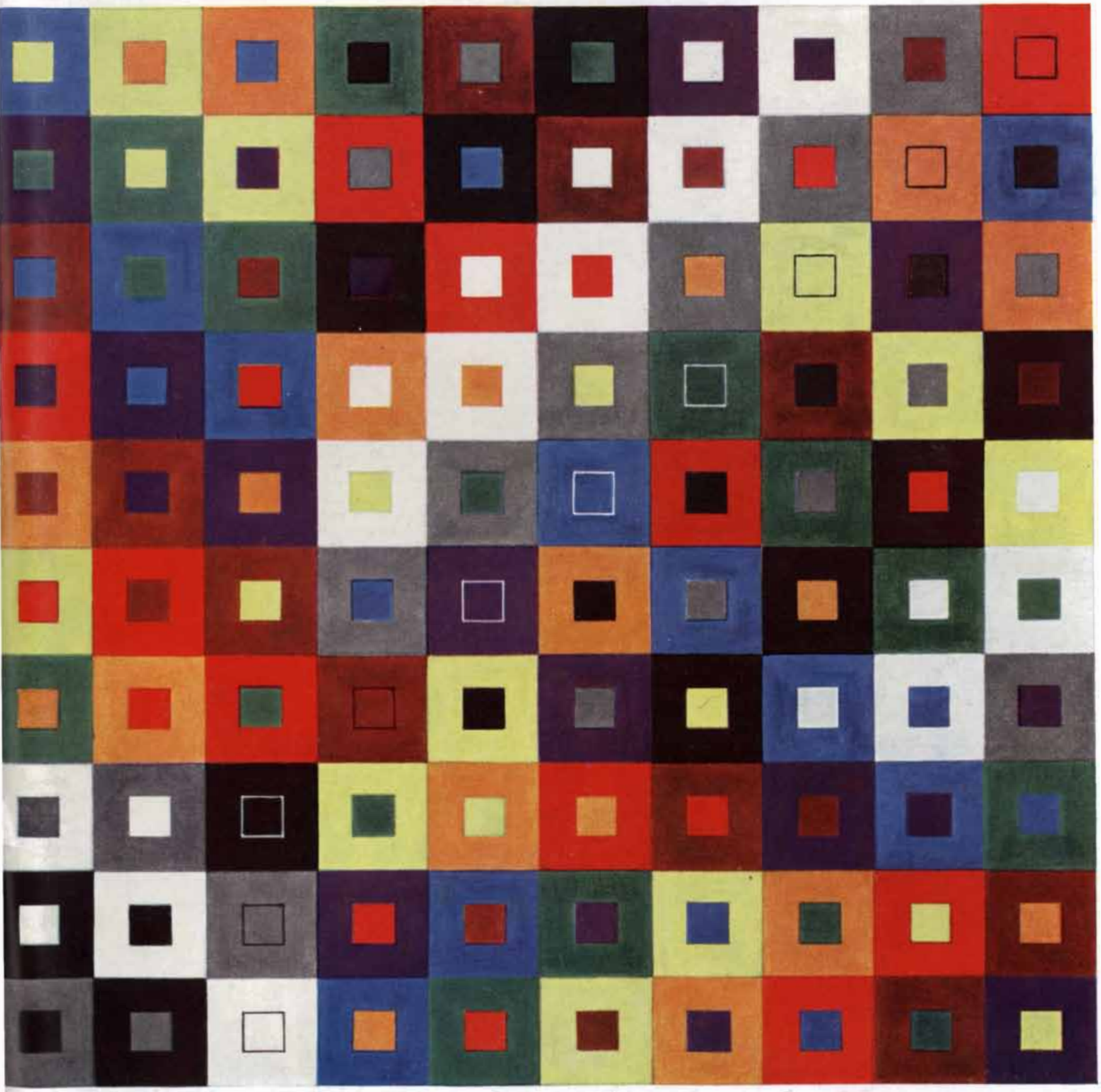
SCIENTIFIC AMERICAN



"GRAECO-LATIN" SQUARE

FIFTY CENTS

November 1959

Both tires shown here have traveled 14,000 miles under identical conditions. Sidewall on right was made with PLIOFLEX "C" type rubber stabilized with new WING-STAY 100.

Now—rubber that keeps its age a secret

Whirling around a test track—or spinning through traffic—tires *age* with wear. The effects of this aging process show up most often in the sidewalls, where small cracks appear. Not only do they mar the looks of the tire, they rob it of strength and cut into its service life.

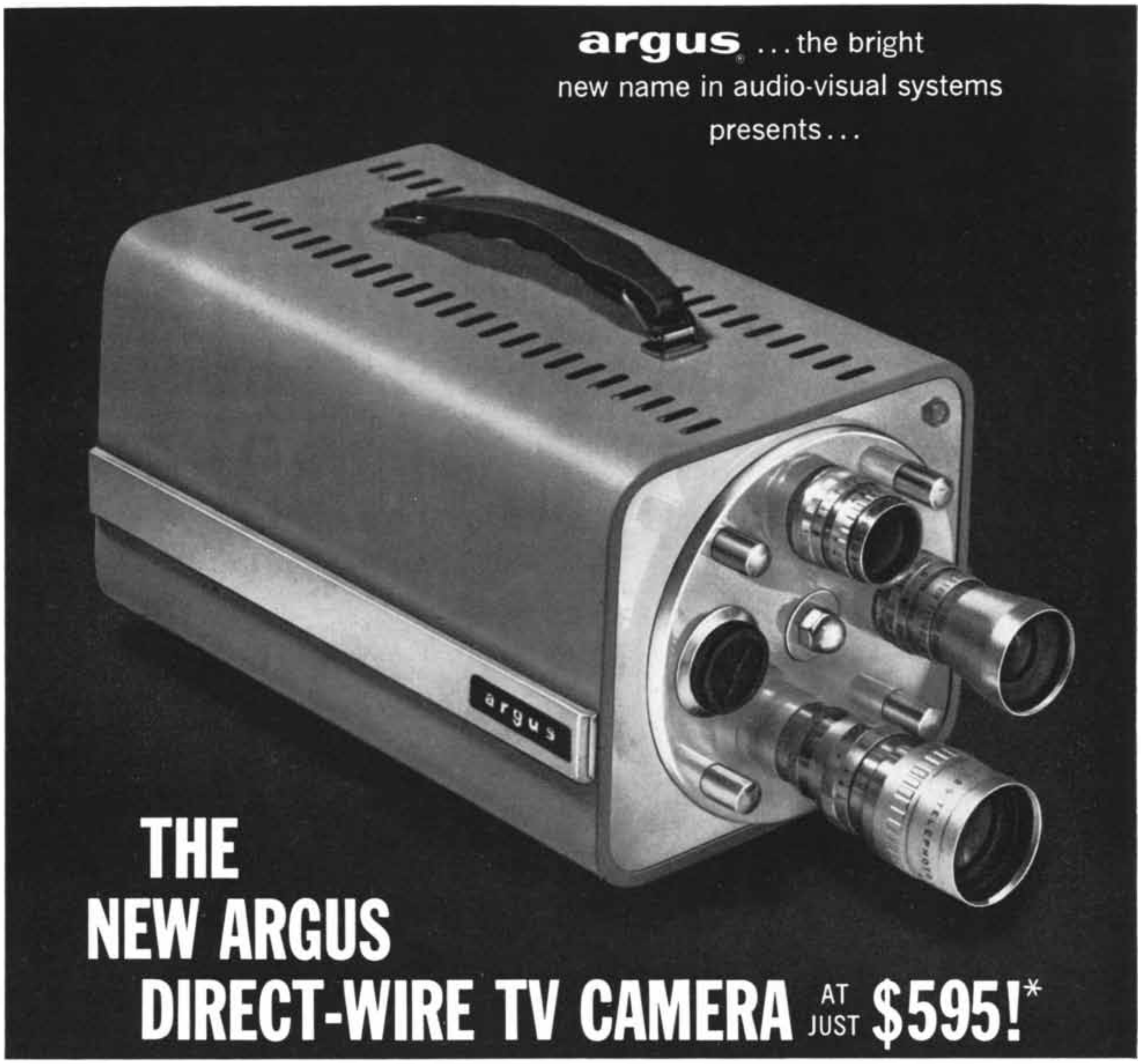
What causes cracking? Two things, mainly—atmospheric oxygen and ozone. To combat them, antioxidants have been developed. So have antiozonants. *But not until now* has a truly effective *combination* of antioxidant and antiozonant been perfected. And that's WING-STAY 100 by Goodyear.

The superior protection of Wing-Stay 100 can be yours in four new PLIOFLEX rubbers. Dynamic aging resistance thus becomes another key advantage of PLIOFLEX 1500C, 1710C, 1712C, and 1714C – along with assured processability, high uniformity and excellent physical characteristics.

For more information and complete technical service on PLIOFLEX "C" type rubbers—plus other rubber chemicals and a full line of synthetic rubbers—write:
Goodyear, Chemical Division, Dept. K-9457,
Akron 16, Ohio

GOODYEAR
CHEMICAL DIVISION

Wing-Stay, Plioflex—T. M.'s The Goodyear Tire & Rubber Company, Akron, Ohio



Argus Direct-Wire TV is the first closed-circuit TV system ever developed for mass production and mass use. It's yours for ⅓ the cost of other systems!

No installation . . . set it up anywhere—Argus Direct-Wire TV weighs only 16 pounds, mounts on a standard tripod indoors or out. Normal room illumination is all you need for a sharp, steady picture.

Direct hook-up to *any* TV receiver—Argus Direct-Wire TV transmits over standard co-ax cable, which connects directly to the antenna connection of any standard TV set. Transmits a perfect picture up to 1000 cable feet without boosters. With boosters, the range is unlimited.

Built-in flexibility . . . three-lens turret—Argus Direct-Wire TV feeds any number of receivers under the same conditions mentioned above. Up to five cameras can be used with one receiver, each with its own channel. *Standard equipment: three-lens turret mount and one 1-inch, f:1.9 lens. Argus Telephoto and Wide-angle lenses, shown above, are available as accessories.

Exclusive Argus features — • Matching, companion Argus TV receivers and monitors are available from $179.95. • Can be serviced by any Radio-TV repairman. • All parts are standard TV parts. You can own a complete, balanced Argus Direct-Wire System for less than the cost of a competitive camera alone.

argus® Audio-Visual Systems Department, Building B
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I'd like more information on Argus Direct-Wire TV.

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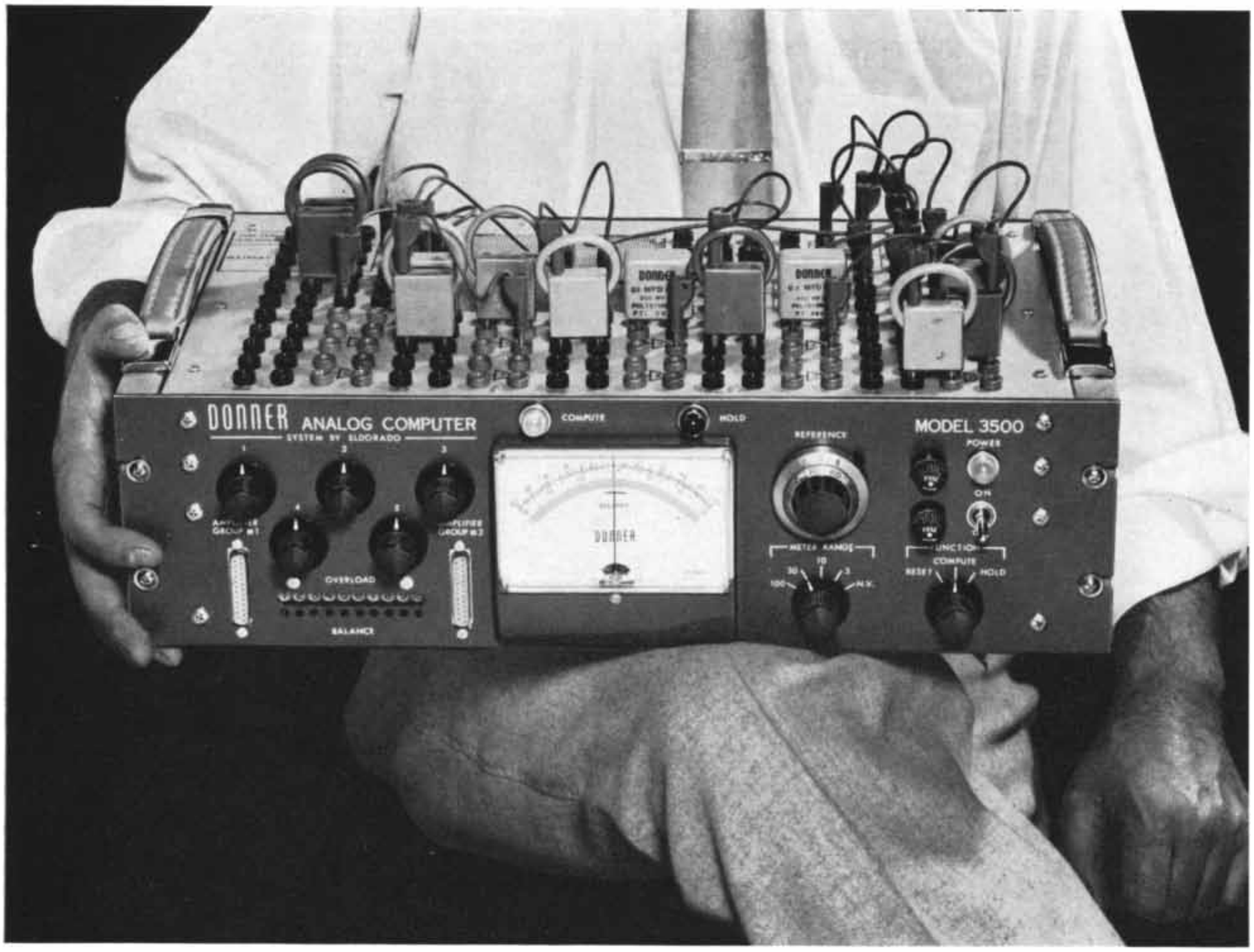

This is the one computer you can take with you

Announcing the Donner 3500

SMALLEST ANALOG COMPUTER EVER MADE

FITS YOUR LAP, YOUR DESK, YOUR BENCH!
Until now, the engineer, teacher, or scientist who needed an analog computer on the job faced an awkward situation. He could take his problem or class to a computing center and wait his turn or, after a thoroughly cumbersome undertaking, set up a big computer on the site. In any event, the task was costly and time consuming.

WEIGHT: 23 POUNDS
A complete computer is only 5¼″ high, 19″ wide, and 10¼″ deep. By simply removing a few screws, the problem board tilts up for rack mounting.

The Donner 3500 furnishes big computer performance in a tiny package. Up to three computers can be slaved together for 10, 20, or 30 amplifier problem solving capacity. Choose 0.1 or 1.0 percent computing components. Amplifiers are available in both stabilized and unstabilized forms. Anytime, unstabilized amplifiers can be converted by adding a plug-in component.

OPERATION SIMPLE, APPLICATIONS BROAD
If you can run a slide rule, you can use the Donner 3500. It's just that easy. Most dynamic equations can be solved and demonstrated. You can solve servo-loop and process control problems on the job with no loss in time. Alternately, use it in the lab as a precision power supply, a low-frequency oscillator, wave analyzer, or function generator.

PRICE
Prices for the Donner 3500 complete and ready to work including the "extras" range from $1200 to $1800. This includes potentiometers and a nominal selection of computing components. A full complement of accessory equipment such as function generators, transport delay generators, and multipliers is available.

WANT MORE INFORMATION?
Your nearby Donner engineering representative will be happy to give you complete information on the Donner 3500 and arrange a demonstration. Or you may write Department 7011.

DONNER SCIENTIFIC COMPANY

19

CONCORD, CALIFORNIA

Established 1845 SCIENTIFIC AMERICAN November, 1959 Volume 201 Number 5

ARTICLES

DEPARTMENTS

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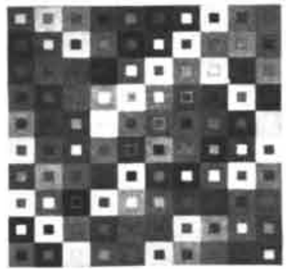


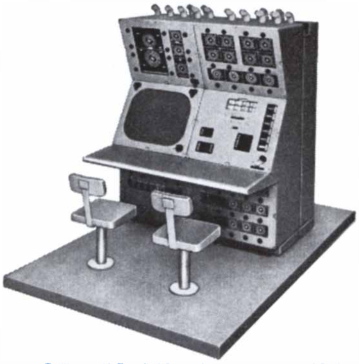
THE COVER

The painting on the cover is a representation in color of a mathematical curiosity known as a Graeco-Latin square of order 10 ("Mathematical Games," page 181). The large square is a 10-by-10 array of smaller squares, each containing a pair of colors, one outside and one inside. There are 10 colors in all. In every row and column each color appears once and only once as an outside color and as an inside color. The great mathematician Leonhard Euler conjectured that such squares of order 10, or any other even number not divisible by four, could not exist. The refutation depicted here was discovered only last year. Graeco-Latin squares provide a method for designing experiments that involve a number of variables.

THE ILLUSTRATIONS

Cover painting by Emi Kasai

Page	Source
62	Irving Geis
63-66	David Linton
67	I. Fankuchen and A. Amendola, Polytechnic Institute of Brooklyn
69	John Langley Howard
70	R. W. Sperry, California Institute of Technology
71-75	John Langley Howard
77-84	James Egleson
98	U. S. Patent Office
101	Edison Library
102-105	New York Public Library
106	Emi Kasai
108	New York Public Library
110-112	Edison Library
119-120	Eric Mose
122	Bell Telephone Laboratories
124-126	Eric Mose
134	Bruno Rossi, Massachusetts Institute of Technology
136-146	Bunji Tagawa
151-158	William Hovanitz
167	New York Public Library
168	Bunji Tagawa
170	New York Public Library
181-184	Emi Kasai
194-204	Roger Hayward

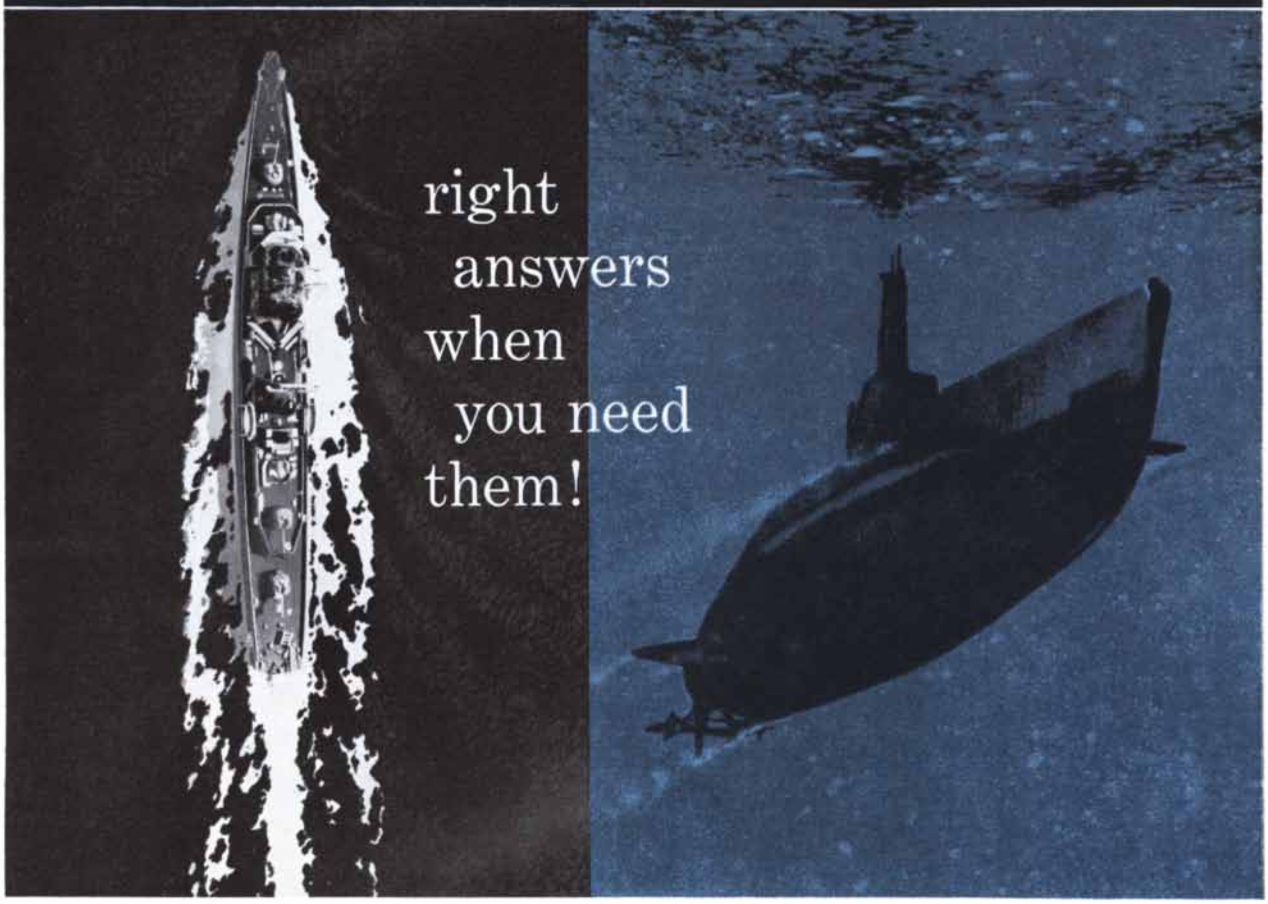


TODAY'S ANTISUBMARINE WEAPONS CONTROL COMPUTER

THE TIME: *Early 1940.* **THE ACHIEVEMENT:** *A small, compact ballistic computer for the U.S. Navy.* **THE RESULT:** *The beginning of Librascope's leadership in the design, development, and production of weapons and navigation control systems and components.*

Today, Librascope-designed and manufactured electronic and mechanical equipment for the MK 113, MK 111, MK 110, MK 107, and MK 105 underwater fire control systems include computers, attack directors, torpedo and missile angle solvers, attack plotters, depth plotters, position keepers, target motion analyzers, stabilization computers, roll and pitch computers, and various indicators and control instruments. ■ Librascope's simulation laboratories provide the Navy with a means for testing and analyzing the performance of equipment under "real attack" conditions. In the field, our engineers assist in the maintenance and improvement of Librascope systems.

SHIPBOARD COMPUTERS



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For information on career opportunities at Librascope, write Glen Seltzer, Employment Manager.

LI 9-8

Librascope's experience creating new concepts in computer—control systems for both military and industrial use can be accurately applied to your specific needs. ■ For detailed information and solutions to your computer problems, write...

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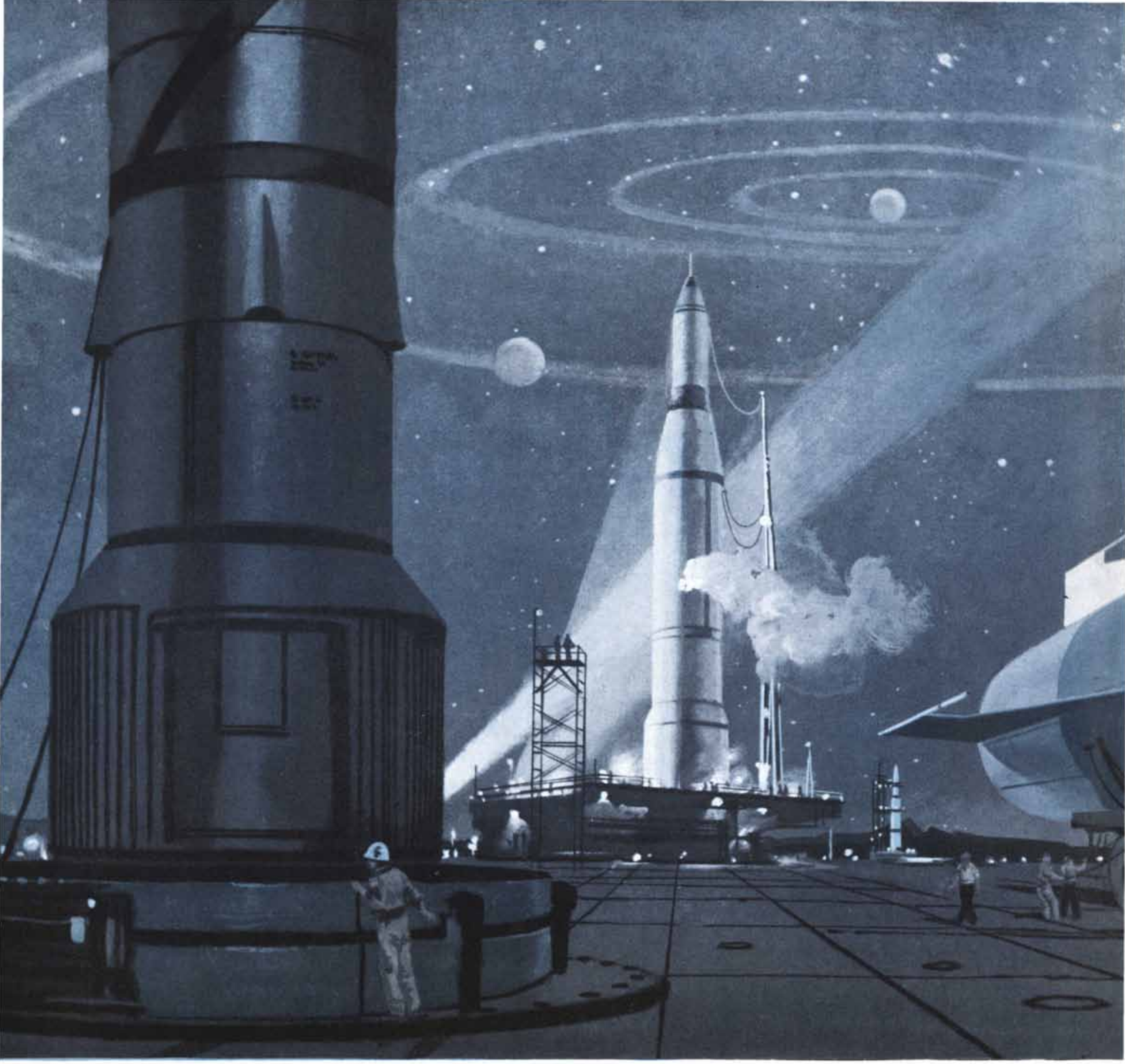

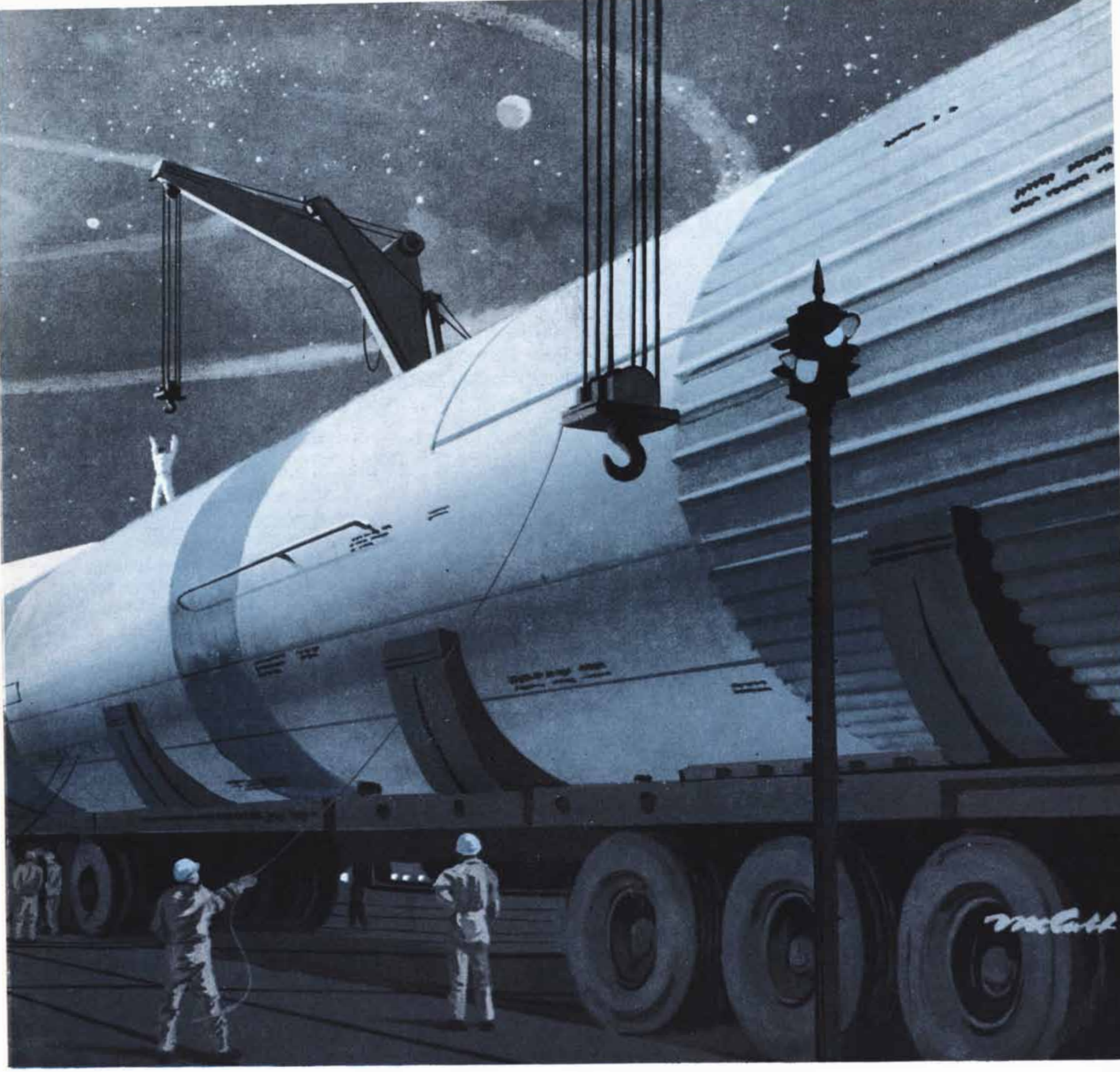

METALGRAMS

. . . news about metals and metal chemicals

UNION CARBIDE METALS

Electromet Brand Ferroalloys and other Metallurgical Products

NOVEMBER - DECEMBER, 1959

With 100 million pounds of polypropylene predicted for 1960 production, Union Carbide Metals' titanium trichloride will reach commercial status as a polymerization catalyst. But the Company's researchers are also looking to other fields for new uses of this high-purity compound. Areas of interest include the chemical and pharmaceutical industries where titanium trichloride has potential as a strong reducing agent ($E^\circ = -1.5$ volts) for nitro compounds, biologicals, and other organics. Request Bulletin TT1-S4 for more details.

* * *

Columbium metal has finally yielded to casting techniques due to the efforts of engineers at Materials Manufacturing Department of the Westinghouse Electric Corporation, Blairsville, Pa. What is believed to be the first columbium casting made is an experimental tube blank measuring 4 in. O.D. by 1¼ in. I.D. and 10 in. long. Using "ELECTROMET" columbium roundels, the metal was melted in a vacuum-arc skull furnace and cast in a graphite mold. Bulletin CB2-S4 gives information on columbium metal and sheet.

* * *

Chloride derivatives of lower valent transition metals are Union Carbide Metals' latest contribution to chloride chemistry. The Company's research team has produced, in experimental quantities, subchlorides of Cb, Cr, Ti, V, W, and Zr. Some of these have not been made before. "Electromet" subchlorides are potentially applicable as catalysts, metal-plating compounds, reductants in organic syntheses, and as intermediates for new organometallics. Bulletin MC1-S4 available.

* * *

The largest order for wrought vanadium ever placed was recently awarded to Union Carbide Metals Company. The contract calls for approximately 300 pounds of vanadium mill products which will be used in an undisclosed military application. The Company's continuing efforts to increase the purity of vanadium metal have led to mill products with improved workability. Get Bulletin VM1-S4 on vanadium metal.

* * *

In resistance to oxidation and corrosion, chromium carbide excels most other metal carbides. Its high hardness makes it useful when bonded with nickel or other metals. For use in the tool industry, Union Carbide Metals' chromium carbide is being pressed or sintered into dies and gage blocks whose thermal expansion characteristics are close to those of steel. This refractory compound has also been applied to surfaces by various metallizing methods. Send for Bulletin CC1-S4.

* * *

Silicon nitride which is 100% beta phase has recently been made possible by improved manufacturing techniques at Union Carbide Metals. Fabricated shapes of this new form of silicon nitride have extraordinary thermal shock resistance compared to previous alpha-beta mixtures. Foreseen applications include a refractory exposed to the combustion products of rocket fuels. See Bulletin SN1-S4.

* * *

Union Carbide Metals Company, Division of Union Carbide Corporation, P. O. Box 330, Niagara Falls, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

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The Silicon Controlled Rectifier

how will it affect your business?

General Electric's revolutionary Silicon Controlled Rectifier was introduced just two short years ago. The SCR has already proved it lowers costs, improves performance and solves old problems in radically new ways. It can replace thyratrons, magnetic amplifiers, power tubes and transistors, relays, switches, and many other devices. These are a few of the changes the SCR is now bringing about:

Vastly superior motor control systems for industry. Faster, more precise, smaller, more versatile, non-mechanical.

AC current for vehicles and aircraft. The SCR is the first really practical means of getting high power AC from variable DC. Static inverters with ratings of several kilowatts are possible.

Simple temperature controls accurate to 1/10th degree or better. Practical for all types of industrial furnaces.

Superior DC motor operation from an AC source. Extends the use of DC where desirable. Eliminates motor generator sets or magnetic amplifiers. Replaces mechanical speed and direction changers.

Stage lighting dimmer controls. Small, precise, reduces cost of installation for the entire system.

Current-limiting circuit breaker. Opens in less than twelve micro-seconds, long before a fault current can reach its peak.

More efficient lighting systems. Much more light per bulb through small, efficient SCR frequency converters that result in higher frequency and smaller ballasts.

How will it affect your business?

You'll be better able to judge after you have read our informative new folder. Write today to General Electric Company, Semiconductor Products Department, Section S85119, Electronics Park, Syracuse, New York.

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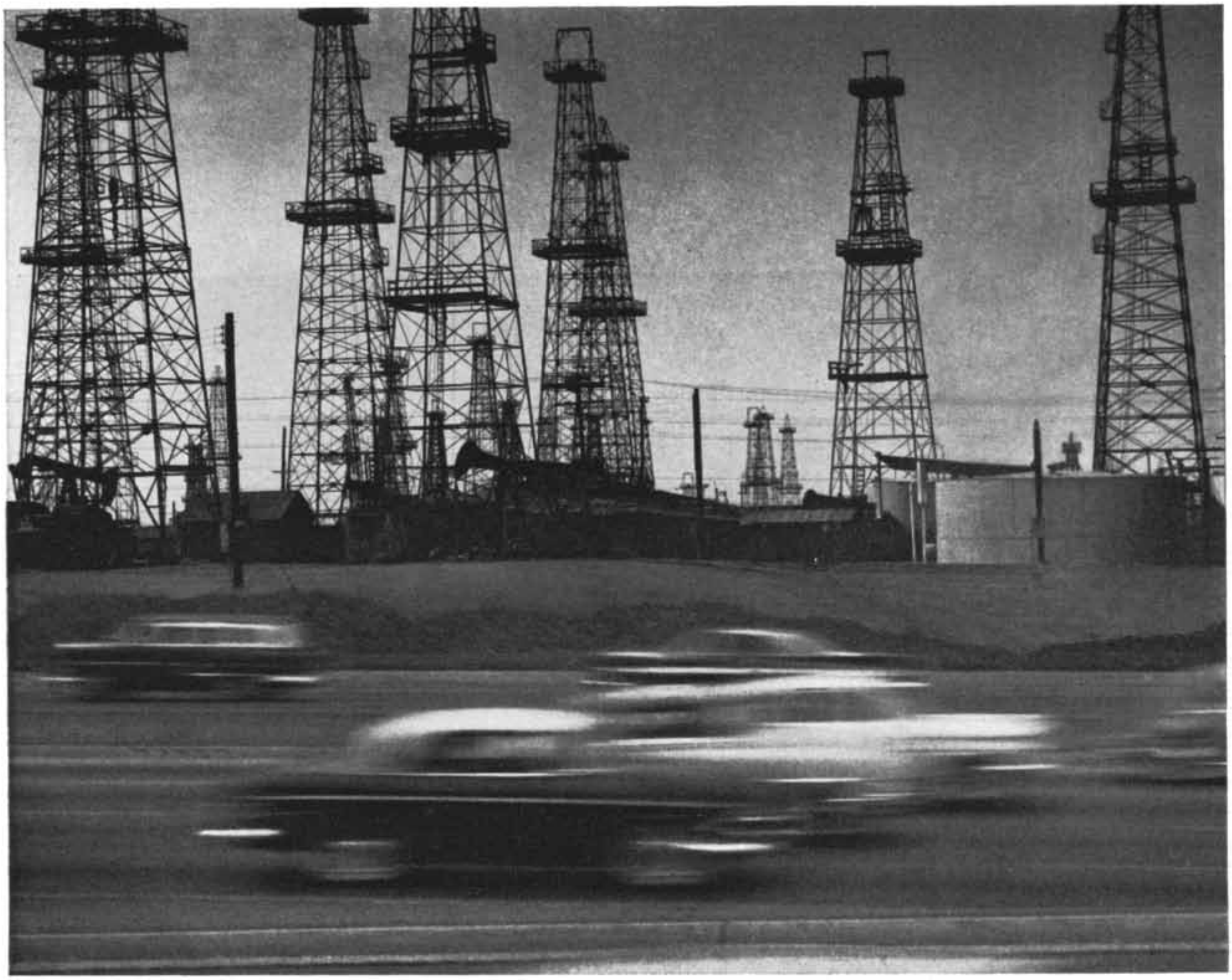


BENDIX COMPUTERS HELP KEEP GASOLINE QUALITY UP—THE PRICE DOWN

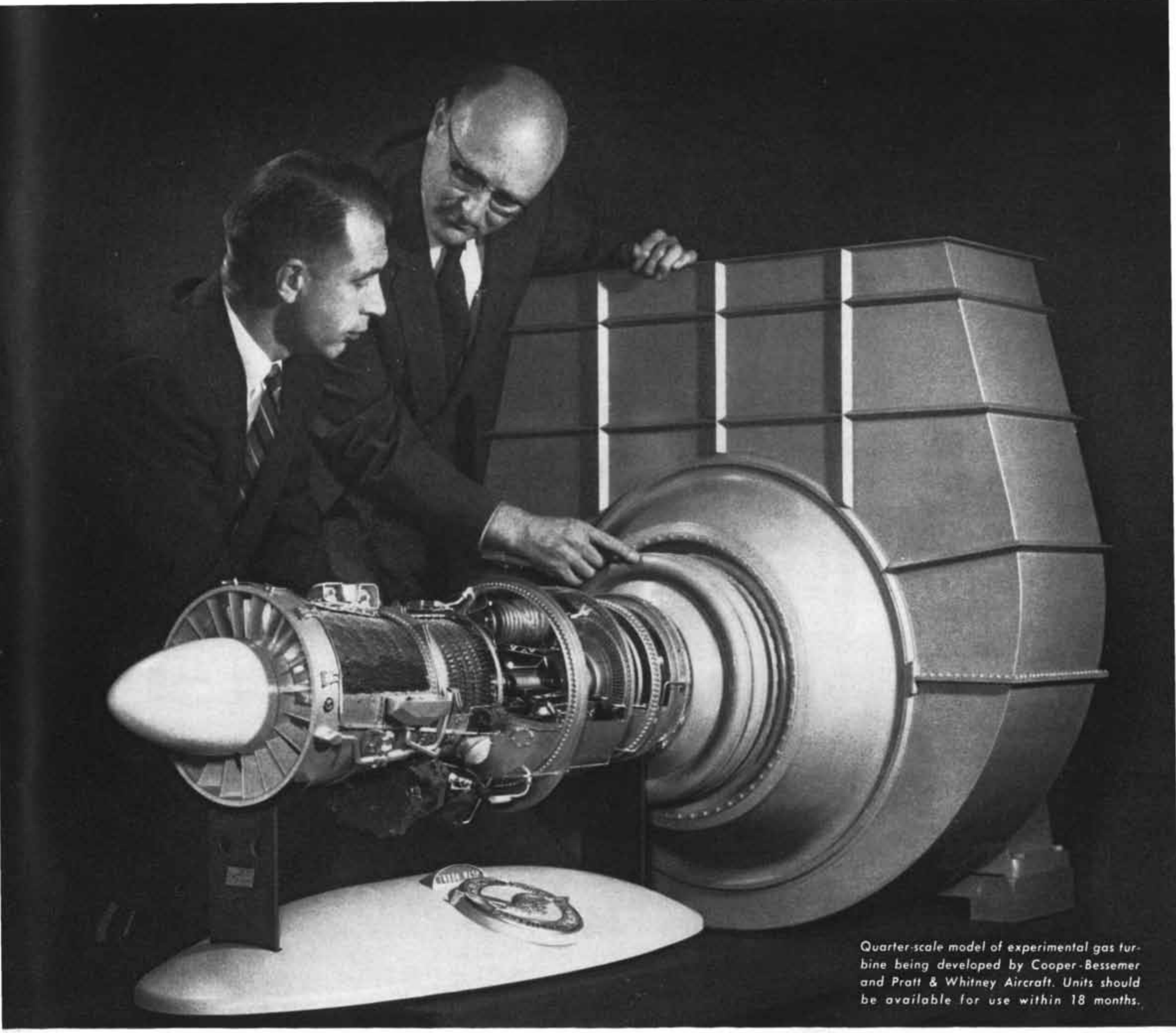
The motorists of this country burn oil and gasoline at a staggering rate. Annual consumption of oil is 3.2 billion barrels, or an average of 800 gallons for every man, woman and child.

To produce better oil and gasoline at the lowest possible cost, Bendix G-15 Electronic Computers are operating in every phase of the petroleum industry . . . exploration, drilling, refining and transportation. For example, where additional oil is to be recovered from an old field, the engineering involved may require as many as 300,000 computations. A staggering job when done manually, but quick work for a G-15.

Problems that were impossible to solve by former methods are now entrusted to these machines while engineers are relieved for other work. Often, in fact, these computers are instructed at the end of the day to complete involved problems at night—having the answers ready in the morning.

Bendix Computers are used *wherever* speed and accuracy of complex mathematical calculations are necessary. The Highway Program depends on their speed and reliability for survey, earthmoving and construction data. You find them in the machine tool, metalworking, textile, optical instrument, marine, power, aviation and missile industries, solving both engineering and data processing problems. These proven, low-cost Bendix Computers have a money-saving application in your business, too. Write our Bendix Computer Division, 5630 Arbor Vitae Street, Los Angeles 45, California.

A thousand diversified products Bendix AVIATION CORPORATION Fisher Bldg., Detroit 2, Mich. *a million practical ideas*



Quarter-scale model of experimental gas turbine being developed by Cooper-Bessemer and Pratt & Whitney Aircraft. Units should be available for use within 18 months.

How Cooper-Bessemer is teaming up with Pratt & Whitney Aircraft to develop JET TURBINE POWER for industry

The cutaway model shown is a revolutionary new concept in gas turbines. The generating unit is a new Pratt & Whitney Aircraft jet engine—a modification of the famous J-57 aircraft engine, designed for gas fuel. The companion power unit is a new Cooper-Bessemer power turbine. This combination, now in the advanced experimental stages, represents the hottest development in industrial power in 20 years. It will mean drastic economies in installations of engine-driven compressors, generators and other rotating machinery.

For example, in gas compressor stations, it is expected to reduce total station cost by 50%!

Plans call for this new gas turbine to be available for broad application within 18 months. In the meantime, watch for reports on further developments in this pioneering teamwork by Cooper-Bessemer and Pratt & Whitney Aircraft.

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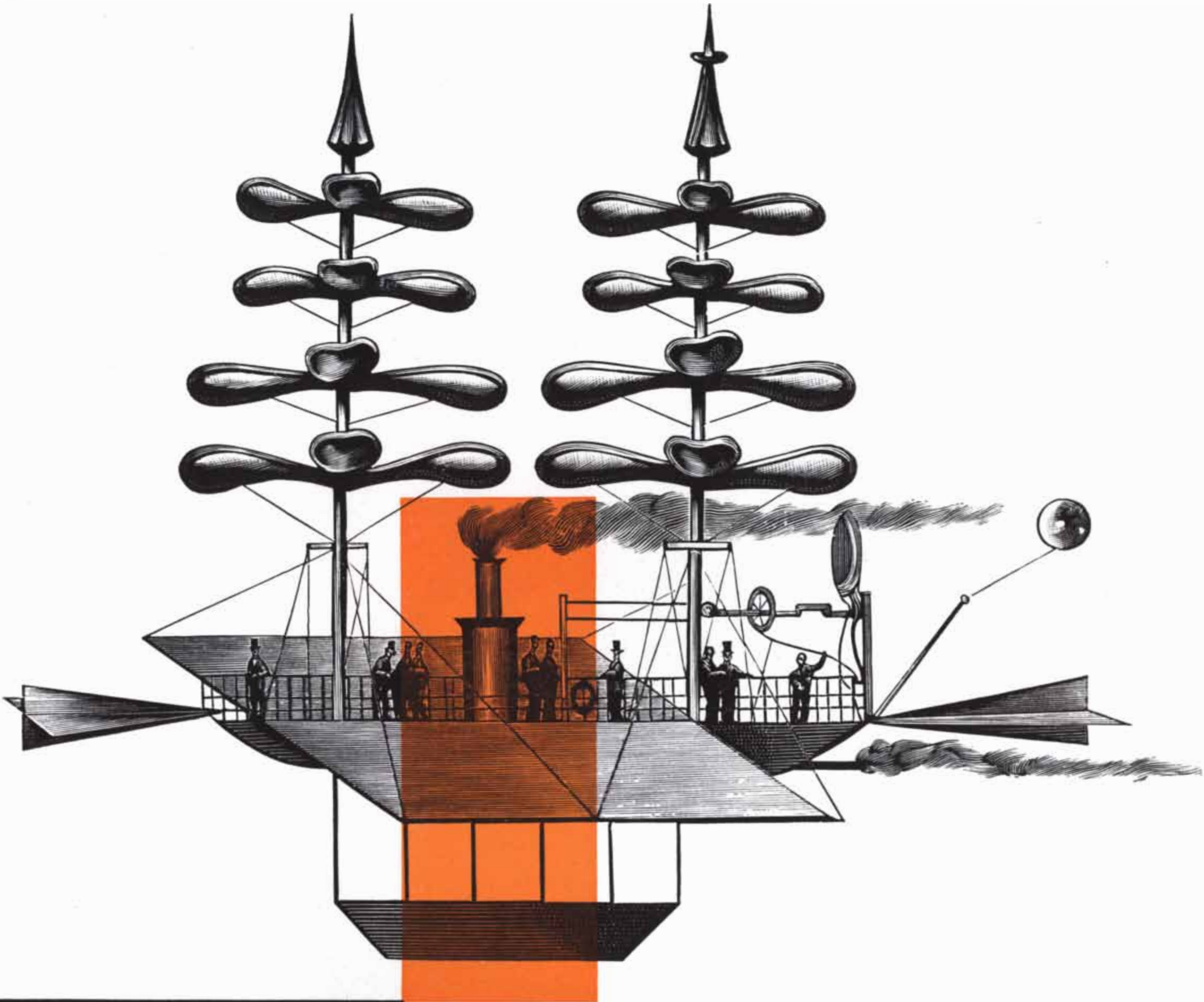

The basic principle of the helicopter was first advanced in 1863 by Gabriel De La Landelle of France. Rising steam was expected to turn the air screws and lift the craft upward. For this illustration, Brussel-Smith has followed earlier renderings of the "Steam Airliner" to create this intricate wood engraving.

IMAGINATION IN SPACE

Since Creation, man has looked out on space. At first, unknowing and incurious; then with the beginnings of understanding; now free and able to explore. Yet to move in space calls for wholly new concepts of energy.

This, then, is the working philosophy of Hercules in chemical propulsion: To design and manufacture highly concentrated packages of energy as propellants and rocket motors; each compatible, controllable, predictable; and each perfected for its specific mission.

HERCULES' BACKGROUND: A half-century of creative imagination in the evolution of propellants, from shotgun powder to the manufacture of the propellants for all the U. S. rockets fired during World War II, and now to space propulsion. Hercules facilities today encompass research, design, engineering, and staff organization for the production of the most advanced propellants. Illustrated brochure available on request.

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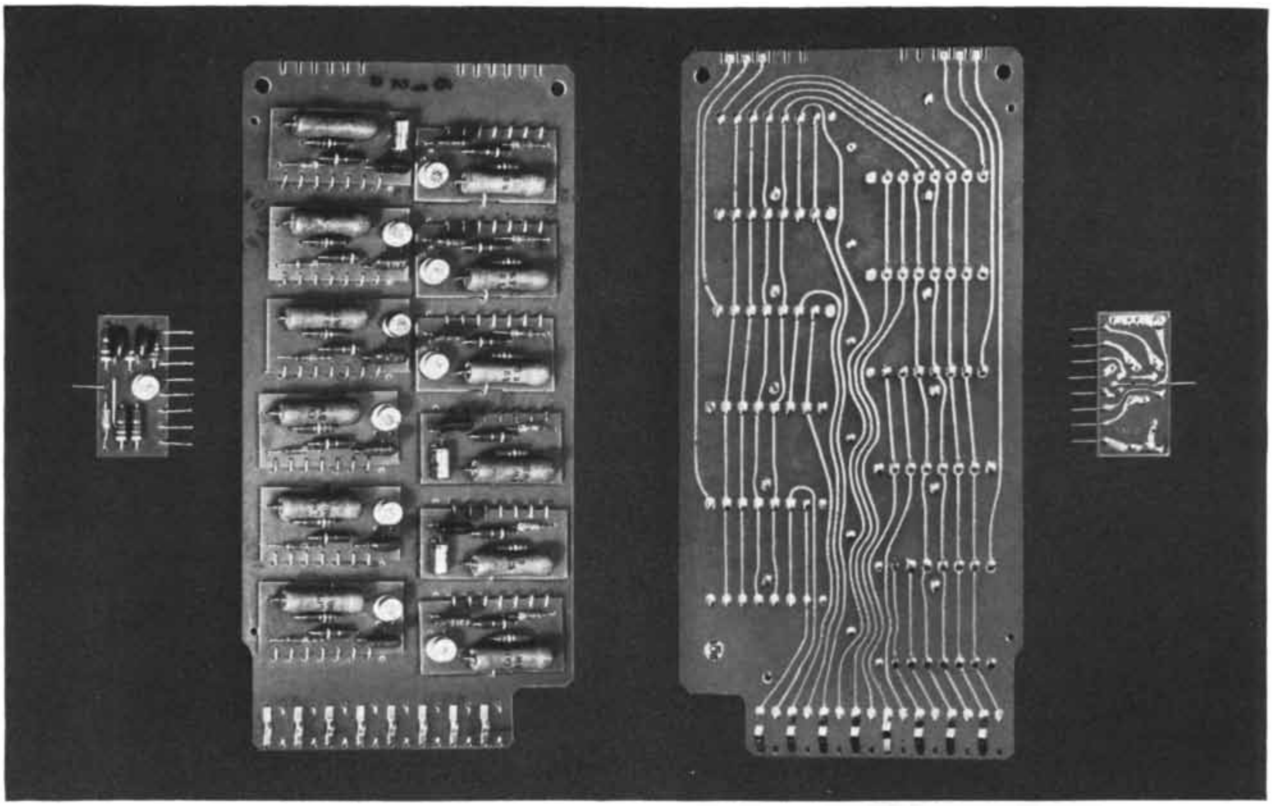
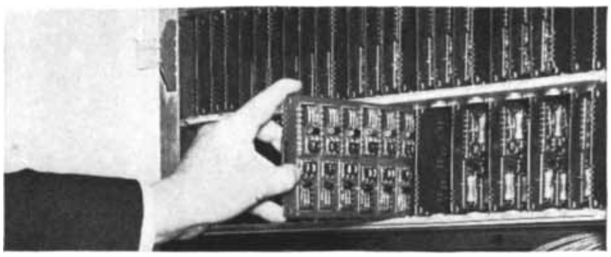


In the electronic logic elements of the RCA "501" data processing system, transistors and other small components are mounted on plastic wafers with printed-circuit wiring (small units right and left, above). The wafers, in turn, are mounted on thin plastic boards, also with printed circuits (center, above). This modular construction reduces size of the system by 75%, increases reliability, reduces maintenance.

PRINTED CIRCUITS OF COPPER AND ALL-TRANSISTOR DESIGN HELP MAKE 75% SIZE REDUCTION IN RCA DATA PROCESSOR



Modularized circuit elements are installed in the system by sliding them in place. Contacts on outside edge make possible quick checkout and testing without removing boards. Many thousands are used in each system.

The "501" is designed to handle paper work—bills, reports, payrolls, etc.—accurately, economically, and at extremely high speed. It serves businesses ranging from banks and utilities to steel mills.

With the growing importance of miniaturization and reliability in electronics and nucleonics, Anaconda electrical copper products take new and varied forms—find new and more sophisticated uses.

In the compact new all-transistor data processing system shown above, the printed circuits are etched from Anaconda "Electro-Sheet" copper foil. This is electrodeposited paper-thin copper with quality carefully controlled to meet NEMA specifications. Bright on one side, it has a matte finish on the other for a firm bond to the circuit board. "Electro-Sheet" is furnished in various thicknesses to exceptionally close tolerances.

In other fields, the growing need for compact electrical assemblies which can handle high current densities calls for hollow copper conductors for fluid cooling. And for new environmental conditions, more difficult application needs, there are new copper alloys.

METALLURGICAL ASSISTANCE. Whatever your problem in electrical conductors, Anaconda metallurgical specialists will gladly help you select the metal—and the form or shape—best suited to your needs. See your American Brass representative or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

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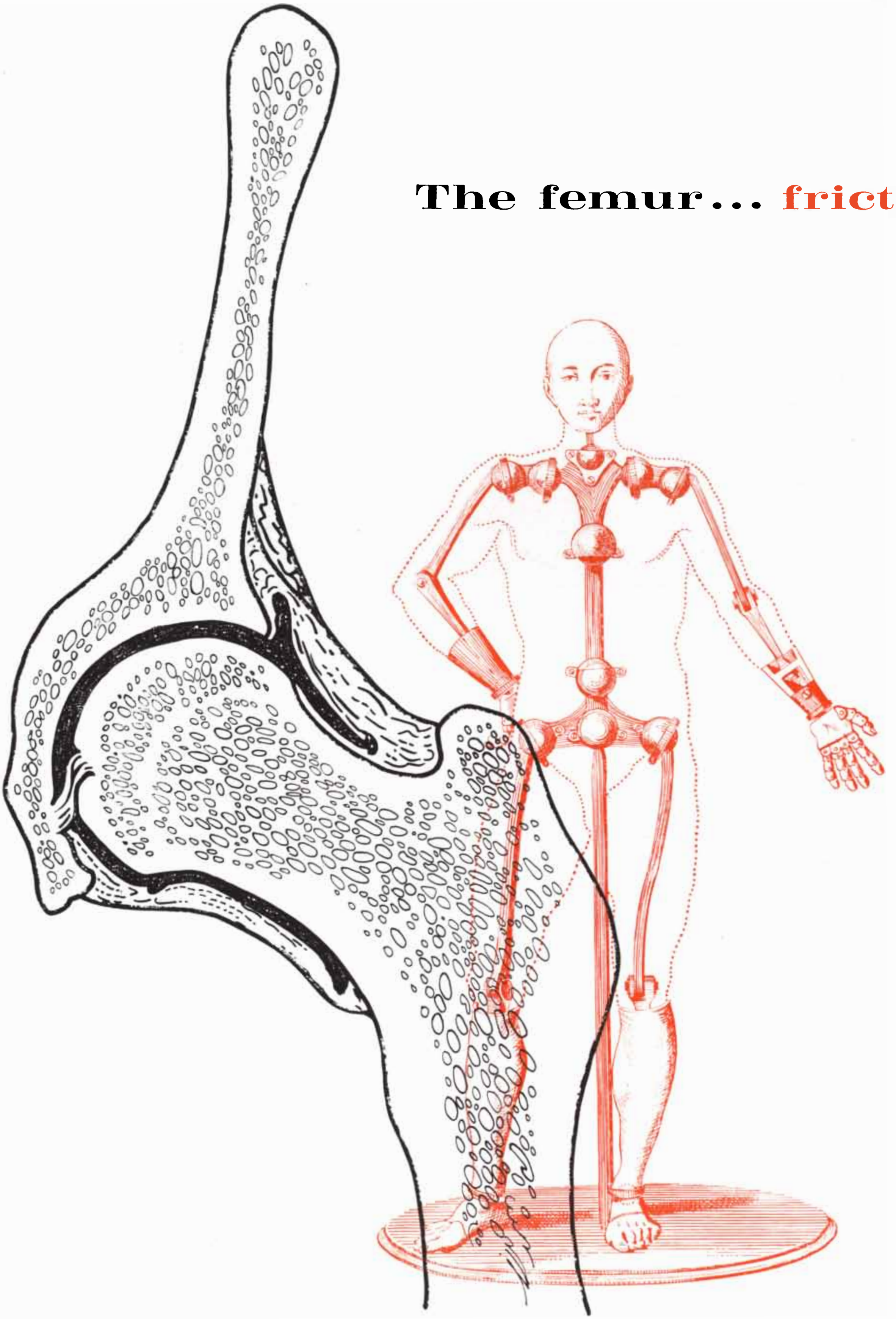
ANACONDA®

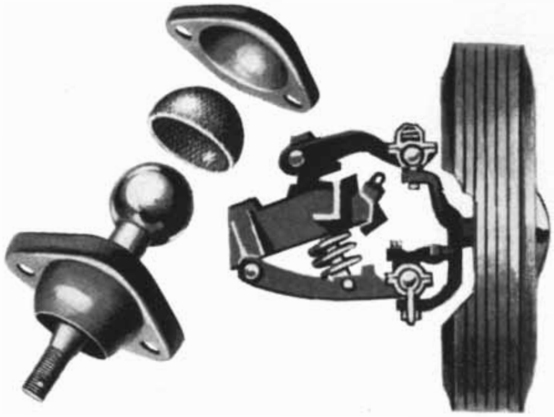
ELECTRICAL COPPER PRODUCTS

Made by The American Brass Company



The femur... friction....

and a greaseless joint



Try as she did, nature couldn't quite make a greaseless joint. Even the near-perfect joint of the femur and acetabulum requires a lubricant to overcome inherent friction.

But man is now able to fabricate non-lubricated joints, thanks to the unique frictional properties of a synthetic fiber — "Teflon" TFE fluorocarbon fiber.

With the lowest coefficient of friction of any known solid (as low as 0.01), and a high resistance to abrasion, this fiber is well suited to a multitude of joints and bearings— particularly in high-load, low-speed applications.

We submit "Teflon" for your appraisal.

Du Pont's family of man-made fibers offers you exceptional versatility. Even now—tailored to specific needs, or combined with other materials—fibers can outperform such materials as steel and wood . . . or even lubricants.

Please tell us *your* requirements. We'll be happy to provide any information or technical assistance regarding your use of Du Pont fibers for industry.

Textile Fibers Department, E. I. du Pont de Nemours & Co. (Inc.), 5518-A Nemours Building, Wilmington 98, Delaware.

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"DACRON"* *polyester fiber*
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"TEFLON"* *TFE fluorocarbon fiber*
"SUPER CORDURA"* *high tenacity rayon yarn*

Du Pont Fibers for Industry

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

*DU PONT'S REGISTERED TRADEMARKS

LETTERS

Sirs:

The summary by James R. Arnold and E. A. Martell of the geophysical applications of radioisotopes was a welcome contribution to your issue on ionizing radiation [SCIENTIFIC AMERICAN, September]. I was especially pleased to see many of the views on fallout distribution first expressed in 1957 by N. G. Stewart and colleagues in England and by R. J. List and myself in this country described to your readers. I presume from past contacts that most of the arguments on this field were advanced by Martell. However, Martell's meteorological interpretation of the distribution of global fallout differs from my own at least in the following respects:

Martell argues that strontium 90 from an equatorial stratospheric cloud spreads more or less evenly over the earth when it falls out. I contend that these equatorial clouds will be deposited preferentially in the hemisphere of the atomic test. We share the belief that the bias toward greater fallout in the test hemisphere is more marked for temperate or polar than for equatorial latitude explosions. The fact that equatorial stratospheric injections, which took place mainly in the Marshall Islands (11 degrees North), are preferentially deposited in the Northern Hemisphere is attested to by observations of tungsten 185, a 74-day half-life radioisotope, which prior to a recent special release

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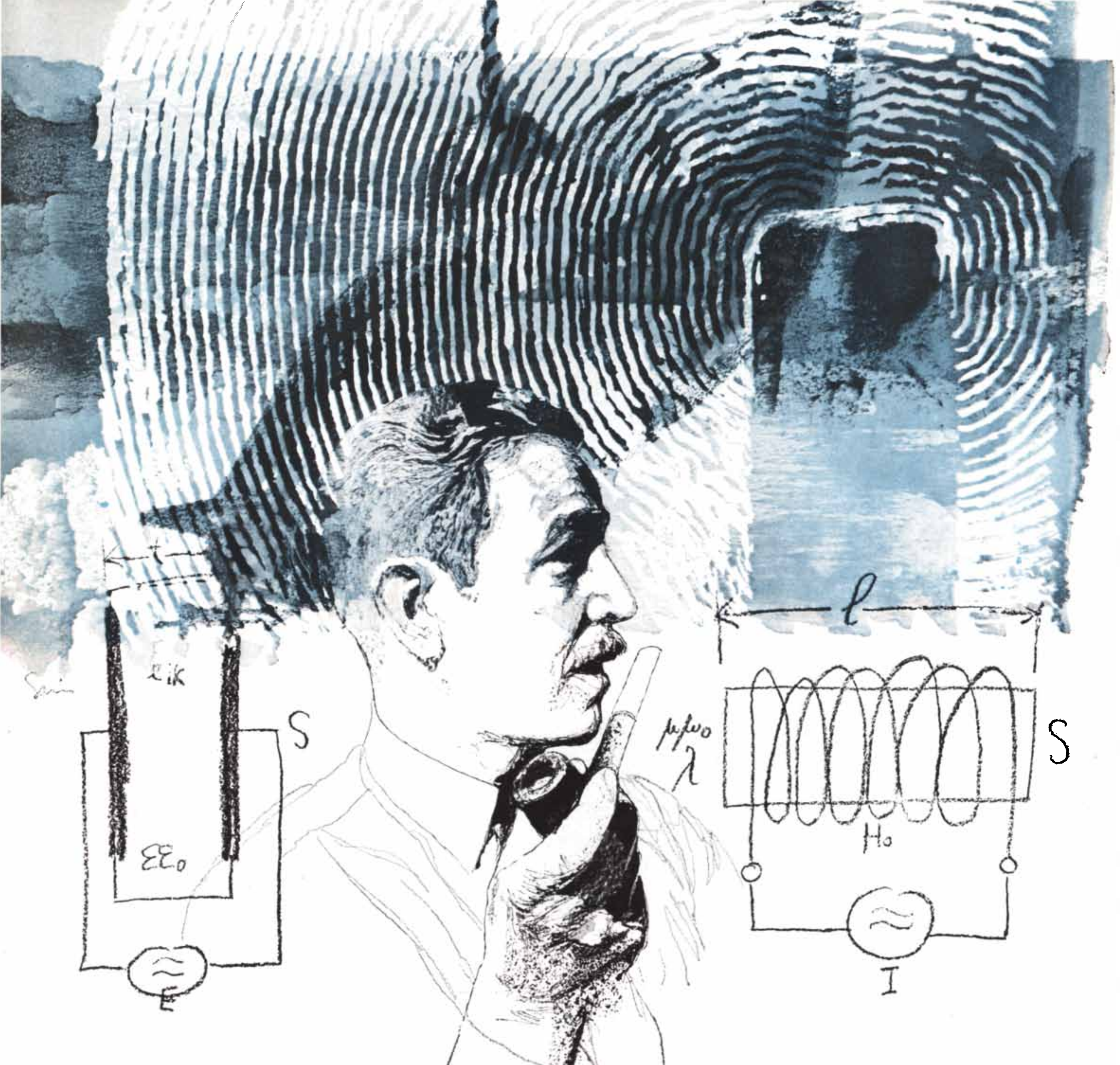


AT RAYTHEON

Scientific imagination focuses on SONICS

Sound waves generated by electro- and hydro-acoustic transducers are used in a wide variety of applications. Flow metering, medical therapy and diagnosis, and degreasing of small parts are a few. Covering about 25 octaves, the sonic spectrum ranges from audible to ultrasonic frequencies as high as 10^9 cycles.

Raytheon scientists have made noteworthy contributions to transducer technology and acoustic propagation techniques. Examples: the development of the first low-cost depth sounder, the practical application of ultrasonics in machining refractory materials, and the use of electromechanical filters for spectrum analysis. Currently, Raytheon is producing for the Navy the AN/BQQ-1 sonar—the most comprehensive underwater sound system yet devised for detecting, tracking and attacking enemy submarines.

Among the distinguished scientists at Raytheon who are expanding basic knowledge of sonics is Dr. Theodor F. Hueter of the Government Equipment Division's Sonar Department.

RAYTHEON COMPANY, Waltham, Mass. RAYTHEON *Excellence in Electronics* was not a constituent of the atmosphere. According to Martell's thesis, this substance should be uniformly spread over the globe after several months. But the observed ground distribution of tungsten 185 is almost as nonuniform as the accumulated strontium-90 in soil. There is a major peak in the North Temperate Zone, a minor peak in the South Temperate Zone and a minimum in equatorial latitudes. The tungsten-185 fallout is evidence of unequal partitioning between hemispheres from medium-yield explosions. A similar case can be made for high-yield explosions, whose clouds rise to greater altitudes.

French Hagemann *et al*, in a recent issue of *Science*, provided the stratospheric distribution of bomb carbon-14 in 1955. The sources of the carbon 14 are the Ivy (1952) and Castle (1954) high-yield tests in the Marshall Islands. The greater concentrations in the Northern than in the Southern Hemisphere are immediately evident from the data.

It is puzzling that Martell has published his ideas on uniform equatorial stratospheric fallout considering that these and other observations were well known to him over four months before publication of his article.

Our differences can be expressed quantitatively. Martell would claim that all Southern Hemisphere fallout and roughly one third of the Northern Hemisphere fallout is from an equatorial source up to October, 1958. I would agree that all the Southern Hemisphere fallout is equatorial in origin but would prefer to attribute about two thirds of the Northern Hemisphere fallout to equatorial sources.

These remarks are not offered to reassign "blame" for the fallout, but rather to point out that the apportionment of the fallout is important in deciding the nature of the meteorological models of stratospheric transport needed to explain the observations. Continued studies of natural and man-made radioactive tracers by Arnold, Martell and others will, I am confident, resolve our differences.

LESTER MACHTA

Chief, Special Projects Section
Office of Meteorological Research
Weather Bureau
Washington, D.C.

Sirs:

My co-author James R. Arnold and I are gratified by Lester Machta's favorable reaction to our recent article in *Scientific American*. Since Machta has

taken exception to one of my statements in the article bearing on the distribution of stratospheric debris from equatorial tests, I am pleased to have the opportunity to clarify my views on the subject. It should be mentioned that my interpretation of the atmospheric aspects of global fallout has differed from Machta's in several significant respects other than the point raised, as the published record will show.

The question of the partitioning of stratospheric debris from past equatorial tests between hemispheres remains, in my opinion, an open one. There is mounting evidence that stratospheric debris will not mix between hemispheres on a time-scale of several months or more. However, the crux of the question raised by Machta is the hemispherical division of stratospheric debris from Operation Castle, the major source of fallout from equatorial tests. Both the Operation Hardtack tungsten-185 activity and the bomb carbon-14 data have numerous obvious objections as indexes of equatorial strontium-90 fallout.

I have assumed approximately equal contribution of equatorial-test debris to each hemisphere on the basis that the greater heights of stabilized clouds for higher-yield shots will be associated with longer stratospheric storage times, thus allowing more time for horizontal mixing. If mixing between hemispheres is inhibited on a time-scale of years, then the initial conditions at cloud height will play a decisive role. Machta's assignment of two thirds of strontium-90 fallout from equatorial sources to the Northern Hemisphere is apparently based on the very qualitative evidence from the tungsten-185 and carbon-14 data. Uncertainties in both the strontium-90 fallout budget and in our knowledge of stratospheric circulation afford ample latitude for the differences in our respective assumptions and estimates.

The several interesting meteorological questions relating to the mixing history for high-yield tests near the Equator should be clarified considerably by atmospheric radioactivity studies already in progress. However, I consider it highly improbable that estimates of the hemispherical division of debris from past equatorial tests can be improved sufficiently to distinguish meaningfully between a 50-per-cent or a 67-per-cent contribution to Northern Hemisphere fallout.

E. A. Martell

Air Force Cambridge Research Center
Bedford, Mass.


CONSIDER...

EXTENSIVE DOW PRODUCTION FACILITIES FASHION VARIED NEW MAGNESIUM WARES

Coiled sheet, thin wall castings, many other production items are now available from Dow's big rolling mill, foundry and fabrication facilities.

Manufacturers on the alert for improved materials and production methods would enjoy a quick tour of the four Dow plants that turn out magnesium products. New ways of forming and fabricating magnesium now being practiced in these plants open up new areas of use for the lightweight metal.

TOOLING PLATE, extra flat, is annealed to eliminate residual stresses.

At the huge Madison, Illinois, rolling mill, for example, they're making magnesium sheet that doesn't require stress relief after welding. This is a major step forward in light metal technology and a boon to manufacturers using magnesium assemblies. Madison has also increased the maximum width of sheet to six feet. Five different sheet alloys, including elevated temperature alloys, are now available either flat or in coils.

To keep abreast of the rapidly increasing demand for precision jigs and fixtures, Madison keeps a close watch on the tolerances of Dow magnesium tooling plate. Typical flatness tolerances, for example, are 0.010 inches in any six feet. This means greater accuracy and less machining for users of Dow tooling plate. A mammoth 13,200 ton extrusion press, also located at Madison, is now turning out magnesium extrusions up to 30-inch circumscribed circle in size.

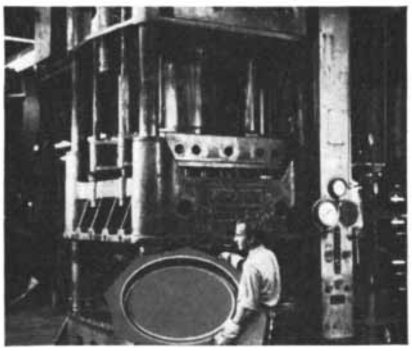
Over in Bay City, Michigan, interesting things are happening, too. At the well-equipped Dow magnesium foundry, largest in the U. S., sand and permanent mold castings of all sizes and shapes are being produced on a volume basis. Complete facilities are maintained for heat treatment, styrene DMI impregnation and chemical treatment. A well-staffed quality control team makes sure that all specifications are met or exceeded, and that the most modern equipment and techniques are fully utilized.

The Bay City foundry casts many complex and difficult designs. Large castings with walls as thin as 0.100 are now being produced. Other useful developments include cast-in tubeless passageways for use as hydraulic lines, special coring techniques for casting enclosed shapes and new magnesium casting alloys.

A new die casting plant is now on stream at Bay City. This facility houses the most advanced magnesium die casting equipment, including cold chamber metering units which automatically feed metal to the machines and contribute to unusually high production rates. To assure close alloy composition control in both die casting plant and foundry, a direct reading spectrometer provides frequent and precise analyses of the molten metal. Similarly, X-ray equipment is also available where radiography is needed in quality control.

The Dow fabrication plant, also in Bay City, offers capacity for volume work on magnesium assemblies. Here, too, developmental work on magnesium is constantly in progress. The plant is set up to handle large or small jobs, and plenty of both. Its activities include deep drawing, bending, spinning, stamping, piercing, machining, arc and spot welding, assembly, chemical treatment and painting. This plant has pioneered many "firsts" in magnesium production, such as hot drawing, spot welding and automatic welding.

DOW FOUNDRY offers production capacity for sand and permanent mold castings of all sizes.



LARGE DRAW PRESS at Dow's fabrication plant forms magnesium sheet in one operation.

WRITE TODAY for more information about Dow's magnesium production facilities. Request "Fabrication Brochure", "Foundry Brochure", "Die Casting Brochure" or all three. THE DOW METAL PRODUCTS COMPANY, Midland, Michigan, Sales Department 1351EQ11.

DOW

THE DOW METAL PRODUCTS COMPANY
Midland, Michigan
Division of The Dow Chemical Company

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INSTRUMENT CORPORATION

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Qualified engineers seeking rewarding opportunities in these advanced fields are invited to get in touch with us.

11RV59

new PICKER electronics for diffraction with digital printout

into this fine equipment have gone all the design skills which distinguish Picker medical and industrial x-ray equipment.

behind it stands the Picker service organization—a nationwide network of local sales and service depots staffed with trained engineers—to assure dependable performance and uninterrupted functioning.

Get the story from your local Picker man. There's probably a District Office near you (see local phone book) or write Picker X-Ray Corporation, 25 South Broadway, White Plains, New York.

Picker nuclear

SAC's BOEING B-52's will have Sperry Countermeasures System to confuse enemy radar and also throw missiles off course. System is designed to assure the effectiveness of our strategic bombers by preventing detection on their missions.

ENEMY EARLY WARNING RADAR, similar to our own shown here, would provide first obstacle for SAC bombers to "deceive" in event of hostilities...

STRATEGIC TARGETS, like the one shown below, are protected by area defense radars, antiaircraft missiles and fighter interceptors. Countering all these weapons is a critical role of Sperry-designed countermeasures equipment.

AT 455° BELOW ZERO, Fahrenheit, components are tested by Sperry scientist for use in advanced countermeasures system. Super-cold temperature obtained by liquid helium within cryostat makes some materials super-conductors, allowing electric current to flow forever without adding power. Such experiments assure even more effective jamming of enemy radars and missiles.

Spreading Confusion

Out of a growing bag of electronic tricks, Sperry engineers are creating new and better ways to mislead potential enemies.

ONE OF A SERIES:

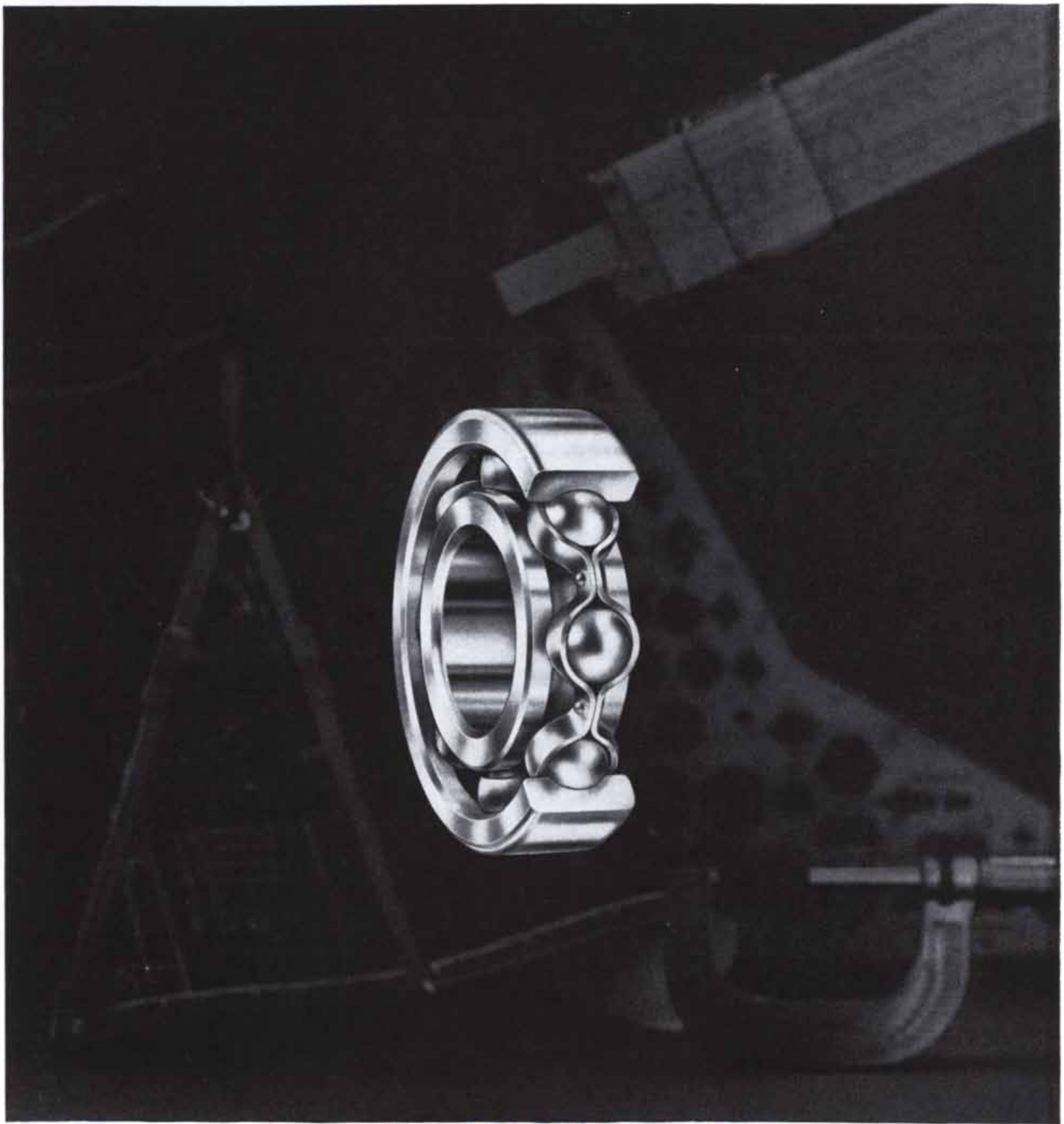
THE STORY BEHIND THE STORY
of Sperry Countermeasures Division

While every effort is being made to make America's radar defense *more* effective—equal effort is being made by a group of Sperry engineers to make radar defenses *less* effective – if the defenses are those of a possible enemy.

In World War II foil called "chaff" dropped from Allied planes cluttered enemy radarscopes—made it difficult to see the attackers. Then came "carpet"—a means of creating noise which again concealed the approach of planes. Since then the task of spreading confusion has become increasingly difficult with the development of sophisticated radars, fighter interceptors and missile defense.

The Sperry Countermeasures System designed for use aboard USAF's Boeing B-52's represents a revolutionary advance in deliberate confusion of the enemy, which greatly enhances the success of the strategic bombing mission and assures protection for plane and crew. In addition to its work with the B-52 program, the Sperry division is also devoted to finding ways of countering every new advance in *offensive* weapons with even more effective *defensive* confusion systems. Countermeasures Division, Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, New York.

SPERRY



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30
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TRW

Ramo-Wooldridge Infrared-Electronics equipment. Photograph by Don Mannix.

ELECTRONICS

The sphere of electronics expands...to meet the complex challenges of modern technology.

At Thompson Ramo Wooldridge Inc. electronic developments include: harnessing infrared radiation for target detection; translating languages automatically; controlling entire industrial processes, such as oil refining; automating machine tools and assembly lines; regulating airline, street and highway traffic for greater safety; building precision switches and controls for missiles; increasing business and industrial efficiency as well as home safety with closed-circuit television; providing stereophonic and high-fidelity music with tape cartridges and sound systems; decreasing circuit size with micro-miniature semiconductors and diodes; all this and more. TRW offers its many customers—commercial, industrial, consumer and military—dependable performance, from basic research through volume production, in the electronics, missile, nuclear, automotive, automation and industrial fields.

