly-UG. Alanine, which is identical with cysteine except that it lacks a sulfur atom, is directed into protein by poly-CG or poly-UCG. Cysteine is transported by one species of transfer RNA and alanine by another. Chapeville and his associates enzymatically attached cysteine, labeled with carbon 14, to its particular type of transfer RNA. They then exposed the molecular complex to a nickel catalyst, called Raney nickel, that removed the sulfur from cysteine and converted it to alanine—without detaching it from cysteine-transfer RNA. Now they could ask: Will the labeled alanine be coded as if it were alanine or cysteine? They found it was coded by poly-UG, just as if it were cysteine [*see bottom illustration on page 89*]. This experiment shows that an amino acid loses its identity after combining with transfer RNA and is carried willy-nilly to the code word recognized by the transfer RNA.

The secondary structure of transfer RNA itself has been clarified further this past year by workers at King's College of the University of London. From X-ray evidence they have deduced that transfer RNA consists of a double helix very much like the secondary structure found in DNA. One difference is that the transfer RNA molecule is folded back on itself, like a hairpin that has been twisted around its long axis. The molecule seems to contain a number of unpaired bases; it is possible that these provide the means for recognizing specific code words in messenger RNA [*see illustration at right on page 85*].

There is still considerable mystery about the way messenger RNA attaches to ribosomes and the part that ribosomes play in protein synthesis. It has been known for some time that colon bacillus ribosomes are composed of at least two types of subunit and that under certain conditions they form aggregates consisting of two subunits (dimers) and four subunits (tetramers). In collaboration with Samuel Barondes, we found

BASES PRESENT IN SYNTHETIC RNA

UA	UC	UG	AC	AG	CG
PHENYLALANINE ▲	PHENYLALANINE ▲	PHENYLALANINE ▲	LYSINE ▲	LYSINE ▲	PROLINE ▲
LYSINE △	PROLINE △	LEUCINE	PROLINE △	GLUTAMIC ACID	ARGININE ●
TYROSINE	LEUCINE	VALINE	HISTIDINE	ARGININE ●	ALANINE ●
LEUCINE	SERINE	CYSTEINE	ASPARAGINE	GLUTAMINE ●	
ISOLEUCINE		TRYPTOPHAN	GLUTAMINE	GLYCINE ●	
ASPARAGINE ●		GLYCINE	THREONINE		

tein by RNA polymers containing two bases depend on the base ratios. When the polymers contain a third and fourth base, additional kinds of amino acids are incorporated into protein. Thus the activity of poly-UCG (an RNA polymer containing U, C and G) resembles that of poly-UC plus poly-UG. Poly-G has not been found to code for any amino acid. Future work will undoubtedly yield data that will necessitate revisions in this table. An RNA-code-word dictionary derived from the table appears on page 93.

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that the addition of poly-U to reaction mixtures initiated further ribosome aggregation. In early experiments only tetramers or still larger aggregates supported the synthesis of polyphenylalanine. Spyrides and Lipmann have shown that poly-U makes only certain "active" ribosomes aggregate and that the remaining monomers and dimers do not support polyphenylalanine synthesis.

A possibly related phenomenon has been observed in living cells by Alexander Rich and his associates at the Massachusetts Institute of Technology. They find that in reticulocytes obtained from rabbit blood, protein synthesis seems to be carried out predominantly by aggregates of five ribosomes, which may be held together by a single thread of messenger RNA. They have named the aggregate a polysome.

Many compelling problems still lie ahead. One is to establish the actual sequence of bases in code words. At present the code resembles an anagram. We know the letters but not the order of most words.

Another intriguing question is whether in living cells the double strand of DNA serves as a template for the production of a single strand of messenger RNA, or whether each strand of DNA serves as a template for the production of two different, complementary strands of RNA. If the latter occurs—and available evidence suggests that it does—the function of each strand must be elucidated.

Ultimately one hopes that cell-free

AMINO ACID	RNA CODE WORDS			
ALANINE	CCG	UCG ■		
ARGININE	CGC	AGA	UCG ■	
ASPARAGINE	ACA	AUA		
ASPARTIC ACID	GUA			
CYSTEINE	UUG △			
GLUTAMIC ACID	GAA	AGU ■		
GLUTAMINE	ACA	AGA	AGU ■	
GLYCINE	UGG	AGG		
HISTIDINE	ACC			
ISOLEUCINE	UAU	UAA		
LEUCINE	UUG	UUC	UUA	UUU □
LYSINE	AAA	AAG ●	AAU ●	
METHIONINE	UGA ■			
PHENYLALANINE	UUU			
PROLINE	CCC	CCU ▲	CCA ▲	CCG ▲
SERINE	UCU	UCC	UCG	
THREONINE	CAC	CAA		
TRYPTOPHAN	GGU			
TYROSINE	AUU			
VALINE	UGU			

△ UNCERTAIN WHETHER CODE IS UUG OR GGU

■ NEED FOR U UNCERTAIN

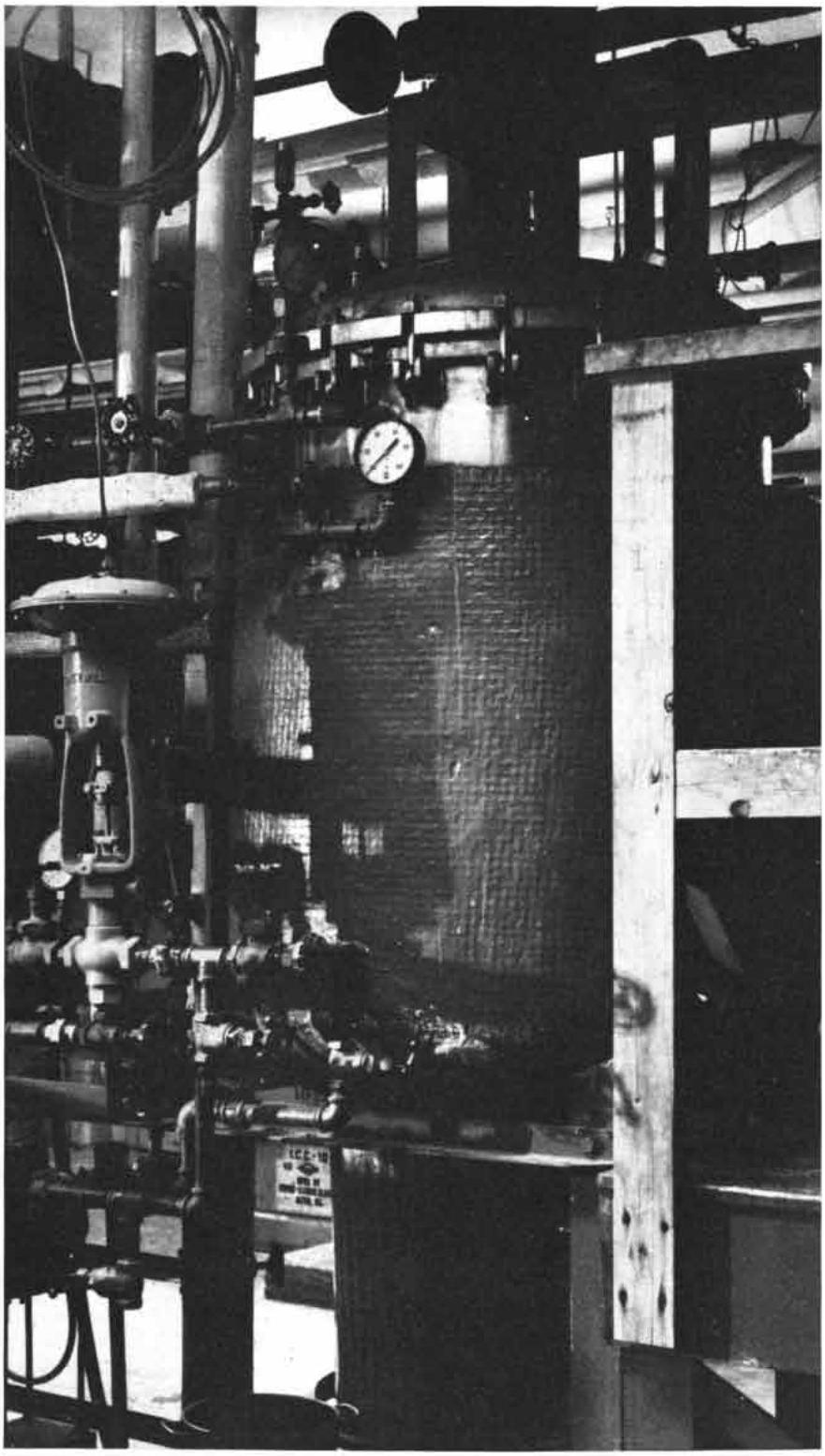
□ CODES PREFERENTIALLY FOR PHENYLALANINE

● NEED FOR G AND U UNCERTAIN

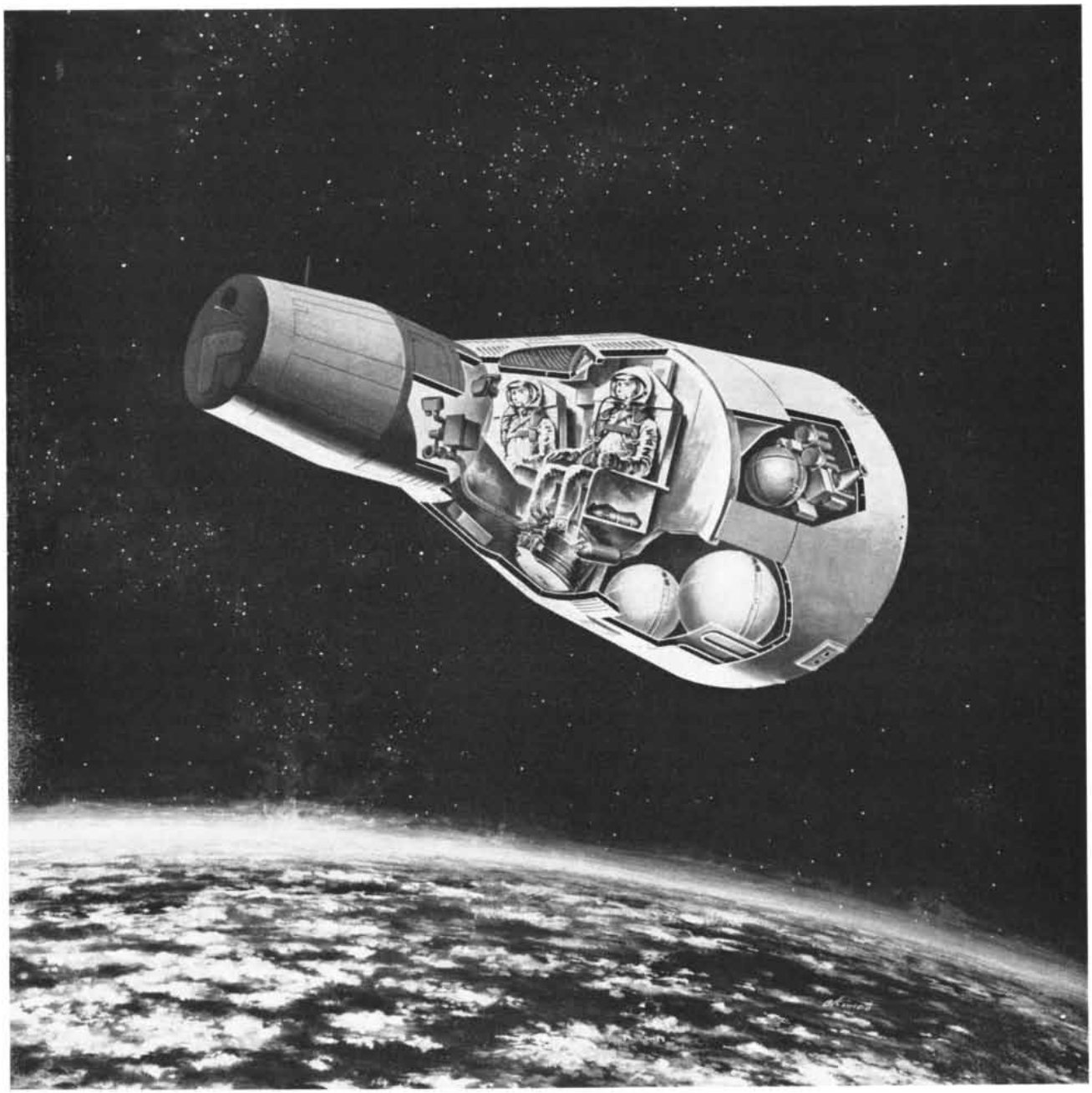
▲ NEED FOR U A G UNCERTAIN

GENETIC-CODE DICTIONARY lists the code words that correspond to each of the 20 common amino acids, assuming that all the words are triplets. The sequences of the letters in the code words have not been established, hence the order shown is arbitrary. Although half of the amino acids have more than one code word, it is believed that each triplet codes uniquely for a particular amino acid. Thus various combinations of AAC presumably code for asparagine, glutamine and threonine. Only one exception has been found to this presumed rule. The triplet UUU codes for phenylalanine and, less effectively, for leucine.

systems will shed light on genetic control mechanisms. Such mechanisms, still undiscovered, permit the selective retrieval of genetic information. Two cells may contain identical sets of genes, but certain genes may be turned on in one cell and off in another in highly specific fashion. With cell-free systems the powerful tools of enzymology can be brought to bear on these and other problems, with the promise that the molecular understanding of genetics will continue to advance rapidly in the near future.



PRODUCTION OF BACTERIA is carried out on a large scale at the National Institutes of Health. The vessel holds colon bacilli that the author and others need for experiments.



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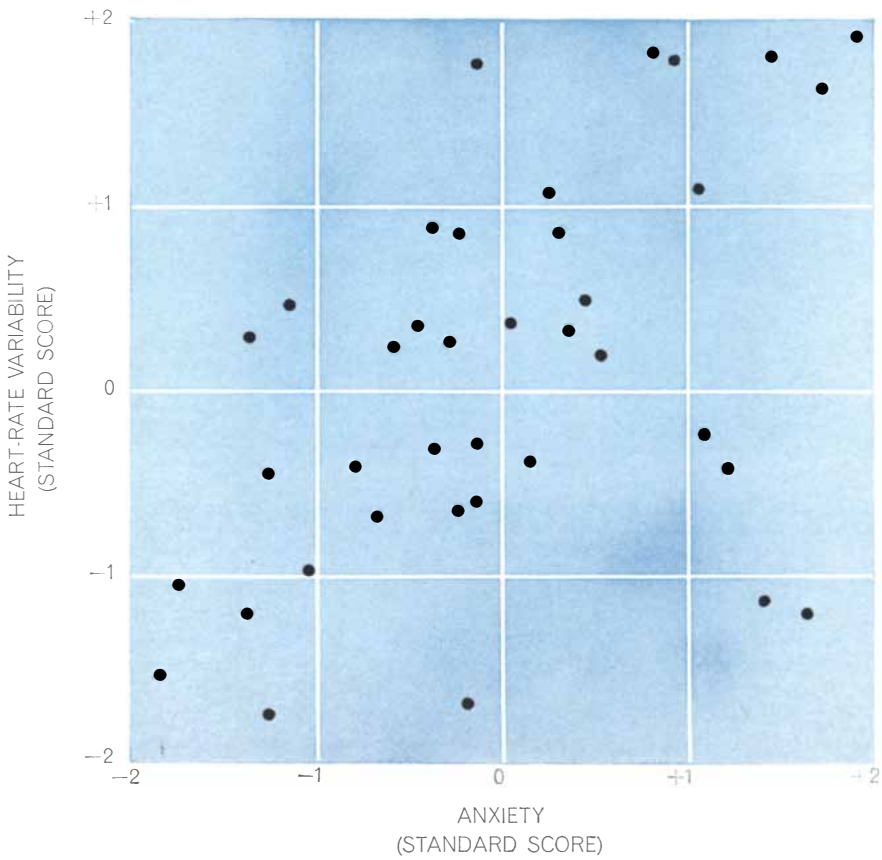
The Nature and Measurement of Anxiety

A psychological entity must be defined if it is to be measured. Through "factor analysis" psychologists seek to define anxiety in terms of the variables that are its clearest manifestations

by Raymond B. Cattell

Ours is said to be the age of anxiety, but what exactly is anxiety and how can it be measured? What are its manifestations and how does it affect the functioning of human beings? The initial difficulty in answering such questions—as in so many problems of psychology—is one of definition. A generation has passed since Edward Lee Thorndike replied to critics of psychological measurement with the dictum: Everything that exists, exists in some degree and can be measured. Since then psychometry—the branch of psychology concerned with measurement—has done rather better at inventing scaling systems, units and tests than at defining the entities to be scaled. In Thorndike's own field the proliferation of empirical definitions of intelligence finally reduced many psychologists to the desperate statement: "Intelligence is what intelligence tests measure." What led to a way out of this morass was the development of the technique of factor analysis by Charles E. Spearman, Louis L. Thurstone, Sir Cyril Burt and other psychologists. In my laboratory at the University of Illinois we have been applying factor analysis to the problem of defining and learning how to measure anxiety.



CORRELATION between a patient's heart-rate variability and his anxiety as rated by psychiatrists is shown by this "scatter plot." The physiological and psychological measurements are reduced to "standard scores," in which the mean is taken to be zero and the deviation from the mean is independent of the raw scores. When the observations are plotted, their elliptical pattern indicates that the variables correlate positively but moderately.

To seek to define anxiety is to attempt to tie down something recognized by everyone in two distinct ways: as an inner experience known from introspection and as a pattern of behavior observable in ourselves and in others as restlessness, irritability, tremor and so on. Sigmund Freud wrote much about anxiety but was content to fall back largely on introspection and semantics for its definition. He pointed to the solid distinction in his native language between *Furcht* (fear) and *Angst* (anxiety), and most psychologists have followed him in considering anxiety to be quite different from fear. At the very least anxiety is viewed as being a fear triggered by cues or symbols for some remote and uncertain danger rather than one physically or immediately present.

Other definitions go further afield. One U.S. school of learning theorists would have us consider anxiety as being the main drive to action. Almost in polar opposition to this view of anxiety as the effective mover is the clinical view expressed by Frank M. Berger (who discovered the chemical that led to the tranquilizer meprobamate) that anxiety is a disorganizer of effective action. Related to this disorganization concept is the psychoanalytic view that anxiety is the

central problem in neurosis. In looser thinking this often degenerates into the notion that anxiety and neurosis are synonymous, with the result that people with a high anxiety level are treated as neurotics. Clearly the various theorists are talking about different things when they mention anxiety, and a heavy preliminary investment of research in simply isolating and measuring anxiety is strongly indicated.

The technique we have worked with, factor analysis, is in principle quite simple, although it does involve some complicated matrix algebra and usually requires the aid of electronic computers. In essence it involves the intercorrelation of a large number of observations to find out what factor or factors control them. The factor—"anxiety," for example—can then be defined and measured in terms of the variables that are its clearest manifestations.

When one looks at a mass of social or biological variables so richly interrelated that one cannot tell which are important and which are incidental, which are dependent on others and which are independent, it is useful to watch their mode of variation under the impact of changing circumstances and see what goes with what and to what extent. So might a hunter peer into a jungle swamp and wait for some telltale movement to show that what looked like two logs is actually one crocodile. The factor analyst uses the correlation coefficient to calculate the precise extent to which two measured variables covary, or move together. The coefficient can range from $+1.0$ through 0 to -1.0, indicating, respectively, a complete positive correlation, no relation at all and a complete negative, or inverse, correlation. A correlation can be demonstrated visually by a "scatter plot" of the kind illustrated on the opposite page. Each dot on the chart represents an observation of a patient at one session during which psychiatrists rated his anxiety level and a record was made of the degree to which his heart rate was varying. When these dissimilar measurements are reduced to "standard scores" and plotted on two coordinates, their pattern indicates the degree of correlation between "anxiety" and heart-rate variability. The fact that most of the dots fall into a rough ellipse (the closest approach to a straight line one can expect when many influences are at work) shows that there is a positive correlation between the two variables. The computation of a correlation coefficient from the actual anxiety ratings and heart-rate measurements gives a value of $+.49$, which is a fairly marked relation as psychological variables go.

Even when such a relation is obtained it can be interpreted as indicating that variable *a* influences *b*, that *b* influences *a* or that some as yet unmeasured entity influences both of them. The investigator usually seeks to fix such causal dependencies by observing in time sequences or by forcibly isolating and manipulating one of the variables. The factor analyst, partly because he often deals with unmanipulable things such as the private lives of clinical patients, takes a different approach. Instead of observing *a* and *b* alone, he may observe a large number of variables in a group of subjects. With values for, say, 100 variables taken on a large number of subjects, he can work out a square correla-

VARIABLE	LOADING
HIGH SUSCEPTIBILITY TO ANNOYANCE	.56
HIGH WILLINGNESS TO ADMIT COMMON FAULTS	.47
HIGH TENDENCY TO AGREE	.38
HIGH HEART RATE	.30
SLOW REACTION TIME	.28
LOW WRITING PRESSURE	.28
LOW TOTAL PHYSICAL STRENGTH	.27
HIGH CRITICAL SEVERITY	.25
HIGH AUTONOMIC CONDITIONING RATE	.25
LOW HAND-STEADINESS	.22
HIGH EMOTIONALITY OF COMMENT	.20
HIGH SELF-CRITICISM	.19
LESS ALKALINE SALIVA	.19
SLOW SPEED OF PERCEPTUAL JUDGMENT	.18

"LOADING PATTERN" for a factor designated as anxiety (U.I. 24 on a Universal Index of factors) shows how highly a number of variables "load" on the factor, or correlate with it. The higher the coefficient at the right, the greater the association with anxiety.

	VARIABLE	LOADING
OBJECTIVE TESTS	RAISED CHOLINESTERASE	.78
	HIGH HIPPURIC ACID	.74
	HIGH WILLINGNESS TO ADMIT COMMON FAULTS	.58
	HIGH SUSCEPTIBILITY TO ANNOYANCE	.46
	HIGH RATE OF RESPIRATION	.45
	HIGH STEROID HORMONE LEVEL	.43
	HIGH HEART RATE	.30
	HIGH SYSTOLIC PULSE PRESSURE	.29
	LESS ALKALINE SALIVA	.23
	FAST REVERSIBLE PERSPECTIVE	.19
	HIGH SALIVA VOLUME	.13
QUESTIONNAIRE PRIMARIES	LOW EGO-STRENGTH (C−)	.77
	LOW WILL-CONTROL (Q_3−)	.51
	HIGH ERGIC TENSION (Q_4)	.48
	HIGH GUILT PRONENESS (O)	.37
	HIGH NONCONFORMITY (M)	.31

ANXIETY can be measured in an individual over a period of time. This is the loading pattern for anxiety as a fluctuating state rather than as the personality trait U.I. 24.

tion matrix containing the coefficients for all the possible 4,950 relations among the variables. By applying factor-analysis computations to this matrix he can discover the number of independent variables, or factors, that must be at work to account for the complex interrelations represented by the coefficients. And he can learn a good deal about the nature of these factors in terms of their pattern of effects on the dependent variables.

In the undisciplined infancy of psychology theorists often fell into the trap, originally pointed out by Francis Bacon, of assuming that because there is one word there must be one thing. An open-minded investigator must begin by questioning that assumption—by asking, in this field, if there is one thing called anxiety or several distinct and possibly unrelated forms of anxiety response.

At various times a variety of introspective, behavioral and physiological manifestations have been alleged to be signs of underlying anxiety. They include low hand-steadiness, inability to look someone in the eye, sinking feeling in the stomach, dry mouth, high irritability, raised muscle tension, decreased power of concentration, high emotionality in word choice, lack of readiness to try new tasks, tendency to jump at noises, high galvanic skin response, more rapid conditioning and a tendency to see threatening objects in blots or unstructured drawings. Between 1948 and 1960 we measured such objective-test variables as these in groups of from 100 to 500 people—young and old, mentally healthy and mentally ill—and then intercorrelated the hypothesized anxiety manifestations. The correlations turned out to be generally positive and significant. And through factor analysis they pointed to the existence of a single, pervasive factor of anxiety.

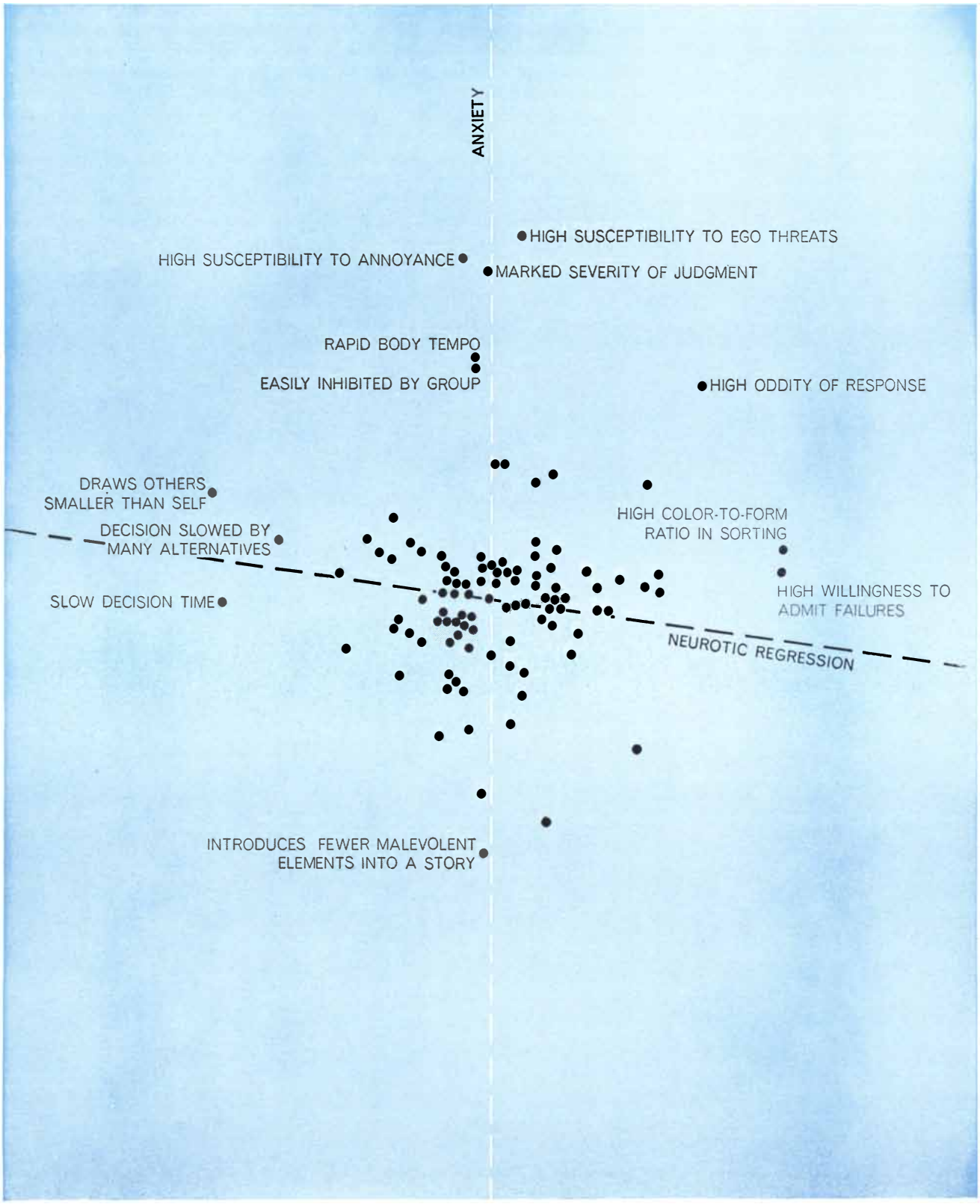
Up to this stage the assumption that there is a single entity that can be called anxiety was vindicated. In major respects the factor agreed with what is covered by the semantic concept of "anxiety." But not every popularly alleged manifestation of anxiety was confirmed. For example, in anxiety salivary output turned out to increase rather than to decrease. General muscle tension did not correlate in the way a tense person might expect from introspection. What correlated with the anxiety factor was tension in the trapezius, the large muscle that runs from the shoulder to the back of the head; handwriting pressure was actually significantly lower in persons of high anxiety.

Once a factor has been checked in several samples of people and across several ranges of measurement, it provides a "loading pattern" [*see upper illustration on preceding page*] that shows the degree of influence of the underlying independent variable on each of the main manifestations in terms of correlation coefficients between the factor—anxiety in this case—and the variable. The loading pattern provides a means of recognizing and identifying the factor and a basis for more developed hypotheses about its nature. It also tells one how to test for the factor. Although anyone is free to affix such names as "anxiety" or "intelligence" to whatever he pleases, there is now an objectively discovered, repeatable response pattern to which one can refer when the label is used. In this case it dictates a particular battery of tests—usually the composite of measurements from the 10 or so most highly loaded manifestations—for anxiety experiments. To avoid merely semantic disputes factors are sometimes indexed simply by number. In a proposed Universal Index of factors that psychologists interested in such matters have been compiling, I have indexed anxiety as U.I. 24. When expert psychiatric diagnosticians rate patients for anxiety level, their estimates correlate more consistently and more highly with the U.I. 24 battery than with any other factor. Although the correlations shown in the U.I. 24 table (which is based on the work of John Hundleby of the University of Illinois and Kurt Pawlik of the University of Vienna) are not high, they are mean values across five experiments, and they have since risen to higher values in longer tests developed after the exploratory research phase.

VARIABLE	LOADING
INABILITY TO DO SIMPLE ADDITION AND SUBTRACTION MENTALLY	.57
STUTTERING AND UPSET OF SPEECH WITH DELAYED AUDITORY FEEDBACK	.57
SLOW AND ERRATIC RECOGNITION OF UPSIDE-DOWN FORMS	.57
ASPIRATION-LEVEL HIGH RELATIVE TO PERFORMANCE	.55
POOR ABILITY TO CO-ORDINATE SIMULTANEOUS SPATIAL CUES	.55
LOW METABOLIC RATE CHANGE IN RESPONSE TO STIMULI	.50
LOW READINESS TO TACKLE UNPLEASANT ACTIVITIES	.47
NUMEROUS "INDECISIVE" RESPONSES IN QUESTIONNAIRES	.44
ERRORS IN RECITING ALPHABET WITH PRESCRIBED SKIPPING	.42
RAPID INCREASE OF ERRORS WHEN MADE TO HURRY	.31
HIGH MOTOR-PERCEPTUAL RIGIDITY	.29
AFFECTED MORE BY COLOR THAN FORM IN ARTISTIC PREFERENCES	.25
HIGH BODY SWAY IN SUGGESTIBILITY SWAY TEST	.20

"REGRESSION" is one of the factors that distinguish neurotics from other people, and is indexed as U.I. 23. This is the loading pattern for some variables influenced by U.I. 23.

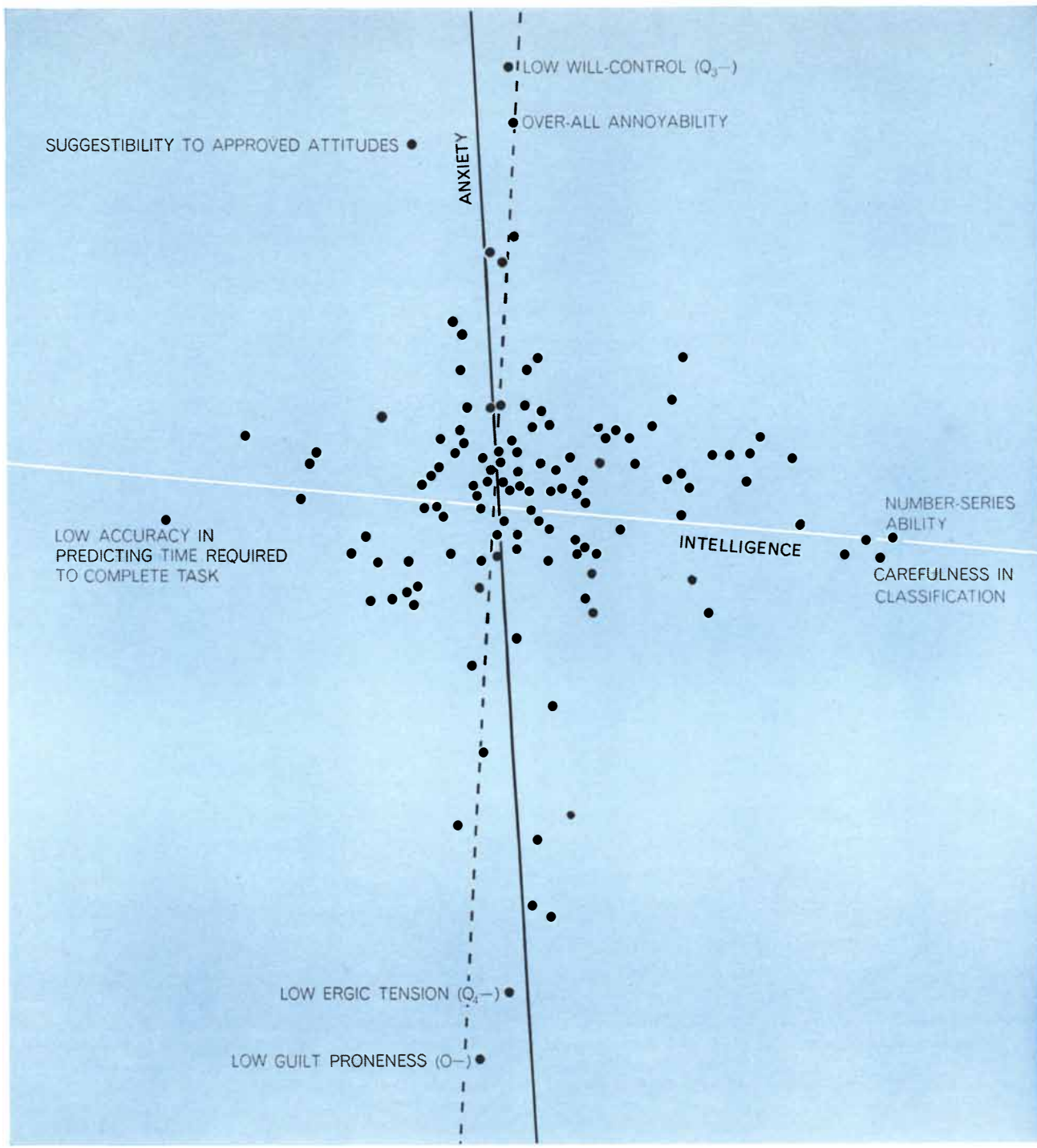
Although a psychologist feels on firmest ground when he has located anxiety as a behavorial pattern in U.I. 24, he is also interested to see how anxiety emerges in the introspective account the subject gives of himself in responding to a questionnaire. The factoring of questionnaire items is an established branch of psychometrics. Among 16 major factors established by David R. Saunders, Glen F. Stice, Richard Coan, Bien Tsujioka, Rutherford B. Porter and me there were a number that appeared to have "anxiety content." One, which I called "ergic tension" or "drive tension" and labeled as factor Q_4, came out of such questions as are listed in the illustration on page 102. Another, indexed as O, had



INDEPENDENCE of the anxiety and regression factors, U.I. 24 and U.I. 23, is shown here in geometric terms. Each dot is the end point of a vector representing a measured variable, its direction and distance from the origin determined by factor-analysis computations. There are as many dimensions in the solid "graph" so produced (from which this is a two-dimensional projection) as there are factors at work on the variables. Test points tend to coagulate in "hyperplanes," or multidimensional galaxies, which indicate the positions in which to place various factors; these factors emerge as axes of the "graph" placed as perpendiculars to the galaxies. Projected in two-dimensional space, a hyperplane should ideally appear as a line, but it is usually (as in this diagram) a lens-shaped swarm of points. A test like "Marked severity of judgment," lying in the hyperplane of neurotic regression, has zero-projection, or "zero-loading," on it; that is, it does not correlate with regression. On the other hand it loads highly on anxiety; it is, in other words, closely associated with anxiety. The greater the angle between two tests or factor axes, the more independent they are of each other. In this case the anxiety and regression axes are nearly perpendicular to each other; they are independent.

items indicating guilt proneness. Still another was the reciprocal of ego strength, or "ego weakness" (C −).

Could the existence of only one functional unity of response in behavior—U.I. 24—be reconciled with several factors in the area of introspection? It is possible in factor analysis to correlate factors themselves and then to factor-analyze their correlation matrix just as one did the original variables. What comes out of this is a "second order" factor. (General intelligence is a second-order factor among such primary abilities as verbal ability, spatial ability, numerical ability and so on.) When we factored some 20 of the personality factors based on data from questionnaires, precisely those six factors that a psychiatrist would consider to have anxiety content—and no others—fell into a single second-order factor. At that point, therefore, we had one factor in behavioral response and one in introspection, but the possibility remained that they would prove to be not the same thing—that people who measured high on the "mental interior" factor might not show identical scores on the behavioral "exterior" factor. A crucial test with more



CLOSE CORRELATION between anxiety as defined by objective tests (U.I. 24) and anxiety as a second-order factor derived from questionnaire data is shown by this diagram: the questionnaire axis (*broken black line*) is nearly aligned with the U.I. 24 behavioral axis (*solid black line*). But the axis for intelligence performance (*white line*) is almost perpendicular to the anxiety axis.

than 500 Air Force men proved that these two ways of measuring were operating on the same entity: the correlation between them was close to +1.0. This close correspondence can be shown in visual terms [*see illustration on opposite page*] by a technique that will be discussed later in this article.

