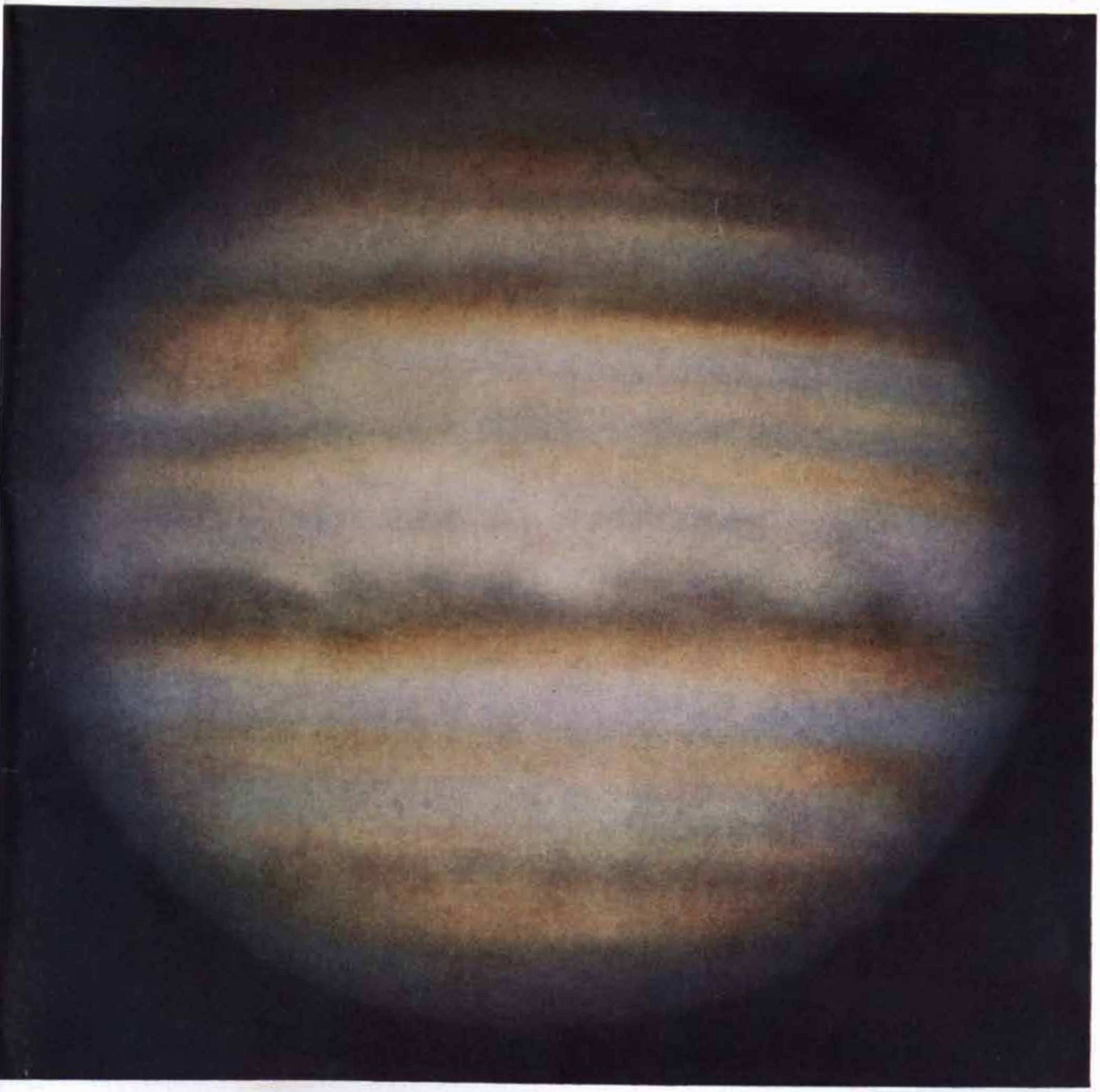
SCIENTIFIC AMERICAN



THE PLANET JUPITER

FIFTY CENTS

June 1956

Chomp, chomp, chomp
the bugs are marching...

... but nowadays they leave no long, long trail of ruined crops. Today's insect invaders find it hard to survive—because of new and potent insecticides.

Shell Chemical insecticides control such major crop destroyers as grasshoppers, boll weevils, and armyworms. By using these powerful insecticides, growers have been able to increase both the quality and quantity of their crop yields.

So economical are Shell Chemical's new pesticides that mere *ounces* will protect acres of crops. Increased yields and better quality crops pay for the cost of treatment many times over.

New and better insecticides, like *aldrin, dieldrin,* and *endrin,* are among many Shell Chemical contributions in protecting agricultural crops throughout the world.

SHELL

Shell Chemical Corporation

Chemical Partner of Industry and Agriculture

NEW YORK

CERIUM OXIDE

—a rare earth that sparked a revolution in a long established art in the glass industry

a report by LINDSAY

SOME twenty years ago in Switzerland, two technicians discovered the amazing glass polishing properties of Cerium Oxide. Soon it was being used extensively for polishing of precision lenses in Europe.

Then came World War II. Scientists in the optical industries in this country heard about Cerium Oxide . . . how it could polish faster and cleaner than any other known material. They thought that maybe this was the answer to the problem of accelerated production of precision optical pieces for our war machine. In a cloak and dagger operation, samples of Cerium Oxide were smuggled out of Switzerland. Tests confirmed the rumors . . . Cerium Oxide was IT!

This was early in the 40's when Hitler held most of Europe and the Japanese were driving toward Australia. The urgency of our growing war effort was putting fantastic demands on the optical industry. Lenses for bombsights, range finders, periscopes and other military instruments were needed desperately. Production had to be increased manyfold with no sacrifice of split-hair accuracy.

Lindsay, the nation's largest processor of monazite (the chief source of rare earths), undertook in 1942 the challenging task of producing Cerium Oxide. Day after day, Lindsay technicians worked with patience and speed to solve the inevitable production problems and in a remarkably short time, Cerium Oxide was being refined with the properties that met the demanding standards of the optical and glass industries. At about the same time, Barnesite, a rare earth oxide for ultra-high precision work, was developed and a few years later Lindsay took over exclusive production.

By war's end, Cerium Oxide had virtually revolutionized glass polishing practices in this country. Today, it is widely used in the production of distortion-free TV tubes, fine quality mirrors and precision optical lenses.

Opticians like Lindsay's Cerium Oxide (sold under the trade name CEROX) because it enables them to polish lenses to prescription specifications faster and to give you glasses exactly as the doctor ordered.

Leading automobile manufacturers use Lindsay's Cerium Oxide to polish out windshield scratches just before shipment. One of the largest producers furnishes its dealers with kits containing Cerium Oxide to remove nicks and scratches picked up in transit.

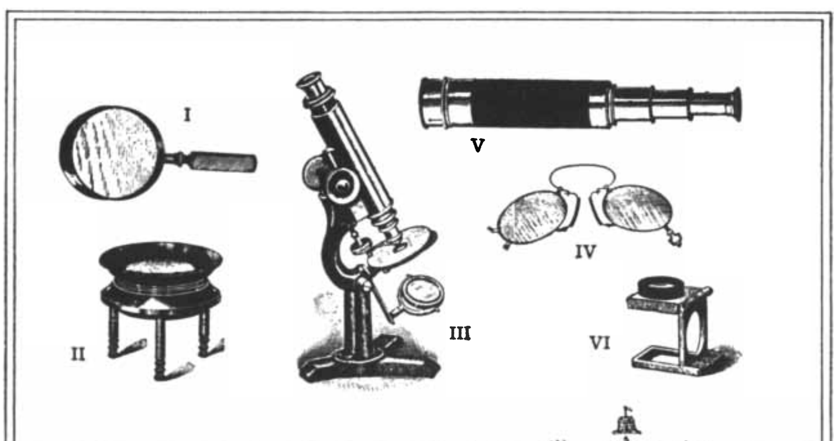
Why is Cerium Oxide such wonderful stuff when it comes to polishing? Frankly, nobody knows. Lindsay's technical people have tested and retested it, put it through countless laboratory analyses and peered at it for hours through high-powered microscopes. Just as scientists know how to *use* electricity, but don't know what it *is*, so too, they know that Cerium Oxide is a remarkably efficient polishing agent but *why* is still a mystery.

Like all the other rare earths, Cerium Oxide is a versatile material. Research disclosed its unique potentials (along with didymium, neodymium, and other rare earths) for use in coloring and decolorizing glass and it is extensively used for that purpose. Another interesting use is as a catalyst with some chemical materials.

Twenty-five years ago, most chemists had little knowledge or curiosity about the rare earths. Then the dramatic emergence of Cerium Oxide as an important factor in the optical industry excited interest in the full range of the 15 rare earth elements—atomic numbers 57 through 71.

There are technical people who think that some of the rare earths have greater possibilities of revolutionizing processes in their industries than Cerium Oxide has had for polishing practices. We are encouraged to think so, too. We are shipping rare earths regularly for use in the production of such diverse materials as steel, aluminum, glass, ceramics, textiles, ammunition and for a variety of applications in the electronic and atomic industries.

We can give you comprehensive data about the many rare earth and thorium salts available. Your technical staff may find it rewarding and profitable to take a long, thoughtful look at these unique materials, to examine their characteristics and, particularly, their potential applications to your own processes.



PLEASE ADDRESS INQUIRIES TO: LINDSAY CHEMICAL COMPANY
264 ANN STREET, WEST CHICAGO, ILLINOIS

Established 1845 **SCIENTIFIC AMERICAN** June, 1956 Volume 194 Number 6

ARTICLES

DEPARTMENTS

THE COVER

The photograph on the cover is associated with two articles in this issue: "The Chemistry of Jupiter" (*page 119*) and "The Amateur Scientist" (*page 156*). It shows the planet Jupiter as photographed in color with the 60-inch reflecting telescope on Mount Wilson. The photograph was made by Robert Leighton with a special guiding device of his own design. The south pole of the planet is at the top. At upper left is the Great Red Spot. Below center are the prominent markings of the Jovian equatorial belt.

THE ILLUSTRATIONS

Cover photograph by Robert Leighton

Page	Source
37-39	Irving Geis
40	Herman Yagoda, National Institutes of Health
41	Irving Geis
42-44	Bunji Tagawa
46	Robley C. Williams (*top*); Roger Hart (*bottom*)
47	Bunji Tagawa
48-52	Eric Mose
56	Chicago Natural History Museum
72	Arnold Newman
74-86	Bunji Tagawa
91	New York Public Library
92	Armed Forces Medical Library
94-96	John Langley Howard
98	Wenner-Gren Foundation for Anthropological Research
100	Cy La Tour & Son
105	British National Institute for Medical Research
106-110	Roy Stevens
112	British National Institute for Medical Research
119-128	Bunji Tagawa
131	Cornell Aeronautical Laboratory
132-138	James Egleson
156	Robert Leighton
157-166	Roger Hayward

KANIGEN®

amorphous nickel alloy coating

Number 4 In A Series

Kanigen is a uniform, hard, corrosion-resistant nickel-phosphorus coating. It can be applied to iron, copper, nickel or aluminum and their alloys as well as ceramics, glass and thermo-setting plastics. This is achieved through a chemical bath without the use of electricity. The coating (probably a solution of nickel phosphide in nickel) exhibits many desirable properties not normally associated with metals or metal plating.

POROSITY

Kanigen nickel-phosphorus coatings, deposited 0.0002" thick on polished steel specimens, display no evidence of porosity when submitted to test in aerated, 185° F water.

Kanigen deposits, 0.0002" thick on polished steel, exhibit zero porosity when subjected to the ferroxyl test for locating pores.

Gaseous diffusion tests show no porosity in a 0.00025" thick Kanigen coating.

A thin coating of aged radioactive iron isotope, emitting soft X-rays which are effectively shielded by nickel, was electro-deposited on mild steel discs. Kanigen was then deposited over the iron isotope in thicknesses of 0.0002", 0.0004", 0.0006", and photosensitive plates exposed to the coated discs. The radiographs thus obtained were free of spots, indicating zero porosity in the Kanigen deposits.

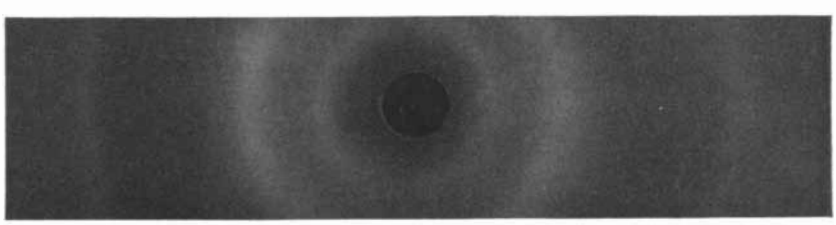
SALT SPRAY RESISTANCE

Kanigen coatings, deposited on cold rolled steel, withstand salt spray test exposure for more than double the time required by ASTM-B-117-49T. When failure finally occurs, the rust spots show no tendency to spread even when the part is left in the salt spray chamber for 1000 hours or more.

The satisfactory performance of Kanigen coatings under salt spray test conditions (and in actual service) depends in great part on the surface condition of the basis material. Smooth, fault-free surfaces permit satisfactory deposition of Kanigen coatings with excellent salt spray test results. Materials which are characterized by pronounced discontinuities (excessive roughness or porosity, sand or slag inclusions, lack of homogeneity in the alloy structure) may not permit perfect Kanigen coating coverage. This condition often will promote premature salt spray test failure, giving an erroneous picture of the potential effectiveness of the coating.

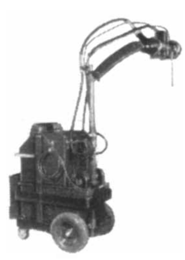
ADHESION

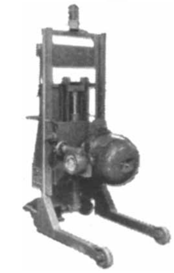
Adhesion of Kanigen coatings is excellent. It is extremely difficult, however, to measure, or to report adhesion since there is no standard measurement technique for metal coatings. Reported values are in the order of 30,000 to 60,000 psi to steel. Kanigen coated steel specimens show no flaking or chipping of the plating when pulled to the breaking point in tension. When Kanigen plated bars are bent 180°, there will usually be checking of the coating parallel to the axis of the bend on the outside of the bend; however, no flaking occurs. Because of its high hardness, a Kanigen nickel-phosphorus coating will sometimes show compression or shear failure (especially in heavy coatings) on the inside radius of a 180° bend test specimen. This occasionally results in some apparent flaking. Actual microscopic observations, in many cases, has shown that the separation line is in the coating and not between the coat and the basis metal. The adhesive forces to the basis metal, in these cases, exceed the cohesive forces of the coating itself.



"X-ray" diffraction pattern showing halo effects denoting the amorphous structure of Kanigen

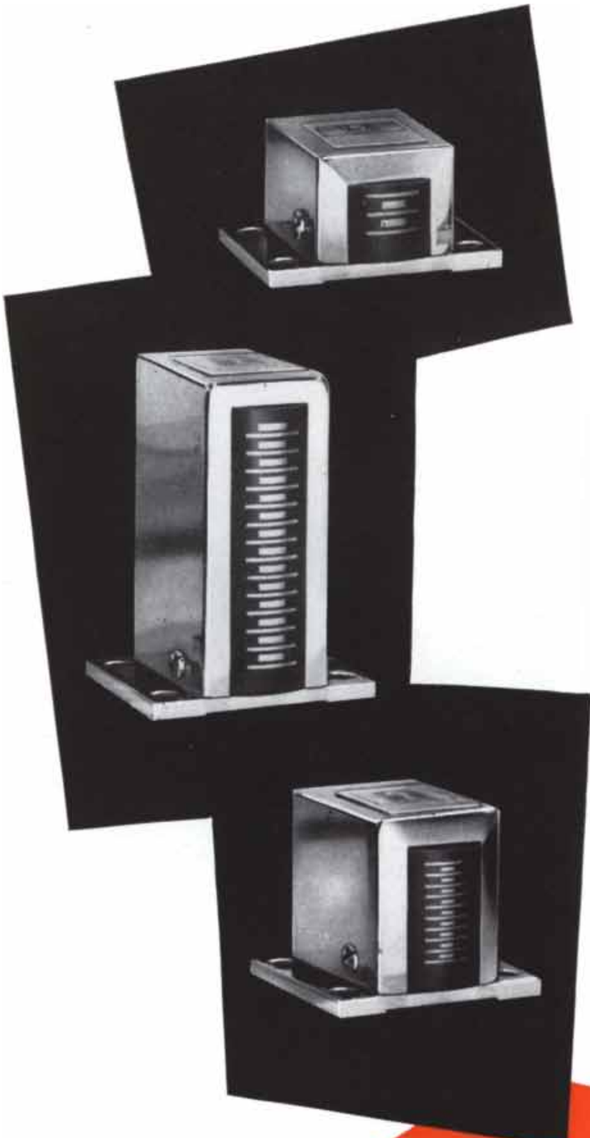
If you have a problem that a Kanigen application may solve or if you'd like further information, write:
KANIGEN DIVISION, GENERAL AMERICAN TRANSPORTATION CORPORATION
135 South La Salle Street, Chicago 90, Illinois.