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THE THOMPSON-RAMO-WOOLDRIDGE PRODUCTS CO., Beverly Hills, California
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PACIFIC SEMICONDUCTORS, INC., Culver City, California
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TRW

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50 AND 100 YEARS AGO

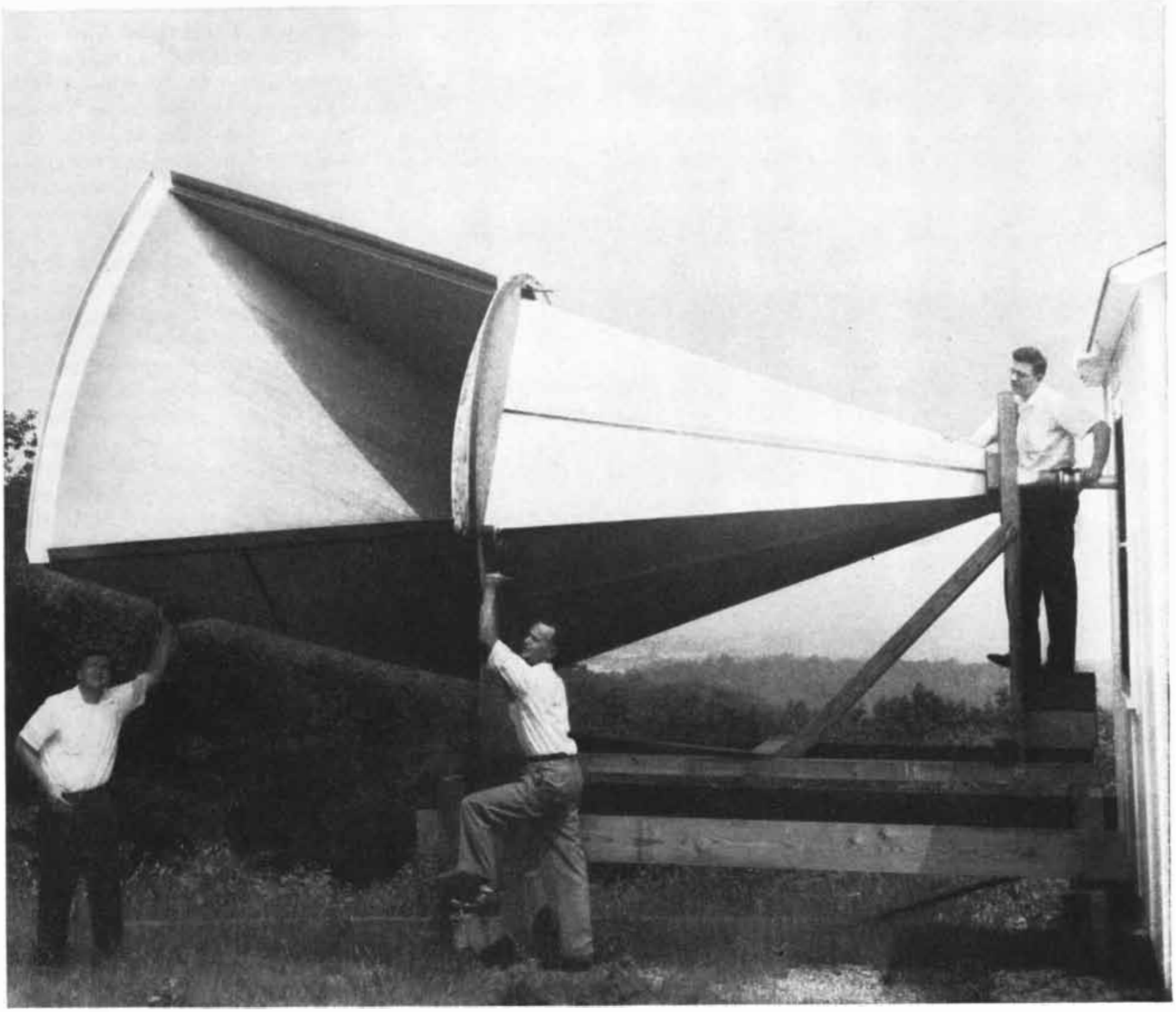
SCIENTIFIC AMERICAN

NOVEMBER, 1909: "After examining the documents presented for consideration by Lieutenant-Commander Peary, the National Geographical Society has come to the decision that he reached the North Pole, and has decided to award him a gold medal for his exploit."

"The $1,000,000 given by John D. Rockefeller will go a long way toward eradicating the hookworm. The worm was identified in 1903 by Dr. Charles Wardell Stiles of the Rockefeller Commission. It is about half an inch long and lives in the small intestine. Soil pollution is responsible for the existence and spread of the worm. It can be eliminated from the human body by a simple treatment of thymol and Epsom salts, the patient in most cases being cured in a few days."

"Wilbur Wright has finished teaching Lieuts. Lahm and Humphreys the operation of the new government biplane at College Park, Md. After being taught for a fortnight how to operate the machine, Lieuts. Lahm and Humphreys on October 26th made their first flights in it alone. Lieut. Humphreys made the first flight, which consisted of two circuits of the field, in three minutes. Lieut. Lahm next flew six times around, and described some small circles as well, his time being 13 minutes. On November 5th, when the two officers were making a flight early in the morning, the motor began missing, and the machine got dangerously near the ground. The end of the lower plane struck in making a turn, and the machine was rather badly smashed, although neither of its occupants was hurt."

"It is probably little realized outside of Southern California that the Los Angeles aqueduct, now about half completed, is by far the largest hydraulic engineering work now in progress, with the exception of the Panama Canal. This immense undertaking was designed to meet the serious problem of a waning



At Bell Laboratories, Holmdel, N. J., a horn reflector antenna is beamed skyward by scientists Edward Ohm, David Hogg and Robert DeGrasse. The maser amplifier, which employs a ruby cooled in liquid helium, is inside building at right. Over-all "noise" temperature of antenna, amplifier and sky is only 18°K at 5600 megacycles.

ANOTHER STEP TOWARD SPACE COMMUNICATIONS

The above antenna is part of a new ultra-sensitive radio receiving system under development at Bell Telephone Laboratories. It has extraordinary directivity. Beamed skyward, it ignores radio "noise" from the earth, yet picks up extremely weak signals from outer space.

The signals are amplified by the latest Bell Laboratories "maser" amplifier. The maser principle was first demonstrated, using gas, by Prof. C. H. Townes and his collaborators at Columbia University. Bell Laboratories scientists applied it to the solid state guided by a theoretical proposal of Prof. N. Bloembergen of Harvard University. Their latest traveling wave maser amplifier employs a ruby mounted in a waveguide. The ruby is excited to store energy. As signals pass through, they absorb this energy and are thus amplified. The device uniquely combines the characteristics needed for practical space communication: extremely low inherent noise and the ability to amplify a broad frequency band.

At present the receiving system is being used to pick up and measure minute radio noise generated by the atmosphere. It also foreshadows important advances in long distance communications. For example, it could extend the range of space-probe telemetering systems, could help make possible the transatlantic transmission of telephone and TV signals by bouncing them off balloon satellites—and has numerous applications in radio astronomy and radar.

This pioneer development in radio reception is one more example of the role Bell Laboratories plays in the pursuit of better communications technology.

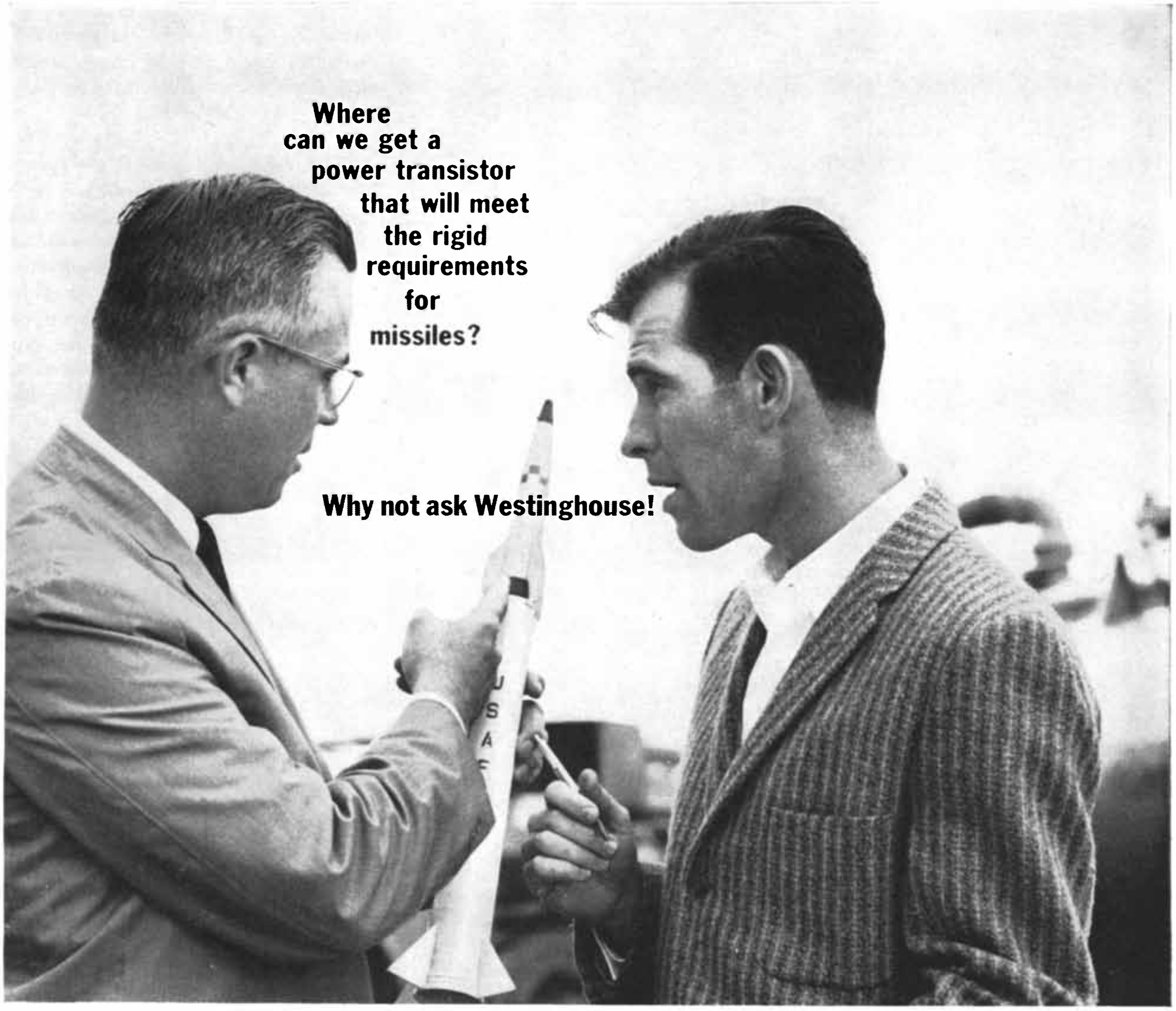
BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT water supply coupled with a growing population in Los Angeles. The aqueduct will be 230 miles long, and will be capable of conveying 280 million gallons of water per day from the Sierra Nevada across the Mojave Desert to the San Fernando Valley, providing water for power purposes and irrigation of the district, as well as for the city supply."

"At the second regular session of the New York Section of the American Chemical Society on November 5th, Dr. Leo H. Baekeland, president of the Electro-Chemical Society, was presented with the Nichols Medal for his papers 'The Synthesis, Constitution, and Industrial Application of Bakelite' and 'Soluble and Fusible Resinous Condensation Products of Formaldehyde and Phenol.' In accepting the medal Dr. Baekeland voiced his thanks for this expression of regard for his work. He then exhibited several industrial applications of the new compound Bakelite, and made an experimental comparison of the resiliency of a ball of Bakelite the size of a billiard ball with an ivory billiard ball. Each ball was dropped from a stand three feet high, the height of its rebound was noted, and the length of time of the rebound until it came to rest. The ball of Bakelite, showing much greater resiliency than the ivory, rebounded at least six inches higher than the ivory ball and took several seconds longer to come to rest."

"Capt. Roald Amundsen, the discoverer of the Northwest Passage, arrived in the United States recently. Capt. Amundsen has come here to make preparations for an expedition to the Arctic which he calculated would keep him away from civilization probably more than five years. His primary object will be to explore the ocean depths of the region, to study the currents and temperatures and the character of the ocean bottom. He will start from San Francisco in July, 1911, in the 400-ton gasoline auxiliary schooner *Fram*, which was used by Nansen in his trip to the North."

"Uranium is found commercially in only two minerals in the United States, pitchblende and carnotite. Pitchblende, which is widely known because of its use as an ore of radium, occurs in quantity in the United States only in Gilpin County, Colo. Carnotite occurs as a bright yellow powder in sandstones in Utah and Colorado. Uranium minerals are radioactive. Uranium has not yet been put to many practical uses. Uranium salts are used in iridescent glass



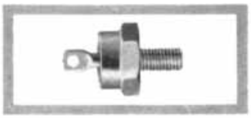
Westinghouse 2N1015 and 2N1016 Silicon Power Transistors meet the transistor requirements for missile application.

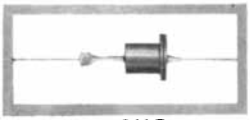
High Operating Temperature—Westinghouse 2N1015 (2 amp) and 2N1016 (5 amp) silicon power transistors are designed to operate at 150°C junction temperature.

High Power—Westinghouse 2N1015 and 2N1016 power transistors deliver maximum power in minimum space and weight because of their very low saturation resistance (0.5 ohms) and extremely low thermal resistance (0.7°C/watt).

High Efficiency—Westinghouse 2N1015 and 2N1016 power transistors operate at the highest efficiency obtainable in the power range of one kilowatt.

Maximum Reliability—Westinghouse *Quality Assurance Programs* include 100% power testing to maximum rated voltage and current, environmental testing, life testing, and other tests that insure extreme reliability.





For additional information on Westinghouse Silicon Power Transistors, contact your local Westinghouse representative or write to Semiconductor Department, Youngwood, Penna.

YOU CAN BE SURE...IF IT'S **Westinghouse**

Semiconductor Dept. Youngwood, Pa.

and in pottery glazes, and uranium compounds are employed in chemistry and medicine. Uranium and uranium salts were imported into the United States in 1918 to the value of $7,145."

"The well-known explorer and sportsman, Prince Scipio Borghese, has tabulated the number of dirigibles and aeroplanes in existence in the world on September 30th. The former number 36; the latter 76. In addition, 68 dirigibles are in course of construction. France possesses more than one third of the aeroplanes in existence and is therefore considerably farther advanced than other nations in this respect."

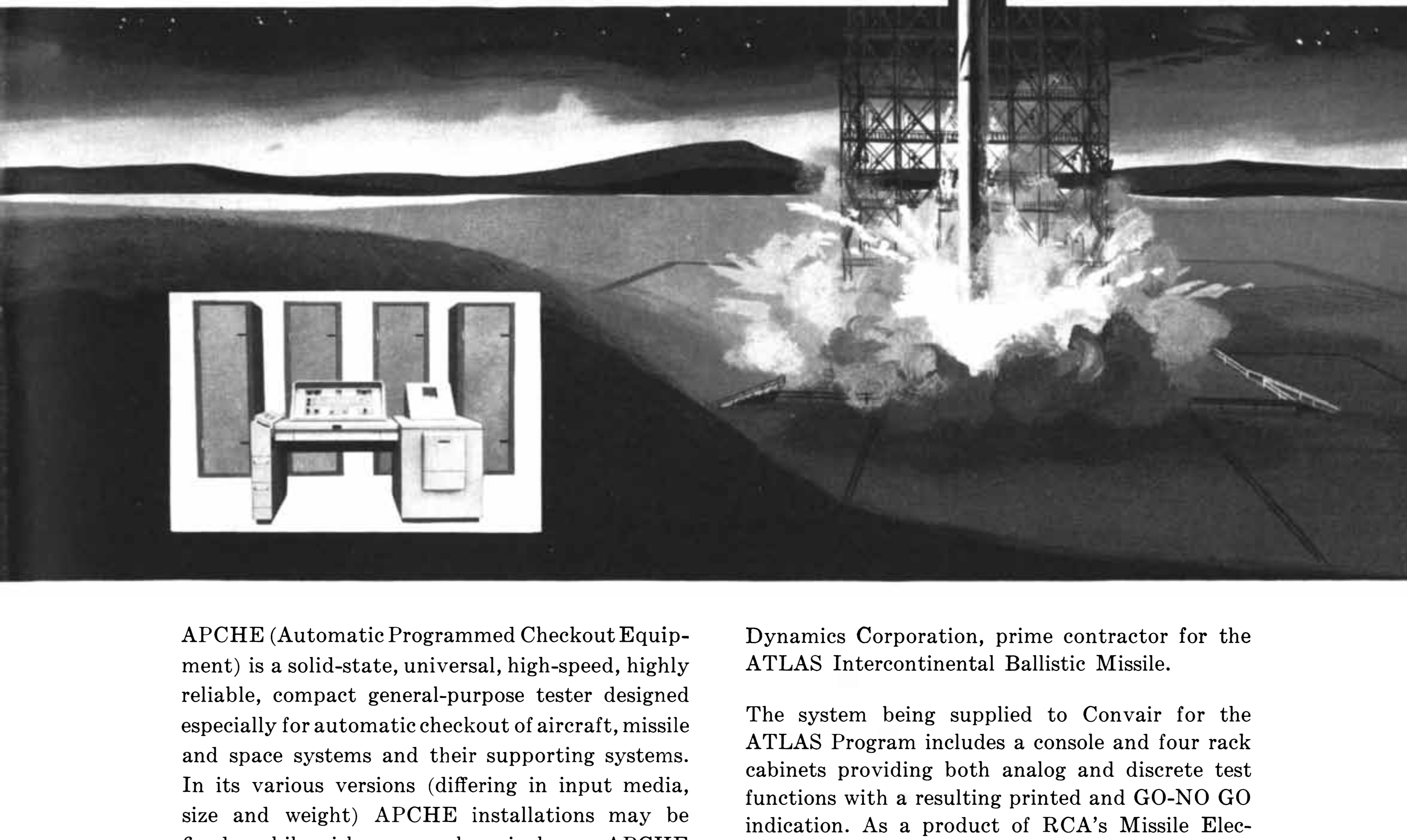
NOVEMBER, 1859: "Quite recently there was a considerable excitement caused by the discovery of a rich oil spring at Titusville, in the northwestern part of Pennsylvania. This excitement is unabated, as extracts from papers issued in the oil region demonstrate: It appears that the 'Pennsylvania Rock Oil Company' purchased the spring of Brewer, William & Co., for the sum of $5,000, and in 1858 leased it to Mr. E. L. Drake, with the understanding that he should gather the oil at his own expense, and pay them 12½ cents a gallon for it. His lease extended for 15 years, with full privilege of working it at his own option. In May last he commenced looking for salt, and after sinking a shaft 71 feet, on the first of last month, he struck a fissure through which he was boring, and the discovery of the subterranean spring of oil was the result. The yield per day, up to the period of the recent fire, had increased from 400 to 1,600 gallons."

"Hitherto the public parks of New York City have been so small as to excite the derision of foreigners; but this city has at last nobly redeemed itself in this respect by the purchase and arrangement of the 'Central Park,' which, when completed, will be one of the largest and most beautiful in the world. The Central Park of New York embraces an area of 843 acres, and is two and a half miles long by half a mile wide. Three artificial lakes are being laid out, one of which covers 20 acres, and forms the skating pond. A large extent for fields and lawns is assigned for the evolutions of military companies, games of ball, cricket and other athletic sports."

The Checkout that says "GO" or "NO GO"

APCHE

(Pronounced "AP-SHE")



APCHE (Automatic Programmed Checkout Equipment) is a solid-state, universal, high-speed, highly reliable, compact general-purpose tester designed especially for automatic checkout of aircraft, missile and space systems and their supporting systems. In its various versions (differing in input media, size and weight) APCHE installations may be fixed, mobile, airborne or submarineborne. APCHE was designed and is being produced as a part of RCA's ground support electronics subcontract from the Convair (Astronautics) Division of General Dynamics Corporation, prime contractor for the ATLAS Intercontinental Ballistic Missile.

The system being supplied to Convair for the ATLAS Program includes a console and four rack cabinets providing both analog and discrete test functions with a resulting printed and GO-NO GO indication. As a product of RCA's Missile Electronics and Controls Department, Burlington, Massachusetts, APCHE is one of the latest RCA developments in the field of military weapon readiness equipments.

RCA Tmk(s) ®

RADIO CORPORATION of AMERICA

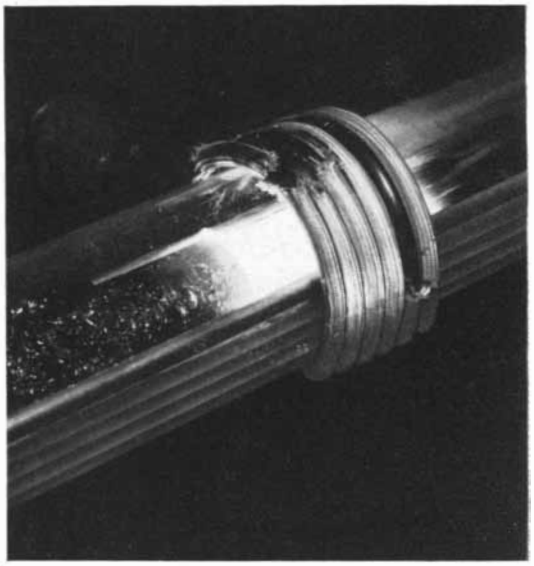
DEFENSE ELECTRONIC PRODUCTS • CAMDEN, NEW JERSEY

How rigorous quality on Sylvania

TODAY, Sylvania Semiconductors are meeting tougher quality standards than ever before. Yet production volume is climbing at an accelerating rate and has already been responsible for repeated reductions in both diode and transistor prices.

Behind this combination of tight quality control with high volume production stands Sylvania's technological leadership in semiconductors. Through exclusive production and processing techniques developed by Sylvania engineers, *quality in quantity* has been achieved.

Here are some of the outstanding quality-control advances made at Sylvania's Semiconductor Division in the basic steps of semiconductor manufacturing:



COMPOSITION CONTROL—Sylvania scientists have developed revolutionary doping processes that achieve a new uniformity in silicon for semiconductor devices.

These processes also prevent unwanted crucible contamination of the silicon.

The result: silicon for microwave diodes of greater uniformity than previously possible.

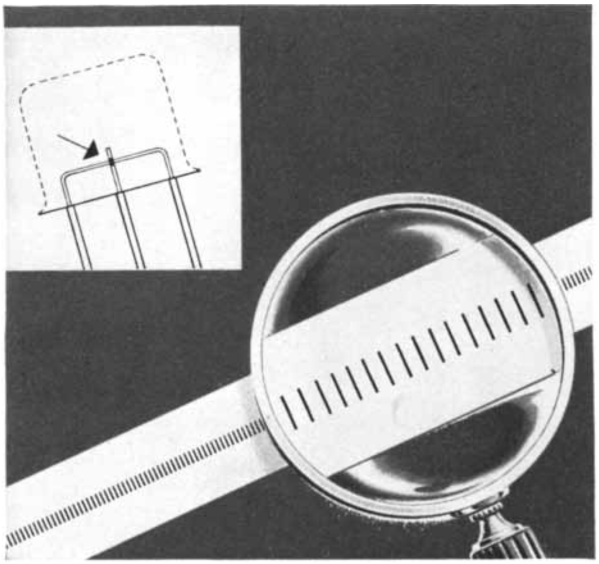
This uniformity can determine, more than any other single factor, the basic quality of the finished semiconductor device.

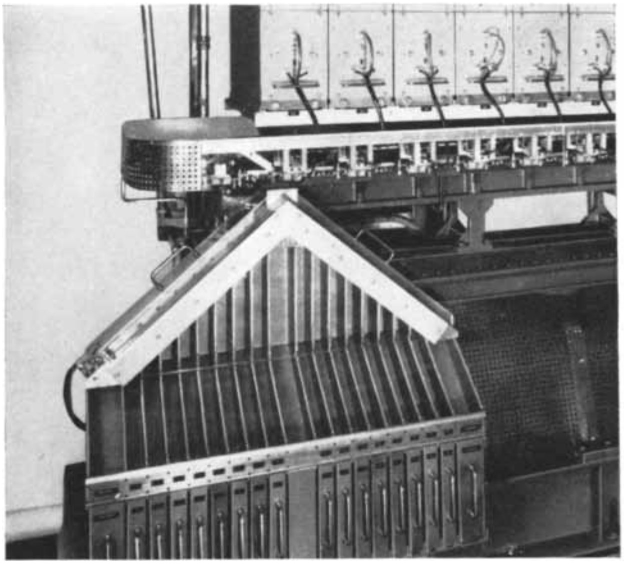
At Sylvania, technological achievements in die sizing, testing, material preparation and in other areas such as mechanized assembly are in progress every day. Always, the objective is to produce the best possible semiconductor device at the lowest possible cost.

IN SEMICONDUCTORS

control lowers prices

Semiconductors





DIE UNIFORMITY—Precise die thickness is vital to the transistor's performance and must be maintained within a ten thousandth of an inch. Highly accurate control of this critical thickness has been achieved by Sylvania through a process that automatically controls die-sizes to microscopic limits. The operation is performed on a mass production basis and is so precise that thickness measurement checks are employed only on a statistical basis. As a result a new standard of uniformity and quality in mass-produced semiconductors has been achieved.

AUTOMATIC TESTING—Now in operation at Sylvania's Semiconductor Division is a Digital Automatic Tester and Classifier. Designed and developed by engineers of the division it automatically subjects finished semiconductors to 16 separate tests and classifies them into as many different categories at a speed of 1500 per hour. It rates each semiconductor on each test. It compares the final test results with predetermined standards and then places each unit in its proper category. Replaceable plug-in test modules enable the device to test for an almost infinite variety of electrical and mechanical characteristics.

SYLVANIA GENERAL SYSTEM

Subsidiary of
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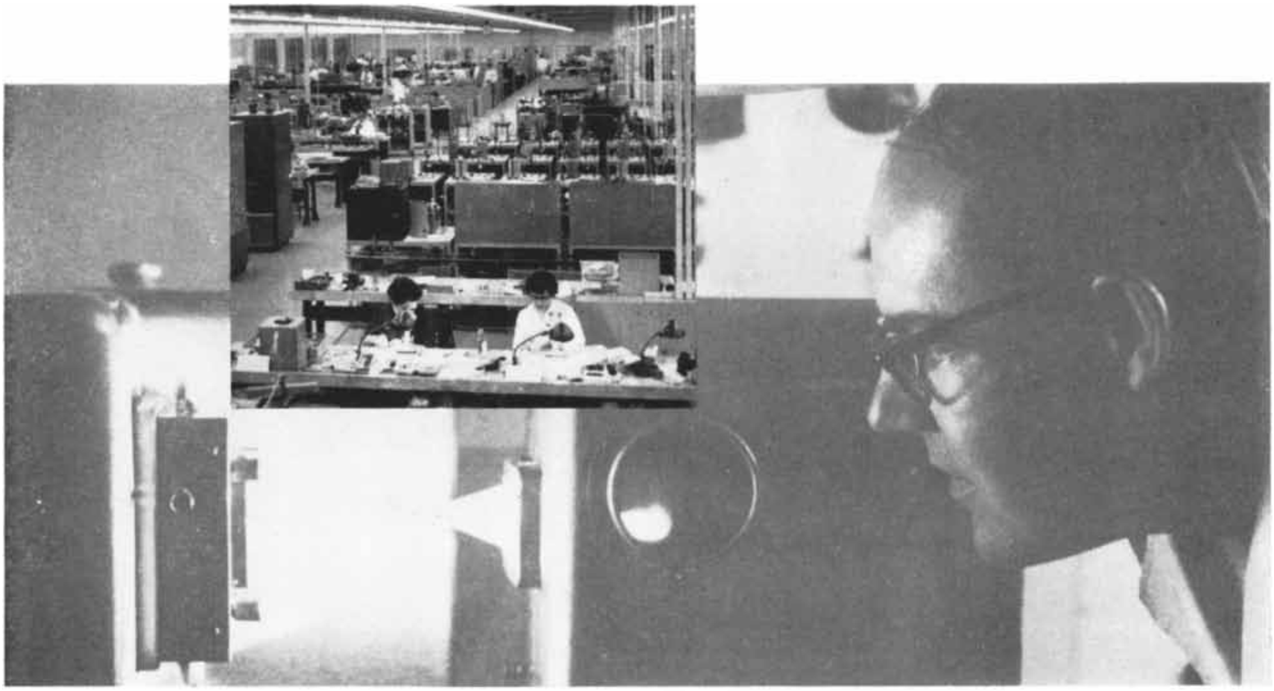
Sylvania Semiconductor Division
100 Sylvan Road, Woburn, Mass.

THE SCIENCE OF PRACTICALITY



The ability to move a highly complex prototype product from the research laboratory into economical **quantity production** is an important reason for the rapid growth of Varian Associates—major producer of microwave tubes, instruments, electronic components and scientific equipment.

And with the recent acquisition of Bomac Laboratories by Varian Associates, depth and versatility have been added to the volume production capacity of microwave tubes and other Varian products.

Advance production techniques are the "science of practicality" at Varian, and in large measure account for the extraordinary performance standards of Varian products . . . the frequency stability of Varian Klystrons, high resolution of the NMR Spectrometers, the high order of vacuum achieved by the VacIon® pumps and the field homogeneity of Varian laboratory magnets. The maintenance of highest standards while at the same time achieving volume production, is an example of Varian creativity at work for science, industry and the military establishment.

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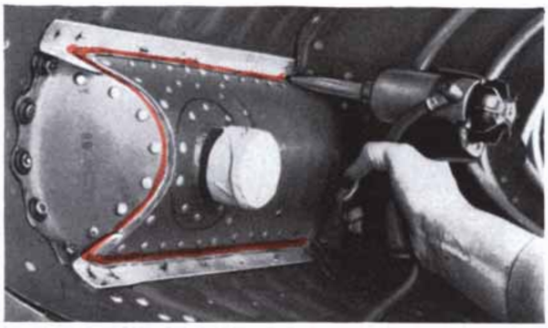
BOMAC LABORATORIES, INC., BEVERLY, MASSACHUSETTS / **VARIAN ASSOCIATES OF CANADA, LTD.,** GEORGETOWN, CANADA / **S. F. D. LABORATORIES, INC.,** SUMMIT, NEW JERSEY

General Electric RTV silicone rubber

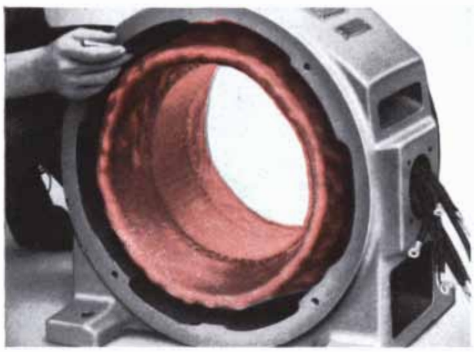
New liquid rubber cures without heat, useful from — 70 F to + 600 F, ideal for sealing, electrical insulation and flexible molds.



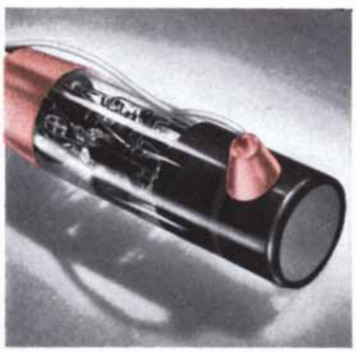
HEAT RESISTANT SEALING, such as shown on this Douglas DC-8 Jetliner, is made possible with RTV (room temperature vulcanizing) silicone rubber. RTV cures without application of heat; won't shrink (no solvents); forms no voids. It has excellent bond strength, plus resistance to high temperatures, moisture, weathering, ozone, aircraft fuels and solvents.

PRECISION MOLDING of prototype and engineering models and replacement parts is simplified and improved with RTV flexible mold material. G-E RTV's low shrinkage permits close tolerances and fine surface detail.

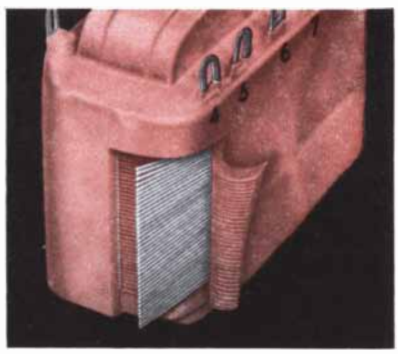
LOW-COST TOOLING with flexible RTV mold material offers added savings in time and expense. RTV's "built-in" release agent provides easy removal of this epoxy coil-winding form from mold. Total cost reduced 81%, delivery time 90%.



ENCAPSULATION OF STATOR WINDINGS, introduced by General Electric motor departments, extends service life of motors. RTV's resistance to moisture and other contaminants enables these dripproof motors to meet certain applications formerly requiring enclosed units.



POTTING OF AIRBORNE EQUIPMENT provides protection from high altitude arc-over and corona as well as vibration and moisture. RTV silicone rubber protects this cathode ray tube up to 70,000 feet.



RTV COIL IMPREGNATION enables this Hughes Aircraft Co. transformer to provide top performance at 250°. Unlike other insulations tried, G-E RTV compounds proved successful both for coil impregnation and full encapsulation.

For application data and samples of General Electric RTV silicone rubber write Section U1114, General Electric Company, Silicone Products Department, Waterford, New York

GENERAL ELECTRIC

Butler's progressive engineering program requires a fast, versatile, and low-cost computer. It must handle complex structural problems and still be simple enough to be used by engineers with no programming experience. The computer's mission: cut engineering unit costs. *"Our own survey proved that the Bendix G-15 digital computer could best do this job,"* says Mr. Rimmer, *"and it does."*

For Butler, part of the cost-cutting versatility of the G-15 stems from the variety of programming methods they can use. For the solution of repetitive problems at highest speeds, they use the machine language system. With the simplified Intercom 1000 system, the entire staff uses the computer for structural design problems. This versatility also means the G-15 can be used for business data processing as well as scientific and design calculations.

Butler is also pleased with the expandability of the G-15. They know that as their computing requirements grow, they can add magnetic tape units, punched card equipment, digital differential analyzers, plotters, and other accessories. Remember, however, that the basic G-15, which includes a unique photo-electric tape reader-punch and alphanumeric typewriter, is more than adequate for most problems.

Find out more about this computer — the *only* medium-scale computer in the low-price field. Inquiries regarding specific applications are welcomed.

Bendix® Computer

DIVISION OF BENDIX AVIATION CORPORATION

DEPT. C-16
LOS ANGELES 45, CALIFORNIA

90 seconds of inferno

...but ROKIDE* Coating will protect the X-15's engine during critical burning time

As the manned X-15 bores into the sky for 100 miles or more in its forthcoming tests, rocket-powered flight will last only for about a minute and a half. However, protecting the engine from the tremendous heat and erosive force of its propellants for even that brief span posed a major design problem. Engineers solved it by coating critical metal surfaces with ROKIDE "Z" zirconium oxide — one of today's most rugged refractory materials.

This is typical of the new and challenging requirements which all three types of hard, crystalline ROKIDE spray coatings ("A", "ZS" and "Z") are meeting in the ever-expanding air and space programs. These outstanding members of Norton Company's large family of refractory materials, as well as other experimental coatings such as chrome oxide, spinel, etc., are providing protection against high heat and abrasion, corrosion and severe thermal shock in supersonic aircraft, missiles and rockets.

Norton Company maintains ROKIDE coating facilities on both coasts: at the main plant in Worcester, Mass., and at its plant in Santa Clara, California. For details, write NORTON COMPANY, Refractories Division, 550 New Bond St., Worcester 6, Massachusetts.

*Trade-Mark Reg. U. S. Pat. Off. and Foreign Countries

A rocket engine capable of more than 50,000 lbs. of static thrust, developed and built by Reaction Motors Division of Thiokol Chemical Corporation, will soon send the fabulous X-15 searing into outer space. To protect the engine from its own fierce blast, key metal surfaces are coated with ROKIDE "Z" coating.

NORTON

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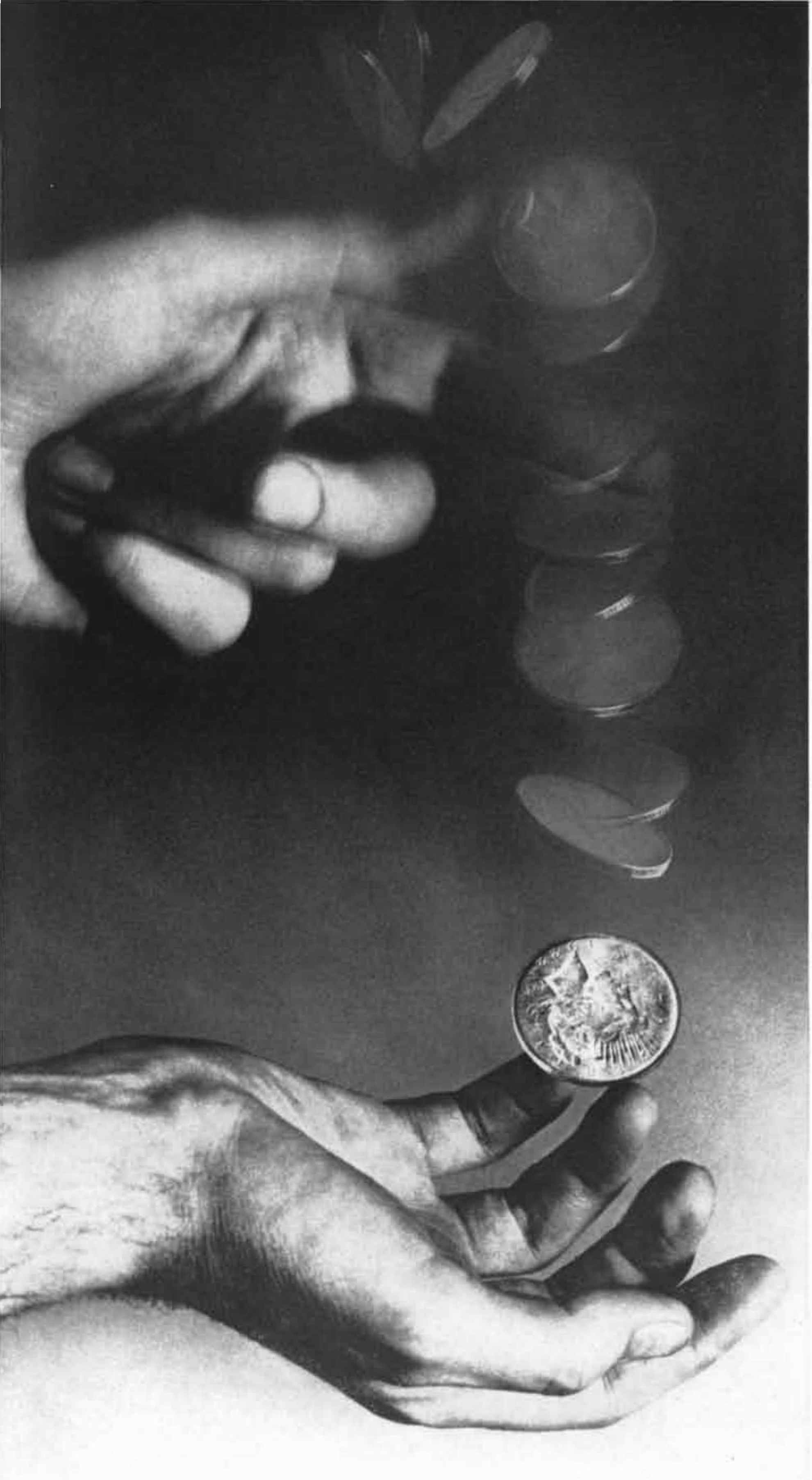
NORTON PRODUCTS Abrasives • Grinding Wheels • Grinding Machines • Refractories • Electrochemicals — BEHR-MANNING DIVISION Coated Abrasives • Sharpening Stones • Pressure-Sensitive Tapes

THE AUTHORS

H. TRACY HALL ("Ultrahigh Pressures") is director of research and professor of chemistry at Brigham Young University in Provo, Utah. He was born in Ogden, Utah, in 1919, and acquired his B.S., M.S., and Ph.D. degrees at the University of Utah. From 1942 to 1946 he was with the Bureau of Mines in Utah, with time out for service in the Navy. He became interested in synthesizing diamonds in 1942, and, he says, "read everything I could find on the subject and conducted many experiments in which I hoped to synthesize diamonds without the use of high pressures and high temperatures. This research was aside from my masters' degree project, which was in the field of electrochemistry." Hall joined the General Electric Research Laboratory in Schenectady in 1948, and in 1951 he "eagerly accepted" the company's offer to work on synthesizing diamonds. The group in which he worked devised the high-pressure, high-temperature apparatus that made the synthesis possible, and Hall himself discovered the proper chemical constituents, geometrical arrangements, pressures and temperatures necessary for the first reproducible synthesis of diamonds. He left General Electric in 1955 to take up his present position in Provo, where he lives with his wife and seven children.

R. W. SPERRY ("The Growth of Nerve Circuits") is Hixon Professor of Psychobiology at the California Institute of Technology. He graduated from Oberlin College in 1935 and took his Ph.D. at the University of Chicago in 1941. Then he was a National Research Fellow at Harvard University and a research associate at the Yerkes Laboratories of Primate Biology. In 1946 he returned to Chicago, serving first as assistant professor of anatomy and later as associate professor of psychology. He spent a year at the National Institutes of Health as chief of the section on developmental neurology, and in 1954 went to his present position at Cal Tech. Another article by Sperry, "The Eye and the Brain," appeared in the May, 1956, issue of SCIENTIFIC AMERICAN.

ELIJAH ADAMS ("Poisons") is professor of pharmacology and director of the pharmacology department of the Saint Louis University School of Medicine. He is a graduate of Johns Hopkins University and took his M.D. at



He took the luck out of heads or tails

This AMF engineer had a delicate problem: to accomplish the separation of the expended stages of a multi-stage rocket. If separation occurs too soon, thrust in the nearly burned out stage may exceed the aerodynamic drag, the tail overtakes the head, and...boom. A million dollar collision and no insurance.

His solution: An acceleration switch that turns the burned out stage loose at the right split second ...a switch that makes rockets think for themselves.

His switch is compact. It is designed to work in any missile at any range with any payload. It is ingeniously simple in conception, design, and operation. A spring is attached to a free swinging hammer, the spring force acting to pull the hammer against the contact plate. At calibration the spring can be set to oppose any G from 1 to 100. When the missile is launched, the hammer is held back by the acceleration forces until the stage decays to the desired separation G. When the spring force overcomes the forces of acceleration, the hammer comes forward, strikes the contact plate, and the circuit required to make separation is closed automatically. No guesswork, no luck, no *collision.*

Single Command Concept

This simple solution to a tricky problem reflects the resourcefulness of AMF people.

AMF people are organized in a *single operational unit* offering a wide range of engineering and production capabilities. Its purpose: To accept assignments at any stage from concept through development, production, and service training... and to complete them faster...in

- *Ground Support Equipment*
- *Weapon Systems*
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- *Radar*
- *Automatic Handling & Processing*
- *Range Instrumentation*
- *Space Environment Equipment*
- *Nuclear Research & Development*

GOVERNMENT PRODUCTS GROUP,
AMF Building, 261 Madison Avenue,
New York 16, N. Y.

AMF

In engineering and manufacturing AMF has ingenuity you can use... **AMERICAN MACHINE & FOUNDRY COMPANY** the University of Rochester in 1942. An Army physician in World War II, he left medicine after the war for research in enzyme biochemistry, later teaching pharmacology at the New York University College of Medicine. He wrote the article "Barbiturates" in SCIENTIFIC AMERICAN for January, 1958.

MATTHEW JOSEPHSON ("The Invention of the Electric Light") is a former magazine editor and the author of many books and articles. He received his B.A. degree at Columbia University in 1920, and was successively an editor of *Broom*, *Transition* and *The New Republic*, which he left in 1932. Among his books are *Zola and His Time*, *The Robber Barons*, *The Politicos* and *Stendhal: Or the Pursuit of Happiness*. He was elected to membership in the National Institute of Arts and Letters in 1948, and has held a Guggenheim traveling fellowship for creative literature.

HUBERT AND MABLE FRINGS ("The Language of Crows") are a husband-and-wife team at Pennsylvania State University, where they study the responses of animals to sound. Hubert Frings took his degrees at Penn State, the University of Oklahoma and the University of Minnesota, where he received his Ph.D. in 1940. He joined the Penn State faculty in 1949 and is now professor of zoology. He and his wife first studied chemoreception in insects but later became "impressed with stories about insects being chased by various sounds." The Fringses sought advice on this phenomenon in the acoustics division of the physics department at Penn State, but there were sidetracked into studying the effects of high-intensity ultrasound on animals. This led to the development of standardized tests for audiogenic seizures in mice, and to the production of stocks of mice with predictable susceptibilities to these seizures. They started their work on birds in 1952 by studying the response of starlings to sounds. The Air Force sponsored this project in the hope of getting rid of starlings around aircraft hangars. Frings and Joseph Jumber, a graduate student, stumbled upon the fact that the recorded distress call of the starling causes a starling flock to leave its roost. Mrs. Frings, a research associate at Penn State, from which she graduated, has collaborated in most of this work.

BRUNO ROSSI ("High-Energy Cosmic Rays"), professor of physics at the Massachusetts Institute of Technology since 1946, has been studying cosmic

Titan's Accurate Guidance System

It has only a few minutes after lift-off to set a 110 ton ballistic missile on course to pinpoint a target area quarter-way 'round the world.

"Threading a needle in space in order to drop a missile on target up to 6,000 miles away." This is the task accomplished by the Command Guidance System now used for the Titan intercontinental ballistic missile.

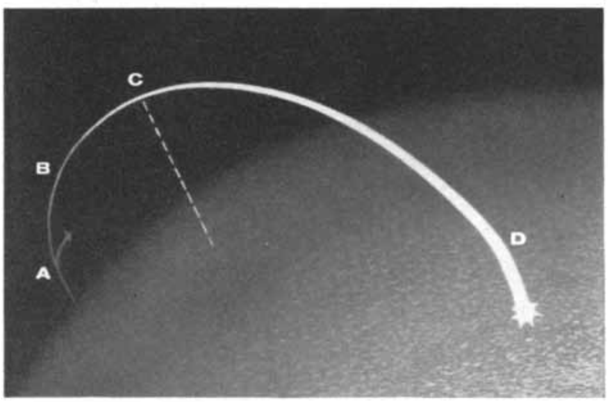
Command guidance is a system developed by the Bell Telephone System's research-production team . . . Bell Telephone Laboratories and Western Electric. The science that developed this and so many of the almost magical electronic devices essential in today's national defense is in large part the same science that provides your Bell telephone service.

The "ballistic" missile

To appreciate the task confronting the Command Guidance System requires a basic understanding of the ballistic missile itself.

Titan is propelled hundreds of miles above the atmosphere at speeds of more than 17,000 miles per hour and with range limits of 6,000 and more statute miles. The missile engines propel it for a fraction of the total distance, guidance being applied only during the powered phase. For the rest of the trip, the missile—including the subsequently detached nose cone—flies like a projectile shot from a gun. It follows a ballistic trajectory to the target.

Classically, the ballistic trajectory or orbit is an ellipse with the center of attraction—in this case the center of earth—at one focus. Determining the exact trajectory required, however, is complicated by such things as earth rotation and the not-exactly spherical aspect of our globe.

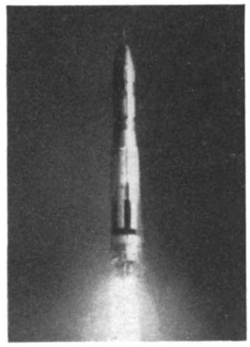


Typical ICBM trajectory showing (A) falling booster stage, (B) end of powered flight, (C) apogee or point of greatest separation from earth, (D) re-entry of detached nose cone into earth's atmosphere.

Need for extreme accuracy

To assure impact on the distant target, six parameters—the positions and velocities along each of three coordinate axes at the instant of termination of thrust—must meet prescribed conditions at a point in space far short of its target—the "needle's eye"! This is to say, the missile must be minutely controlled to satisfy the conditions of position and velocity appropriate to the desired ballistic flight path.

Out at the "needle's eye"—when the missile may be going 25,000 feet per second—an error of one foot per second can cause a miss of one mile at the target.



Titan, America's newest ICBM, is a 110 ton two-stage rocket designed to carry a nuclear warhead in the nose cone attached to the second stage.

How the system works

A single ground-based radar continuously determines the position of the missile during powered flight. A Remington Rand-Univac digital computer—also on the ground—accepts these data and, by reference to previously stored trajectory information for the particular target, computes appropriate orders to steer the missile on its proper flight path. These orders are transmitted by radio to the missile's autopilot and control system—hence the term "command guidance."

Since the radar and computer are ground-based, they can be used over and over again. The expendable portion of the system—in the missile—is kept to a minimum, promoting reliability and reducing cost and weight.

An outgrowth of Nike

The radar employed in the research and development Titan Guidance System at Cape Canaveral is an outgrowth of the target-tracking radar of the Nike-Hercules System. Western Electric—which has been prime contractor of Nike Systems from the beginning—is now producing a new radar redesigned specifically for operational use with Titan.

Proved in flight

The Titan Command Guidance System installed at Cape Canaveral has been put to test in another missile . . . the THOR-ABLE II. With the aid of the guidance system, two nose cones have been recovered after flights of over 5,000 miles. This versatile system is now contemplated for precision guidance of satellite vehicles and space probes in other programs.

Product of telephone teamwork

From the time the Air Force decided to move ahead on the Titan project and entrusted the guidance system to the Bell Laboratories-Western Electric team, Western Electric engineers have worked closely together with those of the Laboratories . . . much as they do in the design and manufacture of reliable equipment needed for Bell telephone service.

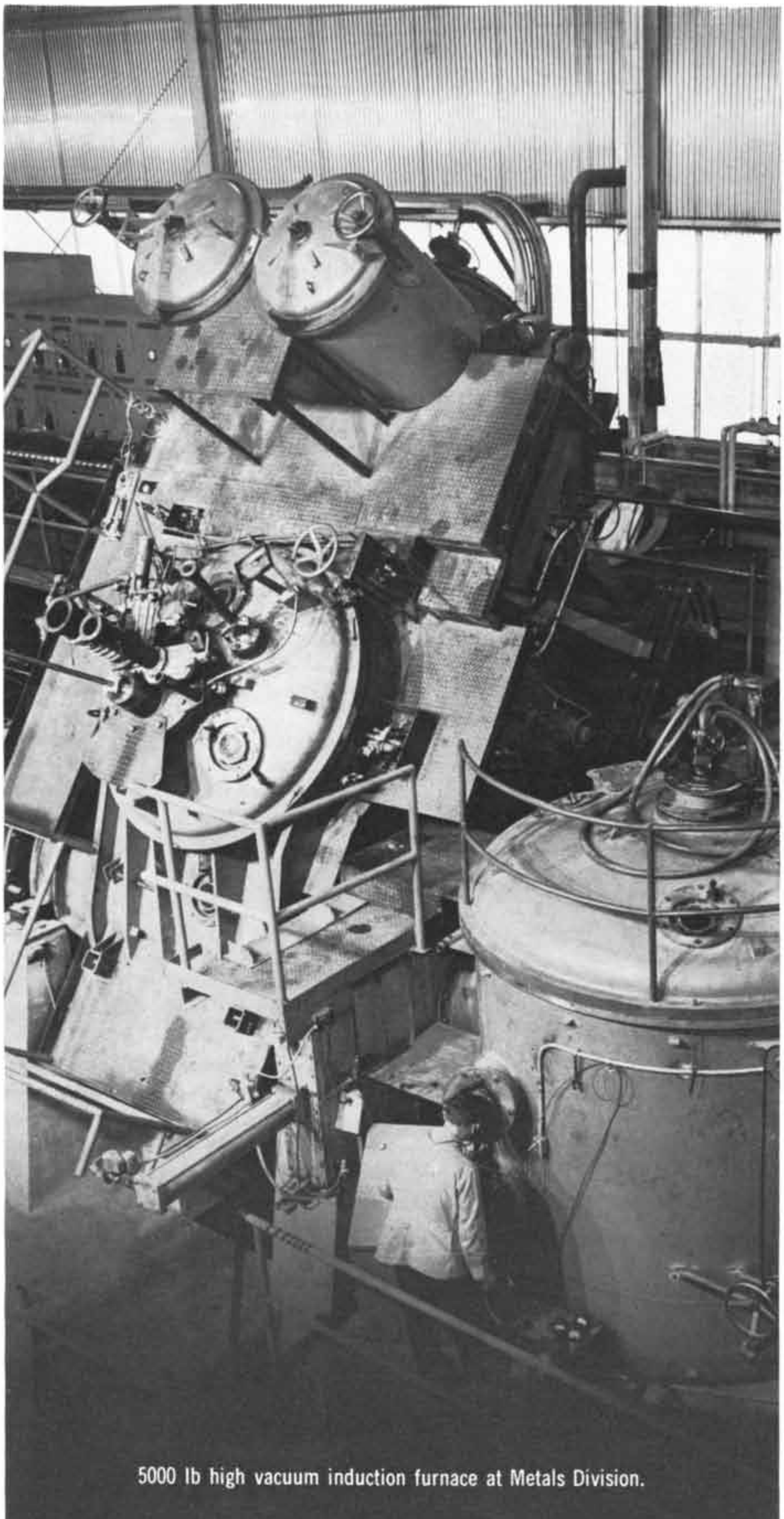
Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM rays since 1930. An article he read at that time inspired him to build his first Geiger-Müller counter; he has been investigating "the mystery of this extraordinary phenomenon" ever since. He was born in Venice in 1905 and studied at the universities of Padua and Bologna. He took his Ph.D. in physics in 1937. He taught at Florence and Padua until the Mussolini government forced him to resign in 1938. After a year in Denmark and England, he came to the U. S. Rossi was an associate professor of physics at Cornell University from 1940 to 1946, with three years out for work at Los Alamos.

WILLIAM HOVANITZ ("Insects and Plant Galls") is an entomologist at the California Institute of Technology. He acquired his B.S. at the University of California in 1938, and his Ph.D. at Cal Tech in 1943. He was a National Research Fellow in South America, Florida and Michigan for two years. Then he was on the faculties of the University of Michigan, Wayne University and the University of California at San Francisco. He went to Cal Tech in 1956.

GLYN E. DANIEL ("The Idea of Man's Antiquity") is a lecturer in archaeology and fellow and director of studies in archaeology and anthropology in St. John's College of the University of Cambridge. A Welshman, he went to Cambridge as an undergraduate in 1932 and has been there ever since, with time out to serve as an intelligence officer in the Royal Air Force during World War II. In archaeology he is mainly interested in megalithic monuments, prehistoric art and the history of archaeological thought. He has excavated in England and Wales and traveled extensively throughout Europe. Daniel has published a number of archaeological books and for six years was chairman of a popular archaeological program of the British Broadcasting Corporation entitled "Animal, Vegetable, Mineral?" He originated another program, called "Buried Treasure," and is now planning a new one called "Man before History." Daniel is the editor of *Antiquity*, the only archaeological journal in the world that is not the organ of any society or museum. He has written two detective stories: *The Cambridge Murders* and *Welcome, Death.*

ERNST MAYR, who reviews Gertrude Himmelfarb's *Darwin and the Darwinian Revolution* in this issue, is Louis Agassiz Professor of Zoology at Harvard University.



5000 lb high vacuum induction furnace at Metals Division.

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100 per cent composition control assured by vacuum induction melting

Highly reactive elements enhance high-temperature alloy properties. Today, only one production metal refining process can effectively control the action of these elements, and—heat-after-heat—meet the most exacting alloy specifications.

The process is vacuum induction melting, and the only specialist in this process is the Metals Division, Kelsey-Hayes Company.

In a specially designed plant which contains seven vacuum induction furnaces with a monthly capacity of 1 million lb, the Metals Division produces over 50 alloys for critical high-temperature, high-stress applications such as aircraft gas turbine buckets and wheels, missile and nuclear components. Alloys like Udimet 500 and 700 were developed by Metals Division. The Division is the leading producer of vacuum induction melted Waspaloy, M-252, and other alloys. Kelsey-Hayes Company, Detroit 32, Mich.

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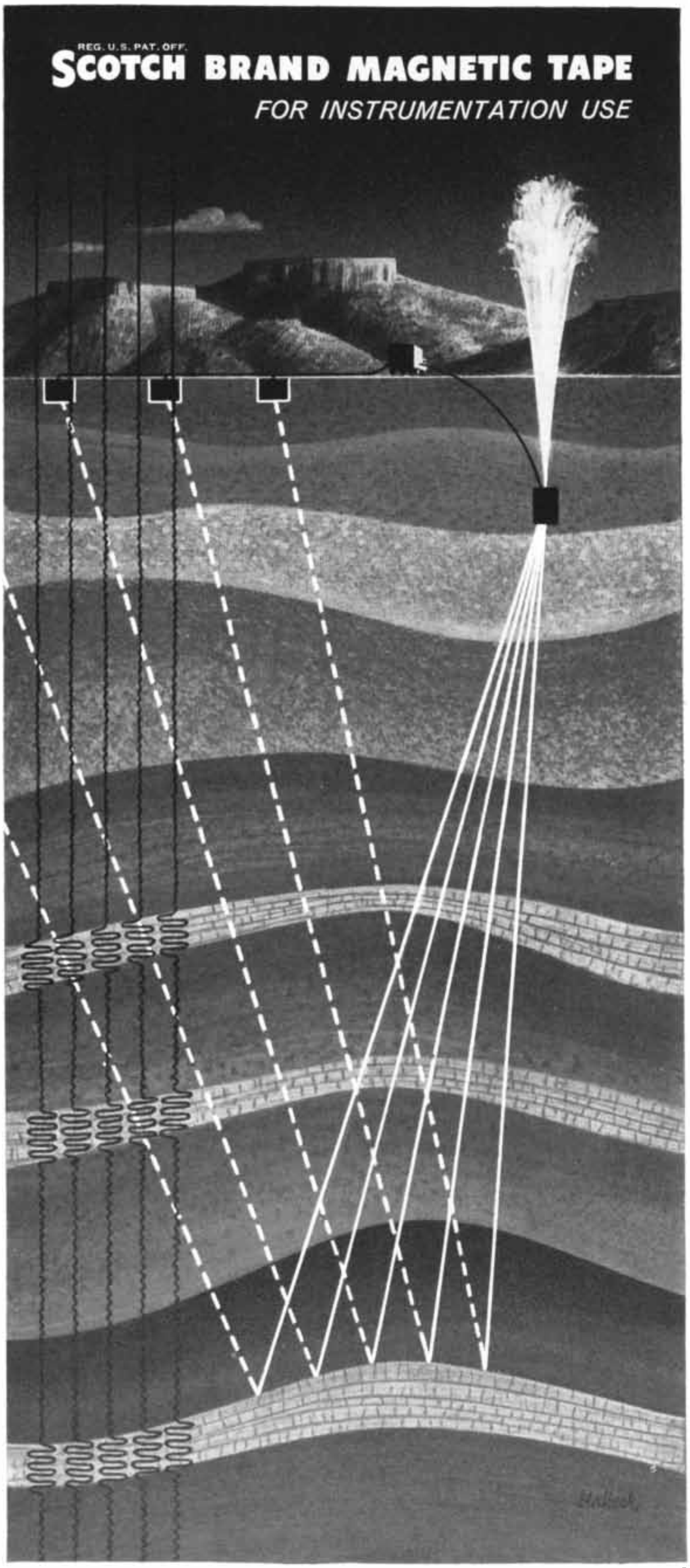

MAGNETIC MEMORY OF AN OIL RESERVOIR 3 MILES DOWN . . . "FOUND" AT THE SURFACE

The boom of a dynamite "shot" sounds in desert stillness. Vibrations reflect from the earth below. Methodically moving across the surface, the geophysicist records messages from the earth's depths on "SCOTCH" BRAND Magnetic Tape.

Rebounding from the stratified earth to a series of geophone pick-ups above, all the reflections are simultaneously taped. These faithful magnetic records of shots—evaluated later—trace the profile of a rock-capped oil reservoir 3 miles down.

"SCOTCH" BRAND Magnetic Tape—the first practical magnetic tape made—will serve you, too, as it keeps its lead in the development of newer, more sensitive instrumentation tapes for science, business, and industry. For information on tape applications, write Magnetic Products Division, Dept. MB0119, 3M Company, 900 Bush Ave., St. Paul 6, Minnesota.

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ALI BABA OPENED ONLY ONE DOOR TO WEALTH...

With Sinclair petrochemicals you can open a dozen doors to more profitable production. For example, U. S. farmers can now harvest the world's most abundant corn crop, using fertilizers made from Sinclair nitrogen products. Industry, too, has many profitable applications for Sinclair Anhydrous Ammonia.

The Sinclair Organization is proud of its reputation for *performance.* Sinclair plants built to supply requirements of chemical users have gone on stream in advance of scheduled completion date with products substantially exceeding customers' specifications—a direct benefit to the chemical manufacturer.

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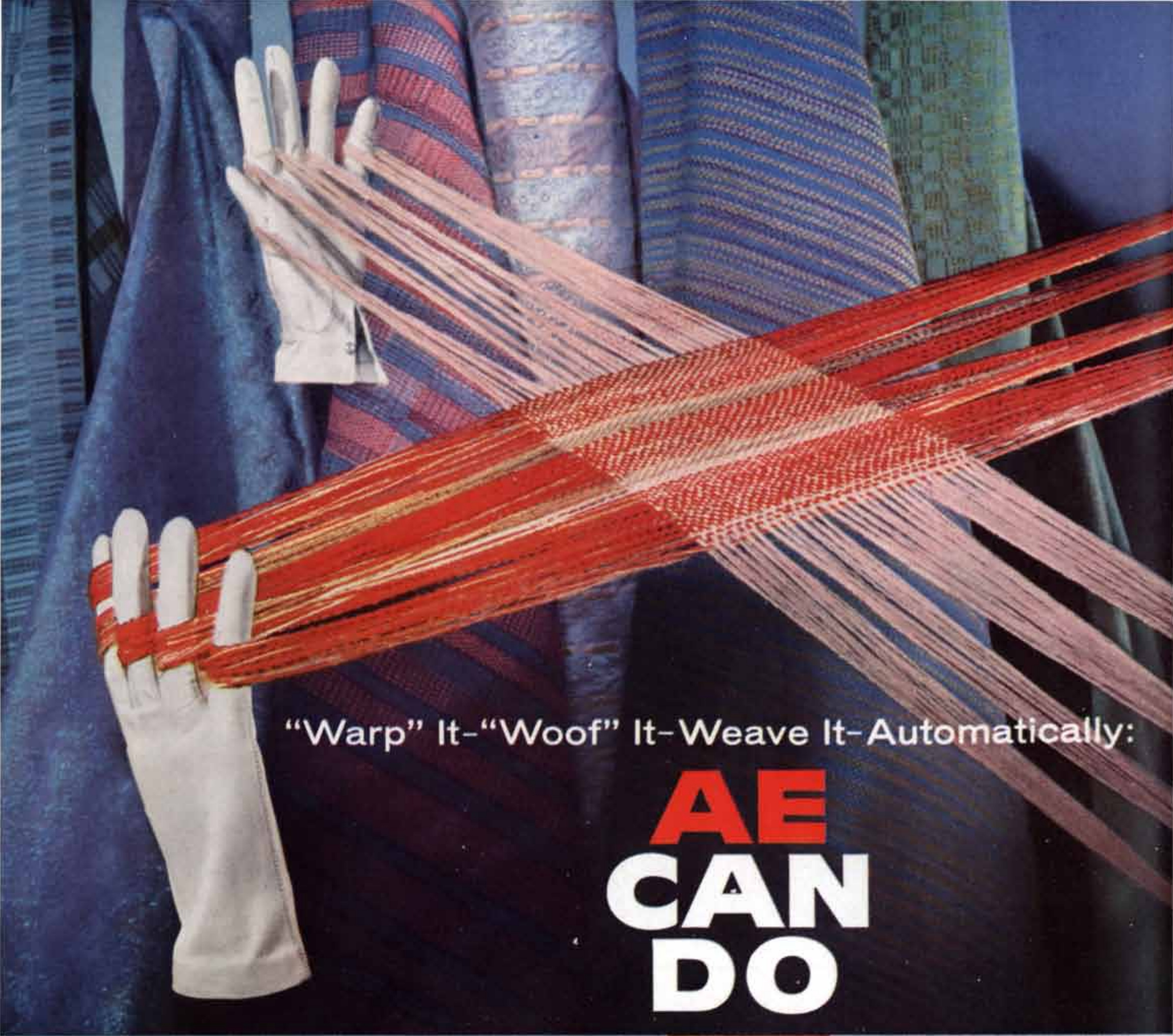
ATLAS utilizes a radio-command guidance system provided by the Defense Systems Department. Depicted here is the dramatic blastoff of the ATLAS which — under radio-command guidance — produced a successful earthly orbit as part of project SCORE.



There *is* a loom that changes weaves on command. It's at work today, thanks in part to Automatic Electric.

The secret: the same basic components used in automatic telephone exchanges. These units make it possible to weave patterns for pretties one minute, an intricate drapery the next. A predetermined design is set up on a "programming plug." When the plug is changed, so is the pattern that is woven.

Making machines like this act automatically is AE's business. Because automatic control is a *telephone art—and AE was one of its earliest practitioners.*

In fact, almost every device or system that is operated automatically uses the type of switching and relay units originated or manufactured by Automatic Electric.

AE has solutions *searching* for problems in communications and control. We may have what *you* want—whether it involves basic components or a control "package." Why not find out by writing the Director, Industrial Products Engineering, Automatic Electric, Northlake, Illinois.

MAKING
IDEAS
WORK
AUTOMATICALLY

AUTOMATIC ELECTRIC

Subsidiary of
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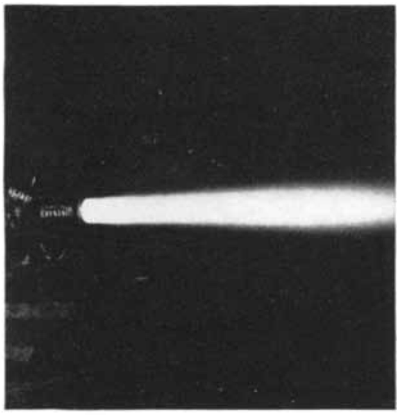
PRODUCT-DESIGN BRIEFS FROM DUREZ

- **Phenolic for a rocket motor**
- **Heat-stable, moisture-stable insulation**
- **Compounds for dip coating**



REDSTONE DIV., THIOKOL CHEMICAL CORP.

It's warm in there

That's the exhaust pattern of a solid-propellant rocket motor. Temperature inside sometimes hits 6000°F.

At the nozzle, fuel-burning releases its full fury. To keep the bird's metal skin from buckling under the combined heat and stress, rocket engineers line many nozzles with a glass-reinforced phenolic, *Durez 16771*. During flight this plastic liner chars—at a predictable rate. It protects the metal nozzle wall from thermal failure.

Equally dramatic, if less spectacular, are the design improvements that *16771* is making possible because of its impact strength (up to 15 ft.-lb./in. Izod) and other properties. One manufacturer molds it into a rugged pump base that won't corrode and that outwears many metals. The U. S. Signal Corps puts its strength to work in boxes that protect the parachutes on droppable radios. Automotive engineers save two-thirds of the cost of automotive oil-pump gears by replacing metal with *16771*—and get gears that run almost three times as long as before.

New bulletin: To help you evaluate *Durez 16771*, we'll be glad to send you Bulletin D203. It gives a good idea of the properties you can expect, discusses current applications, and includes helpful advice on molding, machining, and finishing. If you'd like a copy, just check the coupon.

Insulation at close range

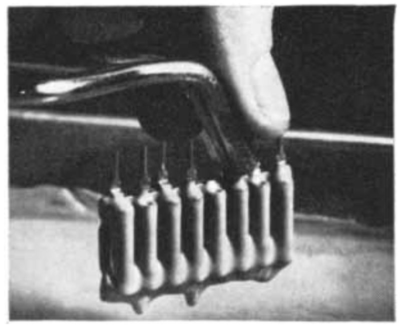
The push for good, compact insulating materials grows stronger. More electronic engineers are cramming more performance into fewer cubic inches than ever before. Under these conditions, cost of an insulator means little—when a pound of the *right* one will make smaller components, and perhaps twice as many of them.

Such a material is *Durez 16694* diallyl phthalate molding compound. We believe it to be the cream of the current plastics crop for molding components and larger parts in which circuits must function with sterling reliability despite heat, moisture, electrical and mechanical stress, and narrow working quarters.

This orlon-filled compound molds well, is not brittle, machines easily with little wear on tools. Its molding characteristics are unvarying from shipment to shipment.

It produces pieces that have very high arc resistance, consistently reproducible. It retains dimensional stability and high insulation values over extended periods at relative humidities above 90%. It does not corrode metal contacts and is virtually free from cold flow and creep.

Durez Bulletin D400 lists the properties of this compound and other electrical-grade materials. The data sheet on *Durez 16694* diallyl phthalate goes into detail on electrical test results. To get both pieces, check the coupon.



Helping resistors resist

Problem: Find a coating material that keeps tiny components like these protected against humidity—and won't peel back under the heat of a soldering gun.

Solution: A dip-coating compound based on Durez phenolic resins.

This thermosetting compound goes on smoothly without running or sagging. It's just porous enough to take a protective wax sealing coat. It cures hard, to allow stamping or color coding. It doesn't migrate or peel back during soldering.

Durez research men worked closely with electronic engineers for more than seven years to develop compounds like this. Improved each year, Durez dip-coating compounds are the most widely used of their type. A check mark on the coupon will bring you specifics about them.

For more information on Durez materials mentioned above, check here:

☐ *Durez 16771,* impact phenolic (Bulletin D203)

☐ *Durez 16694,* diallyl phthalate (Bulletin D400 and data sheet)

☐ Phenolic resin compounds for dip coating

☐ "Durez Plastics News," mailed periodically, shows and describes latest uses of Durez materials.

Clip and mail to us with your name, title, company address. (When requesting *samples, please use business letterhead.)*

DUREZ PLASTICS DIVISION

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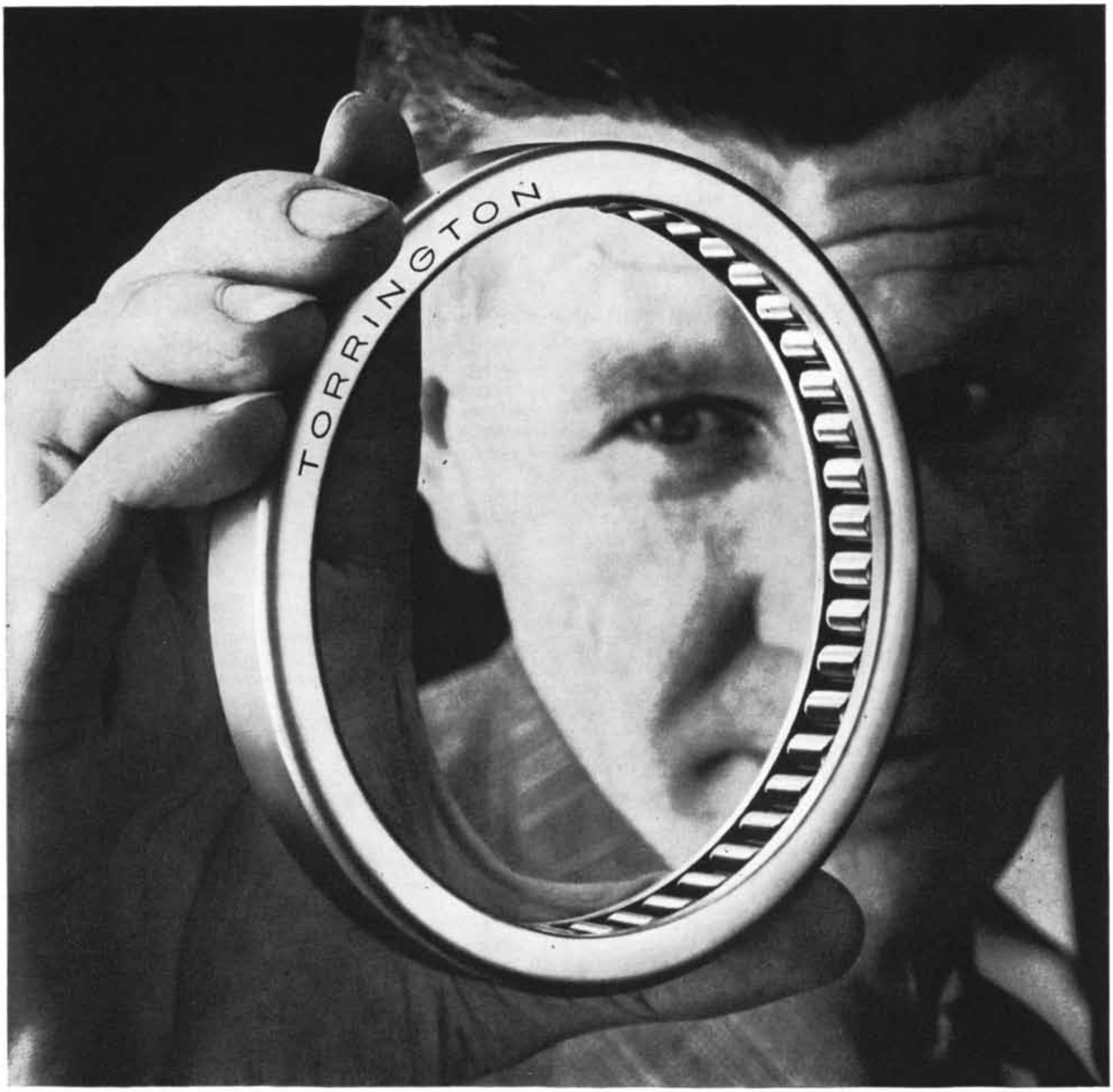
HOOKER CHEMICAL CORPORATION

HOOKER CHEMICALS PLASTICS


TORRINGTON

SERVING SAFETY THROUGH SCIENCE

MOVES AND COUNTERMOVES AT MACH 30 are characteristics of the international chess game now being played.

Our safety in America rests on our potential for making moves and countermoves swiftly...on our ability to take the necessary measures and countermeasures if a showdown is called for.

In that way we keep the game where it belongs—on maps and boards and in bound copies of strategic plans, all marked "TOP SECRET."

Here's the way it works:

The first successful self-powered homing guided missile was developed in the United States eleven years ago. Its guidance system was designed by systems engineers of SERVO CORPORATION OF AMERICA.

That was a move.

Countermove: The enemy could jam our radar signal.

Next move: Devise a guidance system that did not depend on a radar signal. Instead, let it "home in" on the infrared radiation of plane and missile propulsion systems.

Thus SERVO CORPORATION engineers were responsible for the first infrared search and lock-on self-powered homing guided missile system. Today vast numbers of Sidewinder missiles using infrared guidance systems stand ready for instant action at supersonic speeds.

Events move ever more swiftly. Seconds become precious. To gain those seconds, an early warning radar detection system was established. That was a move. Next step: find a way to counteract a countermove.

SERVO CORPORATION worked with the Air Force to develop the first combination of a computer with a ground search radar station and worked out the necessary circuits so that a single radar could track-while-scan. Now one radar station can track hundreds of flying objects at one time.

So it goes . . . every move demanding a countermove.

The complex "chess game" of military systems for our nation's safety leads to systems for peacetime safety as well. Track-while-scan radar lends itself to Air Traffic Control.

But even here, moves and countermoves are called for. Our enemy?—atmospheric conditions, unforeseen eventualities, human limitations. So SERVO CORPORATION engineers found a way to utilize the Doppler Effect to provide more dependable and accurate direction finding systems for air traffic control.

This led to the first VOR Compatible Doppler Omnirange System to provide truly world-wide safe air navigation.

Infrared detection systems, first used on missiles, now provide safe-control devices for industrial processes.

The SERVOSAFE® Hot Box Detective*, now in use on railroads from coast to coast, uses infrared detection to protect against derailments due to overheated journal boxes.

With its skill at Systems and Functional Engineering, SERVO CORPORATION is truly serving safety through science.

SERVO CORPORATION OF AMERICA
111 New South Road, Hicksville, L. I., New York

*Protected by U.S. Patent No. 2,880,309. Other U.S. & Foreign Patents Applied For.

Claude Bernard...on giants and pygmies

"In the experimental sciences, great men are never the promoters of absolute and immutable truths. . . . Great men may be compared to torches shining at long intervals, to guide the advance of science. They light up their time, either by discovering unexpected and fertile phenomena which open up new paths and reveal unknown horizons, or by generalizing acquired scientific facts and disclosing truths which their predecessors had not perceived. . . . Great men have been compared to giants upon whose shoulders pygmies have climbed, who nevertheless see further than they. This simply means that science makes progress subsequent to the appearance of great men, and precisely because of their influence. The result is that their successors know many more scientific facts than the great men themselves had in their day. But a great man is, none the less, still a great man, that is to say, a giant."

—*L'introduction à l'étude de la médecine expérimentale*, 1865

Established 1845 **SCIENTIFIC AMERICAN** November, 1959 Volume 201 Number 5

Ultrahigh Pressures

Laboratory apparatus is now capable of maintaining steady pressures of more than two million pounds per square inch. Under such extreme conditions matter exhibits new properties

by H. Tracy Hall

There is a nice symbolism in the fact that man was able to hit the moon before he could sink a three-mile shaft through the earth's crust. Standing on the threshold of space he has even anticipated by his experiments much of what he will find there. The light, the heat, the nuclear reactions of the stars themselves have been duplicated in miniature. But man has barely begun to approach in his laboratories the outstanding characteristic of the nether world—its enormous static pressure.

The highest steady pressure yet attained in the laboratory is 200,000 atmospheres, almost three million pounds per square inch. (One atmosphere is 14.7 pounds per square inch, the average atmospheric pressure at sea level.) At the center of the earth the pressure is three million atmospheres; at the center of the sun, 100 billion; in white-dwarf stars, something like 10 million billion. On such a scale our efforts seem puny indeed. Viewed in other ways, however, they are nothing to sneeze at. Two hundred thousand atmospheres is the pressure exerted by a column of granite 400 miles high, or a stack of 4,000 Washington Monuments. It is more than enough to manufacture diamonds and other minerals, and it can force matter into entirely new forms never before seen on earth.

This is just a beginning. In the past not nearly so much effort has gone into high-pressure work as into attempts to produce other extreme conditions, such as high temperature and high voltage. Now the pace is quickening and important discoveries can be expected.

Like temperature and voltage, pressure is a component of energy: mechanical energy is associated with matter under pressure just as heat energy is associated with temperature or electrical energy with voltage. Variations in these components cause changes in the behavior of matter: melting, boiling, ionization and so on. When the range of variation for pressure is extended as far as it has been for other components, important new phenomena will surely come to light.

In a general way we know what sort of structural changes pressure induces in matter, but the important details can only be discovered by experiment. If we start with a sample of matter in its least compressed, or gaseous, state, the application of pressure eventually liquefies it (unless its temperature is too high). Further increase in the pressure squeezes out the holes in the complex but not completely disordered arrangement of atoms or molecules in the liquid, decreasing its fluidity. Still higher pressures force the molecules into the highly ordered lattice-structure of a crystalline solid. In many such solids several types of arrangement are possible, and increasing pressure pushes the material into a succession of different "phases" in which the molecules fall into different geometrical patterns as they are packed closer and closer together. After the closest possible packing has been achieved, the atoms themselves begin to deform, their electrons being forced into abnormal quantum orbits. With still higher pressure some electrons will actually be squeezed out of their usual molecular orbits and freed to move through the material. At this point the substance has become a metal. Within the range of laboratory pressures now attainable, samples of all these effects can be observed.

At tremendous pressures, beyond anything that can be imagined in the laboratory but existing in the interiors of stars, matter becomes completely "degenerate." All the electrons have been stripped from their nuclei. Conceivably still higher pressure could bring the nuclei so close together that they would begin to fuse.

Another way of looking at pressure effects is from the viewpoint of thermodynamics and reaction rate. Thermodynamics is the science of the possible. It specifies the conditions—temperature, pressure, electromagnetic-field strength and so on—under which a given reaction can occur. A rise in pressure may transform an impossible change into a possible one.

But to say that something *can* happen is not to say that it will happen in a finite length of time. It is the province of reaction-rate theory to predict how fast reactions will go and to tell how to speed them up or slow them down. In their effects on reaction rates (and on many other properties of matter) pressure and temperature are opposites. Increasing temperature tends to loosen matter, shaking up its atoms and making them react faster. Increasing pressure makes matter more dense, diminishing the mobility of the atoms and slowing down reaction rates.

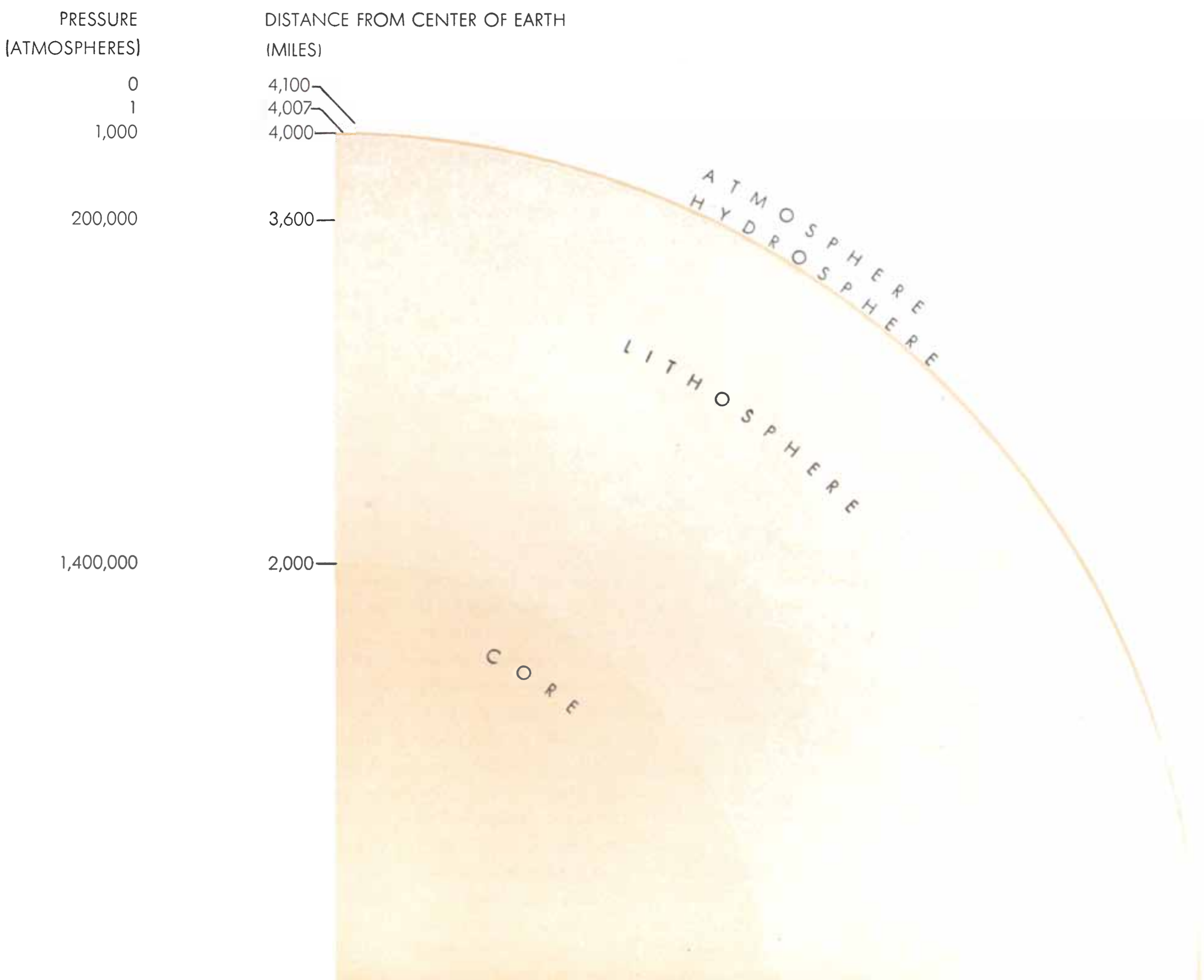
Thermal energy has been widely used to control thermodynamic conditions and reaction rates ever since man started playing with fire. Pressure has rarely been exploited for these purposes, although it can be equally effective. Furthermore, the combined action of pressure and temperature as levers for manipulating a reacting system offers far greater possibilities than does either alone, as we shall see. In fact, many transformations (*e.g.*, graphite into diamond) become possible only under conditions of both high pressure and high temperature.