Why should a first-order factor in one medium turn up as a second-order factor in another? Finding six partially distinct influences in introspection corresponding to one in behavior must mean, in the first place, that introspection is more sensitive. It could also mean that a causal mechanism is being revealed in terms of six different sources of one common pool of anxiety. As usual with purely correlational evidence, one cannot say for sure in which direction the causality acts. But if the anxiety factor represents, as it were, a common reservoir of anxiety to which ego weakness, guilt proneness, frustrated drive and other primary factors contribute, our results would offer striking experimental vindication of some of Freud's theories as to the origin of anxiety in neurotics. At the same time, this experimental approach introduces several concepts beyond any in classical psychoanalysis, because factor analysis, like the microscope, opens up relations that cannot be seen by the unaided eye of the clinician.

The concept of U.I. 24 with which I have dealt so far has rested solely on observations of the individual differences among people, that is, on anxiety as a trait of personality. But anxiety also varies in level in the same person from time to time. The psychologist wants to discover the pattern of anxiety as a fluctuating state and to find out if it is the same as that of the personality trait. This question can be explored through single-person factor analysis, in which one person is measured every day, for perhaps 100 or 200 days, on the various alleged measures of anxiety. When these time series are correlated, a significant positive correlation should exist among variables affected by the same underlying source. For example, if higher systolic blood pressure, irritability, tremor and "Yes" answers to certain questionnaire items are all signs of anxiety, they should vary together as the onslaught of daily events raises and lowers the anxiety level. Investigation showed that the pattern for anxiety as a state is unmistakably the same species of response as that for the trait [*see lower illustration on page* 97]. It differs in some tendency of the physiological variables to load more

highly on the state factor. By working with the same subject one could eliminate individual differences resulting from extraneous influences on the variables.

Experiments with individuals have been particularly valuable in locating the physiological concomitants of anxiety and in distinguishing the anxiety pattern from other states, such as stress, fatigue and excitement, with which it has often been confused experimentally and conceptually. Harold Persky and Roy R. Grinker of Michael Reese Hospital in Chicago, working with paratroopers in training, found that during what appeared to be anxiety periods the level of hippuric acid in the urine and of adrenal cortical steroids in the blood rose, the white-cell count and electrical skin resistance decreased and breathing speeded up. Ivan H. Scheier of my laboratory, together with Grinker, Sheldon Korchin and others at Michael Reese, studied patients undergoing various stresses and located a specific pattern of physiological upset characteristic of anxiety; the patterns for effort stress, excitement and other states differed both behaviorally and physiologically. Further investigations by Roy B. Mefferd and Louis J. Moran at the University of Texas and by Hudson Hoagland at the Worcester Foundation for Experimental Biology leave little doubt that anxiety and effort stress are two different things. Psychologically the effort-stress pattern usually shows no anxiety or other emotionality, only strong concentration and perhaps awareness of effort. High cholesterol levels, which we found to be completely uncorrelated with anxiety, may really belong to the effort-stress pattern. Anxiety seems to affect metabolism primarily by upsetting anabolic processes, which may account for the weight loss suffered by combat soldiers exposed to unremitting anxiety.

There is even evidence in Scheier's results that effort stress (which has resemblances to Hans Selye's "stress adaptation stage one" and arises from physical as well as mental causes) may have some inverse relation to anxiety. When a person grapples with a difficulty, he shows the stress response; when he retreats and attempts escapist solutions, he shows anxiety. The so-called psychosomatic neurotic, who develops a physical symptom from his encounter with a problem, is in this sense the opposite of a neurotic.

Whether or not anxiety originates as a response to prolonged and remote fear signals, it is quite different from fear as an actual response pattern. Fear is associated with the release of adrenalin; anxiety is not. Fear dries the mouth, whereas anxiety produces increased salivation as well as increased gastric secretion. Fear is sometimes described as realistic, whereas anxiety is considered unrealistic and indeed neurotic. Scheier and I found that students showed raised anxiety levels three weeks before an important examination but lowered anxiety and raised effort stress at the examination itself. The raised anxiety may be "neurotic" in the sense that it does no

QUESTIONNAIRE ITEM	LOADING
DO YOU FIND YOURSELF WITH STRONG MOODS OF ANXIETY, AMUSEMENT, SORROW, ETC., WHICH YOU CANNOT ACCOUNT FOR BY ANYTHING THAT HAS RECENTLY HAPPENED?	.60
DO YOU FREQUENTLY GET IN A STATE OF TENSION AND TURMOIL WHEN THINKING OVER THE DAY'S HAPPENINGS?	.57
DO QUITE SMALL SETBACKS IRRITATE YOU UNDULY?	.56
DO YOU, WHEN FORCED TO REMAIN INACTIVE, BEGIN TO DOODLE, DRAW THINGS ON THE MARGIN OF YOUR PAPER, ETC.?	.55

QUESTIONNAIRE ITEMS can be factored like behavioral or physiological variables. The coefficients at the right show how well a "Yes" answer to each question correlates with a factor designated as "ergic tension." When this factor and others based on questionnaires are factored in turn, anxiety emerges as a "second order" factor influencing them. Questions are from anxiety scale published by Institute for Personality and Ability Testing.

good, but it is a response to a real-world danger. If such anxiety is neurotic, so also is fear neurotic when it arises from a present danger about which nothing can be done.

Some years ago Hans J. Eysenck of Maudsley Hospital in London demonstrated that a factor I had measured by objective psychological tests and indexed as U.I. 23 powerfully distinguishes neurotics from normals. Some of the manifestations that consistently correlate with what Eysenck then called the neuroticism factor but that we conceive of as "regression" (only one of the components in neuroticism) are set out in the illustration on page 98.

The factor-analysis evidence for the independence of the influences defined as anxiety and regression can be presented visually. The variables are drawn as vectors from a common origin; the more closely correlated the variables are, the closer together they will lie, so that a group of mutually highly correlated variables will look like a sheaf of arrows. The number of dimensions in the space common to these vectors reflects the number of factors required to explain them. Since any set of variables usually involves a number of factors, a plot of the vectors would not be a conventional two-dimensional graph but an imaginary construct in a "hyperspace" of many dimensions. The nature of the experimental results identifies certain variables as factors; these can be treated as the axes of a co-ordinate system. When the end points of the vectors representing variables are projected on these axes in two dimensions, their location represents their loading on the axes.

Because the angles representing the relations among variables are implicit in the correlation results, the whole vector system is rigid. It can, however, be rotated with respect to the axes. The analyst wants to find the one position in which the factors and variables lie in their true relation. For this purpose he depends on the principle of "simple structure," which assumes that in an experiment involving a broad and well-sampled set of variables it is improbable that any single influence will affect all of them. In other words, it is more "simple" to expect that any one variable will be accounted for by less than the full complexity of all the factors acting together. This implies that there should be dense groups, like astronomical galaxies, constituted by variables unaffected by any one factor. In multidimensional space each such galaxy would lie in a "hyperplane"; in three dimensions

it would be a disk lying in a plane. Projected in two-dimensional space it should reveal itself as a row of variables lining up with "zero loading"—that is, with no correlation or projection—on some factor axis moved to the correct position.

Such dense disks are indeed found in real data. By placing each chosen axis perpendicularly to a well-defined disk, the analyst rotates his results finally to a unique explanatory position. He thereby establishes the factor to which any set of variables is least related and the one with which it correlates most highly. The illustration on page 99 is a plot, in the plane set by the anxiety and regression factors, of data from a study of 111 variables, covering 18 factors, made by Richard Coan of the University of Arizona on a group of 164 seven-year-old children. The variables fall into two hyperplanes seen as rough ellipses (one rarely gets the galaxies exactly on edge in a row) lying along the axes and intersecting at the origin. The fact that these axes are almost at right angles to each other, with very different kinds of variables projecting close to each of them, shows that they are almost completely independent influences, with very different characteristics.

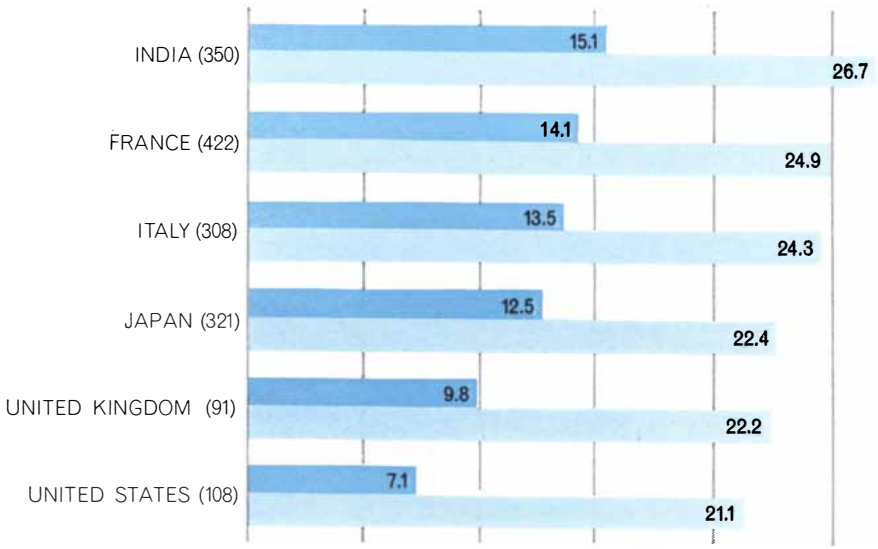
A similar plot makes clear the close relation, reported earlier in this article, of the behavior-based to the questionnaire-based data on anxiety [*see illustration on page 100*]. The axis of the second-order questionnaire factor aligns itself, within the limits of experimental error, with that of the U.I. 24, or behavioral, factor. This diagram is also of interest in that it shows the psychological and statistical independence of anxiety and intelligence. The direction of the anxiety factor is fixed by the hyperplane oriented largely in intelligence-performance results. The axis representing the intelligence factor is approximately perpendicular to the anxiety axes. In this group of airmen anxiety and intelligence were almost completely independent of each other, and this has proved to be the case in most other experiments.

Factor analysis, then, succeeds in sorting out anxiety from two things with which it is constantly confused: the stress reaction and the neurotic-personality maladjustment. The more precise measurements of anxiety that are now possible also clarify the relation between anxiety and a factor such as intelligence and should help to answer many similar questions about the relation between anxiety and various situations and performances.

During the past decade, for example, almost every theoretically possible relation between anxiety and learning has been reported as being experimentally supported. Our results make it seem probable that those who found better school achievement with higher anxiety were mixing a state measure with a trait measure a few weeks before an examination, and that workers who correlated better achievement with lower anxiety were using an anxiety measurement tainted with neuroticism components. The issue was confused by the inclination of many learning theorists to assume that all learning is conditioning. Our experiments do show more rapid conditioning of autonomic, or involuntary, responses with higher anxiety. On the other hand, learning as reflected by grades is slightly but significantly inversely related to anxiety. It still remains to be seen which is cause and which is effect.

New objective and questionnaire-based anxiety batteries developed by Scheier have already yielded verifiable results showing differences in anxiety level with age, occupation, clinical syndromes and national culture. Anxiety fluctuates in early childhood, rises most consistently in adolescence and declines considerably through adulthood until it rises again after 60 or 65. Among occupations, newspaper editors, artists and air cadets in training have been found to have high anxiety; policemen, clerical workers and engineers have lower levels. Probably both personnel selection and the nature of the jobs are responsible for these differences. Among patients in mental health clinics those diagnosed as anxiety hysterics have the highest scores and alcoholics are also far above average. But the average scores for psychotics, whether schizophrenic or manic-depressive, are not very different from those of the general population.

Some surprising results have come from comparisons across cultures. To obtain data the questionnaire items were translated carefully (often back and forth twice) and checked by working out the factor structure until it was practically identical in each of the nations under study. When the scores were compared, some major differences appeared. Indians and Frenchmen, for example, showed substantially higher anxiety and neuroticism levels than Americans did [*see illustration at left*]. This hardly fits the American's treasured view of himself as the most harassed of mortals, or the notion that anxiety is tied up with the pace and complexity of industrialized society. National comparisons are invidious and notoriously tricky, but these results may possibly fit a theory that low anxiety is associated with better economic level and closer political integration. This fits recent data showing still higher anxiety levels in countries that are split culturally and politically and that are low in economic status. Perhaps—and this is a subject for research—the U.S. might head the list in effort stress rather than anxiety. But if the U.S. is the archetypal 20th-century culture, literary psychologists may be far astray when they project their personal feelings to call this the age of anxiety.



INTERCULTURAL DIFFERENCES in anxiety and neuroticism were revealed by questionnaire data. The anxiety score is shown by the dark bars (possible range, 6 to 30) and the neuroticism score by the light bars (possible range, 6 to 54). The differences between countries were statistically significant except, in anxiety, for the U.K. and U.S. and, in neuroticism, for France and Italy. Numbers at left show size of the group tested in each country.

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PULSATING BALL LIGHTNING probably caused the luminous streak at the top of this color photograph. The image may, however, have been caused by bead lightning, a form related to ball lightning. The photograph was taken during a severe thunderstorm at Los Alamos, N.M., in August, 1961, by B. T. Matthias and S. J. Buchsbaum of the Bell Telephone Laboratories. The exposure was made by aiming the camera at an approaching thundercloud about a mile away and leaving shutter open for five minutes.

BALL LIGHTNING

This rare form of lightning may represent a stable configuration of a plasma of charged particles. If it does, it may help to solve the problem of confining a plasma within a thermonuclear reactor

by Harold W. Lewis

A minor legend of the American West relates that forest-fire watchtowers are equipped with tall stools to provide a refuge for the fire warden who is attacked by ball lightning. The idea is that the lightning ball will snap around the legs of the stool and then, frustrated, depart through a door or a window. This is undoubtedly an anthropomorphic exaggeration of the behavior of ball lightning, but the fact is that there are reasonably believable accounts of instances in which balls of lightning have hung suspended in the air or floated eerily through it, have climbed through windows, dived down chimneys, popped out of ovens, glided along fences and telephone wires and performed other improbable maneuvers.

Any normal, cynical scientist, on hearing of ball lightning for the first time, almost instinctively places it in the category of folklore, along with flying saucers and ectoplasm. A brief survey of reported events, however, quickly convinces the skeptic that enough reputable observers have seen and possibly even photographed ball lightning to leave no doubt that the phenomenon is real, although it is rare and as yet unexplained. The fact that lightning balls, in contrast to lightning bolts, have been observed to persist for considerable periods of time has long piqued the curiosity of physicists. In the past five years there has been a surprising resurgence of interest in ball lightning, stimulated by a controversial hypothesis put forward by the noted Soviet physicist Peter L. Kapitza. His suggestion has in turn led to other theories, to renewed but unsuccessful efforts to reproduce the phenomenon in the laboratory and to some rather unlikely conjectures about the possible applications of the ball-lightning "technique" in the control of thermonuclear reactions for the production of power.

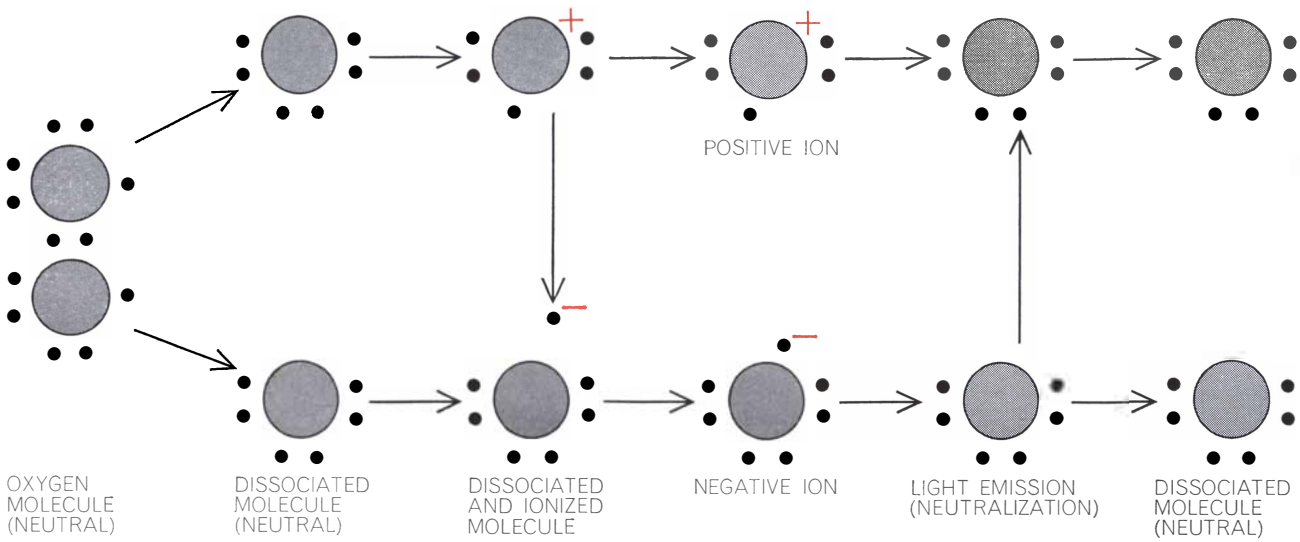
Any explanation of ball lightning must take into account the curious properties attributed to it by those who have seen it. The most recent survey of sightings was conducted in 1960 at the Oak Ridge National Laboratory, where J. Rand McNally, Jr., asked 15,923 employees if they had ever seen ball lightning. The 515 who gave an affirmative response were asked in some detail about the size, duration, color and other physical properties of the ball. These replies, which form the basis of the description that follows, developed a picture substantially like that obtained in previous surveys.

It would appear that the typical lightning ball—or, to use its German name, *kugelblitz*—is a luminous sphere perhaps as bright as a strong household fluorescent lamp. The sphere may range in diameter from a few inches up to a few feet, most often from six inches to a foot. It usually materializes immediately after an ordinary lightning stroke. The ball can be almost any color, although green and violet are rare. Most seem to shine steadily, but some pulsate. Normally the ball moves about, sometimes along a conductor or an insulator and sometimes directly through the air. It can last from a second or less up to several minutes; the median, if one may judge from the estimates of startled observers, is a few seconds. Some balls fade out; others disappear abruptly, occasionally with an explosive report. Lightning balls seldom damage anything badly, although they sometimes leave physical evidence of their occurrence. They have scorched wood and burned through wires. A lightning ball in the U.S.S.R. was reported by a number of observers to have partly melted the tip of the propeller of an airplane that encountered it at an altitude of 10,000 feet. The matter of damage is important because some estimate of the amount of energy stored in the ball is essential to an evaluation of the various theories. Since lightning balls have not been produced in the laboratory, estimates of their energy content are based entirely on the subjective reports and on inferences from their effects.

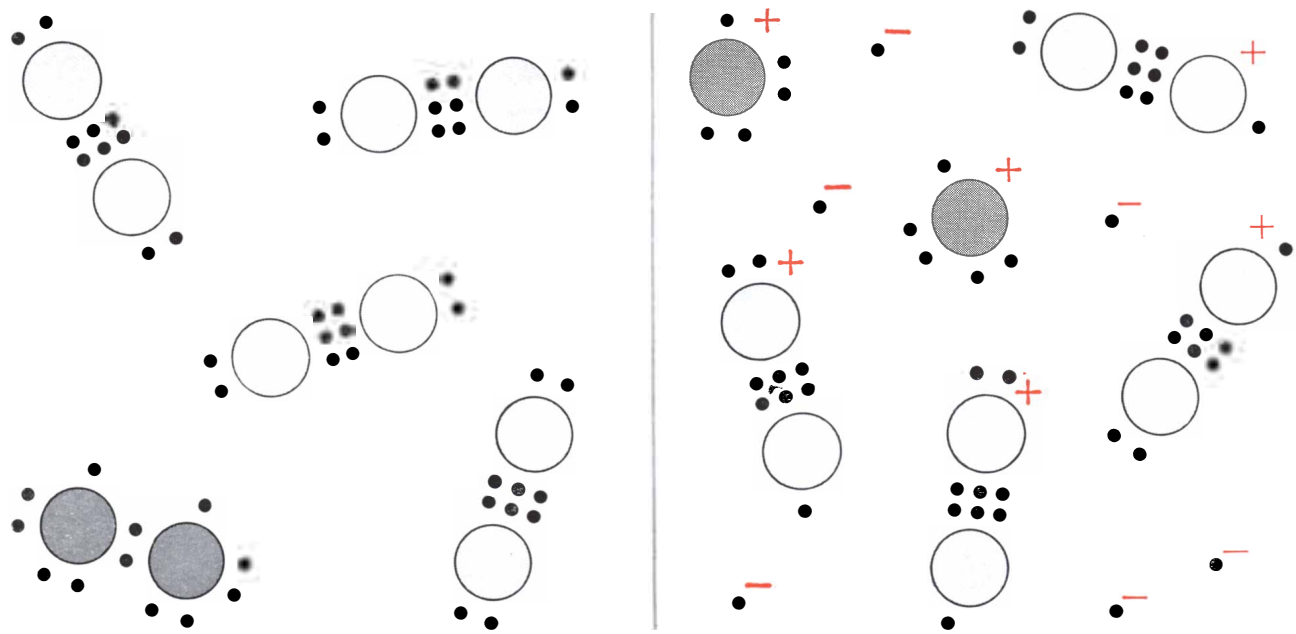
It is easy to set an upper limit to the energy stored in a lightning ball by assuming that the air within the ball is at most singly ionized. This means that each atom or molecule in the air has lost one electron and that there is an equal number of free electrons. A gas in this state is called a fully ionized plasma. The search for a way to control thermonuclear reactions involves the creation and maintenance of a plasma within some sort of magnetic "bottle" [see "Fusion Power," by Richard F. Post; SCIENTIFIC AMERICAN, December, 1957]. In ball lightning the energy that went to ionize the air is stored in the plasma until the charged particles recombine, releasing the energy in the form of light, heat and sound. At sea-level atmospheric pressure, single ionization of the air would produce an energy density of about 100 joules per cubic centimeter. (The joule is a unit of work equal to 10^7 ergs, or to the work done in one second by a current of one ampere flowing through a resistance of one ohm.) An average lightning ball 25 centimeters (10 inches) in diameter and singly ionized at normal atmospheric density would contain about one megajoule (million joules) of energy. I am indebted to M. L. Goldberger of Princeton University for pointing out to me that a megajoule can be visualized as the

amount of energy that would be released by the chemical combustion of a large jelly doughnut.

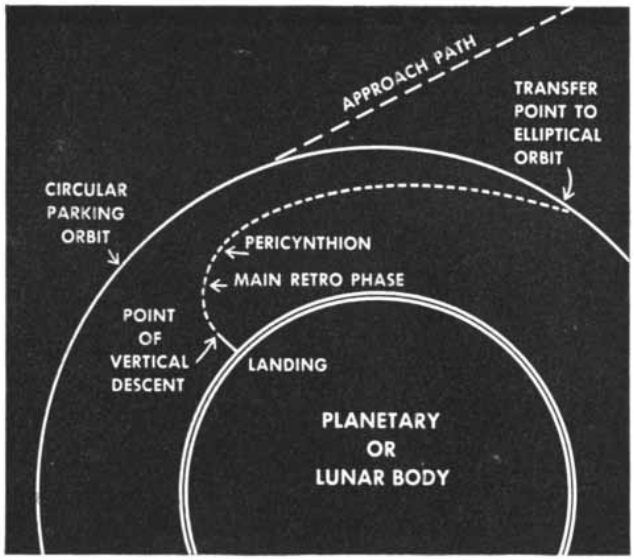
In order to determine the energy content of an object the investigator normally employs calorimetry. He places the object in a known quantity of water and measures the extent to which the water is heated. Obviously catching a lightning ball in a calorimeter, or in any container of water, would be a considerable achievement. The amazing thing is that just such an experiment was accidentally performed by a lightning ball in the presence of an apparently sober and reliable resident of the London area. According to *The Daily Mail* for October 3, 1936, the observer reported that the glowing ball came out of the sky, cut a telephone wire, scorched a window frame as it entered a room and finally dived into a butt (a small barrel) containing four gallons of water. The water boiled "for some minutes," indicating that the lightning ball must have persisted most of this time. In support of his claim that the water actually boiled, the observer testified that he could not keep his hand immersed in it 20 minutes later. To boil so much water the lightning ball must have had an energy of not one megajoule but at least four megajoules and perhaps as much as 10 megajoules. The concentration of energy in the ball must have been considerably higher than that in our 25-centimeter, one-megajoule model: the ball was said to be the size of a large orange. The calculated upper limit of one megajoule for a 25-centimeter ball, although it is less than the energy of the ball in the



ONE TYPE OF IONIZATION that can occur in air involves first the dissociation of oxygen molecules by radiation. The radiation acts further to knock electrons off some of the atoms, which acquire a positive charge. Other atoms may take up these electrons, thereby becoming negatively charged. The process of recombination of a positive atom with an electron is highly oversimplified here.



NITROGEN IONIZATION occurs in air along with the oxygen process. Here four molecules of nitrogen and one of oxygen are shown (air is approximately 78 per cent nitrogen and 20 per cent oxygen). Radiation can cause the dissociation of oxygen molecules and their ionization (*right*); nitrogen molecules usually ionize before dissociating. Recombinations (*not shown*) are highly complex



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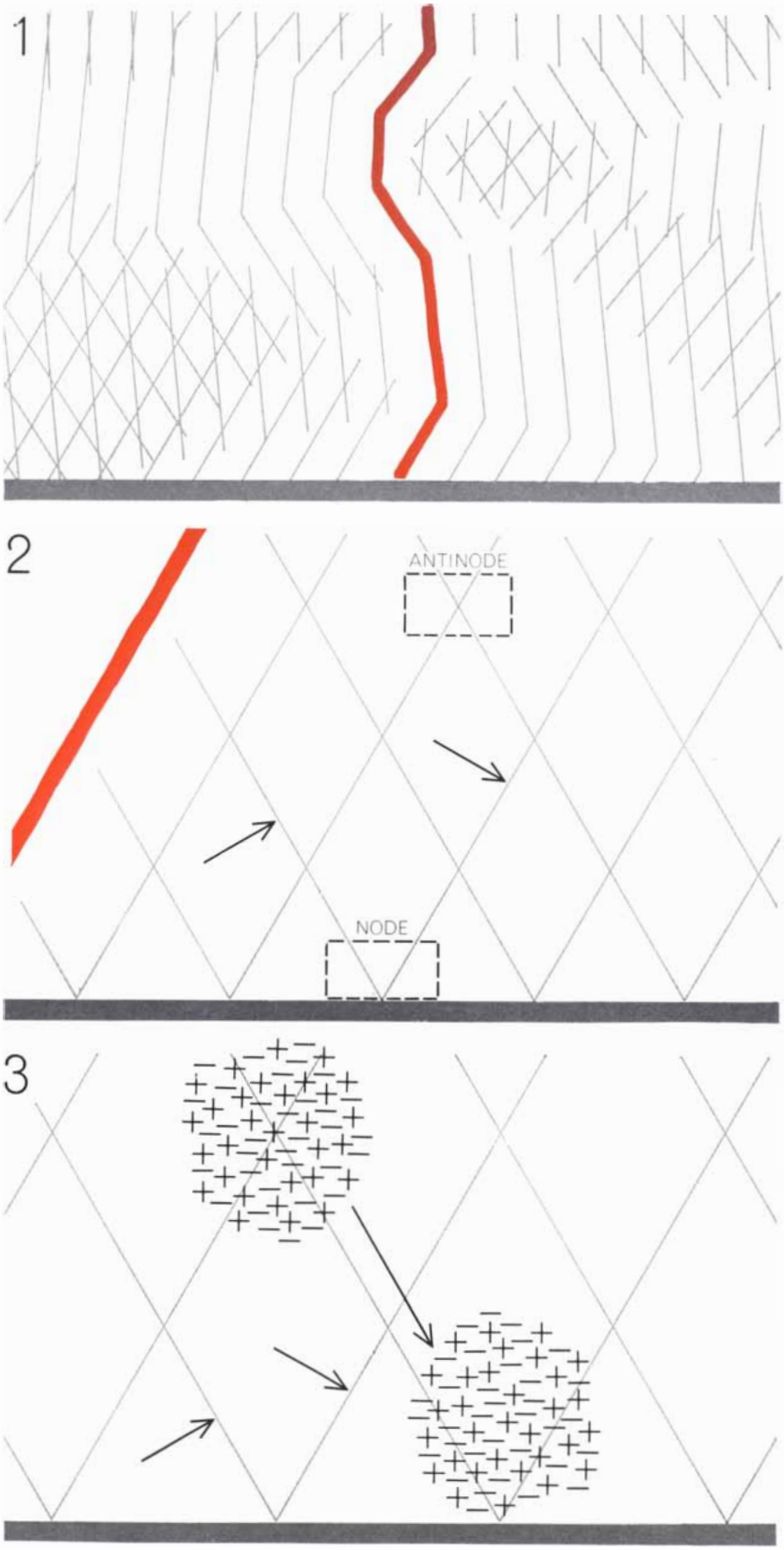

KAPITZA THEORY of the formation of lightning balls postulates the creation (*1*) of electromagnetic waves (*gray*) by a bolt of lightning (*color*). These waves are reflected by conducting surfaces (*2*), including the earth, and set up standing waves. Short arrows show direction of motion of wave fronts. The node is the region of weakest electric field; the antinode, of greatest field strength. Energy from the waves ionizes a region of air at an antinode, creating luminous ball that moves to node (*long arrow*), where radiation pressure holds it (*3*). Energy is fed in continuously. This representation of theory is highly schematic.

water-butt experiment, is at least not too far from the truth.

Now, the only way to store so much energy would be in the ionization of practically all the atoms and molecules in the lightning ball. This constitutes a real dilemma, because it is difficult to reconcile ionization with the length of time the ball lasts. Ionized air is in a highly unstable state. Several mechanisms cause the free electrons to combine either with the positive ions or with electrically uncharged but chemically active atoms, particularly those of oxygen. Ionic capture of an electron, a process known as recombination, neutralizes the electric charge of the ion. If an uncharged atom picks up an electron, an event known as electron attachment, the atom becomes a negative ion. Such an ion regains its electrical neutrality by combining with a positive ion. The pressure, temperature and other characteristics of the gas determine whether neutralization occurs directly or through the intermediate formation of a negative ion. In the lightning ball the latter process is probably dominant. Even though the process is slightly roundabout, calculations based on well-known physical laws show that neutralization of the air in a lightning ball will take only a tiny fraction of a second, far too short a time to account for the relatively long life of the ball. Since not even the wondrous kugelblitz is permitted to amend the laws of nature, one must conclude either that the energy for ionization is being supplied continuously by some outside agency or that there are no free electrons in a lightning ball.

Kapitza employed the former idea in his theory, which he published in 1955. He suggested that the highly electric environment of a thunderstorm could create electromagnetic standing waves. Such a wave arises at the meeting place of two or more wave fronts of the same frequency traveling in different directions. The region where the waves reinforce each other is called the antinode and the region where they cancel each other the node. Kapitza said that at the antinode the waves might be intense enough to separate electrons from atoms in the air, thereby producing a small ionized region. It had been known before Kapitza published his paper that an ionized gas will resonate to and absorb electromagnetic waves of the appropriate frequency; the absorption of energy in this manner will finally result in a cascade of ionization. In the air the cascade would form a lightning ball. The ultimate size of the ball would be directly re-

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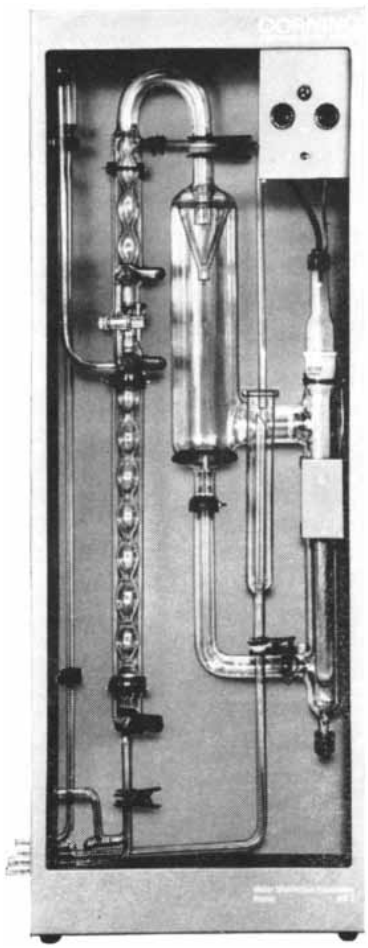

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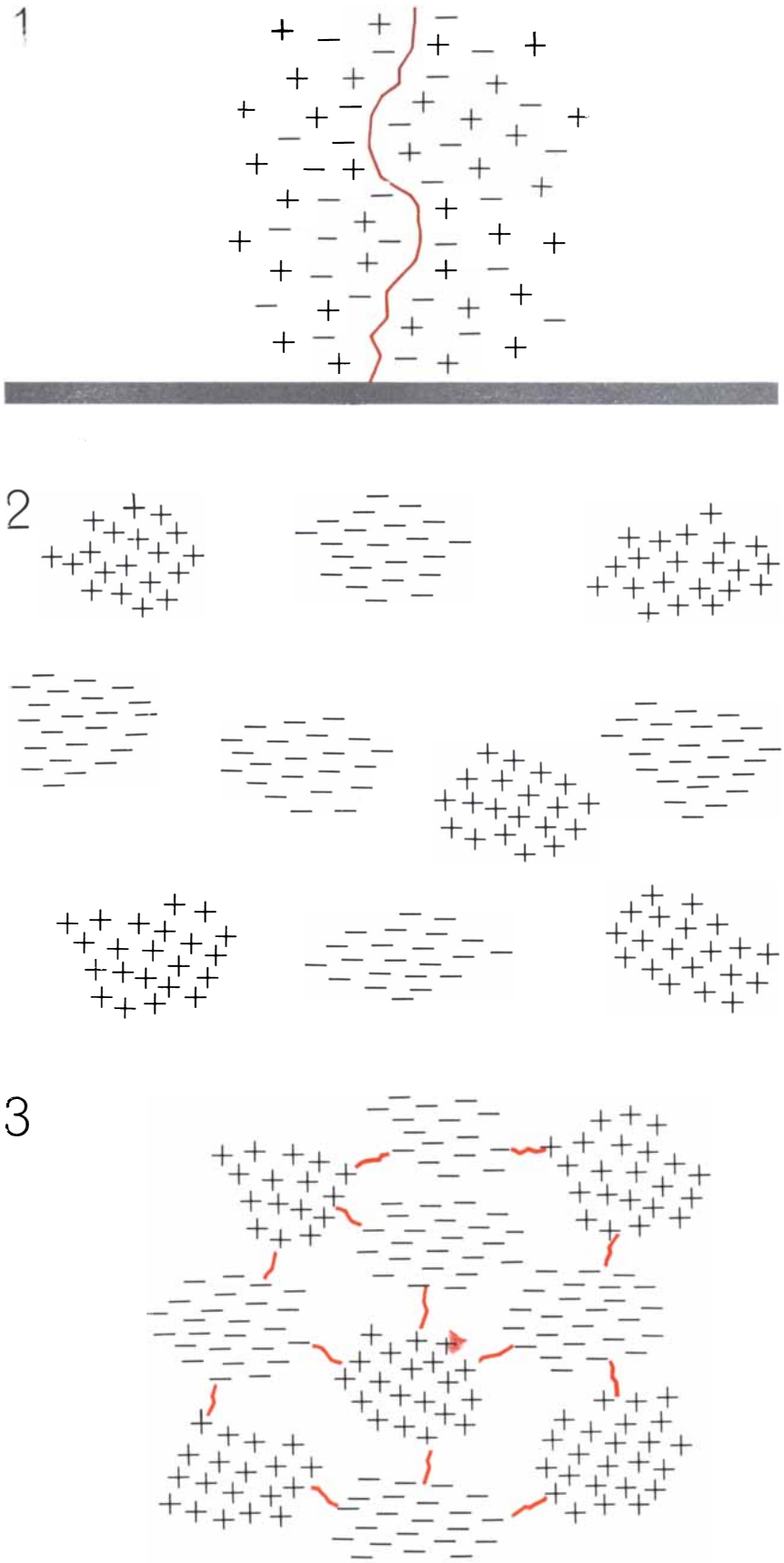


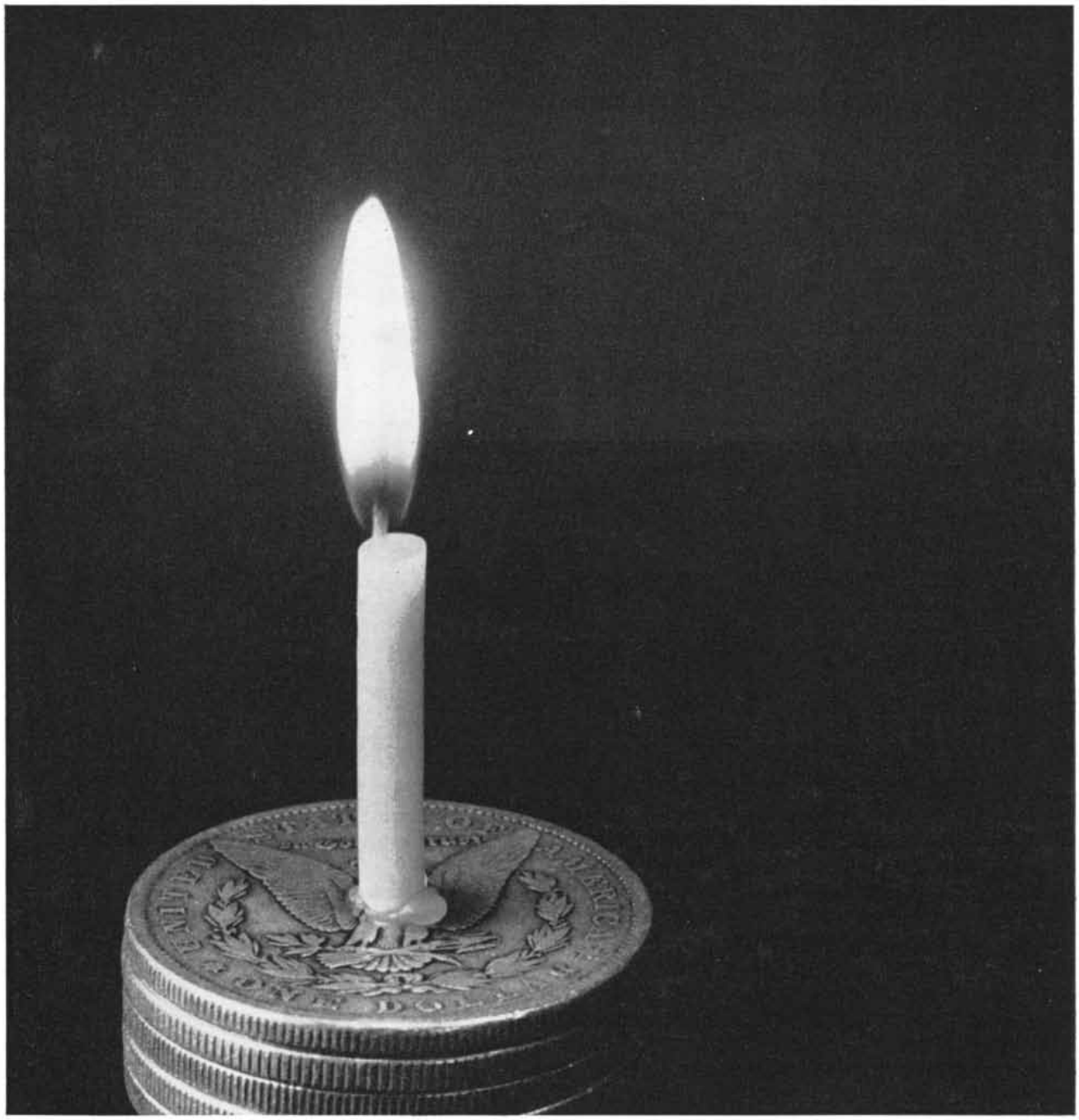
HILL THEORY also starts with lightning stroke that brings on partial ionization in air (*1*). Somehow the charges become separated so that the situation resembles a miniature thundercloud (*2*). Then tiny discharges between parts of the cloud give the ball its appearance of luminosity (*3*). This model stores all the energy inside and has no continuing supply.

lated to the frequency of the radiation furnishing the energy. Kapitza pointed out that the reported size of lightning balls indicates radiation in the range of several hundred megacycles, which is part of the radio-communication band. He simply made the assumption that during a thunderstorm there is a great deal of such radiation around. Noting that lightning balls frequently come through doors and windows, and particularly down chimneys, Kapitza wrote that these apertures were of an appropriate size to act as wave guides for the radiation. Bead lightning, in which small balls appear to be strung together, might arise, he added, from the formation of several small balls at adjacent antinodes.