Heads Up!

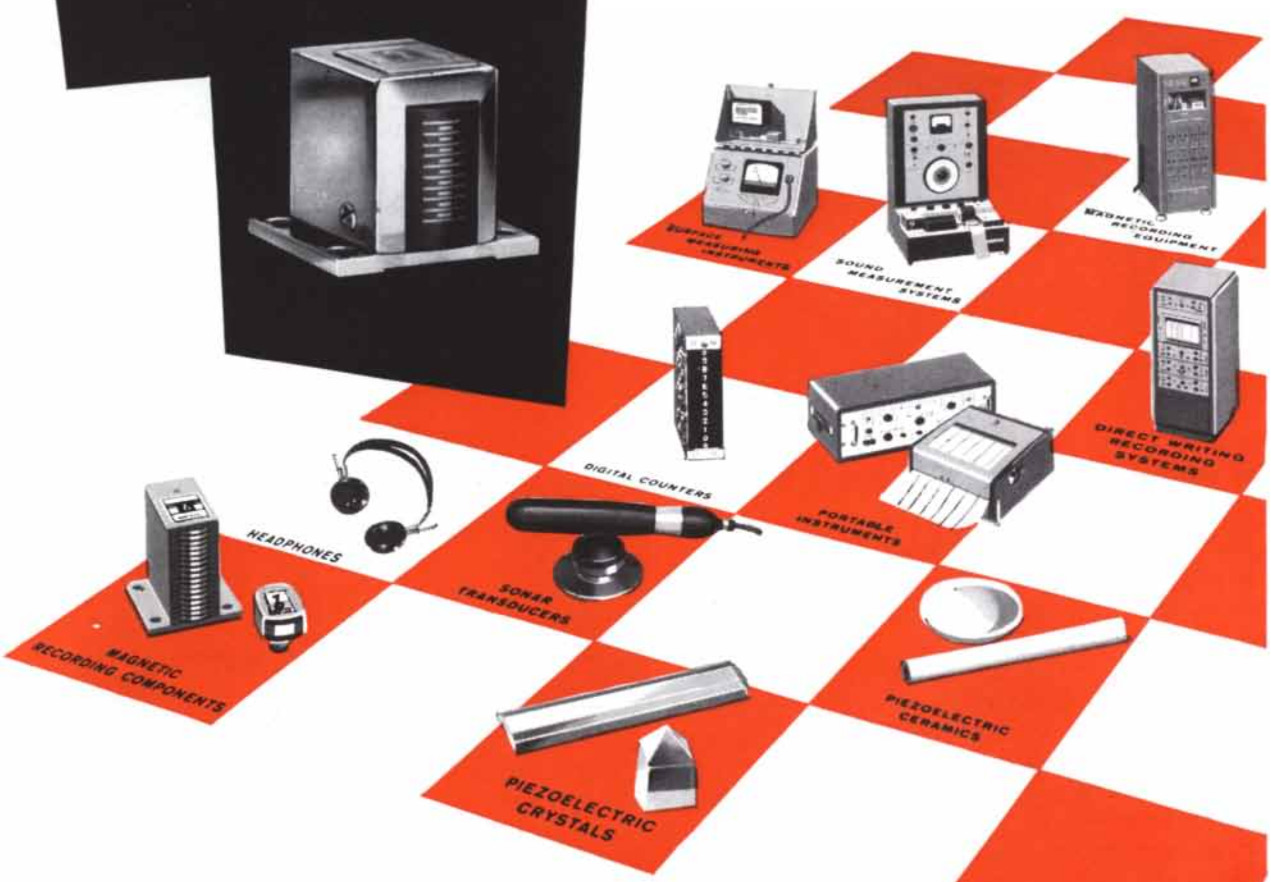
New Brush magnetic recording heads meet the most exacting requirements



Brush has now introduced a new design concept in multi-channel magnetic heads to provide the extremely close tolerances required in airborne, missile, and similar critical recording applications. Brush is the first commercial source of this type head.

By holding tolerances on gap alignment to within ± .0001 inch maximum, outstanding channel-to-channel timing accuracy is provided. Likewise, close tolerances on track width and channel spacing assure uniform output. The new construction technique provides sustained accuracy under severe operating conditions.

Here is another example of Brush design skill and production technique—always ready to serve your needs. For complete information write Brush Electronics Company, Dept. B-6, 3405 Perkins Avenue, Cleveland 14, Ohio.



BRUSH ELECTRONICS COMPANY

3405 Perkins Avenue, Cleveland 14, Ohio

BRUSH ELECTRONICS

DIVISION OF CLEVITE CORPORATION

Anaconda specifies Enjay Butyl rubber

TO DEFY OZONE IN HIGH-VOLTAGE CABLES...

for more current per circuit...more power per dollar

Anaconda specifies Enjay Butyl insulation for high-voltage cables because this rubber has incredible resistance to ozone. Surpassing the industry's standard three-hour specification test, Enjay Butyl insulation used by Anaconda showed *no injury after 72 hours* of ozone concentration tests—24 times longer than specification requirements. Other rubbers would deteriorate and crack in a fraction of this time.

With the help of Enjay Butyl, millions of feet of Anaconda's cable now in use deliver more current per circuit, more power per dollar.

Perhaps *your* product, too, can be improved with versatile Enjay Butyl. It comes in non-staining grades for white and light-colored parts, offers excellent electrical properties, low price and *immediate availability*. For full information, contact the Enjay Company. Complete laboratory facilities and technical assistance are at your service.

ENJAY
BUTYL

Enjay Butyl is the super-durable rubber with *outstanding* resistance to aging • abrasion • tear • chipping • cracking • ozone and corona • chemicals • gases • heat • cold • sunlight • moisture.

ENJAY *Pioneer in Petrochemicals*

ENJAY COMPANY, INC., 15 West 51st Street, New York 19, N. Y.
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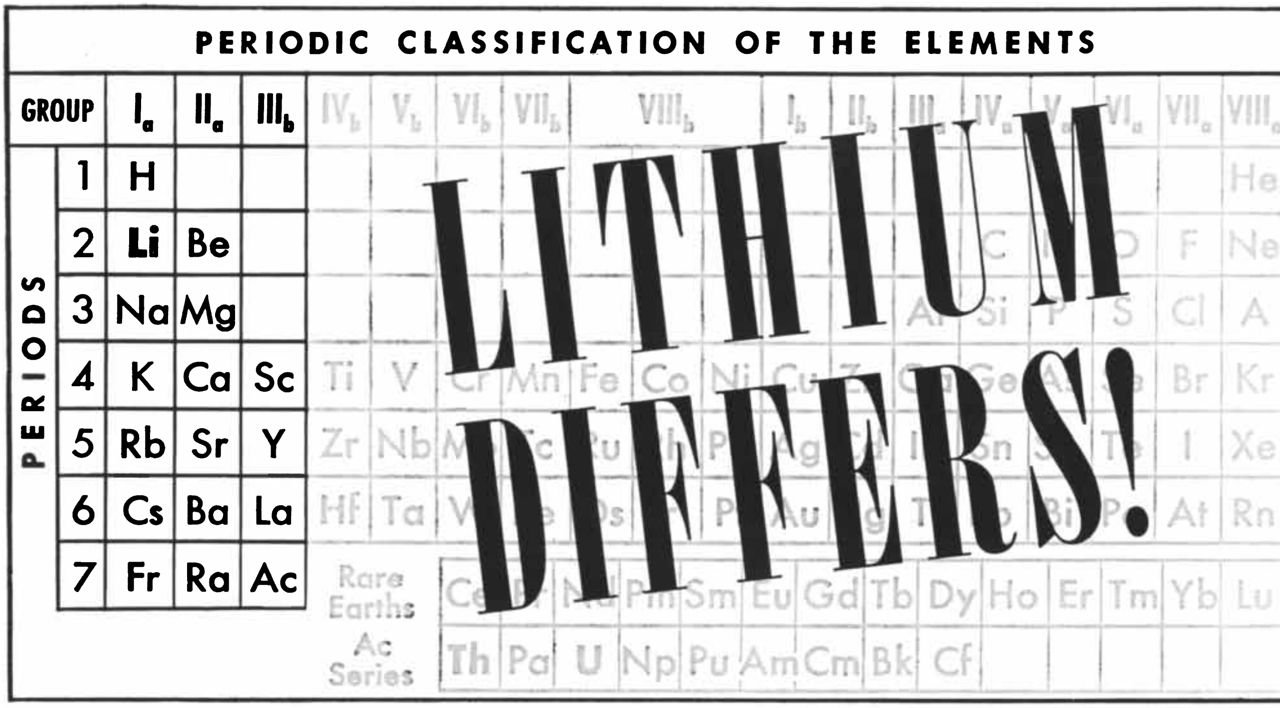


Lithium, by reason of its atomic configuration and general characteristics, is rightfully included as the first member of Group I in the Periodic Table. A detailed study of the properties and reactions of both the elements and their compounds, however, shows that Lithium often resembles the metals of Groups II and III more closely than Group I. Following are some characteristic differences:

Lithium differs in organic chemistry . . .
because its organolithium compounds form a unique class with stability, solubility and activity characteristics intermediate between those of the Group I and Group II organometallic compounds.

Lithium also differs from the other alkali metals in that it serves as a unique catalyst for the polymerization of diolefins to materials of definite and predictable structure. It directs, for example, the polymerization of isoprene predominantly to 1,4 addition structures.

Again, recent investigations have indicated an interesting potential as a direct reducing agent in solvents such as ammonia, low molecular weight amines, and ethylenediamine.

Lithium differs in metallurgy...
inasmuch as the affinity of Lithium for oxygen, for example, is being utilized to reduce porosity in copper and copper alloy castings. Recent research has revealed that Lithium will produce brazing alloys with self-fluxing properties and increase the wetting ability of these alloys.

Lithium differs in inorganic chemistry . . .
the usefulness of Lithium Hydride and Lithium Aluminum Hydride in the preparation of other hydrides having already been widely demonstrated. Recent studies indicate that other complex hydrides prepared in a similar manner may prove to be interesting tools for research. The low dissociation pressure of Lithium Hydride at its melting point, to cite a specific example, is unique among all hydrides. LiH also has some slight solubility in polar organic compounds which is again unique among alkali metals.

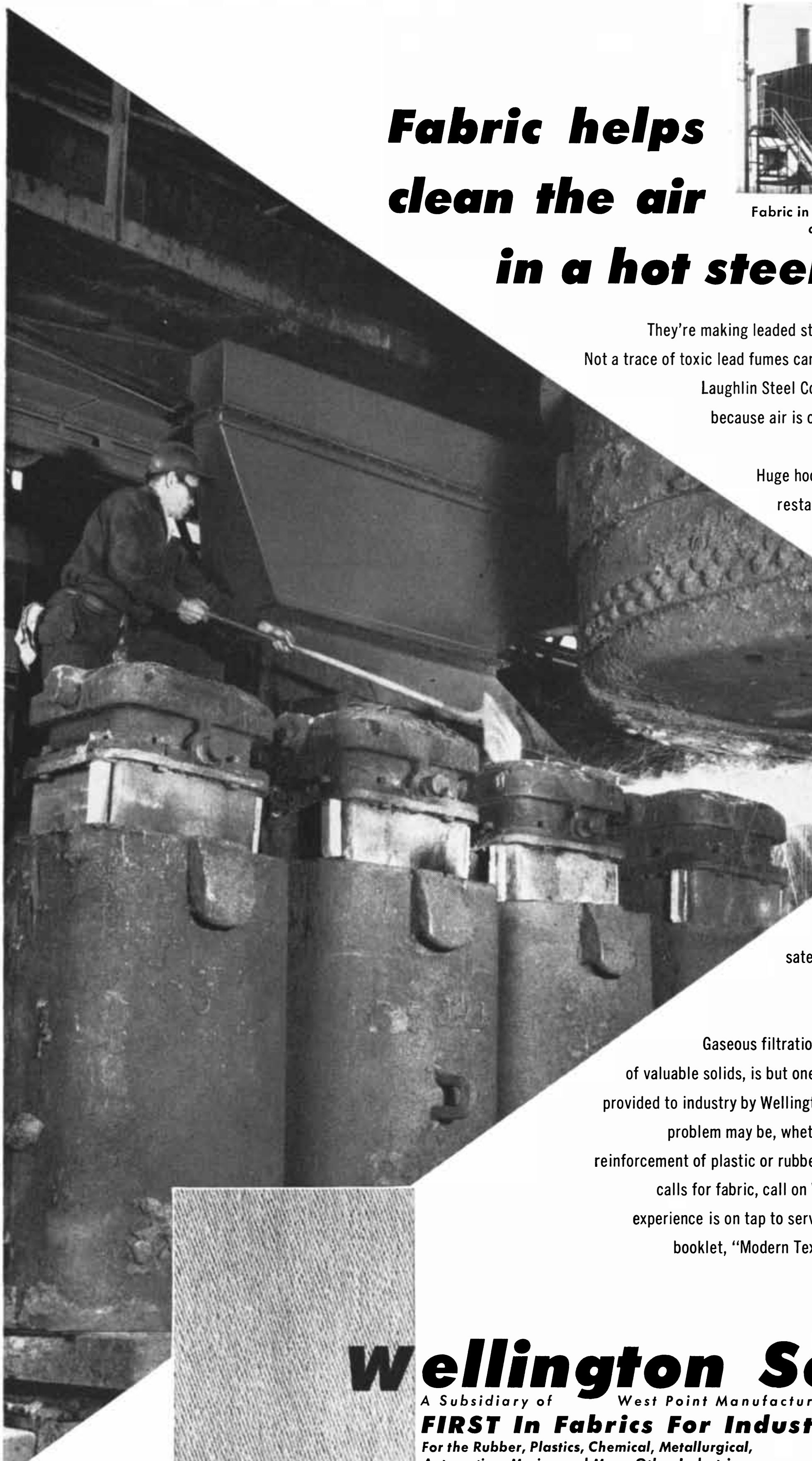
Lithium differs in heat transfer . . .
based on its physical properties it has no equal as a liquid metal coolant. Due to corrosion caused at elevated temperatures by impurities in commercially available Lithium and Lithium Metal, Lithium has thus far found only experimental use.

Why don't *you* take a long look at Lithium? Its uniquely valuable differences in so many diverse fields may prove of great interest—and profit—to *you*. Write our PR&D department giving us details of the application you have in mind. Experimental quantities of Lithium Compounds are available on request.

. . . trends ahead in industrial applications for lithium

LITHIUM CORPORATION OF AMERICA, INC.
2685 RAND TOWER
MINNEAPOLIS 2, MINN.

MINES: Keystone, Custer, Hill City, South Dakota • Bessemer City, North Carolina • Cat Lake, Manitoba • Amos Area, Quebec • BRANCH SALES OFFICES: New York Pittsburgh • Chicago • CHEMICAL PLANTS: St. Louis Park, Minnesota • Bessemer City, North Carolina • RESEARCH LABORATORY: St. Louis Park, Minnesota



Fabric in Dracco Multi-Bag Filter cleans air at Jones & Laughlin Plant

Fabric helps clean the air in a hot steel kitchen!

They're making leaded steel, but they're breathing clean air. Not a trace of toxic lead fumes can pollute the atmosphere at Jones & Laughlin Steel Corporation's Aliquippa (Pa.) Works — because air is constantly cleansed through the use of a Wellington Sears filter fabric. Huge hoods (comparable to those you see in restaurant kitchens) suck in the air right at the pouring platform — some 36,000 cubic feet a minute — whisk it away to a Dracco Multi-Bag Filter.