How are high pressures produced in the laboratory? Basically by the application of principles that have been well known since the time of Archimedes. Pressure is the force exerted per unit area of surface. To make the pressure large, use a large force or a small area. The typical high-pressure device does both. A comparatively small force is applied to a piston in a narrow-bored cylinder filled with liquid. Suppose that the force is 500 pounds and the area of the piston half a square inch. Then the pressure exerted by the piston on the liquid ahead of it will be 1,000 pounds per square inch.

The narrow cylinder connects with a wider one, also filled with liquid. According to an elementary law of physics the pressure is transmitted undiminished through all of the liquid and against the walls of the container. Thus against every square inch of the large cylinder and its piston there is a force of 1,000 pounds. Let us say that the large piston has an area of 200 square inches. The total force pushing it must then be 200 times 1,000 or 200,000 pounds.

Now let the large piston push against a thin rod, say a third of a square inch in cross section. All the force is concentrated on this small area, and the pressure is 600,000 pounds per square inch (about 40,000 atmospheres). Ahead of the rod, and receiving this pressure, is the sample to be studied.

Theoretically there is no limit to the pressure that such an arrangement could produce. In practice the limit is set by the strength of the materials of which the apparatus is made. Eventually the cylinders will burst or the pistons and connecting rods crumble under the

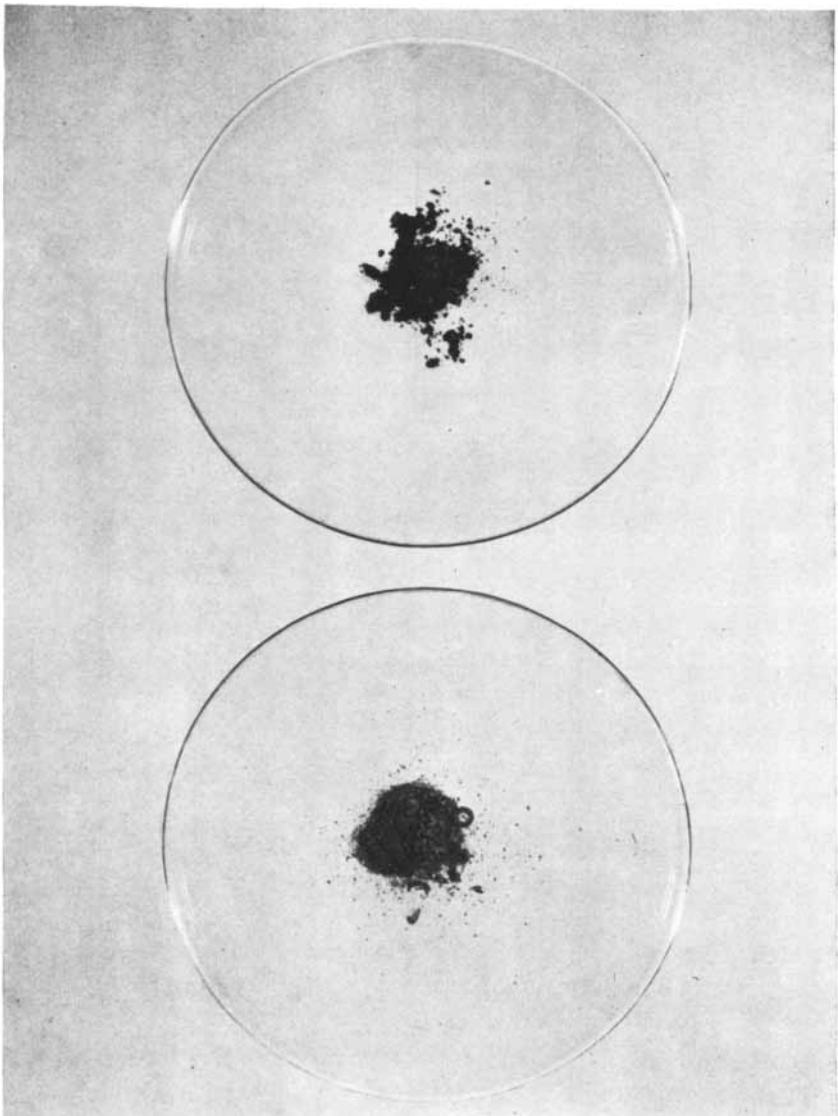


TERRESTRIAL PRESSURES range from zero at the top of the atmosphere to three million atmospheres (44 million pounds per square inch) at the center of the earth. Discontinuities, as between air and water or water and solid earth, are marked by abrupt changes in pressure. The transition from lithosphere to core may be a change in crystal structure, not a change from stone to iron.

huge forces. Of the materials now available cemented tungsten-carbide has the greatest compressive strength. In simple piston-and-cylinder devices it withstands pressures up to 50,000 atmospheres. Although it has a high resistance to crushing, its tensile strength is rather low. Consequently tungsten-carbide cylinders must be supported by massive alloy-steel binding-rings to prevent them from bursting. When the cylinder is adequately reinforced, the pressure can be increased until the piston fails.

One conceivable way to increase the effective strength of construction materials is to "cascade" piston-and-cylinder combinations, nesting one inside the other. Failure results from differential, not absolute, pressure; thus a cylinder containing a pressure of 100,000 atmospheres, but located inside a second cylinder where the pressure is 50,000 atmospheres, is subject to a net pressure of only 50,000 atmospheres. By linking the nesting units so that the large piston of one stage activates the small piston of the next, tremendous pressures could be attained. However, mechanical difficulties have thus far restricted cascading to two stages, and the presses that have been built in this way afford no method of heating the compressed sample.

The most successful and versatile devices now operating above 50,000 atmospheres stem from the apparatus originally developed by Percy W. Bridgman of Harvard University, a lifelong pioneer in high-pressure research. Obviously the weakest link in the pressure chain of the hydraulic arrangement described above is the thin rod that concentrates the thrust of a large piston into a small area. Bridgman replaced the rod by a thick cylindrical "anvil" bluntly tapered at one end. The tapering cone does not extend to a point but is cut off to expose a circular face about a fifth of a square inch in area. This is the working surface, where the total force is finally concentrated. The tremendous load on the face fans out through the mass of material behind it and is thus dispersed. Some of the dispersed force tends to make the anvil explode laterally, and is counterbalanced by steel binding-rings.

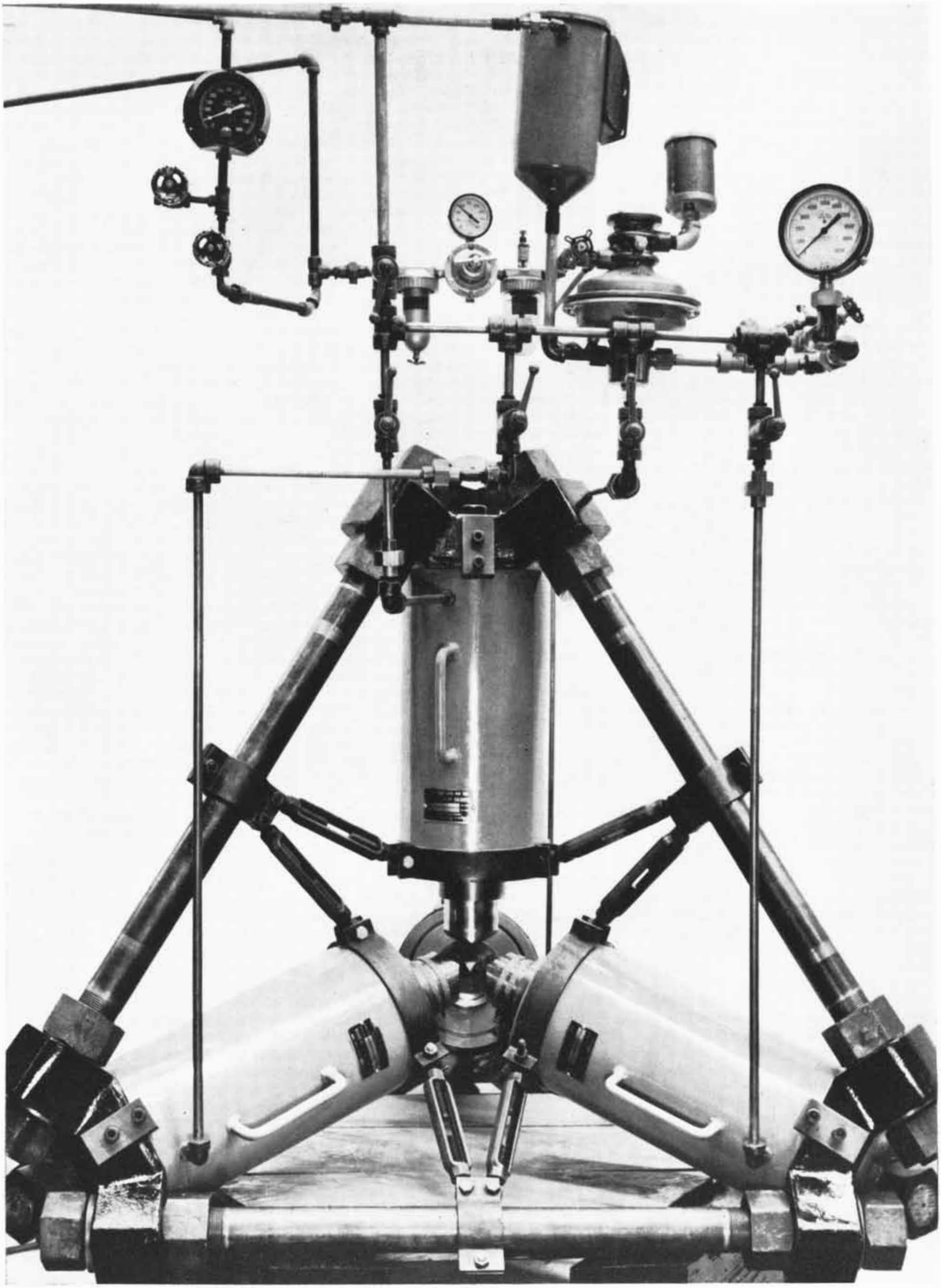


CONVERSION of graphite (*top*) to diamond (*bottom*) is accomplished by applying high pressure and high temperature, and then lowering temperature before pressure.

The complete assembly consists of a pair of opposed anvils, each impelled by a piston-and-cylinder device. The sample to be compressed is prepared in the form of a disk about .01 inch thick and a diameter slightly less than that of the anvil faces. To prevent the sample from being squeezed out from between the anvils Bridgman surrounded it with a thin circular gasket made of catlinite, or pipestone. This fine-grained silicate mineral is easily compressible. Furthermore, its surface friction is high under large forces, and in thin sections it has considerable strength in directions perpendicular to the force. Thus the gasket can be compressed without being extruded, and it holds the sample in place.

Bridgman's anvils can operate at pressures up to 200,000 atmospheres. One of their major applications has been to determine how the electrical resistance of many substances varies with pressure. They have also been used to study the formation of minerals. This process requires high temperatures as well as pressures, so the anvils must be placed in a furnace. Heating weakens them, however. At 1,000 degrees centigrade they can develop only about 20,000 atmospheres before failing. At this temperature and pressure the carbide begins to yield or flow. Another drawback of the Bridgman anvils is the small size of the samples they can handle.

Both these difficulties have been considerably reduced in a device known as the tetrahedral-anvil apparatus. It employs four tungsten-carbide anvils, tapered to end in triangular rather than circular faces [*see illustration on page 65*]. The anvils are arranged symmetrically around a central point and are forced together by a hydraulic mechanism. If they came into contact, they would enclose a volume in the shape of



TETRAHEDRAL-ANVIL APPARATUS consists of four high-pressure cylinders whose pistons actuate the anvils. Three of the cylinders are seen in side view; the fourth, head-on at bottom center. The anvils themselves protrude from the ends of the cylinders.

a regular tetrahedron, or pyramid. Instead they press against the faces of a slightly larger pyramid made of pyrophyllite, a mineral closely related to catlinite. This solid tetrahedron serves as a pressure-transmitting medium, a thermal and electrical insulator and a gasket. The sample is placed in a tunnel drilled through the pyrophyllite [*see top illustration on page 66*]. Around the sample is a carbon or metal sleeve that heats up when an electric current passes through it. Metal tabs run from the ends of the heater tube out to the faces of the tetrahedron, where they pick up current supplied through the anvils themselves. As the anvils move together, the edges of the pyrophyllite are squeezed out and form a gasket.

Tetrahedral anvils have worked at pressures as high as 130,000 atmospheres simultaneously with temperatures up to 3,000 degrees C. During an experiment the sample is of course completely enclosed. The effects of pressure are determined by noting changes in its electrical resistance and by measuring its temperature with a thermocouple. Soon it may be possible to make X-ray diffraction pictures during an experimental run so that structural changes can be followed in greater detail.

With the pressures and temperatures now available it is possible to duplicate some of the geologic processes that have taken place tens of miles below the earth's surface. Many of the earth's minerals have been synthesized, including all the natural garnets (cubic silicate-crystals), some aluminum silicates and other substances known as pyroxenes and epidote-group minerals. Knowing the temperature and pressure required to make these substances, we can deduce the conditions of their natural formation. For example, phase-stability studies on the constituents of so-called eclogite rock show that it could not have been made at a pressure less than 30,000 atmospheres. This means that it originated at least 72 miles below the earth's surface. As these studies continue, the geological history of the earth will become clearer.

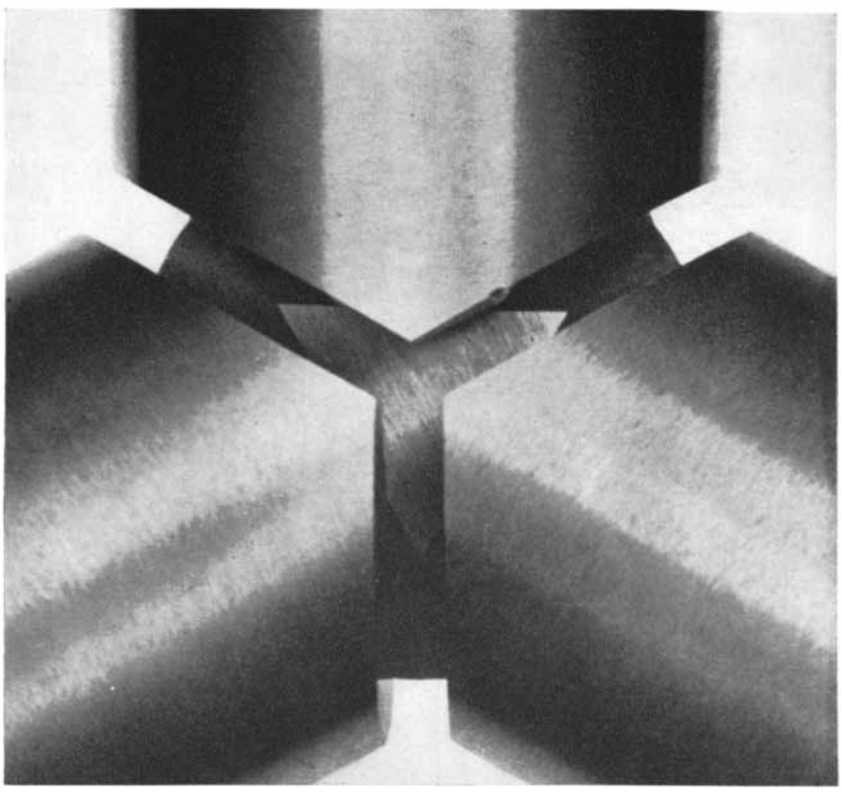
At this point experiments can throw only an indirect light on conditions in the deep interior of the earth, where pressures far exceed the capacity of laboratory equipment. As is well known, the density of matter in the earth increases abruptly from the mantle to the core. It has been generally supposed that this sharp increase represents a change in composition from olivine (an iron-magnesium silicate) in the mantle to iron in the core. Recently, however, some geophysicists have suggested that the core too is composed of olivine. The sudden jump in density is explained by assuming that the tremendous pressure at the bottom of the mantle (1.4 million atmospheres) is just enough to convert the material from its normal state, with a density of 3.3 grams per cubic centimeter, to a metallic substance with a density of 10 grams per c.c. Assuming that all the planets have the same average composition, this idea gains support from the fact that the smallest ones, Mars and Mercury, appear not to have a core. Their interior pressure is presumably not high enough to force olivine into the metallic phase.

Nor, by a long shot, is the pressure attainable in the laboratory. However, similar transitions can be observed. Tin exists in a nonmetallic gray form with a density of 5.75 grams per c.c. Pressure converts it to metallic white tin with a density of 7.28 grams per c.c. Arsenic and phosphorus are other examples of two-phase elements.

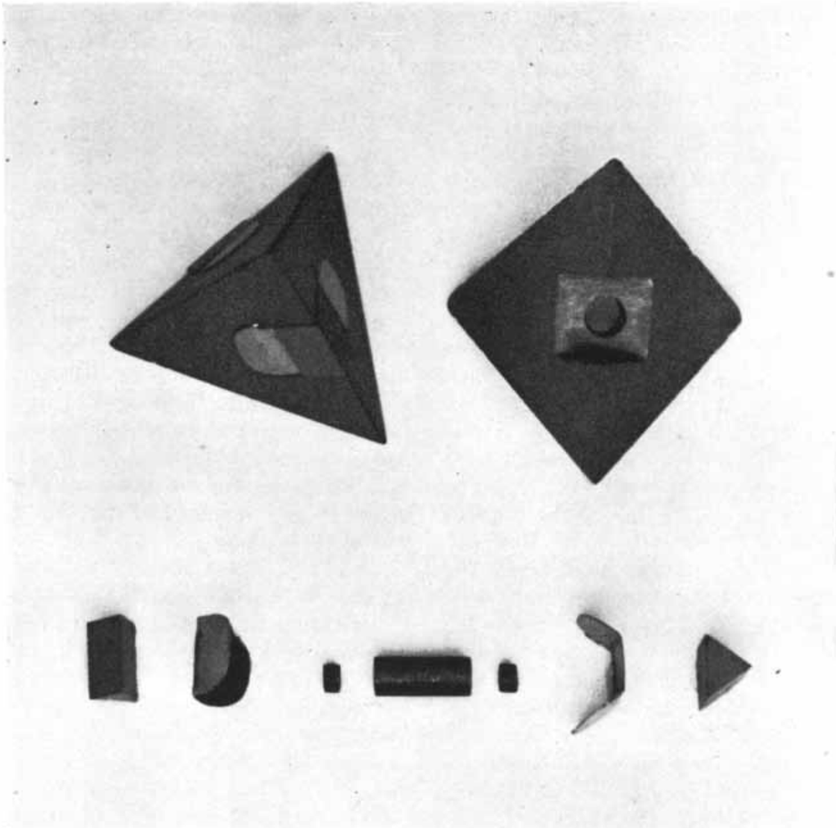
In this connection it is interesting to note that according to theoretical calculations ammonia should change to a metal at something over 200,000 atmospheres, and hydrogen at about 400,000. Such pressures do not seem very far out of reach. Soon it may be possible to create, in effect, a whole new periodic table of the elements!

Of all the naturally occurring substances to be synthesized by high pressures, diamond is undoubtedly the most glamorous [see "Synthetic Diamonds," by P. W. Bridgman; SCIENTIFIC AMERICAN, November, 1955]. Thousands of carats of man-made industrial diamonds have been produced since their synthesis was announced four years ago. Although these diamonds still cost somewhat more than natural ones, their superior performance in certain grinding processes makes them worth the difference. As far as is known no one has yet made diamonds of gem quality and size, but it will surely be done.

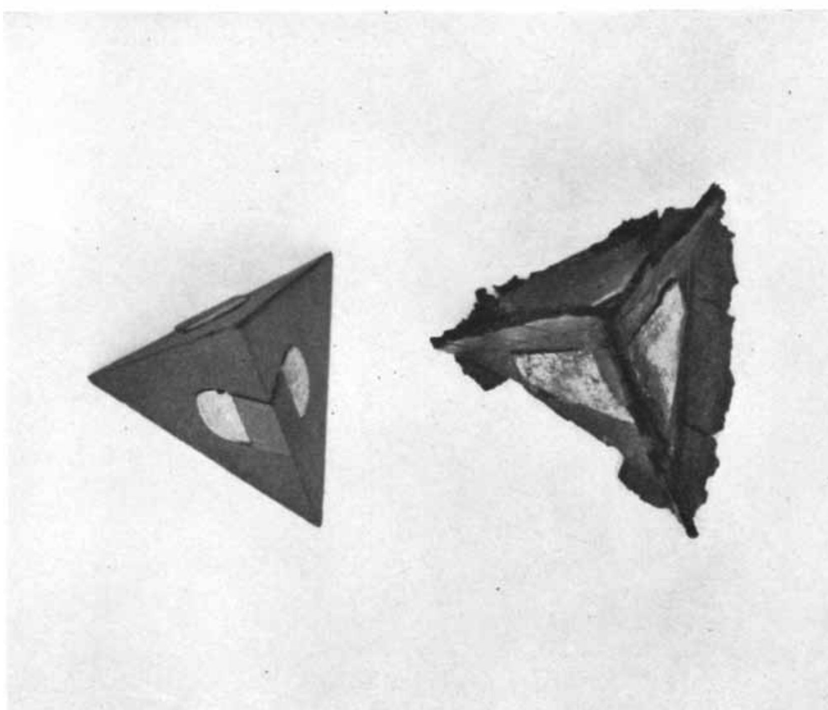
With its separate control over temperature and pressure the tetrahedral-anvil device is a more versatile creator than the earth itself. By means of a four-step operation it can make materials that are not found in nature. The steps are: (1) raise the pressure to a point where a desired transition becomes thermodynamically possible; (2) raise the temperature, increasing the reaction rate enough to make the transition pro-



ANVILS, made of cemented tungsten-carbide, taper to triangular faces about .25 square inch in area. When the four anvils are pushed together, they enclose a tetrahedral volume.



TETRAHEDRAL GASKET on which anvils exert pressure is made of a mineral called pyrophyllite. At top left is an assembled gasket. At top right a gasket is stripped to show hole in which sample is placed. At bottom, from the center out, are the tube which contains the sample, plugs to close the tube, conducting metal tabs and pieces to cover the tabs.



GASKET IS DEFORMED (*right*) by pressure of anvils. The pyramidal structure holds the sample in place, transmits pressure and serves as an electrical and thermal insulator.

ceed at a reasonable speed; (3) after the reaction is complete, lower the temperature, decreasing the reaction rate; (4) lower the pressure. The newly formed material may now be in a metastable state. According to thermodynamics it should revert to its original condition. But it has been frozen into permanence: at the lower temperature the change takes place with almost infinite slowness.

This sequence does not usually occur in nature. When a substance is heaved up toward the surface from a deep region where the temperature and pressure are high, the two variables generally decrease simultaneously. Hence a metastable material will have a chance to change back to its stable low-pressure form. Diamonds are metastable at atmospheric pressure. Rare as they are, it is almost a miracle that they are found in nature at all. Created under conditions of high pressure and high temperature deep in the earth, they should change to graphite as they are brought toward the surface.

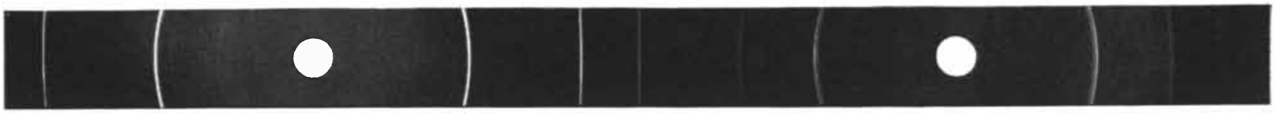
Among the most interesting laboratory creations are the new "minerals" coesite and borazon. The former is composed of silicon dioxide (SiO_2), as is quartz. Its density is three grams per c.c., as compared with 2.7 for quartz. Coesite has the remarkable property of resisting attack by hot hydrofluoric acid, which makes it an ideal material for special laboratory apparatus.

Borazon is a crystal of boron nitride (BN) in which atoms of boron and nitrogen form a cubic array. In its normal, low-pressure form the atoms of boron nitride form a hexagonal array like that of graphite; it is similar to graphite in being a slippery solid, although it is white instead of black. Borazon, the high-pressure form, is completely analogous to diamond. It is about as hard, and apparently more resistant to oxidation and heat. Very likely it will take a place alongside diamond as an industrial abrasive.

Also like diamond, borazon has enormous compressive strength, greater than that of tungsten carbide. It may eventually be used to make cylinders, pistons and anvils which will make possible higher pressures than can now be achieved. Thus high-pressure research may hoist itself by its own bootstraps, manufacturing materials that will carry it into new regions.

The melting point of solids is strikingly sensitive to pressure. Most substances expand upon melting, the liquid being less dense than the solid. As might be expected, increasing the pressure

GRAPHITE has an X-ray diffraction pattern that reveals its hexagonal crystal structure. The sharp luminous bands around the hole at left were formed by X-rays scattered in a forward direction; the faint bands surrounding hole at right, by X-rays scattered backward.



DIAMOND diffraction pattern indicates a cubic crystal. X-ray beam passed through holes in strip of film which surrounded the sample. These X-ray photographs were made by I. Fankuchen and A. Amendola of the Polytechnic Institute of Brooklyn.

raises the melting point of such solids. A higher pressure makes it harder for them to expand, so to speak; therefore they must be heated to a higher temperature in order to melt. Under a pressure of 100,000 atmospheres the melting point of some silicates increases more than 1,000 degrees! Again we have a bootstrap effect. Silicates used as gaskets in the anvil apparatus become increasingly resistant to heat as the pressure goes up, so that experiments can be carried out at higher temperatures than might have been expected.

As a matter of fact it is quite possible to work with "liquid" refractories under high pressure. A liquid can flow only if it contains holes into which molecules can move. At pressures of the order of 100,000 atmospheres the number of holes is greatly reduced, and the material becomes extremely viscous. It maintains its position and shape even though nominally liquid, continuing to serve as a useful container.

There are a few solids, among them ice, bismuth and germanium, that contract upon melting, the liquid having a higher density than the solid. In these abnormal materials pressure lowers the melting point. The melting point of ice decreases uniformly with increasing pressure, from zero degrees C. at one atmosphere to —22 degrees at 2,045 atmospheres. At this point a new ice forms which is denser than water. Hence a further rise in pressure now raises the melting point in the normal way. In fact, as pressure goes higher and higher, ice passes through several different phases, all of them normal with respect to melting point. The same thing happens with bismuth. Its melting point decreases from 271 degrees C. at one atmosphere to 186 degrees at 16,900. Between 16,900 and 120,000 atmospheres seven additional solid phases of bismuth have been discovered, all normal. Germanium's melting point, 936 degrees at one atmosphere, goes down to 360 degrees at 180,000. No new phases have been encountered.

Abnormal solids offer another way of producing high pressures. By enclosing water in a strong, inexpansible vessel and then freezing it, a pressure of 2,045 atmospheres could be attained. Using germanium it should be possible to go higher than 100,000. So far these possibilities have not been exploited in a practical way.

As in the case of melting, the transition between liquid and gas is also related to pressure. The condensation point of a gas or vapor, *i.e.*, the pressure at which it condenses to a liquid, increases with temperature. Every gas has a so-called critical point—a temperature above which no pressure can liquefy it. Do normal liquids have a similar critical point for freezing? Is there a temperature above which no amount of pressure can force the liquid to freeze? Physicists have debated the question for years. It has not yet been answered, but with the help of apparatus to produce high temperature and pressure, it may be soon.

Other intriguing questions suggest themselves. Electrical conductivity increases with pressure. At 100,000 atmospheres the increase is about 20 per cent for most metals, but in a few cases it is as much as 400 per cent. What would happen at still higher pressures? Would some metals become superconducting?

Almost anywhere that physical or chemical change occurs, high pressure has potential applications. As a final example, let us consider the field of metallurgy. Many metals are hardened by heat treatment: they are raised to a high temperature, then plunged into a bath to cool off as fast as possible. Since pressure and temperature are opposites, one wonders whether the same effect might not be obtained in another way: Instead of rapidly lowering the temperature, suddenly raise the pressure. It works. A quick application of high pressure does harden steel and other metals. Furthermore, the hardening extends throughout the mass of the material. In cooling, a hot metal unavoidably loses heat faster from the surface than from the inside. This produces a hardened skin and a softer interior. Pressure, on the other hand, is spread throughout the material almost instantaneously and all parts are equally affected.

When a molten metal solidifies, the process also takes place from the outside in. Again application of high pressure could make all parts solidify simultaneously, giving a product with different properties.

It is common knowledge that metals are not nearly so strong as they might be. Imperfections in the crystal lattices (missing or misplaced atoms and faulty arrangements, or "dislocations") make actual crystals much weaker than perfect ones would be. Furthermore, practically every sizeable piece of metal is an agglomeration of small crystals that does not have nearly the strength of a single large one. All lattice imperfections, and the grain boundaries between small crystals, take up space. The metal occupies a larger volume than if its atoms were all in place in an ideal lattice. High pressure could literally squeeze out imperfections, forcing the metal to become more nearly a perfect single crystal and thus making it stronger.

A new era in high-pressure work, both in the laboratory and on the production line, is clearly on the way. The race to skim the cream is beginning. It should be a fascinating and rewarding sweepstakes.

The Growth of Nerve Circuits

Recent studies of the process of nerve repair have led to a new theory of how the complex networks and pathways of the central nervous system are formed in the embryo

by R. W. Sperry

Severe damage to the principal motor nerve of the face may leave a person afflicted with a condition known as "crocodile tears." As the injured nerve regenerates, fibers that originally activated a salivary gland can go astray and connect themselves to the lachrymal gland of one eye. Thereafter every situation calling for salivation induces weeping from that eye. Often the regenerating salivary fibers invade sweat glands and related organs in the skin, causing profuse sweating and flushing in areas of the face and temple. The random shuffling of motor-nerve connections to the muscles of the face characteristically deranges facial expression, causing a grimace-like contraction of the affected side. Sometimes, to prevent atrophy of the facial muscles when the injured facial nerve fails to regenerate, surgeons will connect the denervated facial muscles to a nearby healthy nerve: the motor nerve of the tongue or the motor nerve of the shoulder muscle. The restored facial movements still lack meaningful expression and tend to be associated with the chewing movements of the tongue or the action of the shoulder muscles.

Naturally the primary concern of the patient in such cases is whether or not normal function can be restored. If the symptoms do not clear up spontaneously, can they be corrected by training and re-education? By faithful practice in front of a mirror, for example, can a patient learn to inhibit the crocodile tears and regain control of facial expression?

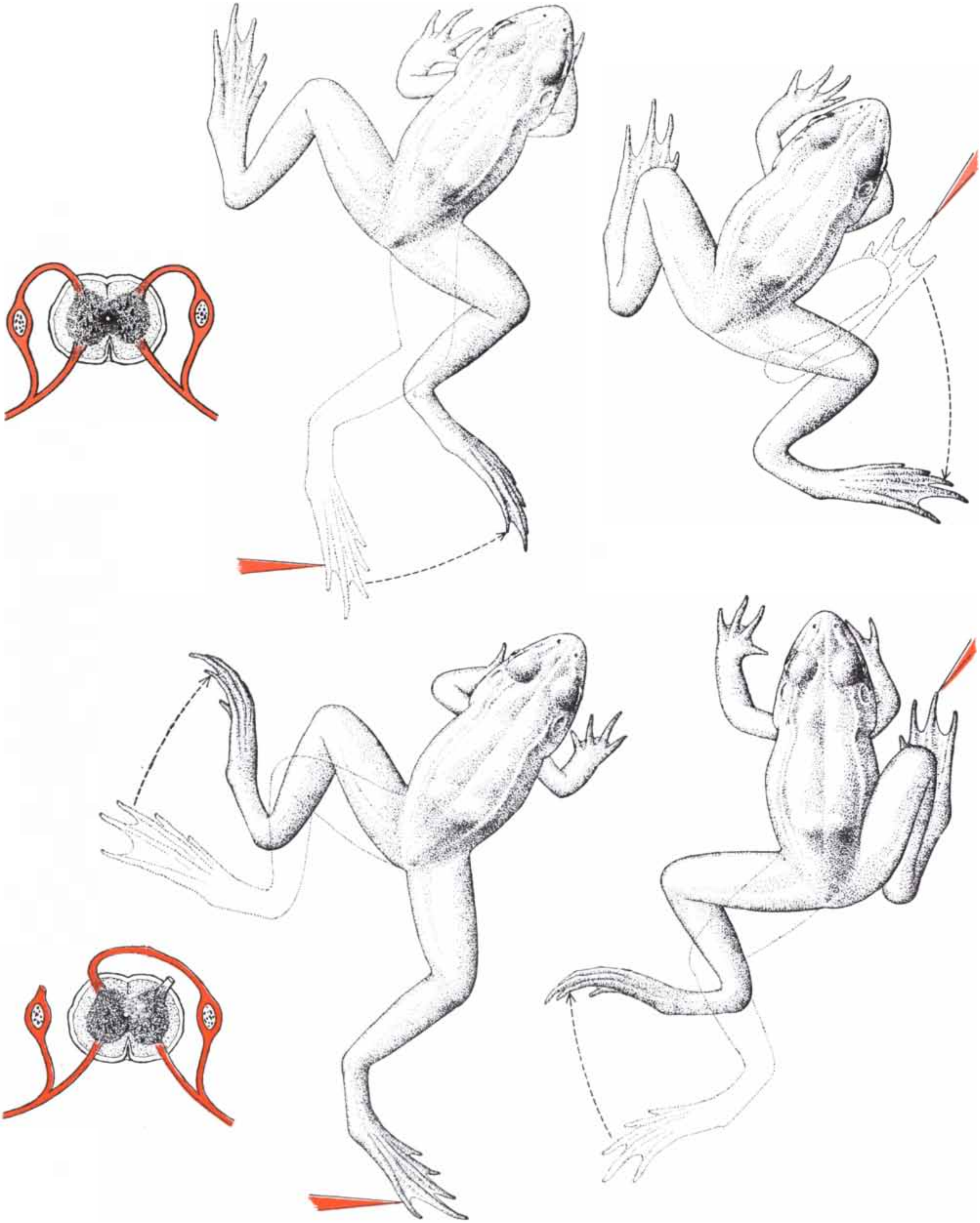
Not so long ago the reply to such questions was a confident "Yes." For most of the present century investigators and physicians were agreed that the central nervous system is plastic enough so that any muscle nerve might be reconnected to any other muscle with good functional success. Sensory-nerve fibers were thought to be equally interchangeable within a given sensory system. It was believed that the central pathways in the nervous system were first laid down in the embryo in randomized equipotential networks. By use and learning these pathways became channelized; connections that proved adaptive in function were reinforced, while the nonadaptive ones underwent "disuse atrophy." Learning thus determined not only the function but also the structure of the nervous system. This theoretical picture was sustained by experiments on animals in which, according to the literature, the crossing of major nerve-trunks was followed by full restoration of function. In the prevailing mood of optimism physicians were able to report encouraging progress by their patients.

During the past 15 years, however, scientific and medical opinion has undergone a major shift, amounting to an almost complete about-face. No longer do physicians encourage the patient with a regenerated facial nerve to try to regain control of facial expression by training; their advice today is to inhibit all expression, to practice a "poker face" in order to make the two sides of the face match in appearance. The outlook is equally dim for restoration of coordination in cases of severe nerve injury in other parts of the body.

This changed viewpoint reflects a revision in the picture of the entire nervous system. According to the new picture, the connections necessary for normal coordination arise in embryonic development according to a biochemically determined plan that precisely connects the various nerve endings in the body to their corresponding points in the nerve centers of the brain and spinal cord. Although the higher centers in the brain are capable of extensive learning, the lower centers in the brain stem and spinal cord are quite implastic. Because their function is dictated by their structure, it cannot be significantly modified by use or learning. Nor can the disordered connections set up by the random regeneration of injured nerves be corrected by re-education.

The evidence for this view, which comes from new experiments and from exacting clinical observations, is so persuasive that it is difficult to understand how the opposite view could have prevailed so long. It appears that most of the earlier reports of the high functional plasticity of the nervous system will go down in the record as unfortunate examples of how an erroneous medical or scientific opinion, once implanted, can snowball until it biases experimental observations and crushes dissenting interpretations.

Hundreds of experiments seemed to support the now-discounted opinion. One of the experiments most frequently cited was first reported in 1912 and was repeated with concurring interpretation as recently as 1941. In several monkeys opposing pairs of eye muscles were interchanged to reverse the movement of one eye. Upon recovery from surgery, the movements of the abnormally connected eye were said to coordinate with those of the normal one. In another oft-repeated experiment the nerves that control the lifting of the foot were crossed. Instead of a reversal of foot action, the animals showed recovery of muscle coordination hardly distinguishable from that on the normal side. Even when nerves from the forelimb were cross-connected to nerves of the hindlimb, the animals appeared to make complete



CROSSED SENSORY NERVES produce incorrect postural reflexes in the frog. The normal connections shown in the cross section of the spinal cord at top left cause the frog to withdraw an extended leg (*top center*) and to extend a flexed leg (*top right*) when a stimulus (*colored pointer*) is applied. If the sensory root entering the right side of the spinal cord is cut and surgically attached to the left side, as shown in the cross section at bottom left, the reactions of the left leg will be determined by the posture of the right.

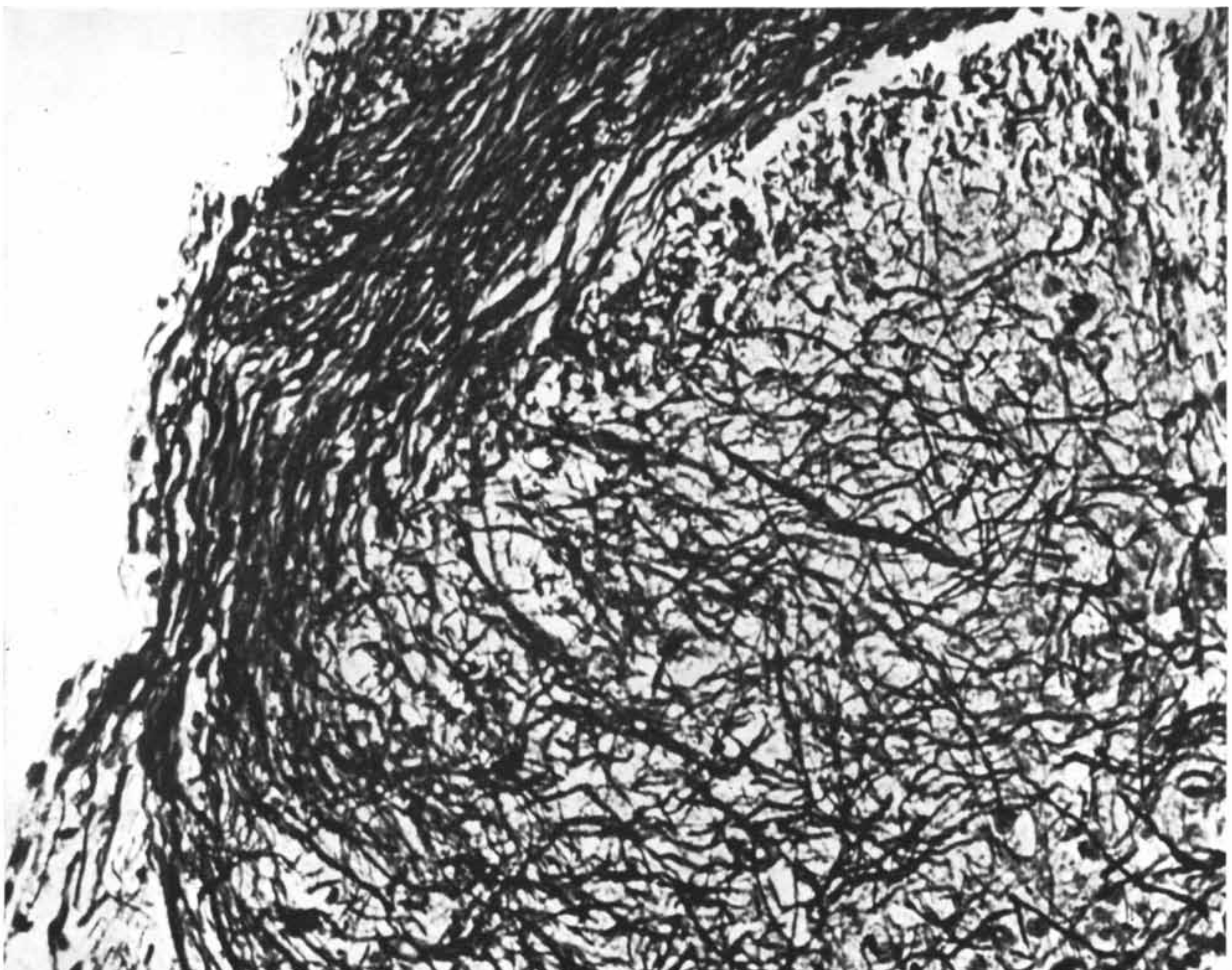
functional readjustment. With such results in the literature there seemed to be few limits to the restorative possibilities of peripheral nerve surgery.

The doctrine of the functional plasticity of the nervous system was sharply challenged in 1938 by Frank R. Ford and Barnes Woodhall of the Johns Hopkins School of Medicine. In an account of their clinical experience with functional disorders following the regeneration of nerves, they declared that these disorders persisted stubbornly in many of their patients for years without improvement. Their report cast serious doubt upon the accepted methods of therapy and the theory that rationalized them.

That same year I began a series of experiments in the laboratory of Paul Weiss at the University of Chicago. The initial aim of this investigation was to find out if functional plasticity was a property of the higher brain-centers only or whether it extended to the lowest levels of the spinal cord as alleged in some earlier reports. To explore the question I started to experiment on the simple reflexes involved in coordinating the foot movements of the rat. These reflexes depend upon a relatively simple circuit called a reflex arc. The fibers that activate the muscle connect to an association neuron in the spinal-reflex center; the association neuron is connected in turn to a particular type of sensory cell, the proprioceptive neuron, the terminal fibers of which are embedded in the muscle. This circuit, with the sensory nerve indicating the state of contraction or relaxation of the muscle and its orientation in space, provides the feedback necessary for proper muscle timing and coordination.

I switched the nerve connections between opposing muscles in the hindlimb of rats in such a way as to reverse the movement at the ankle joint. The nerves were cut, crossed and reunited end-to-end within tubes of dissected rat artery. Now whenever a nerve is severed, all fibers beyond the break degenerate and are absorbed. Even when they are united with the mechanical aid of an arterial tube, cut nerves do not heal together directly. New fibers sprout from the end of the central stump and grow into the muscles within the degenerate framework of the old nerve. After the surgery, I assumed, new coordinating circuits would be established and functional adjustment would follow quickly.

Much to my surprise the anticipated adjustment never occurred. The rats seemed unable to correct the reversals of motor coordination produced by the operation. When they tried to lift the



POST-MORTEM VIEW of the frog's crossed sensory root (magnified 500 diameters) shows that the cut nerve-fibers have regenerated into the spinal cord. Despite their tangled appearance, the fibers have formed the connections necessary for proper muscle timing and coordination. Because the nerves have been transposed, however, frogs display abnormal reflexes shown on preceding page.

affected foot, it pulled downward; when they tried to rise on the ball of the foot, their toes swung up and they fell back on their heels [*see illustration on next page*].

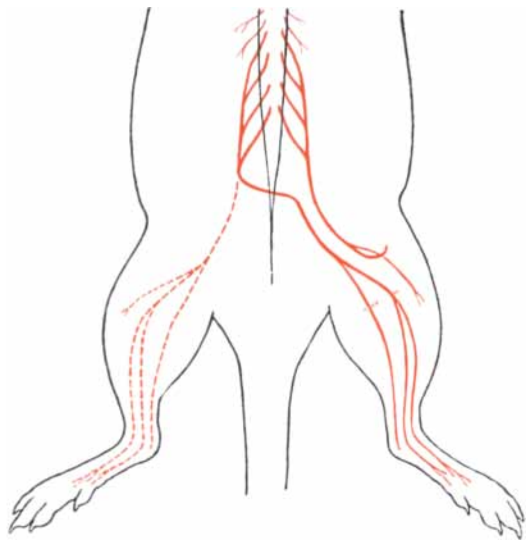
In a parallel experiment I presented the rats with a simpler readjustment problem by switching muscles instead of nerves. The muscles involved were transposed by cutting and crossing their tendons. Strong muscle-action was restored within two or three weeks. Yet the rats were still unable to correct the reversal of ankle movement. To check the experiment I tried crossing both muscles and nerves in a control group. Here the two reversals mutually canceled their effects, and the rat was able to raise and lower the foot in proper timing.

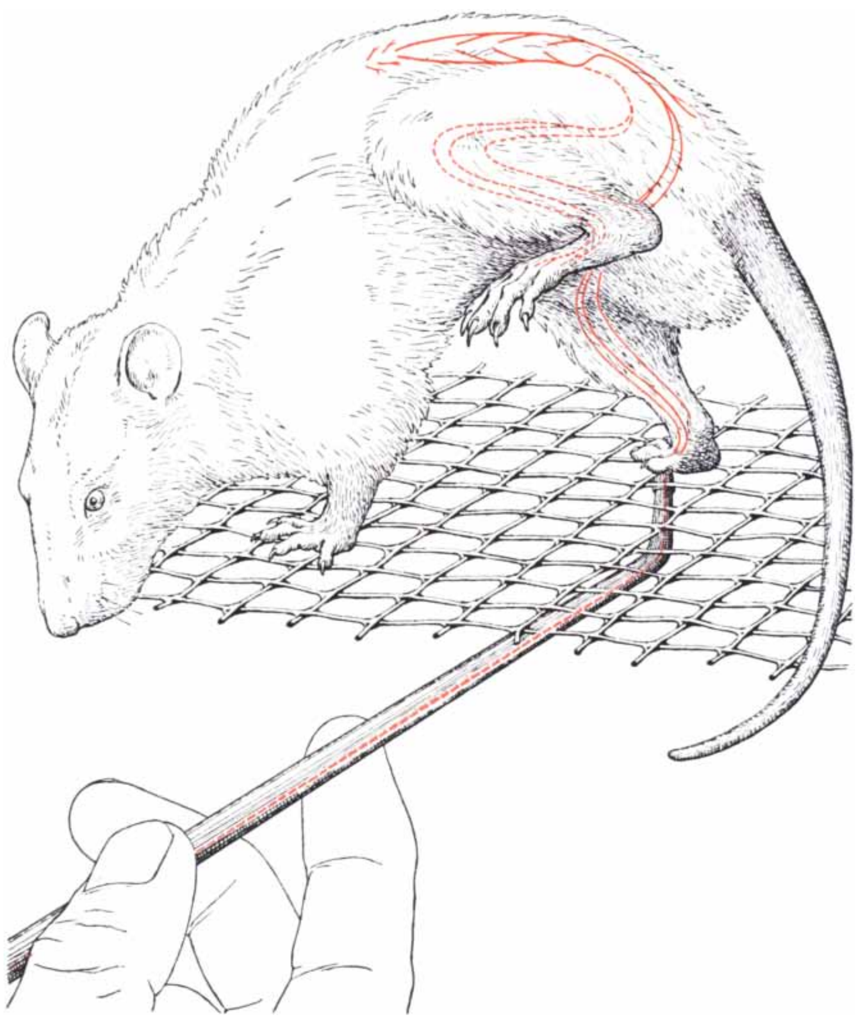
The rats with reversed foot-movements were put on a program of special training: they were forced to climb ladders and stretch upward on their hindlegs many times a day to get food pellets from automatic feeders. Yet the affected feet continued to work backward in machine-like fashion. We carried out a similar series of experiments on the forelimb, in which voluntary movements are under better control. But the rats still could not adapt to the rearrangement of the nerve connections.

When it became clear that re-education had little or no effect in the rat's motor system, we turned to the sensory system. In the laboratory of Karl S. Lashley at Harvard University I transposed the nerves connecting to the skin of the left and right hindfeet [*see illustration at right*]. As the crossed hindlimb nerves regenerated, the rats began to exhibit false reference of sensations. In response to a mild electric shock to the sole of the right foot, the animals withdrew their left foot. This movement shifted their weight to the right foot, thereby increasing its contact with the offending electrode.

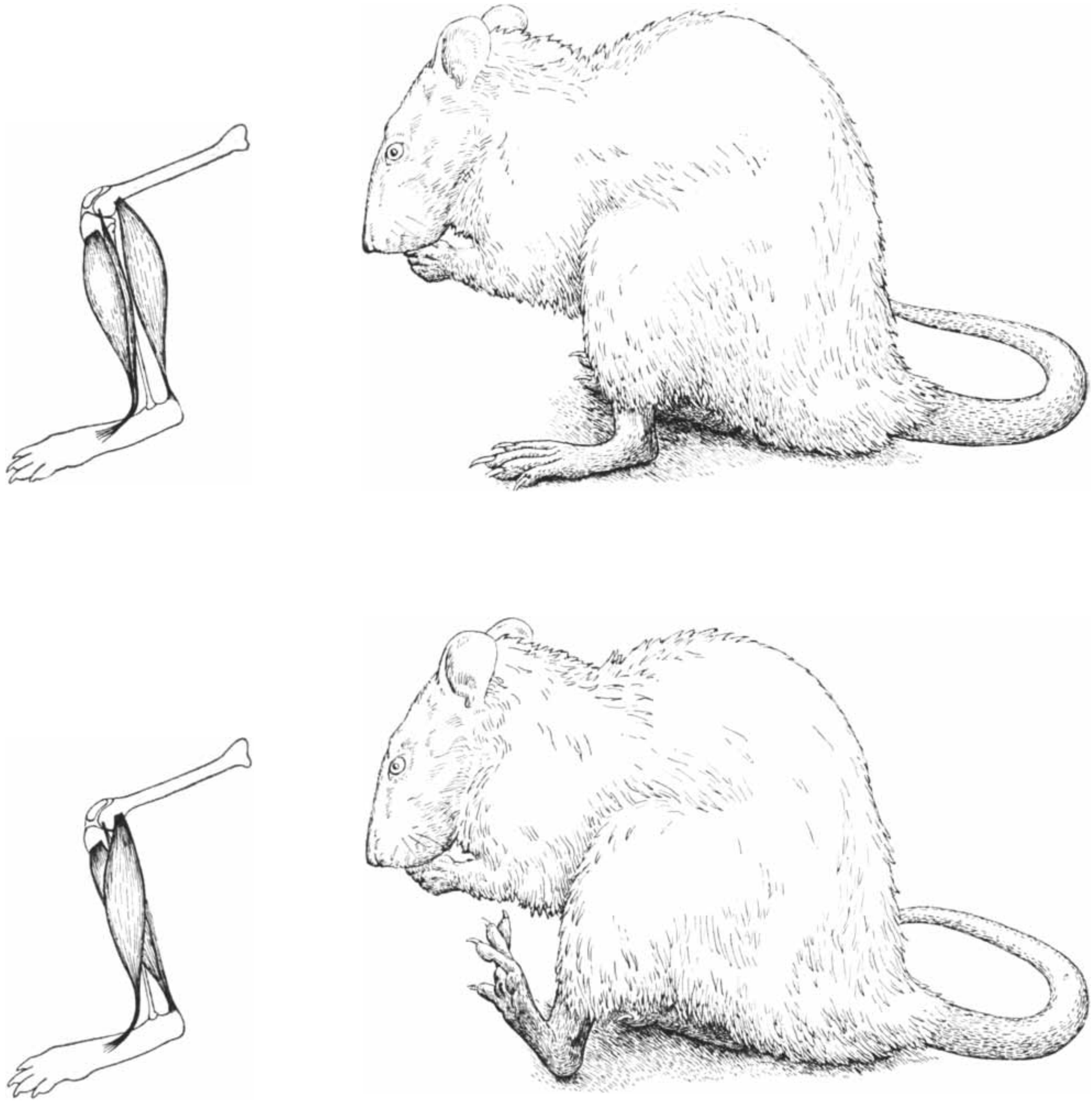
During the course of these experiments several rats developed a persistent sore on the sole of the right foot. Until the sores responded to medication, the animals hopped about on three feet with the fourth raised protectively—but it was always the wrong, uninjured foot that they raised. When they were prompted to lick the injury, they repeatedly licked the uninjured foot. Although this accidental soreness in the re-innervated foot presented the best kind of training situation, the rats still were unable to readapt.

Having concluded that it would be





INCORRECT WITHDRAWAL REFLEX and referred sensations appear in the rat after two sensory nerves are crossed. Here the main trunk-nerve to the left foot (*broken line*) has been crossed and connected to the corresponding nerve on the right side (*colored solid line*). Afterward, when sole of right foot is stimulated electrically, rat withdraws its left foot; if the shock is strong enough to produce soreness, rat licks its uninjured foot.



CROSSED MUSCLES produce the same effects as crossed nerves. In a normal rat (*top right*) the leg muscles are connected as shown at top left. When these connections are transposed (*bottom left*), the posture and movements of the ankle joint are reversed (*bottom right*). When the rat attempts to lift the affected foot, it pulls downward; when the animal tries to rise on the ball of the foot, the toes swing up and it falls back on its heels. Even with prolonged training, the rat can never learn to correct these movements.

difficult or impossible to demonstrate any sort of plasticity in the rat, we began a similar experiment on monkeys at the Yerkes Laboratories of Primate Biology in Orange Park, Fla. At first the monkeys seemed to make more progress than the rats: After we had transposed the nerves of the biceps and triceps muscles of the upper arm, they were quick to notice and to halt the reversed arm-movements that began to appear as the nerves regenerated. Thereafter the monkeys did attain a minor degree of readjustment in arm movement under the most simplified training routine. But after three years of testing and observation, they too failed to achieve any generalized positive correction in the action of the cross-innervated muscles.

The marked conflict between our results and those previously reported prompted us to reproduce the procedures of the earlier studies more closely. Instead of crossing isolated branch-nerves to single muscles I now crossed large trunk-nerves carrying motor impulses to many different muscles. All the muscles in the region were left intact and the nerves were permitted to regenerate into their respective areas at random.

In the hindlimb of the rat this operation produced neither a reversal of movement nor good functional readjustment; instead it caused a spastic contraction of all the muscles of the lower leg. Because of the greater strength of the postural or antigravity muscles, the contraction produced a stiltlike stiffening of the ankle joint in the extended position. This result was highly illuminating. Although the extended leg-posture was clearly abnormal in the rat, it could very easily be mistaken for a return of normal coordination in an animal that walks on its toes, like a dog or a cat. The fact that dogs and cats had been used in most of the earlier investigations made it apparent that nearly all of the hundreds of earlier reports of good functional recovery were subject to reinterpretation.

We know that central nervous system plasticity can be substantiated to some extent in cases where muscles have been transplanted in human patients. But even here we must make a distinction between the degree of plasticity demonstrated after muscle transposition and that shown after nerve regeneration. When a muscle is transplanted with its nerves intact, the motor cells that activate it continue to work together as a unit. On the other hand, in human beings and higher animals the fibers of a regenerating motor-nerve become haphazardly redistributed among the muscles it previously supplied. To restore these muscles to their previous control and coordination the reflex connections in the spinal cord would have to be re-established down to the level of individual nerve cells. Even man's superb nervous system does not possess this degree of plasticity.

In most cases humans can learn to control transplanted muscles only in simple, slow, voluntary movements. The control of complex, rapid and reflex movements is limited at best, and is subject to relapse under conditions of fatigue, shock or surprise. Humans seem to have a much greater capacity for adjustment than the subhuman primates. Such re-education as does occur must therefore be due to the greater development of higher learning-centers in the human brain. Contrary to earlier supposition it does not reflect an intrinsic plasticity of nerve networks in general.

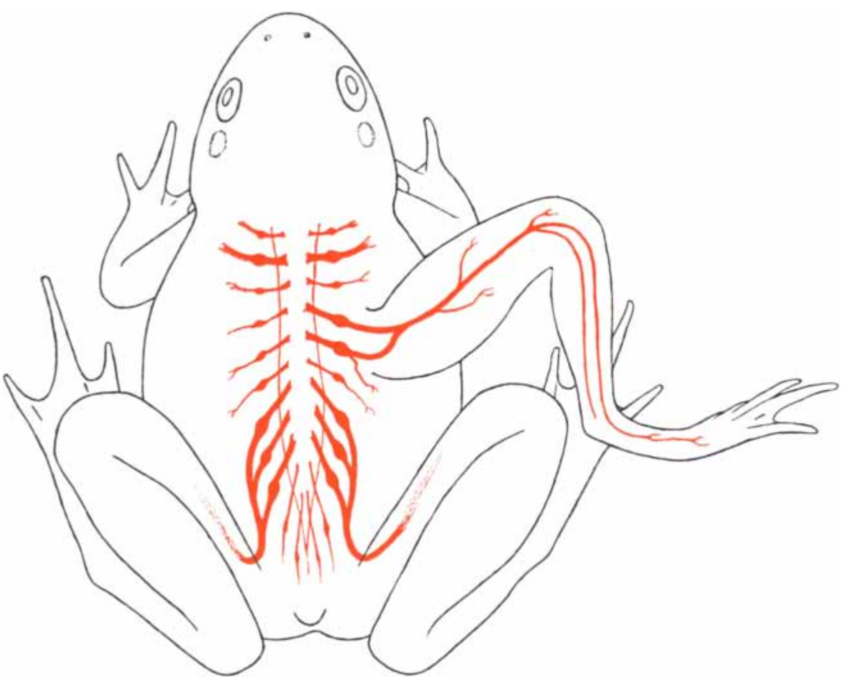
The nervous systems of reptiles, birds, and mammals other than primates show even less functional plasticity than those of primates. Farther down the evolutionary scale in the lower vertebrates, however, we find an entirely different type of neural plasticity: a structural plasticity not possessed by higher animals. Fishes, frogs and salamanders can regenerate any part of the central nervous system—even the tissue of the brain itself. Furthermore, if one of the large motor nerves of a salamander or a fish is cut, the animals re-establish normal reflex-arcs and recover coordination. This occurs even if several nerve stumps in a limb or fin are deliberately cross-connected to produce gross abnormalities in the distribution of the regenerating fibers.

In his pioneering investigations during the 1920's Paul Weiss was able to rule out the possibility that these spectacular recoveries could be based on learning or any other sort of functional plasticity. He transposed the developing forelimb buds of salamander embryos and reimplanted them with their front-to-back axes reversed. When function later appeared, the motor coordination in the transplanted limbs was perfectly normal, indicating that normal reflex-arcs had been established. Because the forelimbs were reversed in orientation, however, they pushed the animal backward when it tried to go forward, and vice versa. The perfectly coordinated reversed action persisted indefinitely without correction.

I was able to confirm the absence of any appreciable functional plasticity in amphibians in a set of experiments on the visual system of frogs and salamanders. In some I inverted the eyeballs surgically, producing upside-down vision; in others I cross-connected the eyes to the wrong sides of the brain, producing vision that was reversed from side to side. The animals never learned to correct the erroneous responses caused by this surgical rearrangement of their eyes [see "The Eye and the Brain," by R. W. Sperry; SCIENTIFIC AMERICAN, May, 1956]. Even when the eyes of frog and salamander embryos were rotated prior to the onset of vision (in later experiments by L. S. Stone at Yale University and George Szekely in Hungary), the same visual disorientation developed and persisted throughout life.

The evidence at present thus indicates that the structural plasticity observed in lower vertebrates is inherent in the growth process and is quite independent of function. It is as if the forces of embryonic development that laid down the circuits in the beginning continue to operate in regeneration. We have as yet only preliminary insight into the nature of these forces.

In studies now in progress at the California Institute of Technology Harbans Arora has made an interesting observation on the regeneration of the nerve controlling the eye muscle in fishes. His findings suggest that fibers directed by chance to their own muscles make connections more readily than foreign fibers reaching the same muscle. As a result the fibers that originally con-



ABNORMAL REFLEX ARCS develop when a hindlimb bud is grafted onto the back of a tadpole. As the tadpole grows, sensory nerves destined for the skin of the back, flank and belly invade the nerveless extra limb and form spinal connections appropriate for limb reflexes. When grafted limb is stimulated in adult frog, muscles of the right hindlimb respond.

trolled the muscle tend to recapture control in regeneration. Such selective reaffiliation of nerve and muscle indicates that some chemical specificity must match one to the other.

Selective outgrowth of regenerating nerves to their proper end-organs seems not to be the rule, however, even in lower forms. Among mammals it has not been found at all, except on the much more gross scale that differentiates sensory from motor endings, smooth muscle from striated muscle, muscle from gland, and so on. Nor does simple selective outgrowth account for the restoration of function in salamanders. The early studies by Weiss showed that fiber outgrowth and muscle re-innervation generally proceed in these animals in a random, nonselective manner, comparable to that in mammals. Upon re-innervation, however, salamander muscles regain their former coordination and timing, even when their function is disoriented by nerve-crossing.

These observations suggest that the rearrangement of connections in the periphery of the salamander nervous system has chemical repercussions that result in a compensatory shift of reflex relations at the centers. It is postulated that the motor-nerve cells regenerating into new muscles take on a new chemical flavor, as it were. Thereupon their old central associations dissolve, and new ones form to match the new terminals in the periphery. The reflex circuit would thus be restored to its original state, with the peripheral and central terminals linked by a new pathway. Higher animals, lacking this embryonic type of structural plasticity, show no restoration of function.

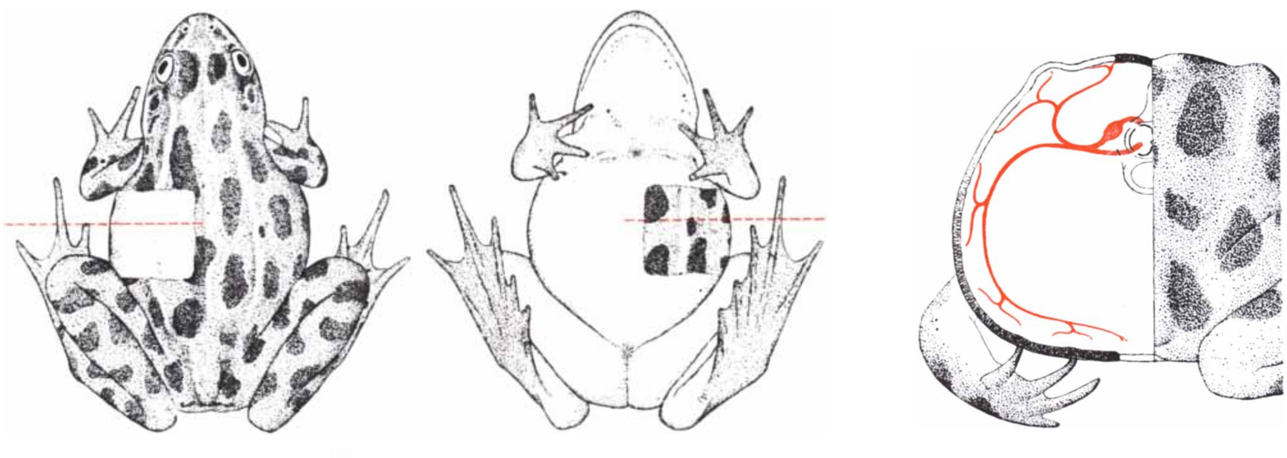
This explanation at first seemed rather far-fetched, especially from the standpoint of electrophysiology, which offers no evidence for such qualitative specificity among nerve fibers. However, the underlying idea is well supported by recent experiments on the regeneration of sensory nerves.

At the University of Chicago Nancy M. Miner, one of my former associates, is responsible for a significant series of experiments indicating the role of some sort of chemical specificity in the hookup of the nervous system. She grafted extra hindlimb buds onto the backs of tadpoles; the buds became connected to the sensory fibers that would normally innervate the skin of the belly, flank and back [*see illustration on preceding page*]. The grafted leg served only as a sensory field for the nearby sensory nerves because there are no nearby limb nerves to invade it. When a stimulus was applied to the grafted limb in the mature frog, the animal moved the normal hindlimb on the same side, just as it would if the normal limb had received the stimulus. The belly and trunk nerves connected to the grafted limb had evidently taken on a hindlimb "flavor" and then formed the appropriate reflex connections in the central nervous system. In another experiment Miner removed a strip of skin from the trunk of a tadpole, cut its nerves and replaced it so that the skin of the back now covered the belly, and vice versa [*see illustration below*]. When the grown frogs were stimulated in the grafted area of the back, they responded by wiping at the belly with the forelimb; when they were stimulated in the grafted area on the belly, they wiped at the back with the hindlimb.

To account for these experimental findings it is necessary to conclude that the sensory fibers that made connections to the grafted tissues must have been modified by the character of these tissues. It is therefore unnecessary to postulate that each nerve fiber in embryonic development makes some predestined contact with a particular terminal point in the skin. Growing freely into the nearest area not yet innervated, the fibers establish their peripheral terminals at random. Thereafter they must proceed to form central hookups appropriate for the particular kind of skin to which they have become attached. It seems clearly to be some quality in the skin at the outer end of the circuit that determines the pattern of the reflex connections established at the center.

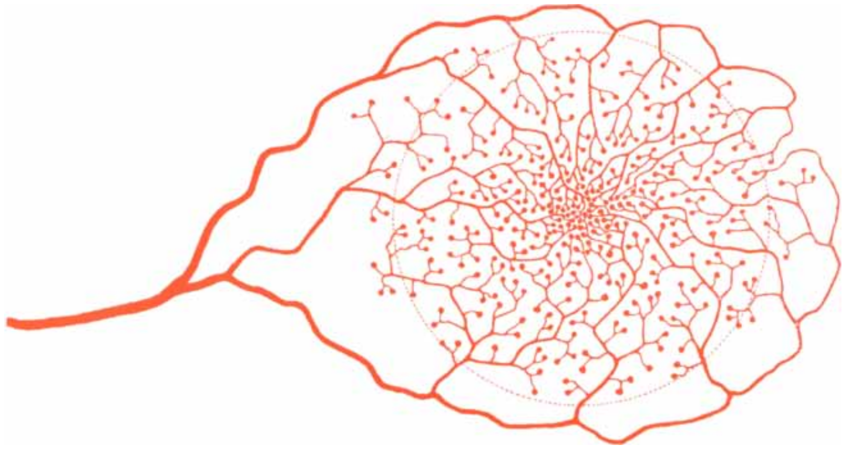
No attraction from a distance need be invoked in this selective patterning of the central hookup. The multiple branches of each nerve fiber undergo extensive ramification among the central nerve cells, with the tips of the branches making numerous contacts with all the cells in the vicinity. Presumably most of the contacts do not affect the growing fiber-tips. It is only when contact is made with central nerve cells which have the appropriate chemical specificity that the growing fiber adheres and forms the specialized synaptic ending capable of transmitting the nerve impulse.

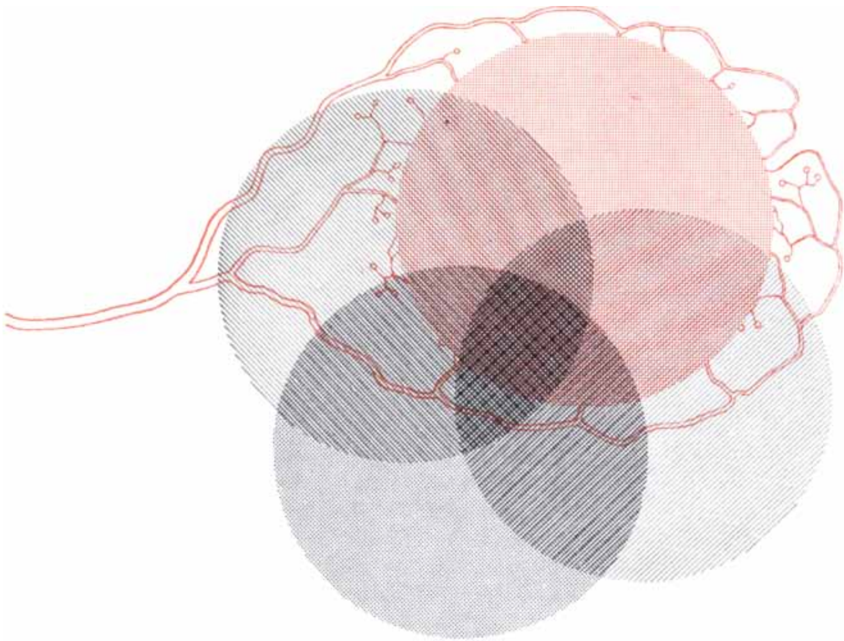
In man these observations and interpretations provide the basis for the new



ROTATED PATCH OF SKIN demonstrates how embryonic nerves respond to the biochemical "flavor" of the tissues they innervate. Here a strip of skin was removed from a tadpole, cut free of all connections, and replaced so that the skin of the back now covered the belly and vice versa. In the grown frog the skin retained its original color and flavor despite its location, as shown in the dorsal and ventral views (*left and center, respectively*). The cutaway view at right (*made along broken lines*) shows how new nerves have invaded the graft and formed spinal reflex-arcs appropriate to the skin's flavor rather than to its location. Thus when the belly skin on the back is stimulated, the frog wipes at its belly; when the back graft on the belly is stimulated, the frog wipes at its back.

view of the nervous system which holds that its networks are determined by biochemical processes in the course of embryonic growth. Let us consider this scheme in connection with the extreme localization of skin sensations that makes it possible to locate a pinprick, for example, anywhere on the body surface. This "local sign" quality depends upon the precise matching between the central and peripheral connection of each one of thousands upon thousands of cutaneous nerve fibers connecting the skin surfaces to the spinal cord and brain. During embryonic growth we may assume that the skin undergoes a highly refined differentiation until each spot on the skin acquires a unique chemical make-up. A mosaic is not envisaged here but rather smooth gradients of differentiation extending from front to back and from top to bottom, with local elaborations of these basic gradients in the regions of the limbs. Each skin locus becomes distinguished by a given latitude and longitude, so to speak, expressed in the tissues as a combination of biochemical properties. The cutaneous nerves, as they grow out from their central ganglia, may terminate largely at random in their respective local areas. Through intimate terminal contacts the specific local flavor is imparted to each nerve fiber. This specificity is then transmitted along the fiber to all parts of the nerve cell including its ramification within the central nervous system. In this way the local-sign properties of the skin become stamped secondarily upon the cutaneous nerves and are carried into the sensory centers of the brain and spinal cord. Precise localization is further enhanced by the overlapping of the terminal connections formed by the fibers in the skin [*see illustration at right*].





OVERLAP OF SENSORY FIBERS permits a subject to localize a pinprick accurately. The schematic diagram at top shows the terminal branches of a single cutaneous fiber; the branches are most abundant at the center of the area they innervate (*broken circle*). Bottom diagram shows how this area overlaps those of three other fibers. As shading indicates, each of the areas transmits a recognizably different signal to the central nervous system.

Implicit in this theory is the assumption that in the embryo the cerebral cortex and the lower relay-centers also undergo a differentiation that parallels in miniature that of the body surface. In other words, just as from the skin to the first central connection point in the spinal cord, so from relay to relay and finally to the cortex the central linkages arise on the basis of selective chemical affinities. At each of its ascending levels the nervous system forms a maplike projection of the body surface.

This mechanism presumably operates not only in the sensory system but in the nervous system in general. Since the organization of the lower nerve centers and the peripheral nerve circuits in higher animals seems to take place only in the early plastic stages of growth, it is clear that injury to them later on cannot be repaired by any amount of re-education and training. In the structural plasticity of the system in lower animals, however, we are able to observe the processes by which our own nervous systems develop.

The new approach provides a sound biological basis for the explanation of built-in behavior mechanisms generally, from the simplest reflexes to the most complicated patterns of inherited behavior. It brings the study of behavior into the realm of experimental embryology on the same basis as other organs and organ systems. Although learning must now yield its former monopolistic status, we must not infer that it has no role in brain development. Particularly in man, whose brain grows and matures for many years, learning is a powerful method of imposing additional organization on the higher levels of the nervous system. Until the neural basis of learning is discovered, however, we cannot say whether it produces this added organization by changing the actual layout and hookups of cerebral networks or simply by increasing the conductance of certain pre-established pathways.

POISONS

What is the molecular mechanism by which a toxic substance produces its effect? In seeking the answer for various poisons, investigators have found invaluable tools for the study of normal cell physiology

by Elijah Adams

"Poisons can be employed as agents of life's destruction or as means for relief of disease, but in addition to these universally recognized uses there is a third that particularly interests the physiologist. For him the poison becomes an instrument that dissociates and analyzes the most delicate phenomena of the living machine, and by studying attentively the mechanism of death in diverse types of poisoning he can learn indirectly much about the physiological processes of life."

After almost a century these words of the eminent French physiologist Claude Bernard still summarize concisely the scientific significance of poisons. Curare, the specific agent that he was discussing, remains one of the best examples of the tripartite nature of this loose category of substances. When curare first came to Bernard's attention, Europeans knew it only as an arrow poison used by Indians in South America to kill game and enemies. Bernard himself first applied it as a physiological scalpel in his pioneering studies of nerve and muscle function. More recently curare has become a "means for the relief of disease": as an adjunct to surgery it relaxes the muscles and thereby obviates dangerously deep levels of anesthesia.

A poison is difficult to define with legalistic rigor. Even distilled water is toxic when it is consumed by the gallon, and considerably smaller quantities of water can cause death when they are inhaled. The accepted pharmacological definition follows popular usage: A poison is any substance that in relatively small quantities can cause death or illness in living organisms by chemical action. The last clause rules out such mechanically lethal effects as those produced by a small quantity of lead entering the body at high velocity.

The list of poisons furnished ready-made by nature has been extended mightily in recent years by human ingenuity and the chemical industry. No reasonable definition of poisons can exclude the thousands of substances which in small doses produce physiological changes but which, being used customarily for the treatment of disease, are identified as drugs. Another deceptive category is that of the pesticides, especially those designed to kill our close physiological relatives the rodents. It is not surprising that poisons represent a major public hazard, particularly to children. In 1955 about 8,000 Americans died of poisons (exclusive of ethyl alcohol). The fatalities were about equally divided between accidents and suicides; homicides accounted for only .5 per cent of the total. Non-fatal poisonings are estimated at a million or more per year, about 25 per cent of them in children under five.

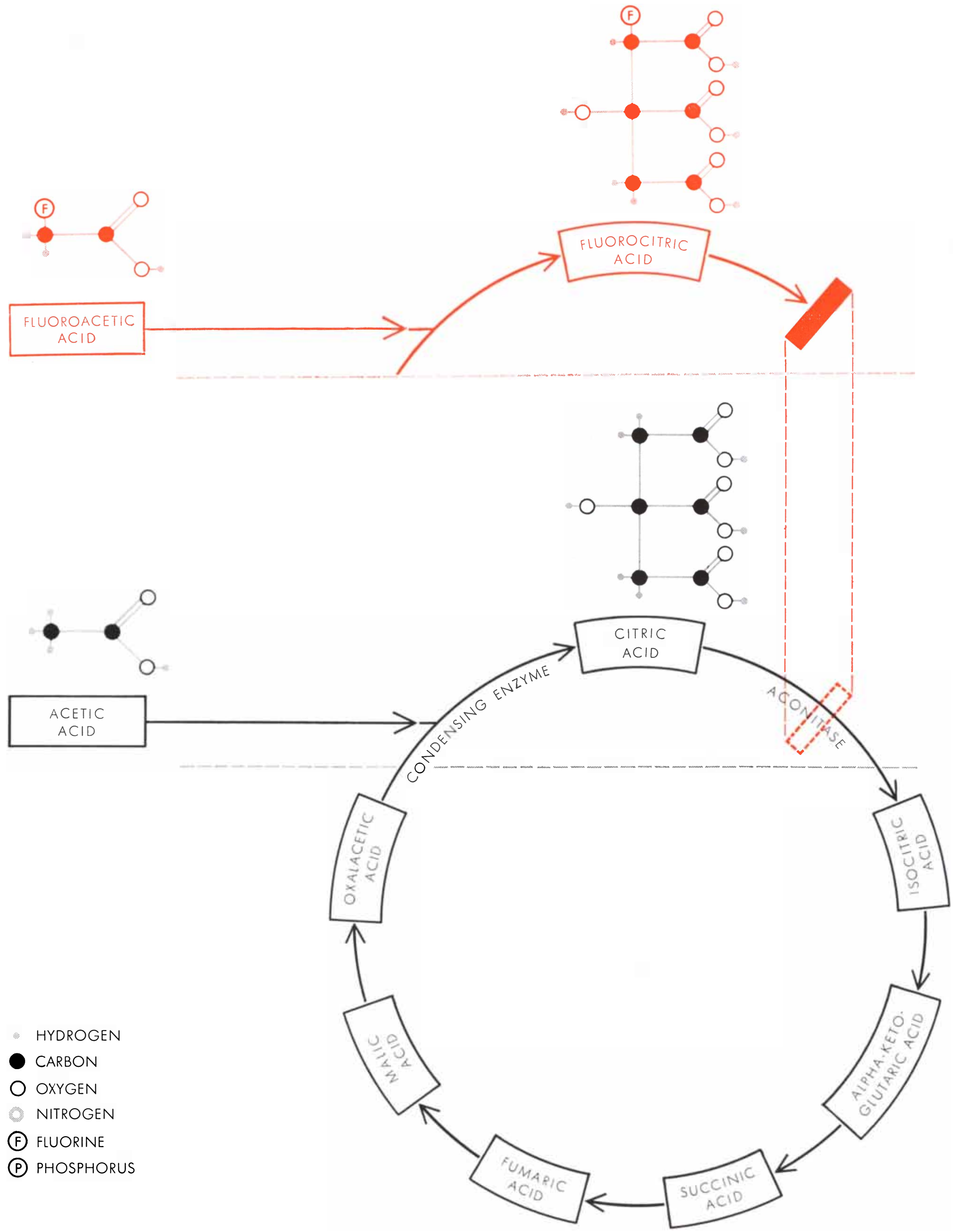
The term "poison" (akin to "potion") originally included medicinal as well as lethal draughts. For example, digitoxin—the medication of choice in certain cardiac conditions—is among the most toxic substances known; its use as an industrial chemical would necessitate elaborate safety precautions. Courses in pharmacology properly emphasize the broad overlap between drugs and poisons, and physicians, nurses and pharmacists dare not forget it.

To the physiologist, on the other hand, poisons are no more interesting than any other physiologically active compound. Like all such substances, they challenge him to interpret their gross effects in molecular terms—to elucidate the chemical mechanisms by which they derange or destroy cells and thereby induce more obvious disturbances of the entire organism. So far the attempt to reduce toxicity to molecular mechanisms has succeeded in only a few cases. As Bernard anticipated, however, it has meanwhile taught us a good deal about the chemistry of living matter.

The corrosive poisons—strong acids and alkalis—have the most obvious effects. At first glance their mode of action seems simple enough. By massive destruction of cells they can produce death from shock, hemorrhage or incapacitation of some vital organ. Thus the corrosive gas phosgene, used in chemical warfare during World War I, reacts with water in the lungs to produce hydrochloric acid. This destroys lung tissue and by its irritant action fills the lungs with fluid. Death ultimately results from asphyxiation. With most corrosive poisons, however, the mode of action is not so clearly discernible. Concentrated sulfuric acid, for example, does so many things to the body that its specifically lethal activities are hard to isolate. Moreover, its catastrophic effects on tissue leave little for the physiologist to examine. Some corrosive poisons may produce death simply by shifting the delicate acid-alkaline balance of the body to the point where vital chemical reactions can no longer occur.

More subtle in their effects are the metabolic poisons, a group that includes most of the drugs in the pharmacopoeia as well as many other substances that have no place in medicine. These compounds do not destroy tissues; many of them produce no visible tissue-change whatever. Instead they accomplish their lethal work by disrupting one or another of the intricate chemical reactions upon which life depends.

The effects of two common metabolic poisons were explained many years ago



CITRIC ACID CYCLE, the basic energy-producing mechanism of the body, is blocked by the poison fluoroacetic acid. In the normal cycle (*black*) partially broken-down foodstuffs in the form of acetic acid combine with oxalacetic acid to yield citric acid. This in turn undergoes a series of transformations, most of which yield energy. In the lethal cycle (*color*) fluoroacetic acid substitutes for acetic acid, forming fluorocitric acid. This substance cannot undergo further metabolism; instead it blocks the normal cycle by inactivating the enzyme aconitase. At lower left is the key to structural diagrams here and on subsequent pages in this article.

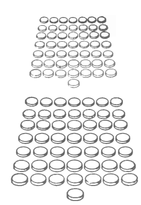
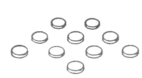
in biochemical terms. One is carbon monoxide (CO), a major constituent of automobile-exhaust gas and currently the leading chemical agent of suicide in the U. S. Its lethal effects seem largely attributable to its strong affinity for hemoglobin, the protein in red blood cells that transports oxygen from the lungs to the tissues. Carbon monoxide combines with hemoglobin 200 to 300 times more readily than does oxygen. Thus a carbon monoxide concentration in the air only .5 per cent of the oxygen concentration will convert half the hemoglobin in the blood into carboxyhemoglobin, a compound that cannot transport oxygen. Moreover, the presence of carboxyhemoglobin alters the properties of normal hemoglobin so that even the remaining fraction functions with reduced efficiency. The victim undergoes a sort of internal asphyxiation.