A number of investigators have studied the problem of the stability of a Kapitza lightning ball and have agreed that the ball would form at an antinode (the point of greatest electric field strength) and then move to a node (the point of least strength), where it would tend to stay. If it should start to move away from the node, radiation on both sides would push it back. Thus the ball would be held loosely in place and would follow the vagaries of the radiation as it moved about. This could account in a reasonably natural way for the apparently capricious motions of some lightning balls.

There are two major troubles with the Kapitza theory. In the first place, a large amount of ultrahigh-frequency radiation has never been detected during a thunderstorm. In fairness to the theory it should be said that such radiation need not arise very often, since ball lightning is so rare. The fact remains that the communication bands in this range of frequencies, which are used by aircraft, are known to be relatively free of static during a thunderstorm. This suggests, of course, that there is little natural radiation at these frequencies.

The other trouble is that the Kapitza theory completely fails to account for the water-butt observation. A ball operating according to the Kapitza mechanism would have had enough energy to burn through the telephone wire and to scorch the window frame, but when it fell into the water butt it would have been completely cut off from its energy supply. Even salt water will not conduct enough electromagnetic radiation to supply a kugelblitz, much less a kugelblitz energetic enough to bring four gallons of water to a boil and keep it there for many seconds and perhaps minutes. Even if the Kapitza model involved energy storage, which it does not, the



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ball would not contain enough energy to raise the water to a high temperature. In the Kapitza model recombination occurs constantly, converting radio energy into light. The energy required to illuminate a sphere 25 centimeters in diameter until its surface glows with the brightness of a fluorescent lamp is 250 watts (allowing for the 10 per cent efficiency of the typical lamp). In fact, although the lamp is a pretty bright object, in four seconds it will use up only a kilojoule (a thousand joules) instead of the megajoule or more that a completely ionized ball of air 25 centimeters across could contain. Hence if one is to accept the Kapitza theory, one must completely discount the water-butt report. Since there is no way to verify the report, the credibility of the Kapitza theory rests in the end on the frequency with which large quantities of radiation accompany thunderstorms, and this remains to be determined.

Two alternative explanations of ball lightning involve the storage and expenditure of energy at a rate suitable for the phenomenon. The first explanation is suggested by the jelly doughnut and its stored megajoule. Chemical energy is in fact very efficient. One ounce of heating oil also contains a megajoule. Could not a flaming mass of pitch, ejected from a tree that has been hit by lightning, account for some observations of ball lightning? Unfortunately there is too much variety in kugelblitze for them all to be explained in this way. The air at 10,000 feet, where the lightning ball damaged the propeller of the Soviet airplane, would not contain lumps of such combustible material.

Edward L. Hill of the University of Minnesota has offered another interesting suggestion. He discounts the plasma aspects of the phenomenon largely because plasmas recombine too quickly. Instead he suggests that the lightning stroke preceding the ball somehow induces a separation of positive and negative charges carried by atoms, molecules, clumps of molecules, bits of dust and other minute objects in the air. It is known that charges carried in this way and not by free electrons and ions do not recombine so quickly as the charged particles in a plasma. Hill's model is virtually a miniature thundercloud. In the full-sized cloud, however, concentrations of positive and negative charge are separated by considerable distances. Hill proposes that in the case of the lightning ball the positive and negative particles stay more or less in their separate locations until the turbulent motion

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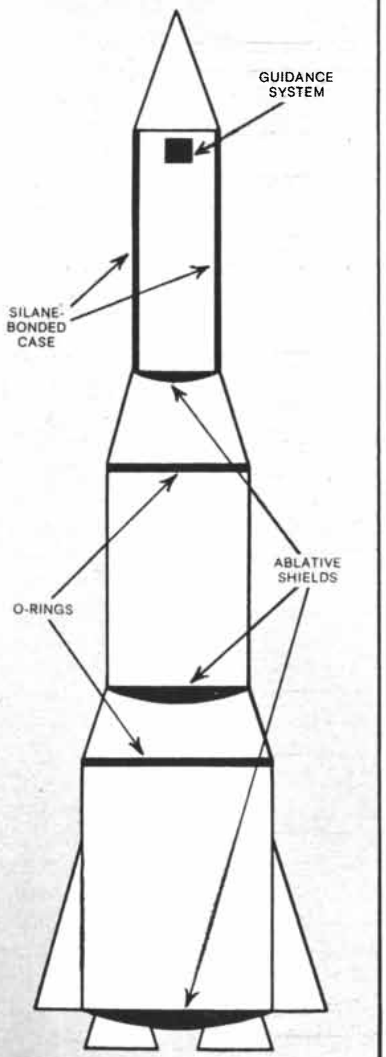

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of the air creates a situation in which the strength of the electric field exceeds the minimum necessary to produce an electric discharge, i.e., lightning. In the usual kind of lightning this occurs over distances so large that well-defined lightning strokes appear; in Hill's model everything happens on such a small scale that the startled observer might see the discharge as a uniformly illuminated ball. Hill's idea may explain the appearance of the ball, but it leaves open the question of how the charges are separated in the first place.

Hill credits the water-butt experiment sufficiently to propose that his model contains at least a megajoule of stored energy. The model would work just as well if it contained only a kilojoule. The theory does not stand or fall according to the amount of energy the ball might contain, as long as the energy is enough to account for the luminosity. Hill's theory is primarily an effort to account for the long life of the kugelblitz.

Several other hypotheses to explain ball lightning have been offered, but they leave us as far from any real understanding of the phenomenon as the Kapitza and Hill theories do. No theory accounts for all the observations. Meanwhile the theories are inspiring efforts to produce lightning balls in the laboratory. The Bendix Research Laboratories has succeeded in creating small localized regions of ionized luminous gas by focusing microwaves in a small volume. Confinement of the luminous region occurs simply because the microwave generators are adjusted to achieve this. The glowing region cannot move about like a kugelblitz. Similar experiments have been performed elsewhere in the U.S., the U.S.S.R. and other countries, but none have made lightning balls.

If it is ever discovered that the lightning ball is a stable configuration for a plasma, the finding will have considerable importance for the thermonuclear power program. This, of course, is why some workers are studying the matter. The Oak Ridge survey was inspired by this possibility; in fact, I became interested in the subject during a summer spent working on the power problem at the Los Alamos Scientific Laboratory. As far as I know, no one working in the field thinks the kugelblitz can serve as a model for a thermonuclear reactor, but it may hold important lessons. Moreover, as long as we do not really know what a kugelblitz is, it holds out the hope that there is such a thing as a stable plasma configuration.

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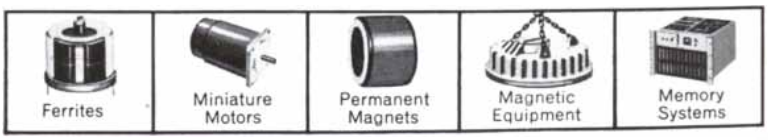


The Operation on President McKinley

An hour after he was shot in 1901, McKinley underwent surgery. A recently discovered record kept by one of his doctors provides a detailed account of the unsuccessful effort to keep him alive

by Selig Adler

The waning summer of 1921 caught the U.S. in a "back to McKinley" mood. Another handsome, genial Ohioan was in the White House, and his "front porch" campaign, a careful imitation of McKinley's, was still fresh in the mind. The unrest of the postwar decade had already begun, but the turbulence only intensified the longing for the old-fashioned Republican normalcy, personified by Warren G. Harding.

Memories of McKinley were particularly keen in the pleasant little city of Kenosha, Wis., because on Labor Day it was recalled that one of the assassinated President's physicians was vacationing in town. Since the next day—Tuesday, September 6—would be the 20th anniversary of the shooting at the Pan-American Exposition in Buffalo, a local reporter interviewed Dr. Charles G. Stockton. The serene, white-mustached internist sat in a comfortable chair on the veranda of the house of his son-in-law's parents.

EDITOR'S NOTE

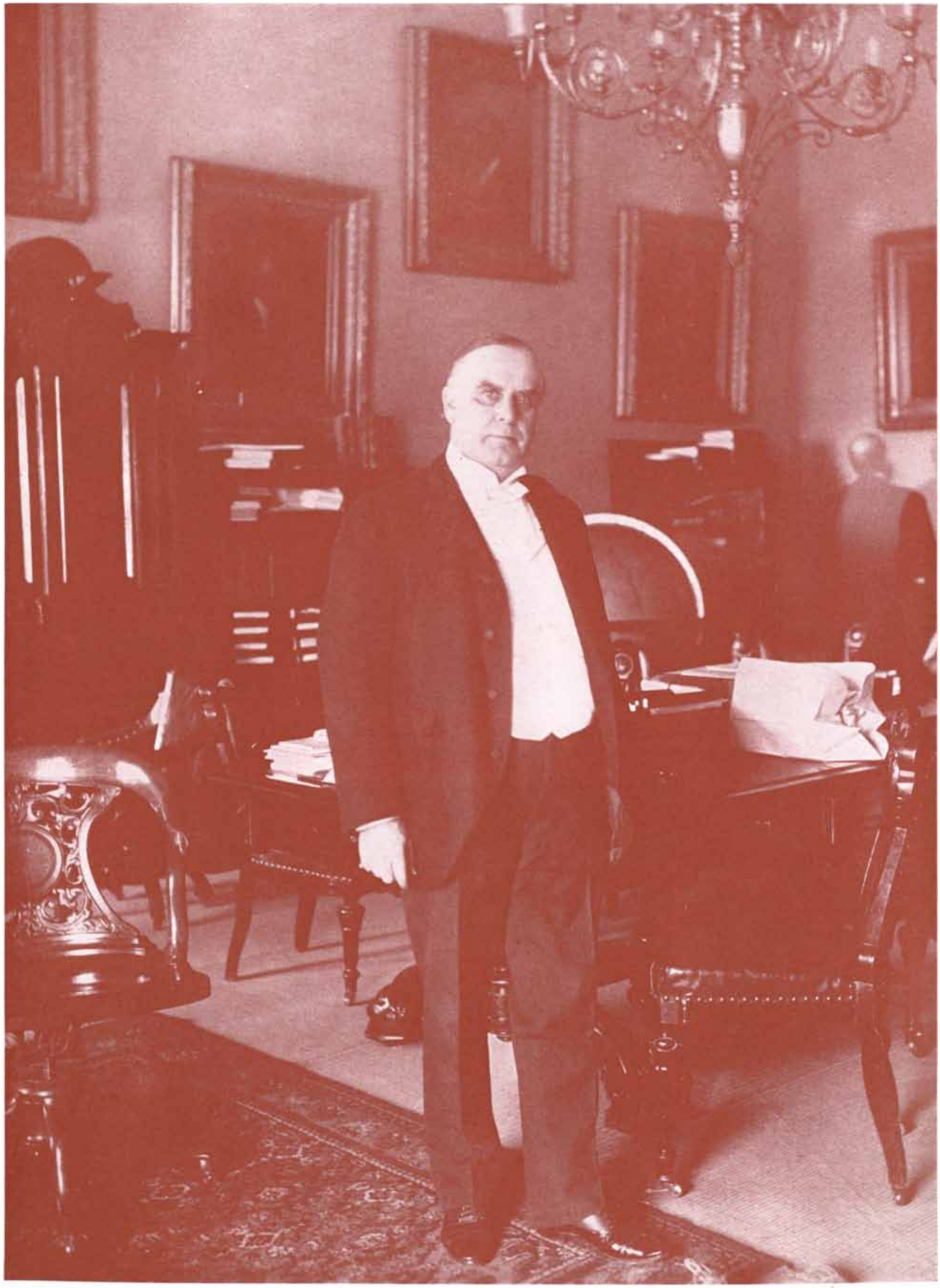
The author wishes to thank his colleagues Professor John T. Horton and Professor Julian Park for their counsel on the historical aspects of this article. Dr. Nathan Back, Dr. Samuel Sanes, Dr. Joseph Sherman, Dr. Herbert A. Smith and Dr. Philip B. Wels assisted him with the medical aspects. He also wishes to acknowledge the kindness of Mrs. Stockton Kimball in making available to him the scrapbook of Dr. Charles G. Stockton, one of the physicians who attended President McKinley after his shooting.

"Yes," he said, "it was my great privilege to attend President McKinley in his last illness. . . . [He was] the best patient I ever had. . . . I am not a surgeon, but I was called to care for the medical aspects of the case." Stockton praised the emergency operation performed on the President but explained that because the bullet had damaged the patient's pancreas he was doomed.

Stockton could have added a good deal more; no one else had in his possession so complete a record of the shooting and its aftermath: letters, newspaper accounts, magazine articles and professional papers, gathered from all over the world and mounted in a thick scrapbook. The reticent physician did not choose, however, to tell all he knew. There was good reason for his restraint. Divergent opinions of the operation were still muted in the surgical clinics of the University of Buffalo Medical School, from which Stockton had retired two years earlier after 31 years of distinguished service. The scrapbook was preserved by his grandson, Dr. Stockton Kimball, dean of the Medical School from 1946 to 1958. Discovered in a closet some four years after Kimball's death in 1958, it was placed by Mrs. Kimball in the hands of the author at the State University of New York at Buffalo. It casts a new light on the events following the shooting.

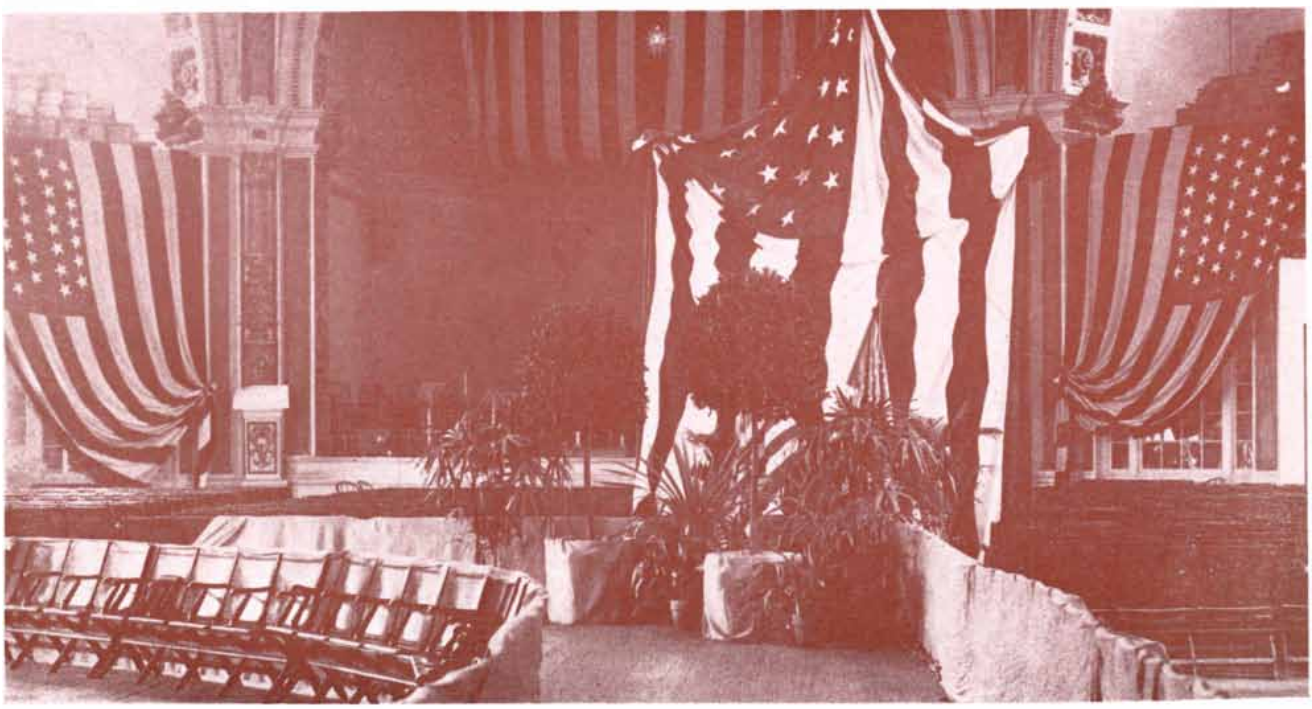
The Pan-American Exposition, writes Walter Lord, "was one of the most imaginative of the great fairs that were currently the rage." Projected shortly before the outbreak of the war with Spain, its main object was to promote New World cultural and economic unity by displaying products of Western Hemisphere ingenuity. The management of the exposition leased a large tract of land in the undeveloped northwestern sector of Buffalo, adjoining the lake in Delaware Park. When the exposition opened on May 1, 1901, it was a remarkable spectacle. With Spanish baroque as its dominant motif, it abounded in pastel missions, gilt-trimmed belfries and coral arcades. To add an authentic Latin touch the Royal Mexican Artillery Band was present. Victorian visitors were pleasantly shocked by bullfights and the dances of "Señorita Chaquita." At the far end of the exposition grounds lay the midway, where those not seeking to be shocked could view a captive balloon, an ostrich farm and a cyclorama of the Johnstown Flood. Towering above the grounds was the huge Electric Tower, a nightly reminder that Buffalo was only 18 miles from Niagara Falls, the waters of which had recently been harnessed for the generation of electric power.

A cool, damp summer kept the total number of visitors below expectation. In August, however, the weather improved, and the exposition's sponsors felt certain that the forthcoming visit of the President would stimulate attendance. McKinley, who had made his Canton, Ohio, home a summer White House, was anxious to make the trip; he regarded such fairs as "timekeepers of progress." His private secretary, George B. Cortelyou, was less enthusiastic. Cortelyou knew that in spite of the assassination of two Presidents within 36 years, his chief would be guarded by only two Secret Service men. He was particularly worried about the public reception scheduled for Friday, September 6. The President had twice refused to cancel any of his plans. Taking what steps he could, Cortelyou put a third Secret Service man aboard the special train that left Canton on the morning of Wednesday, September 4, and wired Buffalo to ask for extra precautions.



WILLIAM McKINLEY, 25th President of the United States, posed for this photograph in his office at the White House at some time in 1898, the second year of his first term. He was assassinated three years later, some 10 months after his election to a second term.

TEMPLE OF MUSIC at the Pan-American Exposition in Buffalo, N.Y., was the site of the public reception at which President McKinley was shot. This photograph, probably made on the day of the shooting, also shows the Horticulture Building, in the background.



INTERIOR OF TEMPLE OF MUSIC is seen as it appeared on the day of the reception. The large flag at center marks the corner of the aisle of cloth-draped chairs along which the public passed. McKinley's approximate position was near the potted bay tree at right.

On its arrival the train of wooden Pullmans carrying the Presidential party was switched over to the special tracks leading to the exposition grounds, which it reached at 6:30 p.m. Factory whistles blew, brass bands played and cannons boomed as the engineer applied his brakes. An inexperienced artillery lieutenant fired his salute so close to the tracks that the concussion smashed the windows in one of the cars. Mrs. McKinley, epileptic and excitable, was so upset that the President hurried the party along to the home of their host, John G. Milburn, a prominent Buffalo lawyer and president of the exposition.

Attendance at the exposition on Thursday, September 5, which had been designated President's Day, broke all records. McKinley's speech was an important event in American history: the Civil War major who had hitherto staked his career on a "prosper America first" protectionism declared economic isolationism at an end and called for a reciprocal tariff policy to promote international trade.

On Friday the President arose refreshed and looking forward to a full day's activities that would include a trip to Niagara Falls and a trolley ride around the scenic Gorge Route. After lunching at the International Hotel at the Falls, the party boarded a special train for the return trip to Buffalo. Reaching the exposition grounds at 3:30 p.m., the President asked his physician to escort his wife to the Milburn home while he made ready for the public reception. The reception was to be held in the Temple of Music, a building garishly decorated with mottled colors. The apprehensive Cortelyou had insisted that it last only 10 minutes.

A crowd queued up at the east entrance of the Temple, awaiting the opening at 4:00 p.m. Inside the building the grand marshal of the exposition, Louis L. Babcock, had arranged an aisle that ran in a straight line to the center of the floor and then turned at a right angle toward the south exit. At the bend of the aisle the President stood under a flag-draped wooden frame flanked by potted palms and bay trees. His guard, totaling about 50 men, seemed adequate; at the last moment Babcock had added 11 enlisted men from the 73rd Coast Artillery to the Secret Service men, exposition guards and Buffalo detectives. Nonetheless, a number of cardinal security precepts were violated. The soldiers who helped the exposition guards to line the aisle were unarmed and untrained in police work. The obvious necessity of keeping a large space clear on all unprotected sides of the chief of state was entirely overlooked. The Secret Service men should have been standing next to the President, and they should surely have checked into the fact that a man standing in the line had his hand bound up in a handkerchief.

The result of these oversights is perhaps too familiar to require detailed repetition. McKinley, who prided himself on a "50 a minute" handshake that firmly but gently prodded the recipient on his way, signaled to hurry the crowd along. As Cortelyou was counting off the minutes remaining before the doors would be shut, two shots were fired; their sound was muffled by the handkerchief, which covered a .32-caliber revolver. The President shivered and doubled forward, clutching his white waistcoat. He muttered "Cortelyou" as the stunned secretary helped him to the nearest chair.

There was a confused scrimmage on the floor, during the course of which a large bystander seized the innocuous-looking redheaded young assassin and a detective punched him in the face. Leon F. Czolgosz was then handcuffed and, because of the distinct threat that he would be lynched, quickly taken from the exposition grounds. Pronounced sane and responsible by five alienists, the pre-Freudian term for psychiatrists, he was declared "the product of anarchy" and received "swift and decent justice" some seven weeks later in the electric chair at the prison in Auburn, N.Y.

Today it would seem that the alienists paid too little attention to the question of Czolgosz' sanity. Lincoln was assassinated in an "age of hate," when the passions generated by four years of war were almost irrepressible. Garfield was killed in an era of intense partisan strife. Correspondingly, Czolgosz was believed to be motivated by a dangerous foreign ideology whose proponents were said to be associated with the assassins of the Empress of Austria-Hungary, the President of France, the King of Italy and the Prime Minister of Spain. There is evidence, however, that Czolgosz had determined to kill the President before he decided he was an anarchist. This latter idea appears to have been a delusion: the anarchists with whom he came in contact regarded him as a spy. To make matters worse for him, McKinley was an amiable man who was widely held in affectionate esteem, even by his political opponents. A clue to these sentiments is provided by the fact that the minister who presided over the Washington funeral services for McKinley said from his pulpit on September 8 that if he had been present at the shooting he would have provided the leadership the crowd needed for an on-the-spot hanging. Shortly after Czolgosz' remains were destroyed by a carboy of sulfuric acid poured into his open grave, two distinguished Boston physicians disclosed that he had suffered a severe mental depression three years before the assassination.

The first physician to arrive on the scene after the President had been shot was George M. Hall of the Sanitary Staff of the exposition. McKinley was carried by stretcher to a motor ambulance, which then clanged its way through a silent crowd to the exposition's Elmwood Avenue entrance. Here stood the tiny Exposition Hospital, staffed by interns, senior medical students and half a dozen nurses who served in rotation. Intended only for emergencies, it was scarcely equipped for major abdominal surgery. After the wounded President had been placed on the operating table and been undressed, a senior medical student, Edward D. Mann, ordered a nurse to administer an injection of morphine and strychnine to ease the pain and quiet the patient for possible surgery. Mann was the son of Buffalo's leading gynecologist, and it is quite possible that as the frantic hunt for surgeons began he told the President's host John Milburn where his father could be reached.

Twenty-two minutes elapsed before the first surgeon arrived at 4:45 p.m. He was Dr. Herman Mynter, who had served in the medical corps of both the army and the navy in his native Denmark before he migrated to Buffalo in the middle 1870's. Recalling that he had chatted with Mynter the day before, McKinley smiled wanly and said: "Doctor, when I met you yesterday, I did not imagine that today I should have to ask a favor of you." Mynter's examination revealed that the wound was deep and reaffirmed the opinion of other physicians present that immediate surgical intervention was necessary. The President was informed of the decision; conscious and composed, he gave permission for the operation.

So far no decision had been made as to who was to be in charge. Cortelyou told Milburn: "You know all these men. When the right one arrives, tell me." A few minutes later Dr. Matthew D. Mann walked in briskly and Milburn whispered: "That is the man for the operation." Mann quickly chose Mynter and

LEON F. CZOLGOSZ was about 28 years old when he shot and killed McKinley. This photograph of him was made several years earlier. He was executed seven weeks after the shooting.

IVER JOHNSON .32 CALIBER REVOLVER was concealed by Czolgosz in a handkerchief. Czolgosz fired two bullets; one bullet (*second from right*) was deflected and later recovered.

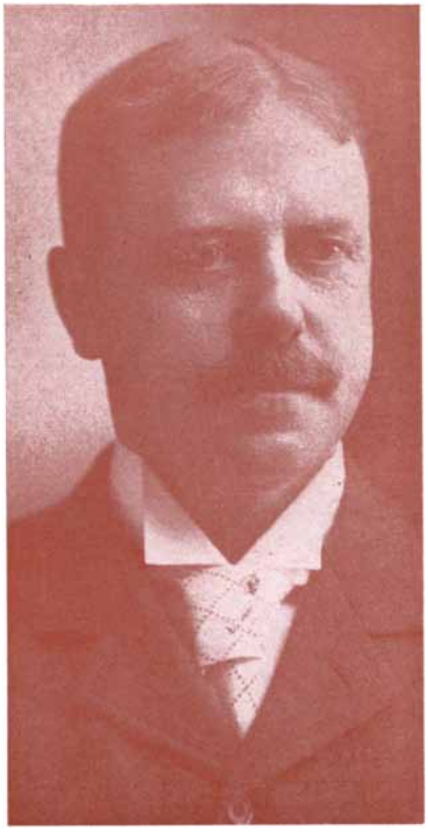
other assistants and they scrubbed up in haste, not waiting to cover their heads and whiskers with caps and masks.

Born in Utica, well trained in this country and abroad, Mann was 56 years old and at the height of his career. Called to Buffalo from the Yale Medical School, he had won wide recognition in the teaching and practice of gynecology. He did not limit his practice to gynecology and obstetrics, but he was not expert in surgery of the upper abdomen, and there is good reason to believe that he had never operated on a gunshot wound. A "beautiful operator" whose neatness and speed were admired even by those who resented his petulance, Mann belonged to the old school of antisepsis. Although he was not unaware of the aseptic surgery that followed the discoveries of Louis Pasteur, he was still attached to the "carbolic acid" system of Joseph Lister, which sought to cleanse a wound rather than to prevent bacterial invasion of it.

It is possible that Mann's extreme self-confidence kept him from insisting that Mynter, who had had much more experience with such cases, perform the operation. On the other hand, much can be said for Mann's insistence on immediate surgical intervention with equipment he knew was inadequate. To have removed the patient to the newly built operating amphitheater of the Buffalo General Hospital and to await there the arrival from Niagara Falls of the most skilled general surgeon in the area, Dr. Roswell Park, would have been gambling on a possibly concealed hemorrhage and might have involved increased risk of postoperative peritonitis. If Mann and Mynter had time for any reflection, they may have recalled that recently published medical statistics had warned that in such wounds the longer the delay, the worse the prognosis. The experience of the recent Spanish-American and Boer wars favored conservative treatment for abdominal wounds caused by rifle bullets, but soft lead pistol bullets of low velocity introduced other considerations. Projectiles of this kind made ragged tears and were likely to carry infectious agents in their passage through the body. It was generally conceded that such wounds demanded immediate and radical treatment, although only 17 years had elapsed since the Swiss surgeon Dr. Emil Theodore Kocher had performed the first successful operation for gunshot wound of the stomach. Mann decided that any delay might result in the President's death.

HERMAN MYNTER was the first surgeon to arrive after the shooting. He reaffirmed the opinion of the physicians already present that immediate surgery was required.

MATTHEW D. MANN, a well-known gynecologist, arrived a few minutes after Mynter and was chosen to operate on McKinley. His assistant in the operation was Mynter.



ROSWELL PARK, a noted surgeon, would have been chosen to operate if he had been available, but he did not arrive until shortly before the operation was completed.

All accounts agree that the operation, which was begun at 5:20 p.m., was performed under heavy handicaps, the heaviest of which was the lack of proper surgical equipment. Of the two bullets fired by Czolgosz, one had been deflected from the breastbone. The other had entered five inches below the left nipple, perforating both front and back walls of the stomach. Mann opened the peritoneum and found the bullet hole in the front wall of the stomach. He had to enlarge the incision to get at the back wall, but he was unable to follow the track of the bullet any farther. All those present concurred in his decision to stop probing; the President's pulse was weakening and signs of shock were apparent. At this point Mann probably should have risked further exploration; subsequent developments were to prove that damage had been done beyond the stomach. It is possible that a surgeon better acquainted with firearms would have known that a jacketless bullet does increasing harm as it makes its relatively slow way through tissue. Mann, however, followed the accepted axiom that "a bullet after it ceases to move does little harm." He found no intestinal wound or damage to the structures behind the stomach; he therefore assumed that the bullet had passed, without doing further serious damage, into the muscles of the back.

Mann trimmed the tissues around the bullet track in the abdominal wall and closed the surgical incision moderately tight. He had already sutured the stomach perforations with fine black silk and had irrigated the stomach wounds with hot salt solution. Because he believed that drainage was not indicated he decided against this procedure—a decision later deplored by his critics.

Granting the assumption that removal of the patient to an established hospital would have involved undue risk, a good deal can also be said in favor of the procedure adopted by Mann. Doctors in those days usually carried their own instruments to operations, but Mann had arrived at the exposition grounds in response to a vague call that did not specify either the patient or the nature of his illness. He used the instruments in Mynter's pocket case, and not until the operation was almost over did he learn that Roswell Park's instruments were in the anteroom. They had been brought there on the insistence of Park's trusted housekeeper, who had told the messenger seeking her employer that he usually carried this case with him to operations. Mann was forced to work without retractors and in the dim light of a low-windowed room shielded by awnings. Moreover, he found the stout President's abdomen so protuberant that he was operating at the darkened end "of a big hole"—a factor that seriously impeded the search for the terminus of the bullet track. The handicap of poor visibility was partially overcome by the arrival of McKinley's personal physician, Dr. Presley Marion Rixey, a peppery, bushy-mustached naval surgeon from Virginia. He immediately made himself useful by trying to direct the fading sunlight into the incision with a mirror, and later by rigging up an electric light.

Before Mann had completed the operation one of the most resourceful surgeons in the country arrived at the scene. Under the circumstances he could only concern himself with minor postoperative arrangements. He was Roswell Park, the son of a Connecticut minister and sometime college president. Reared and

VICE-PRESIDENT THEODORE ROOSEVELT briefs reporters on the condition of the President, who had been moved to the home of John G. Milburn, president of the exposition.

SECRETARY OF THE NAVY JOHN D. LONG is questioned by reporters after leaving the Milburn home. McKinley appointed Long, a former governor and congressman, in 1897.

SENATOR MARK HANNA, with cane, converses outside the Milburn home. At center is Secretary of Agriculture James Wilson and at right Senator Charles W. Fairbanks.

educated in the Middle West, Park had rounded out his professional training in Europe and become a pioneer practitioner of aseptic surgery in the U.S. Called to the University of Buffalo chair of surgery 18 years earlier, Park, at 49, was handsome, vigorous, erudite, versatile, witty and unusually handy with surgical instruments because he was ambidextrous. As medical director of the exposition and the recognized dean of general surgeons in the area, Park would in all probability have been chosen to operate had he been available earlier. Shocked by the mismanagement of the Garfield case, he had written and lectured on the treatment of gunshot wounds. He had long stressed the necessity of surgery extensive enough to include *débridement*—the removal of injured or contaminated tissue—of the entire bullet track and full drainage.

Park had gone to Niagara Falls that Friday to remove some cancerous nodes from the neck of a Mr. Ransom. In the midst of this delicate procedure his assisting surgeon informed him of the shooting in Buffalo and told him that he was wanted at once. Park refused to leave until he was certain that he had done all in his power for his patient and could entrust him to the care of another surgeon. When he arrived at the Niagara Falls railroad station, he was disappointed to find that there was no special train ready for him. He had to wait until the next Michigan Central train came in from Detroit. He boarded it and got off at Black Rock in northwestern Buffalo, where, after another delay, a special engine carried him to the exposition grounds.