There the air is "bagged" by a series of filter compartments made of Wellington Sears cotton sateen fabric: the almost invisible lead particles are recovered, the air is discharged free and clear.

Gaseous filtration, for health protection or recovery of valuable solids, is but one of many jobs performed by fabrics provided to industry by Wellington Sears. No matter what your own problem may be, whether it involves wet or dry filtration, reinforcement of plastic or rubber products or any other need which calls for fabric, call on Wellington Sears. Over a century of experience is on tap to serve you in every way. For informative booklet, "Modern Textiles for Industry," write Dept. F-6.

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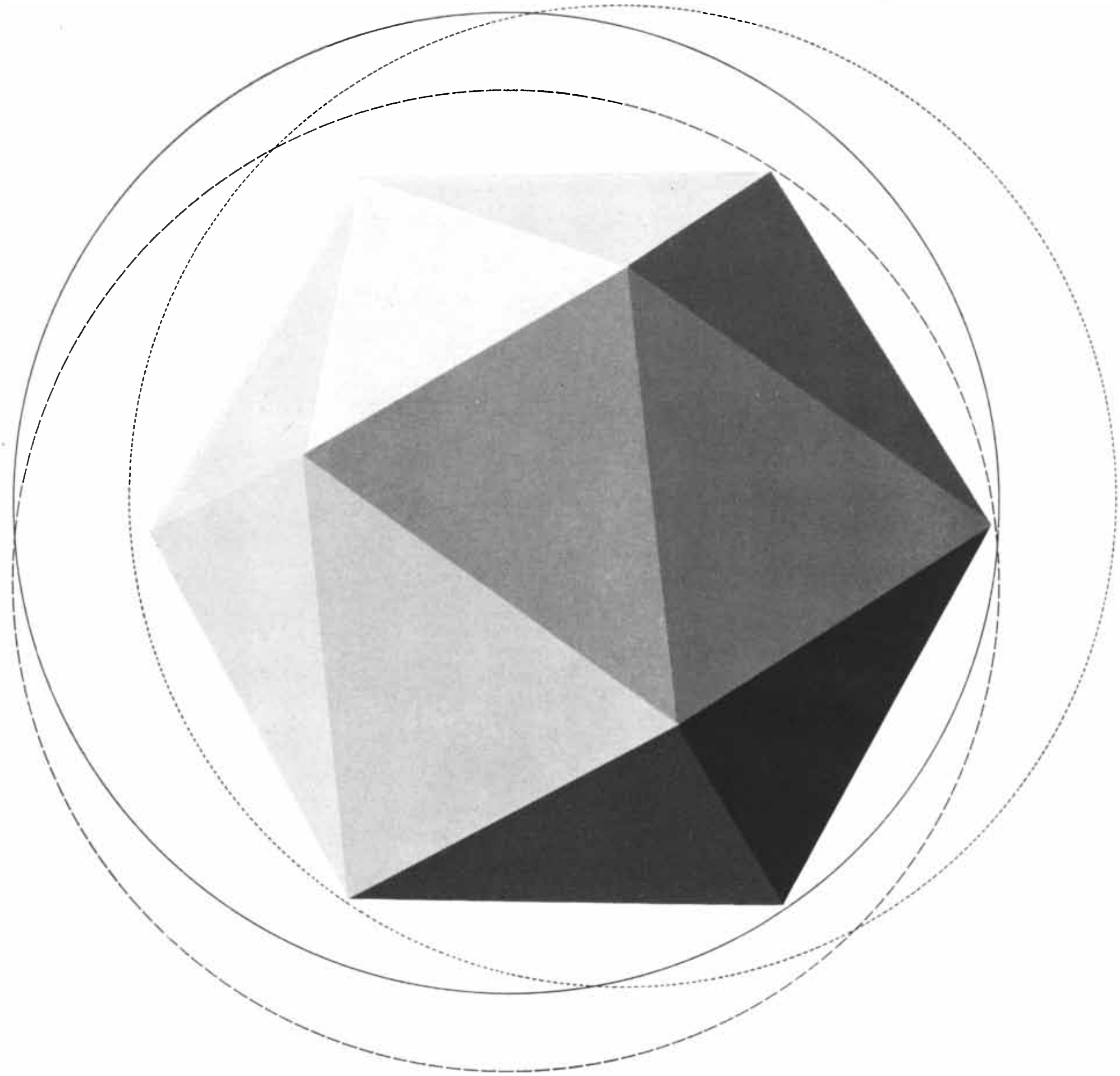
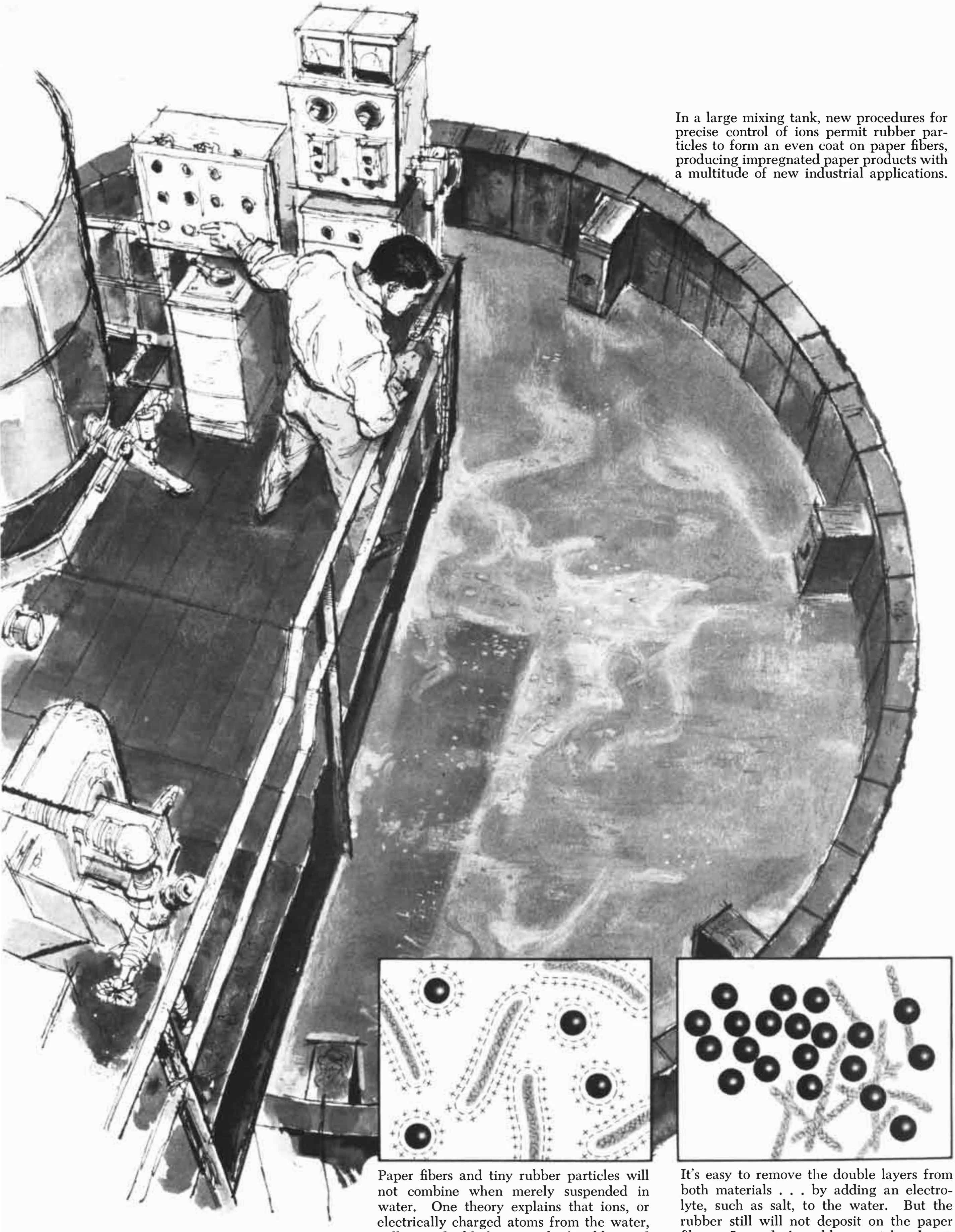




In a large mixing tank, new procedures for precise control of ions permit rubber particles to form an even coat on paper fibers, producing impregnated paper products with a multitude of new industrial applications.

Paper fibers and tiny rubber particles will not combine when merely suspended in water. One theory explains that ions, or electrically charged atoms from the water, collect in double layers on both rubber and paper. These layers act like protective envelopes that keep the two materials apart.

It's easy to remove the double layers from both materials . . . by adding an electrolyte, such as salt, to the water. But the rubber still will not deposit on the paper fibers. Instead, the rubber particles cluster together in stringy masses that research workers were quick to nickname "rhubarb."

How a new method of "ion control" is opening up amazing industrial uses for paper

For years it was believed that a material made of rubber-coated paper fibers would have almost unlimited possibilities—as a base for artificial leathers, as a filtering medium, for use in low-cost gaskets, and in many other industrial applications.

To make such a material, and make it inexpensively, Armstrong research workers felt that the individual fibers had to be coated with large amounts of rubber while they were suspended in a liquid . . . in the watery pulp stage of paper manufacture. But they also knew that suspended paper fibers and rubber normally wouldn't combine uniformly in the right proportions.

The reason for this situation was well known. In fact, the 19th Century writings of a German physicist named Helmholtz describe the phenomenon that occurs when particles of any material are suspended in water. Double layers of tiny electric charges – called ions – form protective envelopes around the particles and keep them apart.

A few years ago, a group of Armstrong research chemists set out to make practical use of the Helmholtz Double Layers. After working through a year-long maze of experiments, they hit upon a process which precisely controlled the layers of ions. With it, rubber could be made to coat paper fibers evenly and thoroughly and in amounts as large as 100 per cent of the fiber weight.

Most important, this new process was adaptable to mass production with virtually no sacrifice of laboratory accuracy. Completely uniform compositions could be made combining rubber and fiber in almost any useful proportion. Saturated papers with wider and more interesting industrial applications thus became possible.

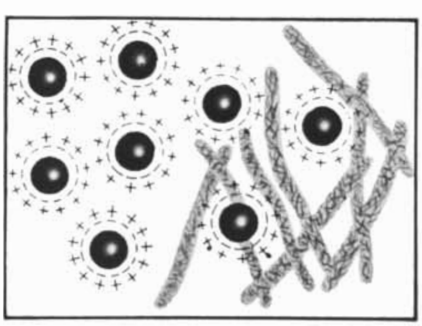
A low-cost gasket material of unusual dependability is one of the many applications of the new Armstrong process. This material, called Accopac®, also contains finely ground cork. It is resilient, dimensionally stable, and impervious to most common fluids, even at bolting pressures as low as 800 pounds per square inch. Accopac already is widely used in automotive equipment, aircraft devices, appliances, and many other consumer and industrial products.

For more information about Accopac, write for the 24-page manual, "Armstrong Gasket Materials." It's free to industrial users. Write Armstrong Cork Co., Industrial Division, 8206 Inland Rd., Lancaster, Penna.

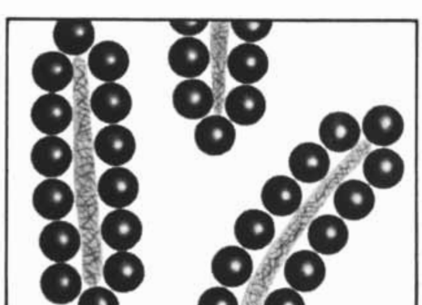
Armstrong INDUSTRIAL PRODUCTS

. . . USED WHEREVER PERFORMANCE COUNTS

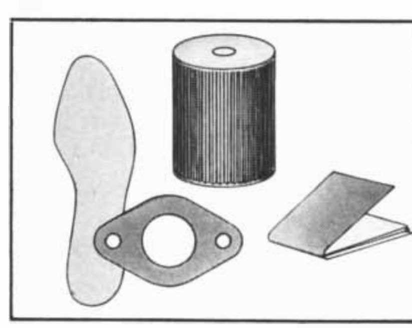
adhesives . . . cork composition . . . cork-and-rubber . . . felt papers . . . friction materials



If you remove the charges from the paper fibers only, the double layers of ions on the rubber particles keep the rubber particles from sticking to each other. But these layers also keep the rubber from sticking to the paper fibers except in a random, haphazard manner. This obviously is not the answer.



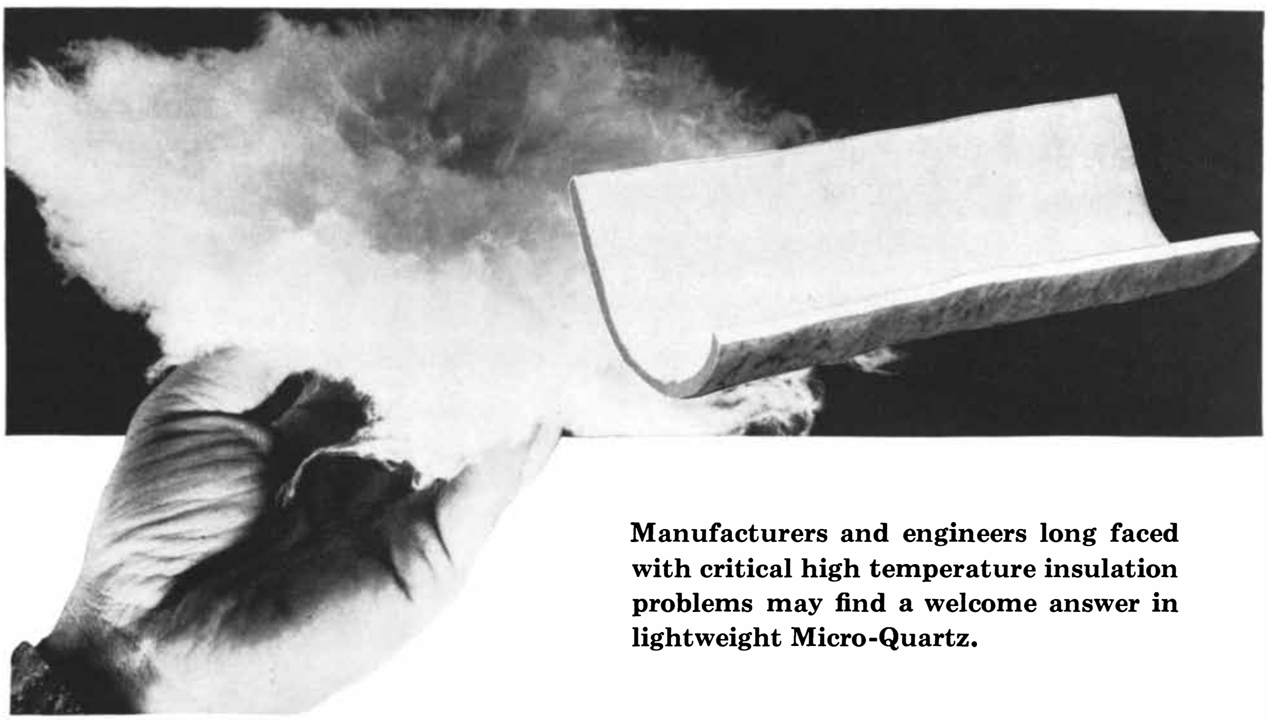
The trick, then, is to remove the double layers from the fibers only, while those on the rubber are merely made thinner. This is managed so the layers on the rubber particles remain thick enough to keep the rubber from bunching, but not thick enough to keep it from coating the fibers uniformly.



A practical and precise method of ion control is what Armstrong research chemists developed. Commercial applications include new and far better saturated papers for artificial leathers, gasket materials, oil filter cartridges, notebook covers, shoe insoles, and many other important industrial uses.

L·O·F Glass Fibers Company Introduces

MICRO-QUARTZ—The new insulation for the 2000°-2500° Temperature Range!



Manufacturers and engineers long faced with critical high temperature insulation problems may find a welcome answer in lightweight Micro-Quartz.

L·O·F Glass Fibers Company announces Micro-Quartz—a remarkable, new insulation for temperatures ranging, under many conditions, up to 2500°!

Micro-Quartz is available in felted form and in bulk. It is light in weight and composed of 98% pure quartz. It is resilient, exceptionally efficient, and resistant to vibration and air flow. Because it has no organic binder, its performance, stability, and thermal conductivity are those of the quartz fibers themselves.