The treatment of acute carbon monoxide poisoning is based on the fact that the association between carbon monoxide and hemoglobin is reversible. If the victim is removed from the contaminated atmosphere and given pure oxygen to breathe, the carboxyhemoglobin gradually gives up its carbon monoxide to yield active hemoglobin. Its "half life" in the blood is about 30 minutes. Unfortunately a few persons who recover from carbon monoxide poisoning suffer damage to vision or to the nervous system that may be permanent.

Cyanide (CN^-), a homicidal and suicidal agent notorious in both medical and fictional literature, resembles carbon monoxide in that it cuts down the body's supply of oxygen. It does so, however, not by hindering the intake or transport of oxygen outside the cells but by interfering with the utilization of oxygen in the cells. The crucial step blocked by cyanide is thought to be the energy-yielding reaction catalyzed by the enzyme cytochrome oxidase. This protein, somewhat similar to hemoglobin, plays an almost ubiquitous role in cellular respiration. The cyanide ion, introduced into the body in the form of hydrocyanic acid or its salts, is believed to inactivate cytochrome oxidase somewhat as carbon monoxide inactivates hemoglobin. This reaction, though it is possibly not the only significant one, adequately explains the deadly effects of small quantities of cyanide (the lethal dose for man is about a millionth of the body weight). Since the process postulates the almost instantaneous choking-off of cellular respiration, it also explains the notoriously rapid action of cyanide. A few tenths of 1 per cent by volume of hydrocyanic acid gas in air can cause death within minutes. The gas facilitates its own lethal action by provoking deep breathing, thus ensuring the rapid absorption of even low concentrations. These properties make it a hypothetically humanitarian agent for gas-chamber execution in several states and aggravate the problem of therapy after acute accidental exposure to large doses.

Current treatment of cyanide poisoning is based upon suggestions made by K. K. Chen of Eli Lilly & Company. Chen took advantage of the fact that sulfur-containing compounds in the body can transfer their sulfur to cyanide ions, converting them to relatively harmless thiocyanate (SCN^-) ions. His treatment neutralizes the cyanide by administering thiosulfate ($S_2O_3^{--}$), the sodium salt of which ("hypo") is used in photographic development.

Subsequent investigations have shown that the transfer of sulfur to cyanide is catalyzed by rhodanese, an enzyme of

TOXICITY RATING	PRACTICALLY NONTOXIC	SLIGHTLY TOXIC	MODERATELY TOXIC	VERY TOXIC	EXTREMELY TOXIC	SUPERTOXIC
EXAMPLES	GLYCERIN, WATER, GRAPHITE, LANOLIN	ETHYL ALCOHOL, LYSOL, CASTOR OIL, SOAPS	METHYL (WOOD) ALCOHOL, KEROSENE, ETHER	TOBACCO, ASPIRIN, BORIC ACID, PHENOL, CARBON TETRACHLORIDE	MORPHINE, BICHLORIDE OF MERCURY	POTASSIUM CYANIDE, HEROIN, ATROPINE
PROBABLE LETHAL DOSE (MILLIGRAMS PER KILOGRAM)	MORE THAN 15,000	5,000 TO 15,000	500 TO 5,000	50 TO 500	5 TO 50	LESS THAN 5
PROBABLE LETHAL DOSE FOR A 70 KILOGRAM (155 POUND) MAN	 MORE THAN ONE QUART	 ONE PINT TO ONE QUART	 ONE OUNCE TO ONE PINT	 ONE TEASPOON TO ONE OUNCE	 SEVEN DROPS TO ONE TEASPOON	A TASTE (LESS THAN SEVEN DROPS)

SCALE OF TOXICITY rates substances according to the size of the probable lethal dose. As the examples indicate, many drugs fall into the highly toxic categories. Drawings suggest the fatal doses of water, whiskey, ether, aspirin, morphine and cyanide, the last three depicted in terms of aspirin-sized tablets. The scale was suggested by Marion N. Gleason, Robert E. Gosselin and Harold C. Hodge.

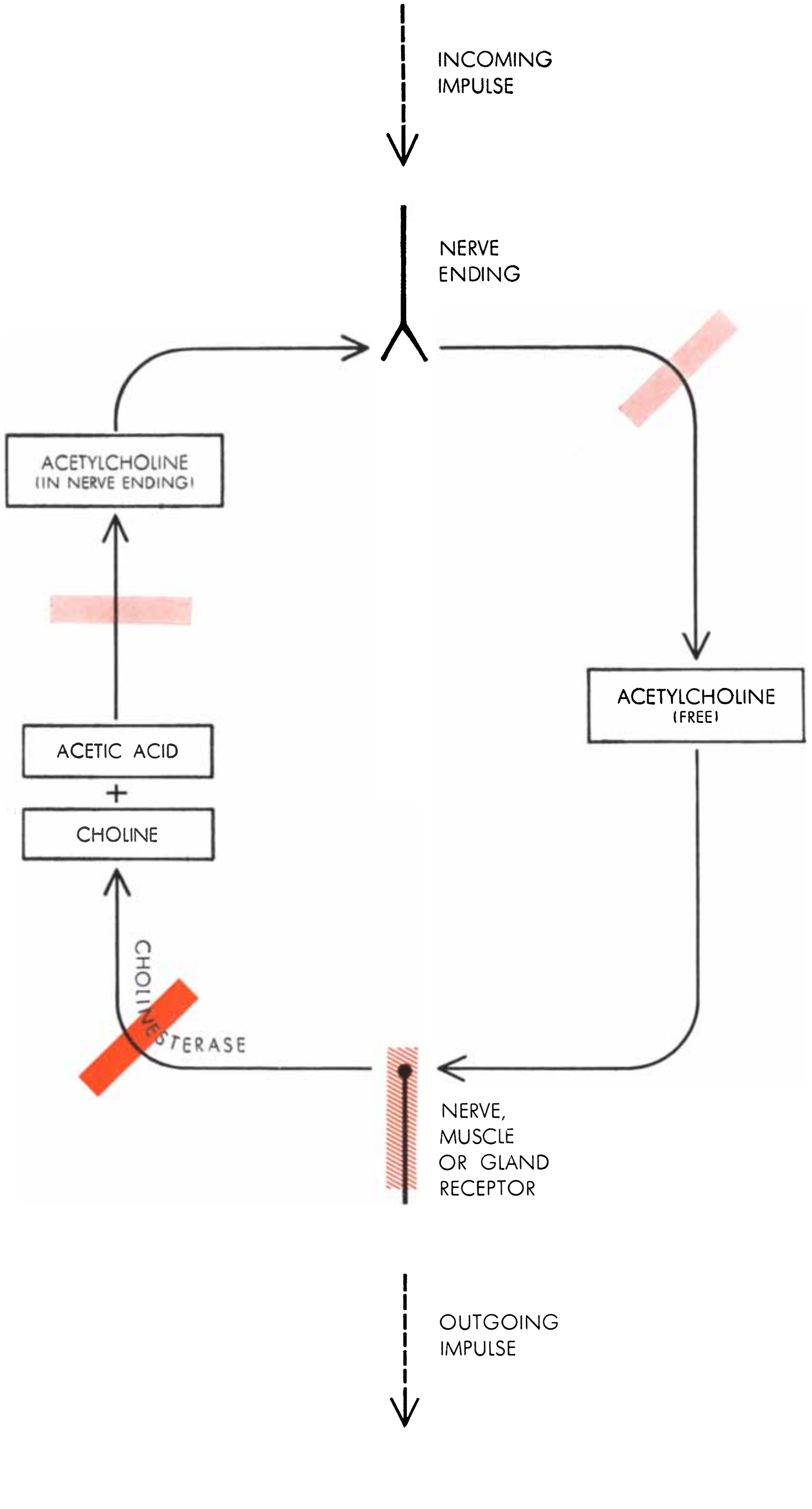
obscure function found in many mammalian tissues. The recent availability of purified rhodanese has suggested the administration of the enzyme along with the thiosulfate. Animal experiments in Sweden by Bo Sörbo and his colleagues indicate that the combined treatment is more effective than the thiosulfate alone. Chen also introduced a parallel therapeutic measure: the administration of compounds such as sodium nitrite that oxidize part of the blood's hemoglobin to methemoglobin. The latter compound combines avidly with cyanide and thus protects the vital cytochrome oxidase at the cost of a little hemoglobin.

These antidotes have proven their efficiency in animal experiments, but are generally most effective when given before or simultaneously with the poison. Few victims of massive cyanide poisoning survive long enough to be treated.

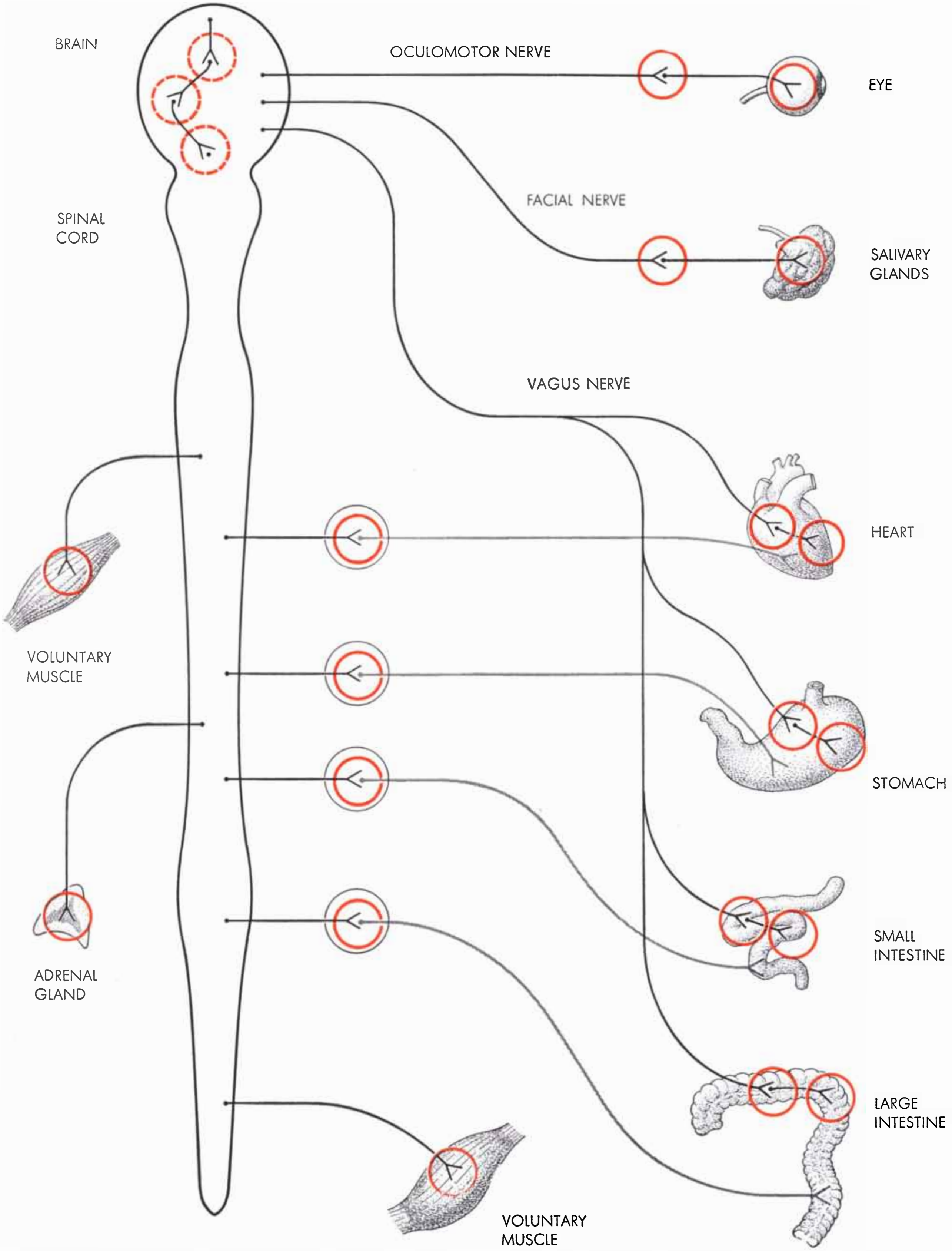
The nervous system, so vital to the regulation and coordination of the body's activities, is the target of a wide spectrum of toxic agents, ranging from classical poisons such as strychnine and atropine to the "nerve gases" developed during World War II. All of these neurotoxins in one way or another disrupt the microchemical mechanisms that transmit nerve impulses. Though their exact mode of operation is in most cases still unknown, many of them have advanced our knowledge of neurophysiology.

Nerve poisons have helped to establish, for example, that the synthesis and breakdown of the compound acetylcholine plays a central role in the body's internal communications. Studies extending over 40 years have identified this substance as the chemical messenger that transmits impulses between motor nerves and voluntary muscles. The list of "cholinergic" nerves also includes important portions of the autonomic nervous system, which controls respiration, digestion and the rest of the body's involuntary activities [*see illustration on next page*].

A nerve impulse reaching the end of a cholinergic nerve rapidly liberates a minute quantity (less than 10^{-9} gram) of acetylcholine. This activates a receptor on the adjacent nerve fiber, muscle fiber or gland, causing the nerve to fire, the muscle to contract or the gland to secrete. To leave the receptor free to receive further impulses the acetylcholine must then be inactivated. The enzyme cholinesterase, present in all nerve tissue, performs this essential task by cleaving the acetylcholine molecule into choline and acetic acid. Other enzymes



ACETYLCHOLINE CYCLE, a basic mechanism in the transmission of nerve impulses, is the target of many poisons. In the normal cycle an impulse reaching a nerve ending liberates acetylcholine, which stimulates a receptor. To free the receptor for further impulses, the enzyme cholinesterase breaks down acetylcholine into acetic acid and choline which other enzymes resynthesize into new acetylcholine. The "anticholinesterase" poisons prevent the breakdown of acetylcholine by inactivating cholinesterase (*solid color*). Botulinus and dinoflagellate toxins hinder the synthesis or the release of acetylcholine (*light color*). Curare and atropine make the receptor less sensitive to the chemical stimulus (*hatched color*).



"CHOLINERGIC" NERVES, which transmit impulses by means of acetylcholine, include nerves controlling both voluntary and involuntary activities. Exceptions are parts (*gray*) of the "sympathetic" nervous system that utilize norepinephrine instead of acetylcholine. Sites of acetylcholine secretion are circled in color; poisons that disrupt the acetylcholine cycle can derange the body's communications at any of these points. The role of acetylcholine in the brain is uncertain, as is indicated by the broken circles.

then reconstitute the two substances into acetylcholine, thus completing the cycle [*see illustration on page 79*].

The nerve poisons that are best understood are those that block the action of cholinesterase. This group includes the alkaloid physostigmine, its synthetic relative neostigmine and the nerve gases. By inactivating the enzyme they prevent the breakdown of acetylcholine. The resulting excess of acetylcholine hyperstimulates nerves, glands and muscles, producing convulsions, choking, heart irregularities and other distressing symptoms. If the victim survives these disorders, the rising level of acetylcholine ultimately brings on flaccid paralysis and death.

Physostigmine (sometimes called eserine), a poison once used in West African ordeal trials, has in recent years worked its way up to clinical respectability. It can temporarily restore muscular strength to an individual suffering from the disease myasthenia gravis and can relieve pressure within the eyeball in the serious eye disorder glaucoma [see "Glaucoma," by Sidney Lerman; SCIENTIFIC AMERICAN, August]. Neostigmine, an improved synthetic substitute, has found additional uses in slowing the rapidly beating heart and in relieving the intestinal paralysis that sometimes follows abdominal surgery.

Both substances are classed as reversible anticholinesterase poisons. Similar in structure to acetylcholine [*see illustration on next page*], they attach themselves semipermanently to the cholinesterase molecule. Their high affinity for it—about 10,000 times that of acetylcholine—ensures that even minute doses can inactivate a dangerously high proportion of the enzyme. If their concentration in the body does not reach fatal levels, however, they slowly dissociate from cholinesterase and are eliminated.

The nerve gases, including DFP (diisopropylfluorophosphate), TEPP (tetraethylpyrophosphate), Sarin and tabun, are termed irreversible poisons. They too attach themselves to cholinesterase, but so tightly that for practical purposes the restoration of normal nerve function must await the formation by the body of new cholinesterase molecules free of the poison.

Their toxic action, theatrical enough to satisfy the most demanding detective-story addict, has been well documented in a number of laboratory accidents and in their field use as insecticides. Exposure to even traces of the vapor produces rapid contraction of the pupils and usually transient constriction of the respiratory passages. Larger doses of vapor bring death in a matter of minutes from asphyxia, heart failure or shock. Some of the nerve gases are as lethal as cyanide and more easily absorbed. Because they are soluble in fat, they can enter the body through the unbroken skin. In one case a five-minute fingertip contact with a few drops of Sarin produced unpleasant symptoms for weeks.

The original treatment for both reversible and irreversible anticholinesterases involved the administration of two counter-poisons: atropine and curare. These substances combat the effects of excess acetylcholine by making nerve, muscle and gland receptors less sensitive to it. The atropine-curare treatment produces only symptomatic relief, however; full recovery must await the elimination of the poisons and (in the case of the nerve gases) the gradual manufacture of unpoisoned cholinesterase. More recently Irwin B. Wilson and David Nachmansohn of the Columbia University College of Physicians and Surgeons have produced an antidote for the nerve gases based on a new principle.

The new treatment is the fruit of fundamental research into the mechanism by which cholinesterase breaks down acetylcholine. Investigators have hypothesized that the enzyme has two "active sites" which interact with different parts of the acetylcholine molecule. By attaching itself to these two sites, the molecule splits into free choline and an acetyl group (CH_3CO^-) that remains bound to the enzyme. The acetyl group then reacts with water, forming free acetic acid and liberating the enzyme for further work [*see illustration on page 83*].

The nerve gases, probably by means of the electron-seeking phosphorus atoms which all of them contain, tenaciously preempt the site on the cholinesterase molecule that normally accepts the acetyl group. However, Wilson and his colleagues were able to devise a compound (pyridine aldoxime methiodide) that can pry the nerve gas loose from the enzyme by attaching itself at one end to the phosphorus group in the nerve-gas molecule and at the other to the choline-accepting site of the enzyme [*see illustration on page 84*]. As anticipated, this compound not only reactivates inhibited cholinesterase in the test tube but also protects experimental animals against otherwise lethal doses of nerve gas.

Though interest in the nerve gases originally stemmed from their possibilities in chemical warfare, the compounds have yielded an abundant nonmilitary harvest. For example, DFP has helped to unravel the fine structure of several enzymes which, like cholinesterase, bind it tightly at their active sites. Molecules of trypsin and chymotrypsin (protein-digesting enzymes secreted by the pancreas) can be labeled with DFP containing radioactive phosphorus atoms and then be degraded into small fragments; the labeled fragments identify the active segment of the molecule. In medicine the nerve gases serve much the same therapeutic purposes as physostigmine and neostigmine; their use as insecticides represents another nonmilitary application.

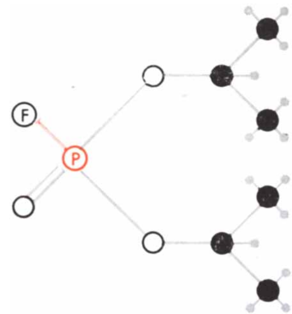
The toxic protein secreted by the botulinus bacillus, occasionally a cause of human food-poisoning, disrupts the acetylcholine cycle no less efficiently than do the anticholinesterase poisons, but is believed to work the opposite side of the biochemical cycle. Instead of raising the concentration of acetylcholine, it lowers it to paralytic levels by preventing its synthesis or its release from nerve endings. Botulinus toxin has the distinction of being the most poisonous substance yet discovered. As methods for purifying it have improved, the apparent minimum lethal dose has correspondingly decreased. According to a recent estimate the lethal dose for a mouse may be as little as 1,000 molecules—less than 10^{-13} gram per kilogram of mouse! Similar in action to botulinus toxin and almost as deadly is the toxin secreted by the poisonous dinoflagellates. These microscopic marine organisms can kill fish by the millions when they multiply explosively in "red tides"; the concentration of their toxin in the digestive tracts of mollusks accounts for many cases of shellfish poisoning in man.

Another potent metabolic poison that is fairly well understood is fluoroacetic acid. This simple compound constitutes the active ingredient in the gifblaar plant, notorious in South Africa as a cattle killer. Pharmacological studies place it, with cyanide and the nerve gases, in the supertoxic class. Dogs, which seem especially sensitive to its effects, may succumb to a dose of .05 milligram per kilogram of body weight. Curiously the fatal concentration of this poison is about 100 times greater for rats and 10,000 times greater for toads. The lethal dose for man, rather unreliably estimated from a few cases of accidental poisoning, is about 2.5 milligrams per kilogram of body weight.

Fluoroacetic acid acts relatively slowly; even when it is injected directly into the bloodstream the symptoms often take several hours to develop fully. They vary in different animals, but involve chiefly the heart and central nervous system. As with many metabolic poisons, the damage is purely functional; examination of the tissues shows no distinctive changes.

A decade ago Sir Rudolph Peters of the University of Oxford and the German biochemist Carl Martius independently suggested that fluoroacetic acid interferes with the citric acid cycle. This is the basic biochemical mechanism by which foodstuffs are oxidized to yield energy. The intermediate breakdown-products of sugar and fatty acids enter the cycle as a form of acetic acid, which combines with oxalacetic acid in the next step of the cycle to yield citric acid.

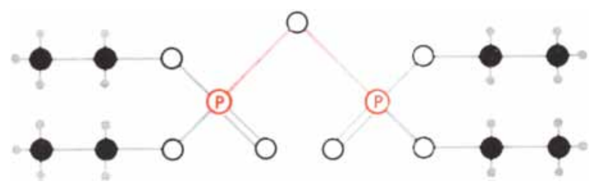
ACETYLCHOLINE



DIISOPROPYLFLUOROPHOSPHATE (DFP)

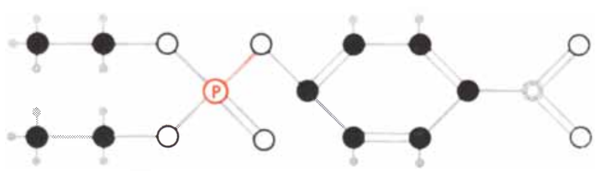
NEOSTIGMINE

SARIN



TETRAETHYLPYROPHOSPHATE (TEPP)

PHYSOSTIGMINE



PARAOXON

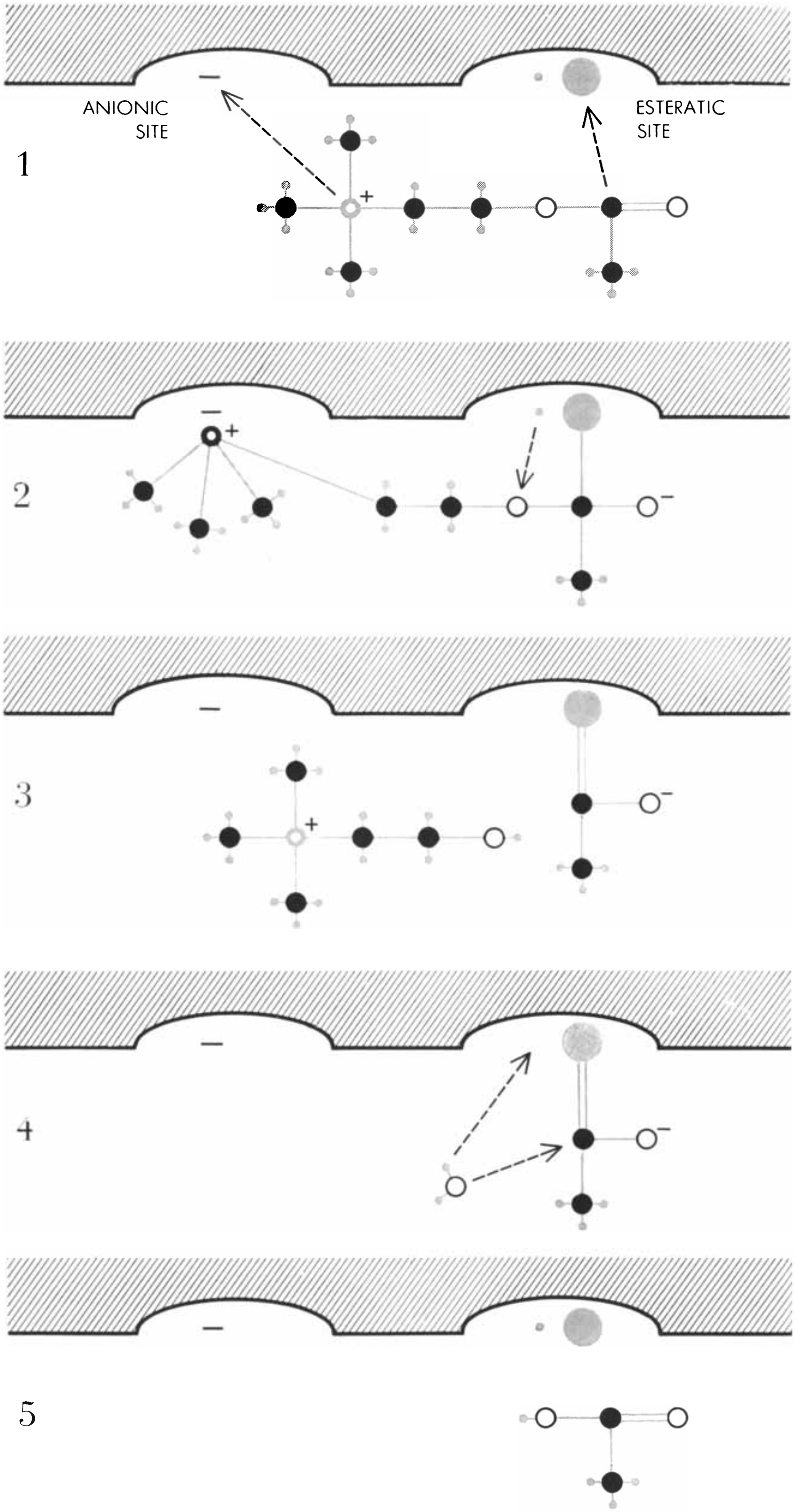
STRUCTURES OF ANTICHOLINESTERASE POISONS help to explain their toxic properties. Acetylcholine attaches itself to the cholinesterase molecule by means of an ester bond and a positively charged nitrogen atom, both shown in color. The poisons neostigmine and physostigmine are structurally analogous (the nitrogen atoms in physostigmine become positively charged in an acid environment). They combine similarly with cholinesterase, but more tenaciously. The "nerve gases" at right all contain a phosphorus atom with an easily broken bond (*also shown in color*). These poisons inactivate cholinesterase as shown in illustration on page 84.

Peters and Martius proposed that fluoroacetic acid, which is structurally similar to acetic acid, can enter the cycle at the same point, forming fluorocitric acid. This is a lethal error, because the fluorocitric acid powerfully inhibits the next enzyme in the sequence, which catalyzes the reorganization of citric acid into isocitric acid [*see illustration on page* 77].

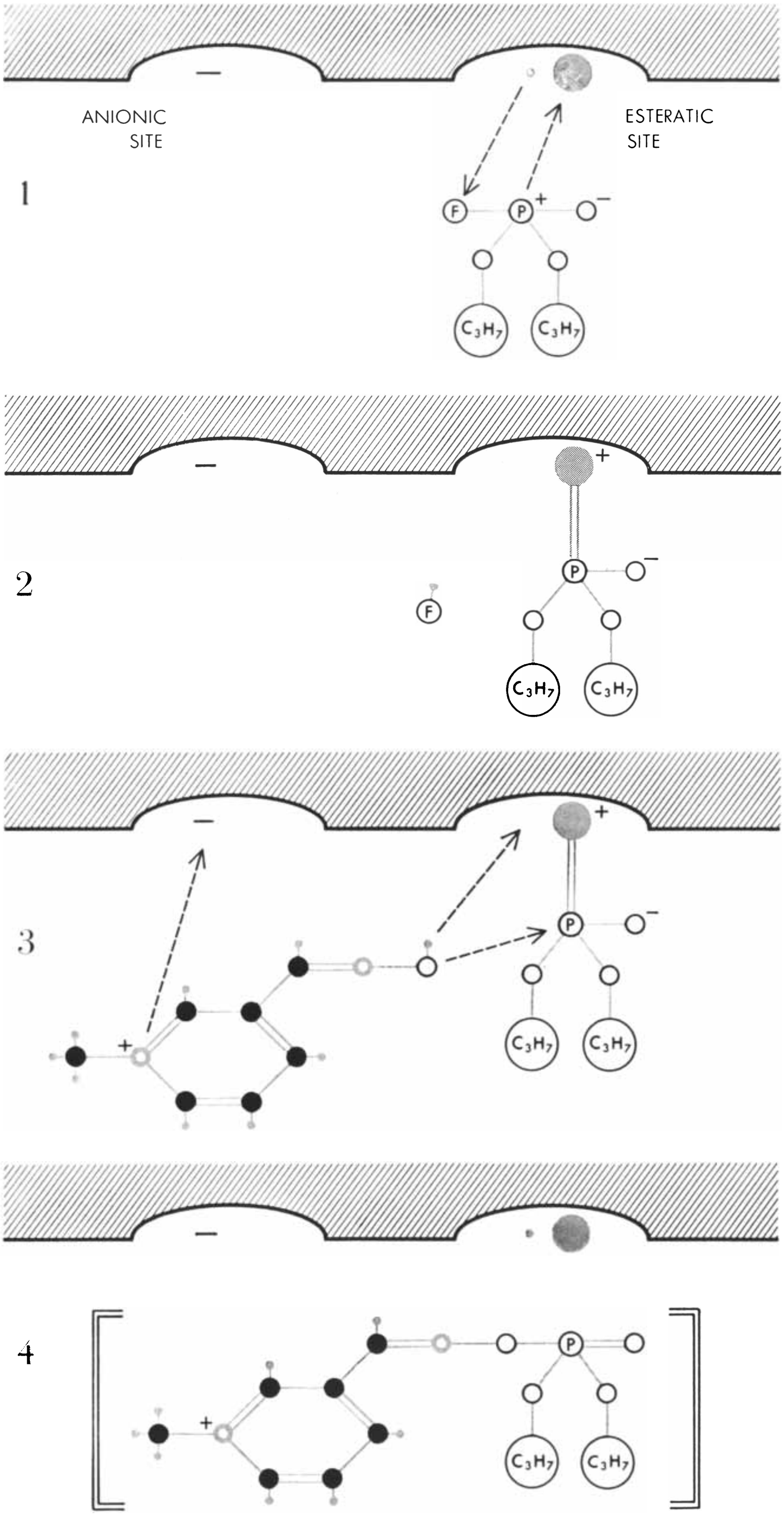
Peters and his colleagues have buttressed this hypothesis with many observations. In test tube preparations of liver cells, fluoroacetic acid and oxalacetic acid yield fluorocitric acid as predicted. Citric acid accumulates in the tissues of poisoned animals, indicating that its conversion into isocitric acid is indeed blocked. At present, however, there are still some inconsistencies that need explaining. It may be that other toxic biosynthetic products of fluoroacetic acid, such as fluorinated amino acids, play a significant part in the chemical pathology.

There is a rich variety of ways to wreck the machinery of a cell, and a corresponding diversity of poisons. Undoubtedly the future will uncover many new poisons, both by accident and design. It seems currently impossible to classify poisons in consistent and logical categories. Such a system might identify each poison by the metabolic reaction which is its target, assuming that toxic mechanisms prove to be that simple when we understand them. Apart from the examples already cited, however, the metabolic targets remain uncertain. Thus the classic poison arsenic, like several other metallic poisons, is known to inactivate enzymes by attaching itself to sulfhydryl (SH^-) groups in their structure, but we can as yet only guess which enzymes are the crucial ones.

The animal venoms alone constitute a remarkably varied group of poisons. All animal phyla, from single-celled protozoans to mammals, include species that produce toxic compounds. Snakebite causes thousands of deaths in tropical regions every year, yet we know little about the chemistry of snake venoms. They are known to contain many enzymes, some of which can break open red blood cells and cleave protein molecules. Rattlesnake venom has become a commercial source of enzymes used to study the structures of proteins and nucleic acids. The truly potent constituents of many venoms, however, appear to be nerve poisons whose specific mechanisms still elude us. Some of these neurotoxins are extraordinarily powerful: the fresh



BREAKDOWN OF ACETYLCHOLINE probably takes place as shown in these diagrams. The cholinesterase molecule (*hatched*) is thought to include a negatively charged anionic site, which attracts one end of the acetylcholine molecule, and an esteratic site whose "nucleophilic" group (*large gray sphere*) attracts the other end. When acetylcholine attaches itself to these sites (1, 2), it breaks into free choline and an attached acetyl group (3). This group then reacts with water (4), forming free acetic acid and returning the enzyme to its active state (5). This scheme was proposed by Irwin B. Wilson and David Nachmansohn.



INACTIVATION OF CHOLINESTERASE by a nerve gas, according to Wilson and Nachmansohn, is illustrated above. The phosphorus atom in the nerve gas binds itself tightly to the nucleophilic group in the enzyme, liberating hydrofluoric acid (1, 2). The compound pyridine-2-aldoxime methiodide (iodide ion is not shown) reactivates the enzyme. By attaching itself to the anionic site and the phosphorus atom (3) it pries the nerve gas loose from the nucleophilic group, presumably forming the unstable molecule shown in brackets (4).

venom of the Australian taipan can kill guinea pigs at a concentration of .025 milligram per kilogram of body weight, even though a considerable fraction of the crude venom must be relatively inert.

The alkaloids furnish another inexhaustible list of poisons, many of which double as drugs. In crude form, indeed, these plant compounds represent both the earliest drugs and the earliest poisons of mankind; the opium poppy is said to have been cultivated in the Stone Age. The alkaloids include, in addition to atropine and curare, such well-known drug-poisons as quinine, morphine, cocaine, strychnine and nicotine. Among the many mysteries surrounding these compounds is why plants produce them [see "Alkaloids," by Trevor Robinson; SCIENTIFIC AMERICAN, July].

The profusion of toxic substances in common circulation and use in this country has created a growing problem for the physician. The pediatrician in particular may at any moment receive a telephone call from a frantic mother whose child has swallowed one of the dozens of household cleaning preparations or one of the 80,000-odd formulations of pesticides. Many of these substances are relatively innocuous, in which case reassurance is the chief therapy, but some represent true pharmacological emergencies requiring prompt and specific treatment.

No physician, of course, can possibly identify by memory the ingredients of these thousands of products, let alone recall the prognosis and therapy appropriate to each. Accordingly health departments in a number of U. S. cities have organized poison-control centers which provide around-the-clock information to physicians and parents on the ingredients of brand-name products and on emergency therapy. Since the establishment of the first of these centers six years ago in Chicago, their number has grown to more than 200. Some have accumulated extensive reference-libraries and have even gone into toxicological research. In 1956 the U. S. Public Health Service organized a national clearinghouse for poison information.

The wide realm of poisons thus includes the savage tending a curare pot, the organic analyst at his microbalance, the pediatrician on the telephone and the industrial physician calculating the tolerable maximum of a toxic vapor. Last and by no means least, it encompasses the biochemist, who is learning to employ an almost infinitely varied set of probes for sounding the recesses of cell physiology.

Kodak reports on:

the nylon rope trick . . . the restraining effect of our inhibitions . . . microfilming brought down to the scientist's level

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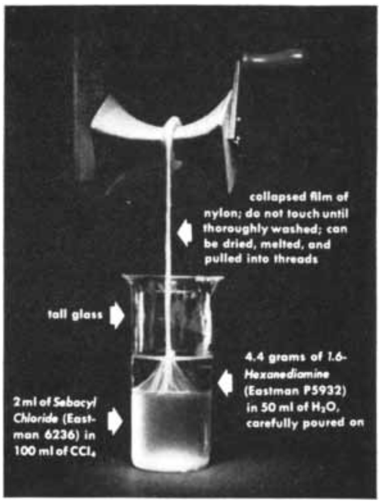

Du Pont, which doesn't ordinarily manufacture its nylon this way, was kind enough to publish this in J. Chem. Education 36, *182. We have been kind enough to prepare an abstract. Price for our minimum package quantities of the two reactants comes to $6.05. Teachers and Yuletide-bent daddies are reminded of the insidious nature of chlorinated hydrocarbons. Anyone inspired to commercial thoughts is advised to consult with his lawyer about U. S. Patent No. 2,708,617. Everyone who wants these or any of the approximately 3700 organic chemicals we stock (and catalog in Eastman Organic Chemicals, List No. 41) should get in touch with Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).*

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If we wanted to, we could in good conscience call "S.O. 260" the fastest color film ever made. We don't want to.

There are other reversal color films you can expose on the assumption of an outrageously high index, force-develop, and obtain an image out of. All we're saying is that outrage for outrage, "S.O. 260" loses less in color saturation, maximum density, and fineness of grain than others. This advantage can be so important in data acquisition—flame studies, aerodynamic studies, attitudes of informatively painted flying objects, for example—that we had better not rely on rumor and word of mouth to spread the news of its existence.

This is not intended for the photohobbyist who gets his thrills by bragging to his buddies, "I shot this at an Exposure Index of 600."* Wise or foolish, we dislike to see him sacrifice the potentiality of pictorial excellence instead of contriving to put a little more light through his lens. Maybe it's none of our business, but such are our inhibitions. We draw to his attention *Kodak High Speed Ektachrome Film*, *Kodak Ektachrome Film* (*Process E-3*), *Kodak Ektachrome Film* (*Process E-2*), and *Kodachrome Film*, any of which can yield him beautiful and impressive transparencies.

"S.O. 260" currently takes the form of 16mm film with a perforation pitch of .3000″ in 100′, 200′, and 400′ lengths and 35mm film of .1870″ perforation pitch in 100′ and 400′ lengths. These are pitches for high speed motion picture cameras. If you recognize that and have a need for data from color changes (changes, *not so much the colors themselves*) *photographed under very unfavorable conditions, initiate an inquiry about "S.O. 260" Film with Eastman Kodak Company, Photorecording Methods Sales Division, Rochester 4, N. Y. You will be put in touch with the proper parties.*

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Our subsidiary, Recordak Corporation, has recently come out with a portable microfilmer that weighs only 24 pounds and lists for only $845. Do you ask what this has to do with science? Then we are wracked by ambivalent feelings toward you. On the one hand, we feel extra respectful in your presence; a mind so obviously unaccustomed to seek solace in gadgetry is scarce. At the same time, we want to turn you gently toward the light. Certainly you're not the type to seek your solace in paper-shuffling, but you have to prove that, if only to yourself.

Think for a moment like that fabled monster, the efficiency expert. His baleful eye casts about for concentrations of paper. When he sees information being extracted from one pile of papers for summary on yet another piece of paper, his mouth waters. When he sees some poor soul toiling at a task that could go undone but for the necessity of preserving proof of the finer details, he pounces. Our subsidiary, Recordak Corporation, watches from the bushes and purrs benevolently. Get the picture?

It all began in banks a generation ago, spread to department stores and phone companies, and in the last decade has reached enterprises like dry-cleaning establishments, dairies, and medical clinics. Now the idea of microfilming while summarizing has been brought down to the scientist's level. The Recordak Portable Microfilmer is of the right scale in size and cost for work of lesser magnitude (from Recordak's special viewpoint) than getting out the monthly statements of a prosperous laundry.

Documents are fed into the machine face up and returned face down in their original sequence. They are freed for other use, or they can be dumped and yet remain retrievable. They can be up to 12 inches wide and of any length. Reduction ratio is 20:1. Forty-six 8½″ x 11″ sheets can be microfilmed in a minute, smaller documents proportionally faster. Two 100-foot rolls of film can be exposed simultaneously to the same subject matter. Film units are readily removable so that "one-subject" records can be kept separate even though microfilming be done intermittently.

Recordak Corporation, 415 Madison Avenue, New York 17, N. Y., has a nation-wide chain of branch offices and processing stations. It is just possible that your problem will remind the salesman of one he solved for the wholesale chicken business and that he will take you out and show you how it works there.

*The fastest black-and-white instrumentation film we currently recommend for esoteric conditions of short exposure is often handled on the basis of an Exposure Index of 1600. It comes in 16mm, 35mm, and 70mm widths as *Kodak Royal-X Pan Recording Film*.

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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

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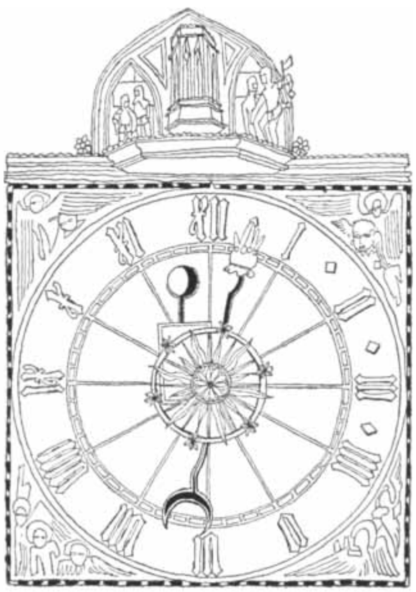


Intelligence from Space

The exploration of space is now a going concern, with a past as well as a future. From the front pages of newspapers and from technical journals information is flowing in a broadening stream.

To the accompaniment of the biggest headlines since the first Sputnik, the U.S.S.R.'s moon rocket hit its target at 5:02:24 p.m. (New York time) on September 14, opening the era of lunar exploration. Three weeks later, on October 3, the frontier was extended with the firing of the second rocket, which went beyond the moon.

The first moon-probe, a spherical container weighing with its instruments 858.4 pounds, plowed into the lunar surface at about 7,500 miles per hour. It had begun its gently hyperbolic journey some 35 hours earlier, at a time of the month when the trajectory would be most nearly parallel with the earth's surface to minimize the backward pull of the earth's gravity. A near-miracle of aiming, the flight was guided from the ground only during its powered stage. (Rocket guidance consists chiefly in adjusting speed rather than direction.) As an aid to tracking, the vehicle released a visible cloud of sodium vapor after entering its orbit. The rocket was sterilized before launching to prevent contamination of the moon by terrestrial organisms. Some fears were expressed, however, that dead microorganisms might serve as templates on which lunar material could organize itself into living matter.

According to Soviet announcements the vehicle contained instruments for studying "the magnetic pole of the earth and the magnetic poles of the moon, the radiation around the earth, the intensity and variation of cosmic radiation, heavy nuclei in cosmic radiation, the gas components of interplanetary substance and . . . meteor particles." Two transmitters telemetered information to ground stations, and an altimeter went into operation a few minutes before the container crashed.

A week after the landing the U.S.S.R. released some preliminary data. As to the moon's magnetic field (the most eagerly awaited result), none was detected. Nor was there evidence of radiation belts around the moon resembling the Van Allen belts around the earth. Since these belts are held in place by magnetic fields, their absence is consistent with the finding that the moon has no magnetism. The sensitivity of the Soviet magnetometer, however, was not disclosed. Some authorities believe that the moon may have a very weak field, perhaps a thousandth of a gauss. (The earth's field is believed to arise from the dynamo action of convection currents in its molten interior. The moon is generally thought to be solid throughout, but the possibility that it has a small, viscous liquid core has not been definitely excluded. If there is such a core, it might give rise to a very weak field by a similar mechanism.) Until details on the threshold of the measuring instruments become available the point is still unsettled.

The density of ionized particles was said to have increased sharply within about 6,000 miles from the moon. This evidence of a lunar ionosphere puzzled U. S. experts, who had not expected it, at least at such a height.

Four days after the moon shot the U. S. closed out its Vanguard program with a third successful launching. *Vanguard III*, a 50-pound instrument package, is in an orbit that takes it 319 miles above the ground at the lowest point and 2,329 miles at the highest. It is equipped to measure the earth's magnetic field, the temperature inside the vehicle, the intensity of solar X-rays, erosion of its skin by atmospheric particles and the impacts of micrometeorites.

There are now nine earth satellites aloft. One is the U.S.S.R.'s *Sputnik III;*

the others are American: three Vanguards, three Explorers, two Discoverers. In addition two vehicles are believed to be in orbit around the sun: the Soviet *Lunik* (or, to give it its Russian name, *Mechta*) and the U. S. *Pioneer IV*.

From *Explorer VI*, the "paddle-wheel" satellite launched in August, came some crude television pictures of the earth and its cloud cover, made at altitudes up to 26,000 miles. In addition, the satellite's radiation counters have revealed a radiation belt beneath the two Van Allen belts; the new belt consists of energetic protons.

A new estimate of solar temperatures, obtained from rocket flights, was also announced last month. A series of Nike-Asp rockets, fired to altitudes of 150 miles, detected X-rays from the sun with energies of 80,000 electron volts, far higher than any that were previously known. Originating in solar flares, such energetic radiation implies a temperature as high as 100 million degrees centigrade in the regions where it was produced. These spots would then be about 10 times hotter than had been thought.

In a report in *Nature* James A. Van Allen and Louis A. Frank of the State University of Iowa described the results of radiation measurements out to 400,000 miles, obtained from *Pioneer IV*. In the outer Van Allen belt this probe registered levels of radiation about 10 times greater than those detected previously, by *Pioneer III* (which remained aloft for 38 hours) and by *Lunik*. Since the *Pioneer IV* flight followed a period of intense solar activity, where the previous flights were made during intervals of comparative calm, the new measurements, according to the authors, "provide the most persuasive direct evidence thus far available for the solar origin of (at least) the outer radiation zone."

The intensity of trapped particles is an index to the strength of the earth's magnetic field. The *Pioneer IV* data indicate that this trapping ability extends outward to about 66,000 miles (14 earth radii). Direct magnetic-field measurements by *Lunik* had shown that, in the range from 8,700 to 13,100 miles, the actual field is substantially weaker than would be expected from extrapolating the values at lower altitudes. The maximum difference came at 13,000 miles, the inner edge of the outer Van Allen belt. Soviet physicists N. Pushkov and S. Dolginov have explained the discrepancy by assuming a strong ring of electric current flowing westward through the charged particles. The magnetic field of such a current would offset that of the earth. "The understanding of the detailed relationship between the Dolginov-Pushkov ring current and the trapped radiation now becomes one of the most challenging and timely problems of geophysics," say Van Allen and Frank.

Astronomical Blackout

The ether-borne chatter of man may soon drown out the music of the spheres, virtually destroying the young discipline of radio astronomy. Leading radio astronomers fear that all but possibly one narrow radio band will be reserved for non-astronomical purposes at the current Geneva meeting of the International Telecommunications Union. Decisions made at this meeting cannot be changed until the Union meets again in 10 years.

Representing the country of the birth of radio astronomy, the U. S. delegation to the meeting is asking that only the band from 1,400 to 1,427 megacycles, where the hydrogen in space emits its signals, be reserved for radio telescopes. The delegation is thus ignoring a recommendation made in April at a meeting in Los Angeles of the Consultative Committee on International Radio, which asked in addition that a number of narrow bands above 30 megacycles be reserved for detecting radio emissions from our own and other galaxies. The astronomers grant that the frequencies they seek are worth perhaps $100 million a year to the communications industry, but they point out that these bands cover only a fraction of 1 per cent of the available frequencies.

So faint are celestial signals and so sensitive are the receivers used to detect them that they can be obliterated by signals of the same frequency from a moderately strong transmitter almost anywhere on earth. The important radio observatory at Leiden in the Netherlands has already suffered interference from a radio station in Alaska. Thus radio astronomers must have bands free of man-made signals if they are to continue their contribution to knowledge of the universe. Leo Goldberg, director of the University of Michigan Observatory and a vice president of the International Astronomical Union, has said that with only the 1,400-to-1,427-megacycle band radio astronomy may soon become "a fossil science."

Man and Man-Ape Linked

At Olduvai Gorge in Tanganyika, L. S. B. Leakey has uncovered, almost intact, a skull that may furnish "the connecting link between the South African near-man or ape-man—*Australopithecus* and *Paranthropus*—and true man as we know him." Leakey believes that his find is between 600,000 and a million years old. If this estimate is supported by radioactive-dating tests soon to be undertaken at the University of California, the skull is the oldest yet discovered of a tool-making man.

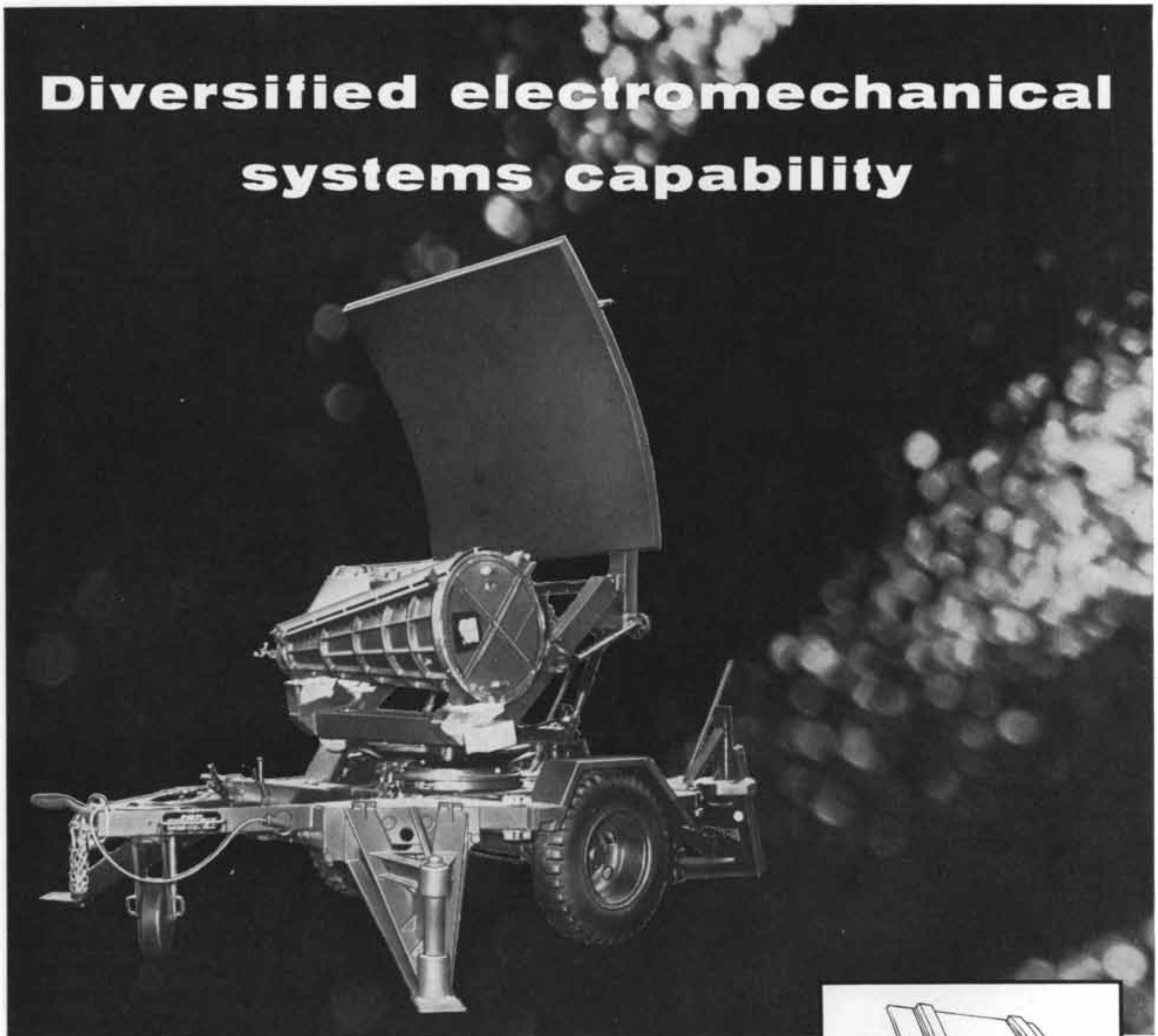
The skull, that of a youth of about 18, was found with "examples of the very primitive stone culture called Oldowan," which Leakey had previously identified in his 27-year investigation of the Gorge [see "Olduvai Gorge," by L. S. B. Leakey; SCIENTIFIC AMERICAN, January, 1954]. The bones of mammals, birds and reptiles indicate that the youth and his contemporaries had begun to diversify a diet that had been composed principally of nuts. According to Leakey, the skull is in some respects (its large teeth and palate) more primitive than that of *Australopithecus*, but in other respects closer to *Homo sapiens*. The lack of fossil evidence had made it difficult to determine whether *Australopithecus* was a well-developed ape or a poorly developed man. Leakey's find suggests that he was definitely a man.

One reason for the scarcity of Lower Paleolithic human fossils was suggested by Leakey in his article for this magazine. The ape-men did not bury their dead but left them exposed to scavengers. The present specimen may be the remnant of a scavenged corpse left in a propitious location and preserved by the flooding of the Gorge.

Plant Growth and Light

In plants as diverse as apple trees and lettuce, investigators at the U. S. Department of Agriculture Research Center in Beltsville, Md., have found a light-sensitive enzyme that regulates plant growth at all stages from germination to the ripening of fruit. They have partially isolated the substance, which is effective in minute quantities, and have reproduced what is apparently its critical reaction in the test tube.

The enzyme exists in two forms and transforms reversibly from one to the other upon exposure to appropriate wavelengths of light. One form absorbs



AiResearch Actuation Systems For Portable Radar represent a typical electromechanical systems application in ground support equipment. Two types of AiResearch actuation systems are now in production for the Army's mobile trailer-mounted ground radar unit. They consist of a manually operated antenna folding storage system and an electrically powered antenna elevation system.

Designed to operate under the most severe environmental conditions, this type of electromechanical system can operate on 60 cycle A.C., 400 cycle A.C., or 28 volt D.C. Other suggested applications include: *missile launchers, missile ground handling and support equipment, armored vehicle fire control and ballistic handling systems, and mobile communications equipment requiring servoed actuating systems.*

AiResearch leadership in the development and production of electromechanical equipment for aircraft, ground handling, ordnance and missile systems of all types also includes such recent examples as spoiler servo control systems, magnetron and Klystron tuning devices, and safe-arm mechanisms for missile igniting. We invite you to submit a problem statement of your electromechanical requirements.

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Systems, Packages and Components for: AIRCRAFT, MISSILE, ELECTRONIC, NUCLEAR AND INDUSTRIAL APPLICATIONS light in the orange to red range; the other absorbs far-red light, near the limit of the visible spectrum. The first form triggers such effects as the reddening of apples and the germination of lettuce seed; the other form promotes flowering and regulates growth.

The predominant form of the enzyme in the plant depends upon the color of light to which the plant is exposed. Both forms are present in about equal amounts after exposure to light in the middle of the red range. At longer wavelengths the reaction favors the orange-red-absorbing form, while shorter wavelengths (toward the yellow) stimulate the production of the far-red-absorbing form. In the living plant the intensity as well as the wavelength of the light influences the function of the enzyme. The investigators found that soybean plants will flower after an extremely short exposure at night to far-red light but will not flower if the intensity of the light is increased 100 times. Exposure at low intensity to the same wavelengths stimulates germination in lettuce seed; exposure at high intensity reduces germination almost to zero.

The research group, led by H. A. Borthwick and Sterling B. Hendricks, is now seeking to purify the enzyme for use in controlling plant development. The discovery may eventually make it possible to grow crops to heights ideal for harvesting or to set flowering times for the farmer's convenience and the avoidance of plant pests.

Transducers in the Skin

To register a sensation such as touch or pressure, the nerve endings in the body must somehow convert mechanical stimuli into electrical impulses. In electronics the task would require a transducer, a device that changes one form of energy into another (a familiar example is the crystal in a phonograph pickup, which uses mechanical energy, in the form of variable stress, to generate an electrical signal).

There is evidence that in the body the pressure-sensitive nerve endings known as Pacinian corpuscles work in much the same way. From their locations in the skin and in connective tissue, these receptors transmit signals that indicate the position of muscles and joints, thereby supplying some of the feedback necessary for proper muscle-coordination.

To determine how the Pacinian corpuscles generate their electricity, Werner R. Loewenstein of the Columbia University College of Physicians and Surgeons connected one corpuscle to a miniature circuit, then stimulated it mechanically with a vibrating glass rod. Writing in *Annals of the New York Academy of Sciences*, he states that his first experiments revealed that the many-layered covering that gives the corpuscles their characteristic onion-like appearance under the microscope could be almost completely removed without impairing the corpuscle's transducer function. Apparently the covering is only protective, although it may also help to distribute pressure stimuli over a larger area.

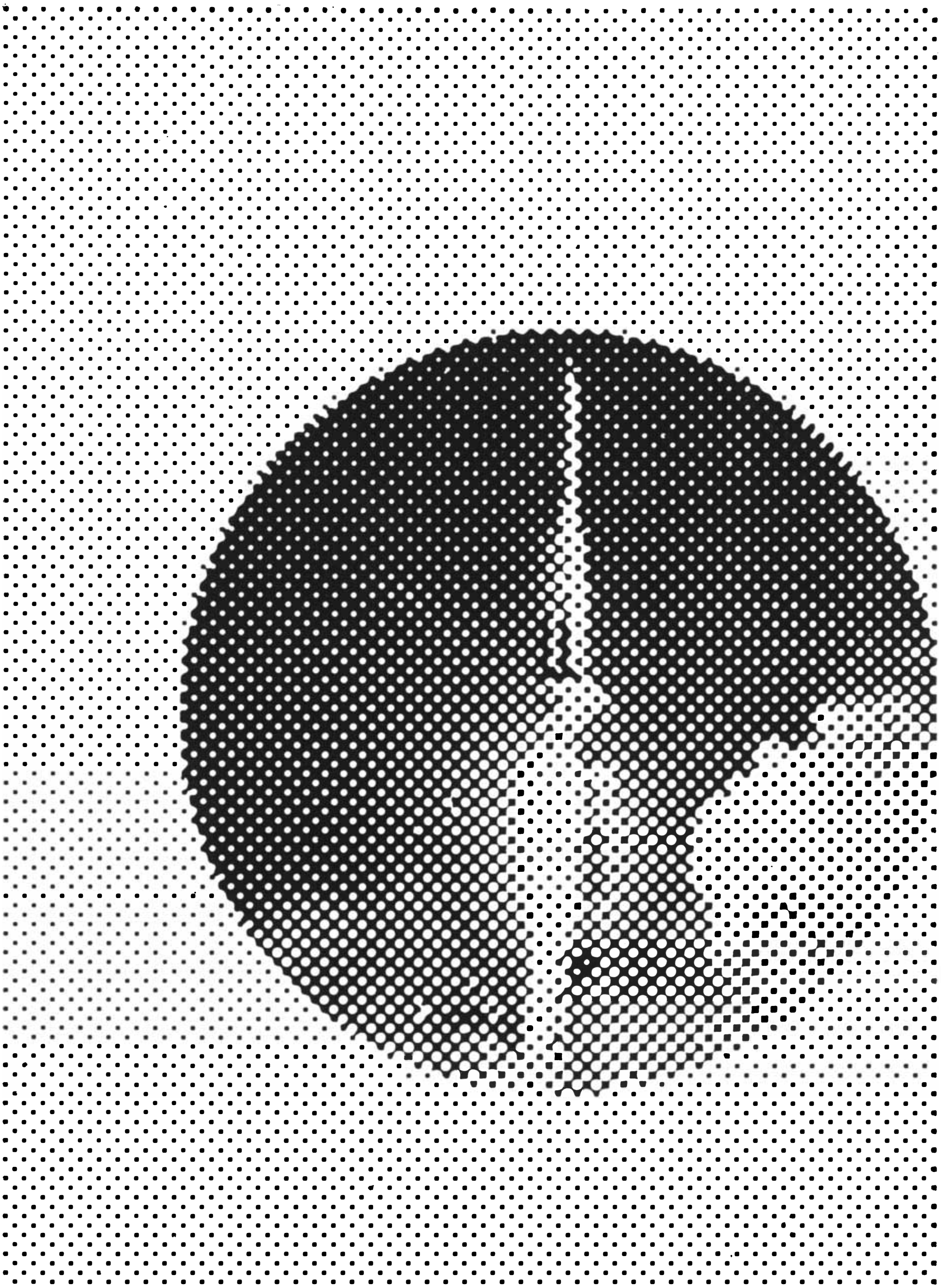
The transducer itself proved to be an unmyelinated nerve fiber projecting into the corpuscle from a sensory axon. Actually the fiber is not a single transducer but many: When stimulated by the vibrator, independent active sites along the membrane of the bare nerve become depolarized, each producing a voltage that is added to that of the others. By summing up these voltages the fiber produces a "generator potential" directly proportional to the strength of the mechanical stimulus. If the generator potential exceeds a certain threshold, it triggers an "all-or-nothing" impulse. This impulse is then propagated along a myelinated sensory axon that carries the signal to the appropriate reflex centers.

Stone Age Navigators

Although they had no written language and no navigational instruments, the Polynesians used celestial navigation to roam the Pacific, according to Frank M. Bateson of Rarotonga in the Cook Islands. He believes that these Stone Age people could find their way around the vast ocean at a time when European navigators were reluctant to get out of sight of land.

In an article in *Publications of the Astronomical Society of the Pacific*, Bateson explains that Polynesian astronomer-priests "knew the names of a large number of stars. More important, they knew at what seasons each was visible and what path it took across the sky. They also understood something of the movements of the sun, moon and planets," as well as of weather, wind and currents.

Bateson says the Polynesian navigator would set out just before dawn. He would note what stars were rising or setting directly over the bow or stern after he had pointed his vessel in the correct direction according to landmarks. He navigated at night by these stars, replacing them, as they set, with others having the same path. By day he steered by the sun and by the direction of waves moving under the influence of the wind and currents. The Polynesians



associated a particular star with each island group, according to Bateson, and therefore knew that when this star was directly overhead they had reached the correct latitude. If the islands were not visible, they presumably sailed due east or west until they found them. Bateson concludes that these island dwellers "were the greatest navigators of the Stone Age."

How Large the Moon?

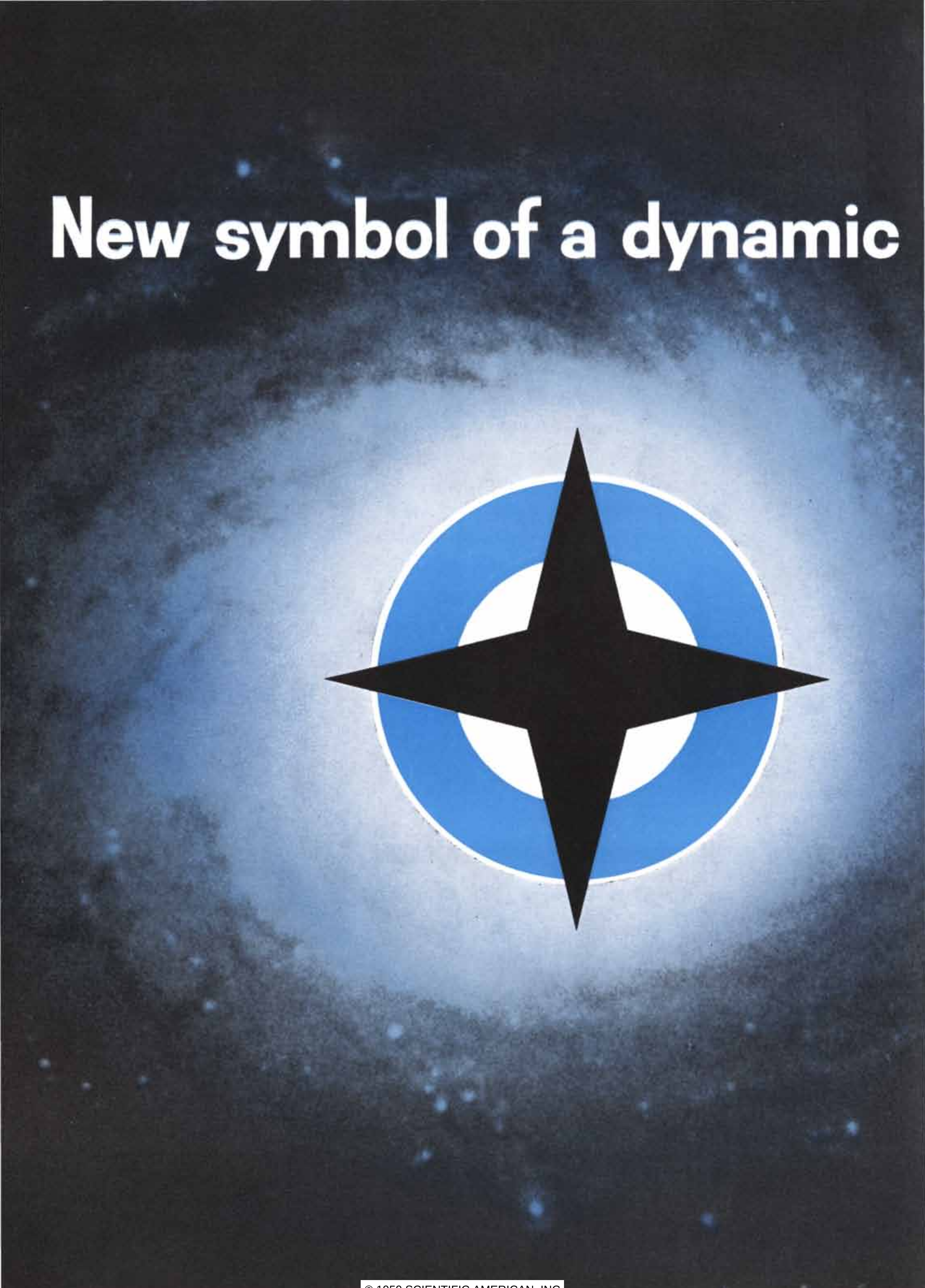
Why does the moon appear larger when it is near the horizon than when it rides high in the sky? Since classical times philosophers and psychologists have puzzled over this problem and have evolved a number of ingenious explanations, none of which has won general acceptance. Some findings by H. Leibowitz and T. Hartman of the University of Wisconsin, reported in a recent issue of *Science*, may help to resolve the dispute.

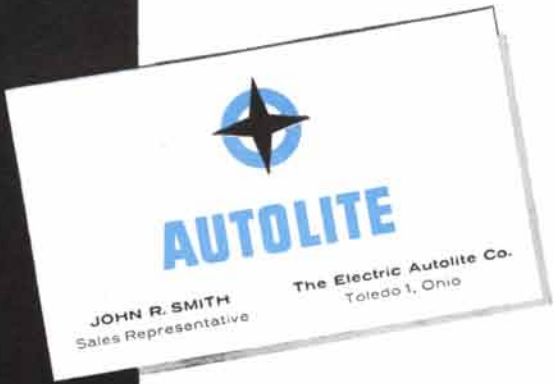
The two experimenters sought to duplicate the "moon illusion" by extending a 20-inch disk from the roof of an 85-foot building. Subjects seated directly below the disk were asked to compare it with disks of different sizes which were displayed at the same distance but in the horizontal plane. In every case the horizontal disk matched to the overhead one was physically smaller, that is, it appeared larger in proportion to its size.

In both experiments children among the subjects underestimated the size of the overhead "moon" more markedly than did adults. The youngest children underestimated the size by about 50 per cent; they matched a 10-inch horizontal disk to the 20-inch vertical one. Adults underestimated an average of 16 per cent.

Leibowitz and Hartman believe that these results bear out the theory that relates the moon illusion to "size constancy"—the process by which the brain "corrects" the small image of a distant object so that the object appears to be its proper size. The correction is presumed to be the fruit of experience. At large distances it often becomes inaccurate, especially in children.

As a result of size constancy an object whose image is over- or underestimated will appear larger or smaller than it really is. Thus the low-hanging moon, lying in the familiar horizontal plane in which we customarily estimate distances, is judged to be farther away than the moon at the zenith and therefore appears larger. To children overhead objects are especially unfamiliar, and the illusion is therefore more pronounced.


New symbol of a dynamic



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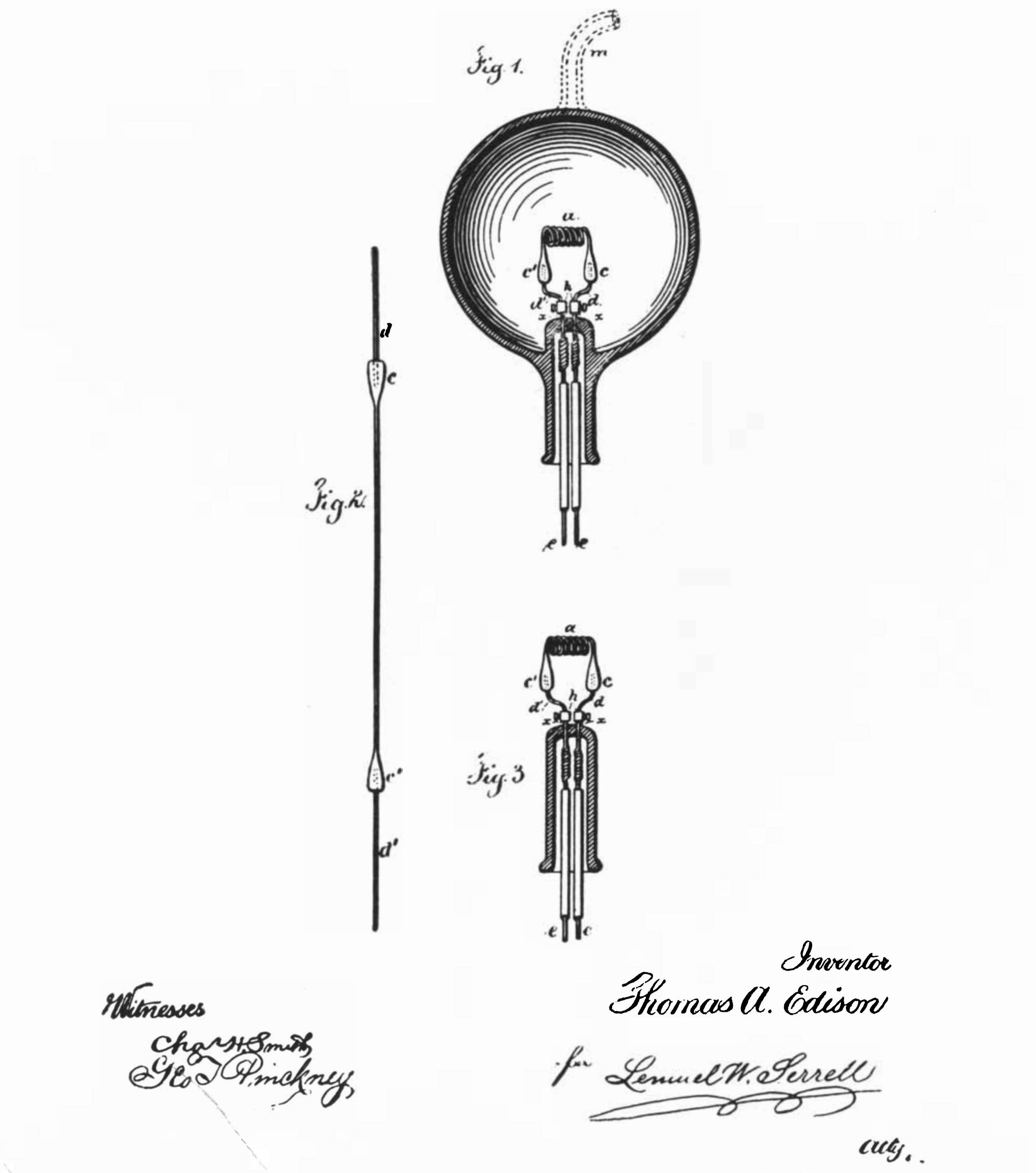
Photograph courtesy Mount Palomar Observatory

T. A. EDISON.
Electric-Lamp.

No. 223,898. Patented Jan. 27, 1880.



EDISON'S PATENT on the incandescent lamp was accompanied by this drawing. The labeled parts are the carbon filament (*a*), thickened ends of filament (*c*), platinum wires (*d*), clamps (*h*), leading wires (*x*), copper wires (*e*), tube to vacuum pump (*m*).

The Invention of the Electric Light

It is generally assumed that Thomas Edison's incandescent lamp was the product of inspired tinkering. Actually it was but one element in a much deeper invention: an entire system of electric lighting

by Matthew Josephson

"I can hire mathematicians, but mathematicians can't hire me!" By such declarations in the time of his success and world-wide fame Thomas Alva Edison helped to paint his own portrait as an authentic American folk hero: the unlettered tinkerer and trial-and-error inventor who achieved his results by persistence and a native knack for things. He is said, for example, to have tried more than 1,600 kinds of material ("paper and cloth, thread, fishline, fiber, celluloid, boxwood, coconut-shells, spruce, hickory, hay, maple shavings, rosewood, punk, cork, flax, bamboo and the hair out of a red-headed Scotchman's beard") until he hit upon the loop of carbonized cotton thread that glowed in a vacuum for more than half a day on October 21, 1879. Today, in a world that relies for its artificial illumination largely on his incandescent lamp, this invention is not regarded as an especially profound contribution to technology. It rates rather as a lucky contrivance of Edison's cut-and-try methods—of a piece with his stock ticker, mimeograph machine, phonograph and alkaline storage-battery—in the esteem of a public that has come to appreciate the enormous practical significance of higher mathematics and abstruse physical theory.

If Edison's contribution to the light of the world consisted solely in the selection of a filament, this estimate of his person and achievements might be allowed to stand. But the history that is so obscured by legend tells quite another story. Edison's electric light was not merely a lamp but a system of electric lighting. His invention was an idea rather than a thing. It involved not only technology but also sociology and economics. Edison was indisputably the first to recognize that electric lighting would require that electricity be generated and distributed at high voltage in order to subdivide it among a great many high-resistance "burners," each converting current at low amperage (that is, in small volume) with great efficiency into light.

In the 15 months between the time he conceived his invention and the date on which he demonstrated it to the public, Edison and his associates designed and built a new type of electric generator, successfully adapted the then much-scorned parallel or "multiple-arc" circuit that would permit individual lights to be turned on or off separately and, last of all, fashioned a lamp to meet the specifications of his system. The laboratory notebooks of those months of frantic labor show the Wizard of Menlo Park endowed with all the prodigious capacities attributed to him by contemporary legend. They show in addition that this self-taught technologist was possessed of a profound grasp of the nature of electricity and an intuitive command of its logic and power.

It was on September 8, 1878, that Edison was inspired to devote his talents full time to the challenge of electric lighting. On that day he went to Ansonia, Conn., to visit the brass-manufacturing plant of William Wallace, co-inventor with Moses G. Farmer of the first practical electric dynamo in the U. S. Wallace showed Edison eight brilliant carbon-arc lights of 500 candle-power each, powered by a dynamo of eight horsepower. It was with such a system that Wallace and Farmer, as well as Charles Brush of Cleveland, were then beginning to introduce the electric light on a commercial scale, for street-lighting and for illuminating factories and shops. Farmer had made the first demonstration of arc-lighting in this country two years earlier, at the Centennial Exposition in Philadelphia, and John Wanamaker's store in that city was already illuminated with arc lights.

Carbon arcs are still employed in searchlights and in theater floodlights and projectors to produce light of high intensity. The current crossing a small gap between the electrodes creates an arc. Ionization and oxidation of the carbon in the heat of the arc generate a brilliant blue-white light.

In the 1870's Europe was a decade ahead of the U. S. in the technology of arc-lighting. Stores, railway stations, streets and lighthouses in Britain and France were equipped with arc lights. Shedding an almost blinding glare, they burned in open globes that emitted noxious gases, and they could be employed only high overhead on streets or in public buildings. Since they consumed large amounts of current, they had to be wired in series, that is, connected one to another in a single continuous circuit so that all had to be turned on or off together. The multiple-arc circuit, with the lights connected as in the rungs of a ladder between the main leads of the circuit, was not adapted to such systems and was considered prohibitive in cost.

Edison himself had experimented with arc lights, using carbon strips as burners. He had also investigated the

EDITOR'S NOTE

The author has based this article on material in his biography *Edison,* just published by the McGraw-Hill Book Company. Copyright © 1959 by Matthew Josephson.

incandescent light, as had many inventors before him. But the slender rod or pencil of carbon or metal would always burn up, sooner rather than later, upon being heated to incandescence by the current. It would do so though substantially all of the air had been pumped out of the glass envelope in which it was contained. Edison had abandoned the effort to devote himself to a more promising invention: the phonograph.

Now at Wallace's establishment, confronted with the achievements of others in the field, he regained his earlier enthusiasm. As an eyewitness recalled, "Edison was enraptured.... He fairly gloated. He ran from the instruments [the dynamos] to the lights, and then again from the lights back to the electric instruments. He sprawled over a table and made all sorts of calculations. He calculated the power of the instruments and the lights, the probable loss of power in transmission, the amount of coal the instrument would use in a day, a week, a month, a year."

To William Wallace he said challengingly: "I believe I can beat you making the electric light. I do not think you are working in the right direction." They shook hands in friendly fashion, and with a diamond-pointed stylus Edison signed his name and the date on a goblet provided by his host at dinner.

From Edison's own complete and explicit notebooks and from the buoyant interviews that he gave to the press at this time we know what made him feel in such fine fettle as he left Wallace's plant. "I saw for the first time everything in practical operation," he said. "I saw the thing had not gone so far but that I had a chance. The intense light had not been subdivided so that it could be brought into private houses. In all electric lights theretofore obtained the light was very great, and the quantity [of lights] very low. I came home and made experiments two nights in succession. I discovered the necessary secret, so simple that a bootblack might understand it. . . . The subdivision of light is all right."

The Subdivision of Light

At this time there flashed into Edison's mind the image of the urban gas-lighting system, with its central gashouse and gas mains running to smaller branch pipes and leading into many dwelling places at last to gas jets that could be turned on or off at will. During the past half-century gas-lighting had reached the stature of a major industry in the U. S. It was restricted, of course, to the cities; three fourths of the U. S. population still lived in rural areas by the dim glow of kerosene lamps or candles. Ruminating in solitude, Edison sought to give a clear statement to his objective. In his notebook, under the title "Electricity versus Gas as a General Illuminant," he wrote:

"Object: E. . . . to effect exact imitation of all done by gas, to replace lighting by gas by lighting by electricity. To improve the illumination to such an extent as to meet all requirements of natural, artificial and commercial conditions. . . . Edison's great effort—not to make a large light or a blinding light, but a small light having the mildness of gas."

To a reporter for one of the leading New York dailies who had shadowed him to Ansonia, Edison described a vision of a central station for electric lighting that he would create for all of New York City. A network of electric wire would deliver current for a myriad of small household lights, unlike the dazzling arc lights made by Farmer and Brush. In some way electric current would be metered and sold. Edison said he hoped to have his electric-light invention ready in six weeks! At Menlo Park, N.J., where his already famous workshop was located, he would wire all the residences for light and hold a "grand exhibition."

Thus from the beginning Edison riveted his attention not so much upon the search for an improved type of incandescent filament as upon the analysis of the social and economic conditions for which his invention was intended. As he turned with immense energy to expanding the facilities at Menlo Park and securing the essential financing, he continued his studies of the gas-lighting industry. In parallel he projected the economics of the electric-lighting system he envisioned.

Gas had its inconvenience and dangers. "So unpleasant . . . that in the new Madison Square theater every gas jet is ventilated by small tubes to carry away the products of combustion." But whatever is to replace gas must have "a general system of distribution—the only possible means of economical illumination." Gathering all the back files of the gas industry's journals and scores of volumes bearing on gas illumination, he studied the operations and habits of the industry, its seasonal curves and the layout of its distribution systems. In his mind he mapped out a network of electric-light lines for an entire city, making the shrewd judgment: "Poorest district for light, best for power—thus evening up whole city." He meant that in slum districts there would be higher demand for small industrial motors. Against tables for the cost of converting coal to gas he calculated the cost of converting coal and steam into electric energy. An expert gas engineer, whose services Edison engaged at this time, observed that few men knew more about the world's gas business than did Edison.

Edison had a *homo oeconomicus* within him, a well-developed social and commercial sense, though he was careless of money and was not an accountant of the type exemplified by his contemporary John D. Rockefeller. Before the experimental work on his invention was under way, he had formed a clear notion, stated in economic terms, of what its object must be. This concept guided his search and determined the pattern of his technical decisions, so that the result would be no scientific toy but a product useful to people everywhere. By his initial calculation of the capital investment in machinery and copper for a whole system of light distribution he was led to define the kind of light he sought and the kind of generating and distributing system he needed.

Backers of the Electric Light

In the crucial matter of financing his inventive work Edison had the generous and imaginative aid of Grosvenor Lowrey, a patent and corporation lawyer well established in the financial community of Wall Street. Lowrey had fallen completely under Edison's spell and regarded him much as a collector of paintings regards a great artist whose works he believes are destined for immortality. Using his extensive connections and the favorable press-notices that he encouraged Edison to secure during late September and early October, 1878, Lowrey assembled a sponsoring syndicate of some of the most important financiers of the time. The underwriters of the Edison Electric Light Company, which was incorporated in mid-October, included William H. Vanderbilt and J. P. Morgan's partner Egisto Fabbri. This was an unprecedented development in U. S. business. Inventors had been backed in the development of inventions already achieved; Edison's financiers were backing him in research that was to lead to a hoped-for invention. In many respects the venture marks the beginning in this country of close relations between finance and technology.

"Their money," Edison said, "was in-

EDISON AND HIS PHONOGRAPH were photographed in 1878 by Mathew Brady. He had worked with electric lights but had turned to the more promising phonograph. In the year that this photograph was made, however, he resumed his work on lighting.