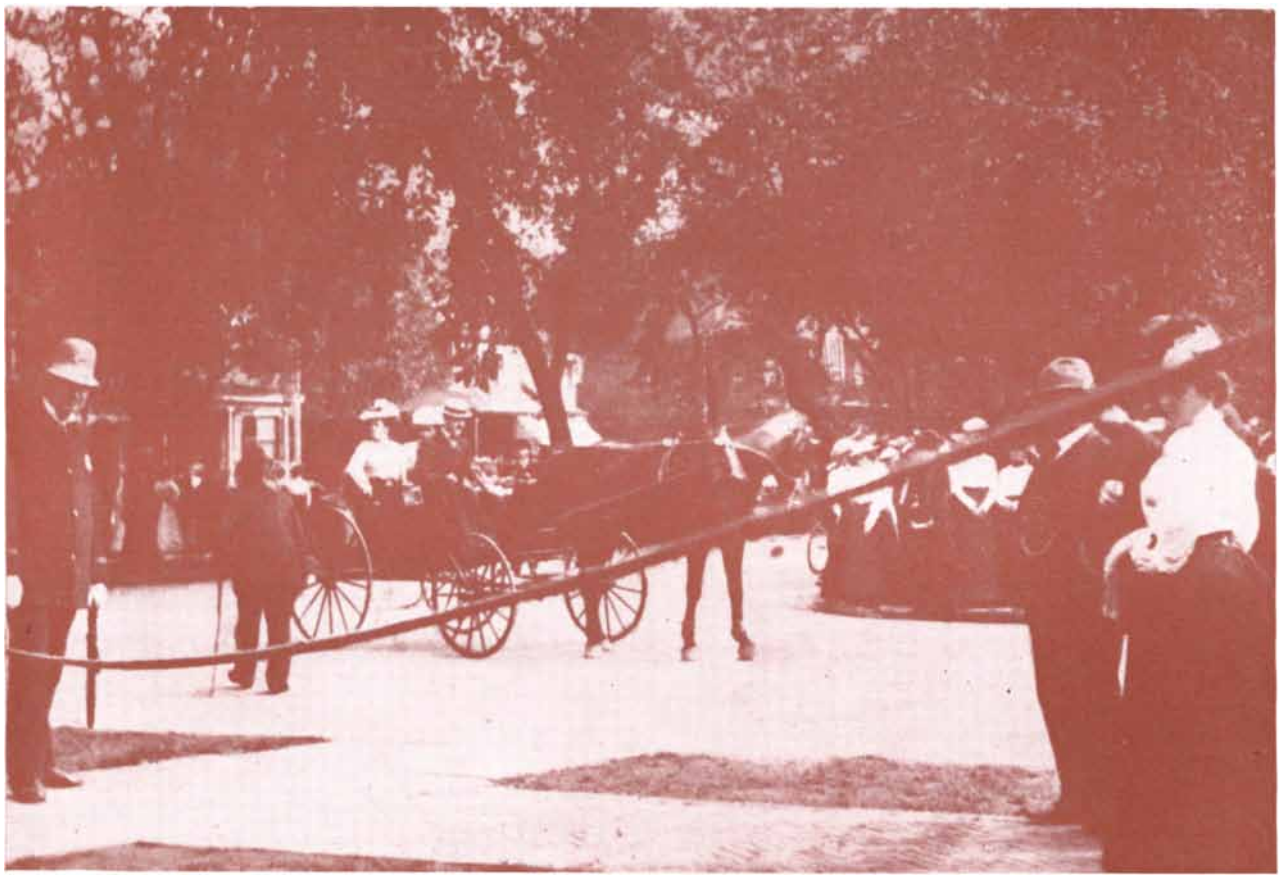
Park removed his suit coat, scrubbed up hastily and found Mann ready to suture. Mynter advised a drain through the surgical incision, but when Park was consulted, he replied that Mann alone had the intimate knowledge of the details that must control the choice. Subsequently Park reasoned that the decision not to drain was "probably unfortunate," that this omission allowed seepage of the pancreatic juices that ultimately proved fatal. According to Julian Park, the son of Roswell Park and long the dean of the University of Buffalo College of Arts and Sciences, it is possible that his father was taken by surprise by the immediate decision confronting him and offered his criticism only in hindsight. In the light of all the evidence, however, another explanation is more plausible. Roswell Park felt that Mann and Mynter had operated in un-

due haste; their preliminary examination should have convinced them that the President, with a pulse of 84, was in no immediate danger. McKinley, Park stated privately to a few close friends, should have been taken at once to the Buffalo General Hospital. Although he thought that Mynter was better equipped to do this kind of surgery, neither Mann nor Mynter, to use his words, "had ever practiced posterior, or through-and-through, drainage of the upper abdomen." Nor is it certain that even the ingenious Park could have accomplished this unusual kind of drainage with a man of McKinley's girth, handicapped as he would have been by poor lighting and meager equipment. Park's most trenchant criticism, it now appears, was against the decision to operate at the exposition grounds, where complete drainage would have been impossible at the hands of men inexperienced in the technique. At the time he probably held his peace because the kind of drainage he really wanted would have necessitated a tour de force at the operating table, and that was entirely out of the question.

A curious event reinforced Park's opinion, although it certainly does not prove that with different treatment McKinley would have recovered. A few weeks later a young woman in Buffalo attempted suicide in a bizarre manner. Having read detailed accounts of McKinley's shooting, she marked a spot on her abdomen and shot herself there. Park, who treated her, found her wound remarkably similar to the President's: the bullet had penetrated both walls of the stomach and had passed on to injure the pancreas. Park made a clean incision of the entire track and drained it from front and back. The patient recovered.

This clinical test of Park's theory came after the fatal termination of the President's case. At 6:31 p.m. on Friday, September 6, the doctors were cautiously optimistic as they acquiesced to the President's request that he be taken to the Milburn home for convalescence. McKinley was groaning audibly as he was carried into the house to a master bedroom that had been made ready for his arrival by two experienced nurses. "The result," stated the physicians in their first official bulletin, "cannot be foretold. The condition at present justifies recovery." This hope was not overoptimistic; Mann had worked quickly and the patient had withstood the operation well. The period of waiting had begun.

By Saturday morning the intersection beside the Milburn house had acquired the appearance of a military out-



CROWD OUTSIDE THE MILBURN HOME awaits news of President McKinley's condition. The watch was punctuated by morning, afternoon and evening medical bulletins, and by the arrivals of cabinet members, senators, congressmen and other Government officials.

post. On orders from the War Department the 14th Regiment, which had just returned from the Far East, camped in a vacant lot across the street and took up sentry duty to prevent all unnecessary disturbances. A special wire connected the Milburn house with the White House. Reporters wrote their stories in a nearby tent. McKinley's chef and house servants were brought from his private Pullman in the railroad yards; they were sorely needed for the 140 meals sometimes served daily to high Government officials who rushed to Buffalo after the shooting. Cabinet members made their headquarters the Buffalo Club, where a special wire to the Milburn residence kept them informed of developments in the President's struggle for life.

Not many hours passed before the watch over the wounded President had become routine. There was little tedium, however; hardly an hour went by without the arrival of some celebrity. Excitement would mount shortly before the release of the morning, afternoon and evening medical bulletins. At first the doctors, apprehensive of blood poisoning or peritonitis, were cautious; they let the public make what it could of temperature readings, pulse and respiration rates, urinalyses and blood counts. An elimination-conscious generation received a full description of the varied and numerous enemas and cathartics administered to the patient.

Park had been told by the President's physician, Rixey, that he considered him in charge of postoperative care. The situation, however, was delicate; since Park had not performed the operation he was reluctant to intrude. This was perhaps unfortunate, if only for the reason that Park was habitually cautious in prognosis. The situation changed on Sunday with the arrival in Buffalo of one of the nation's outstanding abdominal surgery consultants, Dr. Charles McBurney of New York. A dozen years earlier McBurney had pioneered the diagnosis and cure of appendicitis. "McBurney's point" of tenderness in the abdomen was a household medical word, and his celebrated small incision for appendicitis had been widely imitated. After McBurney had examined the President twice, the bulletins to which his signature was now added became increasingly optimistic. On Monday the newspaper accounts written by the more enthusiastic reporters promised recovery.

Stating categorically that he found no evidence of peritonitis, McBurney called the operation "the epoch of the century in surgery." Such an unfavorable symptom as a persistently rapid pulse was rationalized as being natural to McKinley's constitution; his elevated temperature was also declared not alarming. When Mann and Mynter tried to suggest to reporters that the crisis was not yet past, McBurney interrupted their conversation and talked of moving the President to the White House within a matter of weeks. His remarks were embroidered in the newspapers; in one account it was said that the bullet rested in a place in McKinley's back where it could not have shortened Methuselah's life by a single day.

By Wednesday, September 11, the news was so cheery that Vice-President Theodore Roosevelt, reassured by McBurney, left on the morning train for New York. Cabinet members also made their departure, confident of full re-

covery. Before he too left, McBurney declared that the door had been locked against the "grim monster of death" by a triumph of American medical skill.

Bulletin No. 26, issued after McBurney's triumphal departure, described McKinley's condition as being excellent. The President was changed to a fresh bed and given some beef broth, which he welcomed as "a luxurious luncheon." This optimism continued throughout Wednesday afternoon, although the truth was that the patient had been fed by mouth only because he was unable to retain any more "nutritive enemas" of egg and brandy. Moreover, the surgeons had been forced to remove some of the stitches around the incision because of the breakdown of tissue. The fear of peritoneal infection was dissipated, however, when a normal blood count and good peristaltic sounds in the abdomen seemed to indicate that the danger had passed.

McBurney, speeding east on the Empire State Express, had not reached Albany before the Buffalo physicians noted a change. "I am tired, so tired," McKinley muttered. He had not digested some chicken broth, toast and coffee. Searching for the trouble, his attendants noted a jump in the pulse rate and a weakness in the heart sounds. The surgeons, sharing the belief of the day that the contents of the bowel were toxic and could cause intestinal poisoning, called in Charles Stockton for consultation. Stockton, a stomach specialist, promptly ordered a dose of calomel on top of the castor oil that had already been prescribed. When by Wednesday evening the patient had still not completely eliminated the food he had eaten, he was given an additional dehydrating cathartic and enema. After McKinley grew faint as a result, Stockton resorted to heart stimulants.

On Thursday afternoon the patient took a much sharper turn for the worse. A heavy rain drenched the military encampment opposite the Milburn house, but the rain-soaked sentries continued to pace their beats. Soon the word spread that a frantic hunt had begun for the Vice-President in the wilds of the Adirondacks and that Senator Mark Hanna was racing to Buffalo from Cleveland on a special train that was destined to break all previous speed records for the run.

Horses galloped up to the house and away from it all Thursday night, their hoofs ringing out on the asphalt. Occasionally an automobile chugged up to

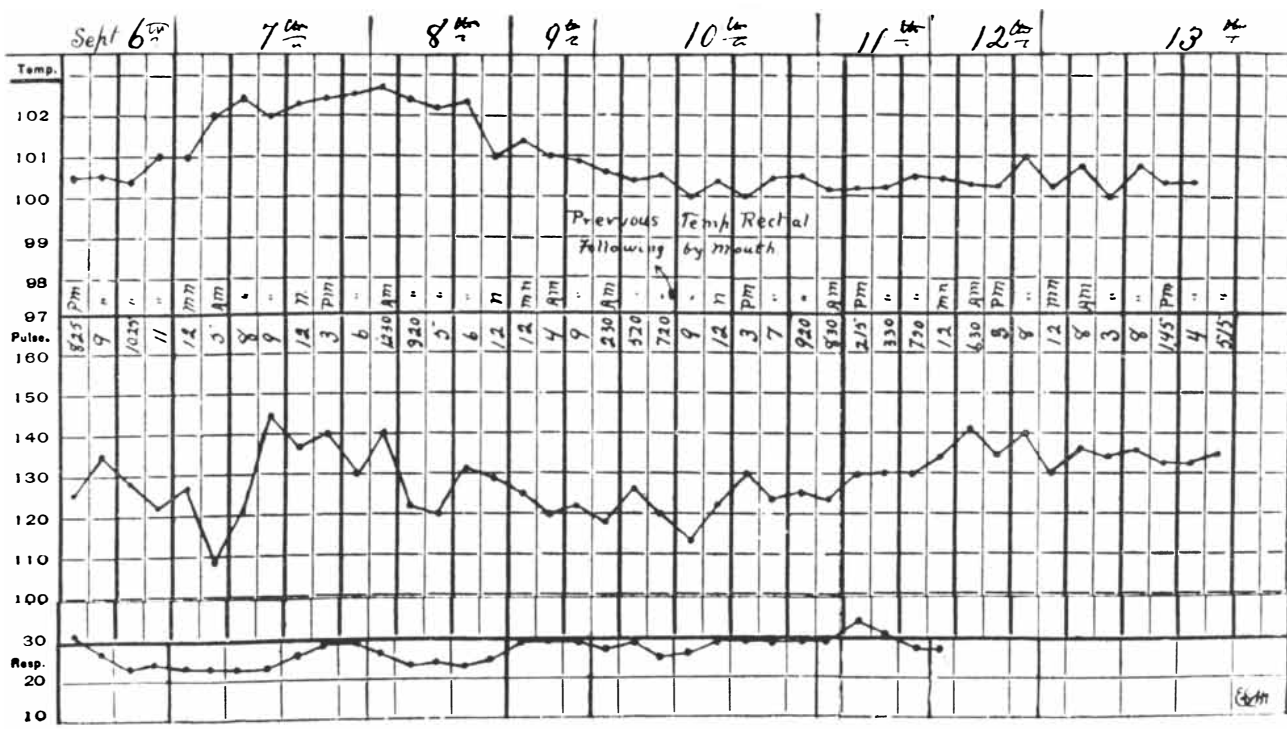
the picket line; with each new arrival the newspapermen rushed from their tent. So it went on Friday the 13th, until the 6:30 p.m. bulletin announced that "the end is only a question of time." The President had already murmured, "Good-by, all, good-by," when a carriage raced up to the Milburn house. McBurney leaped to the ground, but one glance at the waiting reporters told him that the President was beyond help. The hushed crowd outside watched the flickering light in the President's room until 2:15 a.m. on Saturday, September 14. At that hour Cortelyou descended the broad staircase and with a tear-choked voice said: "Gentlemen, the President has passed away."

The autopsy that followed McKinley's death answered few questions and raised many doubts. Conducted by a local pathologist in the presence of physicians representing the Government, the family and the medical profession, the post-mortem was halted by Mrs. McKinley before the bullet could be located. Coroner James T. Wilson oversimplified the findings by a notation on the police blotter that William McKinley, occupation President of the United States, died at 1168 Delaware Avenue of "gangrene of both walls of the stomach and pancreas following gunshot wounds." Published details of the four-hour autopsy, however, gave rise to questions that have never been fully answered.

The surgical incision showed the infection for which it had been opened on the sixth day after the operation. No free pus was found in the peritoneum, which explains the failure of the physicians to note the usual symptoms of serious postoperative complications. There was, however, gangrene in the bullet track behind the back wall of the stomach. The upper portion of the left kidney and the adjacent adrenal gland had been damaged by the bullet, but this trauma was not considered important. The chief post-mortem finding was the injury of the pancreas, with complications. There was a definite fatty change of the heart, a condition that some thought responsible for the rapid postoperative pulse rate and terminal cardiac failure. This evidence, however, was far from sufficient to justify Mann's verdict: that many years of sedentary life had weakened the President's vitality to the point where nature failed to provide a normal healing process.

The united front carefully maintained by the physicians during the course of the illness now fell apart. Mynter, when asked what went wrong, replied bluntly: "I wish you could tell me." Park maintained that the secretions and toxic products escaping from the pancreas had resulted in terminal toxemia. Confusion was compounded when Dr. Eugene Wasdin, present at both the operation and the autopsy, declared publicly that only a poison-tipped bullet could have produced such massive necrosis. Inasmuch as anarchists were known to use poisons, there was much speculation on this score until it was disproved. In the light of our present knowledge, according to a leading pathologist, fluid and electrolyte imbalance must also be taken into account in explaining the unexpected fatal outcome. In passing judgment on McKinley's physicians one must always recall the limitations under which they worked. Laboratory determinations for measuring changes in body chemistry, intravenous feedings, blood transfusions, antibiotics, effective postoperative techniques and medical therapy for acute damage to the pancreas all had to wait for the future.

Certain medical circles in New York City now charged the "provincial" Buffalo surgeons with egregious mistakes in diagnosis, faulty laboratory work that failed to detect the gangrene, limited knowledge of possible complications and, during postoperative care, wholesale ignorance of the true nature of the lesions. Although such charges were disavowed by the majority of the medical journals, many reckless accounts



MEDICAL CHART plots McKinley's temperature, pulse rate and respiration rate, beginning at 8:25 p.m. on the day he was shot. The temperature and pulse readings were discontinued shortly before a bulletin announced that "the end is only a question of time."

were based on them by the newspaper reporters of this heyday of overcompetitive journalism. It is scarcely surprising that *Medical News* published the prayer: "From attendance on persons in high political position, spare us, O Lord."

The McKinley funeral train had hardly left the city when lawyers entered the affair. Ansley Wilcox, a leading Buffalo attorney at whose home President Theodore Roosevelt had been sworn in, was stirred to action by a nasty article in Joseph Pulitzer's New York *World*. Wilcox sent a round-robin letter to Mann and his associates, warning them that they were being slandered. He urged them to meet for sound legal advice in order to "save the profession and the city" from discredit. Meanwhile the Buffalo press issued a counterbroadside ridiculing the "big city" physicians who could produce no better representative than the fallible McBurney. Some New York City newspapers repeated dark hints that McBurney's optimism was a ruse to bolster the stock market for a "well-known New York commercial magnate." In the parlance of 1901 this meant J. P. Morgan, whose name was then a synonym for tricky Wall Street manipulations. Thanks to Wilcox' efforts, the Buffalo physicians issued a statement published throughout the world. They denied serious disagreement, affirmed that conditions prior to the sixth day had warranted a favorable prognosis and repeated their contention that everything had been done to prevent the ultimate catastrophe.

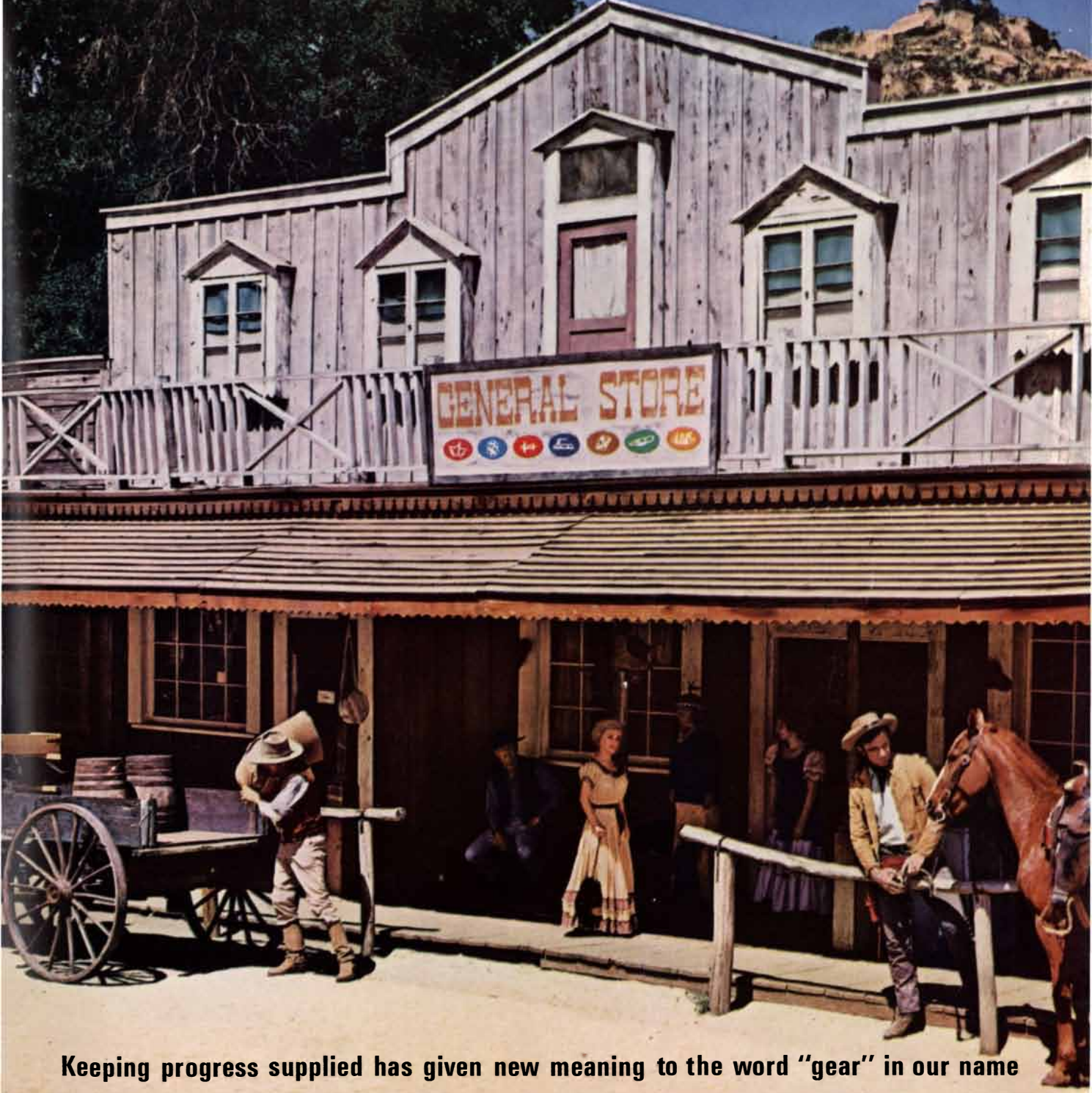
In retrospect the similarities and contrasts between the McKinley and Garfield assassinations are striking. Both crimes were committed by disturbed cranks, sane only in the narrow legal sense of the term. Charles J. Guiteau, who shot Garfield, had a tedious trial in the course of which the prosecution appeared to be seeking fame by taking 11 weeks to prove the obvious. In contrast, Czolgosz' prosecutor, with the tacit consent of the two retired judges who acted as defense counsel, made short work of the trial and execution. Both Presidents were shot twice and in each instance one bullet caused minor damage. There is little doubt that the management of McKinley's case was influenced by the failure of Garfield's doctors to decide on immediate surgery. Mann remarked that if he and his colleagues had not acted promptly the world would have repeated the question asked after Garfield's shooting in 1881: "Why don't they do some-

thing?" Although the wounds of Garfield and McKinley were not at all similar, the autopsies revealed that while both men were alive the doctors did not know where the fatal bullet had stopped. In 1881, with X rays still undiscovered, Garfield's doctors, after unhygienic probing, tried unsuccessfully to locate the bullet by electromagnetic induction and by dissecting bullet-riddled cadavers similar in build to the President. These crude techniques failed to reveal that the slug was only three inches from its point of entry in the lower back. Twenty years later there was an X-ray machine on display at the Pan-American Exposition near the Emergency Hospital, but it was not brought in. Later McKinley's doctors decided that it was not necessary to use the X-ray equipment sent to Buffalo by Thomas A. Edison. Thus when they failed to find the bullet even at autopsy, they were subject to severe criticism.

There were also similar disputes about medical fees following the death of the two distinguished patients. After a good deal of distasteful bargaining, Congress had paid $27,500 for the medical fees incurred during Garfield's protracted fight for life. In 1901 Mann was widely criticized for asserting that McKinley's doctors had been retained by Government officials rather than the family. He added tactlessly that "the dignity of the medical profession demands that Congress pay their bill, and that the services should be handsomely rewarded." The physicians were accused of trying to "mulct" the public treasury by refusing to render a bill to the executors of the late President's rather modest estate. Congress eventually appropriated a sum not to exceed $45,000 for McKinley's last medical expenses. Out of this sum the Treasury Department allotted Mann $10,000, Mynter $6,000, Park and McBurney $5,000 each and Stockton $1,500.

In one fortunate respect, however, the history of the Garfield case was not repeated. Dr. D. Willard Bliss of Washington, in charge of the 1881 group of doctors, lost his lucrative practice and died a poor man. Many of his colleagues also suffered professionally. Mann's reputation was undamaged and his success continued until his death in 1921. The McKinley case probably enhanced the standing of Park, because there was always a strong belief in local circles that he could have saved the President. Nor did McBurney's faulty prognosis harm his later career, which ended just before World War I. The last survivor of President McKinley's principal physicians was Stockton, who died in 1931. Thanks to his foresight in preserving the details, we have this "bedside" view of a surgical episode in American history.

PRESIDENT McKINLEY lies in state at City Hall in Buffalo, on Sunday, September 15. His funeral train traveled to Washington, D.C., and then to Canton, Ohio, where he is buried.



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MICROSCOPIC APHID STYLETS (*vertical orange streak at the bottom of this photomicrograph*) penetrate a single cell in the phloem, or sugar-conducting tissue, of a linden tree. High internal pressures force the sap through the stylet bundle into the body of the feeding insect. The direction of normal sap flow is perpendicular to the plane of this section. Magnification is 2,250 diameters.

How Sap Moves in Trees

It is lifted up to the leaves and flows down with the products of photosynthesis. It can now be delicately sampled by tapping the tiny stylets that a feeding aphid pushes into a single cell

by Martin H. Zimmermann

The topmost leaves of a tree reach for the sunlight dozens and sometimes even hundreds of feet in the air above the deepest-probing rootlets in the ground. From root to leaf an ascending stream of water maintains the living tissues of a tree in the aquatic environment in which plant life originated and in which more primitive plants still flourish. From leaf to root a descending stream of water bears carbon, fixed by photosynthesis in sugar compounds, to build the supporting structure of the tree. Aquatic plants that live entirely submerged do not need a water-conducting system or a self-supporting structure. Practically every part of the plant is capable of photosynthesis, and the cells absorb water and minerals directly from their surroundings. The specialization of tissue to leaf, stem and root came with the conquest of the land. As the competition for sunlight carried the leaves farther and farther from the source of water and minerals in the ground, no evolutionary development was more decisive than that of the two-way water transportation system that appears in its fullest elaboration in the tree.

The mechanism of the ascending stream—which in a tree such as the Douglas fir can lift a prodigious quantity of water more than 200 feet above the ground—was the first to attract the curiosity of investigators. The problem of "the ascent of sap" can now be regarded as solved in its essentials, although many questions remain. The water moves upward, driven by more or less straightforward physical forces, through open conduits formed by cells that have died. What drives the return stream from the leaves is not nearly so well understood, even though the movement is largely downward. Significantly, the cells that convey this stream have not lost their living cytoplasm; physiology as well as physics appears to be involved. For some of the insights into this process that have been gained in recent years, investigators are indebted to the aphid, an insect that feeds on the products of photosynthesis in the stream.

In most trees the water-conducting tissue, called the xylem, and the tissue that transports the products of photosynthesis, called the phloem, appear as distinct systems. Both derive from the cambium, the thin layer of actively growing cells between the bark and the wood. The life cycle of the xylem moves inward into the wood to form the water-conducting conduits and the heartwood of the tree, while the life cycle of the phloem moves outward to form its channels in the innermost layers of the bark. In another large class of plants, which includes the stately palm as well as the grasses and lilies, the two systems can be distinguished only under the microscope, because the strands of xylem and phloem are joined in conducting bundles distributed throughout the cross section of the stem. Movements in the two systems are mostly in opposite directions, but in some cases movement is in the same direction: growing shoots and fruits have to be supplied by both systems simultaneously.

It is a remarkable fact that the xylem cells fulfill their vital function only after their death. By the consequent loss of their cytoplasm and the cytoplasmic membrane that segregates one from the other during growth they form continuous conduits. This, however, is only one of the steps in the transformation that prepares them for their function. Living cells possess a certain rigidity due to the turgor of the fluid contents enclosed in the cell membrane; this turgor is of course lost with the disappearance of the membrane. Before the xylem cells die their cell walls are greatly strengthened with cellulose fibrils and encrusted with lignin. The resulting structure, comparable to reinforced concrete, prevents collapse of the cells when water is pulled through them. Thus the xylem serves a dual function: it not only conducts water but also provides the plant with structural rigidity. It is as though the plumbing system of a house were used as its structural framework as well.

The xylem of the conifers (needle-bearing trees, such as the pine and spruce) shows these trees to be somewhat less advanced on the evolutionary scale than the deciduous, or broadleaf, trees. It is composed of spindle-shaped tracheid cells that overlap one another along their thinner end portions. Water connection between one cell and the cell next in line is provided by small holes called "bordered pits," which allow the passage of water but trap bubbles of air [*see illustration on page 135*]. The wood of the more highly developed broadleaf trees shows the result of another evolutionary breakthrough—a quite literal one. Butted end to end, the water-conducting cells have partly or completely lost their transverse end walls and so form capillaries up to several meters in length. At the same time special fibrous elements have evolved to give the tissue extra mechanical strength.

In certain trees in the early spring, before the leaves are out, water can be found moving in the xylem under positive pressure. If the xylem of the sugar maple is punctured, for example, the sap will flow from the wood. The maple sirup and the sugar that can be boiled from the sap show that it is rich in reserve products of photosynthesis that

have been stored during the previous growing season, ready to support the growth of shoots in the spring. The presence of these materials in the sap of the maple and other trees contributes to the positive pressure—a high osmotic pressure with respect to the water in the ground, which forces the water inward and upward through the trunk.

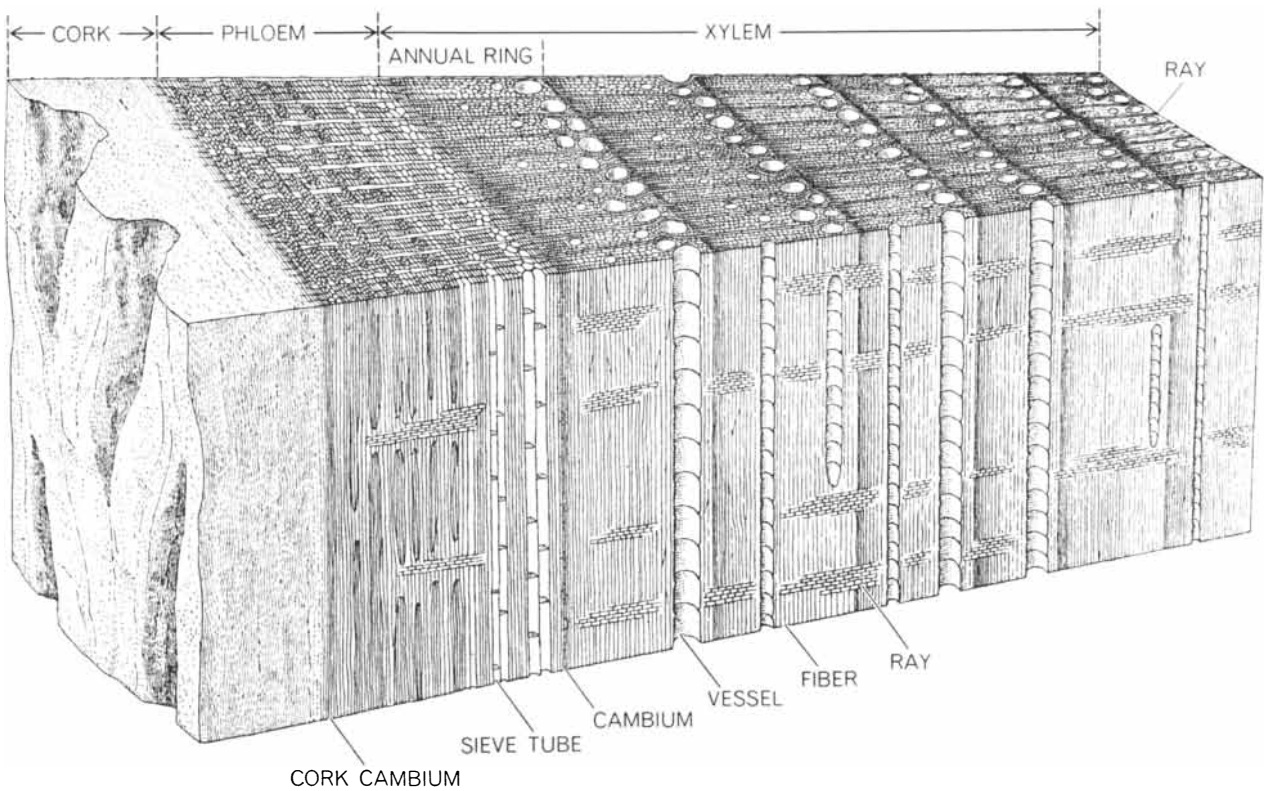
During most of the vegetation period, however, water is pulled up into the trees and the pressure in the xylem is lower than that of the atmosphere. Under the right circumstances, when the xylem is cut, one can even hear the hissing sound of air being drawn into the injured vessels. But this is not the only indication that water is pulled upward in the tree. One of the most beautiful pieces of evidence was developed by the German botanist Bruno Huber in 1935. Huber heated the sap with a small electric element inserted into the xylem and measured the time it took for the ascending wave of warm sap to pass a thermocouple placed a few inches higher on the stem. He found that in the morning water begins to move in the twigs earlier than it does in the stem. In the afternoon, as photosynthetic activity in the leaves begins to lessen, sap movement falls off first in the twigs and only later in the stem. Hence the "motor" of sap ascent must be in the crown of the tree.

This motor is powered, of course, by sunlight. When the leaves are engaged in photosynthesis, they liberate water vapor to the air by transpiration. In fact, they transpire more than 90 per cent of the water that is delivered to their tissues through the xylem. By this apparently wasteful process sufficient quantities of the dilute soil minerals are carried upward in the water.

What puzzled early investigators is the fact that most trees are more than 33 feet tall; a vacuum pump cannot pull a column of water beyond this height. Some trees reach 10 times higher. How could they pull water into their crowns without the breakage of the water column that causes a vacuum pump to fail? The answer is that water in the xylem of trees is pulled up directly and not by vacuum. Through the cell membranes of the tiny stomata, or pores, on the under surface of the leaves, the water is transpired a molecule at a time; the molecules that escape into the air are replaced by molecules pulled up from below by surface-tension forces. The water columns are continuous, all the way from the rootlets to the submicroscopic capillaries in the leaves. They do not, therefore, depend on the pressure of the atmosphere for support but are held up by cohesive forces within the water itself and adhesion between the water and the cell walls.

The underlying principle here was first demonstrated experimentally in 1893 by the Austrian botanist Josef Böhm. By evaporating water from a closed system of tubing connected to a bowl of mercury he was able to lift the mercury in a column to heights of more than 100 centimeters, considerably above the height of 76 centimeters to which it can be pulled by a vacuum [*see illustration on page 137*]. The Irish botanist H. H. Dixon and his collaborator J. Joly repeated this experiment, harnessing the transpiration of a pine twig to lift a column of mercury, and got the same result. These two workers gave the cohesion theory of sap ascent its formal statement in 1895.

The power of the transpiration pump is dramatically demonstrated in an experiment first performed in 1897 by Josef Friedrich at the Forestry Research Institute in Mariabrunn, Austria. Using a sensitive instrument designed to measure the cross-section growth of a tree, he found that the upper portion shrinks in the morning when photosynthesis begins, showing that the loss of water by



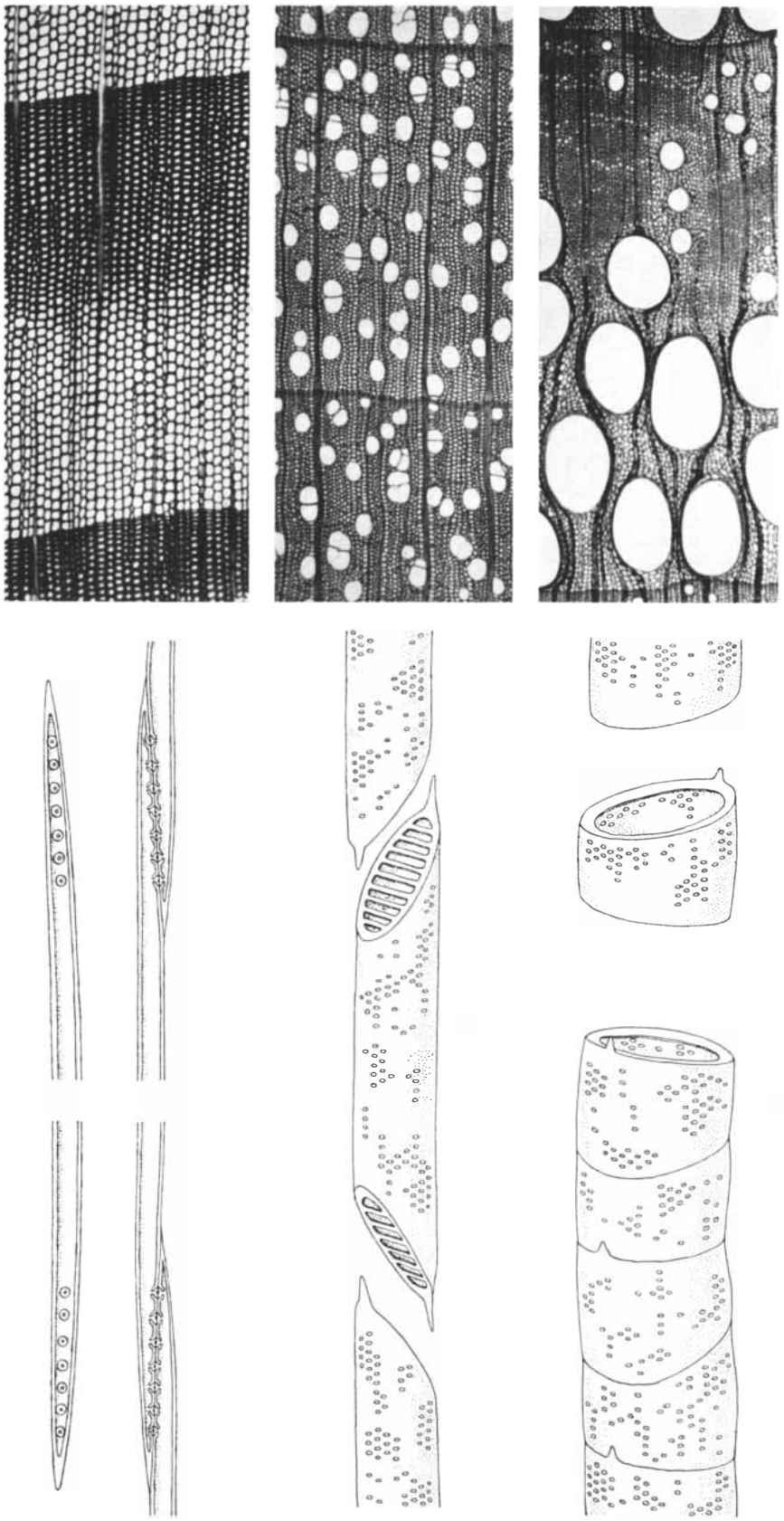
SECTION OF ASH STEM shows the two principal transport systems of a typical deciduous tree. Water ascends from the roots through tubes of dead cells in the xylem. Photosynthetic products descend from the leaves through the living cells of the phloem. Both xylem and phloem cells are produced in the cambium. Only six of this tree's 30 or more annual xylem growth rings are shown.

transpiration runs ahead of delivery from below.