The range of uses to which Micro-Quartz can be put is very broad, with possible applications in all industries doing work in the high-temperature field. It may be the answer to high temperature problems involving low heat capacity and high thermal diffusivity, frequent- or rapid-heating cycles, and problems of weight, space limitations, and vibration.

Micro-Quartz fibers are available in paper form. Can be impregnated or coated for electrical applications.

Requests on your business letterhead for more information, and a Micro-Quartz sample, will receive prompt attention. Write: L·O·F Glass Fibers Company, Dept. 3-66, 1810 Madison Ave., Toledo 1, Ohio.

PRODUCT DATA ON STANDARD MICRO-QUARTZ SHEETS*

Average Fiber Diameter—0.75 microns or 0.00003 inches

Density—Standard nominal density is 3 lbs./cu. ft.

Weight—0.047 lbs. per sq. ft.—0.005 lbs.

Thickness of sheet—Standard nominal thickness is 3/16 inches

Width of sheet—34 inches

Length of sheet—71 inches

*Other thicknesses and densities are available. Sheets can be fabricated to fit your application.

L·O·F GLASS FIBERS Micro-Quartz HIGH TEMPERATURE INSULATION

L·O·F GLASS FIBERS COMPANY

TOLEDO 1, OHIO

Makers of glass fibers by the exclusive "Electronic-Extrusion" process

The New York State Thruway curves gracefully across the Hudson River just north of New York City on the new 16,000-foot Tappan Zee Bridge.

The roadway over Tappan Zee moves on Anaconda Bronze

Arrows show direction of movement, as free end of approach roadway section slides on 8" x 17" phosphor bronze bridge plates.

THE PROBLEM: A bridge roadway is in continuous motion. The sun's heat makes it expand. When the temperature drops, it shrinks. The movement is small and slow, but an important factor in bridge design. For economical construction, the 8000-foot-long western approach to the main span of the New York State Thruway Authority Tappan Zee Bridge, for example, is divided into 50-foot sections. One end of each section is fixed; the other slides freely on bearing plates.

THE SOLUTION: *Cast* bronze bridge plates sometimes crack, causing considerable difficulty in replacement. To meet this problem, Anaconda's American Brass Company developed a rolled bridge plate of *wrought* phosphor bronze — a copper alloy strong enough to carry the weight, tough enough to take the wear, and highly resistant to corrosion. In building this great new bridge, The American Bridge Division of U. S. Steel used thousands of these Anaconda Phosphor Bronze Bridge Plates under roadways.

THE FUTURE: The American Brass Company is constantly improving alloys. A recent development is Duraflex* — a new, fine-grain phosphor bronze with 30 percent greater endurance limit — that is helping industry produce springs and electrical contacts that work better, last longer.

Anaconda's other fabricating company, Anaconda Wire & Cable Company, is blazing new trails in the field of electrical conductors and their insulations.

Whether you need wire or cable of copper or aluminum — or a special alloy or shape in copper, brass, or bronze — get in touch with the *Man from Anaconda* for help in practical solutions to your metal problems. The Anaconda Company, 25 Broadway, New York 4, N. Y. *Trade Mark 56248

ANACONDA®

Avco Crosley

Avco Crosley measures man for tomorrow's machines

There is only one component in a modern machine system which engineers cannot "improve." That is the all-important, "human component"—man, himself.

To adapt changing machines to unchanging human capacities, Experimental Psychologists of Avco's Crosley division are taking a closer look at man—his mind, his body, his reactions. From these patient investigations are emerging ways to make present and future machines simpler, more obedient, more valuable to man.

By measuring man *today*, Avco Crosley "human engineering" helps assure man that he will realize the *full* benefits of the machines he builds *tomorrow*.

To find out how "human engineering" might improve your present or future products—phone, wire, or write to: Avco Defense and Industrial Products, Stratford, Conn.

Engineers Wanted: For top-flight men, Crosley offers unusual opportunities to explore new scientific frontiers. Write to Director of Engineering, Crosley Government Products, Cincinnati 15, Ohio

TODAY'S MILITARY SERVICES, WITH THEIR TREMENDOUS TECHNOLOGICAL ADVANCES MADE POSSIBLE THROUGH SCIENCE, OFFER A VITAL, REWARDING CAREER.

defense and industrial products

Avco Defense and Industrial Products combine the scientific and engineering skills, and production facilities of three great divisions of Avco Manufacturing Corp.: Crosley; Lycoming; Research and Advanced Development—to produce power plants, electronics, airframe components, and precision parts.

FOR A COPY OF THIS PIENING ILLUSTRATION, SUITABLE FOR FRAMING, WRITE TO PUBLIC RELATIONS DEPT., AVCO DEFENSE AND INDUSTRIAL PRODUCTS, STRATFORD, CONN.

LETTERS

Sirs:

Warren Weaver's interesting article, "Lewis Carroll: Mathematician" [Scientific American, April], contained a problem from Dodgson's *A Tangled Tale*. The problem is stated by Dodgson:

Two travelers spend from three o'clock until nine o'clock in walking along a level road, up a hill, back down the hill, along the same road, and home. Their pace on the level is four miles per hour. Find the distance walked and, within a half-hour, when they were on the summit.

I found the distance to be 24 miles, but the time that they were on the summit cannot be determined within the half-hour. If the level and the summit exist at all, we can only say that they reached the summit within six to seven o'clock.

Perhaps it would have been more just to Dodgson to entitle the article "Lewis Carroll: Logician."

Robert Finkel

New York, N. Y.

Sirs:

Warren Weaver's article mentions the monkey and weight problem and implies that what would happen to the weight as the monkey starts to climb would depend on whether the monkey jerked the rope or climbed very gently. A modern version of this problem substitutes a mirror for the weight and asks whether the monkey could get away from his image in the mirror, which image is presumably not to his liking.

Since the rope is weightless and perfectly flexible, and the pulley weightless and frictionless, it is evident that the tension of the rope is the same on both sides of the pulley. Thus the rope always pulls equally hard on both monkey and mirror, and since the force of gravitation is also the same on both, it is plain that the motions of both will be exactly the same.

If the monkey pulls downward on the rope with a force greater than his weight he will of course start to rise; but, since the increased tension in the rope is transmitted over the pulley to the mirror, the mirror will also start to rise at the same rate. If, instead, he were to release the rope both he and the mirror would become freely falling bodies and would continue to remain at a common level. If now the falling monkey were to grab the rope, it would exert a great force on him and stop him. But the rope would exert an equally great force on the mirror and stop it just as quickly.

Thus the monkey cannot get away from his image and it makes no difference whether he climbs slowly or in spurts.

A. G. Samuelson

Hibbing Junior College
Hibbing, Minn.

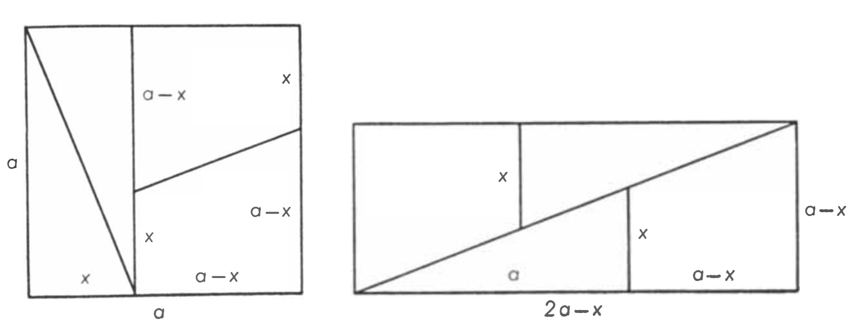
Sirs:

Readers of "Lewis Carroll: Mathematician" might be interested in constructing triangles other than the one shown in the triangle paradox figure on page 120. The equation to be used is:

$$x = \frac{3a - \sqrt{5a^2 \pm 4}}{2},$$

where a and x are integers and where a must be such that $5a^2 + 4$ or $5a^2 - 4$ is a perfect square. With such a choice of a, the area of the derived "rectangle" will differ from the area of the square by unity [*see illustration below*].

The first 15 possibilities for a—start-



A reader generalizes Lewis Carroll's triangle paradox ing with a = 0 in the above equation—are listed in the following table:

a	x	a−x
0	−1	1
1	1	0
1	0	1
2	1	1
3	1	2
5	2	3
8	3	5
13	5	8
21	8	13
34	13	21
55	21	34
89	34	55
144	55	89
233	89	144
377	144	233

The first case with any meaning insofar as our problem is concerned is for $a = 2$ and $x = 1$, but the fit for the "rectangle" is so poor (the angles involved being discordant by 27 degrees) that this "rectangle" would fool no one. The last case shown in the table, where the two areas involved are 142,129 and 142,130, has an angular discordance of only two seconds of arc.

JOHN B. IRWIN

Department of Astronomy
Indiana University
Bloomington, Ind.

Sirs:

I wish to discuss . . . the so-called paradox of the three barbers. Is it possible that this is really a serious problem for the professional logicians? Here we have a perfectly simple set of facts, namely, three barbers and their shop; and two perfectly simple sets of conditions limiting these facts, which any reasonably bright child of ten should be able to manipulate. There is nothing paradoxical or baffling about the problem, and in order to create the apparent paradox it has been necessary to introduce an assumption which violates at least one of the stated conditions, to wit:

All three—A, B and C—being present in the shop, there is nothing to prevent any one of them from leaving at any time. We may therefore properly assume that C goes out first. But with C away, A and B are no longer as free in their choice in regard to going out as they had been, all three being present. The incidence of the conditions has changed through C's departure. C being away, it follows that, though B may still leave at any time he chooses, A *must* stay in, either because B is not there to help him, or because, if B is there to help him and they both leave, the shop will be left empty. It is improper to introduce at this point, C being absent, the assumption that A goes out, a thing impossible for him to do under the conditions. To make such an assumption would require something in the nature of a miracle which suddenly cures A of his infirmity.

ALEXANDER B. MORRIS

San Antonio, Texas

Sirs:

It is very gratifying that several of your readers have been interested in Lewis Carroll's puzzles and paradoxes.

Mr. Finkel is entirely correct in his solution of Knot I in *A Tangled Tale*, but inaccurate in his statement that the time on the summit "cannot be determined within the half-hour." Indeed Mr. Finkel himself says that "they reached the summit within six to seven o'clock." Then the figure of 6:30 is certainly correct within a half-hour.

Mr. Samuelson (and others who wrote in the same vein) are quite correct about the monkey problem, and my remark that the problem is not well defined was an unfortunate one. In the sense that one can say "the weight moves exactly as the monkey does" the problem is, to be sure, well defined. The problem is, however, not completely defined in the sense that one cannot say exactly how the weight moves until one adds details about how the monkey climbs.

Mr. Irwin gives the formula for generalizing the triangle paradox, illustrated

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on page 120 of the article. Any reader who is interested in more of the mathematical and historical details will find them in an article ("Lewis Carroll and a Geometrical Paradox," *American Mathematical Monthly*, Vol. XLV, No. 4, April, 1938, page 234) which I wrote nearly 20 years ago.

A number of readers have written about the barbershop paradox, and all of them have essentially the same complaint—namely, that there is no paradox. To establish that there is really no paradox, the letters attack in two ways. First (and this is the easy one to deal with), some of the letters say in effect: "This barbershop and its three proprietors present a perfectly simple and clear situation, and I can make several obviously correct and noncontradictory remarks about who goes out and who doesn't." This is all well and good. But it fails to meet the real point. The question is not "Can you say something noncontradictory?" The question is "What is specifically wrong with Carroll's argument?"

The second line of attack is well illustrated by the third paragraph of Mr. Morris's letter. It consists in saying that, having assumed C out, one is then not free to go on and say: "Then if A goes out, B stays in."

I am certainly not a logician, and do not wish to pose as one. Hence I can only state what I believe to be the position of the competent experts, and will leave the further discussion in their hands.

In the *Principia Mathematica* of Alfred North Whitehead and Bertrand Russell, one of the basic rules of procedure is the so-called Principle of Exportation. This may be stated in words: if p and q jointly imply r, then p implies that q implies r. As applied to our situation, this Principle of Exportation permits one to proceed from the statement:

If Carr is out, then if Allen is out Brown is in.

Thus under the formal rules of what has now become classical logic the second of these statements can, in fact, be "exported" from the former. Having reached this point, one either has to concede the Russell position (that "if Allen goes out then Brown must go out" is not contradictory to "if Allen goes out, then Brown must stay in"), or he has the paradoxical conclusion that Carr can't go out. Thus if one does not like the Russell escape, then he must find some way around the standard application of the Principle of Exportation.

WARREN WEAVER

New York, N. Y.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1906: "Thanks to the arguments which have been advanced by the President, the Secretary of War, and the Chief Engineer of the Panama Canal, the Senate has voted for a lock canal across the Isthmus. The sharp conflict which has been waged by the advocates of sea-level and lock canals, and which has resulted in a delay both irksome and perplexing to the engineers at Panama, is now happily ended."

"For the last few years Edison has been working steadily and enthusiastically at his alkaline storage battery, and while he has succeeded in developing a cell that is decidedly superior to the lead accumulator for many purposes, a great deal still remains to be accomplished before his success can be called complete. In the course of his investigations Edison has employed and tested a great variety of different metals, and among these recently was cobalt, which is comparatively rare, and consequently expensive. It was reported that cobalt existed in considerable quantities in the neighborhood of Charlotte, N. C., and Edison determined to see for himself whether or not the reports were warranted. For several years past the inventor has been an enthusiastic automobilist, and he decided to make the journey from his home in Orange to Charlotte by means of his two White steam-cars. He strongly favors the steam machine for long and rough trips, and declares that it is far superior to the gasoline car for such purposes."

"The inoculation of mice with cancer is being practiced on a very large scale by Prof. Ehrlich, of the Frankfurt Institute for Experimental Therapeutics. Ehrlich has been led to the conception of 'atreptic' immunity, or immunity due to starvation of the cancer cells. He assumes that the cell of mouse cancer requires for its growth, in addition to the general nutriment which is furnished in abundance by the rat as well as the mouse, a special nutriment which is found only in mice. Ehrlich explains the

RADIO'S ONE-WAY STREET

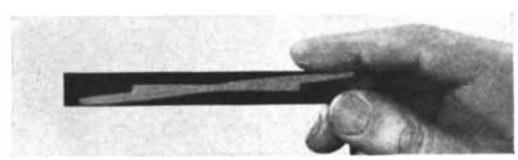
Dr. S. Weisbaum assembles an isolator which he developed for use in a new microwave system. Dr. Weisbaum is a Ph.D. in microwave spectroscopy from New York University. He is one of many young men at Bell Laboratories applying the insight of the physicist to develop new systems of communication.

New radio relay systems for telephone and television now in the making will employ an ingenious device invented by Bell scientists. The device, known as an "isolator," senses which way microwaves are traveling through a waveguide, and stops those going the wrong way.

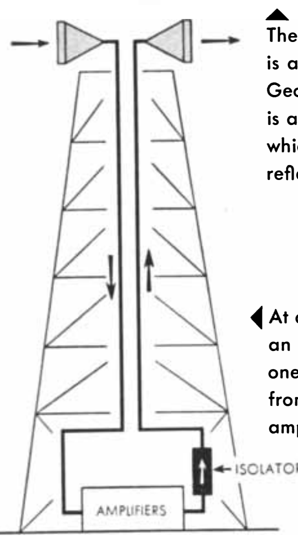
In the new systems a klystron wave generator sends signals through a waveguide to the antenna. The klystron must be shielded from waves reflected back along the waveguide by the antenna. The isolator stops reflections, yet allows the transmitted signals to go through clear and strong.

This isolator is a slab of ferrite which is mounted inside the waveguide, and is kept magnetized by a permanent magnet strapped to the outside. The magnetized ferrite pushes aside outgoing waves, while unwanted reflected waves are drawn into the ferrite and dissipated. This "field displacement" action results from the interplay between microwaves and a ferrite's spinning electrons. Bell physicists discovered this action during their fundamental studies of ferrites.

This is another example of how Bell Telephone Laboratories research works to improve American telephony and telecommunications throughout the world.



▲ The heart of the isolator is a ferrite slab. Geometric pattern is a carbon layer which dissipates reflected signals.