MENLO PARK was depicted in *Frank Leslie's Illustrated Newspaper* for January 10, 1880. The barnlike "tabernacle" of Edison's laboratory is visible at the far right. In its windows passengers on the nearby railroad could see his experimental lights burning.

vested in confidence of my ability to bring it back again." The 31-year-old Edison was by now a well-known figure in Wall Street. His quadruplex telegraph system, by which four separate messages could be transmitted over a single wire, had furnished the pivotal issue in the vast economic war waged between Western Union and the rival telegraph empire of the robber baron Jay Gould. Edison's carbon microphone had transformed the telephone from an instrument of limited usefulness to an efficient system of long-range communication that was now radiating across the country. The shares of gas-lighting enterprises had tumbled on the New York and London exchanges upon Edison's announcement, in the press campaign instigated by Lowrey, that he was now about to displace gas with electricity in the lighting of homes and factories.

The alliance between Edison and his sponsors was nonetheless an uneasy one. The first rift appeared before the end of October, when the rival inventor William Sawyer and his partner Albon Man announced that they had "beaten" Edison and applied for a patent on a carbon-pencil light in a nitrogen-filled glass tube. There was a flutter of panic in the directorate of the Edison Electric Light Company. The suggestion was made that Edison should join forces with Sawyer and Man. Lowrey passed the suggestion on to S. L. Griffin, a former junior executive at Western Union whom Lowrey had hired to help Edison with his business affairs.

Griffin sent back a hasty "confidential" reply: "I spoke to Mr. Edison regarding the Sawyer-Man electric light. . . . I was astonished at the manner in which Mr. Edison received the information. He was visibly agitated and said it was the old story, that is, lack of confidence. . . . No combination, no consolidation for him. I do not feel at liberty to repeat all he said, but I do feel impelled to suggest respectfully that as little be said to him as possible with regard to the matter."

In view of Edison's talent for candid and salty language Griffin's reticence is understandable. After that there was no further talk of consolidation with Sawyer or any other inventor.

The Menlo Park Laboratory

In his belief that he would "get ahead of the other fellows" Edison was sustained by his unbounded confidence in his laboratory, its superior equipment and its staff. The Menlo Park laboratory was still the only full-time industrial research organization in the country, in itself perhaps Edison's most important invention. During this period the physical plant was greatly expanded; a separate office and library, a house for two 80-horsepower steam engines, and a glass blower's shed were added to the original barnlike "tabernacle." Even more important, Edison had collected a nucleus of talented engineers and skilled craftsmen, who were of inestimable help to him in working out his ideas.

The self-taught Edison thought primarily in concrete, visual terms. When he was at work on the quadruplex telegraph, he had even built a model made up of pipes and valves corresponding to the wires and relays of his system, and with running water replacing the electric current, so that he could actually see how it worked. But now he would have to depend far more on theory and mathematics.

One of the happiest effects of Grosvenor Lowrey's personal influence was the hiring of Francis R. Upton, a young electrical engineer who had worked for a year in the Berlin laboratory of the great physicist Hermann von Helmholtz. Edison jocularly nicknamed Upton "Culture," and, according to an oft-told story, put the "green" mathematician in his place with one of his scientific practical jokes. He brought out a pear-shaped glass lamp-bulb and gave it to Upton, asking him to calculate its content in cubic centimeters. Upton drew the shape of the bulb exactly on paper, and derived from this an equation for the bulb's volume. He was about to compute the answer when Edison returned and impatiently asked for the results. Upton said he would need more time. "Why," said Edison, "I would simply take that bulb, fill it with a liquid, and measure its volume directly!"

When Upton joined the staff late in October, Edison had already committed himself to the incandescent light. This, rather than the arc light, was the way to imitate the mildness of gas. But the filament glowing in a vacuum had been sought in vain by numerous inventors for half a century. In choosing the incandescent light rather than the arc light he was "putting aside the technical advance that had brought the arc light to the commercial stage." No one, including himself, had succeeded in making an incandescent lamp that would work for more than a few minutes.

Edison's first efforts in 1878 were not notably more successful. Knowing that carbon has the highest melting point of all the elements, he first tried strips of carbonized paper as "burners" and managed to keep them incandescent for "about eight minutes" before they burned up in the partial vacuum of his glass containers. Turning to the infusible metals, he tried spirals of platinum wire; they gave a brilliant light but melted in the heat. Edison accordingly devised a feedback thermostat device that switched off the current when the heat approached the melting point. The lamp now blinked instead of going out entirely. Nonetheless, with his eye on the problem of financing, Edison filed a patent application on October 5 and invited the press in for a demonstration.

As this discouraging work proceeded in the weeks that followed, Edison turned, with Upton's help, to calculating the current that would be consumed by a lighting system equipped with a certain number of such lamps. They assumed that the lights would be connected in parallel, so their imaginary householder could turn one light in the circuit on or off at will, as in a gas-lighting system. Thinking in round numbers, they assumed that these lamps, when perfected, might have a resistance of one ohm and so would consume 10 amperes of current at 10 volts. Allowing in addition for the energy losses in the distribution system, they found that it would require a fabulous amount of copper to light just a few city blocks. Such a system of low-resistance lights was clearly a commercial impossibility.

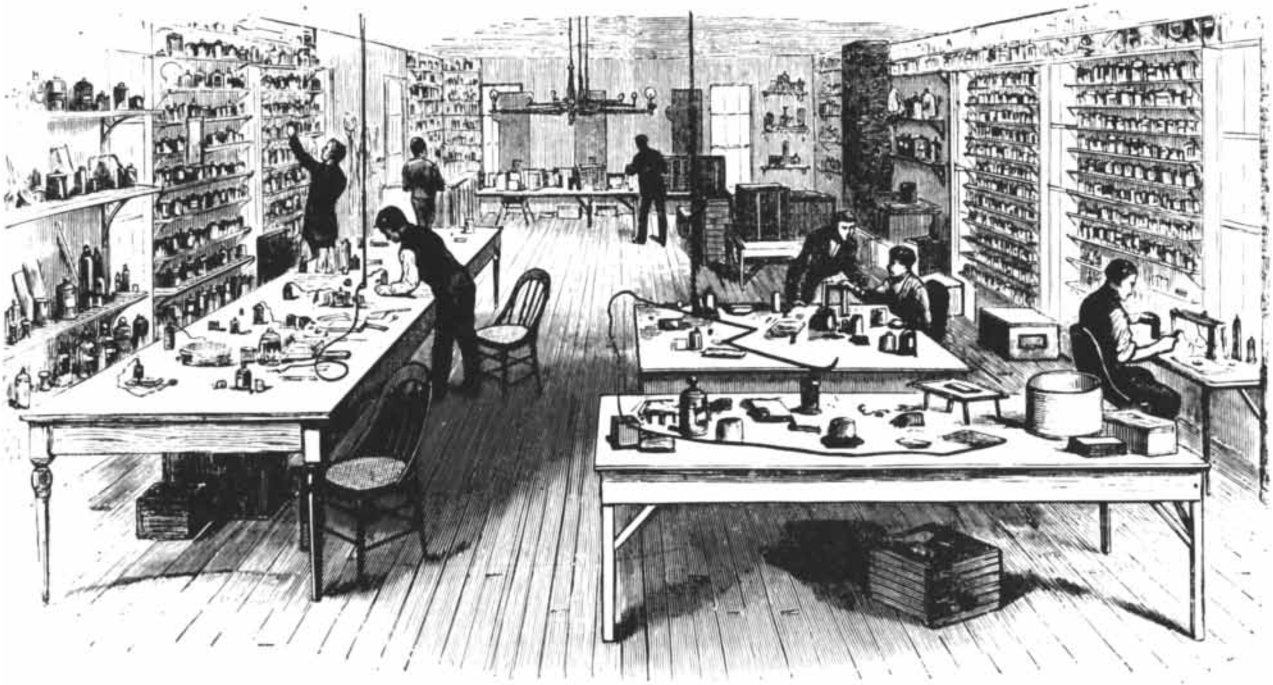
This was the gist of the objections which had greeted Edison's first announcements that he would use an incandescent bulb in a parallel circuit. Typical of the scorn heaped upon him was the opinion expressed by a committee set up by the British Parliament to investigate the crash of gas-lighting securities. With the advice of British scientists, the members of the committee declared that though these plans seemed "good enough for our transatlantic friends," they were "unworthy of the attention of practical or scientific men." From Ohm's law, which governs the relationship between voltage, amperage and resistance in a circuit, the report argued that if an electric light of 1,000 candlepower were divided into 10 smaller lights and connected in parallel, each of the smaller lights would radiate not one tenth but "one hundredth only of the original light." In this judgment such figures as Lord Kelvin and John Tyndall concurred. Before the Royal Institution in London the distinguished electrician Sir William Preece declared: "Subdivision of the electric light is an absolute *ignis fatuus.*"

Ohm's law does indeed show that the amount of current (amperes) flowing in a circuit is equal to the electromotive force (volts) divided by the resistance (ohms) in the circuit. Edison's contemporaries reasoned that an increase in the number of lights in a circuit would increase the resistance and therefore reduce the flow of current to each. It was thought that the only way to provide these lights with sufficient current was to reduce the resistance in the distribution system. In a parallel circuit this meant increasing the thickness of the copper conductors to an impractical degree. Such were the limits on the operation of arc lights, with their low resistance and huge appetite for current. Upton's calculations showed that this conclusion also applied to Edison's first low-resistance incandescent lamps.

Edison now confounded his collaborator by proposing that he make the same sort of estimates for an entirely different kind of circuit. This time he would assume lights of very high resistance, supplied with current at high voltage and low amperage. In November and December Upton made calculations on the basis of the same number of lights, but lights with the high resistance of 100 ohms each. These lights were to operate on the low current of only one ampere. Their high resistance was to be offset, in accord with Ohm's law, by the high voltage of 100 volts in the circuit. The result was astonishing: A high-resistance system would require only one hundredth of the weight of copper conductor needed for a low-resistance system. And copper was the most costly element involved—the decisive economic factor.

The High-Resistance System

Here was the crux of Edison's insight at Ansonia. He had recognized there that the subdivision of light called for lamps of high resistance which would consume but little current; to balance the electrical equation it would be neces-

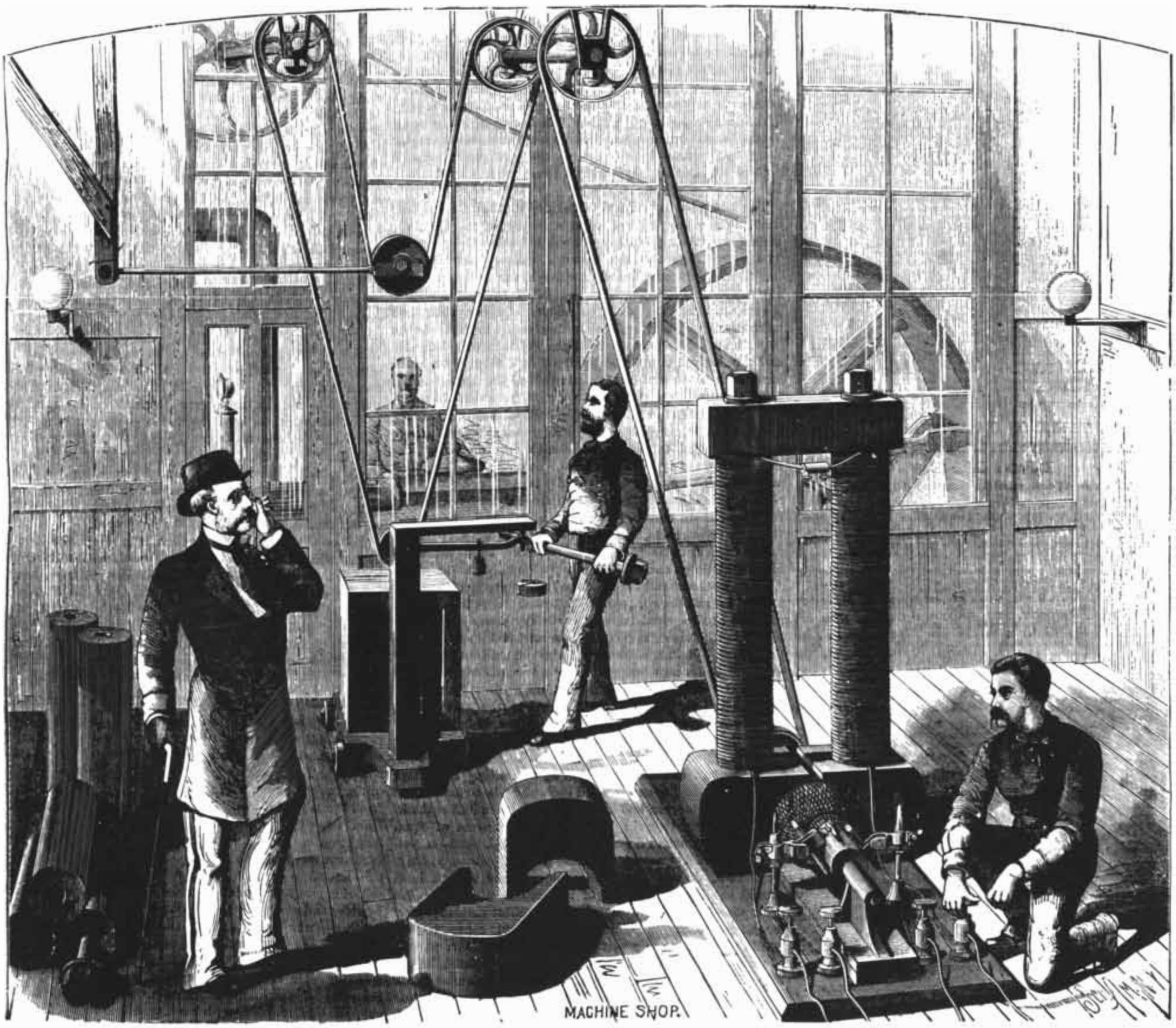


INTERIOR OF EDISON'S LABORATORY at Menlo Park was also depicted in the January 10, 1880, issue of *Frank Leslie's Illustrated Newspaper*. At the time of the work on the electric light the laboratory had expanded into several other buildings.

sary to supply the current at high voltage. This was the "necessary secret" that was "so simple." Today every high-school physics student learns that the power lost in transmitting electric energy varies with the square of the current. Thus a tenfold reduction in current meant a decrease of a hundredfold in the energy wasted (or a hundredfold decrease in the weight of the transmission line). It was a conception easily reached by an elementary application of Ohm's law, but it had not occurred to any of Edison's contemporaries. Even Upton did not immediately grasp the full import of Edison's idea. As he said later: "I cannot imagine why I did not see the elementary facts in 1878 and 1879 more clearly than I did. I came to Mr. Edison a trained man, with a year's experience in Helmholtz's laboratory, . . . a working knowledge of calculus and a mathematical turn of mind. Yet my eyes were blind in comparison with those of today; and . . . I want to say that I had company!"

With Upton's figures before him Edison was convinced that a new and strategic invention lay surely within his grasp. It was clear what kind of distributing system he wanted. And he knew what form of incandescent burner would serve his purpose. To offer the necessary resistance to the passage of current it must have a small cross section and so would have a small radiating surface.

By January, 1879, Edison was testing his first high-resistance lamp. It had a spiral of very fine platinum wire set in a globe that contained as high a vacuum as could be achieved with an ordinary air pump. The results were encouraging; these lamps lasted "an hour or two." He then attacked the dual problem of getting a higher vacuum and improving his incandescing element. After another trial with carbon, he returned to metals: platinum, iridium, boron, chromium, molybdenum, osmium—virtually every infusible metal. He thought of tungsten, but could not work it with existing tools. Discouraged by the problem, Edison tried nitrogen in his globe and then resumed his efforts to obtain a higher vacuum. Hearing of the new and efficient Sprengel vacuum pump, which used mercury to trap and expel air, he sent Upton to borrow one from the nearby College of New Jersey (now Princeton University). When Upton returned with the pump late that night, Edison kept him and the other men on the staff up the rest of the night trying it out.



GENERATOR which Edison developed for the needs of electric lighting appears at right in this engraving from SCIENTIFIC AMERICAN for October 18, 1879 (at that time this magazine appeared weekly). The generator was called the "long-waisted Mary Ann."

At this stage Edison made a useful finding: "I have discovered," he noted, "that many metals which have gas within their pores have a lower melting point than when free of such gas." With the aid of the Sprengel pump he devised a method of expelling these occluded gases, by heating the element while the air was being exhausted from the bulb. The platinum wire within the bulb thereupon became extremely hard and could endure far higher temperatures. Edison later said that at this stage he "had made the first real steps toward the modern incandescent lamp."

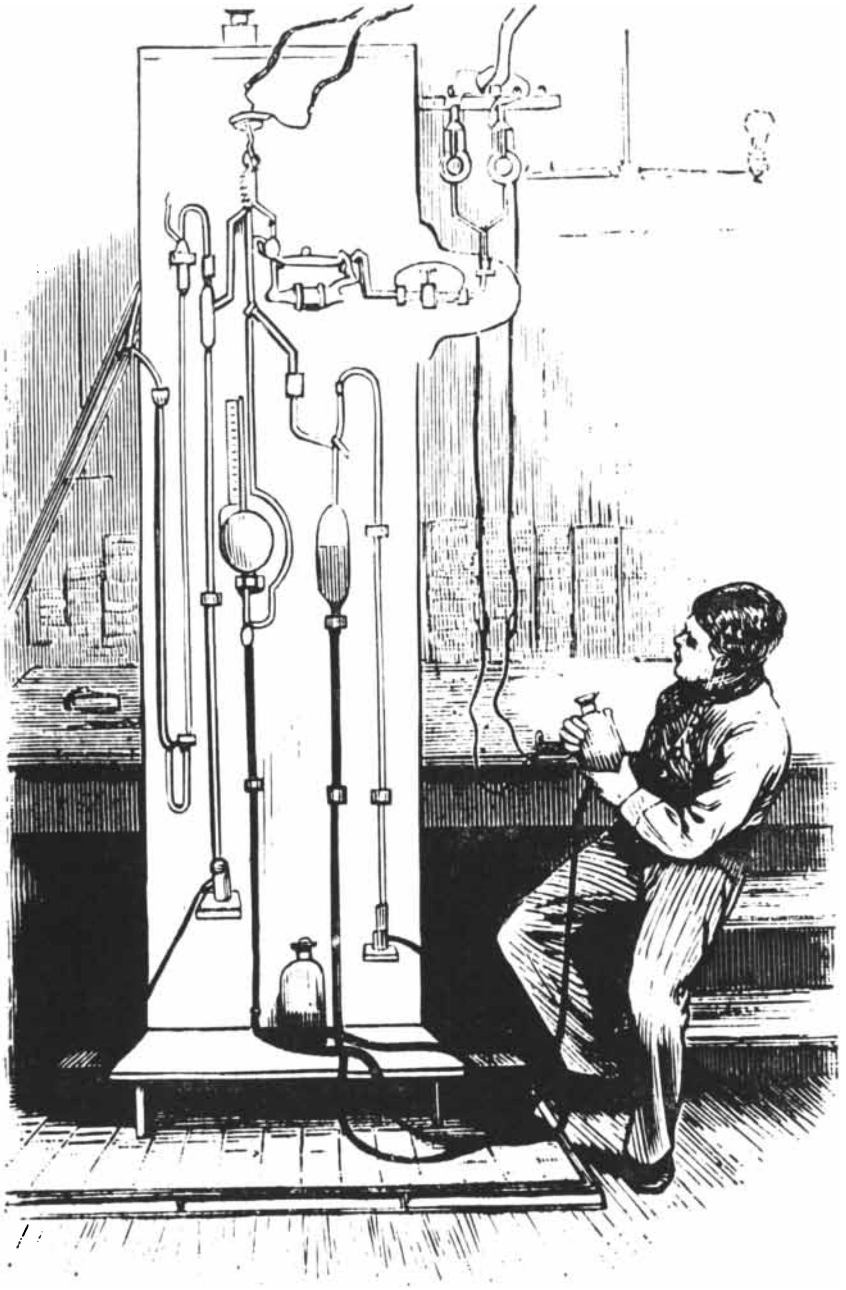
Meanwhile the spirits of his financial sponsors had begun to droop. Their brilliant inventor, far from having achieved anything tangible, was hinting plainly that he needed more money. The first Brush arc lights were ablaze over lower Broadway, and more were being installed elsewhere with impressive effect. Edison's backers began to have serious doubts as to whether he had pursued the right course. To shore up their morale Lowrey arranged to have Edison give them a private demonstration.

In April, as one of Edison's associates recalled it, "They came to Menlo Park on a late afternoon train from New York. It was already dark when they were conducted into the machine shop where we had several platinum lamps installed in series." The "boss" showed his visitors pieces of platinum coil he was using in the lamps, pointed out the arrangement of the lights and described the type of generator he hoped to build. Then, the room having grown quite dark, he told "Honest John" Kruesi to "turn on the juice slowly."

"Today, I can still see those lamps rising to a cherry-red . . . and hear Mr. Edison saying 'A little more juice' and the lamps began to glow. 'A little more,' . . . and then one emits a light like a star, after which there is an eruption and a puff, and the machine shop is in total darkness. . . . The operation was repeated two or three times, with about the same results."

The platinum coils still consumed a lot of power for the light they gave, and they were costly and short-lived. The temporary Wallace-Farmer dynamos heated up badly, and were not powerful enough to enable Edison to connect his lamps in parallel. Edison admitted that the system was not yet "practical."

It was a gloomy gathering that broke up on that raw April evening. All of Lowrey's abounding faith would be necessary to rally the spirits and funds of Edison's despondent backers. Some rumors of the disappointing demonstration leaked out; the price of Edison stock fell sharply, while that of gas-lighting securities rose. "After that demonstration," Edison's associate relates, "we had a general house cleaning at the laboratory, and the metallic lamps were stored away."



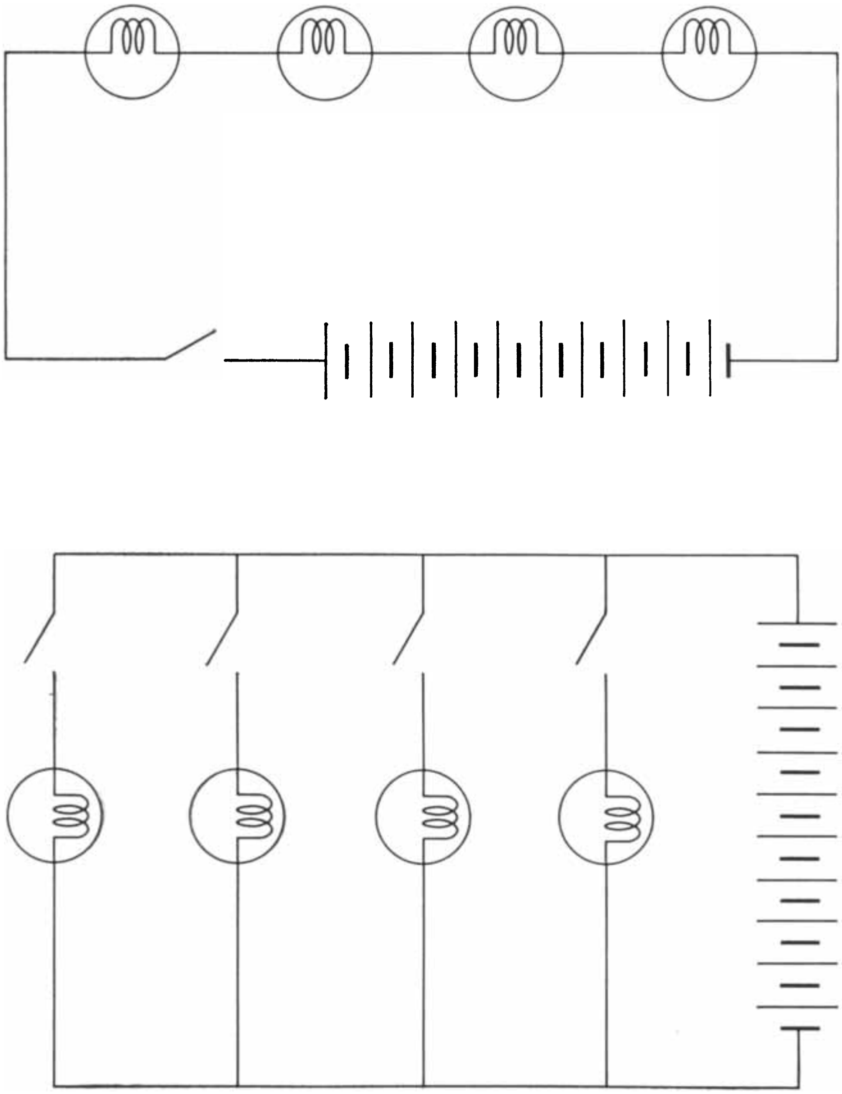
VACUUM PUMP used to remove air from lamp bulbs (*top center*) was of a new type about which Edison had read in a scientific journal. The man is holding a vessel of mercury.

Edison now rallied his staff to efforts on a much broader area of the front "under siege." He followed three main lines of investigation. One group he detailed to the task of developing the dynamo to supply the constant-voltage current required by his high-resistance system. He set another group to pulling down a still higher vacuum in the glass bulbs. The third team, under his watchful eye, carried out the series of experiments in which 1,600 different materials were tested for their worth as incandescent elements.

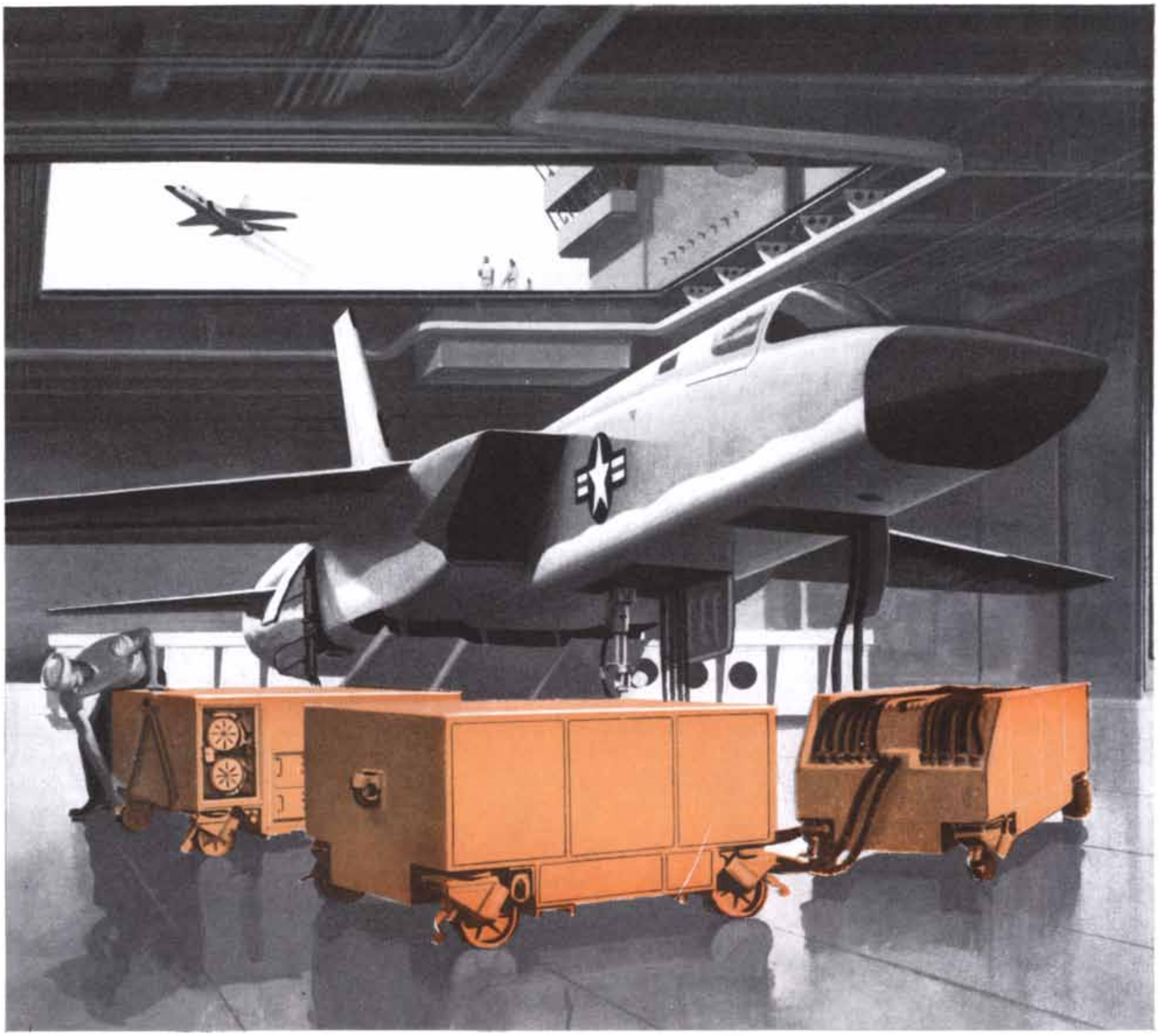
The "Long-Waisted Mary Ann"

To subdivide the electric current for numerous small lights in parallel Edison needed a dynamo which would produce a higher voltage than any dynamo in existence, and which would maintain that voltage constant under varying demands for current from the system. Existing dynamos were designed around the fallacious notion, held by most electrical experts, that the internal resistance of the dynamo must be equal to the external resistance of the circuit. Through study of battery circuits they had proved that a dynamo could attain a maximum efficiency of only 50 per cent. In 1877 a committee of scientists appointed by the Franklin Institute in Philadelphia had been impressed to discover that the most successful European dynamo, designed by Zénobe Théophile Gramme, converted into electricity 38 to 41 per cent of the mechanical energy supplied to it. The efficiency of the Brush dynamo was even lower: 31 per cent. These machines and their theoretically successful contemporaries all produced current at a relatively low voltage.

Edison had concluded, however, that he must produce a dynamo of reduced internal resistance capable of generating current at a high voltage. Such a machine would not only meet the needs of his lighting system but would also convert mechanical energy to electrical energy with far greater efficiency. As his associate Francis Jehl recalled, Edison said that "he did not intend to build up a system of distribution in which the external resistance would be equal to the internal resistance. He said he was just about going to do the *opposite;* he wanted a large external resistance and a low internal resistance. He said he wanted to sell the energy outside the station and not waste it in the dynamo and the conductors, where it brought no profits." Jehl, who carried out the tests



SERIES CIRCUIT (*top*) requires that a number of electric lights (*circles*) be turned on or off at the same time by a single switch (*break in circuit*). Parallel circuit (*bottom*), which was adopted by Edison, makes it possible to turn lights on or off one at a time.



EDISON'S LIGHT.

The Great Inventor's Triumph in Electric Illumination.

A SCRAP OF PAPER.

It Makes a Light, Without Gas or Flame, Cheaper Than Oil.

TRANSFORMED IN THE FURNACE.

Complete Details of the Perfected Carbon Lamp.

FIFTEEN MONTHS OF TOIL.

Story of His Tireless Experiments with Lamps, Burners and Generators.

SUCCESS IN A COTTON THREAD.

The Wizard's Byplay, with Bodily Pain and Gold "Tailings."

HISTORY OF ELECTRIC LIGHTING.

The near approach of the first public exhibition of Edison's long looked for electric light, announced to take place on New Year's Eve at Menlo Park, on which occasion that place will be illuminated with the new light, has revived public interest in the great inventor's work, and throughout the civilized world scientists and people generally are anxiously awaiting the result. From the beginning of his experiments in electric lighting to the present time Mr. Edison has kept his laboratory guardedly closed, and no authoritative account (except that published in the HERALD some months ago relating to his first patent) of any of the important steps of his progress has been made public—a course of procedure the inventor found absolutely necessary for his own protection. The HERALD is now, however, enabled to present to its readers a full and accurate account of his work from its inception to its completion.

A LIGHTED PAPER.

Edison's electric light, incredible as it may appear, is produced from a little piece of paper—a tiny strip of paper that a breath would blow away. Through

FIRST NEWSPAPER ACCOUNT of Edison's brilliant success appeared in *The New York Herald* for December 21, 1879.

of resistance, also remarked that the art of constructing dynamos was then as mysterious as air navigation. All electrical testing was in the embryonic stage. "There were no instruments for measuring volts and amperes directly: it was like a carpenter without his foot rule."

Upton himself had his difficulties in this hitherto unexplored field: "I remember distinctly when Mr. Edison gave me the problem of placing a motor in circuit, in multiple arc, with a fixed resistance; and I . . . could find no prior solution. There was nothing I could find bearing on the [effect of the] counter-electro-motive force of the armature . . . and the resistance of the armature on the work given out by the armature. It was a wonderful experience to have problems given me by him based on enormous experience in practical work and applying to new lines of progress."

The problem of a constant-voltage dynamo was attacked with the usual Edisonian élan. Seeking to visualize every possible structural innovation for his dynamo armature, he had his men lay out numerous wooden dummies on the floor and wind wire around them, spurring them on in their task by laying wagers as to who would finish first.

After Edison had decided upon the form of winding and type of electromagnets to be used, Upton made drawings and tables from which the real armatures were wound and attached to the commutator. Edison eventually worked out an armature made of thin sheets of iron interleaved with insulating sheets of mica; this armature developed fewer eddy currents and so produced less heat than the solid armature cores then used. When the new cores were test-run, it was Upton who made the mathematical calculations from these tests and drew up the final blueprints.

The self-effacing Upton can be given principal credit for interpreting Edison's ideas and translating them into mathematical form. A careful student of contemporary electrical knowledge, he seems to have been conversant with, and to have guided himself by, the design of a German dynamo, made by the Siemens works, that employed an auxiliary source of current to excite its field magnets.

The new Menlo Park dynamo comprised many admirable features for that period. With its great masses of iron and large, heavy wires, it stood in bold contrast to its contemporary competitors. Owing to the two upright columns of its field electromagnets, it was nicknamed "Edison's long-waisted Mary Ann."

When the dynamo was run at the correct speed, the voltage between its armature brushes was approximately 110, and remained fairly constant, falling but slightly when increasing amounts of current were taken out of the machine. Edison and Upton also contrived a simple but ingenious dynamometer by which the torque of a drive belt was used to measure the work output of the steam engine that powered the dynamo. When Kruesi completed the first operating machine, Upton carefully checked the results. To his astonishment—and quite as Edison had "guessed"—the new dynamo, tested at full load, showed 90-per-cent efficiency in converting steam power into electrical energy.

Edison was as jubilant as a small boy. As was usual with him, the world was soon told all about his "Faradic machine." It was described and depicted in SCIENTIFIC AMERICAN for October 18, 1879, in an article written by Upton.

Once more there was scoffing at Edison's "absurd claims." The hectoring of Edison by some of the leading U. S. electrical experts, among them Henry Morton of the Stevens Institute of Technology, now seems traceable to their ignorance. Reading Morton's predictions of failure, Edison grimly promised that once he had it all running "sure-fire," he would erect at Menlo Park a little statue to his critic which would be eternally illuminated by an Edison lamp.

As a matter of fact, this allegedly ignorant "mechanic" was to be found reading scientific journals and institutional proceedings at all hours of the day and night. It was thus that he had learned about the Sprengel vacuum pump. This device enabled him to achieve an increasingly greater vacuum and to test a broad variety of metals, rare earths and carbon compounds under hitherto unexplored conditions.

The globe itself was also much improved, by the inventor's own design, after he had brought to Menlo Park an artistic German glass blower named Ludwig Boehm. Edison one day drew a sketch of a one-piece, all-glass globe whose joint was completely sealed, and late in April, 1879, Boehm, working skillfully with hand and mouth, fashioned it in the small glass blower's shed in back of the laboratory.

"There never has been a vacuum produced in this country that approached anywhere near the vacuum which is necessary for me," Edison wrote in his notebook. After months of effort he could say exultantly: "We succeeded in making a pump by which we obtained a vacuum of one-millionth part of an atmosphere."

In the late summer of 1879 he realized

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TELEPHONE PA 3-7221 • BOX 1717 • MELBOURNE, FLORIDA with growing excitement that a key position had been won. He had a dynamo supplying constant high voltage, and a tight glass globe containing a high vacuum. In his mind's eye he saw what might be done with an extremely fine, highly resistant incandescing substance under these conditions. His state of tension is reflected in the laboratory notebooks by such exclamations as: "S - - - ! Glass busted by Boehm!" All that remained for him was to discover a filament that would endure.

The Carbon Filament

In late August or early September—about a year after he first took up his search—he turned back to experimenting with carbon, this time for good. The rods of carbon he had tried earlier had been impossible to handle, as he now understood, because carbon in its porous state has a marked propensity for absorbing gases. But once he had a truly high vacuum and a method for expelling occluded gases he saw that he might achieve better results with carbon than with platinum.

In a shed in back of the laboratory there was a line of kerosene lamps always burning, and a laborer engaged in scraping the lampblack from the glass chimneys to make carbon cake. But lampblack carbon by itself was not durable enough to be made into fine lamp filaments. Edison and Upton had arrived at the conclusion that, given a 100-volt multiple-arc circuit, the resistance of the lamps should be raised to about 200 ohms; this meant that the filament could be no thicker than a 64th of an inch.

Through the summer months Edison and his staff worked at the tantalizing task of making fine reeds of lampblack carbon mixed with tar. His assistants kept kneading away at this putty-like substance for hours. It seemed impossible to make threads out of it; as an assistant complained one day, the stuff crumbled.

"How long did you knead it?" Edison asked.

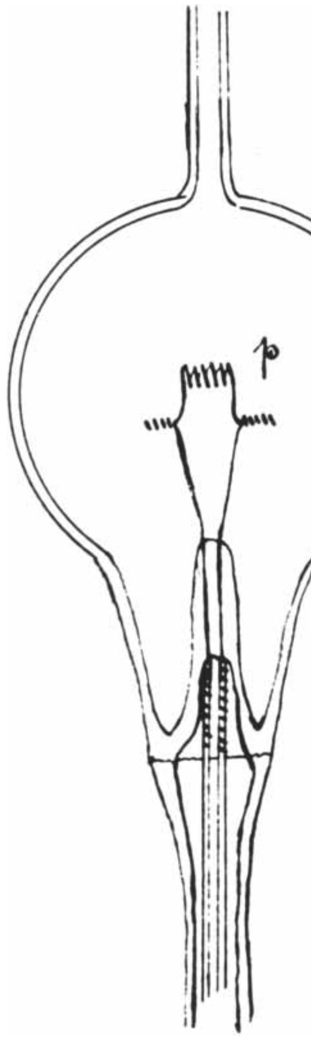
"More than an hour."

"Well just keep on for a few hours more and it will come out all right."

Before long they were able to make filaments as thin as seven thousandths of an inch. Edison then systematically investigated the relations between the electrical resistance, shape and heat radiation of the filaments. On October 7, 1879, he entered in his notebook a report on 24 hours of work: "A spiral made of burnt lampblack was even better than the Wallace (soft carbon) mixture." This was indeed promising: the threads lasted an hour or two before they burned out. But it was not yet good enough.

As he felt himself approaching the goal Edison drove his co-workers harder than ever. They held watches over current tests around the clock, one man getting a few hours' sleep while another remained awake. One of the laboratory assistants invented what was called a "corpse-reviver," a sort of noise machine that would be set going with horrible effect to waken anyone who overslept. Upton said that Edison "could never understand the limitations of the strength of other men because his own mental and physical endurance seemed to be without limit."

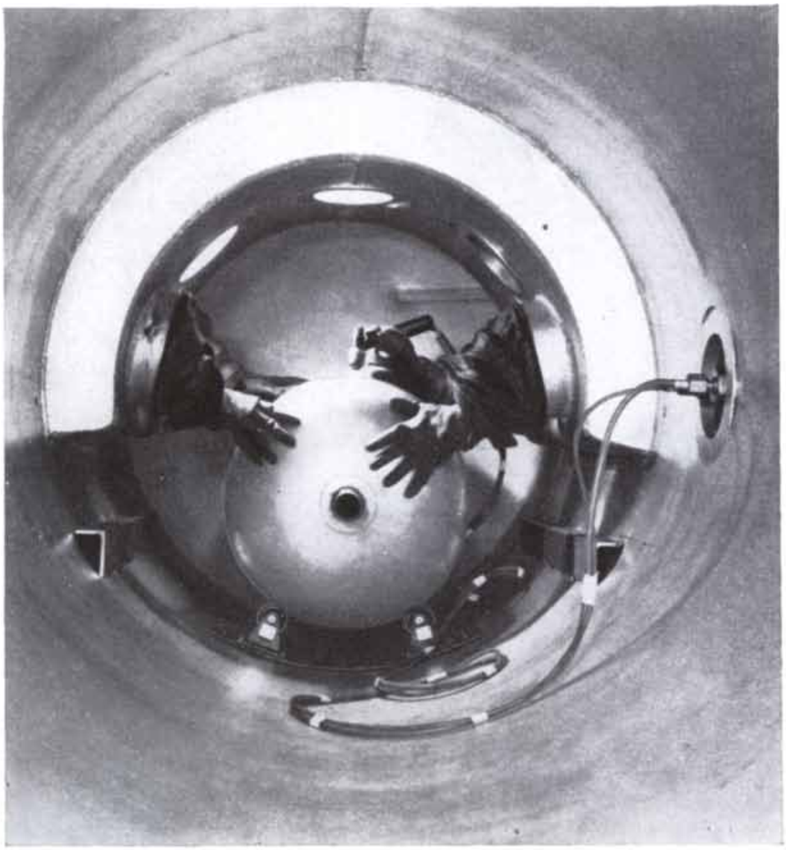
The laboratory notebooks for October, 1879, show Edison's mood of anticipation pervading the whole staff. He pushed on with hundreds of trials of fine filaments, so attenuated that no one could conceive



EARLY EXPERIMENTAL LAMP is depicted in one of Edison's notebooks. This lamp had a filament of platinum. It melted.

HAYNES ALLOYS

RESEARCH REPORTS



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"Haynes," "Haynes Stellite," and "Union Carbide" are registered trade-marks of Union Carbide Corporation how they could stand up under heat. Finally he tried various methods of treating cotton threads, hoping that their fibrous texture might give strength to the filament even after they had been carbonized. Before heating them in the furnace he packed them with powdered carbon in an earthenware crucible sealed with fire clay. After many failures in the effort to clamp the delicate filament to platinum lead-in wires, Edison learned to mold them together with lampblack and then fuse the joint between them in the act of carbonization.

Then, as Edison later related, it was necessary to take the filament to the glass blower's shed in order to seal it within a globe: "With the utmost precaution Batchelor took up the precious carbon, and I marched after him, as if guarding a mighty treasure. To our consternation, just as we reached the glass blower's bench, the wretched carbon broke. We turned back to the main laboratory and set to work again. It was late in the afternoon before we produced another carbon, which was broken by a jeweler's screwdriver falling against it. But we turned back again and before nightfall the carbon was completed and inserted in the lamp. The bulb was exhausted of air and sealed, the current turned on, and the sight we had so long desired to see met our eyes."

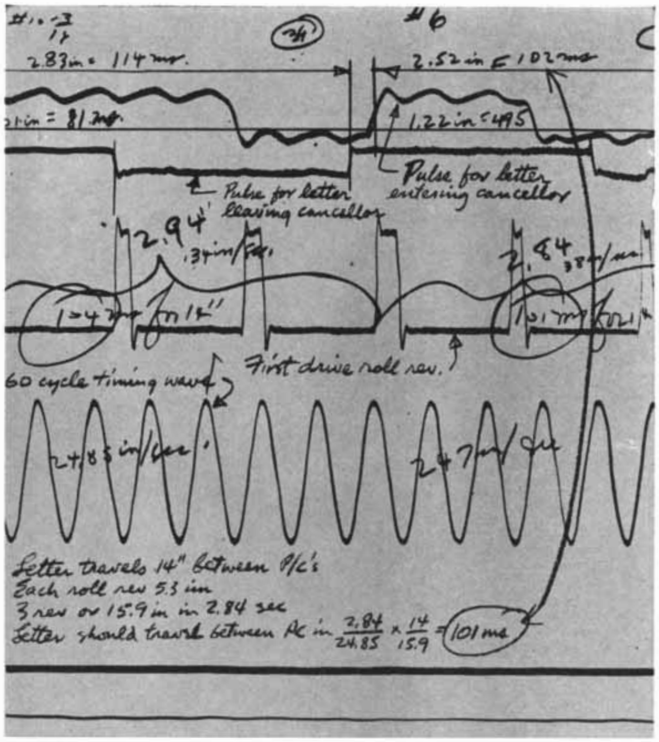
"Ordinary Thread"

The entries in the laboratory notebooks, although bare and impersonal, nonetheless convey the drama and sense of triumphant resolution pervading the laboratory that night: "October 21—No. 9 ordinary thread Coats Co. cord No. 29, came up to one-half candle and was put on 18 cells battery permanently at 1:30 A.M. . . . No. 9 on from 1:30 A.M. till 3 P.M.—13½ hours and was then raised to 3 gas jets for one hour then cracked glass and busted."

As the light went out the weary men

FRANCIS R. UPTON made invaluable calculations for Edison's system. An electrical engineer who had studied with Hermann von Helmholtz, he was named "Culture" by Edison.

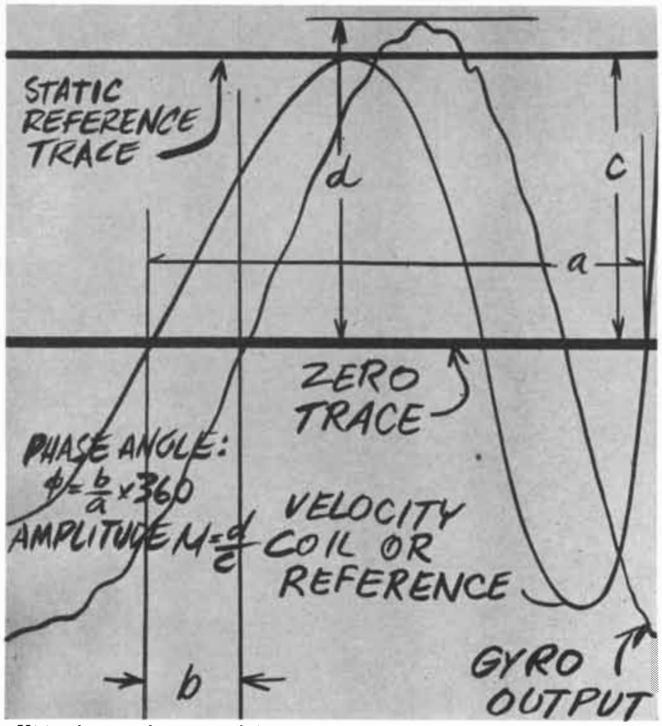
In development test . . .
This directly-recorded Visicorder chart shows a canceller test of a number of letters through a new mail-handling machine developed by Emerson Research Laboratories for the U.S. Post Office Department. The Visicorder test took only 3 hours to solve a 3-week problem: Why letters changed speed as they went through the machine. Constant speed is necessary to register cancellation on the stamp every time. Motor speed variations, belt slippage, and letter slippage in the drive rollers were responsible. A synchronous drive motor, a timing-belt drive, and a better grade of rubber in the drive rollers were added to solve the problem at a vast saving in engineering time. The Emerson machine is designed to cancel 30,000 non-uniform letters per hour. It is under evaluation tests in the Post Office Department Laboratory, Washington, D.C.



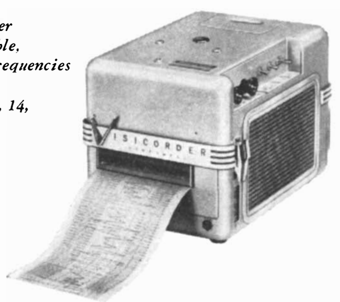
these are records of leadership

In production . . .
This comparison test of a production gyroscope was directly-recorded on a Model 906A Visicorder oscillograph by the test department of Whittaker Gyro, Van Nuys, Calif. Whittaker is a division of Telecomputing Corporation. The record shows how the Visicorder compares controlled angular velocities as a reference base to simultaneously-recorded variables, and how a dual static reference trace galvanometer simultaneously establishes a base line and a calibration line on the chart. In these and in hundreds of other scientific and industrial applications, Visicorders are bringing about new advances in product design, computing, control, rocketry, nucleonics and production.

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



Visicorder records 2/3 actual size.



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Honeywell

Industrial Products Group

Reference Data: Write for Visicorder Bulletins 906A and 1012.

Minneapolis-Honeywell Regulator Co., Industrial Products Group, Heiland Division, 5200 E. Evans Ave., Denver 22, Colorado waiting there jumped from their chairs and shouted with joy. Edison, one of them recalled, remained quiet and then said: "If it can burn that number of hours I know I can make it burn a hundred." Yet all the workers at Menlo Park—Edison, Upton, Kruesi, Boehm and the rest—were completely astonished at their success. They had become accustomed to laboring without hope. "They never dreamed," as one contemporary account put it, "that their long months . . . of hard work could be ended thus abruptly, and almost by accident. The suddenness of it takes their breath away."

For once Edison tried to be discreet and keep his momentous discoveries a secret until he could improve upon his lamp filament. At length, after experimenting with various cellulose fibers, he found that paper, in the form of tough Bristol cardboard, proved most enduring when carbonized. Edison was exultant when this filament burned for 170 hours, and swore that he would perfect his lamp so that it would withstand 400 to 1,000 hours of incandescence before any news of it was published.

On November 1, 1879, he executed a patent application for a carbon-filament lamp. Its most significant passage was the declaration: "The object of the invention is to produce electric lamps giving light by incandescence, which lamps shall have high resistance, so as to allow the practical subdivision of the electric light. . . . The invention consists in a light-giving body of carbon wire . . . to offer great resistance to the passage of the electric current, and at the same time present but a slight surface from which radiation can take place." The specifications called for a distinctive one-piece all-glass container, lead-in wires of platinum that passed through the glass base and were fused to the carbon filament, and joints that were sealed by fusing the glass.

Here were the essential features of the basic Edison carbon-filament lamp, in the form that was to be known to the world during the next half century. It was not the "first" electric light, nor even the first incandescent electric lamp. It was, however, the first practical and economical electric light for universal domestic use.

Edison had spent more than $42,000 on his experiments—far more than he had been advanced by his backers. Now he asked for more money so that he might complete a pilot light-and-power station at Menlo Park. But the directors were still uncertain about the future of the invention. Was it "only a laboratory toy," as one of them charged? Would it not need a good deal of work before it became marketable? Grosvenor Lowrey stoutly defended his protégé. He got no results until he prematurely, and over Edison's objections, made the secret of the electric lamp public.

Rumors had been spreading for several weeks. New Jersey neighbors told of brilliant lights blazing all night at Menlo Park, and railroad passengers between New York and Philadelphia also saw the bright lights with astonishment from their train windows. In Wall Street there was a flurry of speculation in Edison stock; the price rose briefly to $3,500 a share.

Then came a front-page story in *The New York Herald* on Sunday, December 21, 1879. There followed an exclusive article about the inventor's struggles for the past 14 months, told to the world, *con amore*, by Marshall Fox, who had written much of Edison before. The detailed treatment of such an adventure in applied science as a feature story was something of an innovation. Also somewhat unusual in the journalism of the time was its relative accuracy of detail, owing to help provided by Upton, who also supplied drawings for the *Herald's* Sunday supplement. The writer did his best to explain how this light was produced from a "tiny strip of paper that a breath would blow away"; why the paper filament did not burn up but became as hard as granite; and how the light-without-flame could be ignited—without a match—when an electric current passed through it, giving a "bright, beautiful light, like the mellow sunset of an Italian autumn."

In the week following Christmas hundreds of visitors made their way to the New Jersey hamlet. Edison hurried with his preparations for an announced New Year's Eve display as best he could, but was forced to use his whole staff of 60 persons to handle the crowds. He could do no more than put on an improvised exhibition, with only one dynamo and a few dozen lights.

The closing nights of the year 1879 turned into a spontaneous festival that reached its climax on New Year's Eve, when a mob of 3,000 sight-seers flooded the place. The visitors never seemed to tire of turning those lights on and off.

The inventor promised the sight-seers that this was but a token of what was in store. He was awaiting the completion of a new generator, he said, and intended to illuminate the surroundings of Menlo Park, for a square mile, with 800 lights. After that he would light up the darkness of the neighboring towns, and even the cities of Newark and New York.

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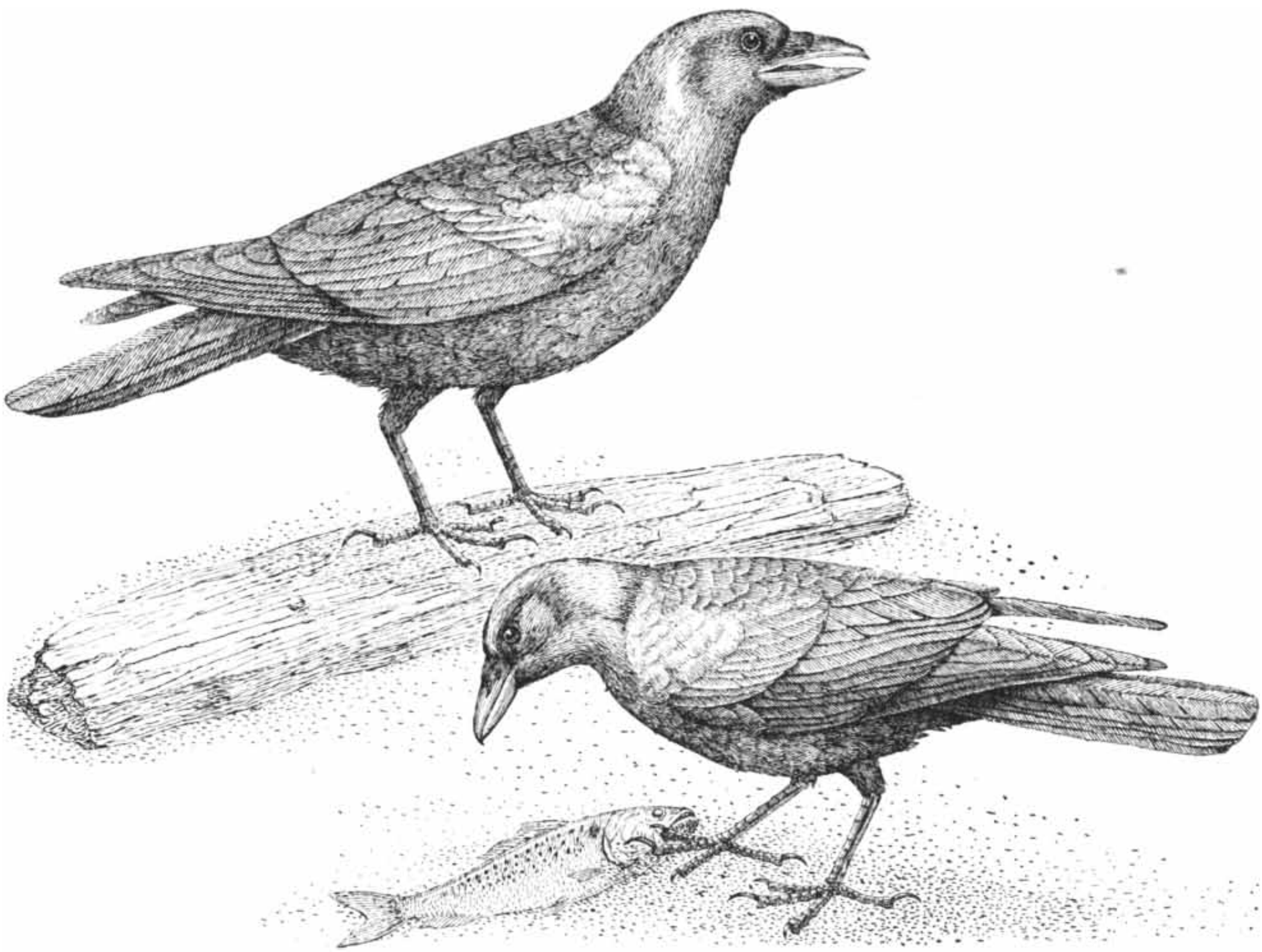
The Language of Crows

One group of American eastern crows responds to recorded distress calls of French jackdaws, but another group does not. The more cosmopolitan life of the former may account for this difference

by Hubert and Mable Frings

A person who has spent all his life in one place and has heard only his local dialect may find it difficult to understand people speaking other dialects of his own language. A person who has traveled more widely, on the other hand, may understand not only other dialects, but also words in languages he does not know. Recently we have been studying the calls of crows and have found a corresponding distinction between the provincial and the cosmopolitan members in this ubiquitous family of birds. For example, American eastern crows that breed in Pennsylvania and winter in the southern states among fish crows will respond to the distress call of the French jackdaw, a relative they have never seen. Eastern crows that breed in Maine and never live with other crows do not react to the cry of the French bird.

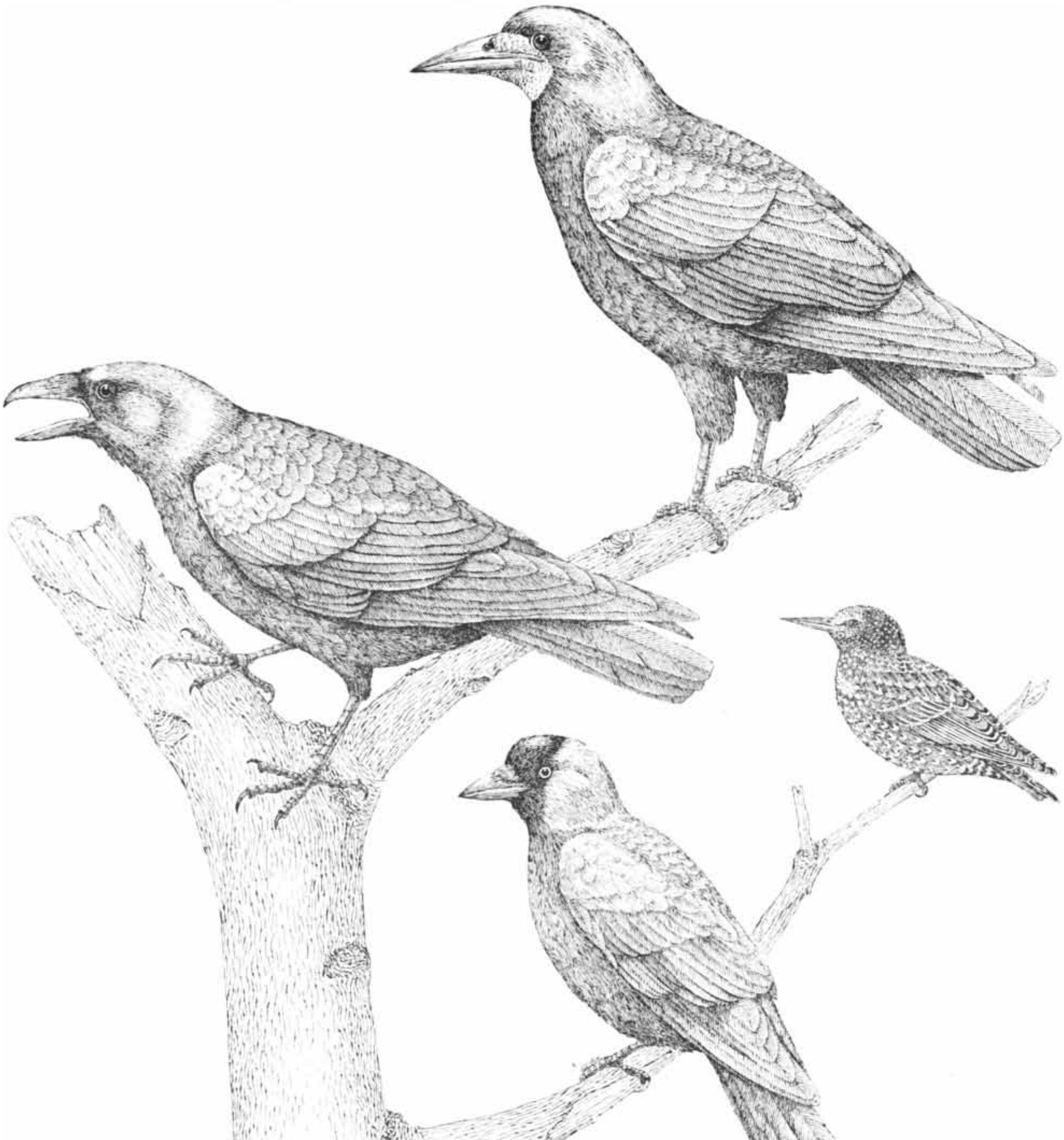
We have been studying international understanding among birds by exchang-



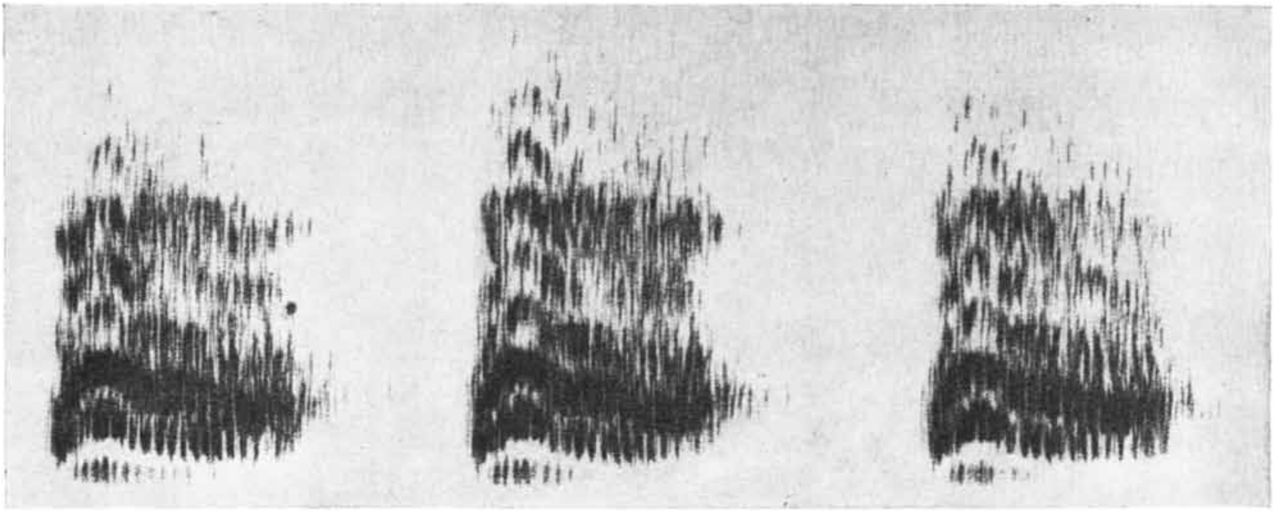
TWO CROWS that live together in southern coastal regions during winter are the fish crow (*with fish*) and the American eastern crow. The latter learns to respond to calls of the fish crow and later "understands" the recorded distress cry of French jackdaws.

ing tape recordings with René-Guy Busnel, Jacques Giban and Philippe Gramet of the Laboratoire de Physiologie Acoustique in Jouy-en-Josas, near Paris. From our laboratory at the Pennsylvania State University College of Agriculture we sent to France recordings of two different calls of the American eastern crow. Busnel and his colleagues sent us the distress calls of three French crows: the so-called jackdaw, the rook and the carrion crow, which live together in winter in mixed flocks. All four birds are members of the genus *Corvus*, but are of different species. We shall call them all crows for convenience, though it is not strictly accurate to do so.

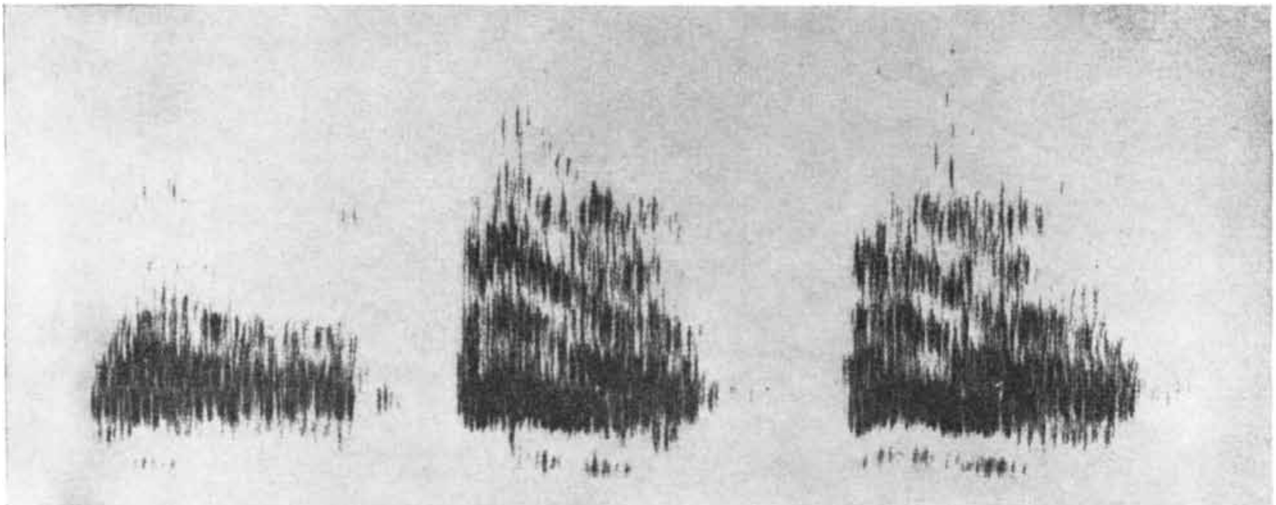
To make our recordings we concealed microphones in places near the Mount Desert Island Biological Laboratory at Salisbury Cove, Me., where the birds rested or fed. The process was slow and taxed our patience; whole reels of tape were often devoid of any recognizable cries. However, we did learn a good deal about the behavior of crows during these sessions, and we frequently recorded



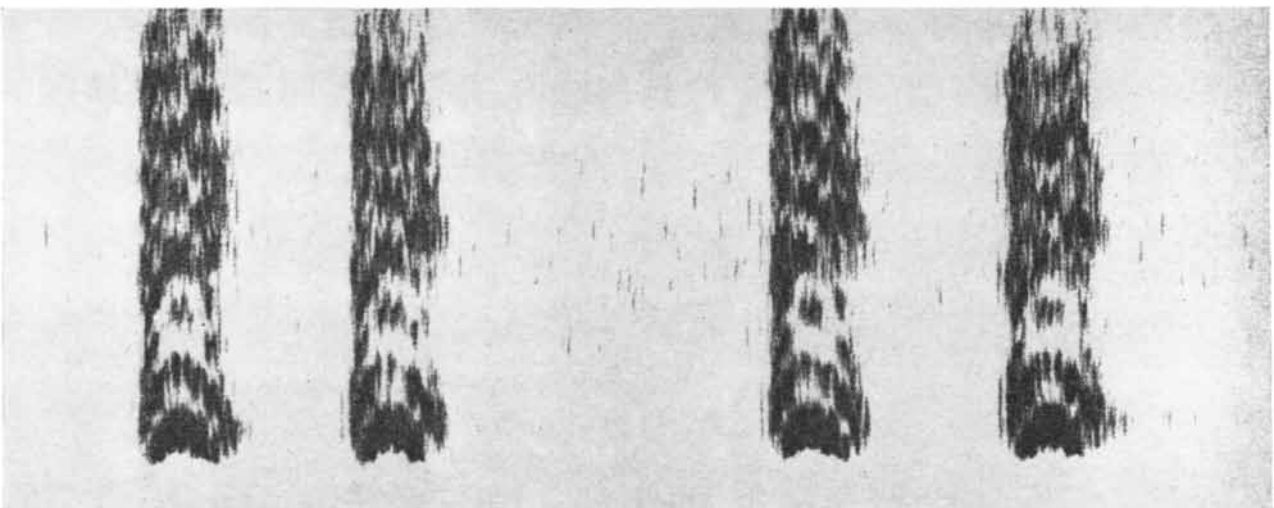
THREE FRENCH "CROWS" that understand each other are the rook (*top*), the carrion crow (*center*) and the jackdaw. The smaller bird on twig at right is the European starling. These birds and American crows on preceding page are drawn to the same scale.



CAW OF THE CROW is shown here in a sound spectrogram made at the Bell Telephone Laboratories from recordings supplied by the authors. Frequencies are shown vertically and time horizontally. A crow will emit only one to five caws at any one time.



ASSEMBLY CALL of the American eastern crow is usually given hundreds of times over several minutes. Here it has a smeared-out pattern like the caw, indicating that it too is quite raucous. Songbird calls create much more delicate spectrogram patterns.



ALARM CALL of the same crow is short and generally falls in a higher frequency-range than the caw and the assembly call. The darker areas in these spectrograms indicate frequencies at which the crow produces sound that most nearly resembles a definite note.

whispered sounds not ordinarily heard by man. Crows are great conversationalists, if we can assume that all their sounds have meaning. From our tapes we finally selected four distinct cries to play back to the birds. We transferred these to continuous-loop tape cartridges that play the same sound over and over. Then we broadcast the cries through a loudspeaker. Two of the calls drew no observable response. The third caused flocks of crows to gather nearby, while the fourth dispersed them. We labeled these two cries the assembly call and the alarm call respectively. A crow that sees an enemy such as an owl or a cat becomes very excited and gives the assembly call. This happens fairly often, so we had no trouble recording the call. The crows give their alarm or dispersal call only rarely, however, and we spent a month obtaining a satisfactory tape of it.

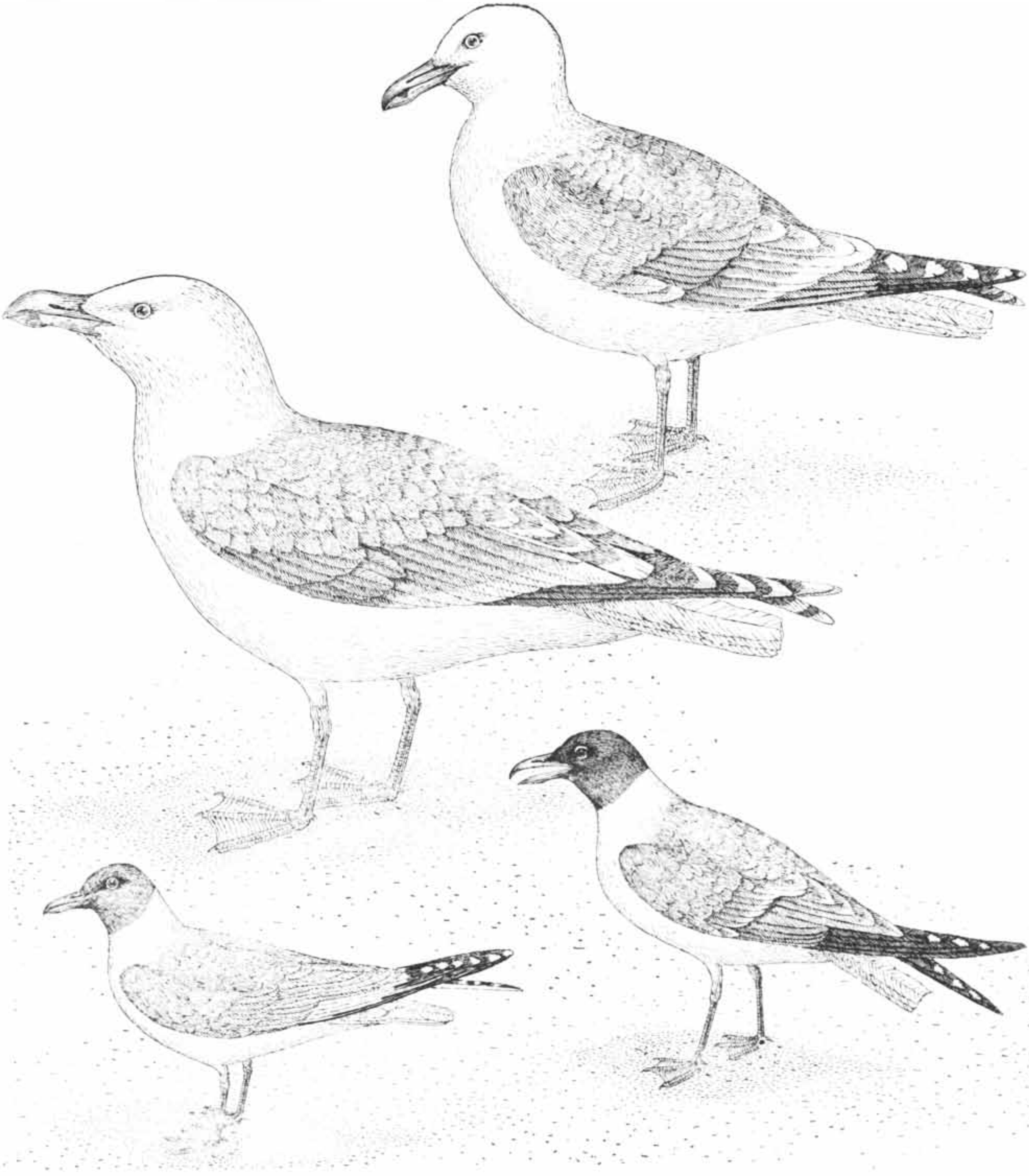
To test our recordings we took our loops of tape and loudspeaker to a spot where we could see no crows for some distance around. Within a few minutes after we had broadcast the assembly call, groups of crows appeared, gathering where they could see us. They would come closer, we found, if we put a stuffed owl out in plain view. The crows would then wait around, talking among themselves. When we wanted to get rid of them, we played the alarm call, and away they went.

The French workers had tested several calls of their crows and then concentrated on what they called the distress cry. Such a call is given by each of the three species of French crow when one of the birds is held by a man or attacked by a falcon. In response to the call as given by any one of the three species, members of all of the species would first approach the loudspeakers and then withdraw singly or in a group. In 1955 we sent Busnel our tape of the assembly and alarm calls. His group discovered that all three French species respond to the assembly call just as they respond to their own distress cries. The French birds, however, did not react at all to the American crow's alarm call. We found it quite remarkable that the French birds had responded to even one of the calls of the American crow.

That same summer we received tapes from Busnel and broadcast them to American eastern crows in Maine. The birds ignored all three French distress calls in repeated tests under varied conditions all over the island. Yet the crows gathered around each time we played the assembly call of the American eastern crow, and they dispersed when we played the alarm call. We repeated these tests in Pennsylvania during the winter of 1955-56, with the same results. Obviously American eastern crows did not understand the Gallic crows. This observation was interesting but not too enlightening. What happened next, however, was downright puzzling.

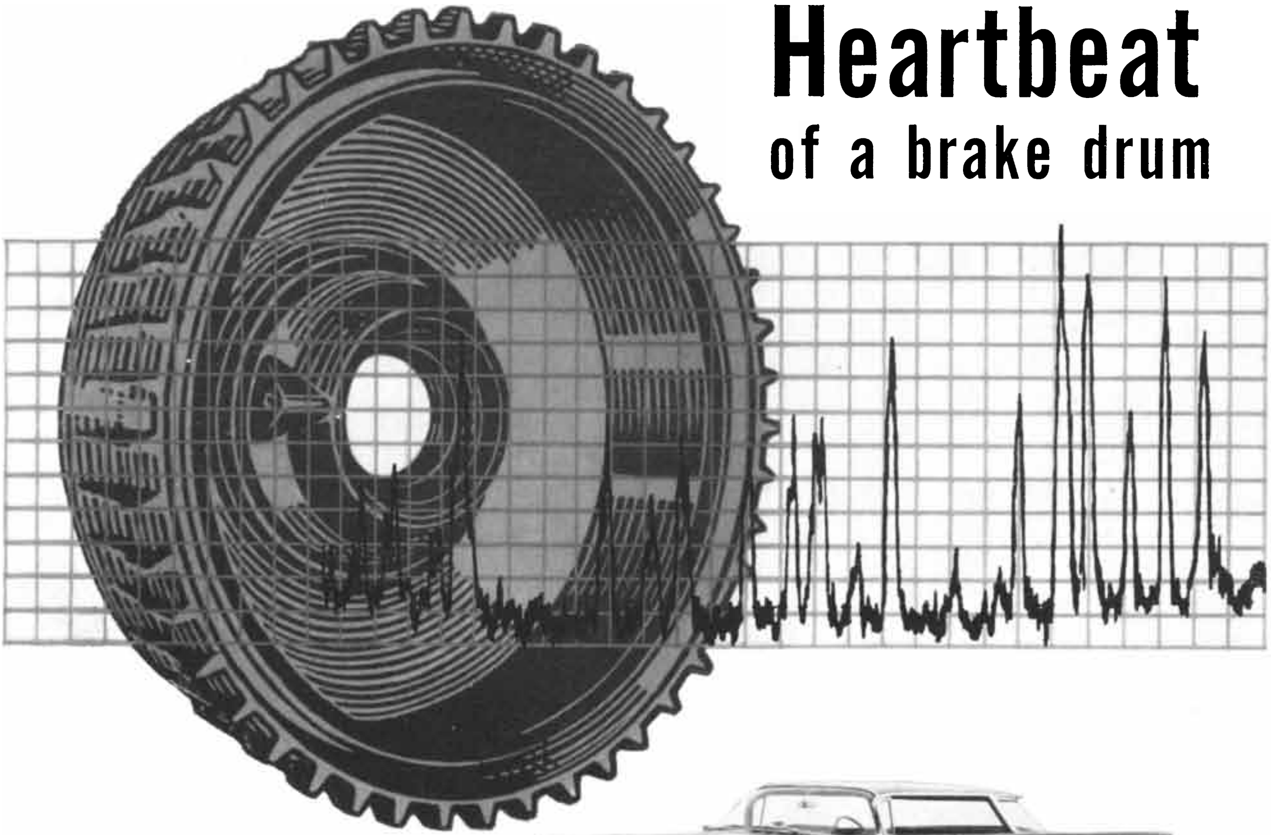
In the spring of 1956 Busnel came to visit our laboratory and brought a new recording of the distress cry of the jackdaw that he and his co-workers were using for most of their tests. To demonstrate to him the total lack of reaction of American crows to the French signal, we broadcast the tape in early June in the mountains of central Pennsylvania. To our amazement, crows assembled.

We thought that perhaps this new recording had something the old one lacked. We could not tell the difference, but maybe the birds could. Then we tested the old jackdaw recording that had previously produced such clearly



FOUR GULLS that were tested by the authors for responses to various calls are shown in this drawing. At top is the herring gull. The large bird in the center is the great black-backed gull. At bottom left is the black-headed gull; at bottom right, the laughing gull.

Heartbeat
of a brake drum



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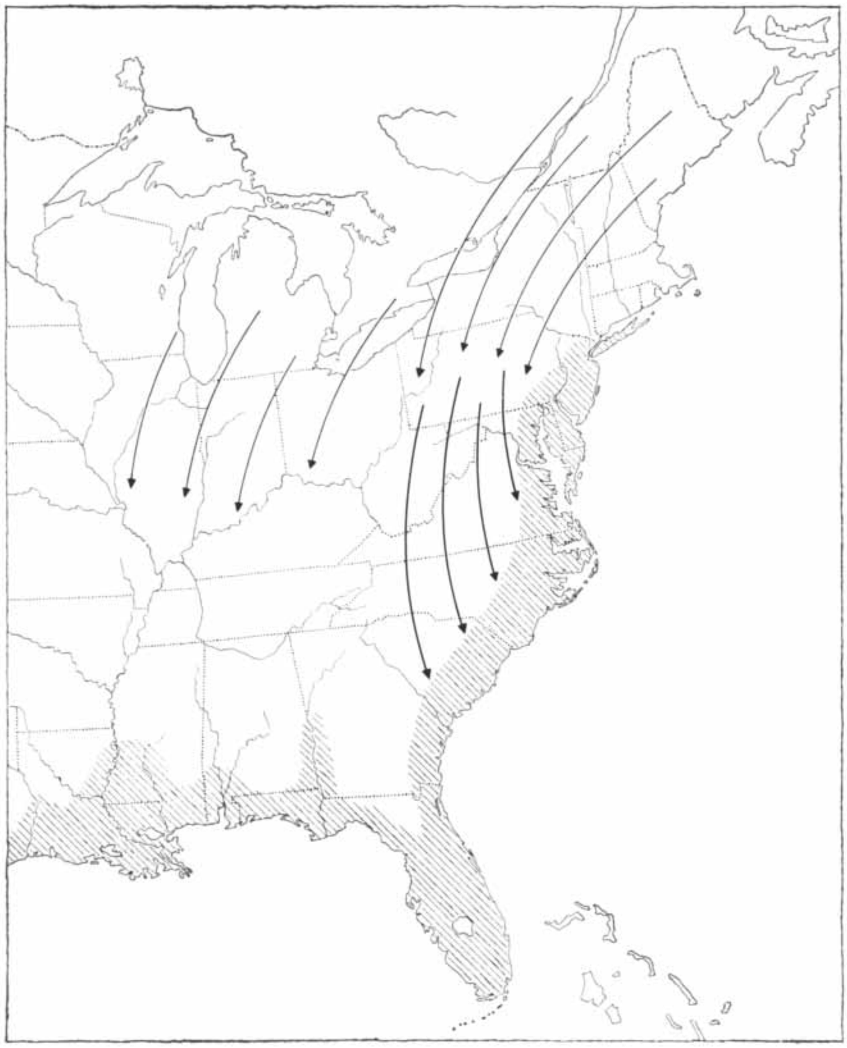

EASTERN CROWS GO SOUTH FOR WINTER, as indicated by the arrows on this map. Those from Canada and New England move into New York and Pennsylvania, where there are no other varieties of crow. Pennsylvania crows move into southern coastal areas with fish crows. Hatched area along Eastern and Gulf coasts indicates range of the fish crow.

negative results. This, too, now attracted the American crows! What had happened?

We considered the possibility that the crows were merely jumpy and responsive to any strange noise, since they were breeding and were simultaneously being heavily hunted by farmers. To try out this idea we broadcast many recorded sounds—the quacks of ducks, the cries of herring gulls, the distress calls of starlings and even the whine of mosquito wings and the chirps of crickets. The crows ignored all of these. Obviously American eastern crows now understood the distress cry of the French jackdaw, but why?