Acceptance of the cohesion theory called for more precise determination of the tensile strength of water and the stress to which the water columns are subjected in the xylem conduits. Theoretical calculations, from heats of evaporation and surface tension, indicate a tensile strength for water of several thousand atmospheres. Experimental values, however, are somewhat lower, ranging from 25 to 300 atmospheres. In one illustrative experiment the British investigator H. M. Budgett wrung two polished steel plates together with a film of water between them. To pull the plates apart required tensions of up to 60 kilograms per square centimeter, or 60 times the atmospheric pressure of one kilogram per square centimeter.

As for the stress to which the water columns are subjected in the tree, these can be measured and calculated only indirectly, because any tampering with the integrity of the xylem conduits necessarily breaks the continuity of the water column. The formation of even the tiniest bubble in the water may break the column. It is apparent, however, that a portion of the tension in the column must correspond to the static stress needed to hold the water at a given height. At one atmosphere for every 33 feet above the barometric height of 33 feet, this would come to nine atmospheres in a 330-foot redwood. To this must be added a dynamic component, corresponding to the force necessary to cause the water to flow in the xylem conduits.

The dynamic tension may approach zero during a rainy night, when transpiration has practically ceased, and will reach a maximum value during a hot, dry summer's day, when the velocity of flow is estimated to run as high as 200 feet per hour in some trees. A theoretical value for the maximum dynamic tension can be computed from this estimated maximum velocity and from the measured diameter of the xylem capillaries. Since the theory assumes an ideal smooth-walled capillary of unlimited length, a correction must be made for the resistance set up by irregularities in the actual xylem conduits. Experimentally one can approximate a measurement of conditions in the living tree by forcing water through a freshly cut log of known dimensions and plotting the volume of flow against the pressure required to attain it. In a tree such as the oak, which has rather long xylem conduits, the experimental resistance proves to be twice the theoretical resistance,



THREE STAGES in the evolution of xylem conduits are represented by the photomicrographic cross sections at top and by the corresponding longitudinal drawings below. In pine (*left*), a primitive conifer, spindle-shaped cells called tracheids conduct water through small "bordered pits" in their lateral walls. In birch (*center*), an intermediate, diffuse-porous wood, conduction takes place through partially dissolved end walls. In oak (*right*), an advanced, large-porous wood, end walls are absent and water passes through a series of squat vessel segments arranged into long, rigid tubes. None of the above cells are alive.

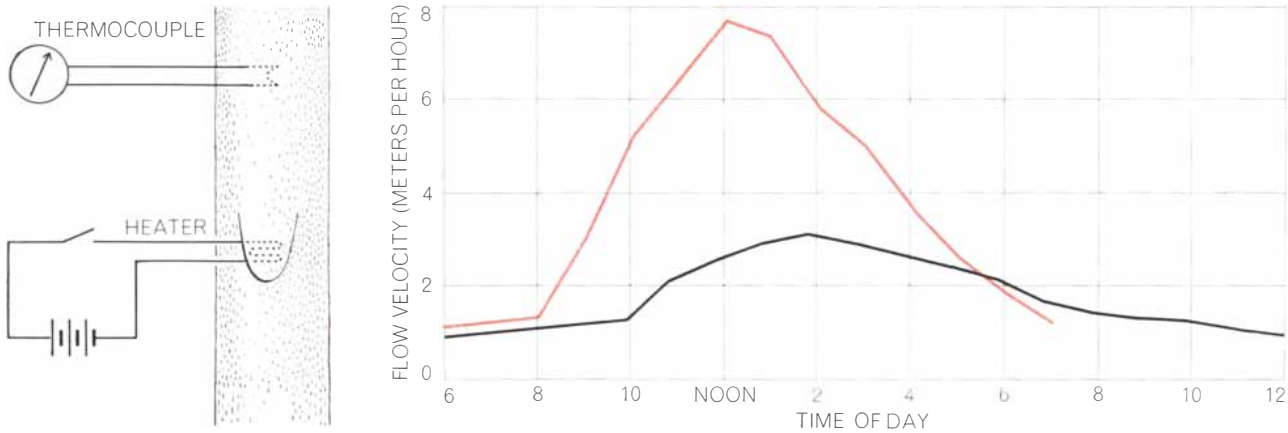
whereas in the birch or maple, with somewhat shorter conduits, it is three times higher. The tortuous tracheid conduits of the conifers, surprisingly enough, offer less resistance—only 1.5 times the theoretical—and the stem of the grapevine, with its very long xylem conduits, shows a resistance even closer to the theoretical value. At its greatest the dynamic component of tension turns out to be smaller than the static. For the tallest trees, therefore, a tensile strength of water of no more than 20 atmospheres is ample to allow smooth operation of the transpiration pump as described by the cohesion theory. This is well within the lowest value found by experiment.

One might still wonder how a mechanism so delicate can function reliably in the high, wind-tossed branches of a tree. The answer undoubtedly lies in the minute subdivision of the chambered structure of the wood. If a column is broken by the formation of a gas bubble, the resulting break remains confined to that column. The Norwegian physiologist P. F. Scholander, now at the University of California at La Jolla, has pointed out a more serious hazard to trees in cold climates. This is the freezing of the water in the xylem; freezing inevitably causes bubbles to form because air is practically insoluble in ice. Scholander has shown that trees do freeze and that bubbles do form in all vessels and tracheids. A reexamination of the anatomy of trees prompted by this observation has shown that the cold-climate species are variously accommodated to survive.

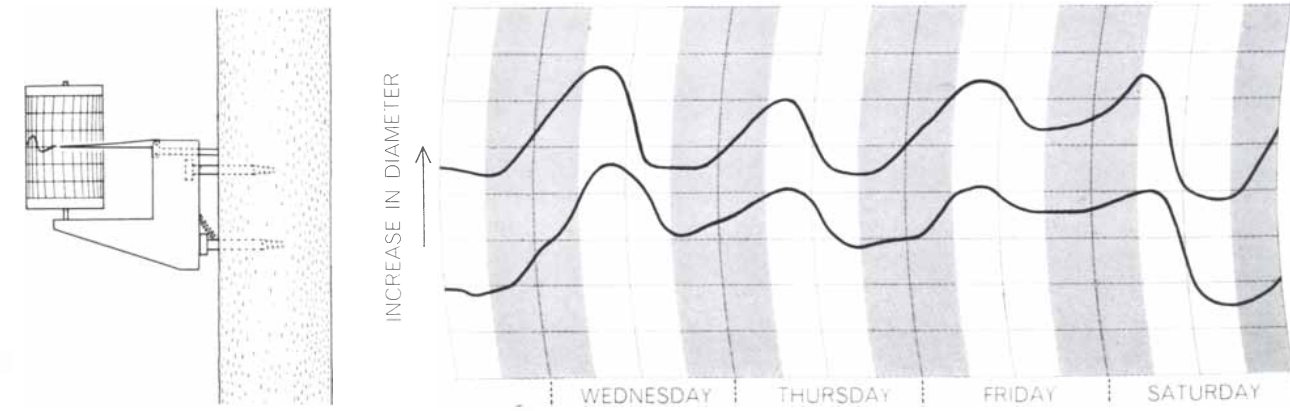
In the conifers, for example, the bubbles in the thawing ice are trapped within individual tracheids. As the weather warms, the gas in the bubbles undoubtedly redissolves in the water. In the birches, maples and grapevines the positive pressures that make the sap flow in the spring also force the gas back into solution in the xylem water. The oaks, ashes, elms and other trees with vessels of large diameter simply lose the past season's water-conducting system by rupture of the water columns; they replace them by forming a new growth ring in the early spring before the leaves come out. During the summer the transpiration stream flows almost entirely in this new growth ring. It is apparent that winter freezing of the xylem plays an important role in the geographical distribution of trees.

Sooner or later, of course, the tracheids and vessels irreversibly lose their conductive capacity and go out of function. Air embolism is the first step in the gradual formation of the heartwood, which ends with the deposition of pigmented excretion substances in the adjacent cells. The center of the trunk is the "dump" of the metabolic processes of the tree.

As these observations suggest, all the essential parts of a tree are renewed at the beginning of each growing season. Buds open, new shoots appear, leaves



VELOCITY OF SAP FLOW in wood is measured by means of the apparatus at left. A small heating element inserted into the xylem heats the ascending sap for a few seconds. A thermocouple farther up the stem records the passing wave of heat. The time interval between these two events indicates the sap's velocity. The graph at right shows that in the morning sap begins to flow first in the twigs (*colored curve*) and later in the trunk (*black curve*). In the evening sap flow diminishes in the twigs sooner than it does in the trunk.



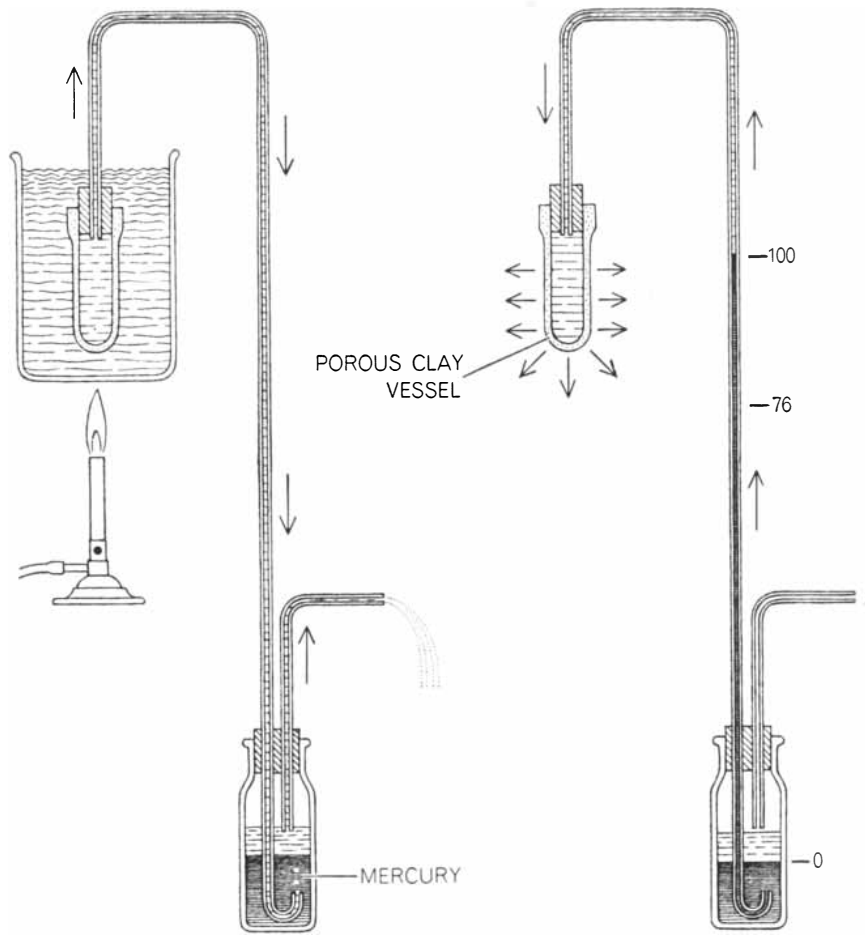
DENDROMETER (*left*) records minute daily fluctuations in the diameter growth of a tree trunk. Simultaneous measurements made at two different elevations (*right*) indicate that morning shrinkage of the upper trunk slightly precedes that of the lower. Early-morning transpiration from the leaves pulls water out of the xylem of the upper trunk before it can be replenished from the roots. As transpiration lessens later in the day, expansion of the upper trunk again precedes that of the lower. The shaded strips signify nighttime.

unfold and the cambium generates new xylem and phloem over the entire surface of the tree, from the twigs down the stem into the roots. These internal changes occur in the evergreens just as they do in the trees that drop their leaves. Even in a 2,000-year-old redwood most of the vital functions are carried out in tissue that is only a few weeks to a few years old. The rhythmic renewal of conductive tissue displayed in the growth rings of Temperate Zone trees makes a record not only of the age of the tree but also of conditions prevailing from season to season.

Growth rings appear in the bark as well. Unlike the wood, however, the bark keeps an impermanent, short-term record. The growth of new phloem tissue taking place inside the cylinder of bark around the tree constantly disturbs and breaks up the outer tissues. Three different regions can be discerned in the cross section of the bark. The most recently produced phloem layer, lying immediately outside the cambium, is the conducting phloem. Outside are the older rings of phloem that have lost their capacity for long-distance transport and serve for a while as storage places for the products of photosynthesis. Farther toward the outer surface of the bark one can see the cork cambium, a layer of rapidly dividing cells that produces the dermal tissue of the stem. All the tissues outside the cork cambium are dead, and in this region the growth rings are disturbed and indistinct.

As in the case of the xylem of various species, the conducting elements in the phloem can be classified into primitive and more advanced types. Conifers show individual sieve cells, similar in shape to the tracheids of their xylem. These cells make intimate contact in "sieve areas" but do not open mechanically into one another. In the hardwoods the sieve cells are lined up in a continuous series, forming sieve tubes comparable to the conduits in their xylem. The abutting end walls of these cells form sieve plates, in the pores of which, as electron micrographs have recently shown, the cell wall has disappeared. In all species the phloem cells retain their cytoplasm, evidently in modified form. The most striking change in the maturation of a sieve element is the loss of the cell nucleus.

The mechanism of phloem transport is, if anything, less accessible to direct study than that of the xylem. It is evident that the fluid in this system, bearing a rich concentrate of the products of photosynthesis, moves under positive pressure. But the pressure and the velocity of flow have been calculated from indirect evidence only. In many species of trees the sieve tubes will produce intense exudations on being punctured. In other species the exudation is sucked into the closely adjacent xylem system by the negative pressure that drives the transpiration stream. The phloem of all species is highly reactive to injury; the sieve tubes quickly interrupt their continuity and shut off the flow of fluid. Certain components of the cytoplasm may instantly plug the sieve plates when pressure is released, and callose, a sugar of high molecular weight, closes the sieve pores with a more permanent seal. It is callose formation that brings phloem transport to a halt in the fall after the leaves have dropped. The same process will plug up the entire phloem in a branch that has been cut from a tree.



TENSILE STRENGTH OF WATER was first demonstrated by the Austrian botanist Josef Böhm in 1893 with an apparatus similar to the one shown here. A porous clay vessel is immersed in a beaker of boiling water (*left*), forcing a continuous stream of water through a glass capillary into a bottle containing a layer of mercury and out through an exhaust tube. When the beaker is removed (*right*), evaporation through the walls of the vessel causes the water to flow up the capillary, pulling the mercury behind it to a height of more than 100 centimeters. The appearance of an air bubble anywhere in the system will cause the mercury column to fall back to a normal barometric height of 76 centimeters. Böhm's device was a simplified mechanical analogue of the xylem transport system of a tree.

Parasites have found a rich source of food in the phloem of trees and lesser plants. Some plants, like the mistletoe, live on the phloem of others and some have lost their ability to carry on photosynthesis. Porcupines, beavers and bark beetles eat the whole bark. Of greatest interest to the plant physiologist are the aphids that are specialized as feeders on the sieve tubes. Small green species live on leaves, and larger brownish or gray ones on the phloem of branches. Their mouth parts consist of a bundle of stylets with which they penetrate the bark to the phloem, where they tap a single sieve cell or tube [*see illustration on page 132*]. The food they obtain in this way is so ample they exude a surplus in the form of "honeydew," which is collected in turn by ants and honeybees.

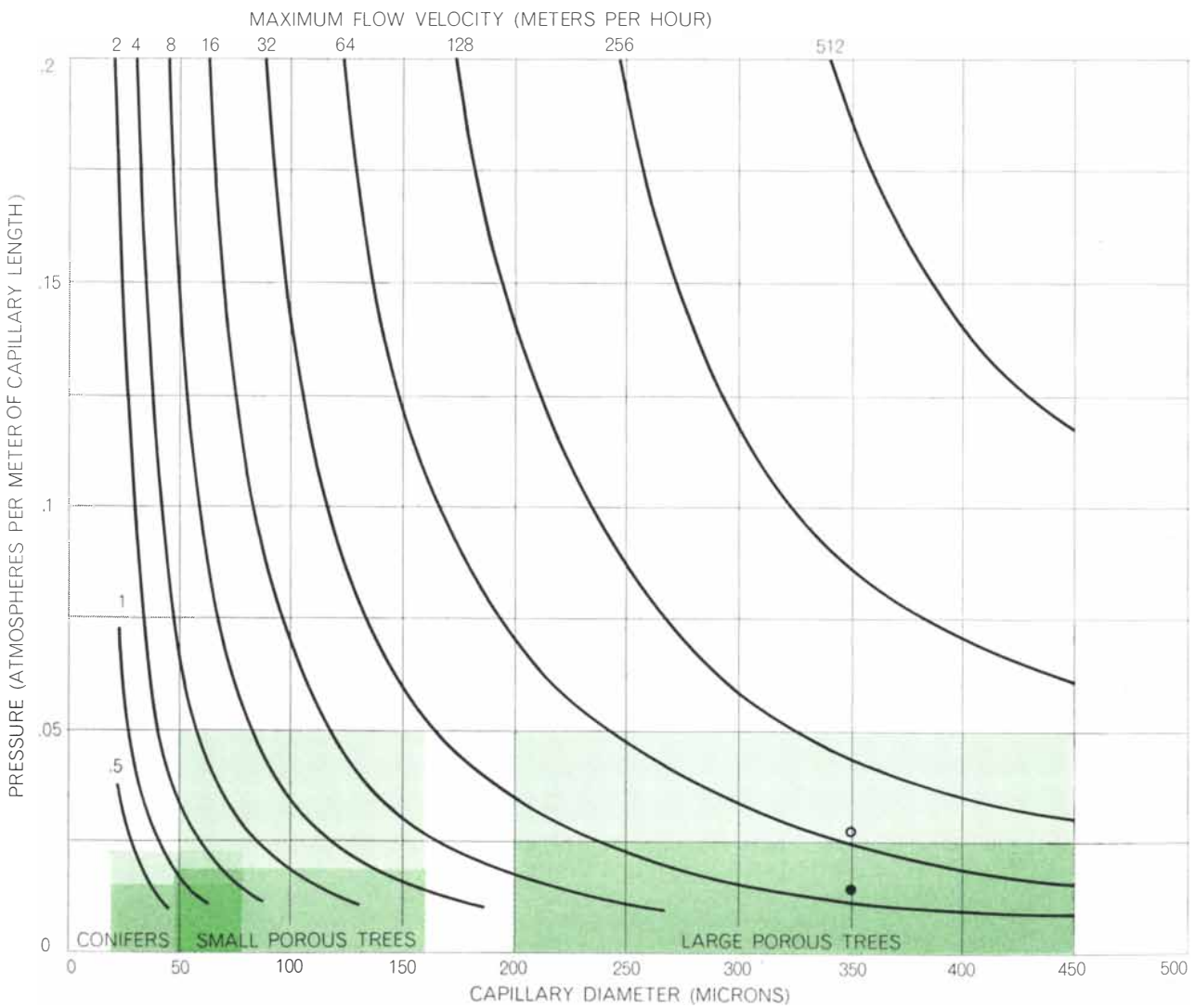
Entomologists long ago noticed that the stylet bundles may continue to exude

fluid from the plant after the aphid has been severed from its mouth parts. Recently Tom E. Mittler, now at the University of California at Berkeley, developed this observation into a technique for the study of phloem transport. The aphid is immobilized with a gentle stream of carbon dioxide and its body is then cut away with a sharp knife, leaving the stylets in place. If the operation is successful, exudation continues, often for days, and the exudate can be collected with a micropipette. As the success of the technique indicates, it works with so little injury to the plant that it does not provoke the defense mechanisms of the phloem. The purest samples of the phloem stream can be obtained in this way and even some indication of rates of flow.

Analysis of the exudates from 250 species of trees shows that a group of compound sugars is carried in the phloem stream in concentrations of 10 to 30 per cent by volume. In addition to sugars the cargo of the phloem stream is made up of sugar alcohols, amino acids, phosphorus compounds and inorganic ions. Some of these substances, particularly the nitrogen- and phosphorus-containing compounds, increase in concentration during the fall. These materials are salvaged from the leaves, which are soon to be lost.

The question of what forces bring about the long-distance transport of materials in the phloem is still far from settled. It is evident that simple diffusion—the universal tendency of solutes to come to equal concentration everywhere in a solution—is inadequate. Yet there is still argument over whether or not phloem transport actually takes place as the mass flow of a solution. The strongest evidence for mass flow is the exudation from phloem tubes, particularly as observed with the help of aphid stylets. The rate of exudation from the stylets is remarkable, in certain cases exceeding five cubic millimeters per hour. Such a rate of flow requires refilling of the sieve element three to 10 times per second. From this and other evidence it is estimated that translocation velocities in the phloem are of the order of 100 centimeters per hour. Some mass-flow process is necessary to explain movement of the fluid at this speed.

Assuming that phloem transport does

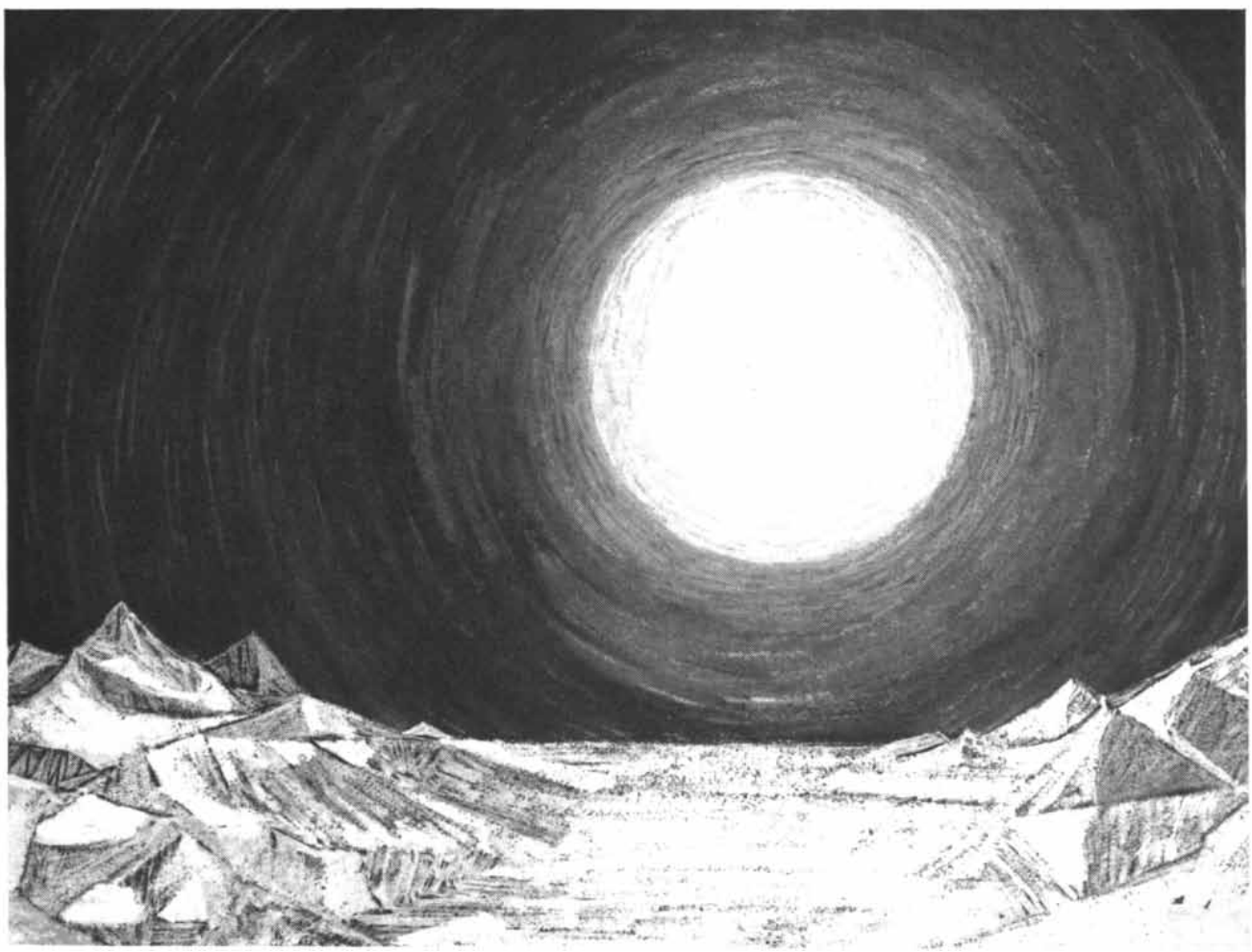


PRESSURES REQUIRED to overcome the resistance to sap flow in xylem capillaries are calculated with the aid of this graph. The dark-colored strips below represent the range of pressures calculated for the three principal types of xylem conduits. The light-colored strips above each of these are the corresponding pressures obtained experimentally. The difference is caused by the fact that most woods do not contain ideal capillaries. A calculated value for a single oak is indicated by the black dot, an experimental value for the same tree by the open circle. In spite of their small diameters, conifer tracheids are surprisingly efficient water conductors.

THE YEAR OF THE QUIET SUN

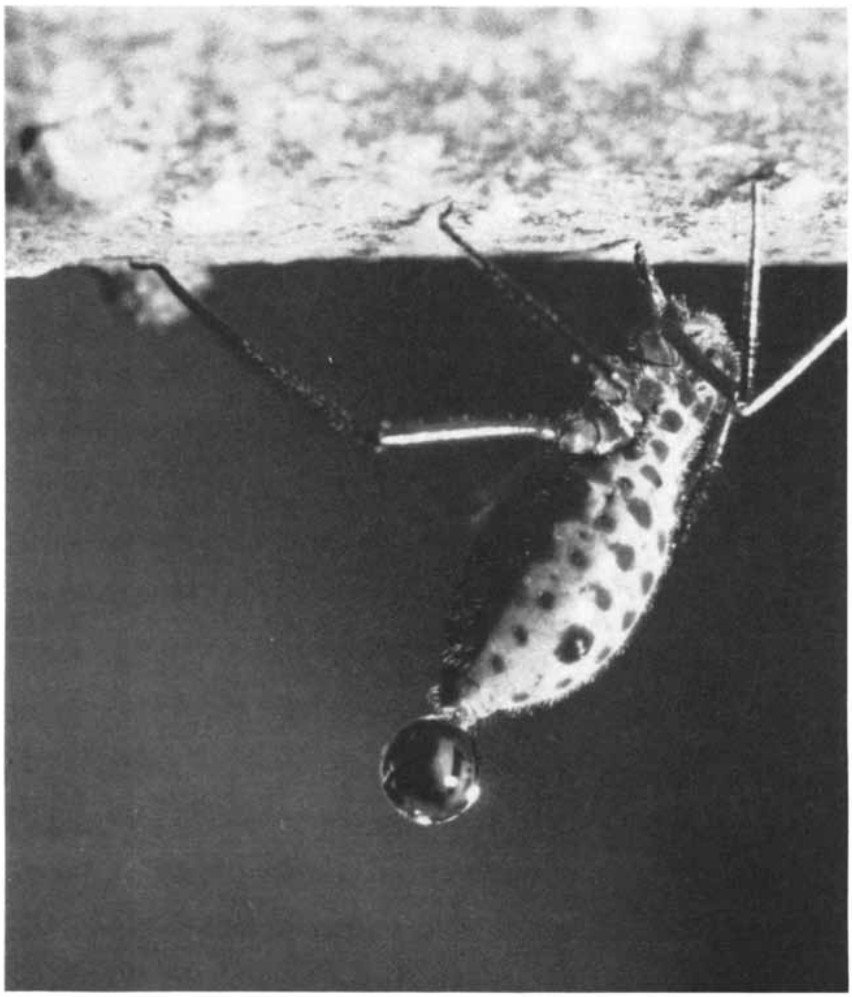
...AND WHAT DOUGLAS IS DOING ABOUT IT

Scientific predictions indicate that solar activity will be at a minimum between July, 1964 and July, 1965. This has been designated as the International Year of the Quiet Sun, and during it a world-wide magnetic survey will take place. □ The Douglas Space Physics and Planetary Sciences Group is studying scientific experiments to be performed on satellite and space probe missions during this period. Instruments to be used will be among the following: magnetometers; ionization chambers; G-M detectors; scintillators; solid state detectors; and spectrometers. □ The present Douglas Antarctica Riometer Station program for the study of cosmic rays will continue through this "Quiet Sun" period and will provide important data relative to solar cosmic ray and auroral events and the geomagnetic K-index. Douglas was invited to participate with the National Science Foundation in this program.

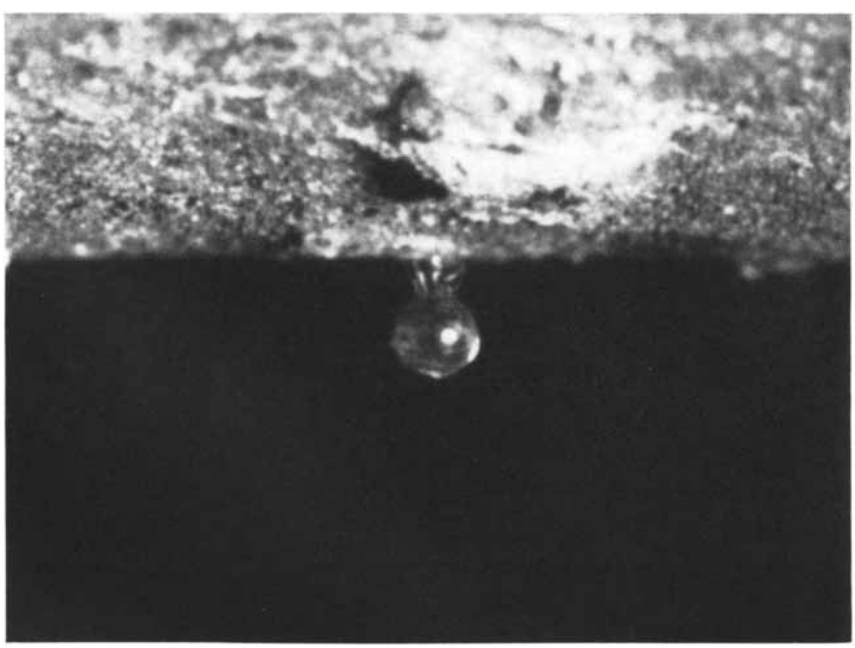


Preparation for the Year of the Quiet Sun world scientific survey is one of more than 500 research projects that are under way at Douglas. Some of these relate to the solution of problems on programs of today and tomorrow. Others range through development and research programs whose effects may not be evident until ten or twenty years in the future.

DOUGLAS



APHID (*Longistigma caryae*) feeds on the underside of a linden branch. The stylet sheath, from which the stylets are projected into the bark, is clearly visible in this photograph. Surplus sugar is released in the form of a "honeydew" droplet about once every half hour.



AMPUTATED STYLET BUNDLE exudes for hours, and sometimes for days, after the aphid has been cut away. The high rate of exudation from amputated aphid stylets supports the mass-flow theory of phloem transport. Stylet exudate is the purest phloem sap obtainable.

proceed by mass flow, the next step is to explain what drives it. The German forest botanist Ernst Münch proposed that differences in osmotic pressure are responsible for the activation and maintenance of the flow. The crucial points in the pressure gradient are located at opposite ends of the tree, in the leaves and in the roots. High osmotic pressure, created by the high concentration of the products of photosynthesis in the leaf, draws water from the capillary end vessels of the xylem into the capillaries of the phloem. Low osmotic pressure in the phloem of the roots, caused by the withdrawal of the products of photosynthesis on the way down, forces the water to flow from the phloem into the negative-pressure system of the xylem or out into the surrounding soil. In effect, it is the initial concentration gradient in the leaves, maintained by photosynthesis, that creates the pressure gradient and causes the mass flow of the phloem solution.

There is a good deal more to the system, however, than this sketchy statement of the hypothesis suggests. To make such a system function, the sidewall membranes of the sieve tubes must be differentially permeable to the passage of the molecules. At the same time the passage from one sieve element to the next must not be hindered by a semipermeable membrane. Electron micrographs of the fine structure of the sieve plates are playing a decisive role in the elucidation of this problem. The main difficulty is presented by the sensitivity of the sieve tubes to injury.

More recently it has been suggested that the electric potentials across the sieve plates (or, in the conifers, sieve areas) may supply the driving force. Osmotic pressure gradients would then merely supply the trigger for electro-osmosis.

The mechanism of phloem transport is as unresolved in grasses and lilies as it is in trees. Because of their size trees supply ideal subjects for experimental studies of this phenomenon. They offer clear lengths of 30 feet or more of uniform conducting tissue, with all the products of photosynthesis concentrated at one end along with the peak of the osmotic pressure thereby generated. For simultaneous, or nearly simultaneous, measurement of pressures and flows at many points on the tree, the aphid and its stylets do not provide a manageable technique. It is therefore necessary to resort to the cruder method of making incisions in the bark. The larger the tree, however, the less disturbing is the effect of these traumas. In a tree with a diameter of eight inches or more one may

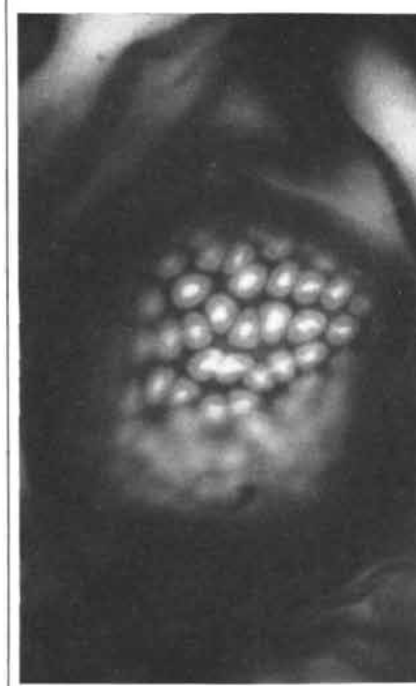
make as many as 100 useful incisions, if they are properly placed. The concentration gradients of the materials transported in the phloem can thus be measured throughout a great length of tissue before and after such experimental treatments as defoliation, interruption of phloem transport and locally applied temperature.

In the Harvard Forest at Petersham,

STYLET PATH extends from sheath (*bottom*) up through several layers of outer bark to an individual sieve element in the conducting phloem (*see enlarged section on page 132*). The four transverse sections that make up this composite micrograph were made by Gerda Aerni of Harvard University.

Mass., we have carried on work of this kind over several growing seasons. We invariably find that the concentration of photosynthetic products decreases down the length of the tree during the summer, when the leaves are exporting this material and growth is taking place in the stem and roots. This gradient disappears soon after defoliation, be it natural leaf fall in autumn or artificial defoliation done at any time in the summer. Analysis of the fluid tapped at intervals down the trunk soon after defoliation shows that the sugars are being converted and removed from the sieve tubes. The measured decline in concentration of the sugars along the trunk provides an index of the velocity of phloem transport. In agreement with findings made by other techniques, this shows values of 50 to 100 centimeters per hour.

It is clear that the two-way water transportation system of trees presents questions that can be approached only in the living organism as a whole. Some of the most interesting questions lie in the cross transfer of substances from the phloem to the xylem, by which trees and other plants distribute vital substances throughout their entire bodies.



PORES OF SIEVE PLATE in this photomicrograph have been partially plugged with callose following an artificial reduction in pressure at one end of the sieve tube. Ordinarily callose formation interrupts the flow of sap through the phloem of deciduous trees in late fall after the leaves have dropped. Magnification is 1,350 diameters.

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MATHEMATICAL GAMES

A new paradox, and variations on it, about a man condemned to be hanged

by Martin Gardner

"A new and powerful paradox has come to light." This is the opening sentence of a mind-twisting article by Michael Scriven that appeared in the July 1951 issue of the British philosophical journal *Mind*. Scriven, who bears the title of "professor of the logic of science" at the University of Indiana, is a man whose opinions on such matters are not to be taken lightly. That the paradox is indeed powerful has been amply confirmed by the fact that during the past 15 years no fewer than 10 learned articles about it have appeared in *Mind*. The authors, many of whom are distinguished philosophers, disagree sharply in their attempts to resolve the paradox. Since no consensus has been reached, the paradox is still very much a controversial topic.

No one knows who first thought of it. According to the Harvard University logician W. V. Quine, who wrote one of the *Mind* articles (and who discussed paradoxes in SCIENTIFIC AMERICAN for April, 1962), the paradox was first circulated by word of mouth in the early 1940's. It usually took the form of a puzzle about a man condemned to be hanged.

The man was sentenced on Saturday. "The hanging will take place at noon," said the judge to the prisoner, "on one of the seven days of next week. But you will not know which day it is until you are so informed on the morning of the day of the hanging."

The judge was known to be a man who always kept his word. The prisoner, accompanied by his lawyer, went back to his cell. As soon as the two men were alone the lawyer broke into a big grin. "Don't you see?" he exclaimed. "The judge's sentence cannot possibly be carried out."

"I don't see," said the prisoner.