◀ At a radio relay station an isolator assures one-way transmission from the output of the amplifier to the antenna.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT growth of tumors, according to the modern cell theory, by assuming that the morbid cells surpass the normal cells in the power to seize and appropriate food. The tumors of mice show great differences in virulence, as appears from the ease, difficulty, or impossibility of transmitting them by inoculation. Most spontaneous cases of carcinoma in mice cannot be transmitted at all, but the most virulent cases often give 100 per cent of successful inoculations. Ehrlich has proved, however, that inoculation from an ordinary, non-transmissible tumor, though it does not reproduce that tumor, has the remarkable effect of making the inoculated mouse immune to carcinoma by repeated inoculations with non-virulent growths."

"If a sportsmanlike chauffeur has any yearning to run down human beings he has but to study Dr. Foote's recent paper on accidents occasioned by wheels. Dr. Foote's investigations were undertaken after a rather remarkable accident. An automobile delivery truck weighing about two tons passed over the trunk of a ten-year-old child without occasioning death. An investigation conducted by Dr. Foote for determining the cause of this abnormal result, led him to consider in a human body extended on the ground a line which he terms the 'line of mortal pressure.' The position of this line is dependent upon a host of factors, such as the weight of the vehicle, the width and elasticity of the tire, the speed of the vehicle, condition of the ground, clothing of the victim, mechanical resistance of the bones, contraction of the muscles. If the wheel of a vehicle strikes that line, death will probably result."

"Henry Norris Russell of the Princeton University Observatory informs us that a faint object was discovered early last spring, which turns out to be a minor planet which is more remote from the sun than Jupiter is. Its period appears to be a few days more than twelve years—more than half as long again as that of any previously known asteroid, and two months longer than that of Jupiter."

SCIENTIFIC AMERICAN

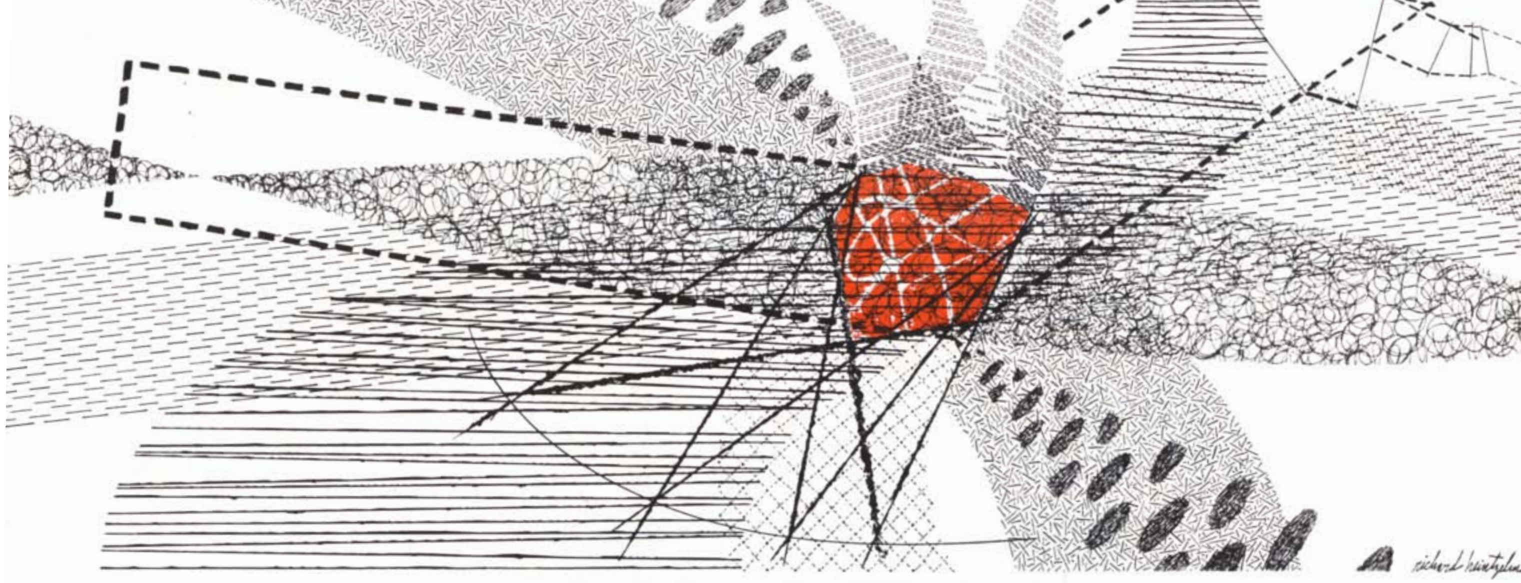
JUNE, 1856: "Mons. Foucault, of Paris, the inventor of the famous pendulum experiments which set the world agog a few years ago, has lately con-

structed an apparatus to demonstrate that motion produces caloric. A thick bar of iron, bent into a horse-shoe form, is converted into an electro-magnet; between its two extremities is supported a disk of copper, to which a rapid rotary motion—300 or 400 revolutions a second—is communicated by toothed gearing. So long as the horse-shoe is not electro-magnetized the disk turns with ease, but so soon as the horse shoe is placed in communication with a battery, and thereby converted into an electro-magnet, a great resistance to the further revolution of the disk is made manifest. If, in spite of this resistance, the disk is turned during a minute or so, and a thermometer be placed upon the disk, the mercury will ascend to 60 or 80 degrees (centigrade). There is, however, no point of contact, no friction, and the disk alone is heated."

"A number of large firms in the flour trade have just commenced to reckon exclusively in the decimal currency, and abolished the shilling and pence business. This was done by a united agreement. It is a strange thing, showing the hold which custom has upon business, that our centesimal currency should be so long in completely overthrowing the old pence and shilling currency."

"Wm. J. Stevenson, of New York City, has recently taken out a patent on an improvement for the purpose of effecting the hermetical sealing of the can by the action of atmospheric pressure on the cap or stopper. Inside the mouth of the vessel there is a shoulder on which is placed a ring of rubber. The cover is simply a flat disk of tin, with cross wires soldered on its top, so as to guide and keep it in the center. When the preserved fruit or other article has been sufficiently heated, the cover is laid on, and the subsequent cooling produces a partial vacuum within the vessel. The consequent atmospheric pressure on the disk embeds it in the rubber, and thus forms a perfectly air-tight joint, without screw or wax."

"The Arabian camels for which a government expedition was sent out to the Mediterranean arrived in the Matagorda Bay, Texas, on the 12th ult. Arab keepers accompany them. They came on shore dressed in their native costume, and were as much objects of curiosity as the camels. An attempt is to be made to acclimate these animals, to employ them as transports on the western deserts of our country, between the Mississippi Valley and the Rocky Mountains."



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THE AUTHORS

EMILIO SEGRE and CLYDE E. WIEGAND ("The Antiproton"), both nuclear physicists at the University of California, are members of the team that discovered the antiproton. Segrè, born in Italy in 1905, took his doctor's degree in physics at the University of Rome under Enrico Fermi in 1928. He worked with Fermi on the radioactivity of neutrons from 1934 to 1936. From there he went to Palermo as director of the physics laboratory. While at Palermo he and C. Perrier announced the discovery of technetium, the first artificially made element. He has been at the University of California in Berkeley since 1938, except for three years at the Los Alamos Scientific Laboratory during World War II. Segrè seems to have a divining rod for discovering elements and particles. Besides the antiproton and technetium, he identified the first plutonium with Glenn T. Seaborg, J. W. Kennedy and A. C. Wahl, and found the artificial element astatine with Dale Corson and K. R. MacKenzie. Wiegand is a physicist at the Radiation Laboratory of the University of California. Born in the State of Washington, he graduated from Willamette University in Oregon in 1940. He became a graduate student of Segrè at California, went with his professor to Los Alamos, and took his Ph.D. in 1950 after their return to Berkeley.

HEINZ FRAENKEL-CONRAT ("Rebuilding a Virus") is a research biochemist at the Virus Laboratory of the University of California. He was born in Breslau in 1910. He obtained an M.D. there in 1933, and in 1936 acquired a Ph.D. in biochemistry in Edinburgh. Since 1936, when he came to the U. S., his prime concern has been the chemistry of biologically active proteins. This has included work on enzymes, snake venoms, hormones, egg proteins and viruses. He worked at the Rockefeller Institute for Medical Research and at the Instituto Butantã in São Paulo, Brazil, before coming to Berkeley, where he has spent the last 18 years. During the 1940s he was with the Western Regional Research Laboratory of the U. S. Department of Agriculture.

A. J. MARSHALL ("Bower Birds") is head of the Department of Zoology and Comparative Anatomy at St. Bartholomew's Medical College of the University of London. He grew up in Aus-

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tralia, is a graduate of the universities of Sydney and of Oxford, where he was a Beit fellow. Bower birds have interested him since school days. His work has been chiefly in the seasonal physiology and migration of birds, and he pursues his research both in the field and in the laboratory. He has collected widely in the tropics and the arctics. Marshall led the Oxford University Expedition to Jan Mayen Island in 1947. He plans to spend this summer in East Africa to collect endocrine glands of frogs, bats and other denizens of regions so close to the Equator that their long-range internal cycles cannot be influenced by photoperiodicity. Like the bower birds, Marshall is a collector of bright objects: his chief hobby, he says, is hunting for 18th-century silver and glass in the junk shops of London's East End.

ERNEST NAGEL and JAMES R. NEWMAN ("Gödel's Proof") are both students of logic and of the philosophy of science, Newman being, in addition, a former student of Nagel. Nagel is John Dewey Professor of Philosophy at Columbia University. He wrote the introductory article to the special issue of SCIENTIFIC AMERICAN on automatic control in September, 1952, and reviewed Galileo's *Dialogue on the Great World System* in the issue of October, 1953. Nagel's most recent book is *Sovereign Reason*, published in 1954. Newman is a member of the Board of Editors of SCIENTIFIC AMERICAN.

LOREN C. EISELEY ("Oreopithecus: Homunculus or Monkey") is a professor of anthropology at the University of Pennsylvania and curator of early man at the University's museum. Eiseley was the author of the article "Fossil Man" in the December, 1953, issue of SCIENTIFIC AMERICAN. He observed in that article that "Piltdown man . . . did not fit into the sequence" of human fossils, and a few weeks later he expressed "relief" when Piltdown man was exposed as a hoax. His most recent piece in SCIENTIFIC AMERICAN was a biographical sketch of Charles Darwin in the February issue.

A. S. PARKES ("The Freezing of Living Cells") is a member of the staff of the National Institute for Medical Research in London. He attended Christ's College at the University of Cambridge, graduating in 1921. "Among my few intimate friends in Cambridge," says Parkes, "was James Hilton, later to become famous as the author of *Lost Horizon* and *Goodbye, Mr. Chips*, and who,

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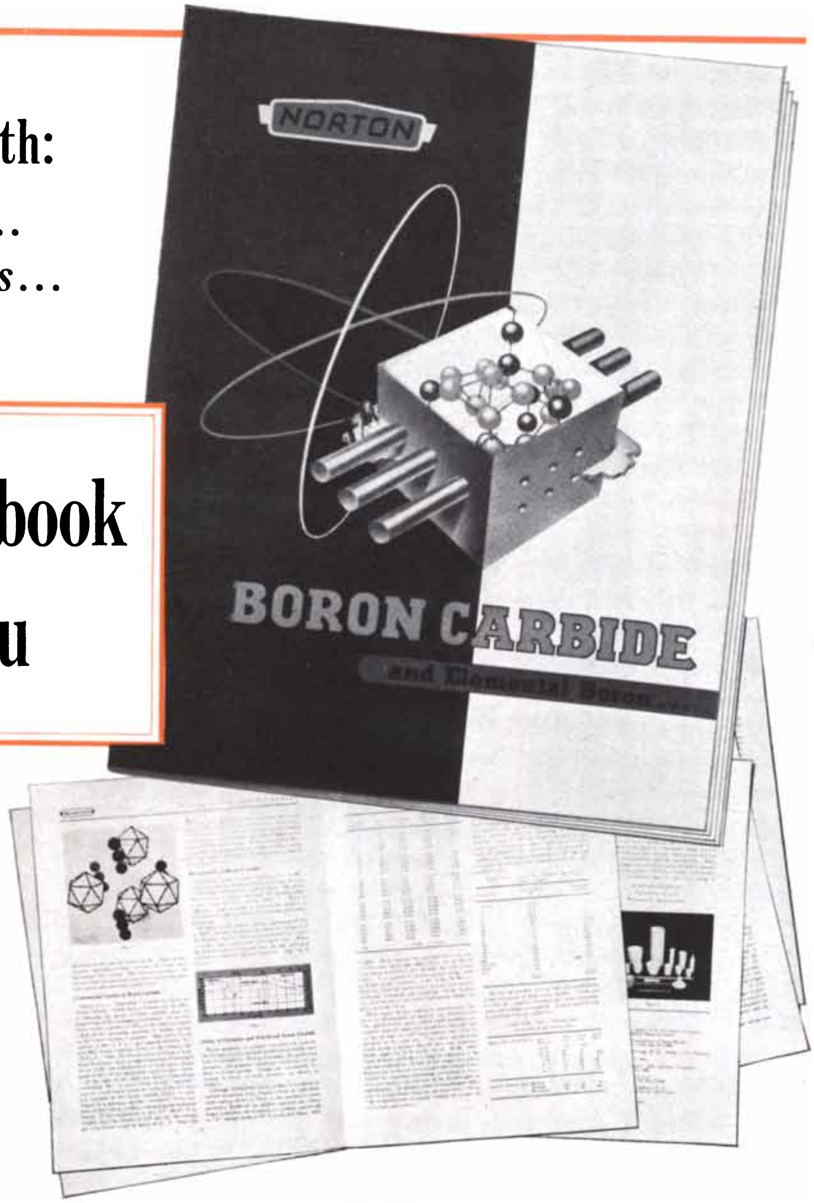

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*Trade-Marks Reg. U. S. Pat. Off. and Foreign Countries even at that time, was writing prolifically and seemingly without any difficulty whatever. James and I shared rooms during our last year in Cambridge, and his example led me to the quite erroneous belief that writing was dead easy. At about the same time I was much intrigued by a semipopular article by Julian Huxley describing the sex chromosome mechanism of sex determination. I spent the next vacation in the library and as a result published my first original paper at the age of 20 years. After this exhibition of an urge to do research, my father, a banker, sent me to Manchester University to do postgraduate work for a Ph.D. degree. I then worked at University College, London, for rather more than eight years, first on the sex ratio in mammals, later on the physiology and endocrinology of reproduction. At the beginning of 1932 I took up a permanent appointment at the National Institute for Medical Research, and have continued as a member of the staff."

FRANCIS OWEN RICE ("The Chemistry of Jupiter") is head of the chemistry department at the Catholic University of America in Washington, D. C. He was born in Liverpool in 1890; he received a degree of Doctor of Science from the University of Liverpool in 1916 and worked in British government chemical plants until the close of World War I. He came to the U. S. in 1919 on a fellowship to Princeton University. After teaching chemistry at New York University and at the Johns Hopkins University he went to the Catholic University in 1938. Rice's work lies mainly in the borderland between physical and organic chemistry, where he has been tracking down the free radicals formed in the intermediate stages of many organic reactions. In 1949 he collaborated with the nuclear physicist Edward Teller on a book entitled *The Structure of Matter.*

MURRAY KAMRASS ("Pneumatic Buildings") is a research engineer at Cornell Aeronautical Laboratory, Inc., in Buffalo, N. Y. He graduated from the University of Michigan in 1942, then spent two years with the Stinson Division of Consolidated Vultee Aircraft Corporation and two years in the Army. Kamrass joined the Cornell Aeronautical Laboratory (which is affiliated with Cornell University) in 1946, and has served in its aerodynamics and industrial divisions. He was project engineer for studies which included not only air-inflated structures but also aircraft and industrial noise and safety.