Two other ideas seemed worthy of investigation: that the new reaction was seasonal, possibly related to the breeding cycle, or that the reaction was geographical. To test both hypotheses simultaneously we took our equipment to Maine to broadcast the jackdaw distress-call to the Yankee crows. They were breeding, as were the crows in Pennsylvania, whereas they had been past the breeding season when we tested them in 1955. The Maine crows, however, did not understand French crows any better in the breeding season than they did at any other time.

The crows we had tested in winter in Pennsylvania had also ignored the jackdaw call. We were forced to consider how the crows that live in Pennsylvania in the spring differ from those living there in the winter. The answer, we decided, can be found in the seasonal movements of the crow population. In general all eastern crows move southward when cold weather comes. The

birds from New England move into New York and Pennsylvania, and those that breed in Pennsylvania fly to the southern states. Thus the crows we had tested in winter in Pennsylvania probably had essentially the same background as those we tested in Maine in the summer. We could therefore expect similar reactions.

But what of the crows found in Pennsylvania during the spring? The results of the tests in France helped us form a reasonable hypothesis about these. The three different French species responded to each other's calls apparently because they fed and roosted together in large communal flocks. It seemed probable that they had learned to respond not only to the specific features of their own signals but also to the more general characteristics of crow signals, since the distress calls of most crows are similar. They therefore reacted as if to their own distress calls when they heard the assembly call that is given by the American crow under similar circumstances. The French workers even cut the tape-recorded French calls in half or played them backward; their birds still assembled, plainly indicating that their response was to the most general features of the calls. Had our Pennsylvania crows been in circumstances during the winter that might have enabled them to learn the calls of related species?

The answer seems to be that they had. A second species of crow, the fish crow, lives in the southern states; the eastern crow from Pennsylvania moves in with it in the winter. The fish crow of course has its own calls. They are much coarser than the cries of the eastern crow and are more like the calls of the French birds. But the basic patterns of fish-crow calls are like those of its cousin from the northeastern states. The most reasonable hypothesis would therefore seem to be that the crows in Pennsylvania in the spring have just returned from their southern sojourn, during which they were probably exposed to the calls of the fish crow. They had thus learned to respond to the more general features of crow calls. These particular American eastern crows, then, would react to the calls of their French relatives. The crows from Maine, on the other hand, had not lived with other crows at any time of the year and so did not react to the calls of other species.

This means that the reactions to the calls are at least partly learned by the crows and are not strictly inborn. W. H. Thorpe and his students at the University of Cambridge and Donald J. Borror of Ohio State University have shown

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that the basic patterns of bird songs are inborn, but features that differentiate the calls and songs of individual birds seem to be the result of copying from other individuals [see "The Language of Birds," by W. H. Thorpe; SCIENTIFIC AMERICAN, October, 1956]. It is probable that reactions to calls are also partly inborn and partly learned.

Our observations of crows and herring gulls in Maine support this idea. On Mount Desert Island the two species rarely feed together, and each responds only to broadcasts of its own calls. But on the nearby Schoodic Peninsula tourists feed both the crows and the gulls, and the birds fraternize. There the two unrelated species respond to each other's calls. We have additional evidence from other birds that the response to calls can be learned. Sometimes a few cowbirds and blackbirds roost with flocks of starlings, and they will respond to the starling distress-call just as starlings do–by leaving the roost and even by staying away if the call is broadcast under the proper conditions. In Maine herring gulls and great black-backed gulls live together, with the former by far predominating. We have found that the black-backs always respond to the herring gull's calls. In New Jersey the laughing gull lives with the herring gull and similarly responds to its cries.

We have also encountered the reverse situation, in which members of the same species do not respond to calls from other members of the same species. In 1954 we studied the cries of the herring gull in Maine and found calls that induced clearly identifiable responses. The gull emitted a distinctive cry upon sighting food, and this attracted large numbers of other gulls. Another cry, given when a gull sights a captive or dead gull, scatters the flock. Our broadcasts of recordings of these calls attracted or repelled herring gulls at distances of at least a mile over open water. In 1955 and 1956 Busnel broadcast our recordings of these two calls to flocks of exactly the same species of gull and to flocks of the related black-headed gull, both of which live on the French coast. Busnel had seen the clear-cut reactions in Maine, but he found that the French gulls completely ignored these American calls, even when he broadcast them at high intensities at close range. Apparently the signals of the herring gull living in Europe differ from the calls of its brothers and sisters in the U.S. Investigators who have heard gulls in Europe tell us that the calls are similar to but not exactly like those of the American gulls. If this is the true explanation, we have found dialects or brogues within the same species.

It would be satisfying to be able to tie all these facts and ideas together in some principles of avian linguistics. Unfortunately we cannot yet do this. We should have tape recordings of bird calls from birds of known sex and age taken throughout the geographic ranges of the species. Then we could test for local dialects and perhaps discover the significance of these in the general patterns of communication within the bird population. Such recordings must in turn be tested with related and unrelated species in many places. These studies may incidentally give us the means to control crows and other birds in situations where they become nuisances. Working out the details of such controls for crows, gulls, starlings and other birds is a technical problem that can be solved.

It is from the standpoint of fundamental biology, however, that recorded communication signals of birds, insects and other creatures hold the most promise. The tape recordings can add a new dimension to our studies: time. We can store recordings, and workers perhaps a century in the future can compare calls then and now. In fact, there is already a growing international repository of such recordings at Cornell University.

Through recordings we can study certain aspects of evolution without waiting for a century to pass. For example, many animals use sound for sexual signaling, and the first step in the evolution of a new species may be a change in sound production by deviant individuals. If these patterns were genetically determined, they could result in selective mating, producing a separate breeding population within a general population of individuals having a similar appearance. The student who bases his classifications on structure alone would see the population as relatively uniform and would think that its members bred freely with each other. Once this behavioral isolation had occurred—and acoustical behavior is only one of many types of sexual behavior by which this could happen—it would be only a matter of time until other genetic changes produced structural differences within the subpopulations. Thus seemingly uniform populations, as judged by structure alone, may in reality be composed of subgroups of differing degrees of separateness. Studies of insects and amphibia by Busnel and others tend to support this concept. Further work along these lines should produce details of which we have only hints today.

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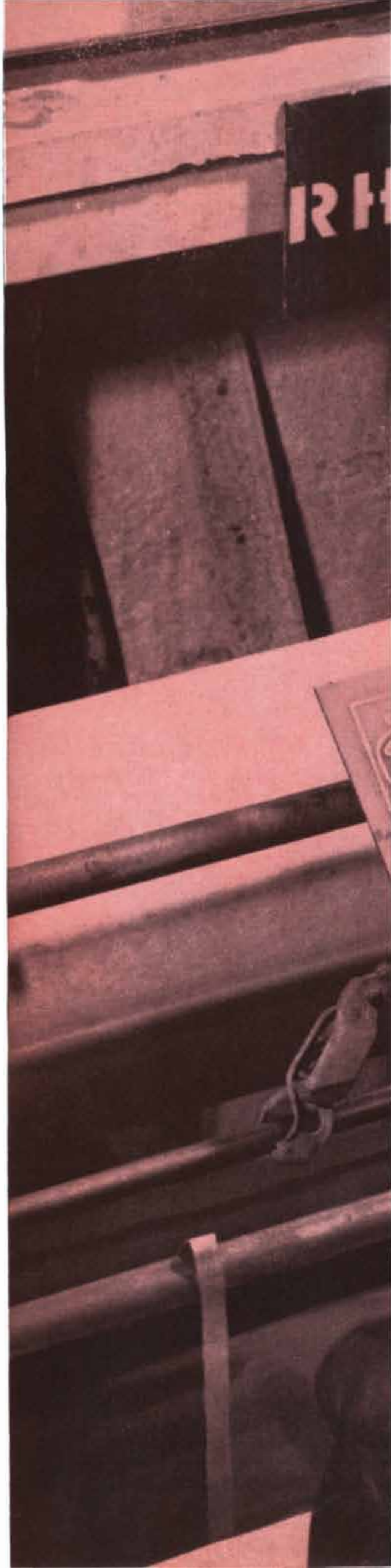

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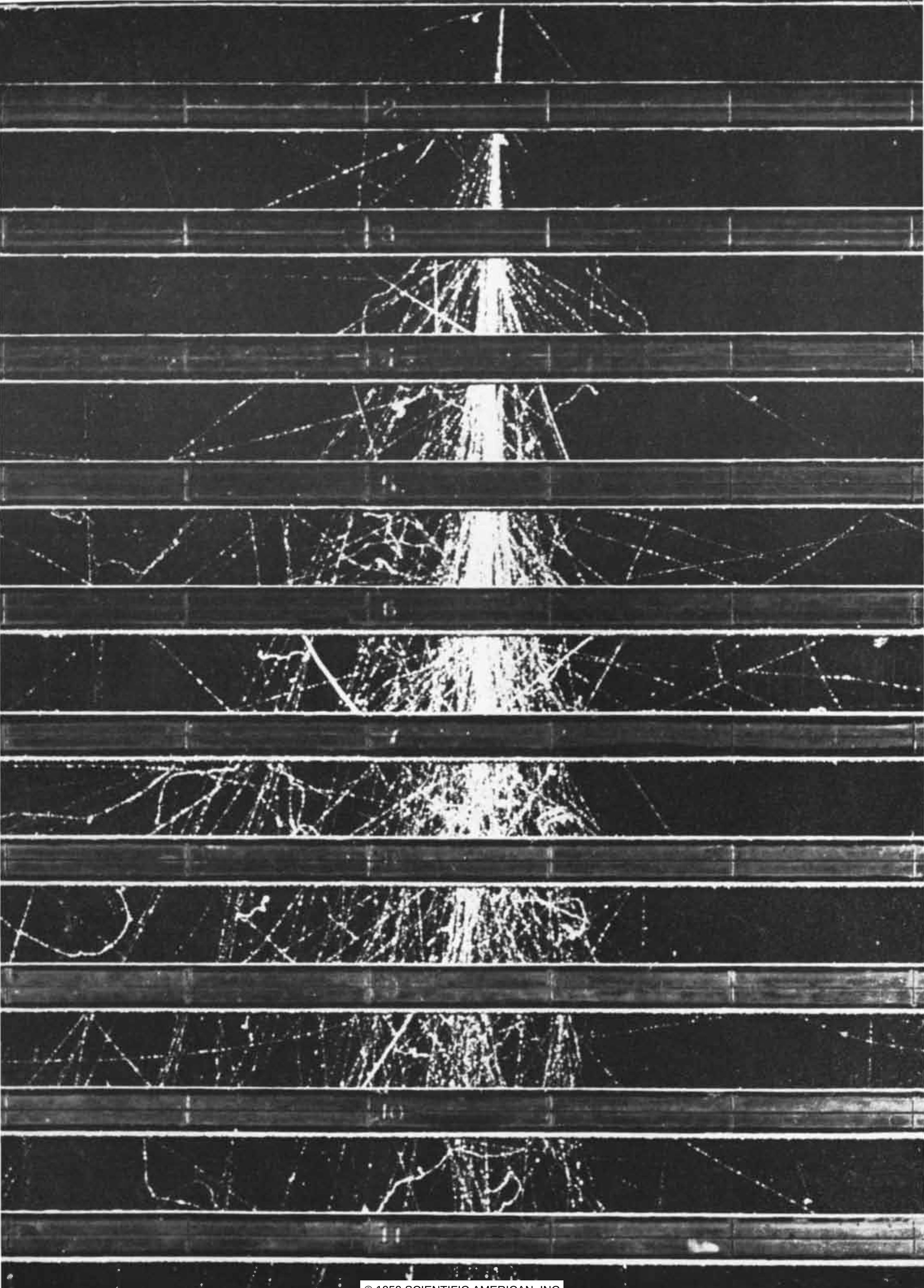


HIGH-ENERGY COSMIC RAYS

Coming from outer space with energies greater than a billion billion electron volts, they provide a clue to the origin of cosmic radiation and suggest a new picture of our galaxy

by Bruno Rossi

Every second nearly a billion billion cosmic-ray particles plunge into the earth's atmosphere from space. An overwhelming majority of them have about as much energy as the particles produced by today's most powerful accelerators: a few billion electron volts. But a tiny fraction of the cosmic rays have somehow been pushed to energies enormously greater than the average—more than a billion times greater. Astrophysicists are keenly interested in these few particles of exceptionally high energy; they may furnish a key to the still-unsolved puzzle of the origin of cosmic radiation.

The chief difficulty we face in trying to find out where cosmic rays come from is that the directions from which they bombard the earth have no discernible connection with their possible points of origin. As they travel through space the charged particles (bare hydrogen nuclei, or protons, together with a few heavier nuclei, also stripped of their electrons) are acted upon by interstellar magnetic fields. These fields force them into spiral paths [*see top illustration on page 138*]. The lower the energy of a particle, the tighter its spiral. Those arriving at the earth with energies of a few billion electron volts have twisted so many times that their paths give no indication of where they started from. Some cosmic rays can be identified as coming directly from the sun during periods of violent solar activity. The rest arrive in equal numbers from all directions. But this does not necessarily mean that their sources are evenly distributed. It can be explained by the magnetic scrambling of their directions.

COSMIC-RAY SHOWER is seen developing in a cloud chamber. Metal plates (*horizontal bars*) provide a dense collection of nuclei and increase the frequency of collisions. High-energy particle struck upper plate, producing bundle of electron tracks at top. Most of the subsequent tracks are also paths of electrons.

As we have mentioned, the curvature of interstellar trajectories depends on energy. The greater the energy, the less the particle is deflected. At very high energies the particles will travel along almost straight lines and thus reveal the direction of their source.

There are at present two competing theories of the origin of cosmic radiation [see "Where Do Cosmic Rays Come From?," by Bruno Rossi; SCIENTIFIC AMERICAN, September, 1953]. According to one theory the particles are emitted with their full energies by certain localized objects in our galaxy, such as supernovae. The low-energy portion of this radiation will be thoroughly deflected, and will give no hint as to its source. But the "stiffer" high-energy particles should tell a different story. When the radius of curvature of the spiral paths becomes comparable with the thickness of the galactic disk (about 1,000 light-years), then particles moving toward the boundaries of the galaxy will pass freely out into extragalactic space rather than curve inward again. From the strength of the galactic field (several millionths of a gauss) we can calculate the energy at which this should begin to happen. It turns out to be between 10^{17} (100 million billion) and 10^{18} (one billion billion) electron volts.

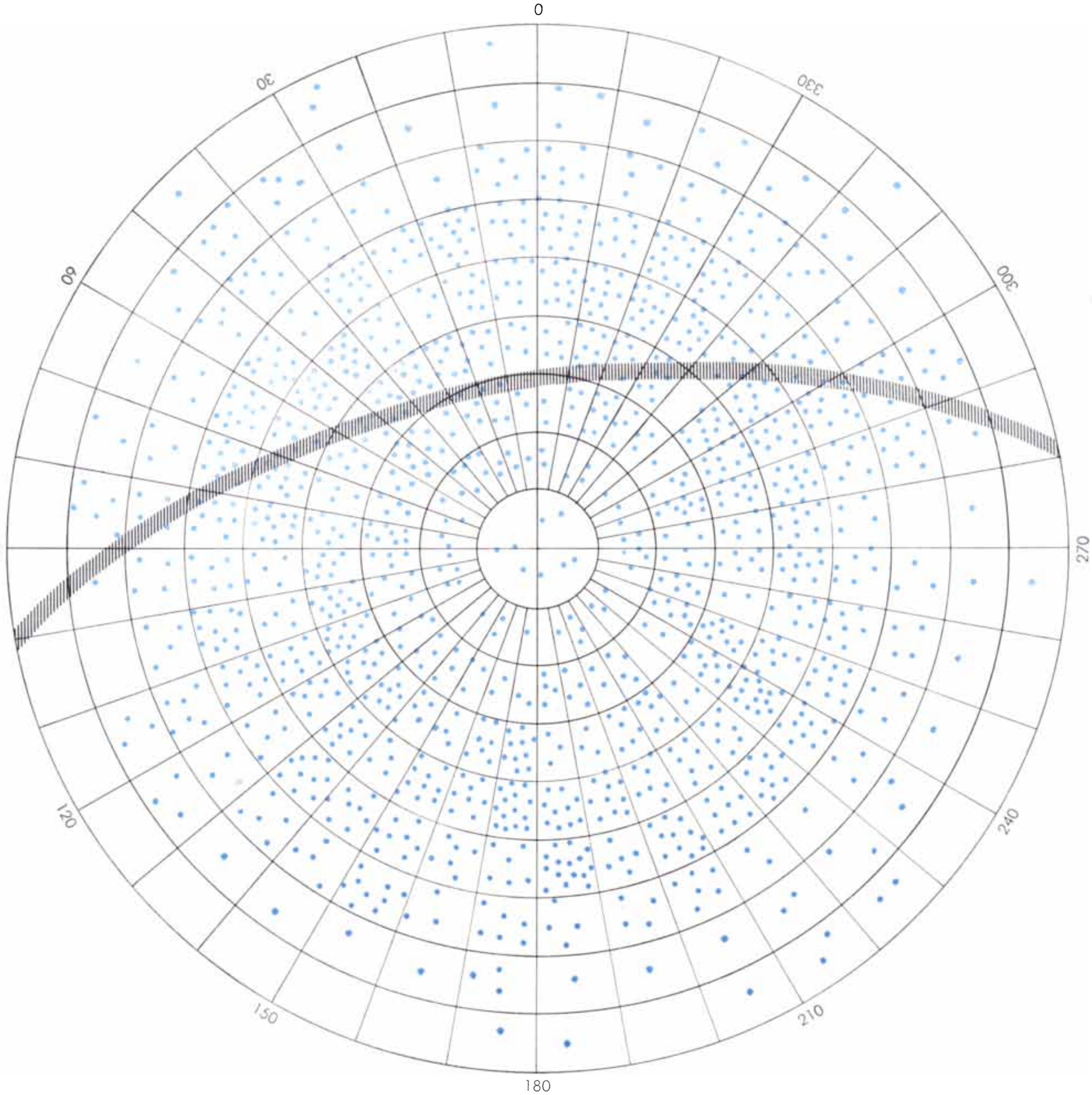
Particles at or above this critical energy can reach the earth only if they were aimed at it from the start. Because the diameter of the galaxy is roughly 100 times its thickness, straight lines from the earth to most cosmic-ray sources must lie in or near the central plane of the disk. There can be very few sources at right angles to this plane in the short distance to the top or bottom of the disk. Thus particles with energies of more than about 10^{17} electron volts should come preferentially from the part of the sky within the Milky Way. If the sources are distributed uniformly throughout the galaxy, the radiation will be equally strong from all directions in the plane; if the sources are not evenly spread, it will be stronger from some directions than from others.

The second theory, originally proposed by the late Enrico Fermi, holds that all cosmic-ray particles are emitted at low energy, presumably by stars like the sun. Then the particles are gradually accelerated as they wander around the galaxy. No one yet knows exactly how the acceleration mechanism works, but the general idea is as follows: Magnetic fields in interstellar space are known to be associated with moving clouds of ionized hydrogen. As the clouds travel about, they carry with them the magnetic lines of force. It is the moving lines of force which accelerate the cosmic-ray particles.

The same magnetic fields produce the spiral paths that trap the particles in the galaxy for millions of years, allowing the slow acceleration process to build up high energies. However, as the energy increases, the trajectories of the particles become less and less curved. When the radius of curvature becomes comparable with the thickness of the galaxy, the particles will escape. In our galaxy, as we have seen, the energy of escape lies between 10^{17} and 10^{18} electron volts. Therefore, on Fermi's theory, we should not find cosmic-ray particles of energy much greater than this critical value.

In any case we should be able to observe some sort of effect in the region of 10^{17} or 10^{18} electron volts, where the magnetic field becomes incapable of holding particles within the galactic disk. If cosmic rays originate in localized sources, we should see the beginning of an uneven distribution, with particles coming chiefly from directions within the Milky Way. If cosmic rays are accelerated as they travel through interstellar space, the number of incoming particles should abruptly drop to zero at energies slightly above the critical value. Moreover, under the assumption of a gradual acceleration it would not be surprising to find asymmetries in the direction of arrival as the critical energy is approached, due to possible irregularities in the magnetic field around the solar system.

It was to find out just what does happen in the critical-energy range that our group at the Massachusetts Institute of Technology set up an elaborate experiment for detecting cosmic-ray particles with energies around 10^{17} or 10^{18} electron volts. We were by no means certain that such particles existed. If they did, the difficulties involved in finding them would be formidable. Each square meter at the top of the atmosphere is crossed by an average of some 1,000 particles each second. But before we started we knew that less than one in 10 billion arrives with an energy greater than 10^{16} electron volts. This means that a detector one square meter in area at the top of the atmosphere would record only a few such particles a year. We also knew that the curve of the energy spectrum is very steep, so that if particles with more

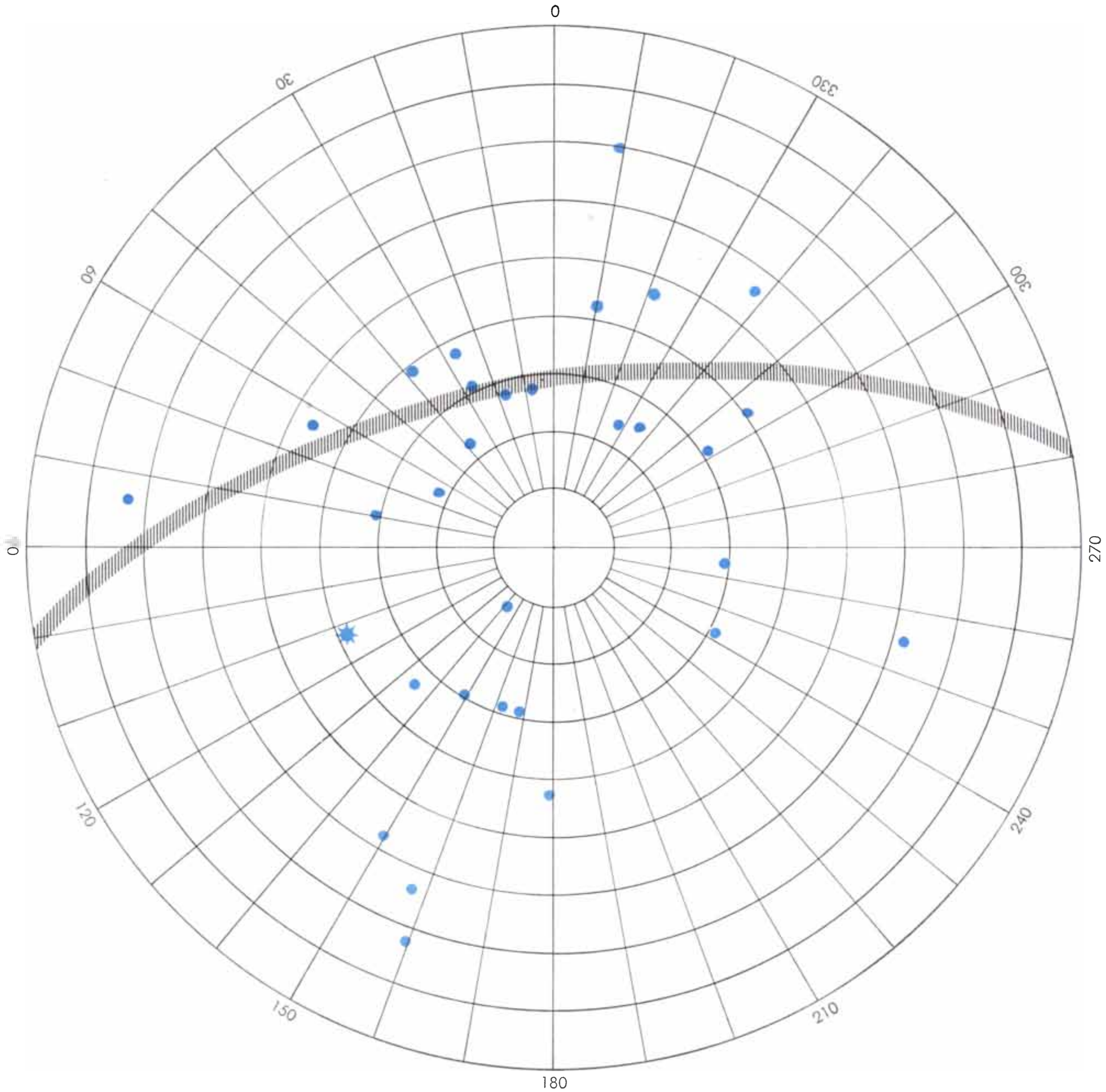


FAIRLY LARGE SHOWERS, of more than two million particles, were recorded in equal numbers from all parts of the celestial sphere accessible to the Agassiz Station. The dots represent the directions of origin of showers; hatched curve, the Milky Way.

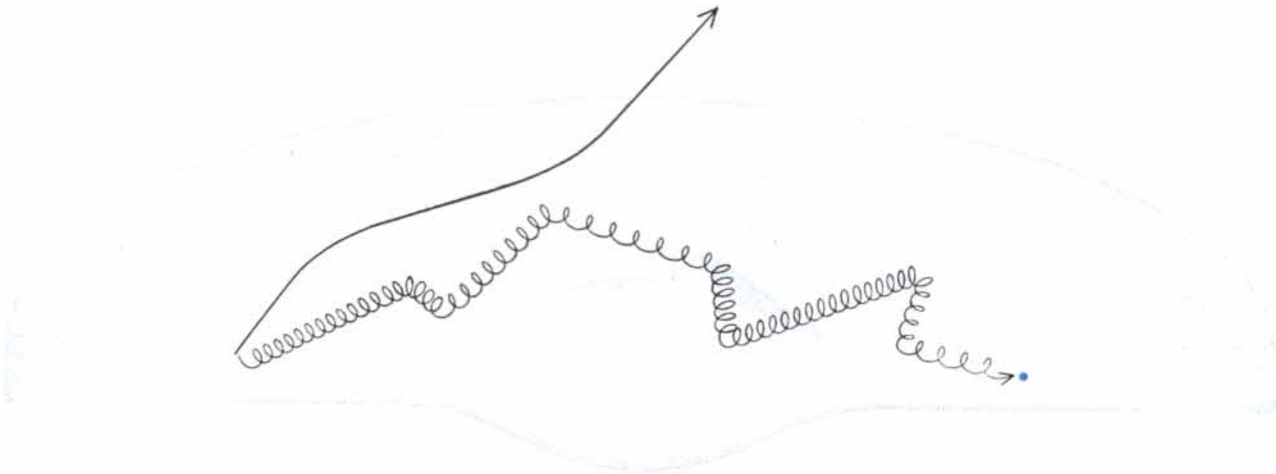
than 10^{18} electron volts existed at all, they would be at least 10,000 times less abundant than those of 10^{16} electron volts. This would mean one particle per square meter every few thousand years or so. Obviously in order to find them our detector would have to have an effective area of thousands or millions of square meters.

Luckily the earth's atmosphere, which often makes the observation of extraterrestrial radiations difficult or impossible, provides exactly the detector we need for high-energy cosmic-ray particles. This is how it works: A primary cosmic-ray particle travels, on the average, through only about a 10th of the atmospheric blanket before it hits an atomic nucleus. The collision produces a number of secondary particles; some are fragments of the struck nucleus and others are created at the moment of impact. Many of the secondary particles strike other nuclei in the atmosphere, giving rise to still more particles, and so on. Thus a single primary initiates a "shower" of many particles.

At each successive generation the energy of the particles decreases. If the primary energy is modest, say of the order of 10^{10} electron volts, the shower will die out before it reaches the ground. If the primary energy is very large, the process continues through several generations, giving rise to an enormous rain of particles (numbering in the millions for a primary energy of several times 10^{16} electron volts) at the surface of the earth [*see bottom illustration on next page*]. Most of them are electrons, with mu mesons the second most abundant component. As they descend, the atmos-



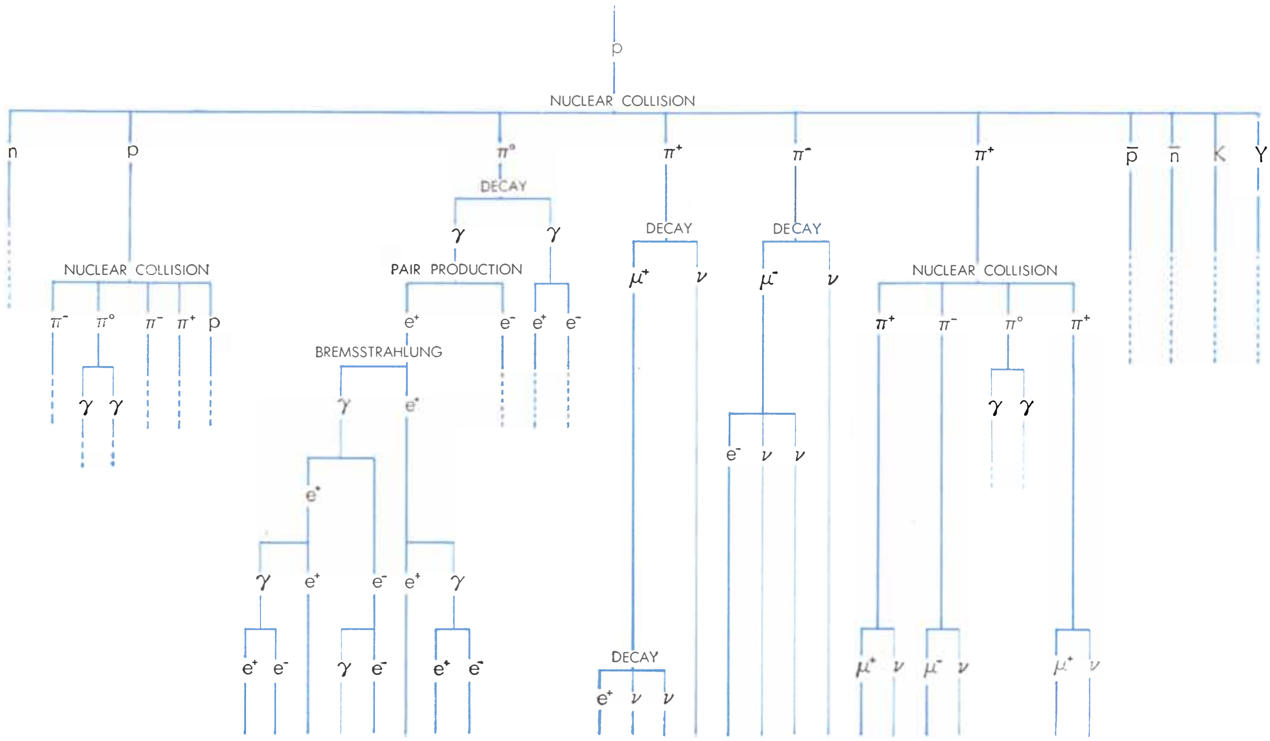
VERY LARGE SHOWERS, of more than 100 million particles, were also widely distributed over the sky. Starred dot at left center represents largest shower, of more than one billion particles. Energy of primary must have been 5×10^{18} electron volts.



CONVENTIONAL PICTURE OF OUR GALAXY, drawn schematically in cross section, is a disk about 100,000 light-years in diameter, with a thickness of 1,000 light-years at the edge and 5,000 at the center. Dot indicates the location of the solar system. Helical line traces path of low-energy particle through magnetic fields of the galaxy; gently curved line, path of a high-energy particle.

phere scatters them sideways. By the time the shower reaches the ground it is spread over a wide area. The density of particles is greatest near the center—the point where the primary would have hit if there had been no collision. But even at large distances from the center there are enough particles to measure: A detector one square meter in area will respond to a million-particle shower out to about 150 meters from the center, and to a shower 100 times as big out to about 700 meters.

In our experiments the detectors are disks of fluorescent plastic, with an area of about one square meter and a thickness of 10 centimeters. Each shower particle that passes through a disk causes a brief flash of light, the total brightness depending on the number of particles. At the center of the disk is a photomultiplier tube that converts the light flash into an electric pulse proportional to the brightness. The pulse from each disk travels through a cable to a central station and is recorded as a spike



SHOWER DEVELOPMENT starts with collision of primary particle, usually a proton, with an oxygen or nitrogen nucleus (*top*). Products include neutrons (n), protons (p), neutral pi mesons (π^0), charged pi mesons (π^+ and π^-), antiprotons and antineutrons ($\bar{p}$ and $\bar{n}$), heavy mesons (K) and hyperons (Y). Neutral pi mesons decay to gamma rays (γ), which in turn materialize into positive and negative electrons (e^+ and e^-). Charged mesons may strike other atmospheric nuclei or decay into mu mesons (μ^+ and μ^-) and neutrinos (ν). The electrons radiate part of their energy into gamma rays in the process known as bremsstrahlung. Broken lines indicate that further interactions will take place. Most charged particles arriving at the surface of the earth are electrons.

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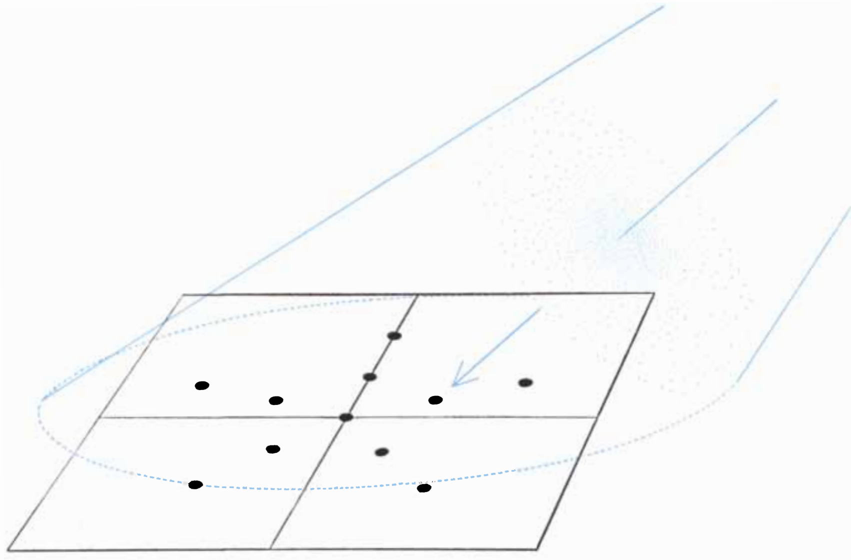
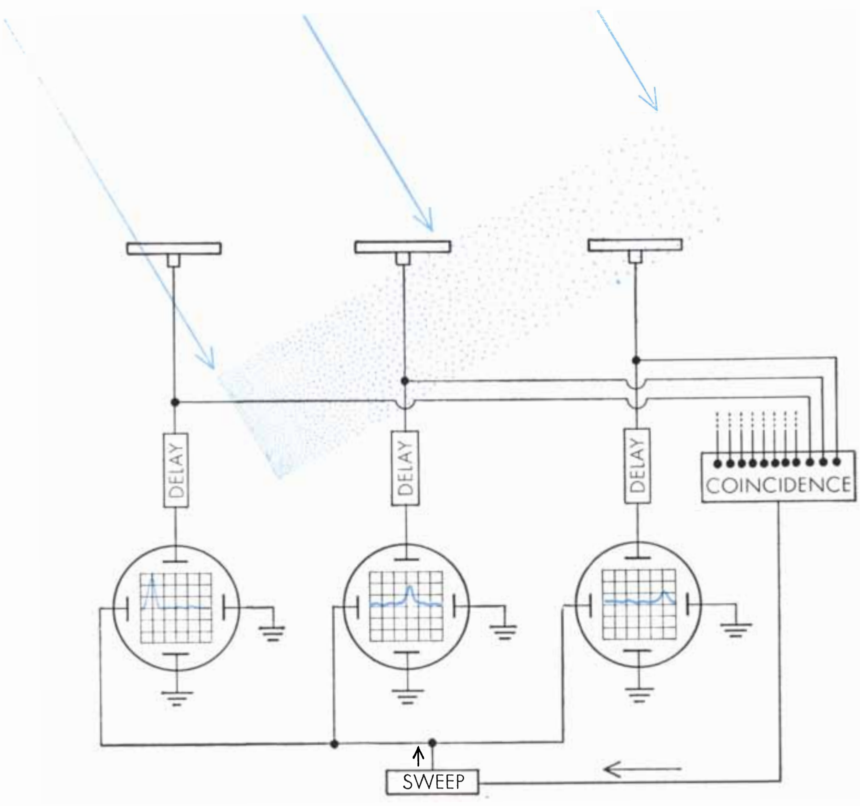


AIR-SHOWER FRONT is a disk of charged particles (*dotted area*) shown descending obliquely in the direction of the arrow on a detecting array (*large black dots*). The broken colored ellipse outlines area on the ground that will be struck by advancing front.



SHOWERS ARE RECORDED as traces on cathode-ray tubes. Plastic disks, of which three are shown at top, emit light flashes when struck by charged particles (*colored dots*). At the center of each disk is a photomultiplier tube that converts the light into an electric pulse whose strength is proportional to the brightness. Pulses travel to vertical-deflection plates of cathode-ray tubes (*circles*) through transmission lines containing delay circuits which equalize the electrical lengths of their paths. Horizontal sweeps of all tubes are triggered at the same time whenever three or more pulses pass through coincidence circuit simultaneously. Heights of spikes indicate number of particles striking the corresponding detectors; spikes' horizontal positions show particles' relative times of arrival.

on a separate cathode-ray oscilloscope. The height of the spike varies with the strength of the pulse. All the oscilloscopes are mounted together, and each time a shower occurs an automatic camera takes a picture of the whole array George Clark, William Kraushaar, John Linsley and I have recently completed a series of observations using 11 detectors distributed over a circular area 460 meters in diameter on the grounds of the Agassiz Astronomical Station of Harvard University.

Because air-shower particles travel at nearly the speed of light, they fan out into a thin, flat disk with a sharply defined front [*see top illustration at left*]. Thus the particles traversing a given detector produce practically simultaneous flashes. These combine to give a single electrical pulse whose amplitude is proportional to the number passing through. If the shower comes down vertically, it strikes the various detectors at the same time. If it comes from an inclined direction, some of the detectors are struck a little sooner; others, a little later. The horizontal sweeps of our oscilloscopes are all triggered simultaneously, so that the position of the spikes on different tube-faces measures the time intervals between pulses from the corresponding detectors [*see bottom illustration at left*]. Knowing the time when the shower front hits each disk, we can compute the direction from which it came. The height of the spikes tells us the density of shower particles at each detector.

We then combine this information to determine the center of the shower and the total number of shower particles. This is done by trial and error. We inspect the record and make a first guess at the position of the center. Next we plot the number of particles recorded by the various detectors against the distances of the detectors from the presumed center. Since the density of shower particles decreases in a gradual and regular way with increasing distance from the center, the points should lie on a smooth curve. If they do not, we try a second guess, using the observed deviations to figure out how to move the center to obtain a better fit, and so on [*see illustration on page 142*]. Once the center is located, we can infer the total number of particles in the shower from the number that struck each detector. The entire analysis is carried out by an electronic computer.

In the course of a little more than a year, during which the Agassiz experiment was in operation, we recorded several thousand large showers. We found that the number of showers striking a

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given area in a given time drops off sharply but smoothly with size. For every million showers containing a million particles there are approximately 1,000 showers of 10 million particles, and approximately one of 100 million. Since the number of particles in a shower depends on the energy of the primary, we can compute the energy spectrum of the primary radiation. In the interval between 10^{15} and 10^{18} electron volts the spectrum turns out to be a smooth curve. Furthermore, this curve is the natural continuation of the spectrum for lower energies, which had been previously determined by other means [*see illustration on page 145*]. There is no indication of a break between 10^{17} and 10^{18} electron volts, such as we were entitled to expect. In fact, we observed a few showers so big that their primary particles must have had energies well above 10^{18} electron volts. The largest one recorded by our array contained 2.6 billion particles. Its primary must have had an energy of about 5×10^{18} electron volts. Similar results have been obtained by cosmic-ray groups at the British Atomic Energy Establishment and at Cornell University.

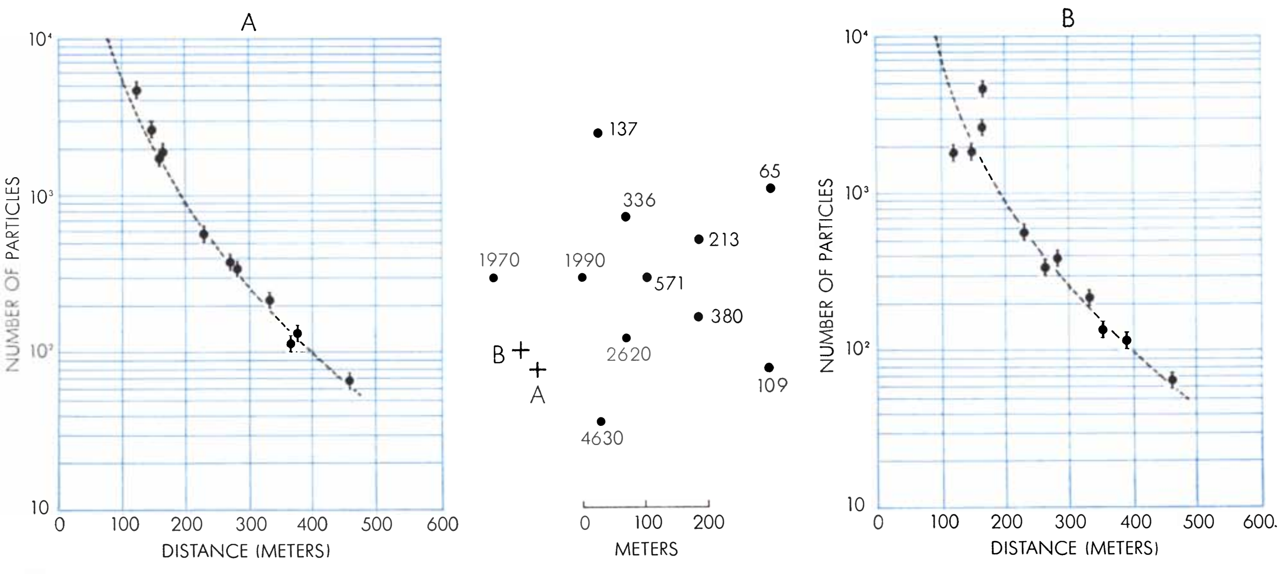
The results of the directional measurements are also puzzling. Particles with energies up to a few times 10^{16} electron volts appear to arrive with practically uniform intensity from all regions of the sky that are visible from our station [*see illustration on page 136*]. Concerning larger showers our information is still rather spotty, but we have detected primaries with energies of the order of 10^{18} electron volts coming from many different directions. There is as yet no clear-cut indication that they originate preferentially in regions of the sky near the Milky Way [*see illustration on page 137*]. However, the present results can only whet our curiosity; they do not enable us to draw any definite conclusion.

In any case our results do not confirm either of the two predictions outlined earlier. These, of course, were based on the assumption that the ionized gases in the galaxy, and their associated magnetic fields, are confined to a region shaped like a thin grindstone with a bulge in the center. But we find particles with energies substantially higher than could be achieved in such a region by an acceleration mechanism, and they do not all come from the Milky Way, as the theory of localized sources requires.

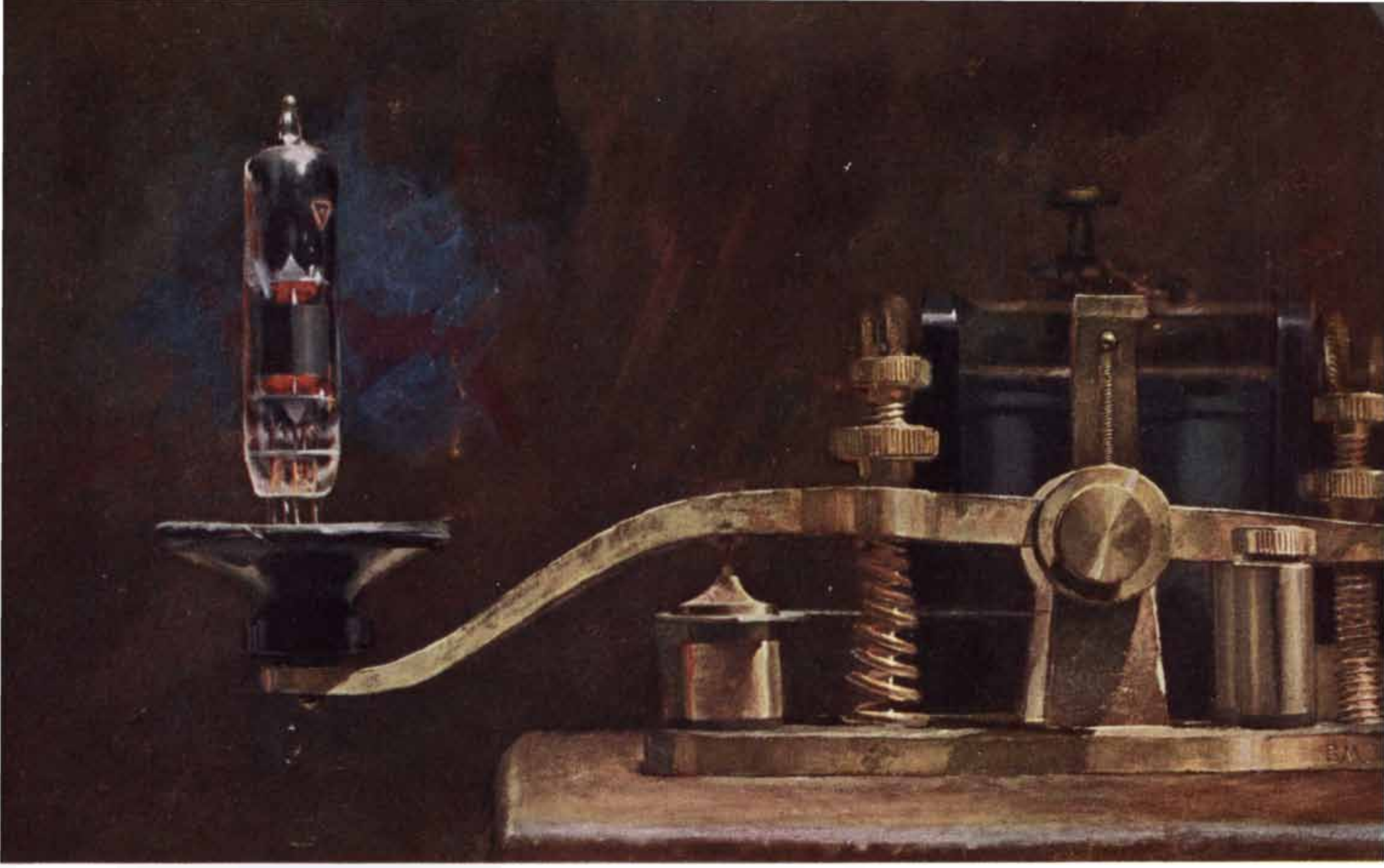
It seems difficult to escape the conclusion that our picture of the galaxy and its magnetic fields needs a thorough revision. Possibly the gas clouds and associated fields extend beyond the flat disk to form a roughly spherical halo. This picture is also suggested by certain radio-astronomical observations which indicate that many galaxies, including our own, indeed have such a halo. It may also be that galaxies are not the sharply defined objects we have considered them. Perhaps ionized gases and magnetic fields spread through all space, reaching their maximum concentration in those regions we call galaxies, which contain most of the stars. Either assumption would explain why high-energy particles do not arrive preferentially from the direction of the Milky Way. A halo would enable the Fermi mechanism to accelerate particles up to a maximum energy of about 10^{19} electron volts, slightly more than the greatest value observed so far. Magnetic fields in intergalactic space might permit acceleration to even higher energies.

To test these hypotheses we have enlarged the scope of our experiments. In the first place we wish to look at regions of the sky that are not accessible from our latitude. In collaboration with the cosmic-ray group at the University of Ahmedabad we installed an air-shower array of modest dimensions at Kodaikanal in India. More than 100,000 showers, representing primary energies of 10^{14} to 10^{15} electron volts, have been recorded. Again the intensity was uniform in all directions. Moreover, early last winter we shipped the equipment from our Agassiz experiment to Bolivia, where it is being operated by the University of San Andres in La Paz.

In the second place we need more information about primary particles with energies greater than 10^{18} electron volts. In particular we would like to find out whether there are showers even larger than those recorded so far, with primary energies over 10^{19} electron volts. If such showers exist, they are extremely rare,



SHOWER CENTER IS LOCATED by trial and error. Black dots in space between the two grids represent detecting disks. Accompanying numerals show number of particles striking each disk. Cross at B is a first guess at the location of the center. Curve at right is a plot of particle numbers against distance of the corresponding detectors from the presumed center. Deviations of points from the best-fitting curve provide data for improving the guess. Cross at A is the best choice, its plot (*left*) lying close to curve.



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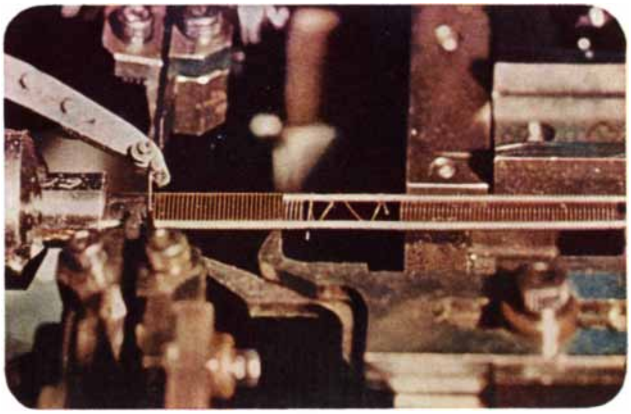

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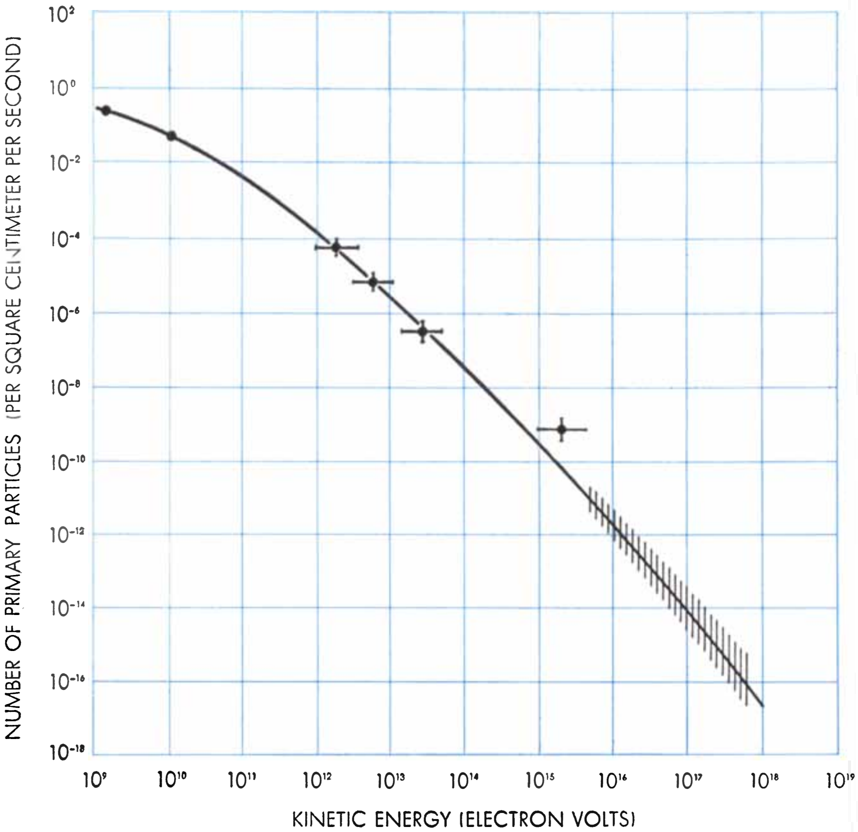


ENERGY SPECTRUM of primary cosmic-ray particles decreases smoothly with increasing energy. Vertical hatching at bottom of curve shows region covered by the experiments described in this article. Height of hatching lines gives the limits of error in measurements. Dots represent data from other types of experiment, with limits of error indicated by horizontal and vertical bars. Vertical axis measures number of particles per second crossing each square centimeter of surface at top of atmosphere; horizontal axis measures energy.

and so we must have a detector array with an area enormously greater than that of the Agassiz experiment—an area of at least thousands of acres.

Such an array has now been set up near Albuquerque, N.M., on a property called the Volcano Ranch. The site is a flat, semidesert area at an altitude of about 6,000 feet. Although not absolutely essential to our purpose, the high elevation will make the experiment much easier. Air showers reach their maximum development at high altitudes and are considerably depleted by atmospheric absorption by the time they reach sea level.

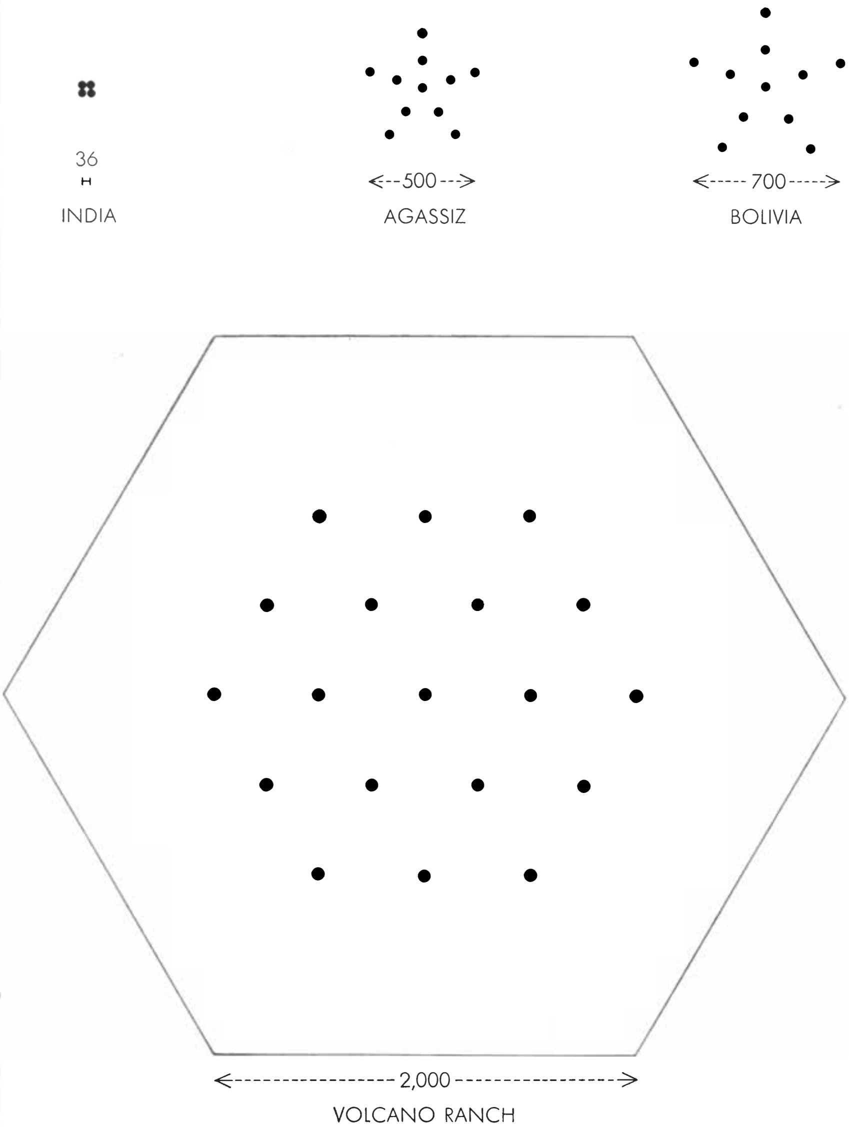
In the Volcano Ranch experiment we use plastic disks just like those in the Agassiz experiment, but each detector consists of four disks instead of one. There are 19 detectors arranged in a regular hexagonal pattern two kilometers across [*see illustration on next page*]. We plan to run the experiment for about six months with this setup and then to double the separation of the detectors. The total surface will then measure about 12 million square meters, or 3,000 acres. Showers produced by primary particles of more than 10^{18} electron volts, which struck in the Agassiz layout once every two months, will hit the expanded Volcano Ranch system at the rate of about one a day. If there is no break in the spectrum, we should record several showers per year with primary energies of more than 10^{19} electron volts.

It is not only astrophysicists who are interested in superenergetic cosmic-ray particles. Students of the fundamental constitution of matter would very much like to know what happens when one of these objects strikes an atomic nucleus. How is its energy distributed among the immediate products of the collision? Just what are these products?

Experiments at lower energies such as are available from existing accelerators—indeed, from any accelerator yet envisaged—give no hint as to the behavior of matter at the fantastically high energies of which we have been speaking. To appreciate just how high these energies are we may recall that in normal circumstances the energy stored in the rest mass of a piece of matter (given by the now-familiar expression $E = mc^2$) is vastly greater than any mechanical energy it may have, as witness the atomic bomb. But at 10^{19} electron volts a proton's kinetic energy is something like 10 billion times the energy stored in its mass. In fact, this almost unimaginably tiny object carries enough energy to keep a one-watt light bulb burning for about a second!

In order to answer the nuclear physicists' questions we shall have to study air showers in greater detail. We need to know the different kinds of particles they contain and the numbers of each, the division of energy among the particles and how they are distributed laterally in the shower. It would also be desirable to study the vertical development of showers, observing them at various heights. One way of doing this might be to place detector arrays at several altitudes, supporting them with captive balloons.

So far our group has concentrated on detecting larger and larger showers. But some detailed studies of the kind mentioned above are already under way, notably in the U.S.S.R. and Japan. We also are about to expand our efforts in this direction.



DETECTOR ARRAYS for various experiments described in this article are illustrated schematically. Dots in Volcano Ranch array show how the detectors are laid out at present. After a few months of operation the array will be expanded to cover the area enclosed by the hexagonal outline. The dimensions of each array of detectors are indicated in meters.

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1912	Built the first American-made air liquefaction plant
1914	Established scientific laboratories for gas and chemical research, experimentation, and testing
1916	First commercial argon production
1917	First natural gas liquefaction plant to produce helium designed and built for U. S. government
1917	LINDE became a part of UNION CARBIDE
1918	Operations extended to Canada
1922	Began commercial production of neon
1928	Started development of system for liquid oxygen and nitrogen
1932	First customer liquid oxygen storage and conversion unit installed
1932	First liquid oxygen truck delivery to customer units
1935	High-pressure conversion equipment adapted to truck use
1937	Powder-vacuum insulation reduced heat leak to contents by a factor of 10
1939	First vacuum-insulated railroad tank car shipment of liquid oxygen
1944	Liquid oxygen producing plants, transport containers, and storage units made for government
1946	Basic patent for powder-vacuum insulation issued
1946	First 25,000,000 cu. ft. liquid storage reservoirs for oxygen, nitrogen, or argon
1948	First 140 ton a day low-purity oxygen-producing unit
1949	First 360 ton a day on-site oxygen-producing unit for chemical industry
1951	Heat leak to contents further reduced by a factor of 10
1953	First 450,000 cu. ft. capacity vacuum-insulated trucks
1955	First 3000 cu. ft. compact cylinder for storage, transport, and conversion of liquid oxygen
1957	3000 cu. ft. cylinder adapted to shipment of liquid nitrogen, argon, and hydrogen
1957	Continuing progress in decreasing heat leak to contents
1957	Liquid oxygen distribution system requiring no external power source
1957	First automatically-operated 120 ton a day on-site oxygen plant
1958	Super insulations developed—hold evaporation of liquid oxygen to less than 5% per year
1959	NASA contracts for large volumes of liquid hydrogen from LINDE built and operated plant, Torrance, Cal.

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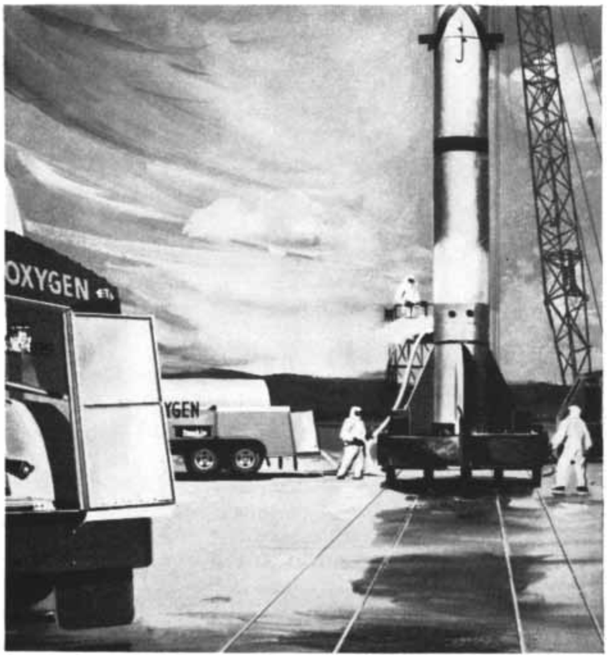

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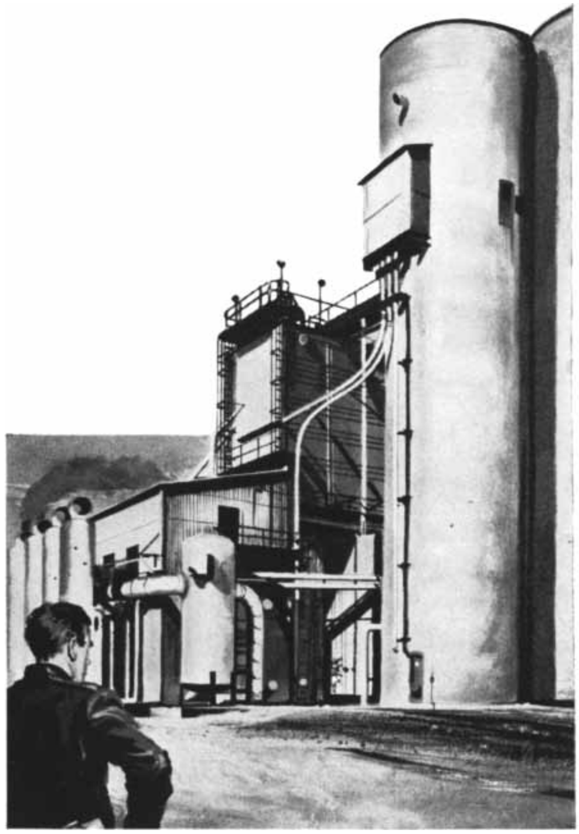

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Ashtabula, Ohio—500 tons a day

Others at Kittanning (700 tons), Seattle (20 tons), Houston (40 tons), Birmingham (20 tons), East Chicago (900 tons), etc. . . .

Most on-site plants operated for single-customer use produce high-purity gaseous oxygen. Capacities range from 10 tons a day to more than 500 tons a day. (One ton equals 24,150 cu. ft., N.T.P.)

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UNION CARBIDE

INSECTS AND PLANT GALLS

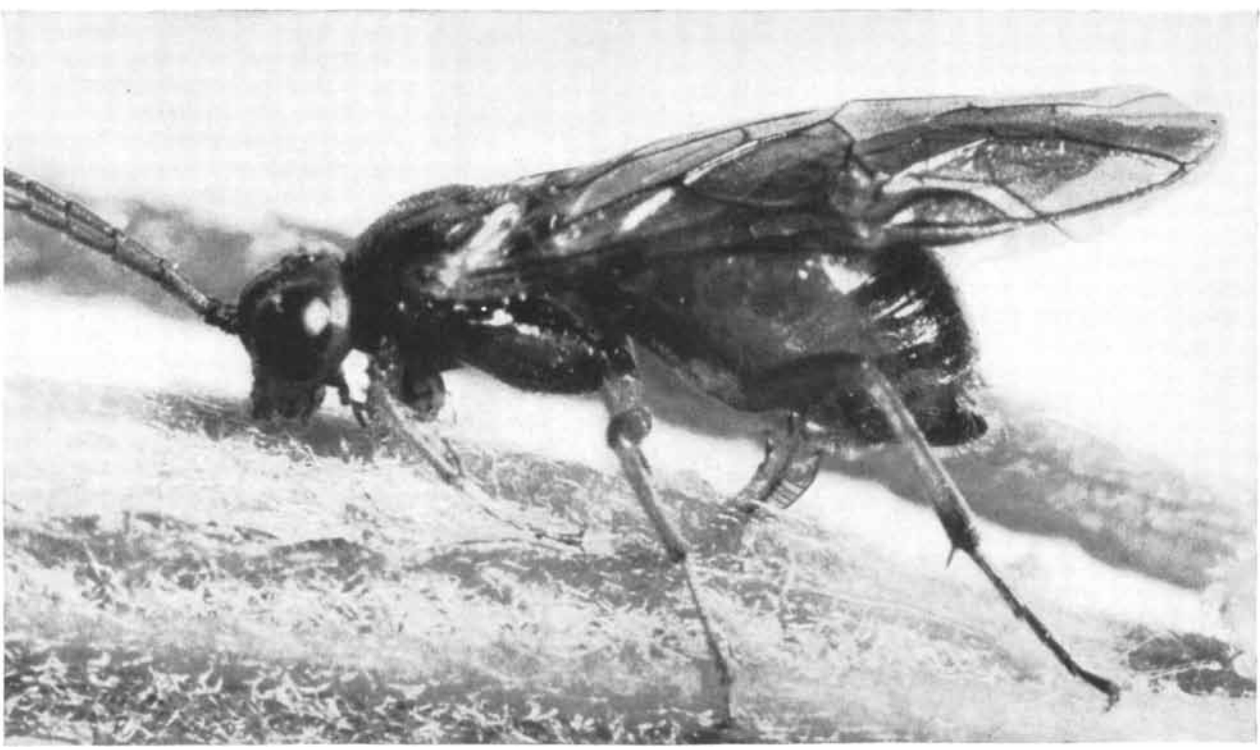
Certain insects lay their eggs in specific plant tissues, causing the formation of a protuberance that nourishes the insect larva. How does the insect induce the plant to grow this abnormal tissue?

by William Hovanitz

The "sere and yellow leaf" of autumn is likely to bear a tumor. These tumors, called galls, may develop in any part of a plant—leaf, stem, flower or root—provided the part contains vascular tissue to keep it supplied with nutrient. The derangement of growth and structure may form a tiny wart or a bulging mass the size of a baseball. Such growths are frequently seen in the fall on the withered stalks of goldenrod.

Plant galls inevitably bring to mind their counterpart in animals: the cancer tumor. In support of this analogy the gall always contains in its interior a mass of amorphous cells. We know, however, that galls are caused by insects or by viruses, molds and other microorganisms. The parasite supplies some sort of stimulus to initiate abnormal growth, and the galls seem to grow only so long as the stimulus persists. Many animal cancers appear to grow indefinitely without external stimulation. On the other hand, it may turn out that these tumors too are caused by viruses or by some other infectious process.

But the plant gall is no mere eccentricity of growth. In the insect-induced leaf gall that we have been studying in the Earhart Plant Research Laboratory at the California Institute of Technology the parasite provokes its host to grow what is in effect a new organ, specifically adapted to shelter and nurture the insect egg and larva. Gall growth always originates in unspecialized tissue; the insect causes this to differentiate into specialized cells and promotes continued growth where no further growth would ordinarily occur. The amorphous cells within the gall which feed the larva are enclosed in an intricate structure of supporting tissues covered on the outside by epidermal tissue characteristic of the



FEMALE SAWFLY, here enlarged about 20 diameters, pushes its sawlike ovipositor into the midrib of a willow leaf preparatory to laying an egg. With the egg the wasp injects a glandular fluid that stimulates the plant tissue to start forming a gall a few days later.

FIVE DAYS after an egg was laid in a willow leaf, a gall is starting to form around it (*lower right*). There is also growth near other wounds in which only glandular fluid was inserted.

EIGHT DAYS after the egg was laid, the larva has hatched inside the large gall and is feeding on it. The two galls lacking eggs have developed slowly and now virtually cease to grow.

NINETEEN DAYS after the egg was laid, the large gall has grown enormously, stimulated by the feeding of the larva inside. The barren galls have increased very little in size.

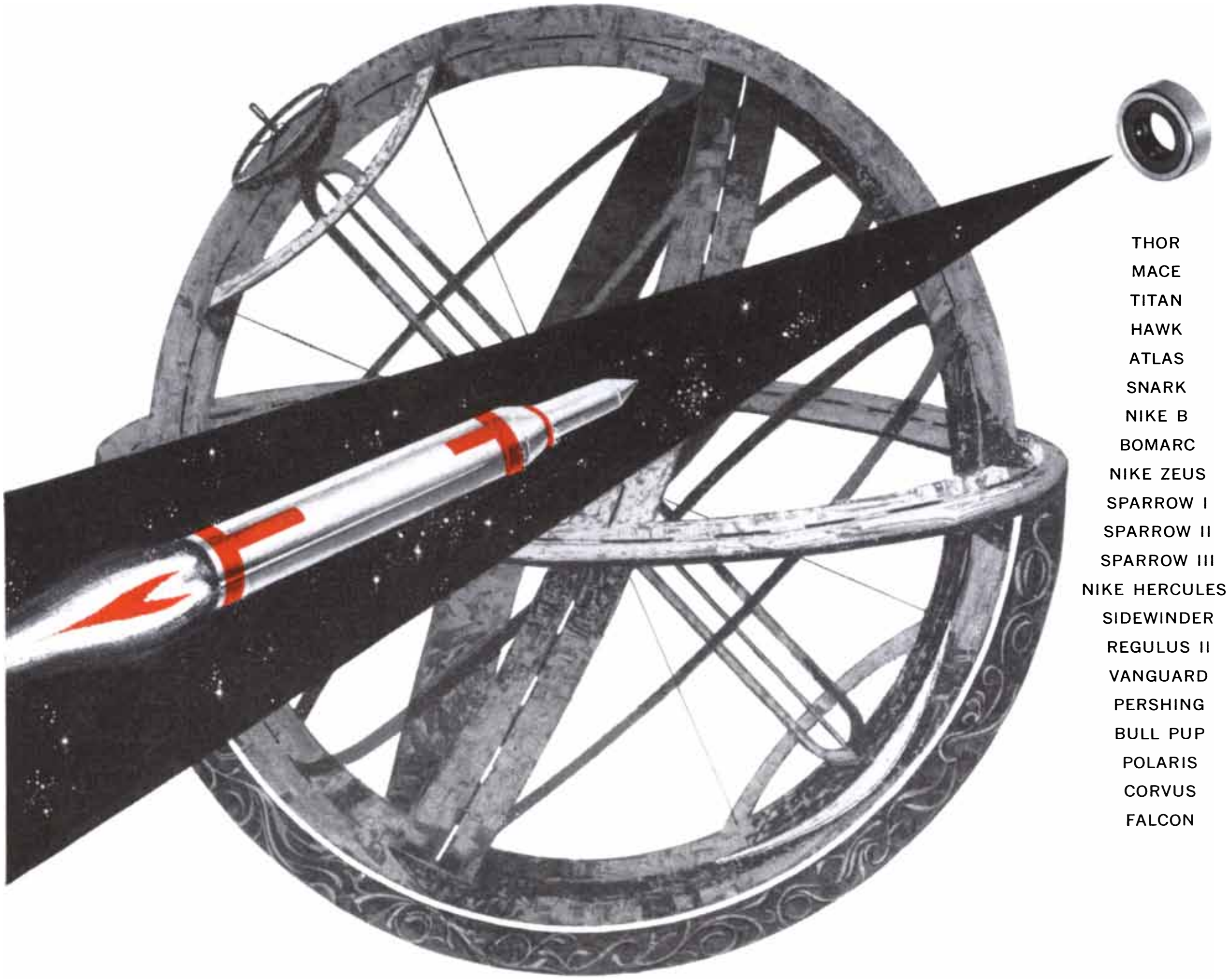
plant stem. No new types of cell appear in the gall; all are duplicated elsewhere in the plant. From the cellular point of view a leaf gall resembles stem more than leaf. The globular gall forms as an appendage to the leaf, a kind of fruit in which the insect embryo takes the place of the plant seed. The insect thus exerts a regulatory power over the growth pattern of the plant that suggests a new line of experimental attack on the secrets of cellular specialization and growth.

Almost every order of insects has its gall-inducers; of the 2,000 such insects in the U. S., some 1,500 are species of gall wasps and gall midges. The oak tree is the particular target of attack by a large variety of wasps; of 591 kinds of wasp-induced gall, 41 occur on roots, 45 on buds, 175 on stems, 275 on leaves, 21 on flowers and 34 on fruits (acorns). In every case the gall is the product of a close relationship between host and parasite. A particular species of insect is adapted to a specific organ of one species of plant and induces the growth of a characteristic type of gall. For this reason it is not easy to study gall formation in the laboratory. We have found that the galls produced on the leaf and stem of the willow by various species of wasp are best suited to our purpose.

These wasps are medium-sized and are called sawflies because of the large, sawlike egg-laying apparatus or ovipositor by which they attack the plant. In the case of the leaf-gall species the female seeks out a new leaf and takes up a position over the midrib on the underside of the leaf's growing tip. Working its ovipositor into the midrib, the wasp makes a hole of considerable size. Fluid, presumably of glandular origin, is injected into the hole; finally the egg is pushed through the midrib to lie in the "mesophyll" space between the upper and lower epidermis of the leaf blade.

About two days after the egg has been laid, the area around it begins to bulge out. After another four or five days, during which the gall continues to grow, the larva hatches out of the egg. The larva remains inside the gall and feeds on the inner mass of plant tissue. Nevertheless the gall continues its growth; in fact, the more the larva eats, the more it stimulates the gall to grow. After a few weeks the gall no longer increases in size, and new tissue grows merely to replace what is eaten.

The larva of the strain we are using pupates 30 to 45 days after hatching and spends a couple of weeks as a pupa before emerging as an adult. At the lat-



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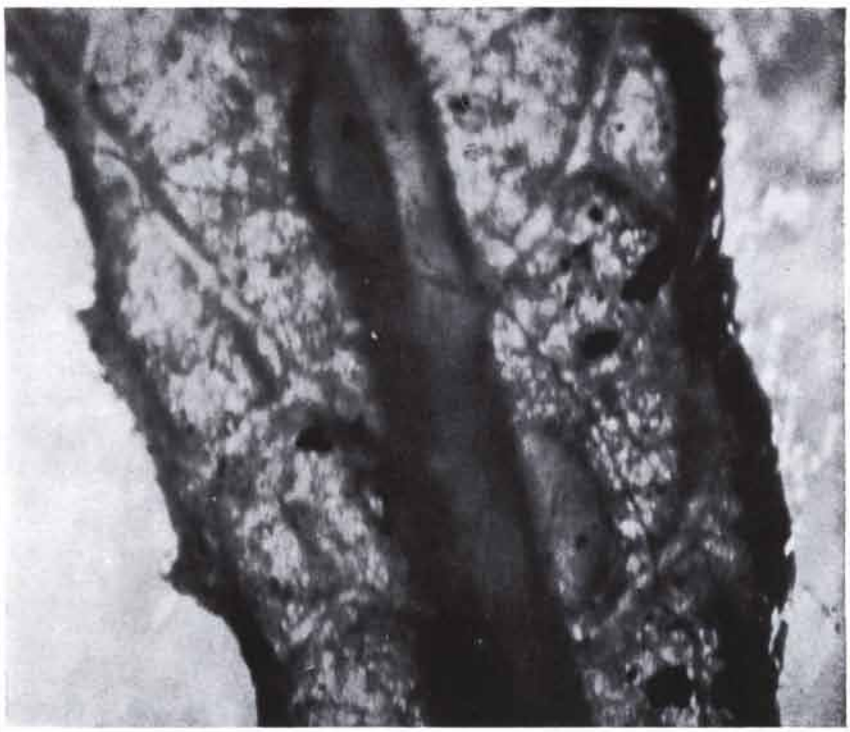
proved reliability you can build around itude of Pasadena about half the offspring are males, but in Canada only 2 per cent of a related species are males, the ratio of male to female being associated, it seems, with climate. The males are not needed, however, to fertilize the eggs. This is a fortunate circumstance for the experimenter, because parthenogenesis yields uniform strains. The female is built strictly for reproduction. Its day or two of adult life is an orgy of egg-laying during which it deposits from 50 to 100 eggs. The insect does not eat, and its tiny remnant of a gut is probably without function. Its huge abdomen is two thirds filled with eggs, and the remaining third is occupied by accessory glands that produce the fluid injected with the eggs.

Our study has disclosed that the sawfly is attracted to the host plant by a chemical factor that is somewhat affected by the conditions in which the plant has grown. Willow leaves raised at relatively low temperatures are more attractive to the sawfly than those raised in a warmer environment. The midrib of the leaf must be of the right consistency and size to permit the wasp to push the fragile ovipositor through the plant tissue and place its tip just inside the mesophyll so that the egg can be laid parallel to and alongside the midrib structure. Few strains of willow are suited to any strain of sawflies. Some willows are too tough for the insect to penetrate at all. The midribs in other willow leaves are of the wrong diameter; thus the eggs may protrude on the opposite side of the leaf or may not get all the way in through the midrib to lodge in the mesophyll layer.

The initial growth of the gall consists of undifferentiated "callus" cells like those that cover a stem wound when a cutting is taken. Cells of this type occupy the interior of the gall all through its life and continue to multiply so long as the larva feeds. Cells on the outer surface of the gall differentiate into vascular tissue and a covering of epidermis that has tiny holes and pores (stomata and lenticels) resembling those in the stem. With callus tissue filling its center, the gall is a fairly solid mass. The gall grows most rapidly over the site of feeding by the larva, but the constant turning of the larva within its cell gives fairly even impetus to growth all around the gall. In gross appearance and cellular structure it contrasts markedly with the leaf from which it grows. The structure of the leaf is basically a sandwich consisting of two layers of green, chlorophyll-containing cells (the palisade and spongy layers) located between an upper and a lower epidermis and strengthened by numerous branching veins that also carry substances to and from the leaf. Leaves generally cease growing



YOUNG WILLOW LEAF was photographed shortly after a female sawfly had laid its eggs. One forms a bulge to the upper left of the midrib; another at the lower right of the midrib.

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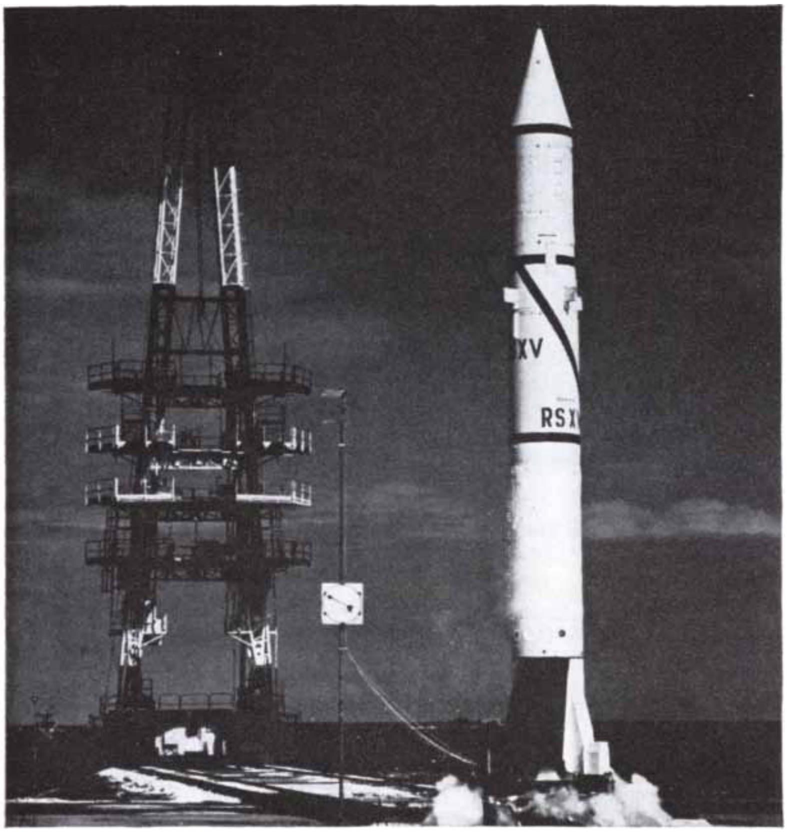
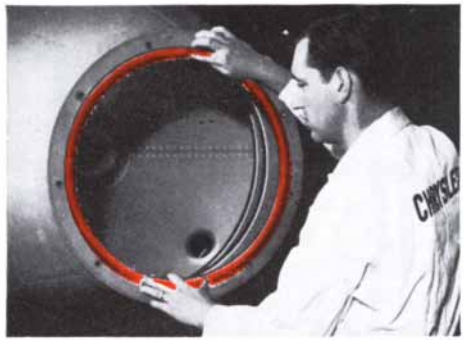
upon maturity, unlike gall tissue, which is capable of continuous growth. A gall can remain alive and green even though the leaf bearing it withers and falls; the gall may then put out roots, as if it were attempting to cling to life.

In our experiments with the rigorously determined host-parasite relationship of the sawfly and its willow plant, we found that the presence of the egg is not necessary to the first phase of gall-growth which precedes the hatching of the larva. We halted the insects in their labors at various times after they had inserted their ovipositors into the leaf. Because the egg is deposited at the end of the process, only those wasps allowed to carry their work to completion actually

EGGS PLACED WRONGLY by sawflies in a willow to which they were not adapted will not hatch and no galls will form. Instead of being placed wholly within the leaf, the egg at top has been pushed through the tissue on the opposite side of the midrib. The egg at bottom evidently was not inserted far enough and can be seen at the right of the hole.

Semper Flexibilis





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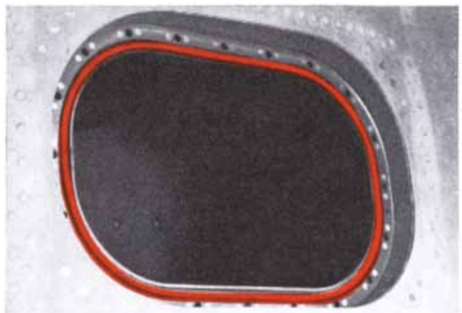

A similar application for Silastic, this time on the Army-developed Jupiter IRBM, another Chrysler-produced missile, is the seal on the angle-of-attack transducer compartment. Silastic was specified because it resists high temperatures encountered in re-entry.