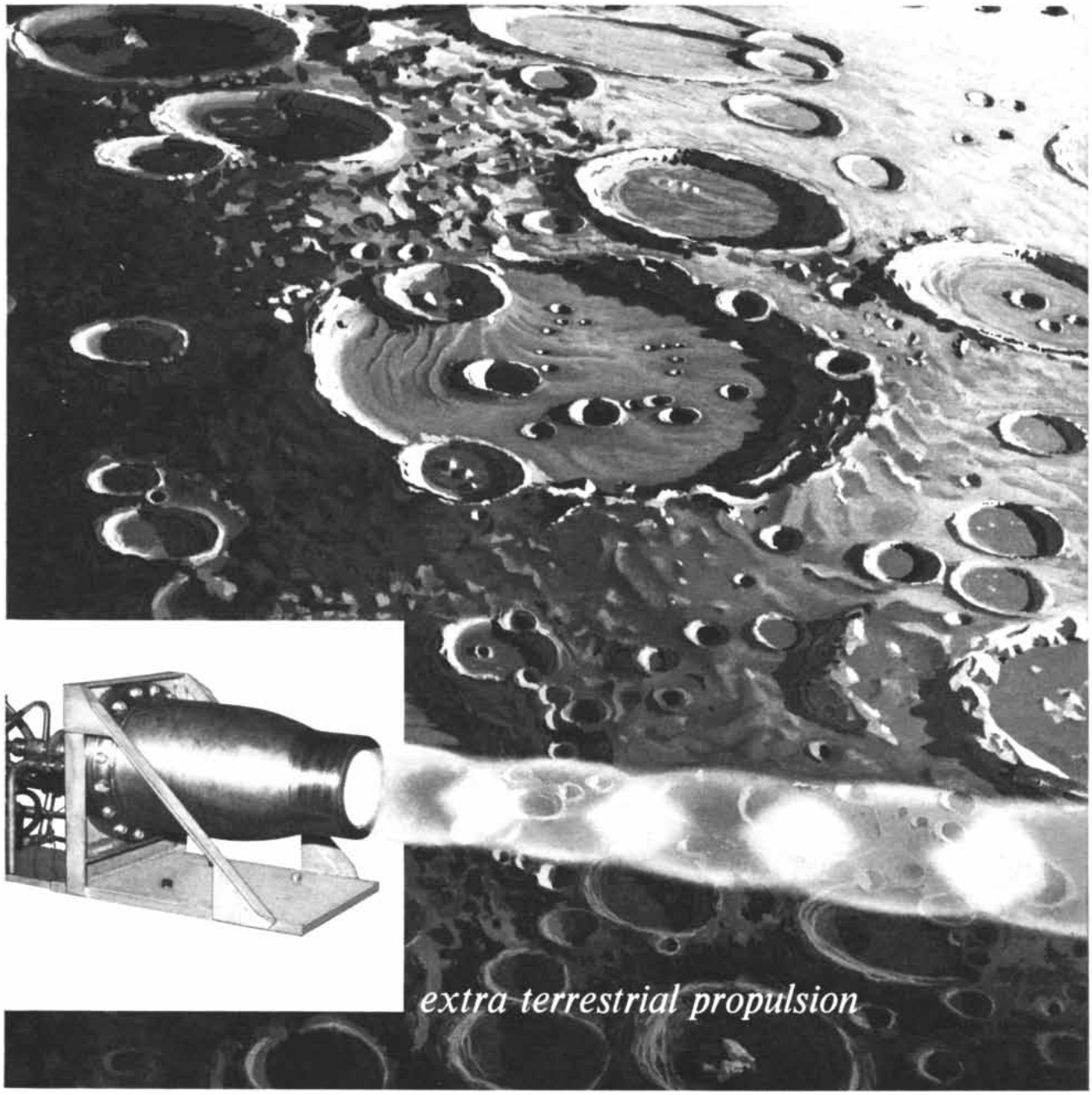
"Let me explain. They obviously can't hang you next Saturday. Saturday is the last day of the week. On Friday afternoon you would still be alive and you would know with absolute certainty that the hanging would be on Saturday. You would know this *before* you were told so on Saturday morning. That would violate the judge's decree."

"True," said the prisoner.

"Saturday, then, is positively ruled out," continued the lawyer. "This leaves Friday as the last day they can hang you. But they can't hang you on Friday because by Thursday afternoon only two days would remain: Friday and Saturday. Since Saturday is not a possible day, the hanging would have to be on Friday. Your knowledge of that fact would violate the judge's decree again. So Friday is out. This leaves Thursday as the last possible day. But Thursday is out because if you're alive Wednesday afternoon, you'll know that Thursday is to be the day."

"I get it," said the prisoner, who was

The prisoner eliminates all possible days



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The paradox of the unexpected egg

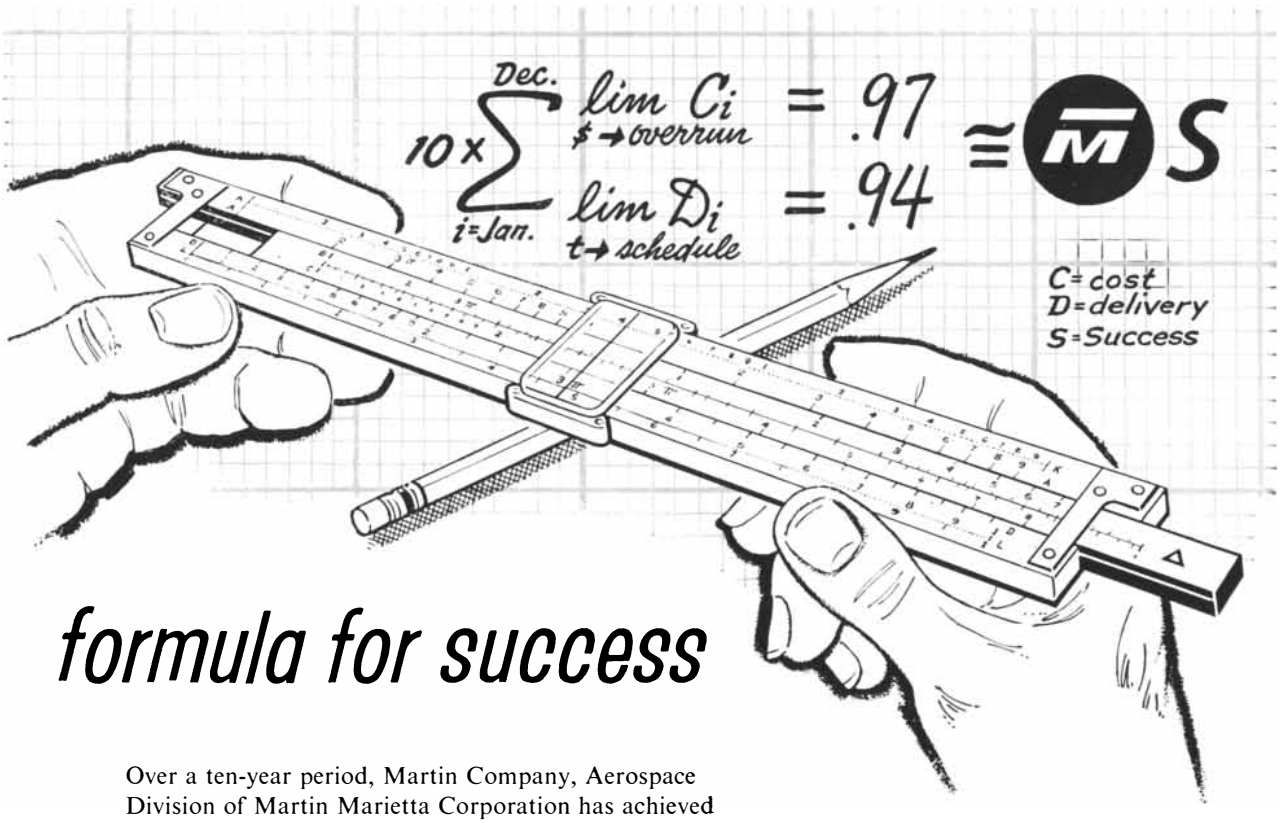
beginning to feel much better. "In exactly the same way I can rule out Wednesday, Tuesday and Monday. That leaves only tomorrow. But they can't hang me tomorrow because I know it today!"

In brief, the judge's decree seems to be self-refuting. There is nothing logically contradictory in the two statements that make up his decree; nevertheless, it cannot be carried out in practice. That is how the paradox appeared to Donald John O'Connor, a philosopher at the University of Exeter, who was the first to discuss the paradox in print (*Mind*, July, 1948). O'Connor's version of the paradox concerned a military commander who announced that there would be a Class A blackout during the following week. He then defined a Class A blackout as one that the participants could not know would take place until after 6:00 p.m. on the day it was to occur.

"It is easy to see," wrote O'Connor, "that it follows from the announcement of this definition that the exercise cannot take place at all." That is to say, it cannot take place without violating the definition. Similar views were expressed by the authors of the next two articles (L. Jonathan Cohen in *Mind* for January, 1950, and Peter Alexander in *Mind* for October, 1950), and even by George Gamow and Marvin Stern when they later included the paradox (in a man-to-be-hanged form) in their book *Puzzle-Math*.

Now, if this were all there was to the paradox, one could agree with O'Connor that it is "rather frivolous." But, as Scriven was the first to point out, it is by no means frivolous, and for a reason that completely escaped the first three authors. To make this clear, let us return to the man in the cell. He is convinced, by what appears to be unimpeachable logic, that he cannot be hanged without contradicting the conditions specified in his sentence. Then on Thursday morning, to his great surprise, the hangman arrives. Clearly he did not expect him. What is more surprising, the judge's decree is now seen to be perfectly correct. The sentence can be carried out exactly as stated. "I think this flavour of logic refuted by the world makes the paradox rather fascinating," writes Scriven. "The logician goes pathetically through the motions that have always worked the spell before, but somehow the monster, Reality, has missed the point and advances still."

In order to grasp more clearly the very real and profound linguistic difficulties involved here, it would be wise to restate the paradox in two other equivalent forms. By doing this we can eliminate various irrelevant factors that are often raised and that cloud the issue, such as the possibility of the judge's changing his



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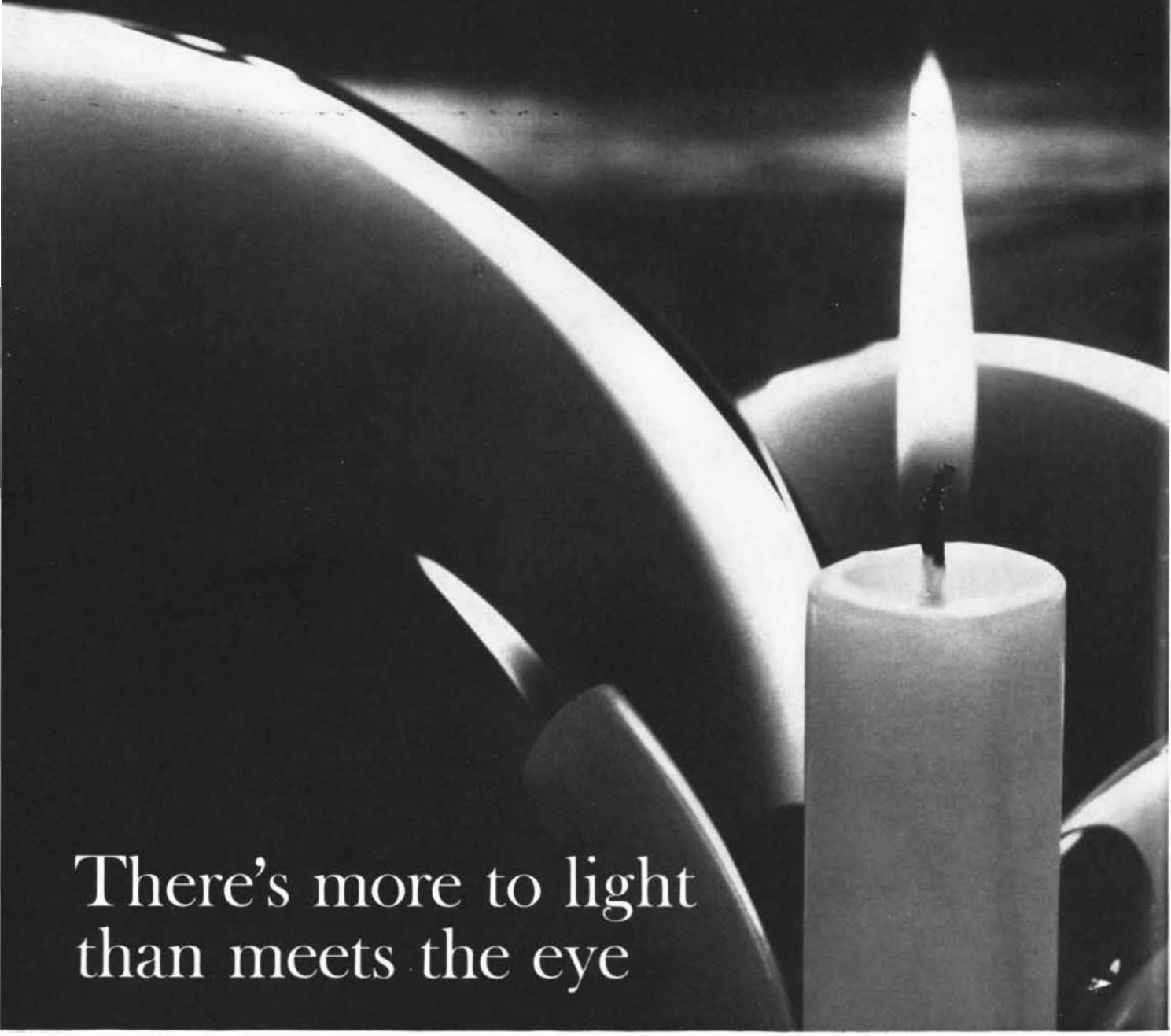

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mind, of the prisoner's dying before the hanging can take place and so on.

The first variation of the paradox, taken from Scriven's article, can be called the paradox of the unexpected egg.

Imagine that you have before you 10 boxes labeled from 1 to 10. While your back is turned, a friend conceals an egg in one of the boxes. You turn around. "I want you to open these boxes one at a time," he tells you, "in serial order. Inside one of them I guarantee that you will find an unexpected egg. By 'unexpected' I mean that you will not be able to deduce which box it is in before you open the box and see it."

Assuming that your friend is absolutely trustworthy in all his statements, can his prediction be fulfilled? Apparently not. He obviously will not put the egg in box 10 because after you have found the first nine boxes empty you will be able to deduce with certainty that the egg is in the only remaining box. This would contradict your friend's statement. Box 10 is out. Now consider the situation that would arise if he were so foolish as to put the egg in box 9. You find the first eight boxes empty. Only 9 and 10 remain. The egg cannot be in box 10. Ergo it must be in 9. You open 9. Sure enough, there it is. Clearly it is an *expected* egg, and so your friend is again proved wrong. Box 9 is out. But now you have started on your inexorable slide into unreality. Box 8 can be ruled out by precisely the same logical argument, and similarly boxes 7, 6, 5, 4, 3, 2 and 1. Confident that all 10 boxes are empty, you start to open them. What have we here in box 5? A totally unexpected egg! Your friend's prediction is fulfilled after all. Where did your reasoning go wrong?

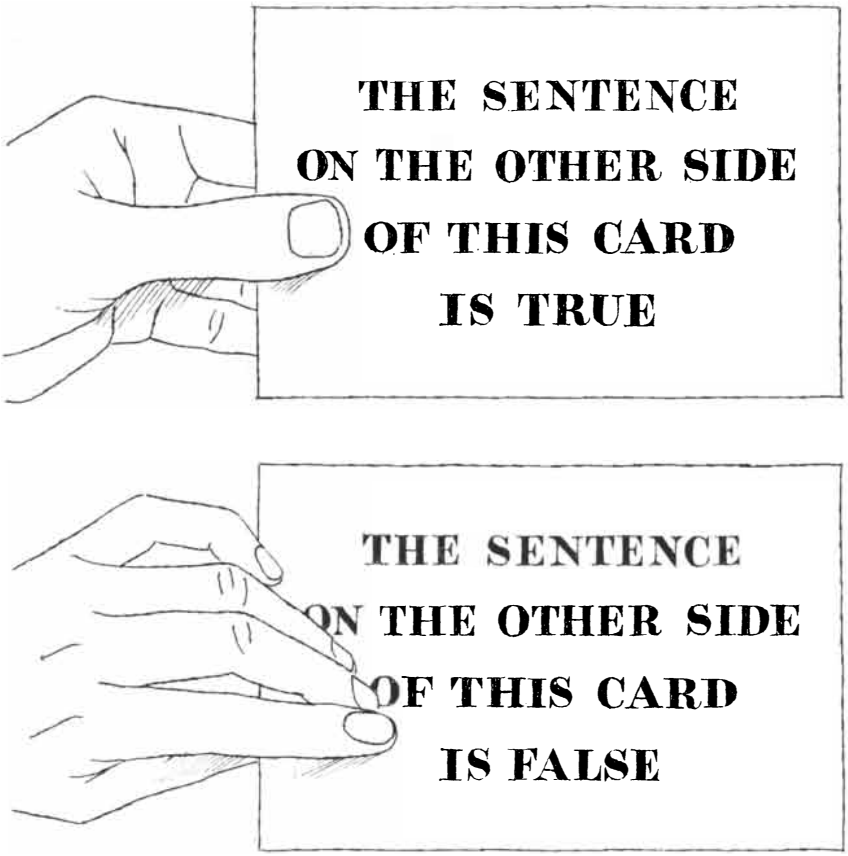
To sharpen the paradox still more, we can consider it in a third form, one that can be called the paradox of the unexpected spade. Imagine that you are sitting at a card table opposite a friend who shows you that he holds in his hand the 13 spades. He shuffles them, fans them with the faces toward him and deals a single card face down on the table. You are asked to name slowly the 13 spades, starting with the ace and ending with the king. Each time you fail to name the card on the table he will say "No." When you name the card correctly, he will say "Yes."

"I'll wager a thousand dollars against a dime," he says, "that you will not be able to deduce the name of this card before I respond with 'Yes.'"

Assuming that your friend will do his best not to lose his money, is it possible that he placed the king of spades on the table? Obviously not. After you have named the first 12 spades, only the king will remain. You will be able to deduce the card's identity with complete confidence. Can it be the queen? No, because after you have named the jack only the king and queen remain. It cannot be the king, so it must be the queen. Again, your correct deduction would win you $1,000. The same reasoning rules out all the remaining cards. Regardless of what card it is, you should be able to deduce its name in advance. The logic seems airtight. Yet it is equally obvious, as you stare at the back of the card, that you have not the foggiest notion which spade it is!

Even if the paradox is simplified by reducing it to two days, two boxes, two cards, something highly peculiar continues to trouble the situation. Suppose your friend holds only the ace and deuce of spades. It is true that you will be able to collect your bet if the card is the deuce. Once you have named the ace and it has been eliminated you will be able to say: "I deduce that it's the deuce." This deduction rests, of course, on the truth of the statement "The card before me is either the ace or the deuce of spades." (It is assumed by everybody, in all three paradoxes, that the man *will*

The paradox of the unexpected spade



P. E. B. Jourdain's card paradox

be hanged, that there *is* an egg in a box, that the cards *are* the cards designated.) This is as strong a deduction as mortal man can ever make about a fact of nature. You have, therefore, the strongest possible claim to the $1,000.

Suppose, however, your friend puts down the ace of spades. Cannot you deduce at the outset that the card is the ace? Surely he would not risk his $1,000 by putting down the deuce. Therefore it *must* be the ace. You state your conviction that it is. He says "Yes." Can you legitimately claim to have won the bet?

Curiously, you cannot, and here we touch on the heart of the mystery. Your deduction rested only on the premise that the card was either the ace or the deuce. The card is not the ace; therefore it is the deuce. But now your deduction rests on the same premise as before plus an additional one, namely on the assumption that your friend spoke truly; to say the same thing in pragmatic terms, on the assumption that he will do all he can to avoid paying you $1,000. But if it is possible for you to deduce that the card is the ace, he will lose his money just as surely as if he put down the deuce. Since he loses it either way, he has no rational basis for picking one card rather than the other. Once you realize this your deduction that the card is the ace takes on an extremely shaky character. It is true that you would be wise to bet that it is the ace, because it probably is, but to win the bet you have to do more than that: you have to prove that you have deduced the card with iron logic. This you cannot do.

You are, in fact, caught up in a vicious circle of contradictions. First you assume that his prediction will be fulfilled. On this basis you deduce that the card on the table is the ace. But if it is the ace, his prediction is falsified. If his prediction cannot be trusted, you are left without a rational basis for deducing the name of the card. And if you cannot deduce the name of the card, his prediction will certainly be confirmed. Now you are right back where you started. The whole circle begins again. In this respect the situation is analogous to the vicious circularity involved in a famous card paradox first proposed by the English mathematician P. E. B. Jourdain in 1913 [*see illustration above*]. Since this sort of reasoning gets you no further than a dog gets in chasing its tail, you have no logical way of determining the name of the card on the table. Of course, you may *guess* correctly. Knowing your friend, you may decide that it is highly probable he put

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down the ace. But no self-respecting logician would agree that you have "deduced" the card with anything close to the logical certitude involved when you deduced that it was the deuce.

The flimsiness of your reasoning is perhaps seen more clearly if you return to the 10 boxes. At the start you "deduce" that the egg is in box 1, but box 1 is empty. You then "deduce" it to be in box 2, but box 2 is empty also. Then you "deduce" box 3, and so on. (It is almost as if the egg, just before you look into each box in which you are positive it must be, were cleverly transported by secret trap doors to a box with a higher number!) Finally you find the "expected" egg in box 8. Can you maintain that the egg is truly "expected" in the sense that your deduction is above reproach? Obviously you cannot, because your seven previous "deductions" were based on exactly the same line of reasoning, and each proved to be false. The plain fact is that the egg can be in any box, *including the last one*. If you find the first nine boxes empty, you will of course be able to deduce that the egg is in the 10th one, but until this occurs you have no firm ground for excluding even box 10 from the range of possibilities.

The Scottish mathematician Thomas H. O'Beirne, in an article with the somewhat paradoxical title "Can the Unexpected *Never* Happen?" (*The New Scientist*, May 25, 1961), has given what seems to me the best analysis so far of this paradox. As O'Beirne makes clear, the key to resolving the paradox lies in recognizing that a statement about a future event can be known to be a true prediction by one person but not known to be true by another until after the event. It is easy to think of simple examples. Someone hands you a box and says: "Open it and you will find an egg inside." *He* knows that his prediction is sound, but *you* do not know it until you open the box.

The same is true in the paradox. The judge, the man who puts the egg in the box, the friend with the 13 spades—each knows that his prediction is sound. But the prediction cannot be used to support a chain of arguments that results eventually in discrediting the prediction itself. It is this roundabout self-reference that, like the sentence on the face of Jourdain's card, tosses the monkey wrench into all attempts to prove the prediction unsound.

We can reduce the paradox to its essence by taking a cue from Scriven. Suppose a man says to his wife: "My dear, I'm going to surprise you on your birthday tomorrow by giving you a com-

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pletely unexpected gift. You have no way of guessing what it is. It is that gold bracelet you saw last week in Tiffany's window."

What is the poor wife to make of this? She knows her husband to be truthful. He always keeps his promises. But if he does give her the gold bracelet, it will not be a surprise. This would falsify his prediction. And if his prediction is unsound, what *can* she deduce? Perhaps he will keep his word about giving her the bracelet but violate his word that the gift will be unexpected. On the other hand, he may keep his word about the surprise but violate it about the bracelet and give her instead, say, a new vacuum cleaner. Because of the self-refuting character of her husband's statement, she has no rational basis for choosing between these alternatives; therefore she has no rational basis for expecting the gold bracelet. It is easy to guess what happens. On her birthday she is surprised to receive a logically unexpected bracelet.

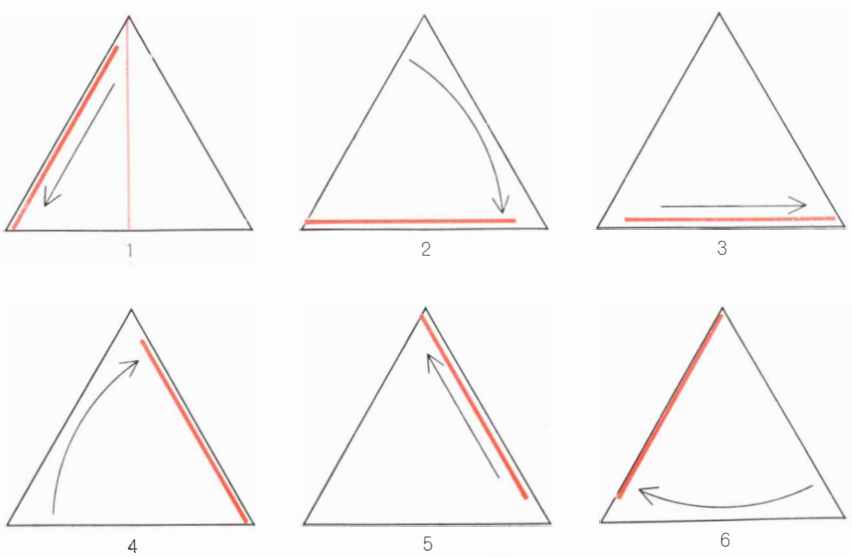
He knew all along that he could and would keep his word. *She* could not know this until after the event. A statement that yesterday appeared to be nonsense, that plunged her into an endless whirlpool of logical contradictions, has today suddenly been made perfectly true and noncontradictory by the appearance of the gold bracelet. Here in the starkest possible form is the queer verbal magic that gives to all the paradoxes we have discussed their bewildering, head-splitting charm.

Last month's problem was to determine the smallest convex area in which a line segment of length 1 can be rotated 360 degrees. The answer: An equilateral triangle with an altitude of 1. (The area is one-third the square root of 3.)

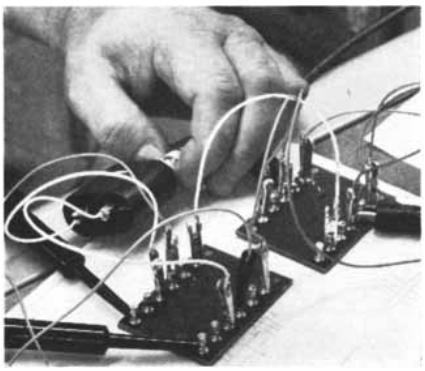
Any figure in which the line segment can be rotated obviously must have a width at least equal to 1. Of all convex figures with a width of 1, the equilateral triangle of altitude 1 has the smallest area. (For a proof of this the reader is referred to *Convex Figures*, by I. M. Yaglom and V. G. Boltyanskii, pages 221 and 222.) It is easy to see that a line segment of length 1 can in fact be rotated in such a triangle [*see illustration below*].

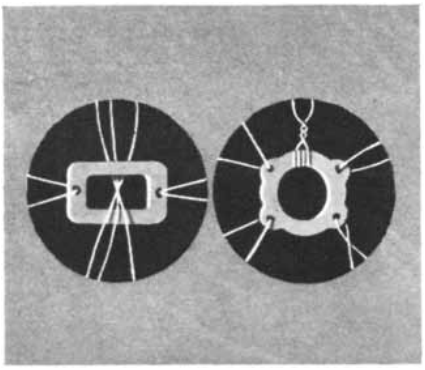
In January I promised to report on any two-word messages other than "Chin up" that astute readers might discover in Louis Aragon's poem "Suicide." At the time this is written, the following people have sent in the phrase "Stop, idiots!" (or "Idiots, stop!"): J. R. Bruman, Sherman Oaks, Calif.; Richard Jenney, Haverford, Pa.; Alex Schapira, New York; Jane Sichak, Canton, N.Y.; Robert Smyth, Los Altos Hills, Calif. "Join up!" was found by Marvin E. Aronson, Philadelphia; "Hoping not" by David B. Harper, Somerville, Mass.; "No hoping" by Harmon H. Goldstone, New York. Judith M. Hobart, Morristown, N.J., spelled out the following telegram from U Thant to President Kennedy and Premier Khrushchev: HINT TO J. F. K., K.: JOIN TO PUT UN ON TOP. IN HOPING, NO POINT; TO HIDING, NO OUT. STUPID IDIOTS, STOP!

Linus Pauling suggested a two-word phrase in which ambiguity is provided by a pun. "My wife and I thought that 'No hiding' would be the solution," he wrote. "Not only is there no way to hide from nuclear war; it is no longer possible for one great nation to give another a hiding."



The answer to last month's needle-turning problem





Despite the tremendous speed and ravenous appetite of today's most advanced computers, scientists at Lockheed Missiles & Space Company's Computer Research Laboratories feel that there is room for a great deal of improvement. They have dedicated themselves to the discovery and development of ways to increase the speed and reliability of computers while simplifying their operation.

Though today's computer circuits are capable of operating at speeds measured in tens of nanoseconds, the useful computation rate is far slower. One of the roadblocks hindering speed is the need for the computer to wait for the carryovers from one column of figures to catch up with the main calculation. A possible answer to this problem is modular arithmetic, which avoids carryover. Based on the ancient Chinese Remainder Theorem, this concept is being re-examined at Lockheed for potential computer applications.

Lockheed's Computer Research Laboratories are studying a very broad group of related computer research areas, and the company can boast that an unusual number of its specialists are at the very forefront of their specific fields.

Among the major areas of research being undertaken at this time are basic physical phenomena, such as phonons; quantum mechanics; switching theory; residue arithmetic (number system research); threshold logic and pattern recognition and logic design techniques.

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Point of View...Times 32

One thing common to RAC professional staff members is their uncommon backgrounds. This is neither a paradox nor unintentional. It is, in fact, a basic clue to much of the value of operations research, at least as it is performed at the Research Analysis Corporation. RAC is a private, nonprofit organization of more than 450 people, engaged in scientific problem-solving in a broad diversity of areas of major national decision—military, political, and economic.

There are 32 different academic backgrounds among RAC's professional staff, and thus 32 points of view to pit against the problems at hand. In a typical RAC research team, the physicist will view a problem area differently than the mathematician, the mathematician will see it differently than the economist, the economist differently than the electrical engineer, and so on. And in addition to its own members, the team can also call in professional staff members of other disciplines to view any special or unusual aspects of the problem.

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THE AMATEUR SCIENTIST

How to make a highly accurate clock that utilizes tunnel diodes

Conducted by C. L. Stong

Anyone can now build an electronic chronometer roughly the size of an alarm clock that will keep time within five seconds per year and run for months on a single mercury battery. The construction is made possible by tunnel diodes, the semiconductor device first described five years ago by the Japanese physicist Leo Esaki. Except in its use of semiconductors, the new chronometer closely resembles the quartz crystal clocks described earlier in this department; its hands are turned by a synchronous motor that operates on a submultiple frequency of alternating current derived from a crystal-controlled oscillator [see "The Amateur Scientist," September, 1957, and June, 1961]. The instrument was designed by R. L. Watters of the General Electric Research Laboratory, primarily to demonstrate the usefulness and reliability of tunnel diodes.

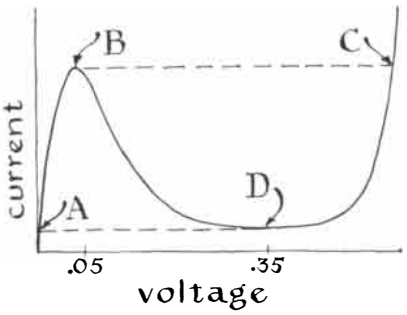
"For reasons not altogether clear," writes Watters, "tunnel diodes have not been greeted with enthusiasm by experimenters, in spite of the fact that when they are supplied with less than a thousandth of a watt, they can function as amplifiers, oscillators and switches through an impressively broader range of frequencies than vacuum tubes or transistors can. Part of the explanation may lie in their strangeness. They have only two terminals compared with the three or more of vacuum tubes and transistors. The techniques of using them differ accordingly. Moreover, the notion seems to have got around that tunnel diodes are not so reliable as the older devices. My experience in applying them to timing devices and similar apparatus that make rigorous demands on reliability does not support this. When used as interlocked oscillators for lowering the frequency of alternating current, for example, tunnel diodes are at least an order of magnitude better than multivibrators employing vacuum tubes or transistors. Any slight change in temperature or abrupt disturbance in the supply voltage to a vacuum tube multivibrator designed for dividing a frequency by 10, for example, may cause the unit to start dividing by 9 or 11. Tunnel diode oscillators divide by 20 routinely and during some experiments have operated without error for hours while dividing by a factor of 100! For this reason tunnel diodes have found an ideal application in clocks of the Marrison type for reducing the high frequency of the crystal-controlled oscillator to the low frequency required by the synchronous motor. The construction of such a clock can serve as a good introduction to these new circuit elements and perhaps suggest other applications for their remarkable properties.

"Like all rectifying devices, including check valves in water pipes, tunnel diodes conduct differently in different directions. They exhibit their most interesting property when conducting in the forward direction. A small voltage must of course be present to induce current in the forward direction, just as some pressure must be applied to force water through a check valve. In a typical tunnel diode the current increases as the applied potential is increased from zero up to .05 volt. As the voltage is increased from .05 volt to .35 volt, however, an astonishing effect is observed: the current decreases! Conversely, as the voltage is lowered through this range, the current increases, an effect that one would expect only if the circuit contained a generator or other source of electrical energy.

"Esaki explained this phenomenon in terms of the tunnel effect, a theoretical concept introduced to describe the behavior of an electron that does not have enough kinetic energy to penetrate an electric field but nonetheless manages to 'tunnel' through the barrier. The potential barrier is imagined as a hill and the electron as a wave that extends through the hill but decreases sharply in amplitude. The resulting shape of the wave is interpreted as meaning that the electron gets through the hill without having been pushed over it. The effect of positive and negative resistances associated with tunnel diodes is shown by the accompanying graph [*top of next page*], in which increasing current is plotted upward on the vertical co-ordinate and increasing voltage from left to right on the horizontal co-ordinate. Observe that as the voltage increases from zero the current rises to point *B*, as one expects of ordinary circuits. From .05 volt to .35 volt, however, the current drops to *D*, in apparent defiance of Ohm's law. Beyond .35 volt the current again increases with increased voltage.

"If the diode interposed no positive resistance, the current would increase without limit, independent of the voltage, and the absence of resistance (zero resistance) would be represented by the vertical co-ordinate of the graph. Similarly, if the diode behaved as an infinitely high resistance, or open circuit, the graph would coincide with the horizontal co-ordinate. Intermediate values of resistance would be plotted as straight lines at intermediate angles, their slope representing the resistance. In this graph the continuously changing slope indicates how the resistance of the tunnel diode changes with applied voltage. At the origin of the co-ordinates (no voltage applied to the diode) the graph rises almost vertically, indicating that the diode has little resistance. At points *B* and *D*, representing applied potentials of .05 and .35 volt respectively, the graph becomes horizontal, indicating infinite resistance. The upward slopes from *A* to *B* and from *D* to *C* indicate the ranges of applied voltage through which the diode exhibits finite values of positive resistance, and the downward slope from *B* to *D* represents the voltage range through which the tunneling effect and phenomenon of negative resistance appear.

"Any device characterized by nega-



Graph of tunnel diode characteristics

tive resistance, whether electrical or mechanical, can be made to generate oscillations if it is coupled to a resonator. In the electrical case this could be a capacitor connected to an inductance; in the mechanical it could be a flywheel linked to a coiled spring. Even short lengths of wire act as small inductances as well as small resistances; adjacent parts of even the simplest circuit constitute a capacitor. Indeed, the simplest tunnel diode oscillator consists of nothing more than the diode, a battery and a rheostat [*see bottom illustration on this page*].

"Assume that such an apparatus has been assembled and that the rheostat has been adjusted so that the average voltage across the diode corresponds to a point on the horizontal co-ordinate of the first graph between *B* and *D*. At the moment the battery is connected the voltage will start to rise across the diode. The rise will not be instantaneous, because a portion of the energy will appear in the form of a growing magnetic field around the conductors. As the portion of the voltage that appears across the diode rises, current will increase to *B*. At *B* the diode becomes an infinite resistance and the voltage across it rises instantly to point *C*, as indicated by the upper broken line in the graph. The magnetic field surrounding the conductors then starts to collapse and generates an opposing potential that in effect gradually lowers the voltage across the diode at a rate indicated by the graph between *C* and *D*. At *D* the negative-resistance effect appears, the voltage across the diode drops abruptly to *A* and the next cycle begins.

"The action can be observed by connecting the vertical electrodes of a cathode-ray oscilloscope across the diode and the horizontal electrodes to an oscillator for sweeping the beam of the oscilloscope across the screen at a uniform rate and in synchronism with the oscillating diode. When the oscilloscope is properly adjusted, the resulting pattern resembles a Z drawn with a vertical rather than a diagonal stroke. The upper bar of the Z represents the time that the diode spends in the high-voltage state, as indicated by the region from *C* to *D* of the graph. The vertical bar of the Z represents the instant at which the voltage snaps from *D* to *A*, and the lower bar the time spent by the diode in the region of positive resistance between points *A* and *B* [*see illustration on opposite page*].

"The frequency at which a tunnel diode oscillates this circuit is determined by the resistance of the total circuit, the included inductance and the magnitude of the battery voltage. The trick in applying tunnel diodes as oscillators consists mostly of connecting a resonant circuit of the desired frequency to the diode and suppressing the influence of those parts of the circuit that resonate at unwanted frequencies. The components used in the chronometer, their physical placement on the chassis with respect to one another and the shielding that surrounds them were all selected to accomplish this objective.