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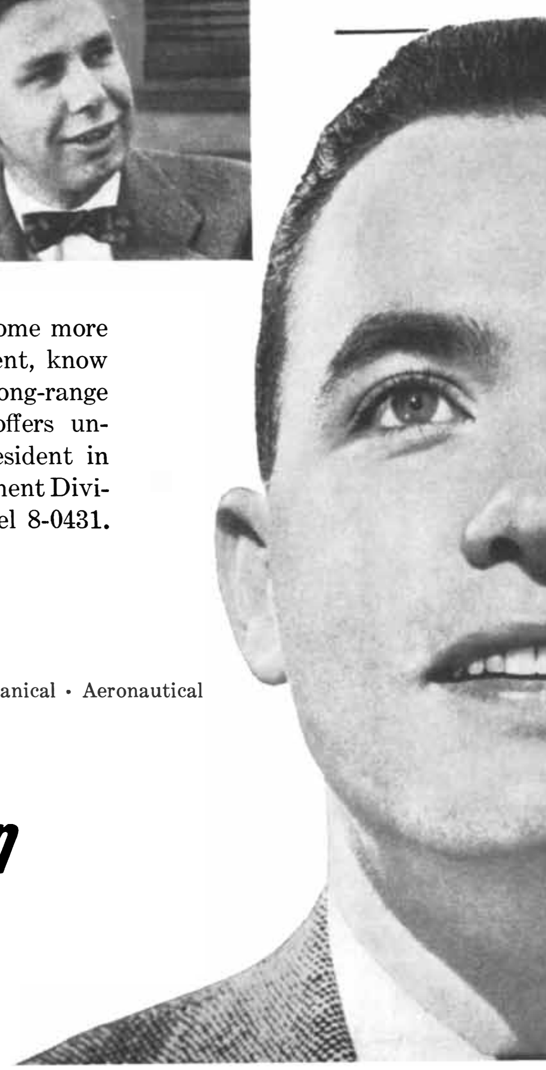

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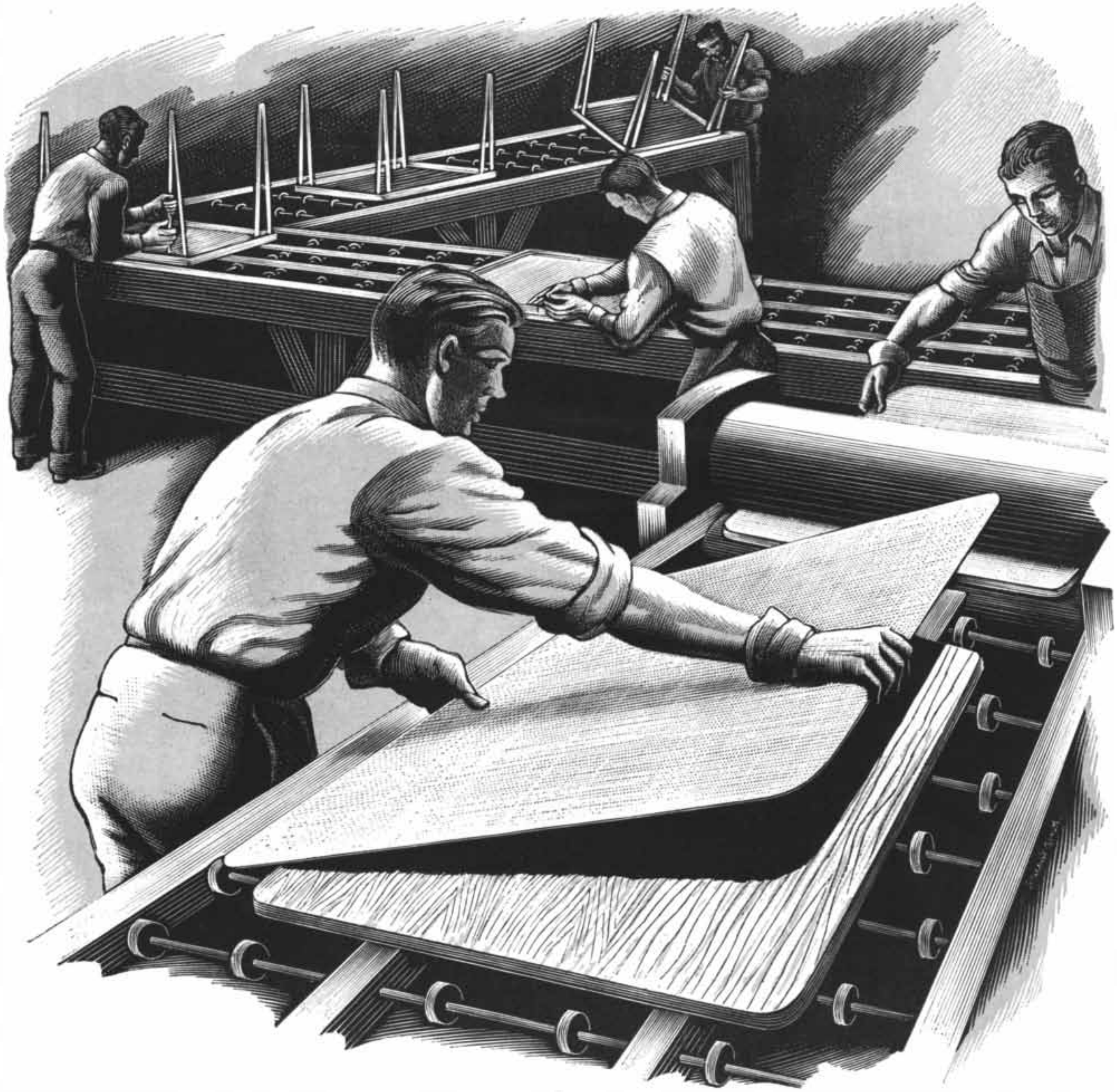

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The Antiproton

A quarter-century ago physical theory pointed to the existence of a fundamental particle of matter with the mass of the proton but the opposite charge. An account of its discovery last year

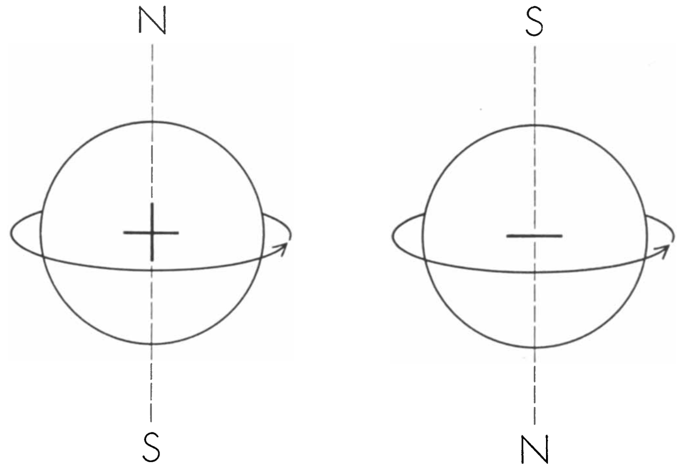
by Emilio Segrè and Clyde E. Wiegand

In the past 10 years physicists have discovered many "elementary" particles (though we must frankly admit that we do not really know how to define an "elementary particle"). Not all of these discoveries have come unheralded. One might suppose that the only way to discover a particle should be by experiment, but this is not so, although of course experiment is the judge of last resort. Sometimes theoretical physicists, from hypothetical equations and calculations with pencil and paper, have predicted the existence of particles that had never been seen. These predictions, however strange some of them may seem, arise from a necessity to preserve basic principles which form the foundation of our present understanding of the physical universe. When necessary, physicists have been willing to entertain the existence of something never seen rather than to imperil these firmly established foundations. This article is the story of how such a prediction was verified.

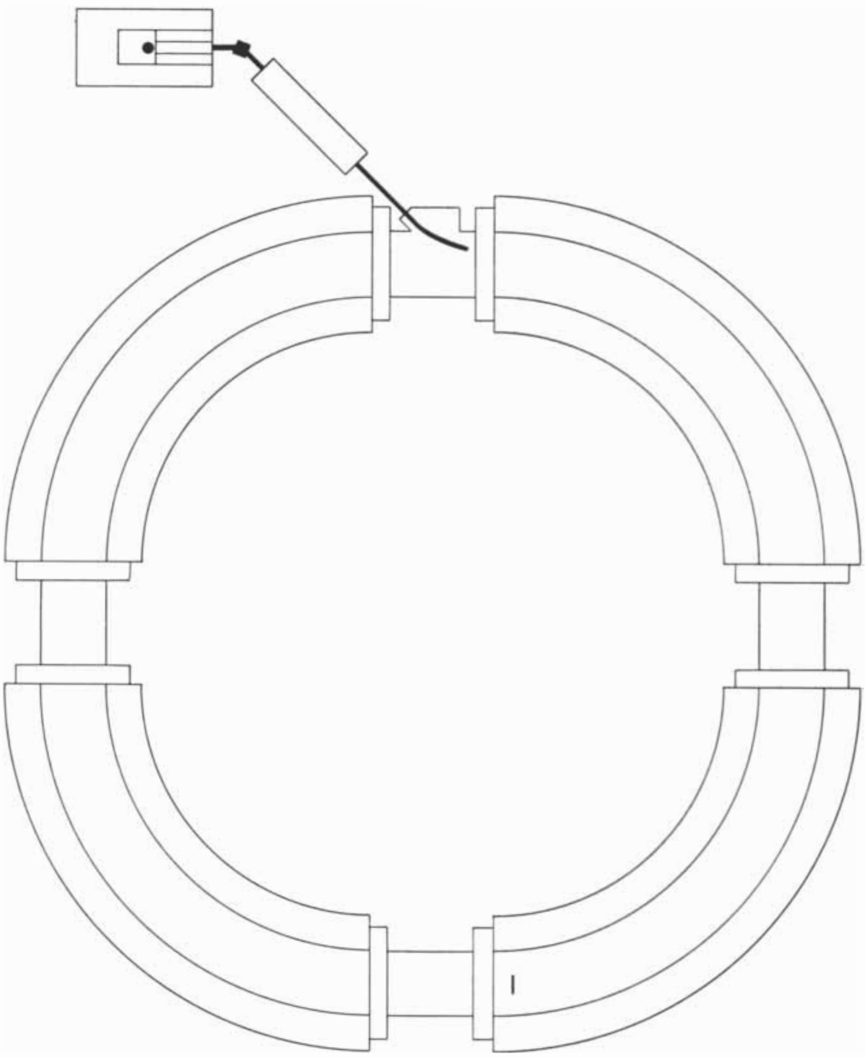
A quarter of a century ago P. A. M. Dirac of the University of Cambridge developed an equation, based on the most general principles of relativity and quantum mechanics, which described in a quantitative way various properties of the electron. He had to put in only the charge and mass of the electron—and then its spin, its associated magnetic moment and its behavior in the hydrogen atom followed with mathematical necessity. The fact that all this could be obtained automatically from one equation without *ad hoc* assumptions for each property was such a spectacular success that great faith was put in Dirac's equation and the theory on which it was based. Its discoverer found, however, that the equation required the existence of both positive and negative electrons: that is, it described not only the known negative electron but also an exactly symmetrical particle which was identical with the electron in every way except that its charge was positive instead of negative. It proved impossible to prevent Dirac's theory from giving both types of solutions. This meant that either Dirac's theory was wrong or there must be a positive electron which no physicist had ever detected or even suspected up to that time.

A few years after Dirac's prediction, Carl D. Anderson of the California Institute of Technology found positive electrons (positrons) among the particles produced by cosmic rays in a cloud chamber. This discovery not only was a triumph for Dirac's theory but also set physicists off on a new and more formidable search for another hypothetical particle—a search which was to take some 25 years and which was finally rewarded only a few months ago.

Dirac's general equation, slightly modified, should be applicable to the proton as well as to the electron. In this instance too it predicts the existence of an anti-particle—an antiproton identical to the proton but with a negative instead of a positive charge. The unknown particle's symmetry to the proton clearly



PROTON (*left*) may be regarded as a spinning sphere weighing 1.6724 x 10^{-24} grams. It has positive electric charge and, as a consequence of its rotation, north and south magnetic poles. The antiproton (*right*) has the same spin and mass. It has the same amount of electric charge, but of the opposite sign. Its north and south magnetic poles are similarly reversed.



BEVATRON at the University of California produced antiprotons by accelerating protons to 6.2 billion electron volts. This schematic plan view shows the four magnet-enclosed segments in which the protons are accelerated. The radius of each segment is 50 feet. The protons are injected into the machine by two accelerators at the top. The copper target in which the antiprotons are produced is represented by the heavy vertical line at the bottom right.

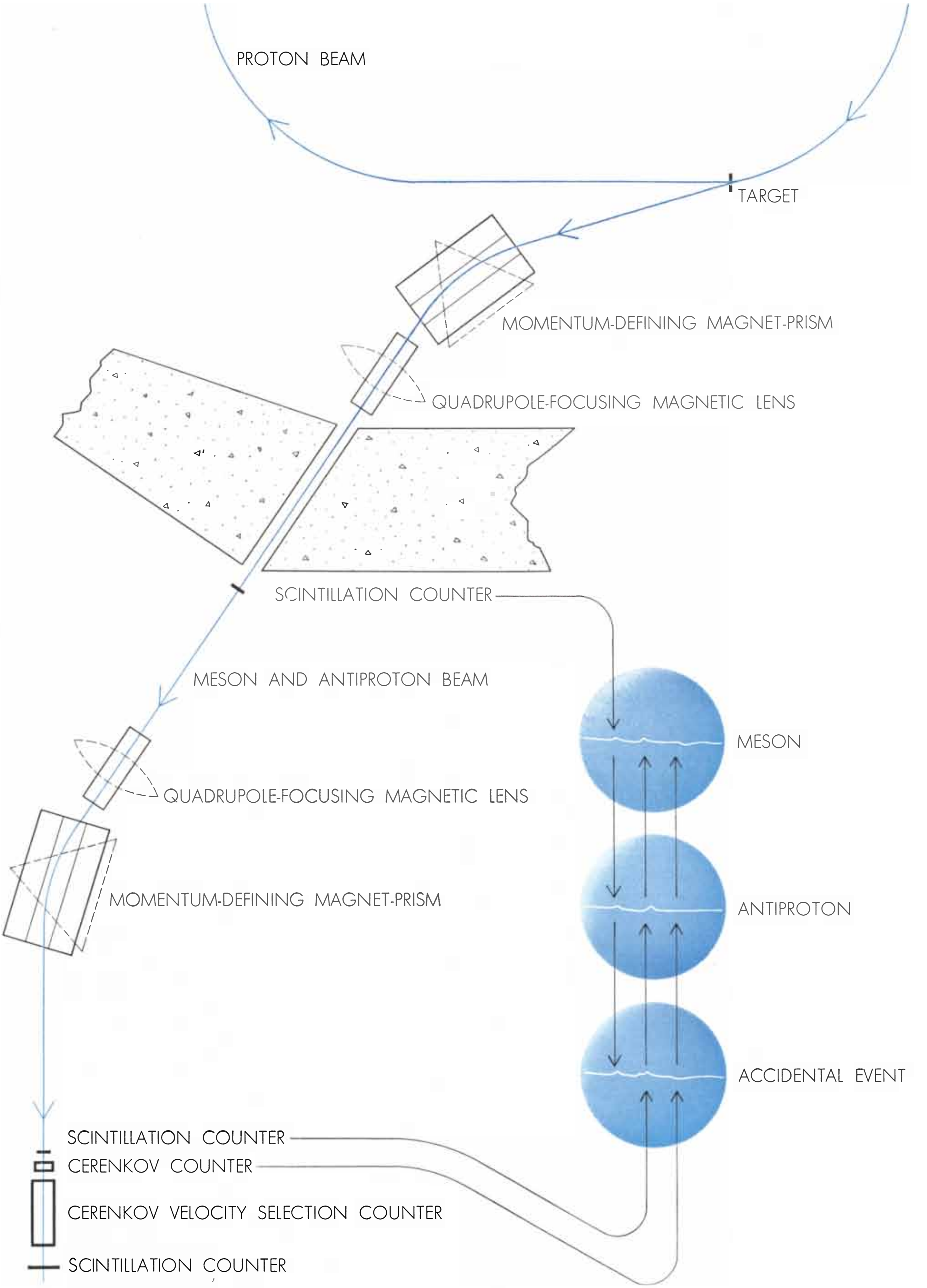
defines some of its properties. A particle in order to have the right to be called an antiproton: (1) must have the same mass as a proton (1.6724×10^{-24} grams); (2) must have an equal charge of opposite sign (4.8028×10^{-10} electrostatic units); (3) must be stable, in the sense that it will not decay spontaneously into a different particle and will last forever in a vacuum; (4) must disappear in a mutual annihilation when it encounters a proton or a neutron, liberating energy equivalent to the mass of the two particles; (5) is never generated separately but only in a pair with a proton or neutron; and (6) must have an angular momentum (spin) equal to that of the proton. Like the proton, an antiproton must also have a magnetic moment (*i.e.*, behave like a little magnet), and when it spins in the same direction as a proton its magnetic moment is equal in magnitude but of opposite sign to that of the proton; that is, the "north and south" poles are reversed.