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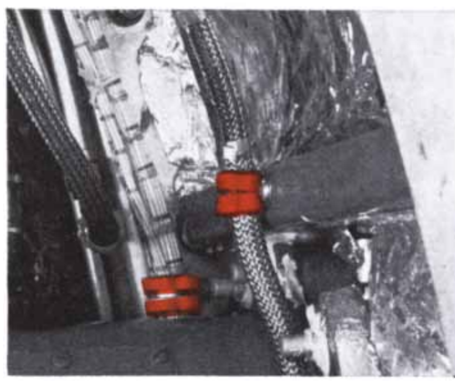

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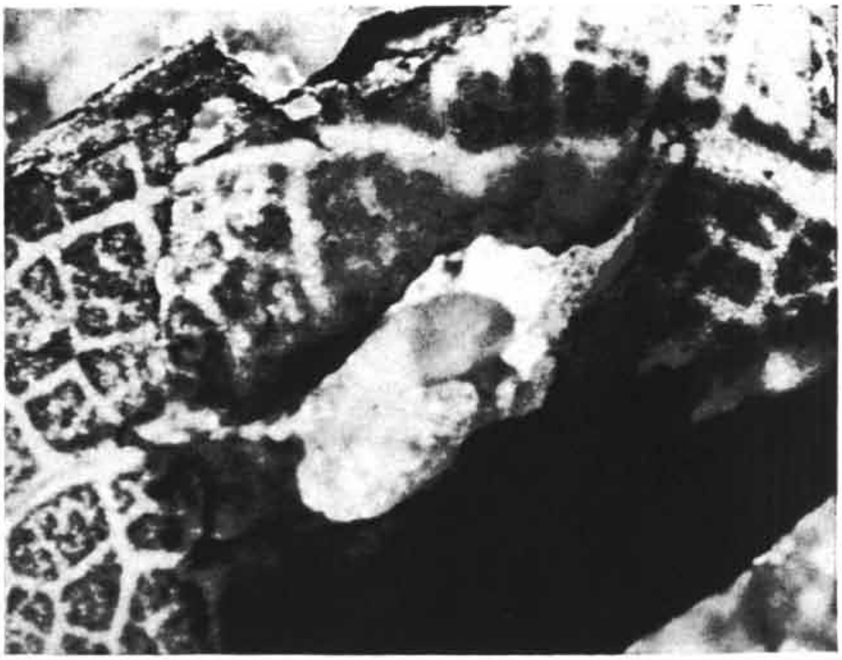
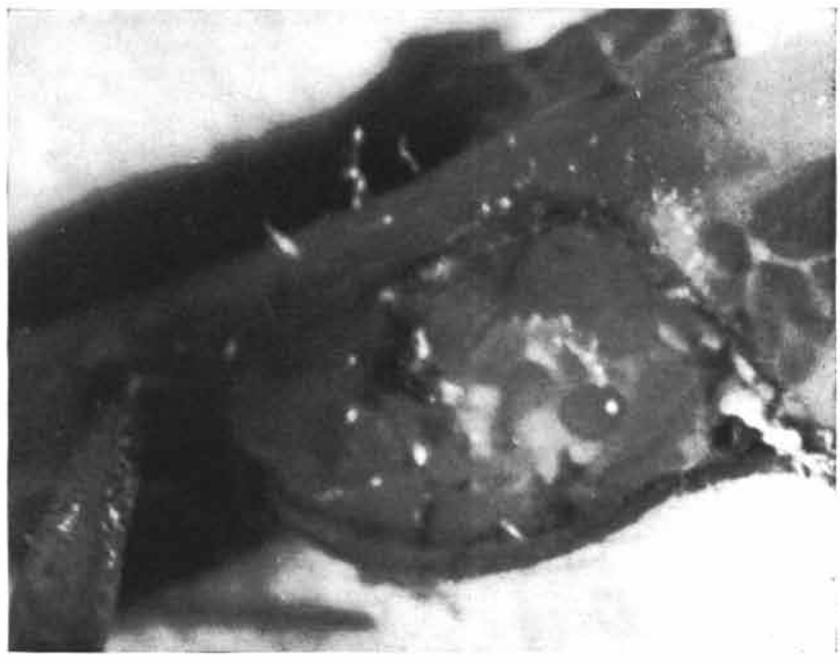


SAWFLY EGG developing inside a willow-leaf gall was exposed on the fifth day after it was laid by cutting the gall open. The eggs normally hatch on about the sixth or seventh day.

placed eggs in the plant tissue. When we examined the plants a few days later, the points attacked for a very short time showed no growth at all—merely a wound. The points where the female had injected fluid but had not laid an egg showed the beginnings of normal gall-development and differed from areas with an egg only in the size of the growing region. Because fluid alone occupies only a fraction of the space taken up by the egg together with fluid, somewhat less plant tissue appeared to be affected in the absence of the egg. If we killed the eggs by puncturing them with a fine needle, the gall nonetheless completed the first phase of growth in about eight days, as usual.

We found that beyond this point, continued growth requires the presence and



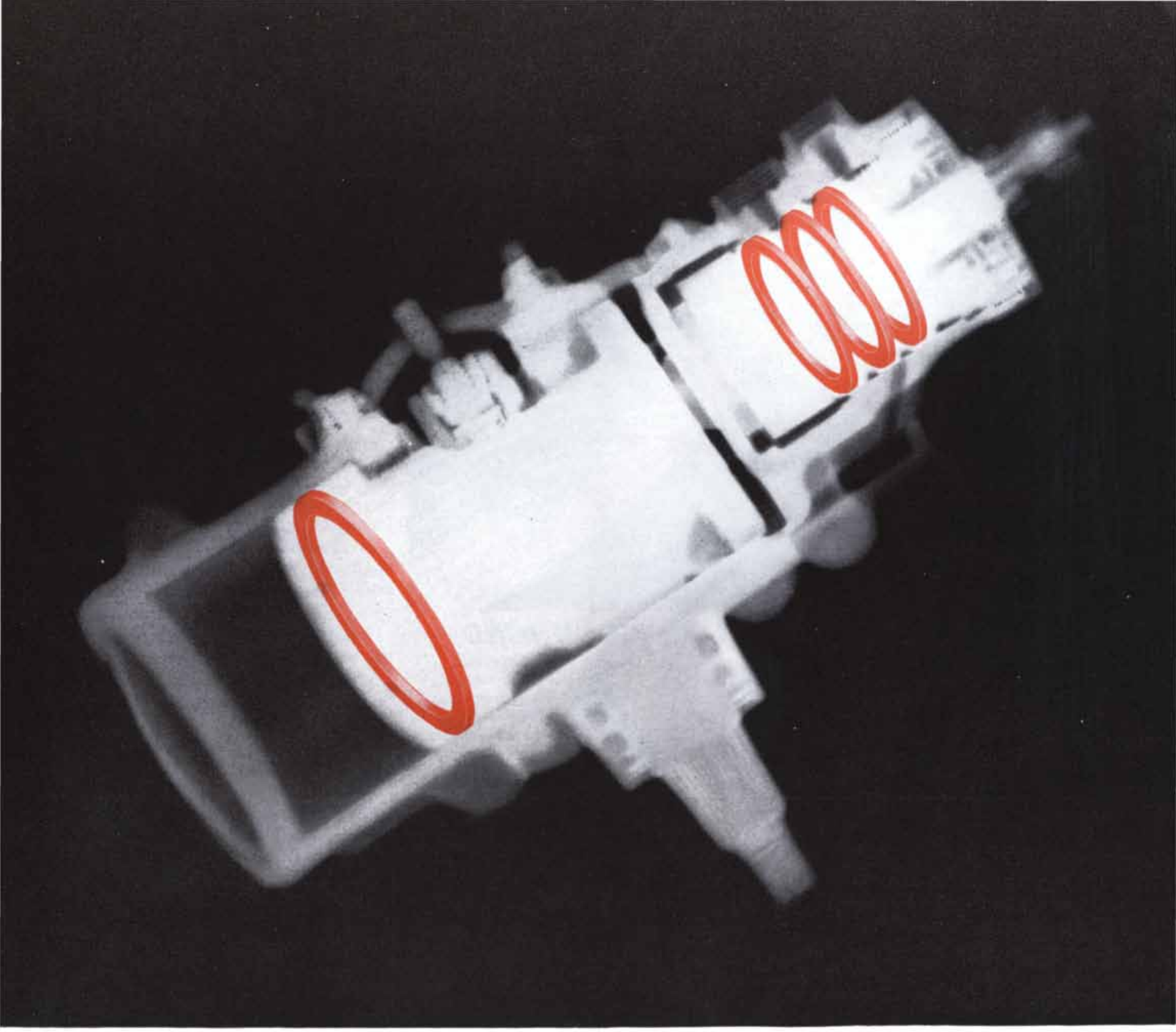
NEWLY HATCHED SAWFLY LARVA was exposed by opening a willow gall on the eighth day after the egg had been laid. The glistening sphere (*bottom right*) is the larva's head.

activity of the larva. Galls lacking eggs, or containing killed eggs, stop growing, and there is evidence that a killed egg may be detrimental to the growth of other galls on the same leaf. Completely normal growth of one gall, with a larva feeding inside it, apparently promotes the growth of adjacent galls even though the latter have no eggs or larvae within them. When we removed a feeding larva from a gall, growth stopped in two days; the same surgery performed without removal of the larva did not inhibit gall-growth.

These observations plainly suggest that the fluid injected by the egg-laying wasp must initiate the growth of the gall, and that some similar factor supplied by the larva sustains it. Accordingly we exposed cultures of willow-plant tissues to the contents of the female sawfly's glandular sac. In a few cases the plant tissue produced a tremendous mass of filamentous strands. In other cases the glandular material did not produce any noticeable effect. Artificial injection of the contents of the glandular sacs into willow leaves also had variable results. Small growths appeared in a few instances, but we could not be sure that they were attributable to the glandular fluid because similar growths often result from damage alone. However, the insertion of minute needles of steel or glass into the midrib did not produce any kind of growth.

The stimulating effect of fluid seems to wear off in about eight days. In the second phase of growth a larval secretion apparently supplies the necessary stimulus. We asked ourselves: If the larval secretion could maintain growth, could not a renewal of the glandular fluid of the adult do the same thing throughout the second phase? About a week after larvae had hatched we removed them from several galls and replaced them with gland sacs. These galls grew almost as rapidly as a normal gall for a time, but then the growth tapered off. When we supplemented the supply of gland material by repeated injections at intervals of several days, however, the gall continued to develop to normal size. Injections of plain water had no such effect. An oversupply of glandular material killed the gall, just as in nature the insect's injection sometimes kills the leaf.

Clearly the glandular fluid stimulates plant tissue. The next step is obviously to analyze it and determine what produces this remarkable effect. Unfortunately the fluid is difficult to handle; in the open air it quickly hardens into a



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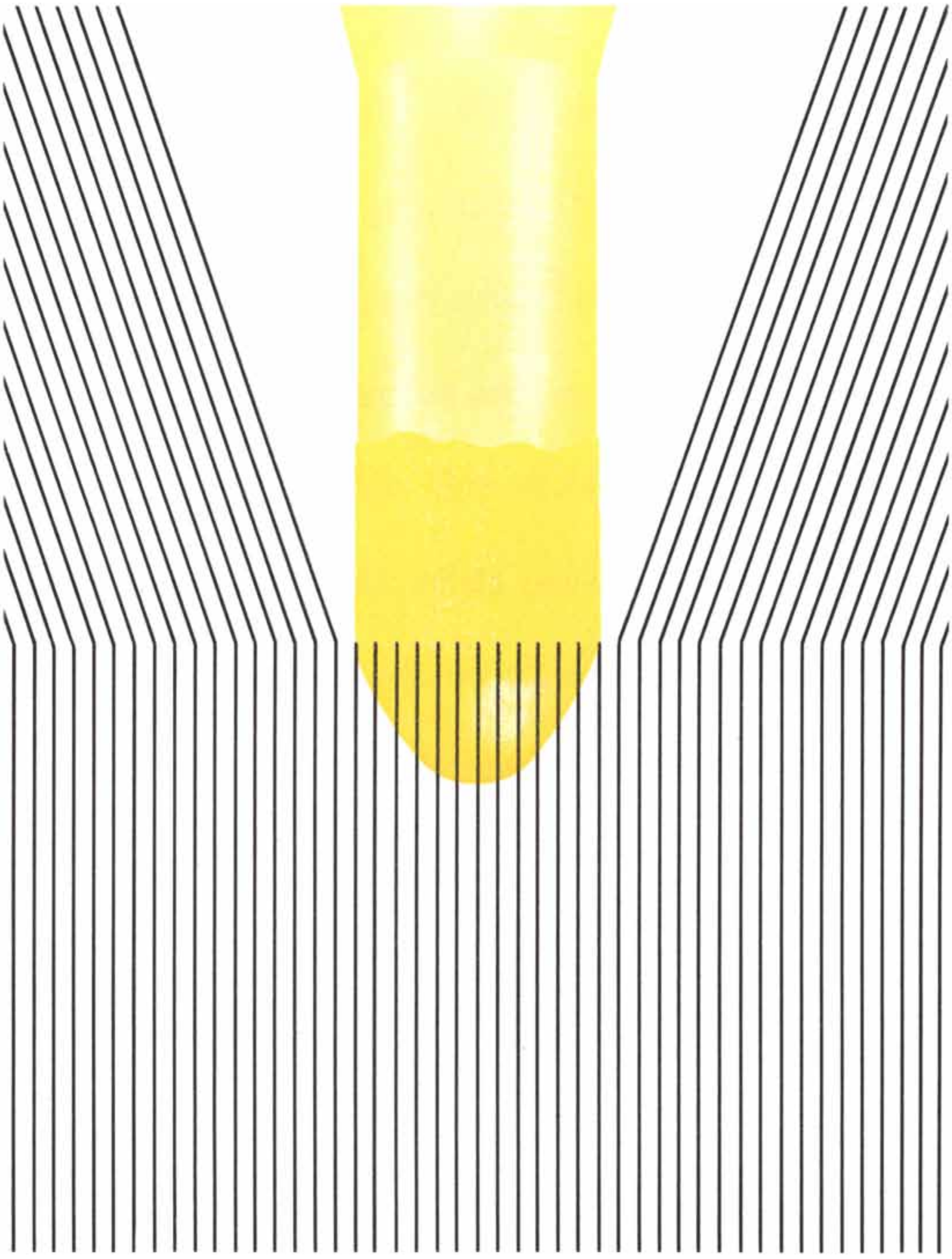
transparent crystalline mass. It is a very complex substance rich in nucleic acid and protein; it also contains carbohydrates and precursors of silk. As yet it has not been possible to isolate or identify the active fraction. Heating, which generally inactivates proteins, does not destroy the effectiveness of the material. It is perhaps significant that the glandular fluid contains nucleic acid, the substance that conveys the hereditary characteristics of cells from one generation to the next.

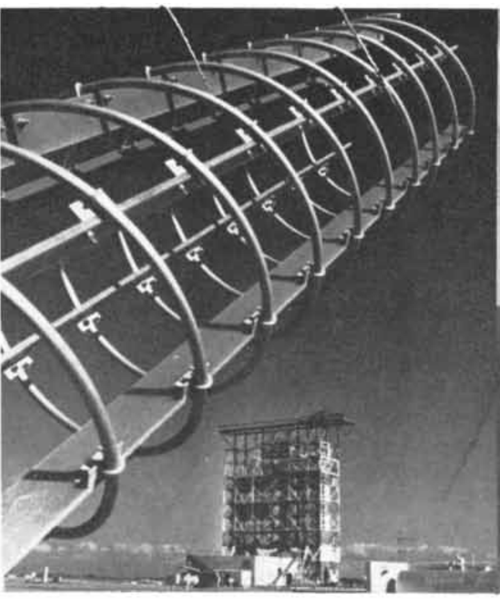
Even less is known about the presumed secretions of the larva. Because we cannot see into the gall to observe the larva's activity, we have attempted to substitute cultures of willow tissues for the interior of the gall. In tissue-culture medium the willow cells form a mound of undifferentiated cells not unlike the callus cells. Larvae taken from galls will live in such cultures, provided the cells come from the same kind of willow as the larva. The presence of the larva stimulates the growth of the cultured tissue in varying degrees. In some cases the larva burrows into the interior of the tissue, and new tissue seals it off. In other cases the larva may feed on the surface; the cells on the edges of the area in which it feeds then increase their rate of growth.

In another type of experiment we have transferred bits of gall tissue to culture medium. Those bits close to the region that had been occupied by the larva grow rapidly; those from other parts grow more slowly or not at all. Thus there is no doubt of the growth-stimulating activity of the sawfly larva.

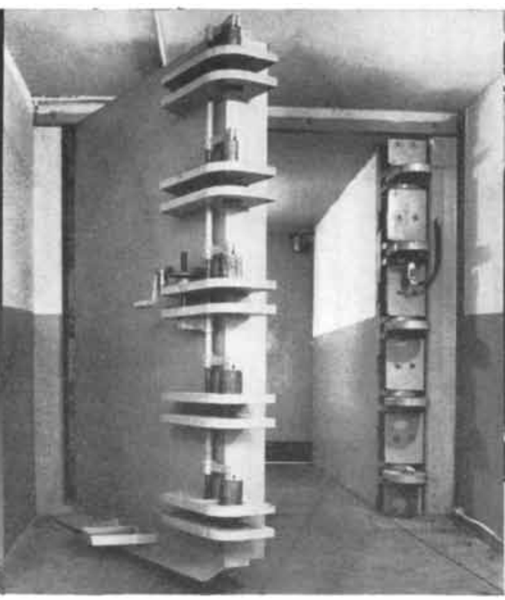
The larvae of some strains of sawfly do not grow and feed uniformly throughout their life. They grow only in the early spring just after hatching and in the fall before pupating for the winter. For four or five months through the summer season they remain inactive and feed little, if at all. When they are transferred to tissue-culture test tubes, larvae of such a strain cease feeding after a while, as they would in the wild. Although the larvae remain alive, they no longer stimulate the growth of the plant tissue around them. Evidently the larvae secrete the stimulating substance when they eat, probably by means of their salivary glands. We do not yet know whether the active factor in the larval secretion is the same as that in the glandular fluid of the adult. This question cannot be answered until we have succeeded in identifying the active fraction of the adult fluid, the problem we are presently preparing to attack.



About the earthly side of Canaveral—Only recently, it spawned little more than snakes and other crawling creatures. Today, high flying birds are poised there, and because they can't jump off from sand, most of the Canaveral manpower and materials go into ground support equipment. And virtually all the steel material required can be purchased from one source—United States Steel. Whether we're talking about carbon steel, high-strength low-alloy steel, constructional alloy steel, or stainless steel, steel fence, electrical cable, wire rope or cement,



On this vertical oscillating radar tracking unit, every nut, bolt, and insulator collar is Stainless Steel. To the right, is a Stainless Steel fuel tank, and beyond that rises the U. S. Air Force Thor gantry tower, with a structural steel frame similar to a nine-story building.



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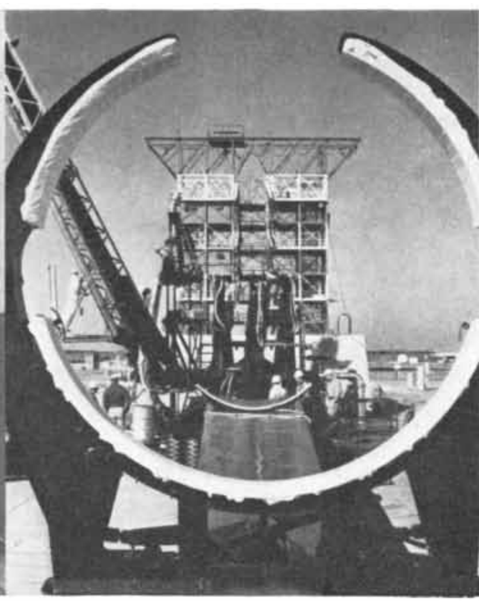

The mobile transporter for the Thor is strong but light on its wheels because it was designed with weight-saving high-strength steels. Slanting to the left is the steel umbilical tower which carries Stainless Steel fuel lines and control lines.

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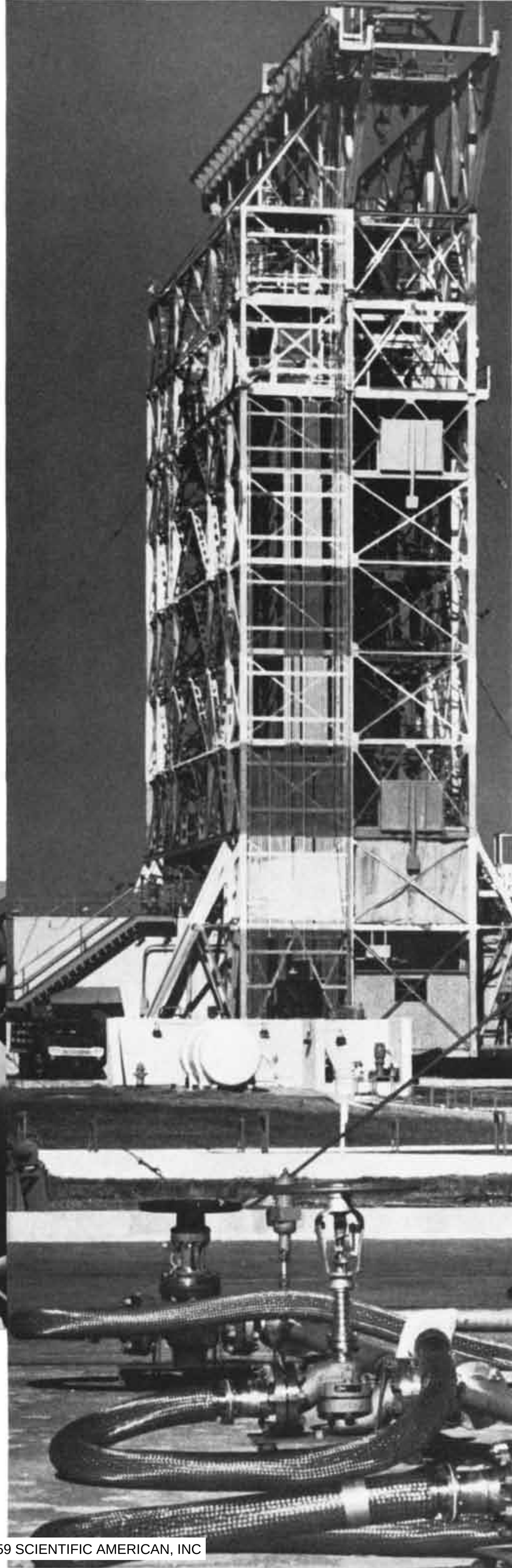

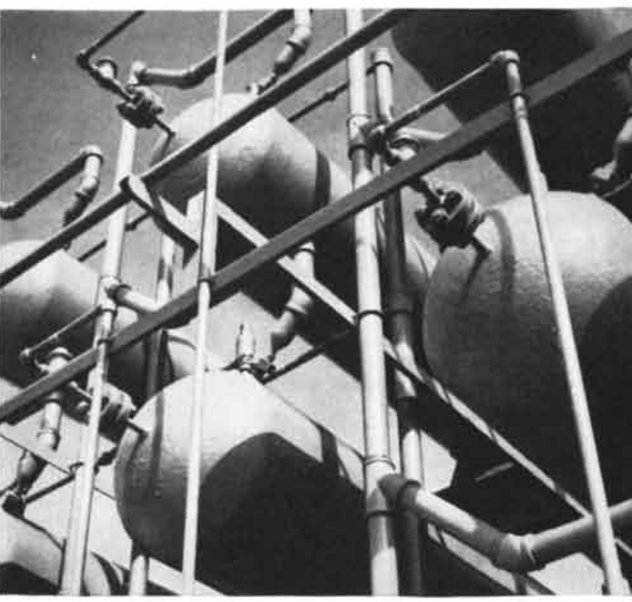

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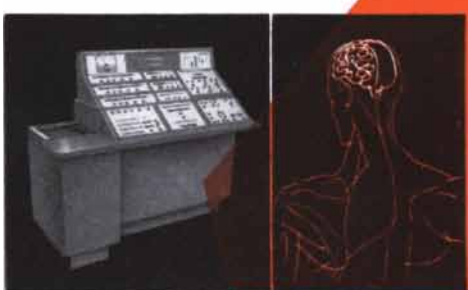

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The Idea of Man's Antiquity

When Father MacEnery found flint implements in the same stratum with the fossils of extinct animals, he pushed human history far beyond 4004 B.C., the date most people took as man's beginning

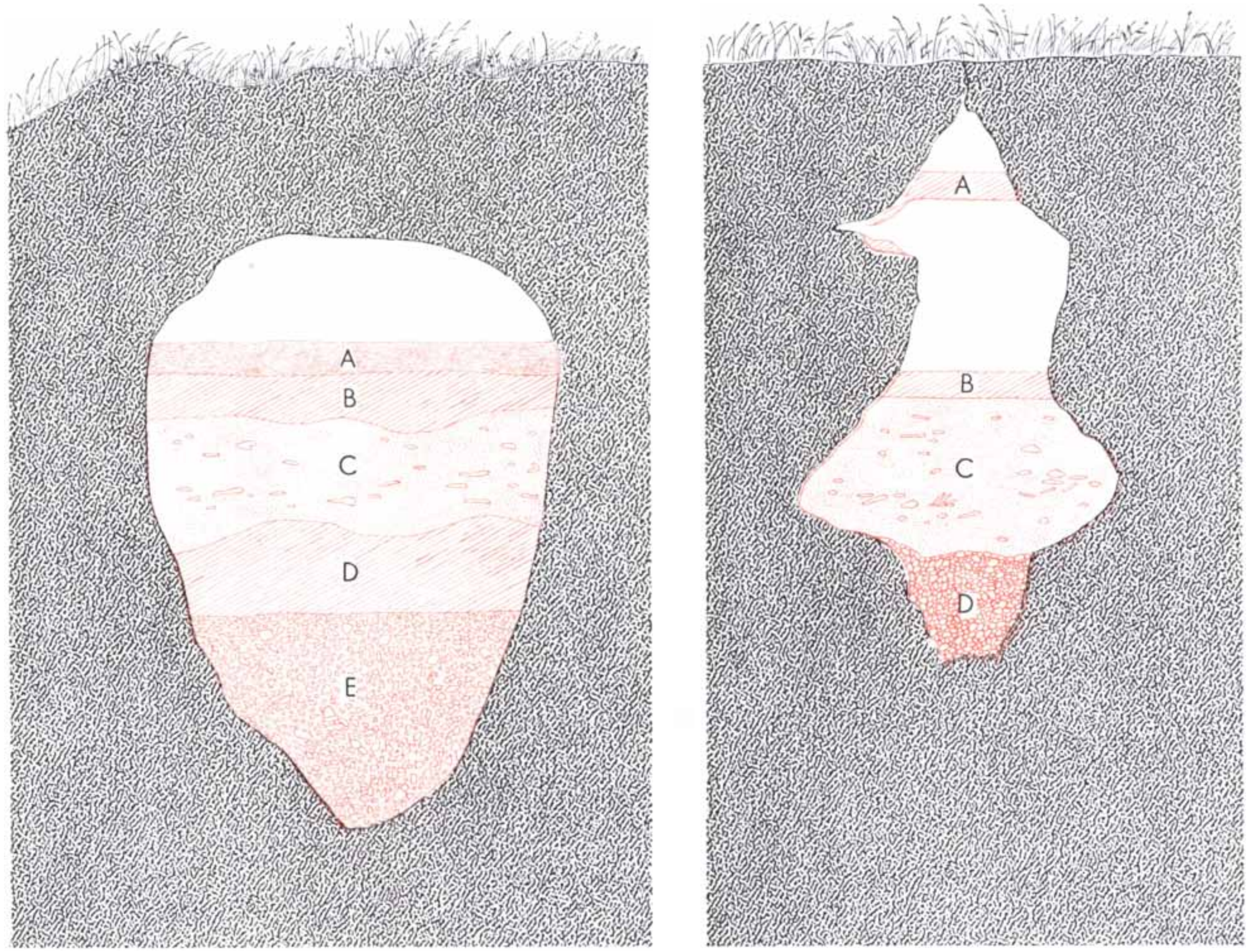
by Glyn E. Daniel

Digging near the Bavarian city of Bayreuth in 1771, Johann Friedrich Esper found human bones at the same level as the remains of extinct animals. He was more startled than elated by his find, because it confronted him with a disturbing anachronism in the then-accepted timetable of the world's history. In the preceding century Archbishop Ussher had worked out this chronology from the complicated genealogies of *Genesis;* he concluded that the world and man had been created in 4004 B.C. Six millennia took in everything, and man was only a trifle younger than time itself. In this view of human history there was no inkling that sources other than written ones existed. The antiquaries of the time were concerned with describing monuments and cataloguing portable relics; they had no idea that history lay in the soil, much less any notion of how to wrest it from its grave. Samuel Johnson spoke for the pre-archaeological scholar when he declared: "All that is really known of the ancient state of Britain is contained in a few pages. . . . We can know no more than what old writers have told us."

Except for a few pagan myths, the old writers did not suggest that there were men before Man. Geology in Esper's and Johnson's time was little more than an elaboration of the Biblical story of Creation and the Flood. In accordance with that tradition it was easy, and not without logic, to explain fossils and river gravels in terms of the Flood, or sometimes of several floods. This was catastrophist or diluvialist geology. There was, to be sure, some talk of animals antedating 4004 B.C., but their fossils were believed to be the remains of creatures discarded by the Creator before his culminating creation: the world of Genesis. But with the creation of Adam, according to the doctrine, further creation ceased. Opposed to this account were the antediluvians—the near-heretics who held that man may have lived before Adam. This was the danger apprehended by Esper, and it caused him to ask: "Did [the bones] belong to a Druid or to an Antediluvian or to a mortal man of more recent time? I dare not presume without sufficient reason these members to be of the same age as the other animal petrifactions. They must have got there by chance."

The "sufficient reason" Esper asked

FLINT TOOL FROM HOXNE IN SUFFOLK is typical of the discoveries that caused speculation about man's antiquity. This hand-axe, dated according to the stratum in which it was found and the workmanship it displays, belongs to the Lower Paleolithic of about half a million years ago. The illustration appeared in 1800 in *Archeologia*, a publication of the Society of Antiquaries of London.



DEVON CAVES IN ENGLAND figured prominently in establishing the antiquity of man. Kent's Cavern (*left*) was the earlier find. Under surface layer (A) lay a stalagmite stratum (B) which sealed the cave earth (C) containing human artifacts amid the remains of extinct animals. Layers D and E are stalagmite and breccia. The floor of the 600-foot long Brixham Cave (*right*) had once been at A, but when excavated in 1858 the stalagmite at B was the cave floor. In the six feet of cave earth (C) were remains similar to those found in Kent's Cavern. Level D is gravel bed. Both the caves measure more than 20 feet from roof to gravel-bed bottom.

for was soon to be forthcoming. James Hutton, in his *Theory of the Earth*, published in 1785, offered the first persuasive alternative to cataclysmic geology. He suggested that the stratification of rocks was due not to floods and other supernatural calamities but to processes still going on in seas and rivers and lakes. He wrote: "No processes are to be employed that are not natural to the globe, no action to be admitted except those of which we know the principle." Hutton's reasoning was carried forward by William Smith—"Strata" Smith as he was called—who assigned relative ages to rocks according to their fossil contents, and who argued for an orderly, noncatastrophic deposition of strata over a long period of time—much longer than 6,000 years.

But the climate of opinion was still catastrophist. In 1797, just 26 years after Esper's discovery, John Frere, a gentleman of Suffolk, sent to the Secretary of the Society of Antiquaries of London some hand-axes and other implements of flint found at Hoxne, near Diss. In his accompanying letter he wrote: "If [these] weapons of war, fabricated and used by a people who had not the use of metals . . . are not particularly objects of curiosity in themselves, they must, I think, be considered in that light from the situation in which they are found, [which] may tempt us to refer them to a very remote period indeed; even beyond that of the present world."

They were indeed to be referred "to a very remote period": modern archaeologists would place them in the Lower Paleolithic of perhaps half a million years ago. But at the time no one took Frere's speculations seriously.

William Buckland, Reader in Geology at Oxford and later Dean of Westminster, perhaps typified catastrophist thinking. In 1823 he published his great book *Reliquiae Diluvianae, or Observations on the Organic Remains contained in Caves, Fissures and Diluvial Gravel, and on Other Geological Phenomena attesting the Action of an Universal Deluge*. Buckland himself had found evidence of the antiquity of man, but he refused to believe it. He had excavated Goat's Hole Cave near Paviland in South Wales and amid Upper Paleolithic implements had found the skeleton of a young man. (He believed it to be that of a young woman, and it is still referred to as the Red Lady of Paviland.) But he insisted that the skeleton was "clearly not coeval with the antediluvian bones of the extinct species" of animals. He made similar discoveries in the caves of the Mendip Hills of southwestern England but again refused to believe they were antediluvian. He argued instead that the caves had "been used either as a place of sepulture in early times or resorted to for refuge by the wretches

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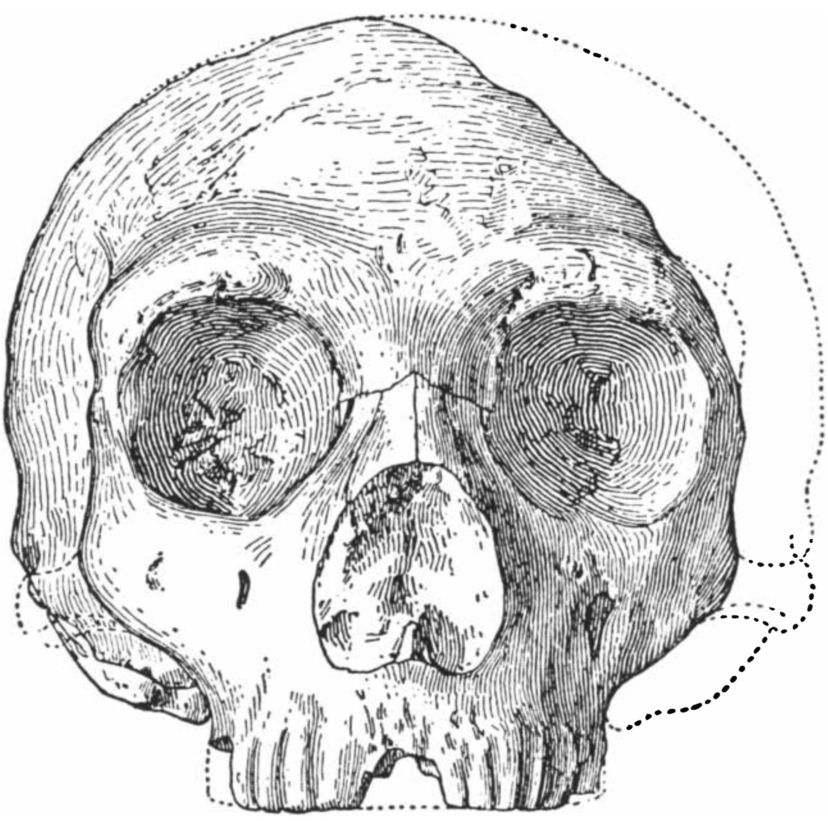
that perished in it, when the country was suffering under one of our numerous military operations. . . . The state of the bones affords indication of very high antiquity but there is no reason for not considering them post-Diluvian."

When a Roman Catholic priest, Father MacEnery, discovered some flint implements at Kent's Cavern near Torquay in Devon, he wrote of them to Buckland. Buckland reacted characteristically. The flints had been found amid the stratified remains of rhinoceros and other animals under the unbroken, stalagmite-sealed floor of the cave. Buckland avoided the implications of this sealed evidence and offered another ingenious and tortured explanation that preserved catastrophist doctrine. He told MacEnery that ancient Britons must have camped in the cave; they had probably scooped out ovens in the stalagmite and in that way the flint implements had got below. Thus, according to Buckland, the association of the flints with the skeletal remains of extinct animals was only apparent. It was all very reasonable, except that, as MacEnery noted, there were no such ovens in the cave. But Buckland was insistent, and out of deference to his views MacEnery did not publish his evidence.

At about this time, however, the National Museum in Copenhagen had been opened to the public with its antiquities arranged in three ages: Stone, Bronze and Iron. This classification was the work of Christian Jurgenson Thomsen, director of the Museum, and he set forth its underlying idea in a treatise that served as a guidebook to the display. His three-age system has been described very properly as "the cornerstone of modern archaeology"; it helped to secure recognition for the view that the human species had come through a long prehistory. (The word "prehistory" did not appear in print until 1851, when Daniel Wilson used it in *The Archaeology and Prehistoric Annals of Scotland.*)

The 1830's were eventful for the emerging new science of archaeology. In 1833 Sir Charles Lyell published his *Principles of Geology*, a powerful contribution to the cause of the fluvialists, as the supporters of Hutton and Smith were called. This book was in its



SKULL OF NEANDERTHAL WOMAN was found in Forbes Quarry at Gibraltar in 1848. First believed to be a new species, Neanderthal was later seen to be a human variant. Missing portions of skull are outlined in this drawing from Hugo Obermaier's *Fossil Man in Spain.*

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way as important as Darwin's *Origin of Species.* Lyell took the many fragmentary observations and insights of the fluvialists and organized them into a coherent system. He stated the principle of uniformitarianism: the central geological idea that strata could only be interpreted correctly by assuming that the agencies that formed them had operated at a uniform rate and in a uniform way, just as they work in the present. Lyell's great book was a staggering blow to catastrophist geology. But though the discoveries of Esper and Frere were thus rationalized, and the work of Hutton and Smith endorsed, this was not yet sufficient to swing general opinion behind belief in the true antiquity of man. More evidence was needed to shatter the old view and establish the new one; it soon came from Devon and northern France.

Boucher de Perthes was a customs official at Abbeville in the north of France. He had become interested in archaeology when he encountered neolithic artifacts and bones—"Celtic" remains as they were called—brought up by the dredging of the Somme Canal. His interest grew as more remains of "diluvial" man and animals were found in the quarries of nearby Manchecourt and Moulin-Quignon. By 1838, some five or six years after Lyell's *Principles* had appeared, de Perthes set forth his views in a five-volume work entitled *De la création: essai sur l'origine et la progression des êtres.* At about the same time he was exhibiting *haches diluviennes*, roughly chipped hand-axes, before the Société Imperiale d'Emulation de la Somme in Abbeville and at the Institut de Paris.

He was received with the same coldness suffered by his fellows in England, and like them he was regarded as a crank. "At the very mention of the words 'axe' and 'diluvium,'" he once remarked, "I observe a smile on the face of those to whom I speak. It is the workmen who help me, not the geologists." But de Perthes worked on and accumulated more evidence. The association he observed of human artifacts and extinct animals in the Somme gravels was compelling and no longer to be explained by the diluvial theory. In 1847 he published the first part of a three-volume work entitled *Antiquités celtiques et antédiluviennes.* The very title of the work indicates the effect his researches had on his thinking: the *haches diluviennes* were now *haches antédiluviennes.*

In England, meanwhile, the new archaeology had found other champions. William Pengelly, a schoolmaster, reworked MacEnery's cavern in Kent and, viewing the evidence there in terms of Lyell's uniformitarianism, saw it as proof of man's antiquity. But he realized that objections could be raised because the cavern had been disturbed by other workers. He found an entirely new site in an undisturbed cave across the bay in Devon above Brixham Harbour—Windmill Hill Cave. To supervise his excavations here he enlisted a committee of distinguished geologists in London. Pengelly, carrying out the actual digging, worked from July, 1858, to the next summer. It was a successful year. On the floor of the cave "lay a sheet of stalagmite from three to eight inches thick having within it and on it relics of lion, hyena, bear, mammoth, rhinoceros and reindeer." Below the floor Pengelly found flint tools.

The Brixham discoveries were compelling. Sir Charles Lyell said of them: "The facts recently brought to light during the systematic investigation of the Brixham Cave must, I think, have prepared you to admit that scepticism in regard to the cave evidence in favour of the antiquity of man had previously been pushed to an extreme."

The revolution was nearing a crisis: within the immediately foreseeable future man's history was to reach back beyond Archbishop Ussher's 6,000 years. The catastrophist theory was once and for all to be discarded and with it the Biblical notion that the world and man represented unalterable acts of special creation.

In 1858, while Pengelly was digging in the Brixham cave, the Scottish geologist Hugh Falconer visited Boucher de Perthes at Abbeville. De Perthes' evidence of man's antiquity immediately convinced Falconer. When he returned to London, he persuaded the geologist Joseph Prestwich and the antiquary John Evans to go and see the finds of Abbeville for themselves. As Evans was leaving for France, he wrote of the widely separated events that were revising men's beliefs: "Think of their finding flint axes and arrowheads at Abbeville in conjunction with the bones of elephants and rhinoceroses 40 feet below the surface in a bed of drift. In this bone cave in Devon now being excavated . . . they say they have found flint arrowheads among the bones and the same is reported of a cave in Sicily. I can hardly believe it. It will make my ancient Britons quite modern if man is carried back in England to the days when elephants, rhinoceroses, hippopotomuses and tigers were also inhabitants of the country."

Evans then records what happened

when they got to France. De Perthes showed them his collection of flint axes and implements "found among the beds of gravel, . . . the remains of a race of men who existed at the time when the deluge or whatever was the origin of these gravel beds took place. One of the most remarkable features of the case is that nearly all . . . of the animals whose bones are found in the same beds as the axes are extinct. There is the mammoth, the rhinoceros, the urus, . . . etc." Then they arrive at the actual gravel pits: "Sure enough, the edge of an axe was visible in an entirely undisturbed bed of gravel and eleven feet from the surface. We had a photographer with us to take a view of it so as to corroborate our testimony."

The evidence at Abbeville convinced Evans and Prestwich as it had convinced Falconer, and this, with Pengelly's work at Windmill Hill Cave, brought the whole matter to a head. When they got back to London, Prestwich read a paper to the Royal Society in which he said: "It was not until I had myself witnessed the conditions under which these flint implements had been found at Brixham that I became fully impressed with the validity of the doubts thrown upon the previously prevailing opinions with respect to such remains in caves." That famous meeting of the Royal Society was on May 26, 1859, and of it John Evans wrote: "There were a good many geological nobs there: Sir Charles Lyell, Murchison, Huxley, Morris, Dr. Perry, Faraday, Wheatstone, Babbage, etc. . . . Our assertions as to the finding of the weapons seemed to be believed."

A week later Evans read a paper on the same subject to the Society of Antiquaries of London. In his account of this meeting he remarked: "I think I was generally believed in."

In August Sir Charles Lyell himself went to see the evidence of the Abbeville pits. He too was convinced, and a month later, in his presidential address to Section C of the British Association for the Advancement of Science, with Prince Albert presiding, he said: "I am fully prepared to corroborate the conclusions recently laid before the Royal Society by Mr. Prestwich." The battle was over; the great antiquity of man was an established fact. Victorian thought had to adjust itself not only to organic evolution but also to the antiquity of man; 4004 B.C. was forgotten.

It is perhaps strange that Charles Darwin himself was not at first impressed by the findings of de Perthes. Later in life he confessed: "I am ashamed to think that I concluded the whole was rubbish. Yet [de Perthes] has done for man something like what Agassiz did for glaciers." Perhaps Darwin held back because he did not want to involve his theory of evolution, at least at the outset, in anything so controversial as the ancestry of man. In the first edition of the *Origin of Species* he refused to discuss the relationship of evolution to man, and made only one cryptic statement on the general thesis of his book: "Light will be thrown on the origin of man and his history." In later editions this sentence was modified to: "Much light will be thrown. . . ."

But Darwin threw no light, not at any rate until 1871, when he published his views on the relation between man and general evolutionary theory in his *Descent of Man*. But this was eight years after T. H. Huxley's *Evidence as to Man's Place in Nature* had been published, and a dozen years after the climactic events of 1859. Thus whatever contribution Darwin made to the discovery of the antiquity of man, it was indirect and unwitting. It consisted entirely in the new way of thinking that he exemplified: uniformitarianism and evolution. The doctrine of evolution had man evolving from a prehuman ancestor; obviously there must somewhere be evidence of his passage from savagery through barbarism to civilization. The roughly chipped tools from Devon and the Somme now were more than credible, they were essential. People now had to accept the discoveries of de Perthes and Pengelly, where only a generation or two before, when the immutability of the species and catastrophist diluvialism were the dominant ideas, such discoveries had been scorned or ignored. Thus though Darwinism did not create prehistoric archaeology, it did give a great impetus to its acceptance and study; it helped set the stage for the acceptance of the idea of man's antiquity.

But even after the idea seemed well established, many students of the mid-century discoveries had misgivings about them. There was one particularly troublesome point: Men had left their axes but no trace of their physical selves, no bones. "Find us human remains in the diluvium," some of de Perthes' countrymen said to him, "and we will believe you." For de Perthes it was a sad challenge; this was 1863 and he was an old man of 75. Unable to dig for himself, he offered a 200-franc reward to the first quarryman to find human remains. With four months' wages as the prize, the quarrymen could not leave it to honest luck. Soon after the offer was made, they "found" human remains; first a human tooth; five days later a human jaw.

Boucher de Perthes was vindicated, and his French colleagues were at last satisfied. But the drama had not played out. Some British archaeologists had long suspected that de Perthes' gravel pits were being salted, and they proved that the jaw and several hand-axes had been inserted into the gravel faces by some of his workmen. It was a cruel blow.

Fortunately the case did not hang by so meager a thread. There was genuine skeletal evidence of man's antiquity. Two years before the 1859 pronouncements about the antiquity of man, the long bones and skullcap of a manlike being had been discovered in a limestone cave in the ravine of Neanderthal near the Rhenish city of Düsseldorf. Hermann Schaaffhausen, who first described these remains, noted the large size, low forehead and enormous browridges of the skullcap. He believed that the Neanderthal skeleton belonged to "a barbarous and savage race," and he regarded it "as the most ancient memorial of the early inhabitants of Europe."

There was still more evidence. A female cranium had been found nine years before that, in 1848, during blasting operations in the Forbes Quarry at Gibraltar. The significance of the relic was not realized at the time, but at this juncture, in 1859, George Busk read a paper on it before a meeting of the British Association. The ebullient Falconer, who had persuaded Evans and Prestwich to visit de Perthes six years before, again apprehended the importance of a crucial find. He perceived that here was a new species of man; he proposed to name it *Homo calpicus*, after Calpe, the ancient name for Gibraltar. He wrote his suggestion to Busk, referring somewhat redundantly to his "Grand, Priscan, Pithecoid, Agrioblematous, Platycnemic, wild *Homo calpicus* of Gibraltar." It was only later realized that this "grand, primitive, manlike, wild-eyed, flat-headed, wild Calpic man of Gibraltar" was not one of a new species but a member of that curious human variant, Neanderthal man.

And so by 1859 all the evidence for proper recognition of the antiquity of man was available: artifacts from the Somme and south Devon and fossils from Neanderthal and Gibraltar. The century since then has been given to building on that premise, to filling in its outlines with new evidence of man's physical and cultural evolution.

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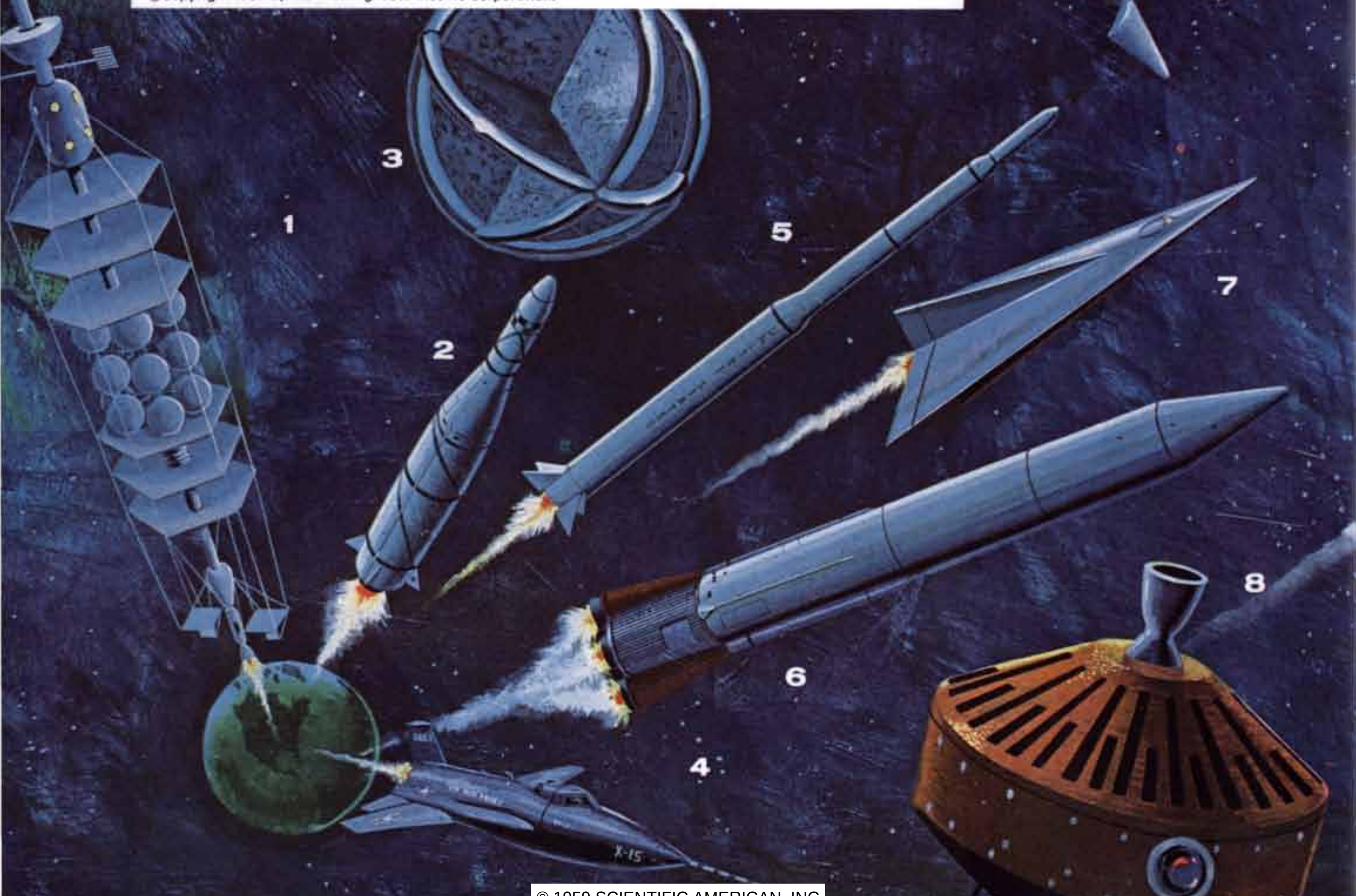


1. two-man deep space ship **2.** Thor-Hustler booster vehicle **3.** radar reflector satellite **4.** The X-15 — first piloted space-airplane **5.** Scout satellite launcher **6.** Vega satellite- and spaceprobe launcher **7.** Dyna-Soar glide bomber **8.** Pioneer I moon probe **9.** reconnaissance satellite **10.** Nova space ship booster **11.** Pioneer IV moon probe **12.** Discoverer second stage **13.** Centaur second and third stage **14.** Saturn booster configuration with Titan second stage **15.** Venus probe with solar batteries mounted on paddles **16.** 100-foot foil satellite for global communications **17.** Mercury capsule for manned satellite.

MATHEMATICAL GAMES

How three modern mathematicians disproved a celebrated conjecture of Leonhard Euler

by Martin Gardner

The history of mathematics is filled with shrewd conjectures—intuitive guesses by men of great mathematical insight—that often wait for centuries before they are proved or disproved. When this finally happens it is a mathematical event of first magnitude. Not one but two such events were announced in April at the annual meeting of the American Mathematical Society. We need not be concerned with one of them (a proof of a conjecture in advanced group-theory), but the other, a disproof of a famous guess by the great Swiss mathematician Leonhard Euler, is related to many classical problems in recreational mathematics. Euler had expressed his conviction that Graeco-Latin squares of certain orders (to be explained below) could not exist. Three mathematicians—E. T. Parker of Remington Rand Univac, a division of the Sperry Rand Corporation, and R. C. Bose and S. S. Shrikhande of the University of North Carolina—completely demolished Euler's conjecture. They have found methods for constructing an infinite number of squares of the type that experts, following Euler, for 177 years had believed to be impossible.

The three mathematicians, dubbed "Euler's spoilers" by their colleagues, have written a brief account of their discovery. The following quotations from this account are interspersed with comments of my own to clarify some of the concepts in it or to summarize its more technical passages.

"In the last years of his life Leonhard Euler (1707-1783) wrote a lengthy memoir on a new species of magic square: *Recherches sur une nouvelle espèce de quarres magiques*. Today these constructions are called Latin squares after Euler's practice of labeling their cells with ordinary Latin letters (as distinct from Greek letters).

"Consider, for example, the square at the left in the accompanying illustration [*below*]. The four Latin letters a, b, c and d occupy the 16 cells of the square in such a way that each letter occurs once in every row and once in every column. A different Latin square, its cells labeled with the four corresponding Greek letters, is shown in the middle of the illustration. If we superpose these two squares, as shown at the right, we find that each Latin letter combines once and only once with each Greek letter. When two or more Latin squares can be combined in this way, they are said to be orthogonal squares. The combined square is known as a Graeco-Latin square."

The square at the right provides one solution to a popular card puzzle of the 18th century: Take all the aces, kings, queens and jacks from a deck and arrange them in a square so that every row and column will contain all four values and all four suits. Readers may enjoy searching for another solution in which the two main diagonals also show one of each suit and one of each value. Even with this added feature there are 72 different solutions, not counting rotations and reflections. One solution will be given in this department next month.

"In general a Latin square of order n is defined as an n-by-n square, the n^2 cells of which are occupied by n distinct symbols, such that each symbol occurs exactly once in each row and once in each column. There may exist a set of two or more Latin squares such that any pair of them is orthogonal. In the second illustration [*next page*] are shown four mutually orthogonal Latin squares of order 5, which use digits for their symbols."

In Euler's day it was easy to prove that no Graeco-Latin square of order 2 is possible. Squares of orders 3, 4 and 5 were known, but what about order 6? Euler put it this way: Each of six different regiments has six officers, one belonging to each of six different ranks. Can these 36 officers be arranged in a square formation so that each row and file contains one officer of each rank and one of each regiment?

"Euler showed that the problem of n^2 officers, which is the same as the problem of constructing a Graeco-Latin square of order n, can always be solved if n is odd, or if n is an 'evenly even' number (that is, a number divisible by 4). On the basis of extensive trials he stated: 'I do not hesitate to conclude that it is impossible to produce any complete square of 36 cells, and the same possibility extends to the cases of $n = 10$, $n = 14$ and in general to all unevenly even numbers' (even numbers not divisible by 4). This became famous as Euler's conjecture. It may be stated more formally as follows: There does not

a	b	c	d
b	a	d	c
c	d	a	b
d	c	b	a

α	β	γ	δ
γ	δ	α	β
δ	γ	β	α
β	α	δ	γ

aα	bβ	cγ	dδ
bγ	aδ	dα	cβ
cδ	dγ	aβ	bα
dβ	cα	bδ	aγ

The Graeco-Latin square (right) *is formed by superposing two Latin squares* (left and center)

0	1	2	3	4
1	2	3	4	0
2	3	4	0	1
3	4	0	1	2
4	0	1	2	3

0	1	2	3	4
2	3	4	0	1
4	0	1	2	3
1	2	3	4	0
3	4	0	1	2

0	1	2	3	4
3	4	0	1	2
1	2	3	4	0
4	0	1	2	3
2	3	4	0	1

0	1	2	3	4
4	0	1	2	3
3	4	0	1	2
2	3	4	0	1
1	2	3	4	0

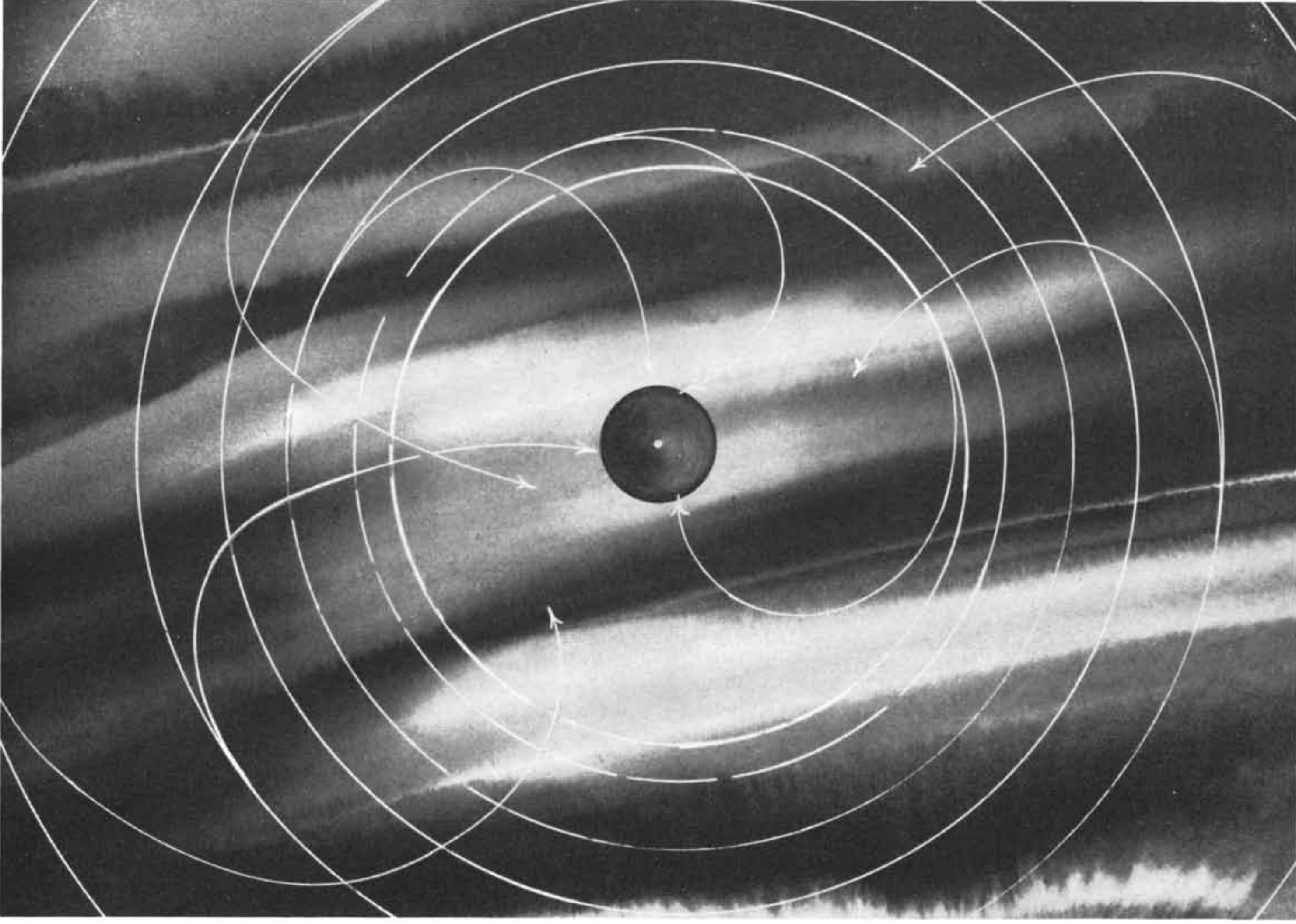
Four mutually orthogonal Latin squares of order 5

exist a pair of orthogonal Latin squares of order $n=4k+2$ for any positive integer k.

"In 1901 the French mathematician G. Tarry proved by exhaustive enumeration that Euler's conjecture is indeed true for a square of order 6. The labor involved in this type of proof goes up rapidly as n increases. Even the next case, $n=10$, is beyond the range of paper-and-pencil trial, and almost beyond the range of modern digital computers. Marshall Hall reported in Vol. IV of *Surveys in Applied Mathematics:* 'Extensive searches on SWAC, the computer at the University of California at Los Angeles, have failed to produce an orthogonal 10-by-10 pair. But even with more than 100 hours of high-speed search, the part of the possible cases tried is so microscopic that no conclusion may be drawn.' Had Euler's conjecture been true for the 10-by-10 square, it would have taken the fastest modern computer at least a century to prove this by running through all possible arrangements of the symbols.

"The last sentence of Euler's memoir reads: 'At this point I close my investigations on a question, which though of little use in itself, led us to rather important observations for the doctrine of combinations, as well as for the general theory of magic squares.' It is a striking example of the unity of science that the initial impulse which led to a solution of Euler's conjecture came from the practical needs of agricultural experimentation, and that the investigations which Euler thought useless have proved to have enormous value in the design of controlled experiments."

Sir Ronald Fisher, now professor of genetics at the University of Cambridge and one of the world's leading statisticians, was the first to show (in the early 1920's) how Latin squares could be used in agricultural research. Suppose, for example, one wishes to test with a minimum waste of time and money the effects of seven different agricultural chemicals on the growth of wheat. One difficulty encountered in such a test is that the fertility of different patches of soil usually varies in an irregular way. How can we design an experiment that



Report from IBM *Yorktown Research Center, New York*

OPTIMUM CONTROL OF DYNAMIC SYSTEMS

A dynamic system is one whose present output depends not only on the present value of the input but also on its past history. To maintain the output as close as possible to a set of desired values, the input is generated from a knowledge of this history as expressed by the state of the system, which must be constantly monitored, and the input-output relationships.

Since the contribution of random disturbances and the effect of the monitoring process itself cannot be precisely determined, statistical procedures must often be relied upon. The difficulties owing simply to the large number of interrelationships involved are magnified in practical cases by the need to perform calculations in real time and to take into account the cost of the control effort. A group of scientists and engineers at the IBM Yorktown Research Center are trying to make this problem manageable through work in stability theory and the development of analytical techniques that take full advantage of the capabilities of digital computers.

The group has employed the Second Method of Lyapunov (a 19th Century Russian mathematician) to distill the necessary and sufficient conditions for the control of certain classes of nonlinear systems. The virtue of this method is that it allows properties of a solution to be studied from the structure of the differential equation, independent of particular solutions. The aim is to set up a scalar function over the state space so that the energy along each solution decreases. This assures that the system—linear or nonlinear—is globally stable.

Members of the group have demonstrated the unifying effect of working directly in the time domain. They have also attempted to simplify the computation through dynamic programming—a technique for solving multistage problems one stage at a time, successively embedding each solution into the next more general solution. The next step is to bring together the various results in a theory of self-optimizing control systems.

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will simultaneously test all seven chemicals and at the same time eliminate any "bias" due to these fertility variations? The answer: Divide the wheat field into "plots" that are the cells of a 7-by-7 square, then apply the seven "treatments" in the pattern of a randomly chosen Latin square. Because of the pattern a simple statistical analysis of the results will eliminate any bias due to variations in soil fertility.

Suppose that instead of one variety of wheat for this test we have seven. Can we design an experiment that will take this fourth variable into account? (The other three variables are row fertility, column fertility and type of treatment.) The answer is now a Graeco-Latin square. The Greek letters show where to plant the seven varieties of wheat and the Latin letters where to apply the seven different chemicals. Again the statistical analysis of results is simple.

Graeco-Latin squares are now widely used for designing experiments in biology, medicine, sociology and even marketing. The "plot" need not, of course, be a piece of land. It may be a cow, a patient, a leaf, a cage of animals, the spot where an injection is made, a period of time or even an observer or group of observers. The Graeco-Latin square is simply the chart of the experiment. Its rows take care of one variable, columns take care of another, the Latin symbols a third and the Greek symbols a fourth. For example, a medical investigator may wish to test the effects of five different types of pill (one a placebo) on persons in five different age brackets, five different weight groups and five different stages of the same disease. A Graeco-Latin square of order 5, selected randomly from all possible squares of that order, is the most efficient design the investigator can use. More variables can be accommodated by superposing additional Latin squares, though for any order n there are never more than $n-1$ squares that are mutually orthogonal.

The story of how Parker, Bose and Shrikhande managed to find Graeco-Latin squares of orders 10, 14, 18, 22 (and so on) begins in 1958, when Parker made a discovery that cast grave doubt on the correctness of Euler's conjecture. Following Parker's lead, Bose developed some strong general rules for the construction of large-order Graeco-Latin squares. Then Bose and Shrikhande, applying these rules, were able to construct a Graeco-Latin square of order 22. Since 22 is an even number not divisible by 4, Euler's conjecture

00	47	18	76	29	93	85	34	61	52
86	11	57	28	70	39	94	45	02	63
95	80	22	67	38	71	49	56	13	04
59	96	81	33	07	48	72	60	24	15
73	69	90	82	44	17	58	01	35	26
68	74	09	91	83	55	27	12	46	30
37	08	75	19	92	84	66	23	50	41
14	25	36	40	51	62	03	77	88	99
21	32	43	54	65	06	10	89	97	78
42	53	64	05	16	20	31	98	79	87

E. T. Parker's Graeco-Latin square of order 10, a counter-example to Euler's conjecture

MIXED TRICKS

. . . for strategic penetration

Like the Oriental juggler, strategic weapons systems need a mixed bag of tricks to be successful. Modern legerdemain for effective penetration may include camouflage, tactics, radar and infrared decoys, radar-busting missiles, bomber defense missiles, and radar jammers. The problem is to select and design the optimum combination of these possibilities for a particular weapon system.

The Bendix Systems Division is working on penetration aids for advanced manned weapons systems. It has also worked on deceptive and jamming countermeasures for unmanned weapons, and has investigated effectiveness of these techniques against defensive systems. Through analysis, simulation, and field experimentation, Bendix has established a broad experience in the capabilities and interactions of weapons systems of the future.

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was contradicted. It is interesting to note that the method of constructing this square was based on the solution of a famous problem in recreational mathematics called Kirkman's schoolgirl problem, proposed by T. P. Kirkman in 1850. A schoolteacher is in the habit of taking her 15 girls for a daily walk, always arranging them three abreast in five rows. The problem is to arrange them so that for seven consecutive days no girl will walk more than once in the same row with any other girl. The solution to this problem is an example of an important type of experimental design known as "balanced incomplete blocks."

When Parker saw the results obtained by Bose and Shrikhande, he was able to develop a new method that led to his construction of an order-10 Graeco-Latin square. It is shown in the illustration on page 184. The symbols of one Latin square are the digits 0 to 9 on the left side of each cell. The digits on the right side of each cell belong to the second Latin square. It is this square, given a quarter-turn clockwise, that is shown on the cover of this issue of SCIENTIFIC AMERICAN; the 10 colors in the cover painting correspond to the 10 digits. You will note that each cell contains a uniquely ordered pair of colors. The outside colors of each cell form one Latin square; the inside colors form the other. In every row and column each color appears only once as an outside color and only once as an inside color. With the aid of this square, the very existence of which is denied in many current college textbooks on experimental methods, statisticians can now design for the first time experiments in which four sets of variables, each with 10 different values, can be kept easily and efficiently under control.

(Note that the gray-black-white 3-by-3 square at the lower left corner of the cover painting is an order-3 Graeco-Latin square. Bose, Shrikhande and Parker have constructed many different squares of order 10, but none that does not contain an order-3 square. It is an open question whether all order-10 squares possess this feature.)

"At this stage," the three mathematicians conclude their report, "there ensued a feverish correspondence between Bose and Shrikhande on the one hand and Parker on the other. Methods were refined more and more; it was ultimately established that Euler's conjecture is wrong for *all* values of $n=4k+2$, where n is greater than 6. The suddenness with which complete success came in a problem that had baffled mathematicians for almost two centuries startled the authors

as much as anyone else. What makes this even more surprising is that the concepts employed were not even close to the frontiers of deep modern mathematics."

The answer to last month's problem of the three prisoners is that A's chances of being pardoned are 1/3, and that B's chances are 2/3.

Regardless of who is pardoned, the warden can give A the name of a man, other than A, who will die. The warden's statement therefore has no influence on A's survival chances; they continue to be 1/3. The situation is analogous to the following card game. Two black cards (representing death) and a red card (the pardon) are shuffled and dealt to three men: A, B, C (the prisoners). If a fourth person (the warden) peeks at all three cards, then turns over a black card belonging to either B or C, what is the probability that A's card is red? There is a temptation to suppose it is 1/2 because only two cards remain face-down, one of which is red. But since a black card can always be shown for B or C, turning it over provides no information of value in betting on the color of A's card. This is easy to understand if we exaggerate the situation by letting death be represented by the ace of spades in a full deck. The deck is spread, and A draws a card. His chance of avoiding death is 51/52. Suppose now that someone turns face-up 50 cards that do not include the ace of spades. Only two face-down cards are left, one of which must be the ace of spades, but this obviously does not lower A's chances to 1/2.

What about prisoner C? Since either A or C must die, their respective probabilities for survival must add up to 1. A's chances to live are 1/3; therefore C's chances must be 2/3. This can be confirmed by considering the four possible elements in our sample space, and their respective initial probabilities:

1. C is pardoned, warden names B (probability 1/3).
2. B is pardoned, warden names C (probability 1/3).
3. A is pardoned, warden names B (probability 1/6).
4. A is pardoned, warden names C (probability 1/6).

In cases 3 and 4, A lives, making his survival chances 1/3. Only cases 1 and 3 apply when it becomes known that B will die. The chances that it is case 1 are 1/3, or twice the chances (1/6) that it is case 3, so C's survival chances are two to one, or 2/3. In the card-game model this means that there is a probability of 2/3 that C's card is red.

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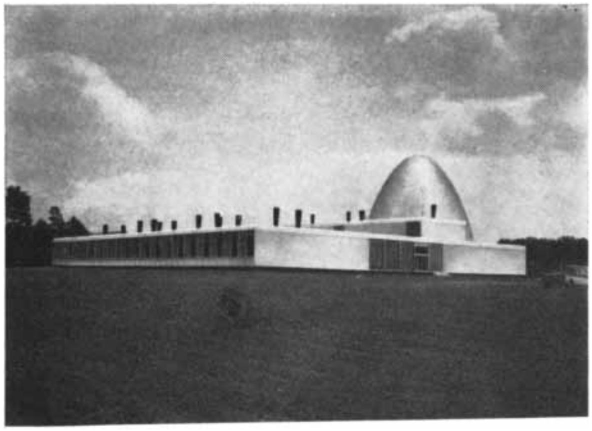

An 87-foot-high aluminum-sheathed concrete dome houses the reactor, and is designed to provide maximum safety from radiation hazards.

instrumentation for safe reactor control

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THE AMATEUR SCIENTIST

How to construct a remarkably simple but serviceable six-inch reflecting telescope

by C. L. Stong

Thirty-four years ago this month an article in SCIENTIFIC AMERICAN described how a group of amateurs in Springfield, Vt., made a reflecting telescope powerful enough to show the mountains of the moon, the rings of Saturn, the Great Nebula in Andromeda and comparable astronomical objects. According to the article the instrument could be duplicated by anyone for $25 and a few hours of labor. The details of construction had been worked out by Russell W. Porter, engineer and explorer, and were described in collaboration with the late Albert G. Ingalls, an editor of SCIENTIFIC AMERICAN. Within a year some 500 laymen had completed similar telescopes and were well on their way to becoming amateur astronomers.

I was one of them. Like many laymen I had wanted to see astronomical objects close-up, but could not afford a ready-made telescope of adequate power. Nor was I acquainted with the owner of one. The description of the Springfield telescope solved the problem. I immediately set out to make a six-inch instrument, and I had scarcely begun to use it when half a dozen of my neighbors started telescopes of their own.

It was not a very good instrument by the standards of present-day amateurs, but it showed the markings of Jupiter and the polar caps of Mars. The fact that scattered light gave the field of view a bluish cast which tended to wash out the contrast, and that the stars wore curious little tails, detracted not a bit from the satisfaction of observing. So far as I knew this was the normal appearance of the sky when it is viewed through a telescope! Over the years I made and used better instruments, and on one occasion I even enjoyed a turn at the eyepiece of the 60-inch reflector on Mount Wilson. By then, however, I had found observing almost routine. Even the Mount Wilson experience did not give me the same thrill as that first squint through my crude six-incher.

In my opinion the beginner should not attempt to make a really good telescope on the first try. Too many who do grow discouraged and abandon the project in midstream. The application of the tests and figuring techniques through which the surface of the principal mirror is brought to optical perfection is a fine art that is mastered by few. I have made more than 50 mirrors and have yet to polish a glass with a perfect figure to the very edge. For all but the most talented opticians neither the tests nor the techniques are exact. After misinterpreting test patterns and misapplying figuring techniques for some months the beginner is tempted to give up the project as impossible and discard a mirror that would operate beautifully if used. Conversely, spurious test-effects have been known to trick veteran amateurs into turning out crude mirrors by the score under the prideful illusion that each was perfect. That such mirrors work satisfactorily is a tribute to the marvelous accommodation of the eye and to lack of discrimination on the part of the observer.

Beginners may nonetheless undertake the construction of a reflecting telescope with every expectation of success. If the amateur has enough strength and mechanical ability to grind two blocks of glass together, his efforts will be rewarded by an instrument far superior to that used by Galileo. He need not concern himself either with tests or elusive figuring techniques.

The simplest reflecting telescope consists of four major subassemblies: an objective mirror which collects light and reflects it to a focus, a flat diagonal mirror which bends the focused rays at a right angle so that the image can be observed without obstructing the incoming light, a magnifying lens or eyepiece through which the image is examined, and a movable framework or mounting which supports the optical elements in alignment and trains them on the sky. About half the cost of the finished telescope, both in money and in labor, is represented by the objective mirror.

The mounting can be made by almost any combination of materials that chances to be handy: wood, pipe, sheet metal, discarded machine parts and so on, depending upon the resourcefulness and fancy of the builder. The mounting designed by Roger Hayward, illustrated on the next page, is representative. The dimensions may be varied according to the requirements of construction.

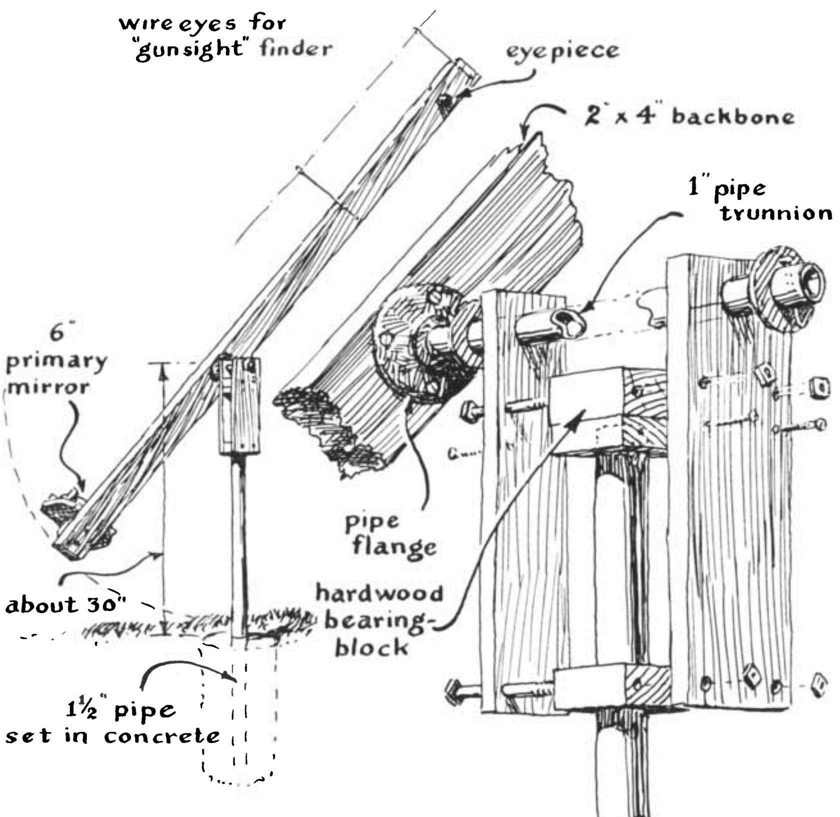
Materials for the objective and diagonal mirrors are available in kit form from dealers in optical supplies such as the Edmund Scientific Corp. of Barrington, N.J., and A. Jaegers of Lynbrook, N.Y. Amateurs with access to machine tools can also make the required eyepieces. The construction is rather tedious, however, and ready-made eyepieces are so inexpensive that few amateurs bother to make their own.

The beginner is urged to start with a six-inch mirror. Those of smaller size do not perform well unless they are skillfully made, and the difficulty of handling larger ones increases disproportionately. Kits for six-inch mirrors retail for about $10. They include two thick glass "blanks," one for the objective mirror and one (called the tool) on which the mirror is ground. The kits also supply a small rectangle of flat plate-glass that serves as the diagonal, a series of abrasive powders ranging from coarse to fine, a supply of optical rouge for polishing and a quantity of pine pitch.

As Russell Porter explained 34 years ago, "In the reflecting telescope, *the mirror's the thing*. No matter how elaborate and accurate the rest of the instrument, if it has a poor mirror, it is hopeless." Fortunately it is all but impossible to make a really poor mirror if one follows a few simple directions with reasonable care. The idea is to grind one face of the six-inch mirror-blank to a shallow curve about a 16th of an inch deep, polish it to a concave spherical surface and then, by additional polishing, deepen it increasingly toward the center so that the spherical curve becomes a paraboloid. The spherical curve is formed by placing the mirror blank on the tool, with wet abrasive between the two, and simply grinding the mirror over the tool in straight back-and-forth strokes. Nature comes to the aid of the mirror-maker in achieving the desired sphere, because glass grinds fastest at the points of greatest pressure between the two disks. During a portion of each stroke the mirror overhangs the tool; maximum pressure develops in the central portion of the mirror, where it is supported by the edge of the tool. Hence the center of the mirror and edge of the tool grind fastest, the mirror becoming concave and the tool convex. As grinding proceeds, the worker periodically turns the tool slightly in one direction and the mirror in the other. In consequence the concavity assumes the form of a perfect sphere because only mating spherical curves remain everywhere in contact when moved over each other in every possible direction. Any departure from a true sphere is quickly and automatically ground away because abnormal pressure develops at the high point and accelerates local abrasion.

The grinding can be performed in any convenient location that is free of dust and close to a supply of water. The operation tends to become somewhat messy, so a reasonably clean basement or garage is preferable to a kitchen or other household room.

A support for the tool is made first. This may consist of a disk of wood roughly half an inch thick fastened to the center of a square of the same material about a foot on a side. The diameter of the wooden disk should be about half an inch smaller than that of the tool. All surfaces of this fixture, except the exposed face of the wooden disk, should receive two coats of shellac. The glass tool is then cemented symmetrically to the unfinished face of the wooden disk by means of pitch. Melt a small quantity of pitch in any handy vessel. Warm the tool for five minutes in reasonably hot water, then dry it and rub one face lightly with a tuft of cotton saturated with turpentine. Now pour a tablespoon of melted pitch on the unfinished face of the wooden disk and press the tool against it so that pitch squeezes out all around the joint. After the tool and supporting fixture cool, they are a unit that can be removed from the bench conveniently for cleaning, which is frequently needed. Some workers prefer to



The mounting of a simple reflecting telescope

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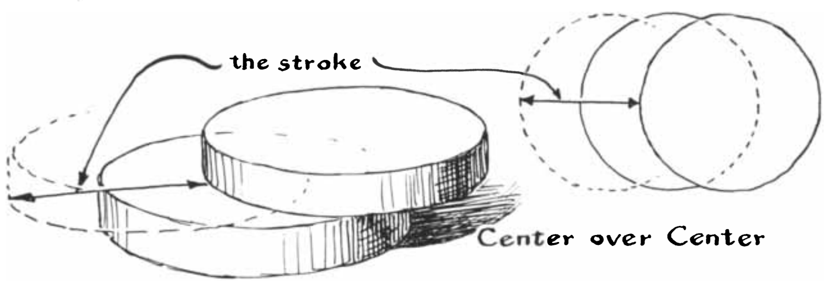

Details of the stroke used in grinding the objective mirror of the telescope

attach the wooden disk to a large circular base. The base is then secured to the bench between three wooden cleats spaced 120 degrees apart. This arrangement permits the base to be rotated conveniently.

The tool assembly is now fastened on the corner of a sturdy bench or other working support, and a teaspoon of the coarsest abrasive is sprinkled evenly over the surface of the glass. A small salt-shaker makes a convenient dispenser for abrasives. The starting abrasive is usually No. 80 Carborundum, the grains of which are about the size of those of granulated sugar. A teaspoon of water is added to the abrasive at the center of the tool and the mirror lowered gently on the tool. The mirror is grasped at the edges with both hands; pressure is applied by the palms. It is pushed away from the worker by the base of the thumbs and pulled forward by the fingertips. The length of the grinding strokes should be half the diameter of the mirror. In the case of a six-inch mirror the strokes are three inches long—a maximum excursion of an inch and a half each side of the center. The motion should be smooth and straight, center over center, as depicted in the drawing above. Simultaneously a slight turn is imparted to the mirror during each stroke to complete a full revolution in about 30 strokes. The tool should also be turned slightly in the opposite direction every 10 or 12 strokes, or, if he prefers, the worker may shift his position around the tool. Learn to judge the length of the stroke. Do *not* limit it by means of a mechanical stop. Beginners will tend to overshoot and undershoot the prescribed distance somewhat, but these errors average out.