"The circuit of the chronometer consists of three sections: the crystal oscillator, frequency dividers and the power amplifier, together with its associated motor. The components are appropriate for use with either a 100-kilocycle or a 120-kilocycle quartz crystal, except that each crystal requires a minor change in the oscillator circuit. Moreover, a 50-cycle motor must be used with the 100-kilocycle crystal and a 60-cycle motor with the 120-kilocycle crystal.

"A sheet-metal chassis some six inches square and two inches high accommodates all wiring and circuit components. I combined two units measuring 6½ by 3⅛ by 1½ inches, but a single one of adequate size that provides *complete* shielding from external electrical disturbances will suffice. Power for driving the motor is provided by a transistor amplifier that is mounted on the terminal board of the motor. The accompanying circuit diagram and photograph show the wiring and the physical arrangement of the parts [*see pages 160 and 162*].

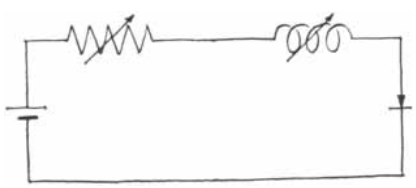
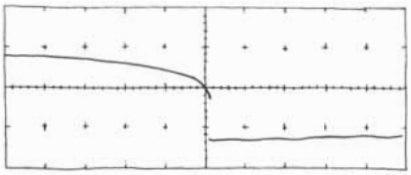


Diagram of tunnel diode oscillator



Oscilloscope pattern of oscillating diode

"The accuracy of the chronometer depends on the performance of the quartz crystal. For maximum frequency stability the crystal should not be subjected to wide variations in temperature. Preferably one should use a vacuum-mounted GT-cut quartz crystal that has been aged, such as those manufactured by the Northern Engineering Laboratories of Burlington, Wis. Vacuum-mounted DT-cut crystals are less expensive and may be substituted. When using a suitable DT-cut crystal, one can expect a frequency change of about one part per million for a 10-degree-centigrade temperature change. Other electrical properties of quartz crystals, such as the equivalent series-resonant resistance, are important in this application; this article should therefore be mentioned when the reader is ordering a crystal for use in the chronometer.

"The schematic diagram shows one small fixed capacitor and two small variable capacitors connected to one side of the crystal, a total of 110 micromicrofarads that can be increased or decreased through a range of about five micromicrofarads in either direction. The combination serves as the load capacitor and is appropriate for a GT-cut crystal. For a DT-cut the five-micromicrofarad range is inadequate. It can be increased by substituting a trimmer capacitor of wider range such as a JFD VC-23G. If this expedient proves to be inadequate, small fixed capacitors can be added as required. Small changes in the frequency of the crystal are made by altering the setting of the trimmer capacitors. They serve as the fast-slow adjustment of the chronometer.

"The clock motor operates on less than 300 millionths of a watt. It is the modest power requirement of this motor that enables the clock to operate for six months on a fresh mercury battery. If extended battery life is not a consideration, the experimenter may substitute a conventional two-watt clock motor by adding an appropriate transistor amplifier to the output. Orders for the low-power motor should be addressed to the attention of J. H. Robinson, Clock

and Timer Department, General Electric Company, Ashland, Mass.

"The assembled clock is placed in operation by adjusting the several circuits so that the motor runs on the desired submultiple of the crystal frequency and indicates the correct time. The tools for making the adjustments include two milliammeters, one of which indicates two milliamperes full scale and the other one milliampere; a high-impedance voltmeter calibrated to indicate about two volts full scale; a 1.5-volt dry cell; an oscilloscope (preferably calibrated); a 5,000-ohm, 10-turn helipot; a 1,000-ohm variable resistor and an assortment of clip leads.

"Proper voltages (biases) are first applied to the diodes, and the frequencies of the oscillators that function as frequency dividers are adjusted to the desired values. In the case of a chronometer that operates from a 100-kilocycle crystal oscillator, the first divider oscillator is designed to operate just below 10,000 cycles per second. When the high frequency of the crystal unit is coupled to this tunnel diode, every 10th pulse from the crystal arrives just in time to advance the action of the diode slightly and thus force it to oscillate precisely 10,000 times per second. Similarly, the output of the 10,000-cycle unit is superimposed on the succeeding diode, which in the absence of external disturbance is designed to operate just below 1,000 cycles per second. The remaining stage is similarly interlocked to its predecessor and reduces the frequency to 50 cycles per second.

"To make the required adjustments disconnect the battery lead from the motor and the 2.5-millihenry choke from the transistor. Connect a clip lead across the oscillator tunnel diode. Set the 100-ohm variable resistors in the divider circuits at maximum resistance. Replace the mercury battery with the 1.5-volt dry cell in series with the two-milliampere milliammeter and the helipot, set at maximum resistance. With the oscilloscope connected between the ground and point *A*, as indicated in the circuit diagram, adjust the first divider so that it spends half of the operating period in the high-voltage condition. The adjustment is made by lowering the settings of the 100-ohm variable resistor and the helipot. This is a matter of trial and error. The desired oscilloscope pattern is shown in the accompanying illustration [*page 159*]. The second and third dividers are similarly adjusted. Then, using the calibrated sweep rate of the oscilloscope to measure the time, adjust the period of the first divider circuit to about 100 microseconds by altering the setting of the 13-to-25 microhenry inductor and similarly adjust the inductors of succeeding divider circuits for ratios of 10:1 and 20:1. The latter ratio is associated with the UTC choke.

"The division ratios are determined simply by counting the number of pulses displayed by the oscilloscope. The UTC choke requires extra attention. If it is adjusted from a low value upward, a mechanical shock will increase its inductance. Similarly, if it is adjusted to a low value, a mechanical shock will decrease it further. For proper adjustment the knob of the unit should be rotated plus and minus 10 degrees on each side of the desired value and then gradually centered. Two expedients are available if the highest setting of the UTC inductor is inadequate. First, select for this func-

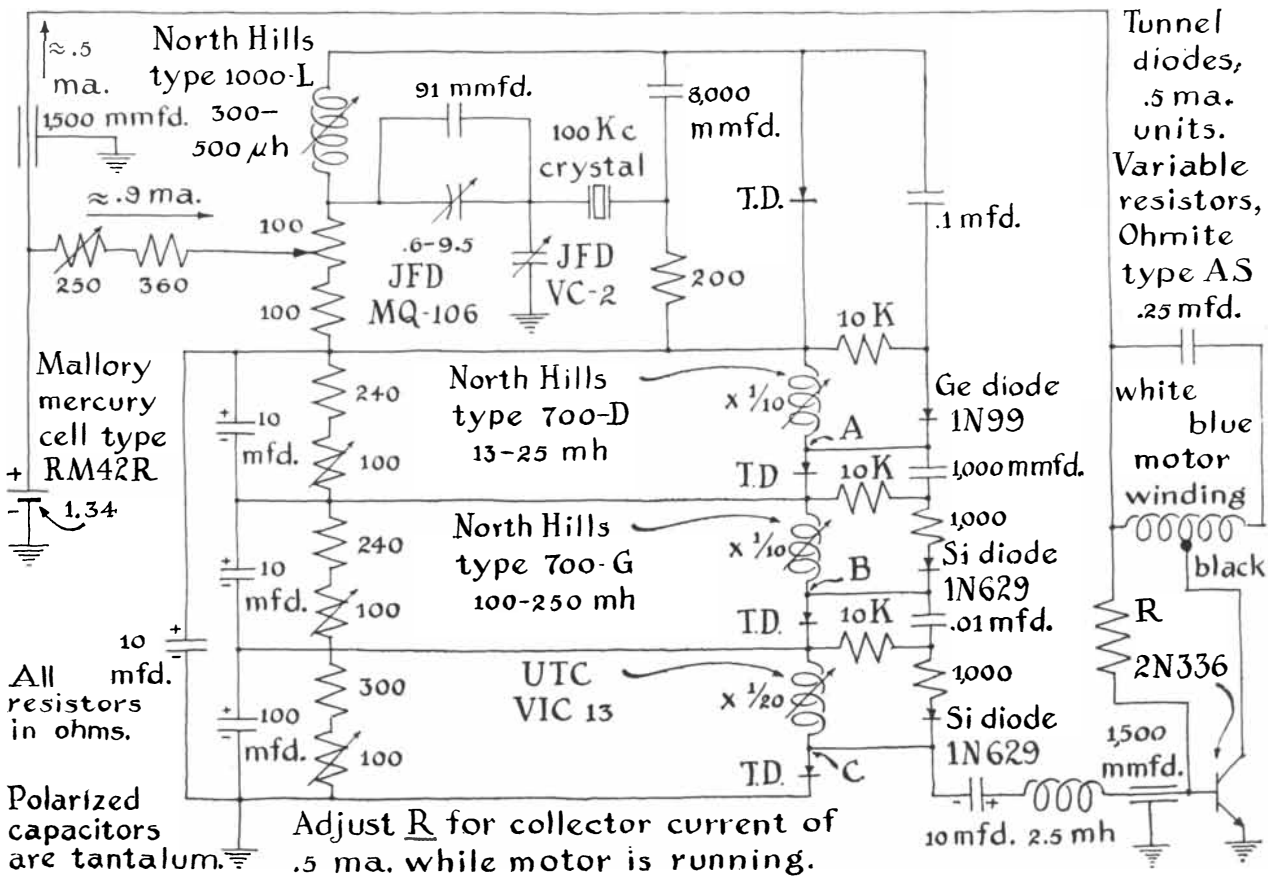


Diagram of the tunnel diode clock circuit

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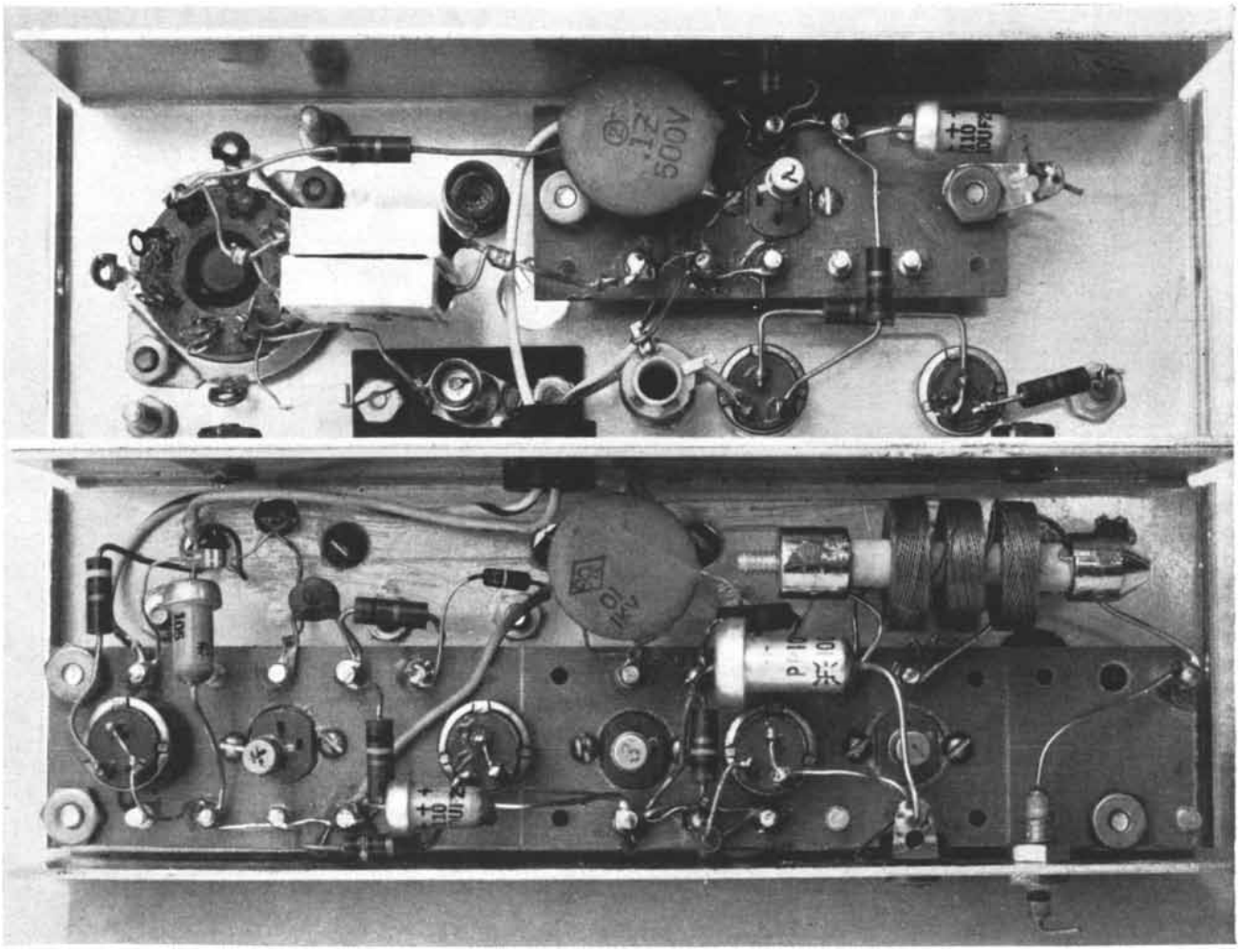
tion the tunnel diode that is marked with the highest current value by the manufacturer. (These tunnel diodes come so marked.) Then, if the unit still refuses to operate properly, replace the 1,000-ohm resistor that is connected to the associated IN629 diode with a resistor of higher value, up to 7,500 ohms, but do not use more resistance than is necessary.

"Vary the helipot and note the current range through which the correct frequency ratios obtain. The sequence of adjustments of the inductors and the 100-ohm resistors should be repeated until the current range for proper operation of the last two counters is a maximum. Record the current range (.85 to one milliampere) as well as the current required for the 50 per cent duty cycle (.95 milliampere). This information is essential for making subsequent adjustments.

"Next, disconnect the 1.5-volt dry cell and reset the helipot to maximum resistance. Remove the clip lead that was across the oscillator tunnel diode and connect it between the ground and the junction of the 100-ohm and 200-ohm fixed resistors in the oscillator circuit. This short-circuits all the divider circuits. Set the 300-to-500 microhenry inductor at minimum inductance. Connect the oscilloscope between the ground and the junction between the oscillator tunnel diode and the 8,000-micromicrofarad capacitor. Reconnect the battery and adjust the helipot and the 100-ohm control in the oscillator circuit so that the oscillator is running and draws the same current (.95 milliampere) as was recorded for the 50 per cent duty cycle. Again vary the helipot and note the current range for oscillation. This should easily bracket the divider-current range (.85 to one milliampere).

"Disconnect the dry cell, remove the clip lead and connect a high-impedance voltmeter across the battery input terminals. Reconnect the 1.5-volt dry cell and adjust the helipot and the 250-ohm variable resistor so that voltage at the battery input terminals is 1.35 volts and the current is that corresponding to a 50 per cent duty cycle (.95 milliampere) in the dividers. Make sure that the crystal oscillator is operating. The three divider inductors should be trimmed to maintain the proper division ratios while the input voltage is decreased by increasing the resistance of the helipot. Now adjust the 250-ohm resistor and the helipot so that the input voltage indicated is again 1.35 volts but the current is larger (although somewhat less than the maximum for proper operation). Connect the 2.5-millihenry choke to the transistor. Connect the motor circuit to a separate mercury battery in series with the one-milliampere milliammeter and the 1,000-ohm variable resistor, set at zero resistance. Select a biasing resistor (R) for the transistor so that the motor draws approximately .5 milliampere while running. The required resistance will be on the order of 40,000 ohms. Doubtless it will be necessary to readjust the 100-ohm resistor in the 20-



Chassis of the clock seen from below

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to-1 divider circuit so that the associated tunnel diode spends half of its time in the high-voltage condition, as it did before the transistor was connected. Remove the temporary power supplies and reconnect the motor circuit. Install the mercury battery. (Incidentally, I use two battery holders so that a battery can be replaced without stopping the chronometer.) If the quartz crystal oscillator does not start, it may be necessary to adjust the 250-ohm variable resistor. After the crystal goes into operation the resistance is promptly restored to its former value.

"The chronometer will now run when the 'start' control of the motor is operated. After the hands have been set to the correct time and the rate of the crystal oscillator has been regulated, the instrument is ready for service. The rate should be adjusted first. The 5,000-kilocycle carrier frequency that is broadcast by the National Bureau of Standards' radio station WWV can be used as a reference. A signal from the crystal oscillator can be picked up by inserting a small coil consisting of a few turns of magnet wire through the hole in the chassis near the oscillator coil. The output of this coil is amplified to drive a frequency multiplier set for the 50th harmonic. The output frequency of the multiplier will be close to 5,000 kilocycles. It is mixed with the incoming signal of WWV

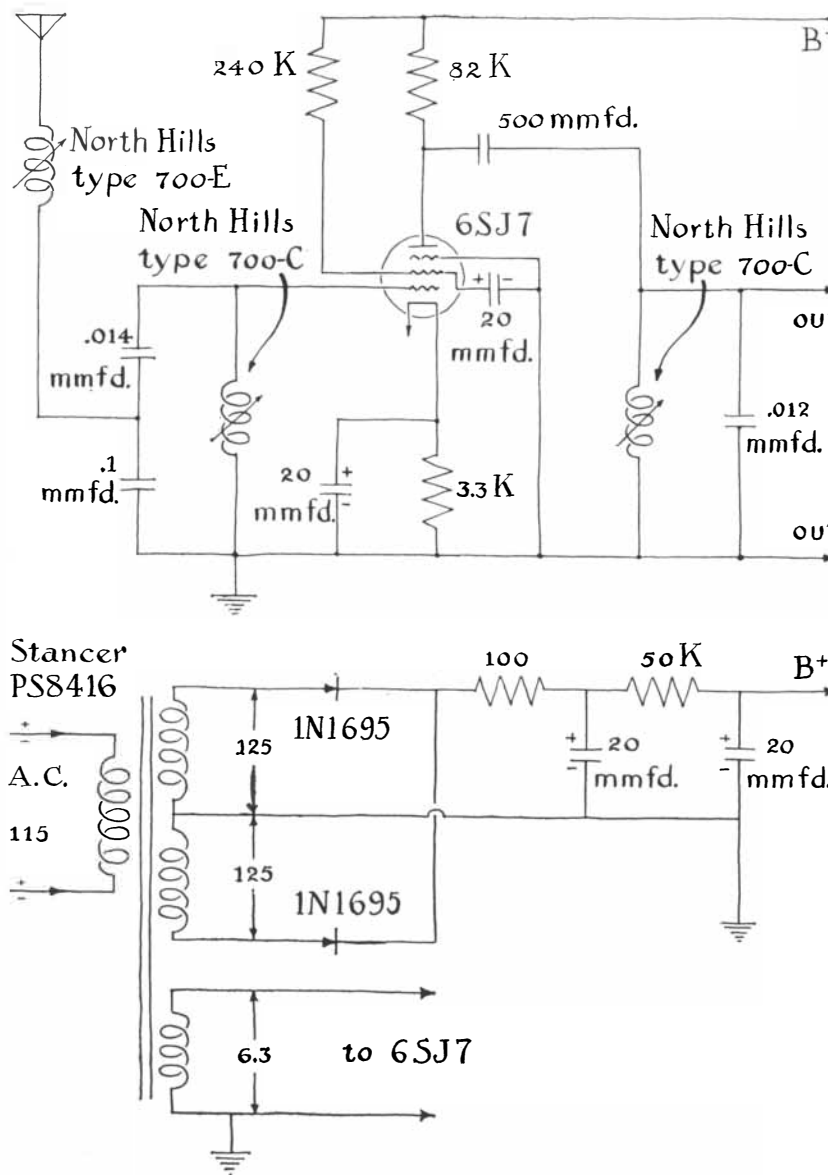

Diagram of circuit for clock radio receiver

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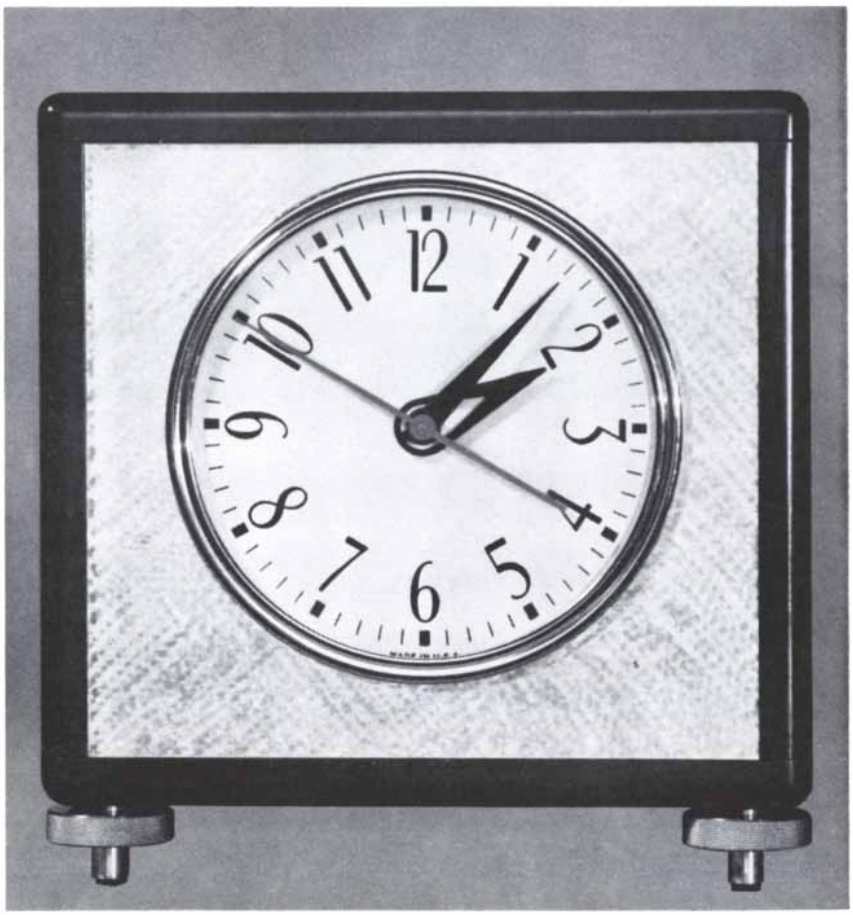
and the resulting beat frequency is observed on an oscilloscope. Adjust the oscillator for zero beat with the carrier frequency At Schenectady, N Y., it is possible by this method to regulate the chronometer to within a few parts in 10 million of the WWV signal.

"I usually start the chronometer so that the second hand is about five seconds ahead of the seconds signal of WWV. Then, by temporarily decreasing the setting of the 250-ohm variable resistor (the resistor connected in series with the battery), the last frequency divider is made to operate at a division ratio of 21 to 1 instead of 20 to 1. When the second hand falls into step with the correct seconds signal, the resistor is quickly restored to its former setting. A word of caution The gears of the motor have some backlash, so always read the time at the same second each minute. I make adjustments just as the second hand crosses 12.

"The carrier frequency received from WWV at locations more than 100 miles from the transmitter are subject to unpredictable error. The signal is received after one or more reflections from the constantly moving ionosphere and the frequency is accordingly altered by a Doppler shift. Some of the very-low-frequency radio stations maintained by the Navy blanket the nation with direct signals unaffected by the ionosphere and regulated to the same accuracy as WWV. Stations such as NAA at Cutler, Me. (14.7 kilocycles), and NSS at Annapolis, Md. (22.3 kilocycles), are examples. They can be picked up by means of a single-tube receiver [*see illustration on page 164*]. The frequency of these stations is evenly divisible by 50. The triggered horizontal sweep of the oscilloscope can therefore be synchronized with the chronometer output frequency for displaying the radio signal on the screen. Zero beat is indicated when the oscilloscope pattern stands still.

"A somewhat more formal paper that supplements this account of the chronometer is now available. Requests for copies should be addressed to: R. L. Watters, Semiconductor Studies, General Electric Company, P.O. Box 1088, Schenectady, N.Y."



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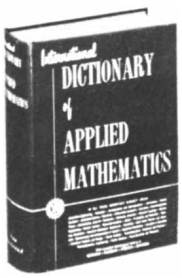

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BOOKS

The lively story of how Neptune was discovered

by James R. Newman

THE DISCOVERY OF NEPTUNE, by Morton Grosser. Harvard University Press ($4.95).

Never in the history of science was there a more dramatic discovery than that of the planet Neptune. Never was there a more spectacular demonstration of the extraordinary power of the mind's eye. So much is true, and the feat is grand enough to nourish human pride; but it is also true that the story has its share of the comic and the ridiculous, of jealousy and vanity, of ignoble ambitions and nationalistic passions. In this fresh account Morton Grosser, a young historian of science, describes the men involved and follows the principal events from the discovery of Uranus to the absurd conflict over priorities that followed the actual telescopic identification of Neptune at the Berlin Observatory on the night of September 23, 1846. The story has been told many times, one of the best versions being that of the late Sir Harold Spencer Jones, published in 1947, but Grosser's small book (regrettably unillustrated and overpriced) presents what is, as far as I know, the fullest, most detailed study both of the main circumstances and the side lights. He has gone through the documents at the University of Cambridge and the Paris Observatory and carefully examined the other primary sources, without allowing the sheer weight of the material to stifle his narrative. What he gives us is a first-rate scientific report any reader can follow, a proper tribute to the men who did the work and a diverting commentary on sundry attendant foibles and foolishnesses that in no way detracted from the great achievement.

A good place to begin the tale is with William Herschel, the second son of an oboist in the Hanoverian foot-guards band. At the age of 14 Herschel himself became an oboist in a military band. But this was not to his taste, and five years later he deserted and went to England, where he became a music teacher and attained considerable success as a violinist and organist. Music earned him an excellent living, but his restless intellectual curiosity dictated leisure pursuits that included the study of languages, harmonic theory, mathematics and, finally, the passionate cultivation of astronomy. "When I had read of the many charming discoveries that had been made by means of the telescope, I was so delighted with the subject that I wished to see the heavens and planets with my own eyes thro' one of those instruments."

He began in his spare time to build telescopes, and after five years of grinding and polishing parabolic mirrors he was turning out reflectors that were better than any at the Royal Observatory. Equipped with a 6.2-inch reflector, he set himself a stupendous task, a single-handed, complete and systematic survey of the heavens: noting and describing every visible object and determining, and later rechecking, its co-ordinates. On the night of March 13, 1781, while examining the small stars in the neighborhood of H Geminorum, he was struck with one that was "visibly larger" than the rest; moreover, it had a magnifiable disk and it was, he convinced himself, in motion relative to nearby stars. This curious object, he decided, was a comet—what he would have called a "charming discovery." He was wrong. It was a major discovery. He had, as he soon learned, found the seventh planet, later called Uranus.

That he did not initially consider this possibility is understandable. For more than 2,000 years the world had been content with six planets. Astronomers often disagreed about their size, distance and arrangement, but there was no reason to suppose that a seventh existed. Now came an oboist to confound accepted beliefs and upset the established order.

The then Astronomer Royal, Nevil Maskelyne, at once recognized that the object might be a planet. Many astronomers attempted to determine its motion. To Anders Johann Lexell, astronomer at St. Petersburg, goes the credit for calculating the first circular elements of the new planet's orbit.

Uranus was a troublemaker from the start. It was an unwanted child. It disarranged the mythological family of the heavens. The computation of its orbit was inordinately difficult: its disk was a mere four seconds of arc and the planet had been under observation for only a very short period. Even the christening stirred confusion. Out of gratitude to his royal patron Herschel suggested the name "Georgium Sidus." From an Uppsala astronomer came the proposal "Neptune" (!); from Lexell "Neptune de George III" and "Neptune de Grande-Bretagne"; "Minerva," "Cybele" and "Austräa" were among other names entertained. The editor of the *Berliner Astronomisches Jahrbuch*, Johann Bode, pointed out that if the new planet were named "Uranus," the solar system would once again represent a "coherent mythological family: Uranus, the god of the sky and husband of Earth, was the father of Saturn and the grandfather of Jupiter, who in turn fathered Mars, Venus, Mercury and Apollo (or the Sun)." Many European astronomers fell in with this proposal, but in France, Joseph de Lalande's suggested name of "Herschel" had already won wide favor. The result of all this delightful nonsense was that for 60 years after its discovery three different names and two symbols for the same planet were used simultaneously.

In time things appeared to settle down. The radii of the orbits of the six inner planets follow a series of numbers called Bode's law (which was named after the above-mentioned Bode but was not discovered by him). A suitable juggling of the law gave the new planet an orbit within 2 per cent of the radius calculated from observations. Thus the "empirical black sheep" of astronomical formulas was elevated to a high position of scientific respectability, and Uranus itself became respectable, coursing demurely in the orbit that theory had decreed for it. Because Uranus' radius left a vacant place in the numerical series,

Bode himself now leaned to the view that there was an undiscovered planet lying between Mars and Jupiter. Some astronomers shared his faith, but there were many skeptics. Enough, after all, is enough. No one was more dogmatic in subscribing to this apothegm than the fledgling philosopher Georg Wilhelm Friedrich Hegel, who in his dissertation published at Jena proved by impeccable logic that the number of planets could not exceed seven. Thereby he disposed once and for all of Bode and the future of astronomy.

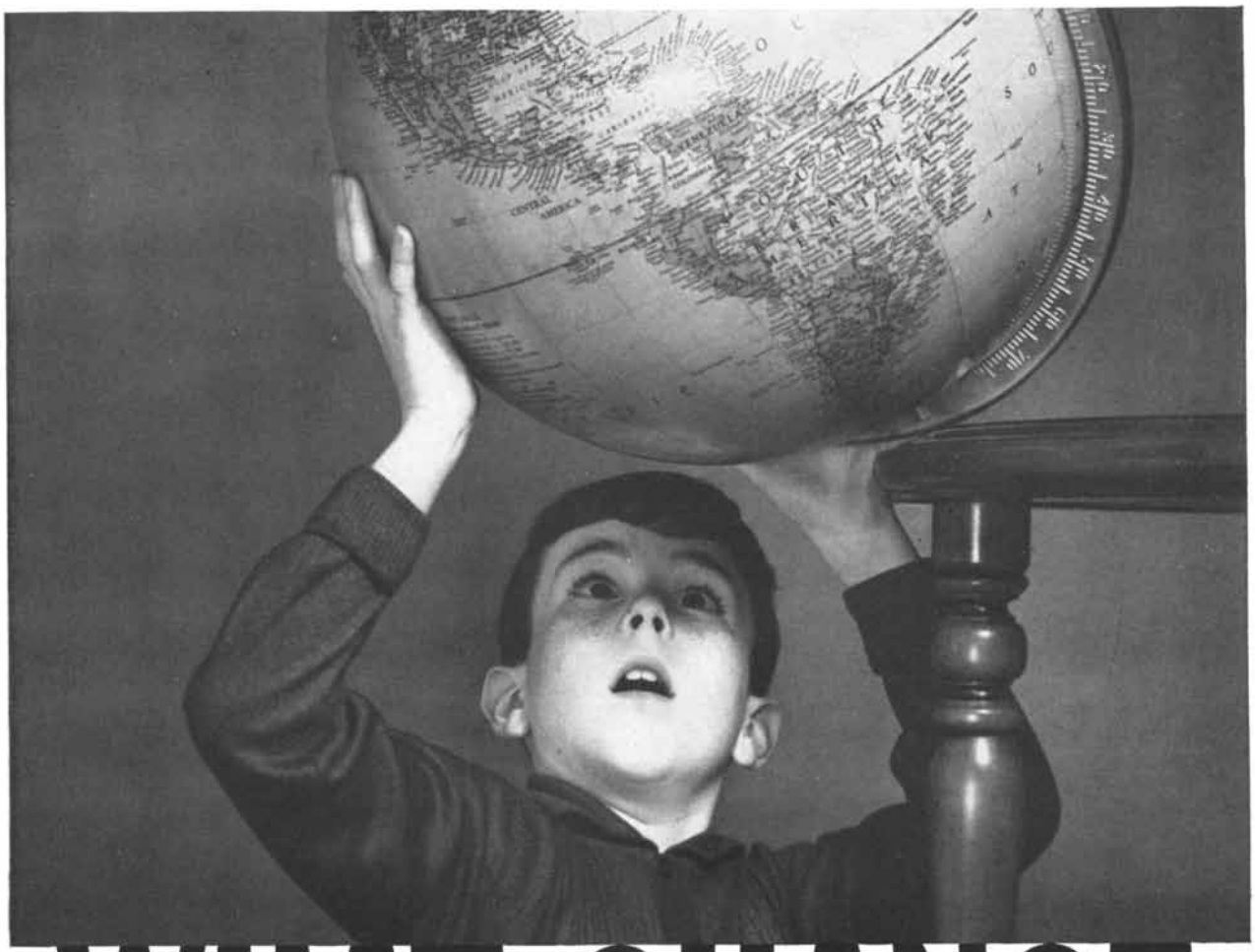
Over the next 50 years or so astronomers continued to ply their trade, to find comets and planetoids, to elaborate planetary theory. There was one powerful advance. In 1801 the incomparable Karl Friedrich Gauss solved the general problem: "To determine the orbit of a heavenly body, without any hypothetical assumption, from observations not embracing a great period of time, and not allowing a selection with a view to the application of special methods." Eight years later, in 1809, these new methods "of unprecedented conciseness and elegance" (together with his presentation of the invaluable method of least squares) were published in the famous *Theoria motus corporum coelestium in sectionibus conicis solem ambientum.* With Gauss's apparatus it was possible to determine an orbit from only three observations, and from four observations of which only two were complete. A new epoch had begun in mathematical astronomy.

It was not too soon. Uranus, once thought to be safely tucked away, was again misbehaving. Searching older records, from the 17th and 18th centuries, astronomers discovered that Uranus' positions had in fact been observed repeatedly before it was known to be a planet. Every attempt, however, to reconcile the old and the new observations failed; not only did they fail, but also the discrepancies steadily widened. The astronomical tables were becoming as useless in representing the true motion of Uranus as a defalcating bookkeeper's records in showing his employer's assets. For years the true (heliocentric) longitude of Uranus remained steadily in advance of the computed longitude; then it suddenly began to drop at a rapid rate until in 1829 and 1830 the tabular and observed longitudes coincided. This gave momentary reassurance (although it added to the confusion about the validity of the tables). Even this was short-lived; the planet soon began to fall behind its calculated place more and more rapidly. When in 1832 it became known that tables constructed only a few years earlier were currently in error (in geocentric longitude) by nearly half a minute of arc—a much larger discrepancy than for any other celestial body—the pressure, Grosser says, to devise some explanation became overwhelming.

Various hypotheses were put forward, among them the notion, frequently bruited since the beginning of the 18th century, that Newton's law of gravitation admitted exceptions. In this instance, it was suggested, Uranus' tremendous distance from the sun required modification of the inverse-square relation. The idea appealed to that school-bright, hapless donkey George Biddell Airy, appointed Astronomer Royal in 1835, of whom we shall hear more. He espoused it, pronounced on it and by reason of his official eminence gained a few nervous adherents. But the great majority of astronomers were not persuaded. They favored another hypothesis: that the aberrant behavior of the seventh planet was due to an eighth planet as yet undiscovered. By 1838 this belief was widely held.

One of its ardent exponents was Johann Heinrich von Mädler, director of the Dorpat Observatory. In his book *Populäre Astronomie* ("a book that would not be considered 'popular' in the remotest sense by 20th-century publishers") he pointed out that the current error of Uranus' radius vector arising out of the periodic differences between its calculated and its observed motions was larger than the distance from the earth to the moon. By astronomical standards this distance may not have been very great, but, like the more recent astronomical metaphors of A. S. Eddington, it lighted the imagination. Summing up, Mädler concluded: "... we arrive at a planet acting upon and disturbing [Uranus]; we may even express the hope that analysis will at some future time realize in this her highest triumph, a discovery made with the mind's eye, in regions where sight itself was unable to penetrate." Two young mathematicians were shortly, and independently, to fulfill this expectation. One was the Frenchman Urbain Jean Joseph Leverrier; the other, the Englishman John Couch Adams.

Leverrier was born in 1811 in the Norman town of Saint-Lô. His father was a minor civil servant who was ambitious for his son and decided to give him the best education he could possibly manage. He even sold his house so that young Leverrier could go to college. This faith was justified; by his industry as well as his gifts Leverrier rose to the first rank of scholars. He began his career in



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Paris in Joseph Louis Gay-Lussac's laboratory as an experimental chemist; he was then recommended for the post of *répétiteur* in astronomy at the École Polytechnique. He accepted the change in professions readily, turning his formidable analytical skills to a mastery of celestial mechanics. One attribute always stood him in good stead: an unusual aptitude for vast, laborious calculations. Computing the elements of an orbit, an exacting and deadly task even with the help of Gauss's methods, was his meat. Leverrier wrote several important papers on planetary orbits, studied the perturbations of Mercury and the behavior of various comets. His reputation made, he shifted his attention during the summer of 1845, on the suggestion of Dominique François Arago, to the puzzling motions of Uranus. Thus his path began converging with that of John Couch Adams, who had by then been working on the same problem for two years.

Adams, born in Cornwall in 1819, was the son of a tenant farmer. Like Leverrier, he was a bright child whose parents strongly encouraged and supported him. Mathematics and astronomy were his best subjects. He was fascinated by comets and eclipses, and he began making modest observations with a spyglass and entering scientific notes in his diary. He won a scholarship to Cambridge, entered St. John's College and during his course there won the highest mathematical awards, including senior wrangler in the formidable tripos examination and the coveted Smith's Prize. So prodigious was his mathematical skill that another competitor, one Goodeve, on looking over Adams' shoulder one afternoon toward the end of the six-day tripos (there were 18 three-hour papers to be completed) was so staggered at his record "that he straightaway left Cambridge and did not put in an appearance for the papers of the last two days." (To relieve the reader's mind it should be added that poor Goodeve, in spite of his lapse, came out well and afterward became professor of applied mechanics at the Royal School of Mines.)