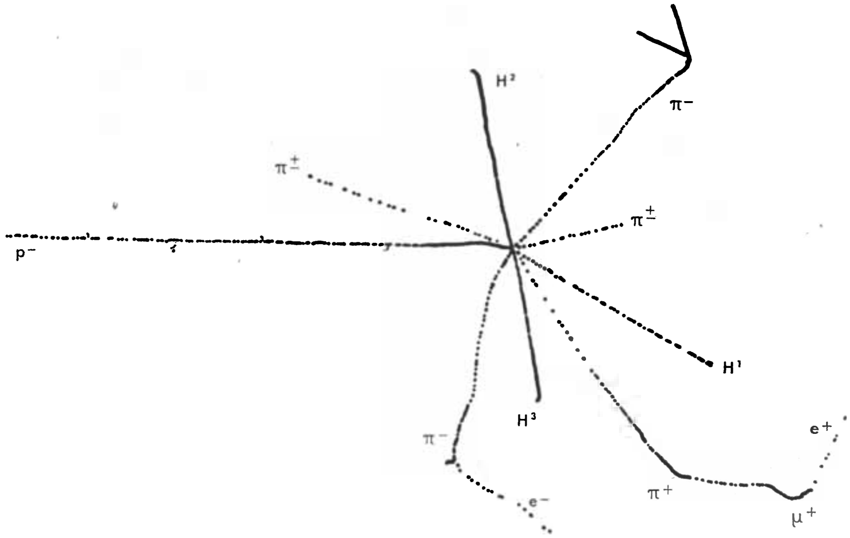
With all these clues, physicists naturally began an intensive search for the antiproton. Since it was apparent that creation of the particle required tremendous energy, the most likely place to look for it was in cosmic rays. On a few occasions investigators found events which seemed to signal the generation of an antiproton, but there was never sufficient information to identify it with certainty. The question then arose as to how much energy would be needed to create antiprotons in the laboratory with an accelerator.

Because an antiproton can be created only in a pair with a proton, we need at least the energy equivalent to the mass of two protons. Albert Einstein's theorem, $E=mc^2$, tells us that this amounts to 2×938, or 1,876 million electron volts (*i.e.*, about two billion electron volts). However, we need much more than two Bev in the proposed laboratory experiment. To convert energy into particles we must concentrate the energy at a point; this is best accomplished by hurling a high-energy particle at a target—*e.g.*, a proton against a proton. After the collision we shall have four particles: the two original protons plus the newly created proton-antiproton pair. Each of the four will emerge from the collision with a kinetic energy amounting to about one Bev. Thus the generation of an antiproton by this method takes two Bev (creation of the proton-antiproton pair) plus four Bev (the kinetic energy of the four emerging particles). It was with these numbers in mind that the Bevatron at the University of California was designed. It was built to accelerate protons to a kinetic energy of more than six Bev, with the hope of producing antiprotons.

When the Bevatron began to bombard a target made of copper with six-Bev protons, the next problem was to detect and identify any antiprotons created. A plan for the search was devised by Owen Chamberlain, Thomas Ypsilantis and the authors of this article. The plan was based on three properties which could conveniently be determined. First, the stability of the particle meant that it should live long enough to pass through a long apparatus. Second, its negative charge could be identified by the direction of deflection of the particle by an applied magnetic field, and the magnitude of its charge could be gauged by the amount of ionization it produced along its path. Third, its mass could be calculated from the curve of its

EXPERIMENTAL SETUP which demonstrated the existence of the antiproton is depicted on opposite page. The colored line at the top is the orbit of the protons in the Bevatron. The path of the antiprotons and other particles produced in the target is traced by the colored line from upper right to lower left. From the target to the last scintillation counter the particles travel 80 feet. At the lower right the various events of the experiment are represented by their characteristic cathode ray traces. Above the center of the diagram is the concrete shield of the Bevatron. The prisms and lenses superimposed with broken lines on the four magnets symbolize their function. The experiment is described in detail by the text of this article.


PROTON BEAM
TARGET
MOMENTUM-DEFINING MAGNET-PRISM
QUADRUPOLE-FOCUSING MAGNETIC LENS
SCINTILLATION COUNTER
MESON AND ANTIPROTON BEAM
MESON
QUADRUPOLE-FOCUSING MAGNETIC LENS
ANTIPROTON
MOMENTUM-DEFINING MAGNET-PRISM
ACCIDENTAL EVENT
SCINTILLATION COUNTER
CERENKOV COUNTER
CERENKOV VELOCITY SELECTION COUNTER
SCINTILLATION COUNTER



NUCLEAR EMULSION PHOTOGRAPH reproduced by tracing shows the death of an antiproton (p^-) in a "star" of pi mesons (π) and hydrogen nuclei (H). One of the pi mesons has decayed into an electron (e); another into a mu meson (μ) and an electron.

trajectory in a given magnetic field if its velocity was known.

The trajectory of a charged particle in a magnetic field depends on its momentum: once the trajectory is known, the momentum can be calculated. Now if we also measure the velocity of the particle (say by timing its travel between two given points in the apparatus), we can compute the mass from the momentum and velocity, using the relativistic equation which connects momentum, rest mass and velocity.

All this sounds very simple, but the main difficulty in the experiment arises from a complication which we have thus far neglected to mention. When the beam of 6.2-Bev protons hits the target, it generates a great many other particles which have the same momentum as the antiprotons. Most of them are mesons, the particles supposed to represent the cement that holds the nucleons together in the nucleus. It turned out that there were about 40,000 mesons for each rare antiproton in the stream of emerging particles focused by our magnets. The mesons follow exactly the same trajectory as the antiprotons, but they are lighter and travel with a velocity practically identical to that of light, whereas the heavier antiproton moves with 78 per cent of the velocity of light. The problem was to pick out of the stream the occasional heavy particle (one in 40,000) moving with the right velocity to be an antiproton.

An extensive array of bending magnets, magnetic focusing lenses and detectors was set up to comb out the antiprotons [*see diagram on page 39*]. From the spray of charged particles emerging from the copper target a bending magnet first sorted out the negatively charged particles of the desired momentum, bending them in a particular trajectory. This stream was then focused by a magnetic lens. The focused beam now encountered a detector—a disk of plastic material which scintillates when charged particles pass through. The main purpose of the detector was to serve as a "stop watch" for timing the passage of particles so as to measure their velocity: precisely 40 feet farther on they hit a second scintillating detector, and the velocity was reckoned from the time taken to travel the distance between the two "stop watches." The flashes of light from each scintillator were translated by photosensitive tubes into pulses of electric current, and these pulses were recorded as pips on a cathode ray screen. This timing system could measure differences of one billionth of a second in the travel time of particles over the 40-foot interval. In our experiment the antiprotons cross the 40-foot distance in 51 billionths of a second, whereas the mesons take only 40 billionths of a second.

However, we found that we needed an independent measurement of the particles' velocities as a check against accidental coincidences. So many mesons were streaming through our "speed trap" that sometimes one meson triggered the first stop watch and another triggered the second after an interval that corresponded to the travel time of an antiproton. We therefore placed a velocity-selecting counter just beyond the second scintillator. This unique selector makes use of the Cerenkov effect, discovered many years ago by the Russian physicist Pavel Cerenkov. He found that when a charged particle passes through a medium such as glass or quartz with a velocity greater than the velocity of light in that medium, it emits light—an effect analogous to the shock waves produced in air by a jet aircraft exceeding the speed of sound. Now the angle at which the Cerenkov light radiation is emitted, with respect to the path of the particle, depends upon the velocity of the particle. An analogy is the wake of a boat: the faster the boat travels, the narrower is the angle of its wake. Taking advantage of this fact, we put a piece of quartz in the path of the beam and arranged a system of mirrors and light shields so that Cerenkov radiation was recorded only from particles traveling at 75 to 78 per cent of the velocity of light—the speed of the antiproton. We took two other precautions against spurious identification. To make sure of weeding out mesons and other unwanted particles we placed in front of the velocity selector a "guard" detector of the Cerenkov type which gave a warning signal of the arrival of any particle exceeding 78 per cent of the velocity of light, and to exclude particles that might come from outside the system we used a final scintillation counter which recorded only particles traveling in the direction of the beam.

Thus a particle would be identified as an antiproton only when all the following conditions were fulfilled: the "stop watch" counters indicated that a particle had passed through with the correct velocity (crossing the 40 feet in 51 billionths of a second); the guard counter gave no warning signal; the velocity selector registered a particle with velocity between 75 and 78 per cent of the velocity of light; and the final scintillation counter showed that the particle had coursed through the length of the selector. When all these things happened, a characteristic sweep was traced on the oscilloscope [*see page 39*]. Many more tests were made to confirm that this type of sweep really meant that an antiproton had passed through the system.

When the discovery of the antiproton was announced last October, 60 of them had been recorded, at an average rate of about four to each hour of operation of the Bevatron. They had passed all the tests which we had preordained before the start of the experiment. We were quite gratified by the comment of a highly esteemed colleague who was visiting from another university where he had just finished an important and difficult experiment on mesons. After examining our tests, he said, "I wish that my own experiments on mu mesons were as convincing as this." At this time several long-standing bets on the existence of the antiproton started to be paid. The largest we know of was for $500. (We were not personally involved.)

It was still highly desirable to have some information on the process of annihilation of the antiproton when it encountered a proton. The first experiment along this line was performed by a group consisting of J. Brabant, B. Cork, N. Horowitz, B. Moyer, J. Murray, R. Wallace and W. Wenzel. They arranged to trap an antiproton from our apparatus in a piece of glass. On being stopped, the antiproton, and the proton which presumably was annihilated with it, emitted charged particles which moved fast enough to release considerable light by Cerenkov radiation. A study of this light confirmed that the particle selected as an antiproton was definitely not a meson.

While all this was going on, another experiment for detection of the antiproton was started by the authors, Chamberlain, W. Chupp and G. Goldhaber, in collaboration with a team of physicists in Italy: E. Amaldi (a former fellow student with Segrè of the late Enrico Fermi), G. Baroni, C. Castagnoli, C. Franzinetti and A. Manfredini. It was decided to try to find the tracks of antiprotons in photographic emulsions. If we could detect them there, we could get direct information about the antiproton's destruction.

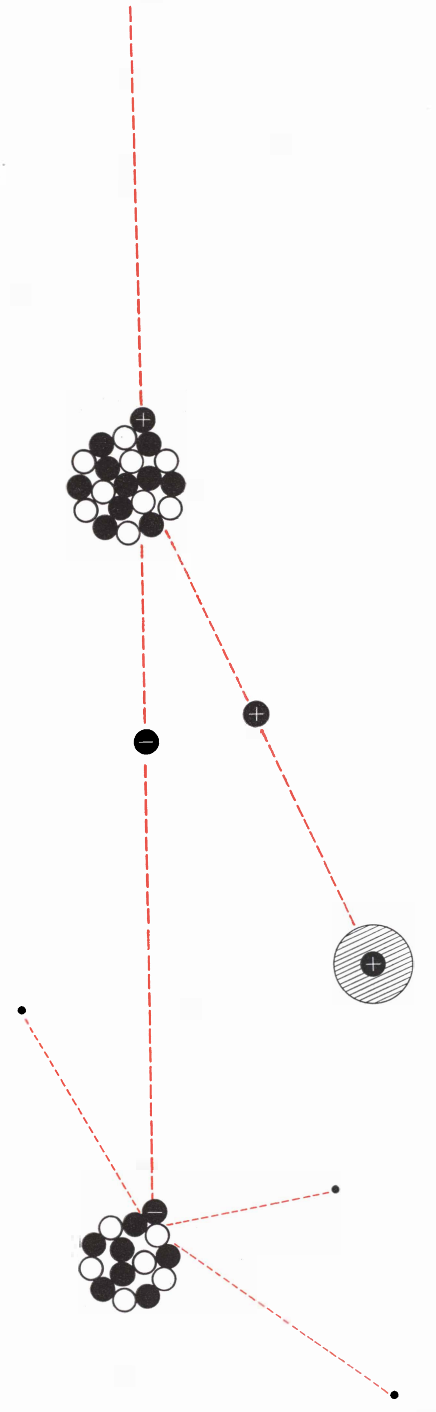
We exposed photographic plates in a beam which should yield antiprotons and then sent some of the plates to Rome and examined some ourselves in Berkeley. In spite of strenuous efforts by both groups, only one star that might represent a proton-antiproton annihilation was found—by the scanners in Rome. Later experiments by our group (including D. Keller and H. Steiner) indicated that absorbers which we had used to slow down the antiprotons before they entered the photographic plates had unexpectedly destroyed many of the antiprotons. The absorbers were then removed and new plates were exposed, with the result that tracks of about 20 antiprotons have now been detected in emulsions by observers in Berkeley.

A star of annihilation is pictured at the top of the opposite page. The track of the incoming antiproton has the range predicted for it. The particle lost its kinetic energy by collisions and ionization and came to rest in the emulsion. It was then captured by a nucleus in the emulsion and promptly annihilated itself with another nucleon. Many of the charged fragments into which it broke down can be identified by their tracks; others cannot be named with certainty; still others were neutral particles which made no tracks in the plate. At all events, we know for certain that the total energy released in the annihilation was greater than the mass equivalent of the antiproton—proof that another nucleon was annihilated along with it.

As usual with all discoveries, the advent of the antiproton has launched a host of new questions, on which work is progressing. For the time being only Berkeley has an accelerator powerful enough to produce antiprotons. The next to enter the picture, according to reports at the Geneva conference of last summer, should be a U.S.S.R. machine, now in an advanced stage of construction.

An interesting subject for contemplation is the possible existence of an "anti-world." This would be a world in which all particles are opposite in charge to our own: the hydrogen atom, for instance, would have an antiproton as its nucleus and a positron in place of the electron. We know of no method by which we could recognize the existence of such a universe by astronomical observation. But if antimatter exists and if it should come into contact somewhere with ordinary matter as we know it, the two forms of matter would annihilate each other with a huge release of energy, mostly as mesons. Whether we would see this event would depend on the density of the matter colliding. If it were spread out as thinly as the average density of matter in the galaxies, the effect might not be very conspicuous. It is also possible that a collision even between concentrated masses of matter and antimatter would not be very spectacular astronomically, for they probably would repel each other, by radiation pressure, as soon as they came into contact.

If the universe originated from the transformation of pure energy into nucleons and electrons, we must suppose, in order to preserve the principle of the constancy of the number of these particles, that somewhere there are antinucleons and antielectrons equal in number to those of our world. It is a speculation which gives a highly satisfying symmetry to creation.



LIFE CYCLE of an antiproton is schematically depicted. A high-energy proton (*black ball with plus sign at the top*) collides with another proton in the target nucleus. This gives rise to a new proton (*black ball with plus sign at right center*) and an antiproton (*black ball with minus sign*). The new proton travels until it comes to rest as the nucleus of a hydrogen atom (*right*). The antiproton continues until it encounters another nucleus (*bottom*). The antiproton and a proton or a neutron are then both annihilated in a shower of various particles.