Fresh Carborundum cuts effectively, and the grinding is accompanied by a characteristic gritty sound. Initially the work has a smooth, well-lubricated feel. After a few minutes the gritty sound tends to soften and the work has a gummy feel. Stop at this point, add another teaspoon of water and resume grinding until the work again feels gummy. Both the mirror and tool are removed from the bench and washed free of "mud," the mixture of pulverized glass and powdered abrasive that results from grinding. This marks the end of the first "wet." Fresh Carborundum is now applied, and the procedure is continued for three additional wets. The stroke is then shortened to a third of the diameter of the mirror (two inches in the case of a six-inch mirror) for two more wets. The mirror should now show a uniformly ground surface to the edge of the disk in every direction. If not, continue grinding until this is achieved.

The ground surface now has the form of a shallow curve and must be tested for focal length. This is easily accomplished on a sunny day. The test equipment consists of a square of light-colored cardboard about a foot across which serves as a screen on which the image of the sun is projected, and a supply of water to wet the roughly ground surface of the mirror and thus improve its effectiveness as a reflector. Stand the cardboard on edge at a height of about six feet so that one side faces the sun squarely; then take a position on the shady side about 10 feet from the screen. Dip the mirror in the water and, with the ground surface facing the sun, reflect sunlight onto the screen. The image will appear as a fuzzy disk of light, doubtless somewhat smaller than the diameter of the mirror. The size of the image will change as the mirror is moved toward or away from the screen. Find the distance at which it is minimum. This is the approximate focal length of the mirror. At this stage of grinding, the focal length will doubtless be of the order of 15 feet. The object is to shorten it to six feet by additional grinding. Wash the tool, apply fresh abrasive, grind for five minutes and repeat the test. It is advisable to make a chart on which the focal length is recorded after each spell of grinding. The chart aids in judging progress toward the goal of six feet. When the desired focal length is attained, thoroughly scrub the mirror, tool, bench, utensils and all other objects likely to be con-

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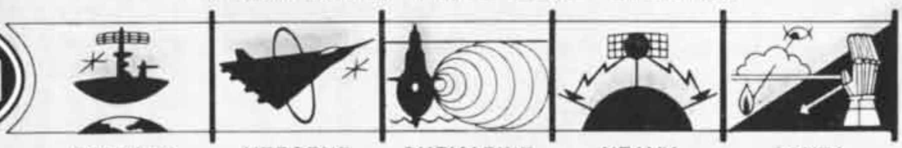
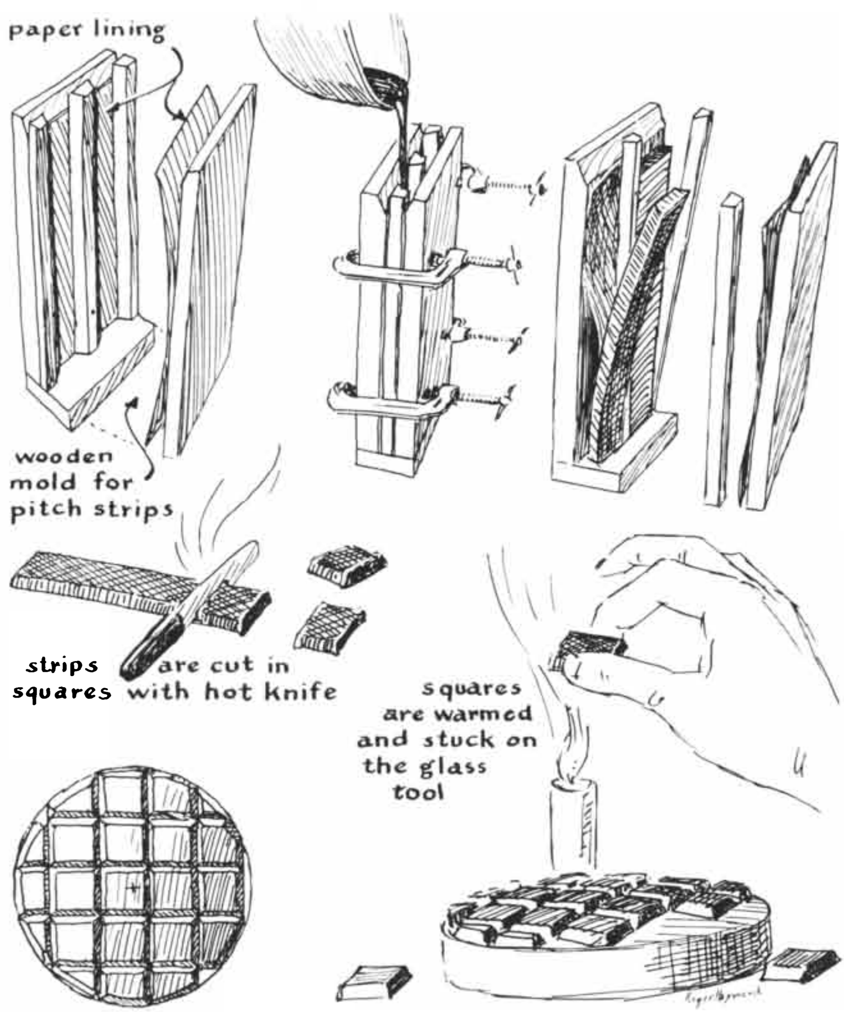


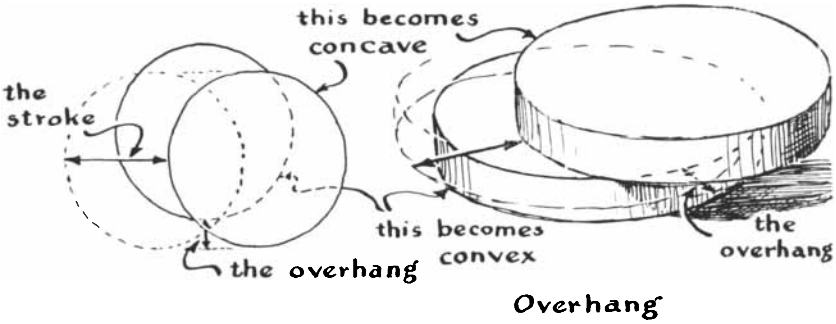
SYSTEMS MANAGEMENT | AIRBORNE ELECTRONIC | SUBMARINE SIGNAL | HEAVY ELECTRONIC | SANTA BARBARA taminated with No. 80 abrasive. Grinding is then continued with successively finer grades of abrasive. The same stroke is used: two inches in length and center-over-center. Usually the second grade is No. 180, which has the texture of finely powdered sand. The grinding technique is precisely the same for all subsequent grades of abrasive; each stage of grinding is continued until all pits made in the glass by the preceding grade have been removed. Usually six wets with each grade is adequate. On the average each wet will require about 15 minutes of grinding. Examine the ground surface by means of a magnifying glass after the sixth wet. If any pits larger than average are found, continue grinding for another wet or two and examine again. Persist until all pits larger than average disappear. There is one exception to this procedure. Sometimes a stray grain of No. 80 or one of the intermediate grades will find its way into work that has reached the terminal stages of fine grinding. A scratch or groove will appear that is so deep that it cannot be removed by a reasonable amount of fine grinding. The only solution is to return to the offending grade and repeat all the intermediate work. Gloves are notorious grit-catchers. Never wear them when grinding. Try to prevent clothing from coming into contact with loose grit. Abrasives supplied with representative kits include Nos. 80, 180, 220, 280, 400, 600, FFF and rouge.

The beginner is urged to purchase an extra mirror-blank. The object is to make two mirrors simultaneously, select one for immediate use and reserve the second for subsequent refinement. Those following this suggestion should grind the mirrors alternately. Complete a wet of a given grade on the first mirror and proceed with the same wet on the second. After all grinding is completed, the mirrors are polished independently.

The operations of grinding and polishing glass are similar in that both re-



Details of the construction of a pitch lap



Details of the stroke used to parabolize the objective mirror

quire the use of a material which is harder than glass. In grinding, the abrasive material is used between a pair of hard surfaces, either two pieces of glass or glass and cast iron. In rolling between the surfaces under pressure the hard particles erode the glass by causing tiny conchoidal fractures in its surface. Glass can be polished with the same hard particles merely by replacing the hard tool with an appropriately soft and yielding one. The theory of the polishing action is not well understood. It is clear, however, that the abrasive particles do not roll. Held firmly by a yielding medium, their protruding edges may act like the blade of a plane.

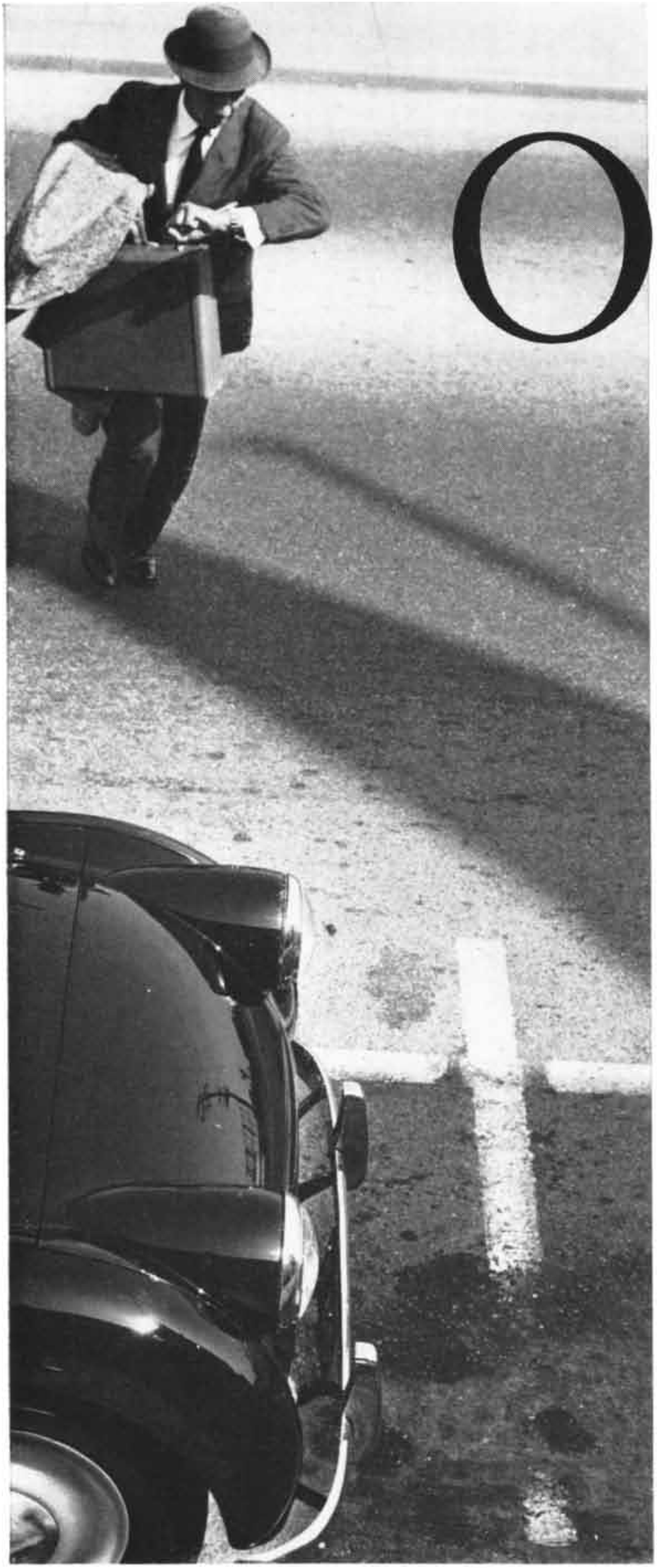
Most amateurs use a polishing tool, or "lap," of pine pitch divided into a pattern of facets and charged with rouge. To make the facets, pitch is first cast into strips about an inch wide, a quarter of an inch thick and eight or 10 inches long. An adequate mold of wood (lined with moist paper to prevent the strips of pitch from sticking) is depicted on page 198. Melt the pitch over a hot plate, not over a direct flame. Do not overheat the pitch; it burns easily. The fumes (largely vaporized turpentine) are highly combustible, so prevent direct flame from reaching the open part of the container.

The strips of cool pitch are cut into square facets by means of a hot knife and stuck to the ground surface of the tool in a checkerboard pattern as shown. Begin by locating one facet somewhat off-center in the middle of the tool, and work outward. Adhesion is improved by first warming the tool, smearing it with a film of turpentine and warming the face of each square of pitch before placing it in contact with the glass. The pitch facets should be beveled, which can be accomplished in part by cutting the edges of the wooden divider-strips of the mold at an angle. This also facilitates the removal of the strips from the mold. Pitch yields under pressure, so unless the facets are beveled the space between adjacent facets soon closes during the polishing operation.

Trim all boundary facets flush with the edge of the tool by means of the hot knife. Then invert the completed lap in a pan of warm water for 10 minutes. While the pitch is warming, place a heaping tablespoon of rouge in a clean wide-mouthed jar fitted with a screw cap, and add enough water to form a creamy mixture. Remove the lap from the pan, blot it dry and, with a quarter-inch brush of the kind used with water colors, paint the pitch facets with rouge. Now place the mirror gently and squarely on the lap and apply about five pounds of evenly distributed weight to the mirror for half an hour until the pitch facets yield enough to conform with the curve of the glass. This process is called cold-pressing. At the end of the cold-pressing interval slide the mirror from the lap and bevel the edge facets to remove any bulges that have formed.

The mirror must now be fitted with a shield to insulate it from the heat of the worker's hands. In the case of a six-inch mirror cut a disk of corrugated cardboard eight inches in diameter and notch its edge every inch or so to a depth of one inch. Center the cardboard on the unground side of the mirror, press the notched edges down along the side of the glass and secure them with several turns of adhesive tape. The cardboard form now resembles the lid of a wide-mouthed jar.

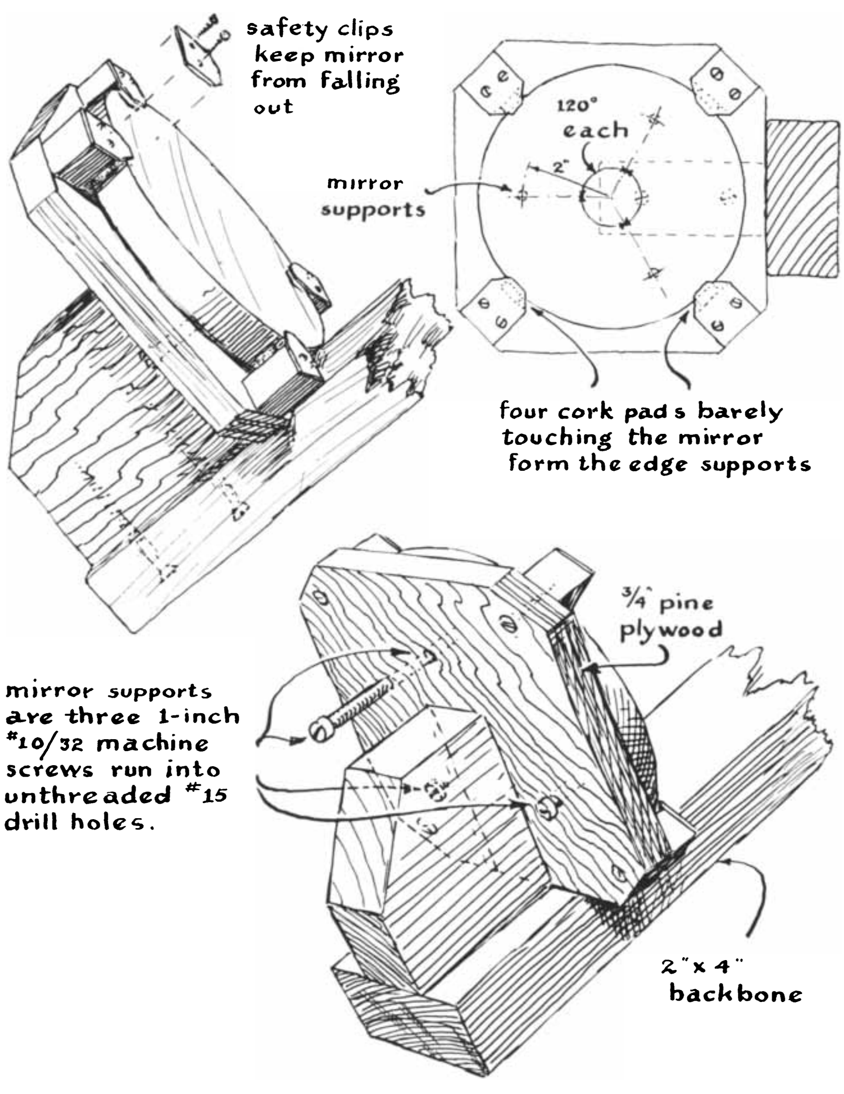
Paint the facets with fresh rouge, add half a teaspoon of water to the center of the lap and, with the heat-insulating shield in place, lower the mirror gently onto the lap. Polishing proceeds with strokes identical with those used in grinding; they are two inches long and center-over-center. When the work develops a heavy feel, stop, add half a teaspoon of water and resume. Continue polishing for 20 minutes. Then cold-press for 10 minutes. Proceed with this alternating routine until no pits can be detected when the surface is examined



with a high-powered magnifying glass. If the fine grinding has been performed as directed, the mirror can be brought to full polish in three hours or less. When work must be suspended for some hours, coat the lap with rouge and cold-press without added weight. It is well to brace the mirror around the edges when it remains on the lap for some hours, because pitch flows slowly and may deposit an unbraced mirror on the floor.

The shape of the mirror is now close to a perfect sphere. The center will doubtless have a somewhat longer radius than the region near the edge. Precisely the reverse situation is desired: a curve whose radius increases from the center outward. A minute thickness of glass must therefore be removed from the center of the mirror and a somewhat lesser amount removed toward the edge. The mirror is put back on the lap and, with a fresh charge of rouge, polished by a modified stroke. The length of the stroke is not altered, but the mirror is now made to follow a zigzag course laterally across the lap at right angles to the worker. The first stroke follows the conventional center-over-center course away from the worker but on the return stroke and subsequent strokes it is pushed about an inch to the right side. It is then gradually worked back across the center until it overhangs the lap on the left hand side by an inch. This operation is repeated over and over for 15 minutes. Simultaneously the mirror is rotated slightly in one direction during each stroke and the tool is periodically rotated in the other direction to distribute the abrasive action uniformly.

After a thorough cleaning the mirror is ready for silvering. Amateurs formerly coated their mirrors at home. But silver



Details of wooden cell for the objective mirror

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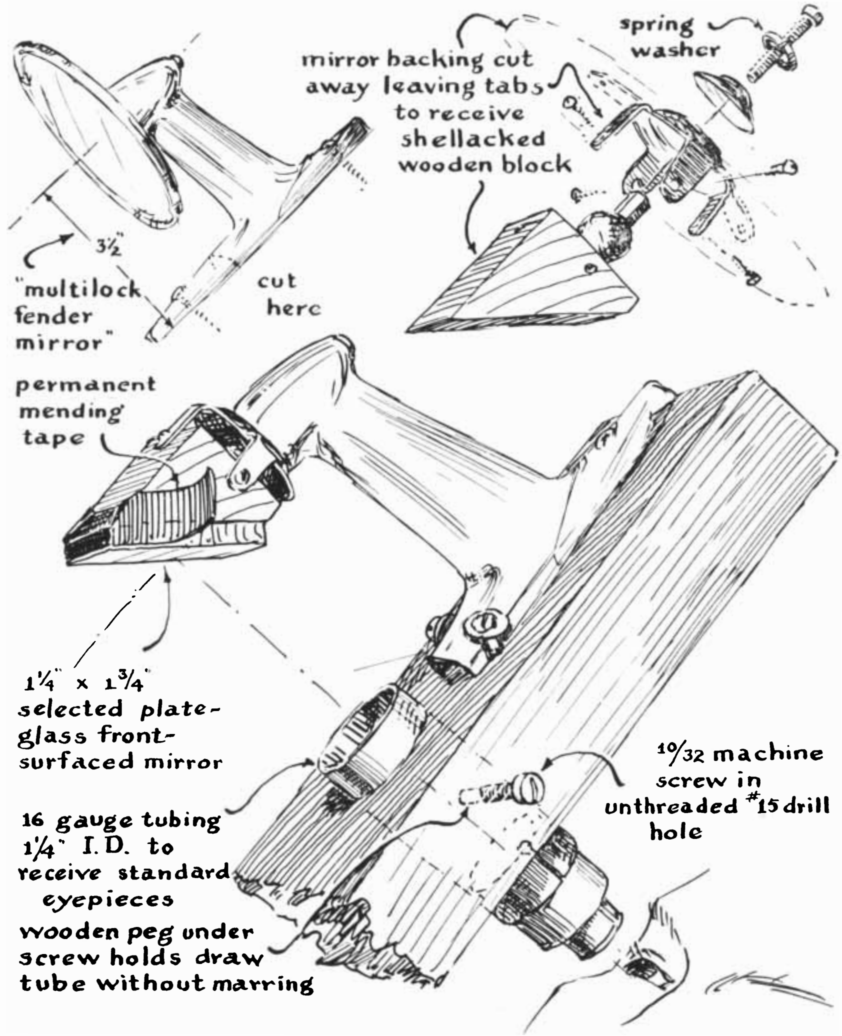


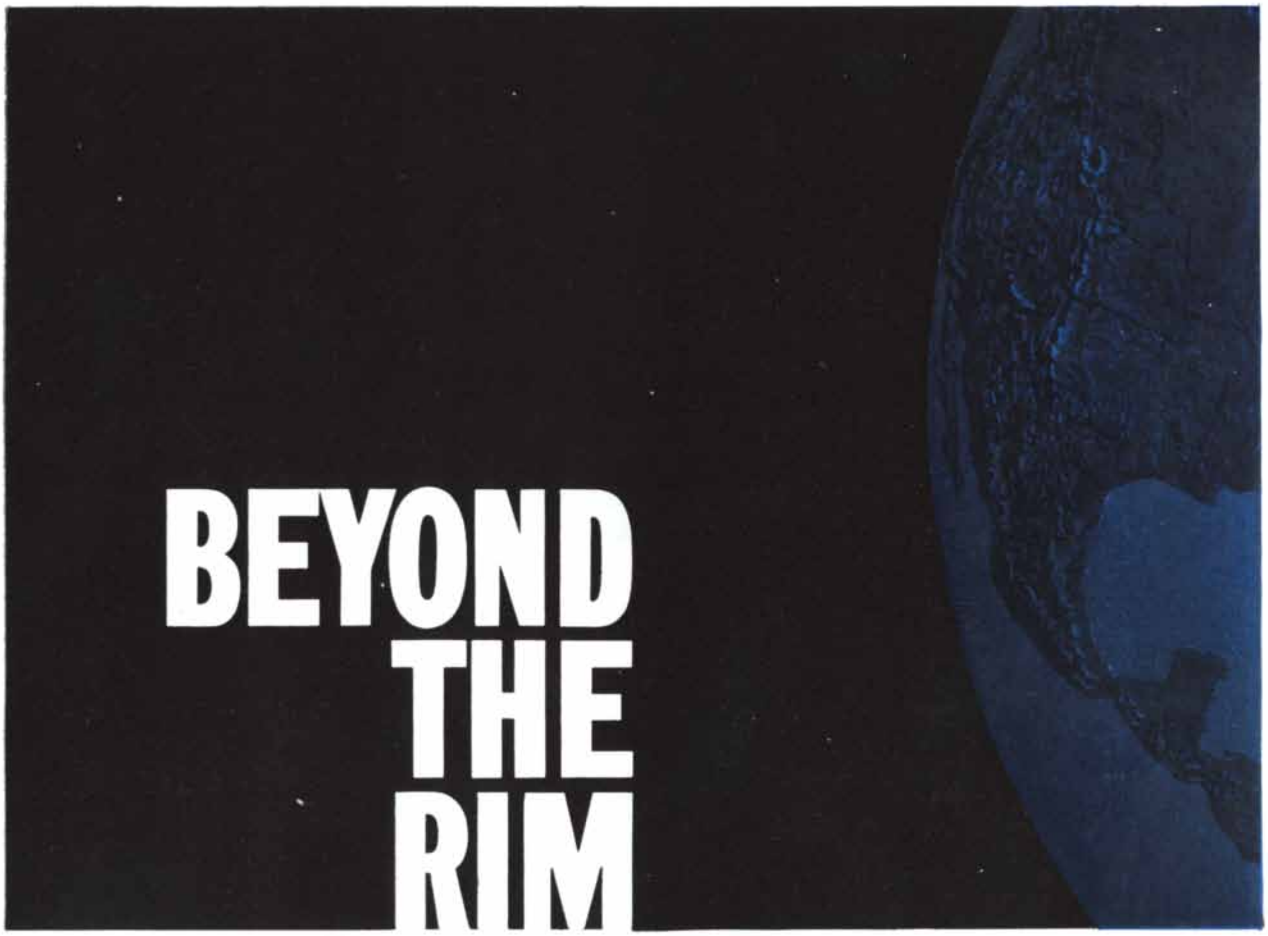
Details of fixture to support the diagonal mirror

is difficult to apply and tarnishes quickly. Most reflecting telescopes are now aluminized, a process too tricky to be undertaken by beginners. The mirror is placed in a highly evacuated chamber and bombarded with vaporized aluminum. On being exposed to air the metal acquires a transparent and durable film of oxide. Firms that specialize in this work charge about $5 to aluminize a six-inch mirror. The beginner is urged to have both his objective mirror and the diagonal coated in this way.

The mounting may be constructed while the mirrors are being coated. In designing the mounting never permit appearance to compromise sturdiness. This telescope will have a maximum magnifying power of about 250 diameters and any jiggle arising in the mounting will be magnified proportionately. The objective mirror is supported in a wooden cell fitted with screw adjustments, as shown in detail on page 202. Fine-grinding and polishing will have reduced the focal length to about five feet. The center of the diagonal mirror is spaced approximately six inches from the focal point of the objective (about 4.5 feet from the objective), thus bending a six-inch cone of rays into the eyepiece, as shown in detail above.

After assembly the optical elements must be aligned. Remove the eyepiece, look through the tube in which it slides and adjust the diagonal mirror until the objective mirror is centered in the field of view. Then adjust the tilt of the objective mirror until the reflected image of the diagonal mirror is centered. Replace the eyepiece in its tube and you are in business.

Those who construct this telescope will ultimately discover that it is not the best that can be built. To improve it consult the books recommended in the bibliography on page 232 and tackle the fine art of figuring the second mirror by means of the fascinating tests and techniques described therein.



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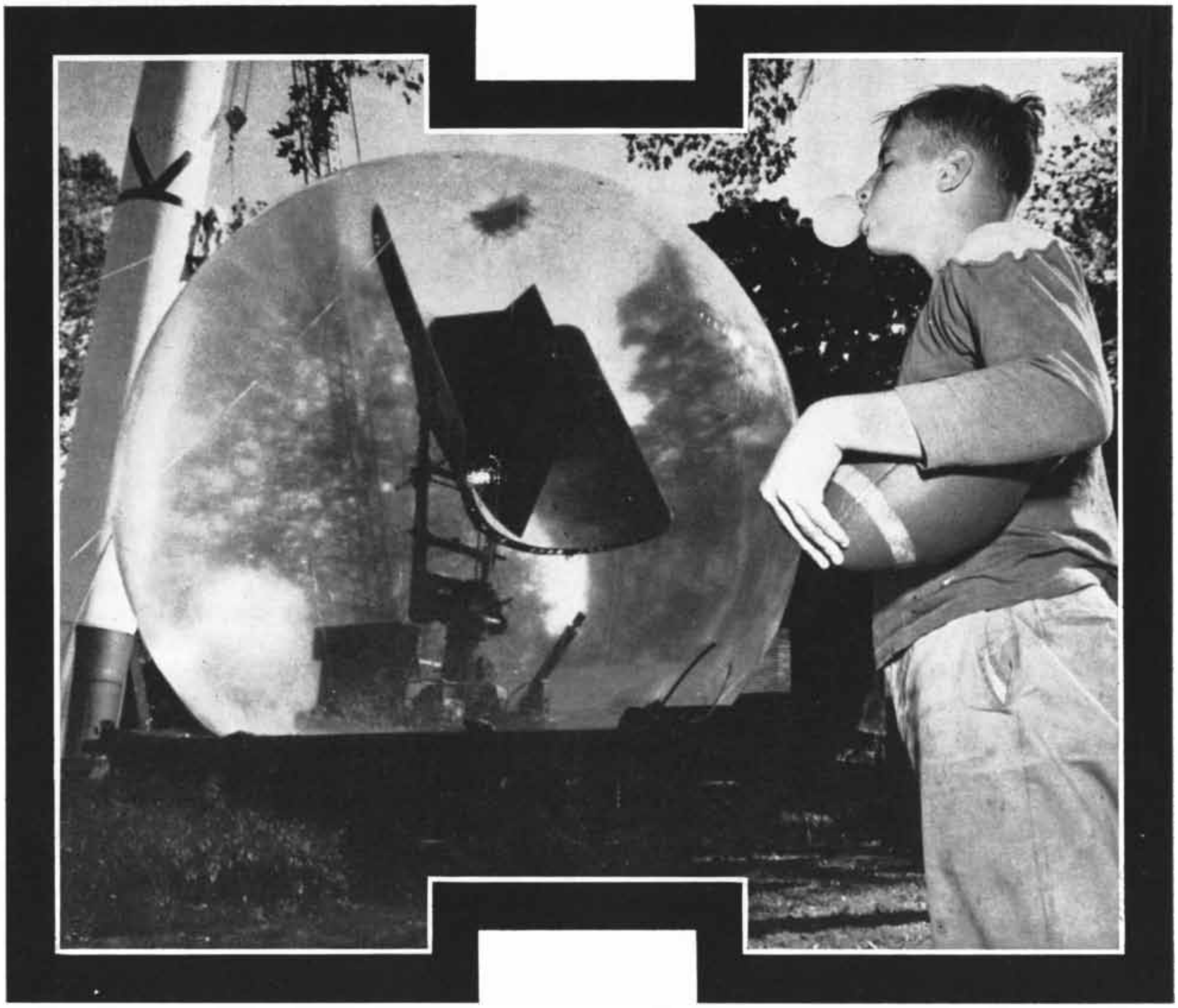

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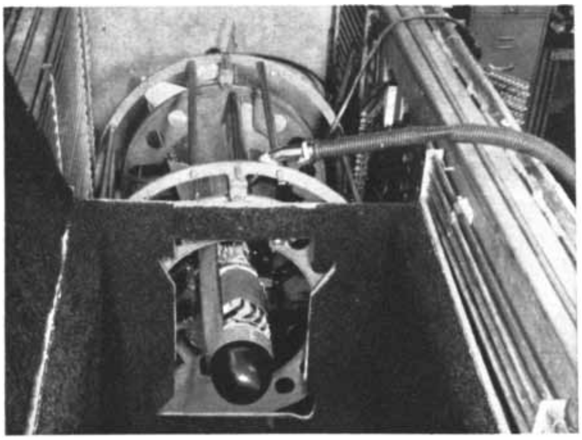

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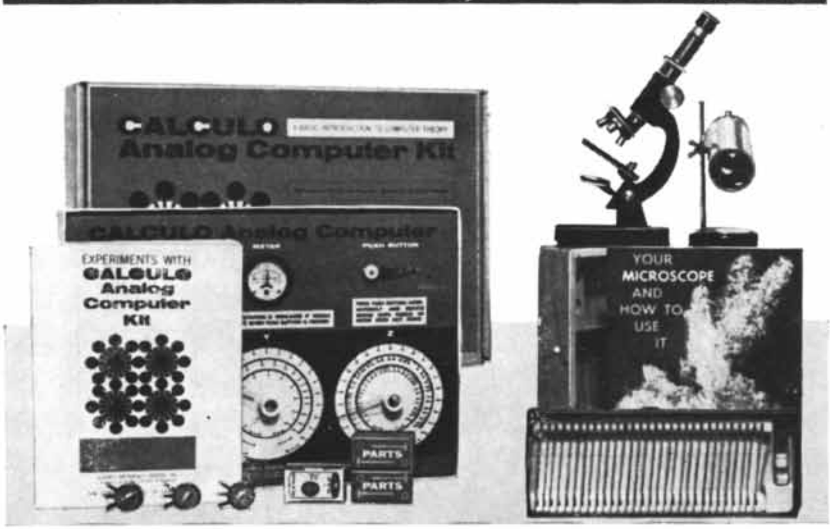

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BOOKS

Concerning a new biography of Charles Darwin, and its scientific shortcomings

by Ernst Mayr

DARWIN AND THE DARWINIAN REVOLUTION, by Gertrude Himmelfarb. Doubleday and Company, Inc. ($5.95).

The hundred years that have passed since the publication of Charles Darwin's *Origin of Species* have enabled us to evaluate the book far more objectively than Darwin's contemporaries could. The *Origin* is one of those fortunate works that seem to gain in stature as time goes by. H. J. Muller has written: "Darwin's theory of evolution through natural selection was undoubtedly the most revolutionary theory of all time. It surpassed even the astronomical revolution ushered in by Copernicus in the significance of its implications for our understanding of the universe and of our place and role in it." Surely no other theory has had such a heavy impact on politics, economics, religion and culture. In view of these ramifications, it is not surprising that hardly anyone seems able to regard Darwin and his work without emotion. Evaluations range all the way from that of Louis Agassiz—who referred to the theory as a "scientific mistake, untrue in its facts, unscientific in its methods, and mischievous in its tendency"—to complete hero-worship. This may explain why we still lack an outstanding biography of Darwin. It should be added, however, that Darwin's autobiography has preempted the field, and that many potential biographers have doubtless been scared off by the need for a deep understanding of evolutionary theory which the task would demand.

Gertrude Himmelfarb has attempted to fill this deficiency with a Darwin biography that has been widely praised in reviews. Dr. Himmelfarb is not a scientist but a historian and a biographer of Lord Acton. Her specialty is England in the mid-19th century. What interests her most about Darwin is his impact on the contemporary scene, as opposed to his impact on the development of biology. Her principal method is in the tradition of historians: she examines Darwin on the basis of his own writings. The approach is on the whole successful in the first 14 chapters of her book, which deal with Darwin's life and intellectual development, with the emergence of his theory and with the reception of the *Origin*. Her narrative and evaluation are intelligent, critical and well informed. Many of the small inaccuracies copied from one Darwinian author to the next are corrected. She gives a stimulating description of Darwin's scientific method, which was neither pure induction nor pure deduction. Though this method was not originated by Darwin, no one before him had applied it so consistently and to such good advantage. Chapter 6 ("Portrait of the Scientist") contains a penetrating and altogether sympathetic picture of Darwin. It places just the right stress on Darwin's admirable qualities and on his foibles and weaknesses. His "modesty of manner," "sense of dedication" and dogged determination to pursue his scientific career in spite of all obstacles are admirably portrayed. Dr. Himmelfarb's grasp of mid-19th century English literature has enabled her to use many previously untapped sources. In Chapter 10 she gives an excellent survey of the climate of opinion in England preceding the publication of the *Origin*. Herbert Spencer's evolutionism, Alfred Tennyson's poems, the fashion of geologizing—all were the expression of a general movement. To emphasize the widespread speculation on evolutionary themes prior to Darwin is important because it has often been minimized by Darwin's idolators. This is one of the best and most original chapters of the book. Yet Dr. Himmelfarb does not explain (nor, for that matter, has anyone else) the paradoxical fact that the joint publication by Darwin and Alfred Russel Wallace of the theory of natural selection in 1858 fell so completely flat. Instead of causing an explosion, as did the publication of the *Origin* one and a half years later, it caused hardly a ripple.

The competence of Dr. Himmelfarb's treatment of historical and biographical matters is not matched in scientific matters. Indeed, she almost totally ignores the more recent biological literature. This leads to misinterpretations, a neglect of important developments and a general unevenness. An example is her treatment of the pre-Darwinian history of evolutionary theory. Here she gives an excellent account of Erasmus Darwin and demonstrates convincingly how similar some of his ideas were to those of his grandson. She points out how unaware Darwin was of most of his predecessors, yet to my mind she fails to bring out how different most of the earlier notions were from a genuine theory of evolution. This is precisely why Darwin's forerunners failed to convince contemporary authorities such as Baron Cuvier, Richard Owen and Agassiz. She does not appreciate the role that Linnaeus played in preparing the ground for a sound evolutionary theory by his insistence upon the fixity of species and his opposition to prevailing notions of spontaneous generation. Like other historians she misinterprets the celebrated discourse in 1830 between Cuvier and Geoffroy Saint-Hilaire. This was not primarily a dispute between an evolutionist and an anti-evolutionist, but rather a debate between two schools of comparative anatomy. Here again Cuvier's victory ultimately made things easier for the evolutionists. Her unfamiliarity with creationist literature prevents her from giving Darwin full credit for his discoveries in the Galápagos Islands and in South America. If she had thoroughly understood the core of the argument, she could not have claimed that what Darwin had discovered in the Galápagos was old stuff known to such men as the Comte de Buffon, Alexander von Humboldt and Charles Lyell. The observation that so excited Darwin had been known to others before him, but they had failed to see its evolutionary significance. This observation was that each species is localized and may be replaced by related species in adjacent areas with an essentially identical geology and climate. The conclusions that Darwin based on this fact were essentially new and not at all anticipated by Lyell, although Buffon had guardedly played with them. The distribution of related species was crucial in the refutation of creationism, as was demonstrated by the famous dispute between Agassiz and Asa Gray in 1858. This relation in space was similarly the crux of Darwin's argument on the South American faunas. Dr. Himmelfarb entirely misses the fact that a succession of fossil faunas in different geological strata was not the point. Such a succession was not claimed by Darwin as a new discovery; indeed, it was readily admitted by antievolutionists like Cuvier and by out-and-out creationists like Agassiz. What Darwin saw—and he was decidedly the first to see it clearly and to appreciate its deadly impact on creationism—was (1) that the different fossil faunas in South America were more closely related to one another and to the modern South American fauna than to the faunas of other continents, (2) that the different climatic zones of South America were inhabited by different adaptive types of a single fauna rather than by separate creations and (3) that the faunas of adjacent islands like the Falklands and Galápagos were not independent creations but were clearly derived from the mainland fauna. Creationism was unable to account for such regularities in the pattern of distribution.

Here as in many other places Dr. Himmelfarb seems to have been misled by a peculiar urge, so often encountered in biographical literature of the debunking sort, to prove that Darwin's ideas were neither new nor correct. In short, she is sympathetic to Darwin the man and hostile to Darwin the scientist. In her introduction she refers to him as "limited intellectually and insensitive culturally," and from then on she misses no opportunity to denigrate him. Her arguments in this regard are, to put it mildly, eccentric. On one page she speaks of "the laws [Darwin] claimed to have deduced from" his fossil discoveries; a few pages later she makes the contradictory statement: "Darwin never claimed that such principles . . . were original to him."

The last six chapters of Dr. Himmelfarb's book are devoted to the "analysis of the theory" and to "Darwinism." It is here that she entirely overlooks the modern literature on evolution. She fights the 19th-century battles of "missing links," "nature red in tooth and claw," "cooperation versus selection," but is unaware or disdainful of recent developments. It is evident from her acknowledgments that she did not show her manuscript to a single evolutionist. The evolutionary theory has remained remarkably alive and has within the past 30 years undergone dramatic changes, most of them of direct relevance to the interpretation of Darwinism. All of this is ignored in Dr. Himmelfarb's account. Her lack of knowledge of modern evolutionary literature is nowhere more apparent than in her discussion of the old claims of absence of intermediates in the fossil record. In discussing the evolution of the eye she makes the curious statement: ". . . the eye is obviously of no use at all except in its final, complete form." The fact is that even among living animals we find almost every intermediate step in the development of the eye, from a light-sensitive pigment spot to the superb optical mechanism of the vertebrates. It is not surprising that the discussion based on this ill-advised assumption is quite meaningless. Even more damaging to Dr. Himmelfarb's argument is her lack of knowledge of modern genetics. Without such knowledge it is quite impossible to discuss many of the phenomena that puzzled Darwin. To ignore genetics is to ignore the causal basis of the Darwinian theory.

Dr. Himmelfarb's bias is nowhere more conspicuous than in her discussion of the cornerstone of Darwin's theory: natural selection. She misses no opportunity to discredit it and labors mightily to refute it. Darwin was rather puzzled at the extreme hostility with which his principle was received by many of his contemporaries, and this puzzlement is shared by the modern evolutionist. After all, natural selection is not even a theory; it is merely the statement of an observable fact. In any species far more individuals are produced in every generation than will be able to become the progenitors of the next generation. Since no two of these individuals are genetically identical (in sexually reproducing species), the probability of being among the survivors that reproduce depends partly on luck and partly on genetic endowment. Because each species is composed of hundreds of thousands or millions of individuals, each gene is found in thousands of them. Genes which on the average add to the fitness of the organism, that is, to the probability of its survival, will automatically increase in frequency. This, in brief, is the principle of natural selection. Actually, as many recent authors have stressed, it is not so much survival that counts but the probability of reproducing more copiously, that is, of adding more genes to the gene pool of the next generation. This is why natural selection is so often referred to in the

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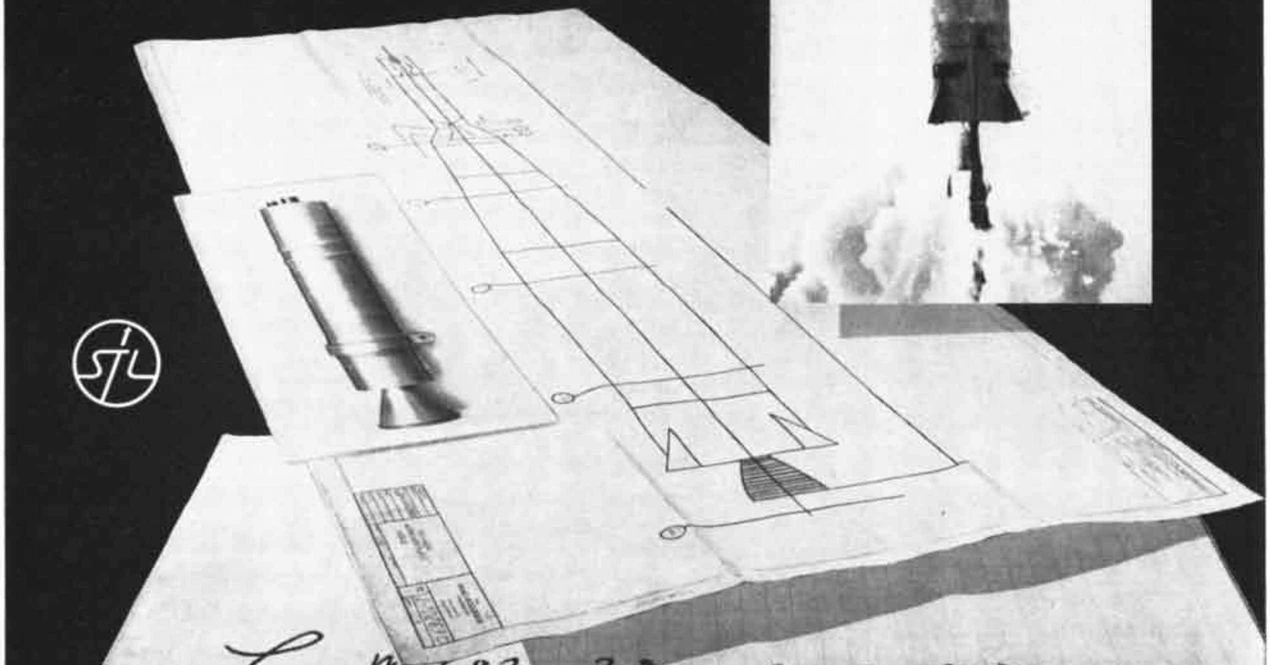

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modern literature as "differential reproduction." Theory starts where one interprets specific evolutionary phenomena as the result of natural selection.

The hostility of many historians and sociologists toward natural selection appears to have two sources. The first is that they interpret it as an all-or-nothing phenomenon in which the "fittest" survive and all others are exterminated. The unfortunate pre-Darwinian terms and slogans—*e.g.*, "nature red in tooth and claw" and "struggle for existence"—are in part responsible for the misinterpretation. Darwin himself was too good a biologist to hold this gory view. In Chapter 3 of the first edition of the *Origin* Darwin says: "I use the term struggle for existence in a large and metaphorical sense, including dependence of one being on another, and including (which is more important) not only the life of the individual, but success in leaving progeny." He was fully aware of the statistical nature of natural selection and indeed stated the principle so well that its definition could hardly be improved.

The other source of hostility is egalitarianism. The idea of a biological nonidentity among individuals on the basis of different genetic endowments has always been an anathema to certain ideologies. Yet the biological fact of such difference has been so decisively established, in literally thousands of selection experiments, that it would seem time to stop fighting the battle. Egalitarians have tried to expand the principle of democracy—"equality of opportunity, equality before the law, and equality before God"—to "biological identity." They seldom perceive that equality in spite of biological nonidentity is a higher ethical principle than equality because of identity. Dr. Himmelfarb's statement that "one of the . . . least appreciated aspects of Darwin's theory [is] the location of the struggle for existence primarily within species rather than between species" indicates a total misunderstanding of the essence of natural selection. "Least appreciated" when Darwin and his followers have stressed this point above all others! Darwin devoted more chapters of the *Origin* to variation within species than to any other subject, and later he wrote a two-volume work about it. The primary significance of intraspecific variation is its role as the raw material for selection within species.

Evolutionary biology has never been closer to Darwin's original concepts than it is today. It can be stated dogmatically that the few who still object to natural selection are among those who have not kept up with genetic theory. I flatly challenge Dr. Himmelfarb's statement that "a growing number of scientists . . . have come to question the truth and adequacy of natural selection." The exact opposite is true. Natural selection as a principle is inseparable from variation, its raw material, and in the understanding of variation great progress has been made since Darwin. What is evaluated by selection is not a mutation, not a "naked" gene, but the finished organism that results from the interaction of all its genes. Selection deals with combinations; this is why today it is quite rightly considered a creative process. It brings together novel combinations of genes and characteristics which, as a new complex, may add far more to fitness than the separate components individually. Those who stress the negative aspects of selection—the elimination of the unfit—do so because they fail to perceive the creative aspects. In her accounts of sexual selection and of "cooperation" Dr. Himmelfarb follows the 19th-century writers who accepted these principles as alternatives to natural selection. She fails to understand that sexual selection is only one of many forms of natural selection, and that cooperation (part of Darwin's "dependence of one being on another") has high selective value whenever the "unit of selection" is more than a single individual. If she had had a better understanding of modern genetics, she could never have arrived at her judgment: ". . . the difficulty with natural selection . . . is that if it explains too much, it also explains too little, and that the more questionable of its hypotheses lie at the heart of its thesis. Posing as a massive deduction from evidence, it ends up in an ingenious argument from ignorance."

Dr. Himmelfarb's chapter on the origin of man is one of the most astonishing in the whole book. The discovery of fossil man is entirely post-Darwinian except for some poorly understood Neanderthal remains. A wealth of "missing links" has been discovered in the last half-century: Australopithecus (the South African "man-ape"), Pithecanthropus and early *Homo sapiens*, all of which cast an entirely new light on the history of man. Yet Dr. Himmelfarb manages to discuss the origin of man in total seriousness by analyzing statements in Darwin's *The Descent of Man* as a philologist would analyze a literary text. She makes a single exception by discussing Piltdown man, which never fitted into any restoration of hominid phylogeny and was long ago declared an artifact by Franz Weidenreich and other outstanding workers. Piltdown man had to be "explained away" in every discussion of human ancestry, and it was reinvestigated again and again because it did not fit; this, indeed, is how the clever fraud was eventually discovered. Dr. Himmelfarb's assertion that "its exposure as a fraud leaves the theory, after a century of search, without the much-desired missing link," carries little conviction because it had been accepted as a missing link only by a few chauvinistic anthropologists.

Her treatment of other achievements of Darwin is not much better. In her discussion of Darwin's theory of the origin of coral reefs by subsidence she speaks of the fallaciousness of Darwin's method, the result of which was "that the theory eventually gave way." The fact of the matter is that much recent geological work, particularly deep drillings in the West Indies and in the Marshall Islands, have brilliantly confirmed Darwin's theory. This theory is not in the least weakened by the fact that the modern synthetic theory of coral-reef formation allows for the contribution of additional geological events, such as the rise of submarine volcanoes and Pleistocene fluctuations of the sea level. Here as in so many places Dr. Himmelfarb seems to think that any one theory excludes all others, and that there is only a single pathway toward a given end product. Just as disturbing as these erroneous evaluations is the author's lack of interest in much of Darwin's life work. Six of his publications are dispatched in a single sentence by listing their titles. That Darwin was the founder or at least a major pioneer in whole branches of biology, such as ecology and biogeography, is not even mentioned by this Darwin biographer.

In her discussion of Darwin's scientific method Dr. Himmelfarb stresses, quite rightly, how much he "speculated," or, as we would now say, how readily he would develop new working hypotheses. She does not seem to appreciate how much collecting of facts and observations usually preceded the formulation of these "speculations." For example, she takes great pains in her chapter on the voyage of the *Beagle* to disprove the notion that this voyage was "a preview of the *Origin*." She evidently does not realize that Darwin's observations on the *Beagle* revealed to him discrepancies in the accepted theories of creationism. From that point on it was only a matter of time, of the leisure for further thinking and of additional reading until he had his flash of inspiration. To claim, as Dr. Himmelfarb does, that "there is, in fact, no real continuity between the

Beagle and the *Origin*" reveals a failure to understand the working of the scientific mind. How often has a scientist had the experience that an observation lies dormant in his mind for years, like a time bomb, only to "explode" quite unexpectedly at the appropriate time.

Dr. Himmelfarb criticizes Darwin repeatedly for his "ineptness" as a philosopher. Yet she does not seem to realize that this very weakness was Darwin's strength. Instead of getting tangled up in philosophical premises, as did Agassiz and the highly competent contemporary German and French zoologists and botanists, Darwin was able to pursue his biological speculations unfettered. Indeed, one might go further and say that Darwin was an important philosopher, even though he himself never articulated and formalized his philosophy. To me it seems a major gap in Dr. Himmelfarb's presentation that she nowhere discusses the enormous impetus Darwin gave to "population thinking," and the mortal wound he inflicted upon "typological thinking" (idealism). It is Darwin more than anyone else who rescued us from Plato's *eidos*. Darwin's role in the argument between continuism and discontinuism, his particular contribution to materialistic thinking (so utterly different from the materialism of philosophers like Julien Offray de la Mettrie and Baron d'Holbach) and his clear separation of ontogenetic and phylogenetic evolutionism are mentioned by Dr. Himmelfarb, but nowhere analyzed in the way one would expect in a volume devoted to the "Darwinian revolution."

Her discussion of Darwin's relation to teleological thinking fails to penetrate to the core of the issue. Neither she nor the majority of philosophers seem to realize that the "Why?" that Darwin asks so often is not the teleological "What for?" but the scientific "How come?." The investigator who asks, "Why are there tides in the ocean?," is inquiring into their causation. The anti-teleological impact of this kind of "Why?," correctly emphasized by John Dewey, is missed by Dr. Himmelfarb entirely when she calls Darwin's questioning a "preeminently teleological inquiry." No wonder she is puzzled "that Darwin, the least philosophical of men, should have fastened upon that most philosophical and metaphysical of all questions [and yet that] his questions, while fundamental, were never abstract." The reason is that Darwin was intensely interested in ultimate causes, but never in "final" causes.

One might claim that these errors are irrelevant in a book primarily concerned with the Darwinian revolution, the impact of Darwin on the contemporary scene. But even here I feel that Dr. Himmelfarb has not done Darwin justice. She describes quite correctly how bewildered Darwin was about the social and ethical applications of Darwinism. He certainly would not have excused war, class struggle, robber baronism and racism as logical consequences of Darwinism. Yet she nowhere points out that it is totally unjustifiable to interpret such things in terms of Darwinism. It does not matter which of Darwin's basic principles one takes: the population principle or the principle of the biological contribution to the next generation (the true touchstone of natural selection); applying either of these principles to "social Darwinism" shows that they are in complete opposition to it. The adoption of pseudo-Darwinism by all-or-nothing philosophers, by typologists and by others unable to think statistically has led to all sorts of monstrous ideologies that no true Darwinian could ever have conceived. It is the term "struggle," which Darwin so unfortunately took over from Thomas Malthus and Lyell, that seems to have given misinformed laymen the idea that physical struggle was the basic principle of Darwinism.

What final verdict can a biologist render on Dr. Himmelfarb's book? As I have indicated, the first half of her narrative, which is mostly concerned with Darwin and the intellectual milieu of the *Origin*, is one of the better contributions to Darwinian literature. The less said about the second half of the book, which deals with Darwinian theory, the better. I can only hope that it will spur evolutionists to redouble their efforts to make the findings of evolutionary biology available to the nonspecialist.

Short Reviews

My Philosophical Development, by Bertrand Russell. Simon and Schuster, Inc. ($3.75). For Bertrand Russell both art and life have been long, a fact for which the world should be grateful. His work is for the moment less in fashion than it once was (he speaks wryly of being regarded as antiquated), but one doubts that this causes him serious distress. Nor should it. Almost anything in contemporary philosophy worth looking at reflects his influence: much of what is now being said he once said better, or else what is now being said attempts to refute one of his earlier views. He has, to be sure, held many views, and nothing is easier than to find conflicting statements in his philosophical writings. This has therefore become a favorite pastime among the small fry. But the pastime lacks savor because no one has exposed more contradictions in Russell's work than Russell. Alan Wood reminds us of Napoleon's reassurance to the innkeeper in Bernard Shaw's *The Man of Destiny*: "You will never be hanged. There is no satisfaction in hanging a man who does not object to it." Philosophers of mettle have better things to do than to search for Russell's faults and weaknesses. This book itself is an exercise in self-criticism—an enthralling intellectual autobiography. Of Leonhard Euler it was said that he calculated without apparent effort, "as men breathe, or as eagles sustain themselves in the wind"; it does not strain the image to extend it to Russell's philosophizing. This is not to say that he is a stranger to intense and prolonged concentration, that his ideas and insights have come easily, that he has not known the struggles, torments and frustrations of other philosophers. But two things are altogether clear from his work: He sought out the hardest problems, and he has been able to say what he has to say about them with unsurpassed lucidity.

His philosophical development, he tells us, began at the age of 15. It was dominated by mathematics, but, he writes, "the emotional drive which caused my thinking was mainly doubt as to the fundamental dogmas of religion." The specimens he offers of his philosophical reflections recorded in a notebook at the age of 16 (he used Greek letters and phonetic spelling "for purposes of concealment") are extraordinarily sensitive and moving. His growing disbelief first in free will, then in immortality and finally in God frightened and confused him, for these were the teachings of his youth. "I do not think," one entry reads, "it [the search for truth] has in any way made me happier; of course it has given me a deeper character, a contempt for trifles or mockery, but at the same time it has taken away cheerfulness and made it much harder to become bosom friends and, worst of all, it has debarred me from free intercourse with my people, and thus made them strangers to some of my deepest thoughts which, if by chance I do let them out, immediately become the subject for mockery which is inexpressibly bitter to me though not unkindly meant." But neither then nor afterward would such painful experiences deter his desire to know and "to clear away muddles." As the story unfolds we learn of his excursion into idealism, his early passion for Hegel, his revolt, in company with G. E. Moore, into pluralism. He avidly took up questions of mathematics and the philosophy of physics, wrote long papers and books about them, some of which acted like a cathartic. His first major work, *An Essay on the Foundations of Geometry*, he now dismisses as containing nothing valid; of a mathematical paper he remarks that it was "unmitigated rubbish"; of other early efforts, that they were "complete nonsense." His mother-in-law, a famous and forceful religious leader, assured him that philosophy "is only difficult because of the long words it uses. I confronted her with the following sentence from notes I had made that day: 'What *is* means is and therefore differs from *is*, for "*is* is" would be nonsense.' It cannot be said that it is long words that make this sentence difficult." But as time went on he ceased to be troubled by such problems.

The chapters on his introduction to mathematical logic, and to the work on the *Principles of Mathematics* and the *Principia*, are fascinating. Taken in conjunction with his discussion of Ludwig Wittgenstein, they evidence his candor, for he shows us the shatteringly self-defeating climax of his prodigious labor. Having entered upon the mathematical task in search of "splendid certainty," Russell brilliantly frustrated himself by finding contradictions not to be reduced (except by adopting theories "which may not be true and are certainly not beautiful"). And the whole of mathematics, as he has come to believe, though very reluctantly, consists of tautologies, so that "to a mind of sufficient intellectual power" the entire subject would appear trivial, "as trivial as the statement that a four-footed animal is an animal." Russell sets before us the development of his beliefs as to consciousness and experience, language, the nature of truth, the theory of knowledge. In his view we do not directly perceive the external world; what we see are images in our heads from which the world is inferred. But a certain correspondence of structure must be supposed between perceptions and the facts of nature, otherwise understanding would be impossible. This is one of the five principles of "non-demonstrative inference" at which he has arrived. With the whole of Russell's thought synoptically spread out, one is struck by two major tendencies. At times he is a merciless dissector of ideas and language; nothing is accepted at face value, there are no agreed-upons, he cuts familiar notions into thinner and thinner slices as with a microtome. In the *Prin-*

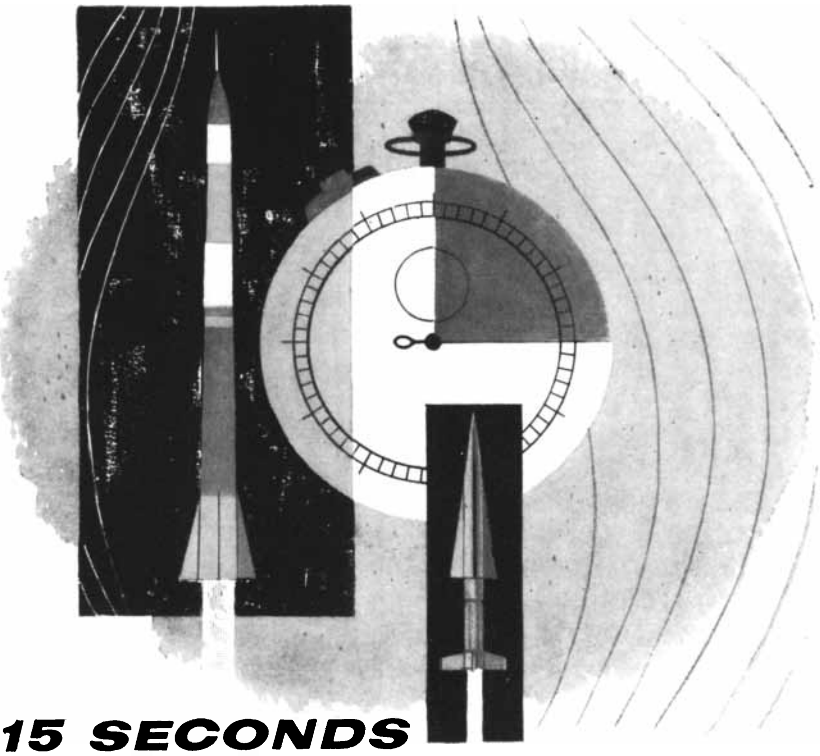
cipia, for example, it takes a formidable apparatus to prove that one plus one equals two, and he will examine a single word as if it were an infinitely complex crystal, with depths within depths. On the other hand, he will even in a technical philosophical discourse use a plain man's language, now appealing to common sense, now accusing a critic of drowning an issue in subtleties. *An Inquiry into Meaning and Truth* is devoted to demonstrating that, despite the complexity of apparently simple things, and the uncertainty that infects even the most plausible premises, probably the best answer to the question: "How do you know I have two eyes?" is "What a silly question! I can see you have." Russell's easy use of the word "science" (as if its meaning were as univocal and transparent as "Mount Everest"), contrasted with the exhaustive analysis of a word such as "the," must disconcert even his most faithful disciples. His justification for the use of "common sense metaphysics" on some occasions, and the precision machinery of mathematical logic and analysis on others, is that both are needed to make even a little temporary sense of the world. The philosopher's task is to try to understand the world; but he must recognize that this is impossible, that the most he can hope for is to expose illusion, to demonstrate what is false rather than to establish what is true. Complete skepticism is self-annihilating and insincere; this is where common sense comes in. On the other hand, one must not be too certain of anything, and analysis is needed to show the fugitiveness of timeless truths. Russell's reconciliation of his passion for mathematics and his sympathy for mysticism, of his common sense and scientific outlook, of his reverence for cold and stern perfection and his interest in the less sublime concerns of man is summed up in these words he once wrote: "I have always ardently desired to find some justification for the emotions inspired by certain things that seemed to stand outside human life and to deserve feelings of awe, . . . the starry heavens, . . . the vastness of the scientific universe, . . . the edifice of impersonal truth which, like that of mathematics, does not merely describe the world that happens to exist. Those who attempt to make a religion of humanism, which recognizes nothing greater than man, do not satisfy my emotions. And yet I am unable to believe that, in the world as known, there is anything I can value outside human beings. . . . Impersonal non-human truth appears to be a delusion. And so my intellect goes with the humanists, though my emotions violently rebel."

The Mammals of North America, by F. Raymond Hall and Keith R. Kelson. Ronald Press Company ($35). This huge technical work of some 1,250 pages, with 500 distribution maps, 538 figures of skulls and 186 life drawings of mammals, is a systematic reference compilation, primarily based on previously published material, treating the more than 3,800 named kinds of mammals inhabiting the region from Greenland to Panama. The authors provide information on taxonomy, distribution, habits, ecology, dimensions; there is an extensive bibliography and 158 pages of indices to vernacular and technical names. Only professional mammalogists, for whom this publication is intended, can judge its merits, and then only after continued use; that it will be used, and that despite possible shortcomings it will become a standard, is beyond question.

Sigmund Freud, Collected Papers, edited by Ernest Jones. Basic Books, Inc. ($25). Freud's major studies of dreams, sexuality, totemism and so on have long been available to the English-speaking public; his clinical investigations, however, which may be regarded as the basis of his grand system, were long buried, as Ernest Jones observes, in a foreign tongue. This central lacuna was filled with the publication in Britain some years ago (and extending over a considerable period) of the International Psycho-Analytical Library, of which five volumes were devoted to English translations of Freud's *Sammlung kleiner Schriften zur Neurosenlehre*. Basic Books has now made these volumes available in a U. S. edition. The papers go back almost to the beginning of Freud's professional career—the first, an essay on J. M. Charcot, appeared in a Vienna medical weekly in 1893—and conclude with a fragment, "Some Elementary Lessons in Psycho-Analysis," written in 1938 and published posthumously in 1940. Thus they afford a unique picture of the development of Freud's work, disclosing, Jones says, "a beautiful example of the way in which ideas are gradually unfolded—and constantly extended and modified—under the pressure of widening and deepening experience." One need not fully accept the editor's opinion that the papers as a whole represent "the very antithesis of the promulgation of an *a priori* philosophical system such as has sometimes been ignorantly imputed to [Freud]" to realize that Freud was not inflexible, that he was sensitive to fresh material, could learn, could make detours, embark on new paths, even "retrace his steps." But his basic beliefs, as is plain to see, remained pretty firm, and he possessed the necessary skill and imagination to make the windings artistically fit the core. This is what gives his system its coherence, strength and symmetry; this is why it continues to exercise a formidable influence, almost as much upon those who would modify or even repudiate it altogether as upon those who regard it as sacred and complete. To whichever group one belongs, one cannot deny that the papers record one of the great intellectual adventures. The five volumes of the papers comprise the following contents. The first contains miscellaneous early papers and a history of the psychoanalytic movement up to 1914; the second consists of clinical papers and papers on technique; the third is made up of five case histories, including the noted analysis of a case of hysteria, the analysis of a phobia in a five-year-old boy and notes upon a case of obsessional neurosis; the fourth presents eight papers on metapsychology and 16 papers on applied psychoanalysis; the fifth assembles miscellaneous papers, some omitted in earlier collections. The translations by various hands have been carefully supervised and are satisfactory; those by James Strachey are first-rate.

VISUAL PROBLEMS OF COLOUR. Her Majesty's Stationery Office ($7.56). The appreciation of color by the human eye formed the theme of the British National Physical Laboratory's Eighth Symposium, held in September, 1957. Research workers on vision from Europe, Canada and the U. S. contributed 40 papers dealing with recent developments in the field; the papers and ensuing discussions are contained in these two volumes, together with the Selig Hecht Commemorative Lecture "Retinal Chemistry and the Physiology of Vision," with which George Wald opened the Symposium.

A STUDY OF BLACKBIRDS, by D. W. Snow. George Allen and Unwin, Ltd. (21 shillings). The author spent four years studying a small community of blackbirds in the Oxford Botanic Garden, which he could see from his window at the Edward Grey Institute. He concentrated on aspects of the blackbirds' life that interested him, and now offers a modest essay on what he learned. He describes the birds' plumages and moults, their food and feeding habits,



their strongly territorial disposition (in the Botanic Garden the average size of a territory was about half an acre), their songs and calls, their threatening and fighting practices. He discusses population problems, the hazards of city life, sexual displays, pair formation and pair-bond, nesting, care of the young, breeding season, clutch size and so on. This story of birds living their lives and making a society in a tiny green world surrounded by buildings and busy streets has gentle charm as well as scientific merit. Pleasing illustrations.

SOAP BUBBLES, by C. V. Boys; MAGNETS, by Francis Bitter; ECHOES OF BATS AND MEN, by Donald R. Griffin; THE NEUTRON STORY, by Donald J. Hughes; HOW OLD IS THE EARTH?, by Patrick M. Hurley. Doubleday Anchor Books (95 cents each). The appearance of this new series of science paperbacks has been preceded by considerable fanfare. The books are published as part of a program, based at the Massachusetts Institute of Technology, for reforming the teaching of physics; the program includes the writing of a new textbook, the preparation of a film series and the design of laboratory apparatus. The Federal Government and private foundations have supported the work with large grants, and a group of physicists, high-school teachers, journalists and others have cooperated in designing and creating aids to the learning of physics. It cannot be said that the division of the program represented by these books exhibits a soaring flight of imagination, either in planning or individual performance. With the exception of Boys's charming late-19th-century lectures on soap bubbles, a small classic of popularization which one is glad to see back in print, the other four 156-page monographs, though competent, do not sparkle. Bitter's book, subtitled "The Education of a Physicist," combines autobiography—how he got interested in physics and how he tackled problems of research—with a resumé of what is known about magnetism and electricity, ferromagnetism, nuclear magnetism and related matters. The autobiographical parts are more interesting than the straight exposition. Not to mention electron spin is a curious omission even in a book for beginners; and it is something of a feat to make occasional references to the history of magnetism, as the book does, without even mentioning Michael Faraday. Griffin's story is in many respects a shorter version of his excellent *Listening in the Dark*, reviewed in this department some months ago. He discusses, among other things, the nature of sound waves, airborne echoes of audible sounds, the language of echoes, sonar and radar, echo-location as a tool for the blind. *The Neutron Story* is a pallid affair. It presents the fundamentals of atomic and nuclear physics; then explains how neutrons were discovered, what they do, what is known about their structure and how they are used. Other writers with more verve and imagination have told this story much better. Hurley's primer deals satisfactorily with questions about the structure of the earth, radioactivity as a major heat-producer, the measurement of geologic time, memorable dates of surface history, the earth's beginnings. Illustrations for the series are of average quality, neither original in conception nor conspicuously well drafted; any good physics text published in recent years is likely to have far superior pictures. The merit of the books is that they usually approach their business directly and do not evade or dulcify the hard problems in the way that popularizations are apt to do. This at least is the way to talk to high-school students; if they care for science let them face some of its intricacies and headaches right off. The Science Study Series is a sound idea, and one hopes to see it better served in future volumes; the first batch gets off the ground with a ladder, but not very high.

RECORDS OF THE AMERICAN-AUSTRALIAN SCIENTIFIC EXPEDITION TO ARNHEM LAND, VOL. III: BOTANY AND PLANT ECOLOGY, edited by R. L. Specht and C. P. Mountford. Cambridge University Press ($19.50). The first volume of this fine expedition report, dealing with the art, myth and symbolism of Arnhem Land in Australia was reviewed in these columns some time ago. Volume III treats of the history of botanical exploration in the Aboriginal Reserve, of the botanical specimens collected by the party, of the climate, geology, soils and plant ecology of northern Arnhem Land, and of the geographical relationships of the flora. There are many illustrations. The two volumes still to follow will cover natural history, anthropology and nutrition.

THE MOLECULAR BASIS OF EVOLUTION, by Christian B. Anfinsen. John Wiley & Sons, Inc. ($7). The principal aim of this book is to examine a method for the study of evolution based on the hypothesis that the individual proteins which characterize a particular species are unique reflections of the genes which control their synthesis. According to the author, the evidence thus far available, though limited, suggests that the structure of proteins may be a relatively direct expression of gene structure and that comparative protein chemistry may furnish a qualitative view of genotypic differences and similarities. If we accept the general hypothesis, we are led to infer, for example, that the "insulin-determining" genes of the pig and the sperm whale are identical, like the insulins whose structures they determine.

THE PUMA'S CLAW, by Simon Clark. Little, Brown and Company ($4.95). A very well-written, zestful, unpretentious story of seven young Englishmen, the oldest 24, who went to Peru to climb Pumasillo, a 20,490-foot terror of a mountain, hitherto unconquered and almost unknown. Clark says the climb was made "for the hell of it" and was not intended to prove anything; he and his companions had a dangerously exciting and gratifying adventure; they enjoyed themselves immensely and so will the reader.

CANCER IN FAMILIES, by Douglas P. Murphy and Helen Abbey. Harvard University Press ($2.50). This book reports on a study of the male and female relatives of 200 women who had suffered from cancer of the breast. One hundred ninety-eight control families were investigated in a similar manner. Earlier studies in this field yielded contradictory results as to whether or not cancer occurs with unusual frequency among the relatives of cancer probands; on the other hand, there seemed to be "almost universal agreement" that breast cancer occurs with unusual frequency in the relatives of patients who have the disease at that site. The present carefully planned and executed inquiry produced no evidence that the disease occurs more frequently, either in the breast or elsewhere, among the relatives of breast-cancer patients than among the relatives of the controls.

INYANGA, by Roger Summers and others. Cambridge University Press ($9). A description of an archaeological investigation into the ruins and terraces of Inyanga, a mountainous region on the eastern borders of Southern Rhodesia. The monuments include roads and pathways, water furrows, pits, enclosures, forts, cairns and monoliths; and while these are only a few hundred years old, it was necessary in reconstructing the past, because of the absence of written evidence, to make use of archaeological methods such as are used in studying the prehistoric cultures of older civilizations. A beautifully produced volume.

The Silent Language, by Edward T. Hall. Doubleday & Company, Inc. ($3.95). It is an important part of our culture to talk without saying anything; but in our culture, as in many others, a great deal can be said without talking. The silent language is in fact capable of conveying more deeply felt meanings than words. Its vocabulary is large and varied; manners, gestures, the way we regard property, our notions and prejudices of social order, our everyday use of time and space concepts, are essential parts of this vocabulary. Indeed, this book makes the point that culture in its entirety is a form of communication. The author is an anthropologist who has done field work in different parts of the world and has directed a training program in the State Department for overseas technicians and administrators, instructing them on the local traditions and taboos of the countries to which they were to be sent. He gives many examples of how we and other people express ourselves by actions or in coded speech, and he shows how easy it is to misunderstand messages of a silent language if one is ignorant of the culture of which it is a part. This is an interesting essay, but it bogs down when it tries to be profound.

The Hand of Life, by Ritchie Calder. Weidenfeld and Nicolson (30 shillings). This year marks the 10th anniversary of the foundation of the Weizmann Institute of Science at Rehovoth, Israel. It has become, despite severe handicaps, one of the scientific centers of the world, conducting research in geology, agriculture, nuclear physics, chemistry, biochemistry, animal-breeding, pure and applied mathematics, electronics, experimental biology and biophysics. Its success is attributable to Chaim Weizmann's original leadership, to the memory of his devotion to the highest scientific ideals, and to the passion and skill of young men and women from all over the world who have dedicated themselves to serve not only the needs of their country but of the wider world of science. The story is sketched in this well-illustrated book by an able British science-journalist.

Notes

Thermodynamics and Statistical Thermodynamics, by John Geldart Aston and James John Fritz. John Wiley & Sons, Inc. ($8.25). A survey of recent advances in methods for calculating thermodynamic properties through the use of statistical mechanics.

THE ASTRONOMER'S UNIVERSE, by Bart J. Bok. Cambridge University Press ($3.75). This little book based on lectures given at the University of Canberra is a readable report, designed for the nonspecialist, on recent advances in astronomy: problems of the solar system, studies of stellar populations, work on the age and evolution of the galaxies, developments in radio astronomy.

COMPREHENSIVE ANALYTICAL CHEMISTRY, edited by Cecil L. Wilson and David W. Wilson. Elsevier Publishing Company; D. Van Nostrand Company, Inc., Distributors ($17.50). The first of five volumes of a detailed reference work covering all types of analytical determination from the theoretical and the practical aspects. This volume deals with the introductory and general material usually called classical analysis.

EXPERIMENTAL NUCLEAR PHYSICS, VOLUME III, edited by Emilio Segrè. John Wiley & Sons, Inc. ($23). Papers on radioactive decay, alpha radioactivity, gamma rays, beta rays, particle accelerators, experimental techniques, significant facts and data, theoretical interpretation.

FROM EUCLID TO EDDINGTON, by Sir Edmund Whittaker. Dover Publications, Inc. ($1.35). A paper-back reprint of Whittaker's Tarner Lectures of 1947, in which he attempted to trace the development of theories in natural philosophy from the rediscovery of Euclid by Western scholars to the present time.

A SYMPOSIUM ON MOLECULAR BIOLOGY, edited by Raymond E. Zirkle. The University of Chicago Press ($7.50). Lectures in a seminar series and symposium held at the University of Chicago in 1956-57, dealing with various aspects of research on the problem of explaining life phenomena in terms of molecules and their properties.

TEXTBOOK OF PHYSICS, edited by R. Kronig in collaboration with others. Pergamon Press ($15). A revised English edition of a better-than-average Dutch survey of classical and modern physics, including new material on atomic structure, instrumentation and measurement, and medical physics. The preceding edition, which was 10 per cent shorter, cost only $10; why should students be held up in this way?

INDEX OF ADVERTISERS

NOVEMBER, 1959

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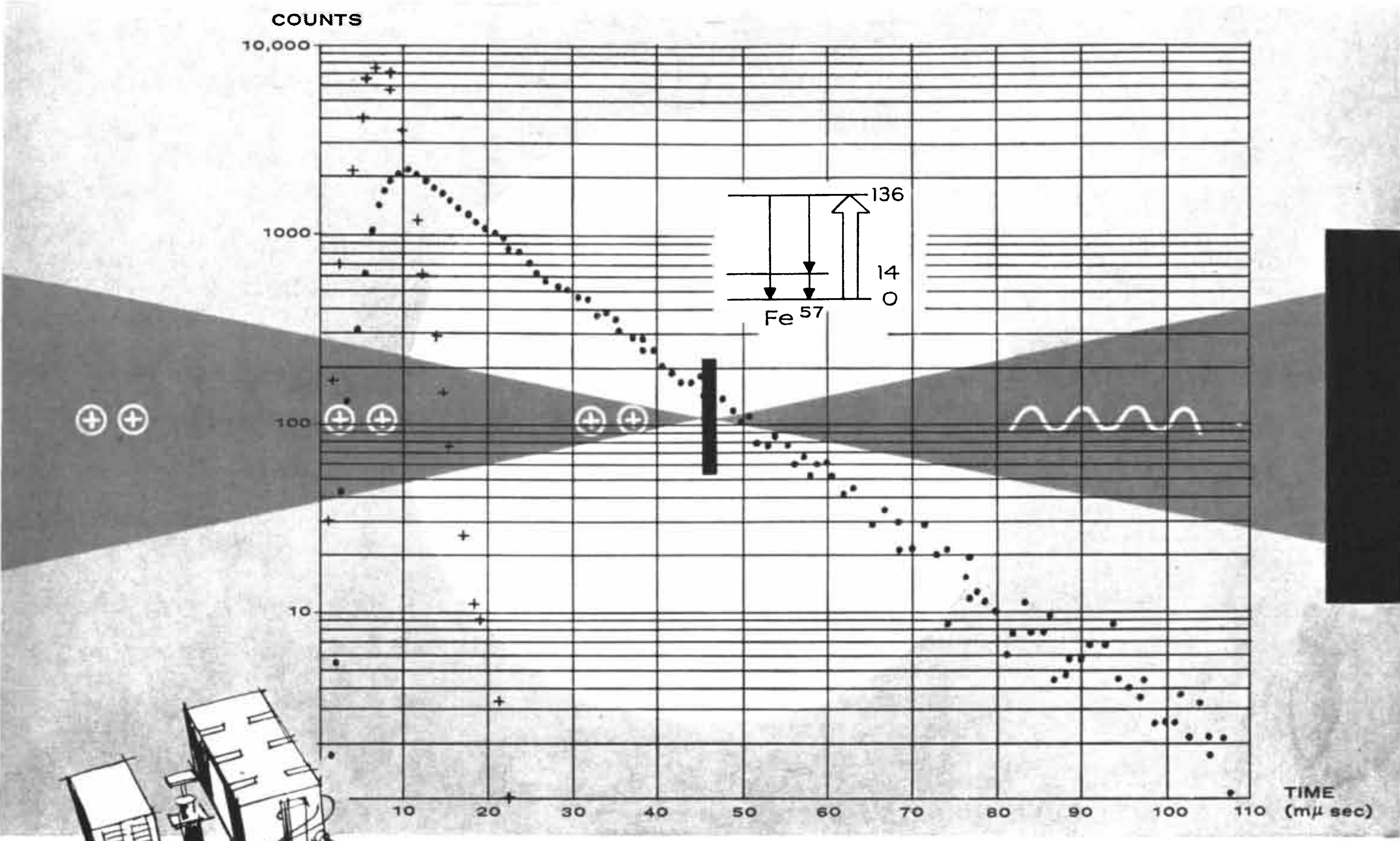
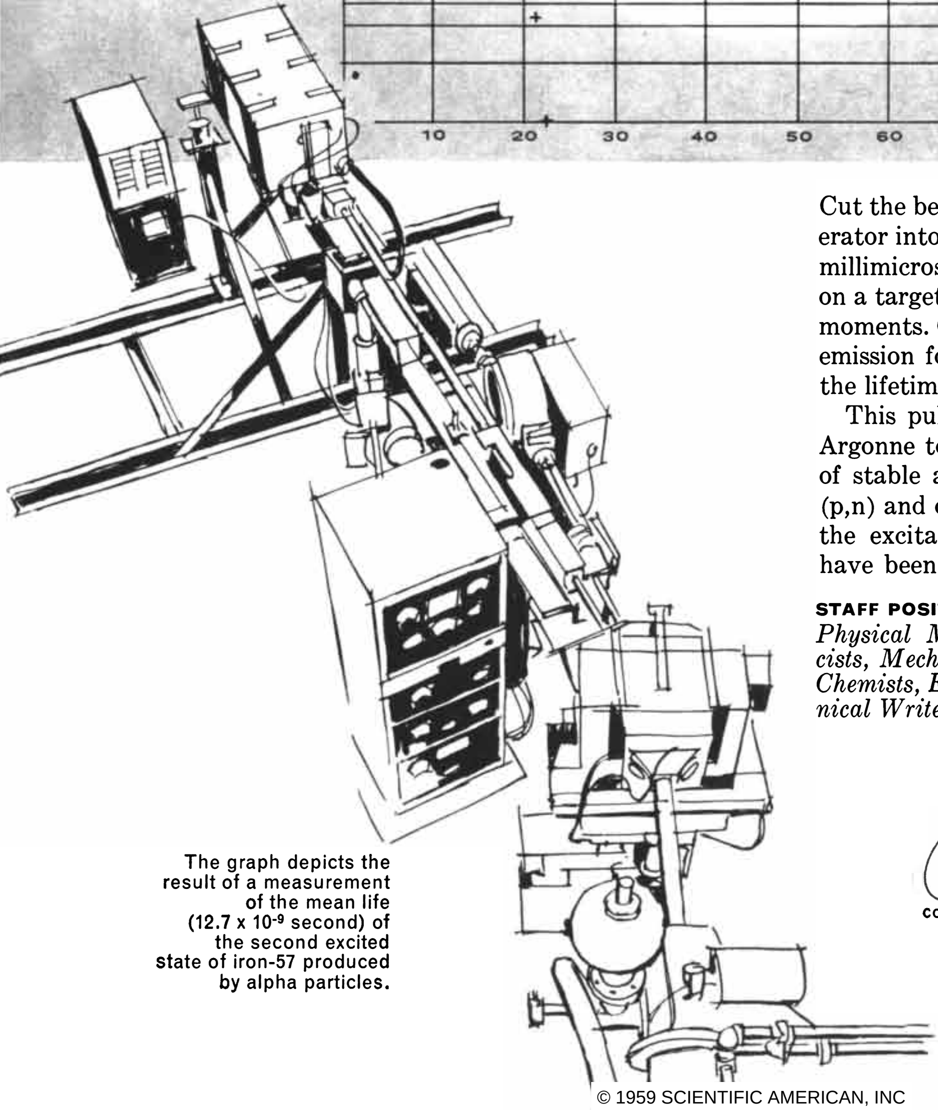
MEASURING LIFETIMES OF EXCITED STATES OF NUCLEI





The graph depicts the result of a measurement of the mean life (12.7×10^{-9} second) of the second excited state of iron-57 produced by alpha particles.

Cut the beam of particles from an electrostatic accelerator into pulses one millimicrosecond long and 140 millimicroseconds apart. Allow this beam to impinge on a target and produce nuclear excitation at precise moments. Observe the rate of decrease of gamma-ray emission following each pulse and from this obtain the lifetime of the excited state.

This pulsed-beam technique has been applied at Argonne to the study of a number of excited states of stable and unstable nuclei. Coulomb excitation, (p,n) and other reactions have been used to produce the excitation. Lifetimes as short as 10^{-10} second have been measured.

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