While at St. John's, Adams turned increasingly toward astronomy. A diary entry for July 3, 1841, reads: "Formed a design, in the beginning of this week, of investigating, as soon as possible after taking my degree, the irregularities in the motion of Uranus, wh. are yet unaccounted for; in order to find out whether they may be attributed to the action of an undiscovered planet beyond it." And to a fellow student named Drew, who said that he intended to go into the Church and asked Adams what he was going to do, Adams answered: "You see, Uranus is a long way out of his course. I mean to find out why. I think I know."

He did not waver in his resolve. Shortly after his election to a fellowship at St. John's he outlined to James Challis, Plumian Professor of Astronomy at Cambridge, his proposed analysis of Uranus' orbit. Adams could not undertake it during term at the college because he devoted all of his spare time to teaching private pupils, and he sent the income from this work to his parents to repay them and assist in the education of his younger brothers. But on the first long vacation at home he began his difficult calculations. Night after night they occupied him. Even in his walks his mind turned over the problem. By October, 1843, he had gained a preliminary solution. It confirmed his belief that an exterior planet was the cause of Uranus' perturbations.

The problem of perturbation Adams was working on divided, as Grosser describes it for us, into four parts: "(1) determining the perturbation of Uranus for any given time; (2) resolving this perturbation into known and unaccounted-for components; (3) formulating equations in which the unidentified forces were related to the mass and elements of the hypothetical disturbing planet; (4) solving the equations for numerical answers." In plain language, he had to compute, on the basis of grossly imperfect data on the motion of one planet, the location and motion of another whose very existence was unproved. Adams used Bode's law in assuming that the theoretical planet was about twice the mean distance of Uranus from the sun, and he hypothesized that its orbit could be approximated by a circle. On the second go-round of his analysis, completed in 1845, he made the orbit eccentric, abandoning the simplified assumption of circularity.

Challis had been helpful and encouraging in various ways. Adams reciprocated by calculating at Challis' request the elements of de Vico's comet —a labor that delayed considerably his work on Uranus. When Adams finally published his elements of the comet in *The Times*, it turned out that Leverrier had anticipated his results. This was a foretaste of the much heavier disappointment still to come.

Airy now reappeared on the stage. In 1844 Challis had asked him for certain data about Uranus on Adams' behalf. Airy supplied them by return mail. When in September, 1845, Adams had completed his new solution, Challis wrote Airy of Adams' progress and, since the

latter was about to leave for his parents' home in Cornwall, wrote a letter of introduction for him so that he could deliver his results to the Astronomer Royal. They included a significant addition to the elements of the hypothetical planet, namely its geocentric longitude (on September 30, 1845), which was an essential for telescopic observation, making possible the detection of the disk. With this direction Challis' own Northumberland instrument was easily capable of resolving the disk and identifying the planet, but he did nothing; and Adams himself ignored an opportunity presented from another quarter to crown his efforts. Instead he set off for Greenwich to see Airy. A ludicrous chain of events ensued.

When Adams arrived at the Royal Observatory, Airy was in Paris attending a meeting of the French Institute. On his return a week later he found Challis' letter of introduction and replied to it immediately, saying he was sorry to have missed Adams and would be glad to see him. A couple of weeks later Adams returned to Greenwich and again tried to deliver his results. The Astronomer Royal was not at home, and Adams left his card and a note containing a short statement of his results, promising to call again later. When he did, Airy's butler told him that the Astronomer Royal was at dinner—Airy, on his doctor's insistence, dined at precisely 3:30 every afternoon—and could not be disturbed. (The butler, it should be noted, never informed Airy of Adams' second visit.) Feeling rebuffed, Adams returned to Cambridge. It had been a feckless series of arrivals and departures.

To be sure, one could blame the butler for the whole business. But it is likely that even if Adams had got to Airy he would not have fared much better. When Airy, having dined and digested his dinner, finally perused Adams' summary, he had a "strong negative reaction." This was typical. Airy was a small, "markedly asocial" man, who at an early age learned double-entry bookkeeping, a system that permeated his soul and to which "he attached a special and distorted value... throughout his life." Sober and unusually conceited, his policies were dominated, Grosser says, by two ideas: practicality and order. Theoretical investigations were abhorrent to him. The main thing was to keep books. He carefully kept every kind of document—check counterfoils, circulars, bills, correspondence. He dreaded disorder even in the smallest matters. "As an example, he spent a whole afternoon writing the word 'Empty' on large cards, to be nailed upon a

great number of empty packing boxes, because he noticed a little confusion arising from their getting mixed with other boxes containing different articles." Coupled with this compulsiveness was a consuming despotism and a bitter jealousy of his assistants—or of any young astronomer. He treated his aids as though they were children, and even packed soap and towels for them, with their instruments, when they went on journeys to make observations.

A few days after Adams left his summary, Airy wrote him a condescending note, referring to his "assumed" perturbations. Adams replied explaining his conclusions. Airy pigeonholed the matter.

Meanwhile Leverrier was hard at work. In June, 1846, he sent Airy the results of a memoir on Uranus, which differed from Adams' results by little more than one degree of arc. A Frenchman seemed less of a threat than a compatriot, and Airy replied that he felt "delight and satisfaction" at receiving the findings. He now wrote to Challis asking him to "sweep for the possible planet" but gave him directions so inefficient that Grosser compares them to a plan for finding a particular bright pebble on a beach by removing, one by one, thousands of other pebbles from a large area around the point where the desired pebble is thought to be. Challis began some trial observations; Airy himself, reluctant as always to alter the routine of his observatory, did nothing. His public excuse was that his best telescope was not good enough for the job; it is true that the Northumberland instrument was more powerful than any at Greenwich. In spite of the cumbrousness of Airy's directions, Challis came within a hair of identifying Neptune. He did in fact observe it twice, in July and August, when it wandered into the zone he was searching, but an almost inexplicable failure to make certain crucial comparisons, which would have shown him that a star of the eighth magnitude present in the series recorded on one date was missing from the same series on another, cost him the prize. His subsequent excuses, which Spencer Jones characterized as "pitiable," were that he was occupied with certain comet reductions and thought a much longer search would be needed to ensure success. (He also confessed later that he had too little confidence in "the indications of the theory.")

Adams meanwhile was revising and re-revising his calculations. On September 2 he sent Airy his sixth corrected solution of the problem of Uranus. The Astronomer Royal was not at home to receive it. He had left with his wife for

Wiesbaden in Germany to take the waters. The chief assistant he left behind, the Reverend Robert Main, sent Adams an inane reply. Main was probably afraid to blow his nose without permission, let alone look for a new planet.

Circumstances were kinder to Leverrier. The French astronomers were, to be sure, no more helpful to him than the British astronomers were to Adams. A third memoir on Uranus, presented to the Académie des Sciences on August 31, 1846, gave the solution of 33 equations of condition that fixed the co-ordinates of the missing planet with remarkable completeness and precision; nevertheless, Leverrier's exhortations failed to stir his stargazing colleagues to action. He now ran out of patience and decided, even at the cost of patriotic allegiance, to find a foreigner who would search for the planet. The person he fixed on was Johann Gottfried Galle, a young assistant at the Berlin Observatory, who a year earlier had sent Leverrier a copy of his dissertation (having to do with the work of Olaus Roemer). Leverrier had not bothered to reply, but now he needed help. He wrote Galle a letter of fulsome praise—ending with an urgent request that he look for the perturbing planet.

When the letter arrived, Galle, obviously flattered, immediately asked his superior, Johann Franz Encke, for permission to make the search. Encke, molded along Airy's lines, regarded his assistants as "drudges" and was not above passing off their achievements as his own. He was unreceptive. Galle persisted; Encke finally yielded. The same night Galle, assisted by a zealous young student astronomer, Heinrich Ludwig d'Arrest, trained his telescope, a nine-inch refractor, at the point where Leverrier predicted the planet lay: right ascension 22 hours 46 minutes; declination, minus 13 degrees 24 minutes. He was on the lookout for the three-second disk that Leverrier had predicted. He could not find it, and d'Arrest suggested using a star map—the purpose being to discover an object that was not on the map. D'Arrest found in a cupboard a chart, Hora XXI of the Berlin Academy's *Star Atlas,* which mapped the area under search but had not yet been distributed to other observatories. Galle, at the telescope, called out the appearances and positions of the stars in his sector while d'Arrest checked the information on the map. "Only a few had been checked when Galle described a star of the eighth magnitude, right ascension $22^h\ 53^m\ 25^s.84$. D'Arrest exclaimed, 'That star is not on the map!' It was, at last, the eighth planet."

Shortly after midnight d'Arrest excitedly reported the discovery and Encke hurried to the dome. The three astronomers tracked the object until it set at about 2:30 a.m. They were still not positive it was a planet, and so during the night of September 24 they continued their observations. Soon they were sure. The measurements were amazingly close to Leverrier's predictions. Among other things, Leverrier's elements gave the geocentric longitude of the planet on September 23.5, 1846, as 324 degrees 58 minutes; the longitude observed by Galle at September 23.50001 was 325 degrees 52 minutes 45 seconds—a difference of about 55 minutes of arc, less than a single degree. On September 25 Galle wrote Leverrier a triumphant letter beginning with the famous line: "The planet whose position you have pointed out *actually exists*."

How the denouement affected the various actors is the subject of Grosser's last chapter. Airy learned of the event on September 29 while he was in Germany, but he did not write to anyone about it for more than two weeks. Challis, on receiving the news, was mortified and admitted it. Leverrier thanked Galle and informed him that the French Bureau of Longitudes had decided on the name "Neptune." A little later he changed his mind and implored Arago to suggest that the planet be named after himself. Arago made an impassioned speech before the Académie des Sciences—he was forever making impassioned speeches—vowing "never to call the new planet by any other name than Le Verrier's Planet." This proved, he said somewhat irrelevantly, his love of science and his patriotism. On October 3 John Herschel (the son of William) wrote to the London *Athenaeum* describing Adams' work; this was the first public notice of it. Airy, in congratulating Leverrier, mentioned that "collateral researches" had been going on in England that led "to precisely the same results as yours" but omitted Adams' name and assured Leverrier that he was "beyond doubt . . . the real predictor of the planet's place." When Leverrier learned of Adams' claims, he became angry and upset. A detailed account (by Challis) of the British investigation reached France and the fat was really in the fire. The Académie des Sciences had an uproarious session. A leading Parisian journal described the stormy scenes as worthy of the Chamber of Deputies. Arago tore more passions to tatters. The French press took up where he left off, with violent attacks on England, brutally satirical caricatures of Adams and so on and on. Airy and Chal-

lis came under heavy fire in Britain; indeed, most British astronomers supported Leverrier's claim. The Royal Society of London placed its stamp of approval on it by awarding him its highest scientific honor, the Copley Medal.

The tempest spent itself; the bitterness waned. Adams gained just recognition and honors. The French astronomer Jean Biot published an article that decried the "narrow spirit of geographical selfishness so wrongly called patriotism" and referred to Adams as "a talented young man who has been served badly by circumstances this one time, and whom one must applaud in spite of it . . . in [his] own mind, [he knows] that the new planet was known in theory to [him] before any other person . . ."

In their behavior the principals set an example for others. They were not embittered. At the June, 1847, meetings of the British Association for the Advancement of Science, Leverrier and Adams met for the first time. John Herschel invited them to his house and to his delight "they were immediately taken with each other." They remained friends for their entire lives. They had shared a great adventure and together they left to science a memorable legacy.

Short Reviews

THE TOADSTOOL MILLIONAIRES, by James Harvey Young. Princeton University Press ($6). An able social history, at once entertaining and sobering, of patent medicines in the U.S. before Federal regulation. (The title is from Oliver Wendell Holmes's rebuke of the "greedy, dishonest, obscene and heartless" proprietors of American nostrums of secret composition, whom he called "the mushroom, say rather, the toadstool, millionaires.") The racket got under way with the importation in the 18th century of patented brands from England: such concoctions as "Dr. Bateman's Pectoral Drops," "Hooper's Female Pills," "Daffy's Elixir" and "British Oyl" (extracted from a "Flinty Rock for the cure of Rheumatick and Scorbutick and other Cases"). The climate of the 18th century nourished the business. It was at once an age of enlightenment and a time of superstition. A revolution had created a new physics and astronomy, and it seemed not too much to hope that biology and medicine would soon be similarly transformed. But living organisms are more complex than stars and the laws of digestion are more intricate than those of falling bodies; moreover, medical knowledge was "still so small and the weight of past traditions so press-

ing that even the keenest minds were perplexed." When physicians became disillusioned about the possibility of discovering universal biological laws, they either abandoned the scientific method altogether or erected grand theoretical medical schemes by speculative logic, schemes that at best let the patient fight his own way to health but more often made him sicker or accelerated his demise. In this setting patent medicines were bound to flourish. Since doctors were no good, why not urge people to doctor themselves?

There were neither legal nor moral restraints; *laissez-faire* smiled on the manufacture of medications; nothing could have been more brazen or extravagant than the claims made for the various pills, elixirs, powders, ointments and salves. Dr. John Hill (who, as everyone knew, could change water into ass's milk) marketed an American balsam that cured every ailment from whooping cough to the "hypochondriacal disease." Dr. Elisha Perkins sold "metallic tractors" that became a national mania. Dr. Samuel H. P. Lee made a fortune on "bilious pills." Pulmonic sirups and pectoral lozenges vied with "Waterproof Anti-Consumptive Cork Soles" and "Medicated Fur Chest Protectors" in the fight against tuberculosis. Samuel Thomson, a New Hampshire farmer, patented a system of medical treatment founded on the notion that all disease is the effect of one general cause, namely cold, and therefore the remedy was heat, which was to be administered by means of steam baths, hot and cold botanicals such as red pepper, emetics, purgatives and enemas, and best of all by the herb *Lobelia inflata*, which had the same effect on the human system as clearing a stove and pipe when it is clogged with soot so "that the fire may burn free and the whole room be warmed as before." William Swain, a New York harness maker, invented a panacea that took care of such misfortunes as syphilis and a contaminated state of the blood. Dr. William Brandreth peddled "Vegetable Universal Pills," a sovereign purgative. Dr. C. P. Bellingham mixed an "Onguent" that allegedly raised Abraham Lincoln's beard in six weeks. Henry T. Helmbold wrote a "Patient's Guide" that enabled one to diagnose one's own ailments from sexual impotence and epilepsy to diabetes, rheumatism and masturbation. Dr. Jacob Hostetter's "Bitters" cured diarrhea and had enough alcohol in it to quiet any other pain one might have.

The show went on through the 19th century. Even as medical knowledge found firmer scientific foundations the

patent medicines multiplied, the quacks became slicker and more dangerous and trained physicians were themselves prescribing all kinds of proprietary humbug. Newspapers carried more and more nostrum advertising. The magic name of science, the lure of the exotic and the unintelligible, the symbols of patriotism —all were used to bolster appeals (Uncle Sam, for example, was shown seated at a table affixing his signature to a document that read: "This is to certify that I am using 100,000 boxes of Ex-Lax every month"). Religion was a mighty fortress in which the nostrum maker took refuge. Testimonials from ministers were a great help. By eating a bowl of Grape-Nuts "after my Sabbath work is done," observed one pastor, "my nerves are quieted and rest and refreshing sleep are ensured me." Ayer's sarsaparilla got a testimonial from the Sisters of Charity, who ran St. Mary's Infant Asylum in Massachusetts. Remedies were named for St. Anne and St. Joseph, not to mention Father Koenig and Father John (Sir William Osler postulated that "those among the clergy who had wandered farthest from the decrees of the Council of Trent were the most susceptible to quackery").

Finally, in 1906, stimulated by a famous series of articles in *Collier's* by Samuel Hopkins Adams, legislation was passed establishing pure food and drug standards and a regulatory commission. It was an important turning point in patent medicine history, but the law has serious shortcomings and is imperfectly enforced, and large-scale nostrum abuses and frauds are still cruelly perpetrated on the people of this country. Particularly naïve was the original notion that figured in the drafting of the law, namely that the common man would refrain from buying a concoction if the label on the bottle plainly indicated that the contents, even if innocuous, were altogether useless. Tonics, pills and the like continue to be advertised, lied about and bought in enormous quantities. Former Postmaster General Arthur Summerfield charged that more money is being made today in medical quackery "than in any other criminal activity." For the promoters of specious medication the annual "take" is said to exceed a billion dollars. Half a billion dollars goes into the nutrition racket; another quarter-billion is spent for medical gadgets falsely purporting to promote recovery from arthritis and rheumatism; $100 million goes for ineffective reducing remedies; $50 million for fake cancer cures; and millions more for panaceas that hold out "the vain promise of curing ailments

ranging from the common cold to heart disease." As Young points out in the epilogue to his very good book, there is greater need than ever for improved legal regulations, for more rigorous and prompt enforcement of existing laws, for muckraking, for popular education, for congressional inquiry. In 1955 Food and Drug Commissioner George P. Larrick observed: "I know it is common to speak of the 'good old days' of snake oil and soothing sirup as though they were gone forever. The amazing fact is that to a very great extent those good old days, so-called, are still with us." The toadstool millionaires are still getting away with murder.

ATLAS OF THE BRITISH FLORA, edited by F. H. Perring and S. M. Walters. Thomas Nelson & Sons ($22.50). This volume, the product of an effort organized by the Botanical Society of the British Isles, contains some 1,600 maps showing the distribution of 1,700 flowering plants and ferns growing in Britain. The maps relate to some 3,500 squares (each is 10 kilometers square) forming the British National Grid, and the presence of a species is represented by a dot on a map. Altogether more than 1.5 million separate records were prepared in this way by amateur and professional botanists. Thereafter modern data-processing equipment, including mechanical map makers, was used, thus making it possible to prepare finished maps within a short time after the information was collected. Also included are 12 transparent overlays, fitted into a pocket at the back of the book, that help the users of the atlas to interpret the maps, furnishing information as to climate, topography, altitude range, soil preferences and so on. An impressive work.

INFORMATION U.S.S.R., edited and compiled by Robert Maxwell. A Pergamon Press Book. The Macmillan Co. ($30). By far the greater part of this volume is a translation into English of Volume 50 of the *Great Soviet Encyclopedia*. Appendixes have been added containing statistical tables on the U.S.S.R. and miscellaneous information such as addresses of some universities. Copiously illustrated, the book contains a mass of data on the geography, geology, climate, soils, vegetation and animal life of the U.S.S.R.; on population; on the history of Russia; on the Communist Party; on trade unions; on the national economy; on such diverse subjects as public health, education, the press and broadcasting, the armed forces, science and scientific institutions, literature and the arts. There

are also separate articles on the Union Republics.

THE SEA: IDEAS AND OBSERVATIONS ON PROGRESS IN THE STUDY OF THE SEAS. VOLUME I: PHYSICAL OCEANOGRAPHY. Edited by M. N. Hill. Interscience Publishers. John Wiley & Sons, Inc. ($25). Since Sverdrup, Johnson and Fleming's masterly treatise *The Oceans* was published in 1942 no comparable comprehensive work has appeared, although much progress has been made in oceanographic research during the past 20 years and many journal papers and studies more limited in scope have appeared throughout the world. The purpose of the present book is to give a balanced account of oceanographic advances over the past two decades. In its several sections are essays on the interchange of properties between sea and air, the dynamics of ocean currents, the transmission of sound, light and other electromagnetic radiation, sound scattering by marine organisms, sound production by marine animals (the squeals and clicks of porpoises, the drumming of fiddler crabs, the grunts and croaks of grunts and croakers, the noises made by snapping shrimps and pistol prawns, the steady sound made by schools of swimming fish, the boat-whistle-like toots of toadfishes and so forth), waves, turbulence, the physics of sea ice. Two volumes still to come will cover the composition of sea water, and the earth under the sea. A scholarly, handsomely produced, well-illustrated book.

ARCHAEOLOGY OF EASTER ISLAND: VOLUME I. Edited by Thor Heyerdahl and Edwin N. Ferdon, Jr. Rand McNally & Co. ($25). This monograph of the School of American Research and the Museum of New Mexico is the first volume of the reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific. The objectives of the expedition are set forth, its itinerary and organization, followed by a general account of the geography and history of the island. The archaeological reports themselves are concerned with the ceremonial sites, the dwelling sites, the stone statues and quarries, the important ditch across the neck of the so-called Poike headland (the purpose of the ditch is in dispute, one suggestion being that it was a defensive structure, another that it was to provide a moist area for the growing of bananas, sugar cane and taros), radiocarbon dates, sundry surface artifacts such as tools and weapons, fishhooks, utensils, ornaments, sculptures, rock painting, wood carvings.

In a general conclusion Heyerdahl offers his interpretation of the finds; combined with certain legends that he accepts as true, they solidly support, in his view, the theory on behalf of which he made his celebrated raft journey across the South Pacific, namely that Polynesia was first settled by people from South America. The four archaeologists of the expedition (William Mulloy, Arne Skjölsvold, Carlyle S. Smith and Ferdon) are far from endorsing this theory, and from what they write one must infer that the scholarly community as a whole regards the question as still very much up in the air. In spite of Heyerdahl's special pleading, this is a most interesting and valuable book and the volume itself well turned out.

ASTRONOMY OF THE 20TH CENTURY, by Otto Struve and Velta Zebergs. The Macmillan Co. ($12.50). This book by a noted astronomer and his research assistant is a considerable achievement. Beginning with a description of the state of astronomy at the turn of the century, it continues with an account of the major advances of the past 60 years, dealing with such topics as photography of the Milky Way, determination of radial velocities, photometry, radio astronomy, solar research, physics of the solar system, spectral classification, stellar structure, stellar evolution, Hertzsprung-Russell diagrams, double stars, pulsating stars, exploding stars, interstellar matter, galactic nebulae and galaxies. Neither a popular exposition in the usual sense nor an advanced work, the book succeeds by reason of its clarity and the skillful selection of material and quotations from key sources in combining important features of both of these approaches. Ordinary readers, students and professional astronomers will all find much to enjoy in these pages. Of conspicuous merit are the biographical sketches and out-of-the-way stories about the leading astronomers of the century, many of whom Struve knew personally. Illustrated with more than 200 photographs and diagrams. Highly recommended.

STANDARD ENCYCLOPEDIA OF THE WORLD'S OCEANS AND ISLANDS, edited by Anthony Huxley; STANDARD ENCYCLOPEDIA OF THE WORLD'S MOUNTAINS, edited by Anthony Huxley. G. P. Putnam's Sons ($10.95 each). Each of these volumes contains a series of popular geographical articles, mostly of medium length. Those in the first volume describe oceans and islands, where "oceans" include, in addition to the major oceans, the bays, channels, straits, sounds,

canals, seas and gulfs, and where "islands" include capes and peninsulas. Those in the second describe the most important mountain peaks, ranges, glaciers and passes. Prepared by many different contributors, the material is very well handled. The entries are literate and impart abundant factual information as to physical features and a good deal of historical and related data, which give the reader a feeling for the places described that cannot usually be got from encyclopedia articles. The volume on mountains has many absorbing stories about discoveries, famous climbs and so on. There are good color plates and photographs—some of which are only indifferently reproduced. Each volume has a gazetteer and an index. The maps, however, are not only pedestrian but also fail to give, as do the articles, information as to latitude and longitude. This is bad enough in an encyclopedia of mountains but in an encyclopedia of oceans and islands it is absurd.

NATURAL HISTORY OF INFECTIOUS DISEASE, by Sir Macfarlane Burnet. Cambridge University Press ($6). The third edition of an excellent book, first published nearly 25 years ago, that is occupied with two central themes: infectious disease as part of the general evolution of life, and the influence of infectious disease of man on his past, present and future. It has been necessary to incorporate much fresh material because of discoveries and advances in biology, in the field of antibiotics and the synthetic insecticides, in immunology, in chemotherapy and other fields. Most of the chapters have been extensively rewritten.

AMERICAN ARCHITECTURE AND OTHER WRITINGS BY MONTGOMERY SCHUYLER, edited by William H. Jordy and Ralph Coe. The Belknap Press of Harvard University Press ($12.50). A two-volume collection of essays on architecture written between 1880 and 1910 by one of the most perceptive and thoughtful of American architectural critics. Schuyler understood architecture, had well-formed tastes and knew how to write about the subject without indulging in the pretentious double talk so characteristic of most of today's architectural criticism. The volumes contain 167 illustrations of the structures Schuyler discusses and a long introduction by the editors.

MATHEMATICS IN YOUR WORLD, by K. W. Menninger. The Viking Press, Inc. ($5). A readable potpourri of methods, problems and ideas from

various branches of mathematics such as geometry, topology, number theory, probability, analysis and algebra. No *expertise* is required and one can dip into the book anywhere and follow the discussion without having to read the preceding material. Menninger is an old hand at popularization in German (this book is a translation) and he handles his material with authority.

THE CHOLERA YEARS, by Charles E. Rosenberg. The University of Chicago Press ($7.50). A somewhat repetitious and pedantic but occasionally interesting account of the cholera epidemics that struck the U.S. in 1832, 1849 and 1866 and raged not only in the great cities but also crossed the continent and struck down victims everywhere. The book draws on contemporary newspapers, journals and letters and reports the views of physicians, ministers, public officials and the rich and poor in every walk of life. Why an unillustrated 257-page book should cost this much is hard to understand.

NORTH ATLANTIC LINERS, illustrated and described by Laurence Dunn. Hugh Evelyn, Limited, and the Stephen Greene Press ($20). An attractive color-plate book that portrays some of the finest liners built between 1899 and 1913 to operate in the North Atlantic. In the group are such fine examples as the *Oceanic*, the *Empress of Britain*, the *Mauretania*, the *Olympic*, the *France*, the *Bergensfjord* and the *Imperator*. The accompanying text gives details and interesting information about each of the ships. This volume is in the genre of the same publisher's volumes on classic motor cars.

THE IMPORTANCE OF LANGUAGE, edited by Max Black. Prentice-Hall, Inc. ($1.95). A collection of illuminating and enjoyable essays about language. Represented, among others, are Aldous Huxley, Samuel Butler, Bronislaw Malinowski, Friedrich Waismann, Gilbert Ryle and Alan S. C. Ross (by his now celebrated piece "U and Non-U," which first appeared under the title "Linguistic Class-Indicators in Present-Day English" in a Finnish philological journal). The editor has been ingenious in extracting these essays from books and recondite journals in which the average reader would be unlikely to see them.

THE GEOLOGY OF EGYPT, by Rushdi Said. American Elsevier Publishing Co., Inc. ($27.50). A comprehensive survey of Egypt's geological evolution.

Part of the material in the book is original, but the larger part has been collected from other sources. Many excellent maps and an exhaustive bibliography. An important scientific work, much in advance of any survey that has appeared hitherto.

Notes

A DICTIONARY OF BIOLOGY, by M. Abercrombie, C. J. Hickman and M. L. Johnson. Aldine Publishing Co. ($5). A hard-cover edition of a compact and useful dictionary that was first published as a Penguin book. The illustrations are minimal and inadequate.

PHOTOGRAPHY: ITS MATERIALS AND PROCESSES, by C. B. Neblette. D. Van Nostrand Co., Inc. ($15). The sixth edition of a work, first published in 1927, that offers a comprehensive survey of the materials and processes of photography. In addition to Neblette himself 20 specialists have contributed chapters on various topics.

RAND MCNALLY COSMOPOLITAN WORLD ATLAS. Rand McNally & Co. ($14.95). A revised edition of a standard world atlas with many new maps of African countries, new large-scale maps of Switzerland and the U.S.S.R., a section on satellites and space, 27 historical maps portraying major periods of world history and updated population figures.

THE EARTH AND YOU, by Norman J. G. Pounds. Rand McNally & Co. ($6.95). A panorama of world geography that for each region synthesizes information about the physical elements, agriculture, industry and transportation. Illustrations and maps.

PREHISTORIC CRETE, by R. W. Hutchinson. Penguin Books ($1.95). A richly illustrated, well-written, authoritative account in the Pelican series of what is known today of the Minoans: their origins, social organization, trade, religion, art and so forth. This is an original volume written for the series by a leading archaeologist who has taken part in many excavations in different parts of the world.

TRAVEL AND DISCOVERY IN THE RENAISSANCE, 1420–1620, by Boies Penrose. Atheneum Publishers ($1.95). A soft-cover reissue of a fine general account of the exploration and exploitation of non-European areas by Europeans during the 15th and 16th centuries. Maps and a valuable bibliography.

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Destination: EARTH

After a final, over-the-shoulder glance at the craggy lunar scene, moon explorers will apply themselves to the new task at hand — getting back home. How will the lunar declination at time of lift-off be interrelated with earth landing site latitude, time of flight and landing range from re-entry at $\gamma = -6°$ to touchdown?

Curves Provide Key

The curves at upper right provide the key. Window AB describes the range of lunar declinations, from $+0.5°$ to $-20.5°$, acceptable for returning to an earth landing site at a latitude of $+10°$, for a 2.5 day time of flight with a landing range of 2000 n.mi. from re-entry at $\gamma = -6°$ to touchdown. The schematic illustration shows the trajectory plane for a lunar declination of $-10°$. As lunar declination varies through the acceptable range shown in the curves, the trajectory plane will rotate around the radius from earth center to landing site.

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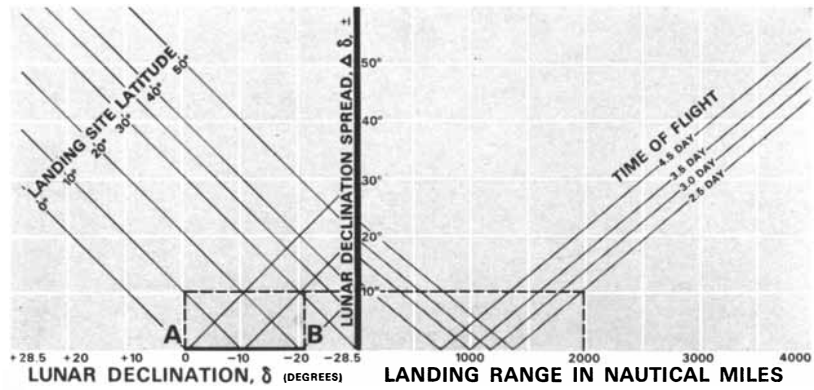
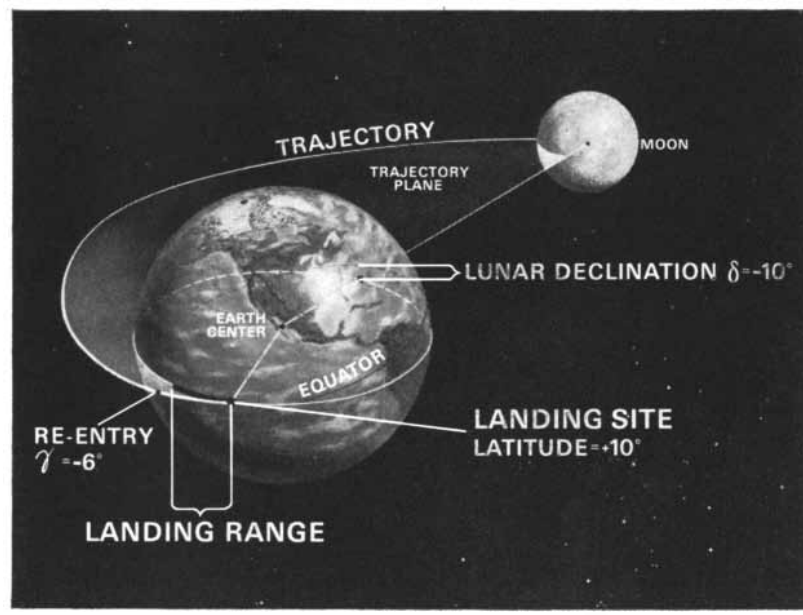
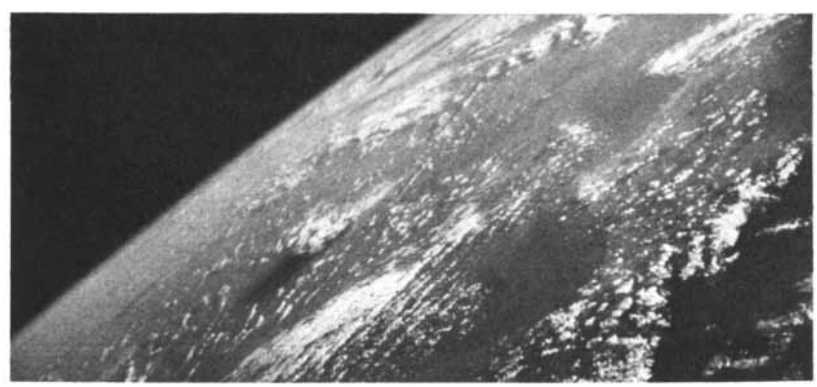




LUNAR LIFT OFF AT $\delta = -10°$ *Heading for an earth landing site latitude of $+10°$, a vehicle will describe this approximate trajectory over a 2.5 day time of flight. Landing range from $\gamma = -6°$ to touchdown would cover some 2000 n.mi. in this case.*



RE-ENTRY MINUS 60 SECONDS *The earth will present this aspect to returning moon explorers as they near their destination. This photograph was taken at an altitude of 100 miles from a NASA Mercury capsule, boosted into orbit by an Atlas space launch vehicle.*

GENERAL DYNAMICS | ASTRONAUTICS

AN EQUAL OPPORTUNITY EMPLOYER

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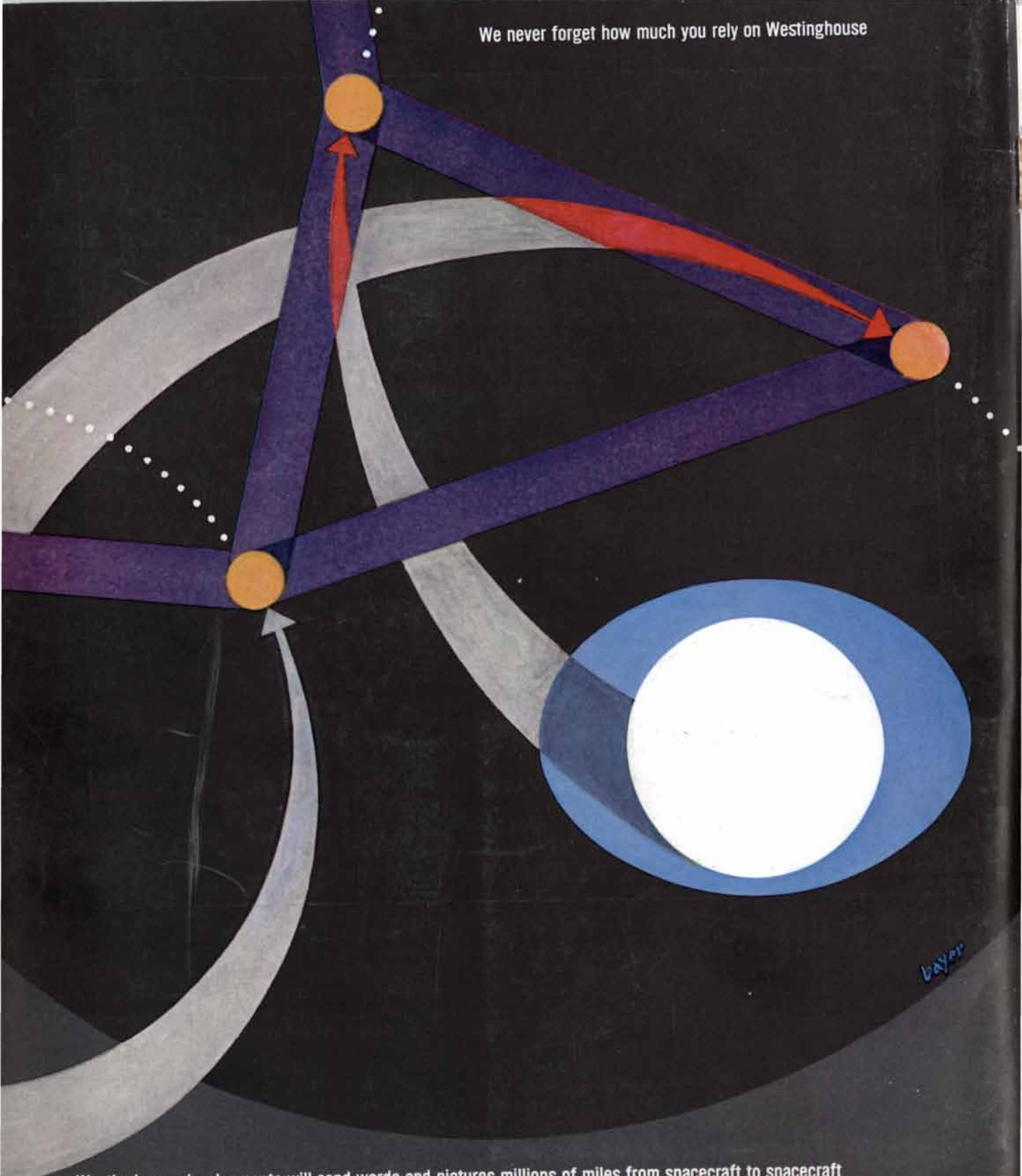

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