REBUILDING A VIRUS

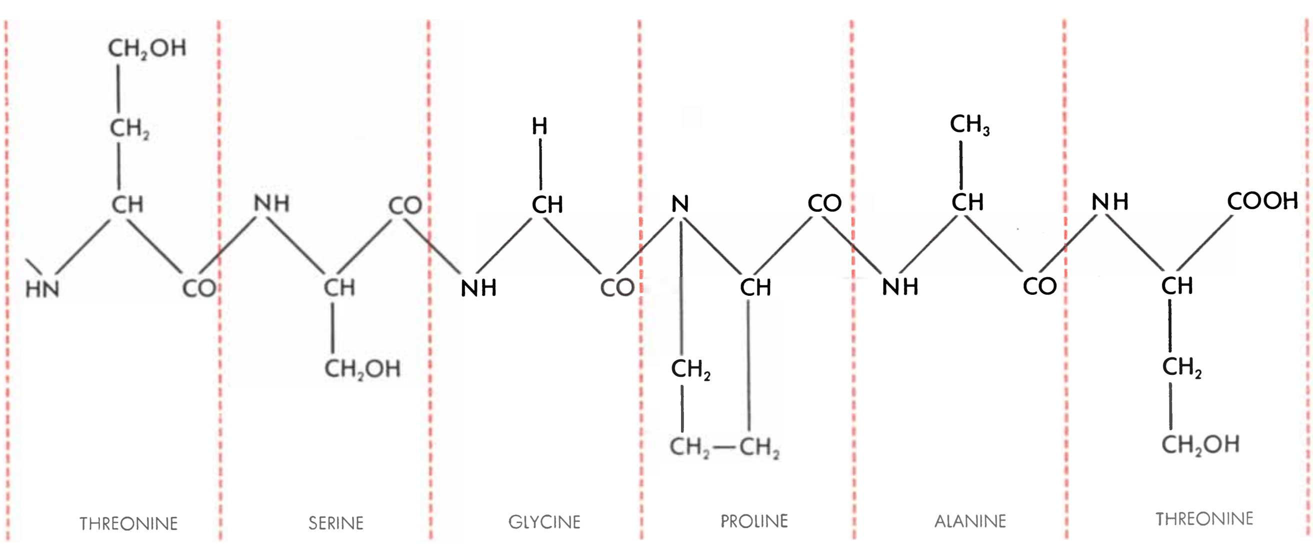
The tobacco mosaic virus is composed of protein and nucleic acid, which may be separated by gentle chemical treatment. When the two components are mixed together, they form infective virus particles

by Heinz Fraenkel-Conrat

A few months ago a flurry of excitement was caused by newspaper stories about "creation of life in the test tube" at the University of California Virus Laboratory. Actually what the Laboratory had reported was something at once more specific and less romantic. Let us be clear about the scope of this work. It was found that after the tobacco mosaic virus had been split into its two components—protein and nucleic acid—these components could, under suitable conditions, recombine to form particles which looked like the original virus and displayed its properties: that is, the ability to infect and multiply in tobacco plant cells. The aim of these studies is not "creation of life" but an attempt to analyze the organization of biologically active structures in terms of chemistry. What we learn about viruses specifically helps in the fight against virus diseases. And the information we can gain about the chemistry of these organizations, which occupy the no-man's-land between the so-called living and nonliving worlds, should improve our understanding of the line of evolution from mere molecules to living organisms.

Ever since Wendell M. Stanley, now the director of our laboratory, first isolated the tobacco mosaic virus in crystalline form at the Rockefeller Institute for Medical Research in 1935, this virus has been a main focus of attention in general virology. Its biological activity has been investigated extensively; it has been examined exhaustively under the electron microscope, and it has been analyzed chemically. The investigations, including recent studies by workers in our laboratory, give the following picture. The tobacco mosaic virus (known to its investigators as TMV) is a rod-shaped particle 300 millimicrons long (about one 100,000th of an inch). It consists of two parts: a thick-walled cylinder of protein and a rodlike core of nucleic acid inside the cylinder. The protein accounts for about 94 per cent of the virus's substance and the nucleic acid for the remaining 6 per cent. Its nucleic acid is the type known as RNA (ribonucleic acid). X-ray and chemical studies suggest that the inner rod of nucleic acid is not solid but a hollow, tube-like structure composed of intertwisted strands.

The protein of the virus can be broken down by moderate chemical treatment into subunits, each of which is a single peptide chain containing about 150



PROTEIN MOLECULE of the tobacco mosaic virus appears to consist of five or six single-chain units. One end of each chain forms a loop; the other end has been chemically analyzed into the structure diagrammed here. The chain is composed of subunits which form amino acids when it is taken apart. The names of the amino acids corresponding to the last six subunits are given at the bottom.

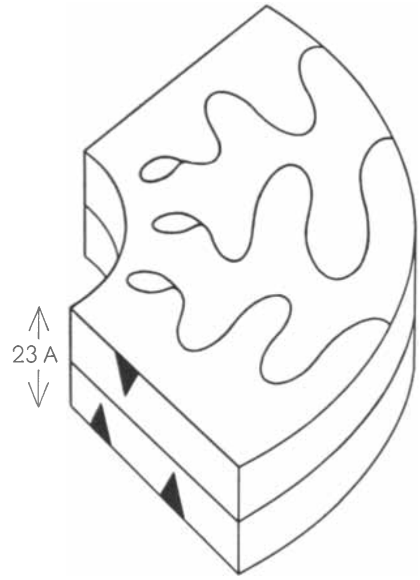
amino acids. The subunit is being analyzed and parts of its structure have been worked out [*see illustration on the opposite page*]. In this form the protein is "denatured": it has lost its stable, orderly architecture, is insoluble and is incapable of recombining into the original protein complex.

With gentler chemical treatment the protein of the virus can be separated from the nucleic acid in its "native" state. It then appears to be composed of five or six of the single-chain units, bonded together in a stable configuration. The native TMV protein is soluble in water and possesses a remarkable tendency to form a large aggregation of molecules. The character of this build-up is highly unusual. By virtue of special sites of "auto-affinity" on the sides, the protein molecules join together side by side. They must form structures like sectors of a pie, which then unite and pile up in a spiraling manner [*see illustrations on this and the following page*]. Eventually they build up a supermolecule of a characteristic shape—the shape of a rod.

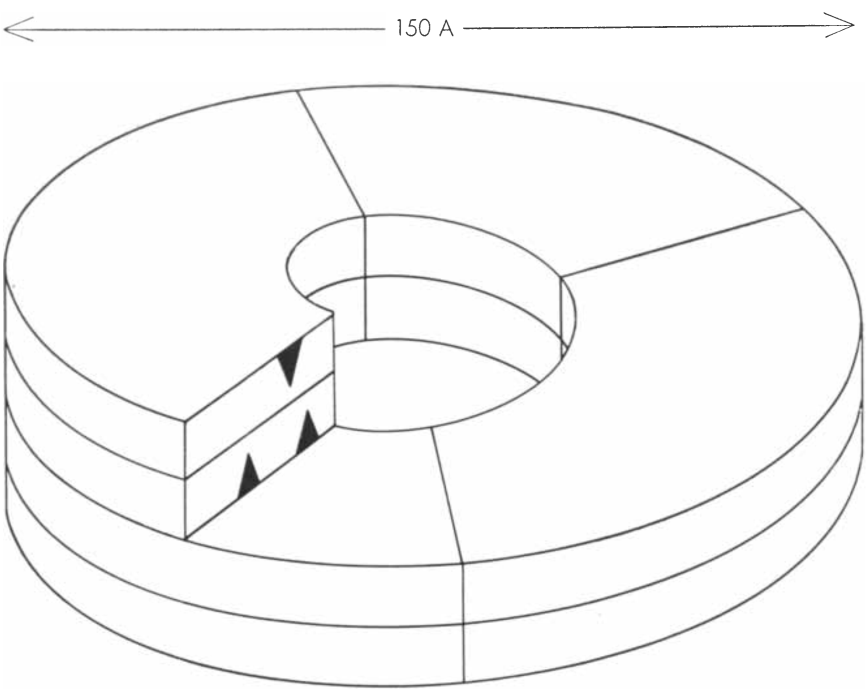
Robley C. Williams of our laboratory has photographed stages of this process under the electron microscope. In a slightly acid solution (a pH of about 6) the protein forms little disks with a hole in the center, like faucet washers, all of the same diameter. Now if the solution is made a little more acid (about pH 5), rods begin to appear, evidently built by further spiraling growth of the washers. The rods grow to various lengths, and some of them are indistinguishable in appearance from the virus itself.

The protein rod alone does not behave like a virus—it is completely noninfectious. But if the protein is mixed in a slightly acid solution (between pH 6 and 7) with freshly prepared nucleic acid, the two will combine into particles which give every indication of being viruses. They are rods of the same diameter and length as the original virus [*see illustration at top of page 46*]. Roger Hart of this laboratory has clearly demonstrated that the reconstituted rods also have the virus structure: a protein cylinder enclosing a thin inner rod of nucleic acid. And they produce the tobacco mosaic disease when applied to the leaves of plants.

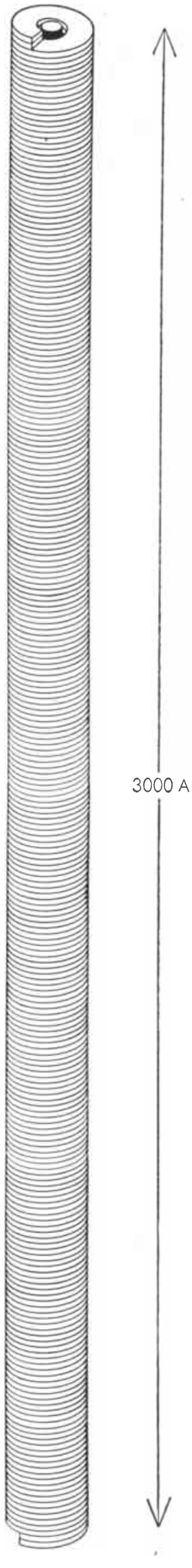
When these experiments were first performed, there was great skepticism, both on the part of the author and of his associates, that the plant lesions were actually caused by viruses newly formed in the reaction mixture. There were, to be sure, several good reasons for believing that this was the case. First, the material was infectious only when recombined virus-like particles appeared in the mixture. Second, no activity developed unless a substantial concentration of the components (about 1 per cent of protein and .1 per cent of nucleic acid) was allowed to interact at a favorable pH for a definite time. Third, if the nucleic acid preparation was not fresh or if it was treated with a destructive enzyme (ribonuclease) before being introduced into the mixture, the material failed to become infectious. Yet there still remained the possibility that the so-



LOOPED CHAINS of tobacco mosaic virus protein may be arranged in two layers, making a molecule 23 Angstrom units thick. On one side of this schematic structure are three black triangles symbolizing sites that have an affinity for complementary sites on another molecule.



THINNEST DISK of tobacco mosaic virus protein revealed by electron micrographs appears to be made up of molecules joined in a helix by the complementary sites on their flat sides. The disk is 150 Angstrom units across. The hole has a diameter of about 50 Angstrom units.



lutions were contaminated with active viruses which had escaped being broken down into the two components in the first place. Perhaps such lurking viruses, though they showed no activity in the degraded batch, in some way became more aggressive when the reaction mixture was "incubated."

Viruses, of course, cannot multiply except in a living cell. One way to examine the question as to how far residual undegraded virus might be responsible for the infectivity of the mixture is to determine exactly how much active virus has survived. Such analyses indicate that the separated protein contains no more than one part in a million of undegraded virus, and the nucleic acid probably less than 30 parts per million. Whether this amount of contamination can be shrugged off as insignificant depends critically on the next question: Could it account for the amount of infectious activity developed by the mixture? The answer is that the infectivity is sometimes as much as 100,000 times as great as could be produced by the amount of undegraded virus that may be present. It seems inescapable that new pathogenic virus actually is formed by recombination of the separated components.

Recently this conclusion has been confirmed by biological evidence which seems to amount to absolute proof. It was furnished by experiments in combining components from different strains of the tobacco mosaic virus.

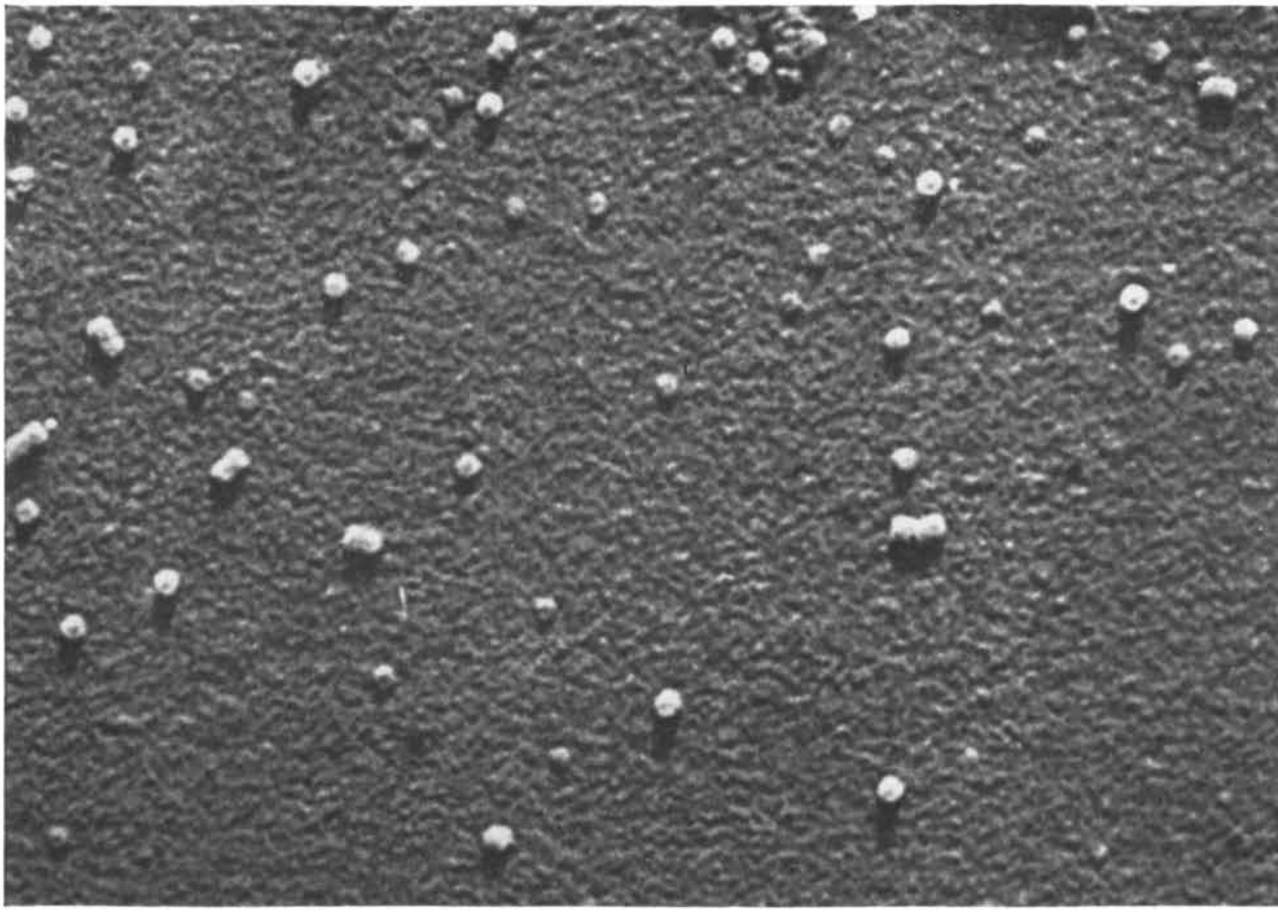
One of the crucial properties of living matter is the ability to mutate. When viruses multiply in host cells, they show this property: virus mutants emerge which can attack other hosts or produce disease symptoms different from the original. Many mutants of the tobacco mosaic virus are known. Some are closely related to the common strain; others are so different that they must be the product of a series of mutations. All known mutants of the tobacco mosaic virus appear to be of the same shape and size, but differences in their chemical composition have been established. These distinguishable variations lie in their protein. Some mutants contain slightly more or less of one or two amino acids than the common TMV strain. Others differ from it markedly. One strain, called HR, has different proportions of almost all the amino acids and in addition contains two amino acids absent from common TMV [see "The Mutation of Viruses," by C. A. Knight and Dean Fraser; SCIENTIFIC AMERICAN, July, 1955]. As for nucleic acid, the mutants must differ in this component too, but these differences have not so far been detected by chemical analysis.

Now it was found possible to separate the protein and nucleic acid components of different strains and to cross-combine them, forming active "hybrid" viruses. In each case the "hybrid" produced in test plants the disease symptoms characteristic of the parent virus that had supplied the nucleic acid. Regardless of their differences in protein, the hybrid virus preparations appeared to cause the same disease so long as they contained the same nucleic acid. This clearly demonstrated what researchers had long suspected: The nucleic acid is the main carrier of genetic information from parent to offspring. A great number of beautiful studies from several laboratories had indicated that desoxyribonucleic acid (DNA) plays this role in bacterial viruses; the experiments with tobacco mosaic virus showed directly for the first time that RNA also can serve as the main carrier of genetic information.

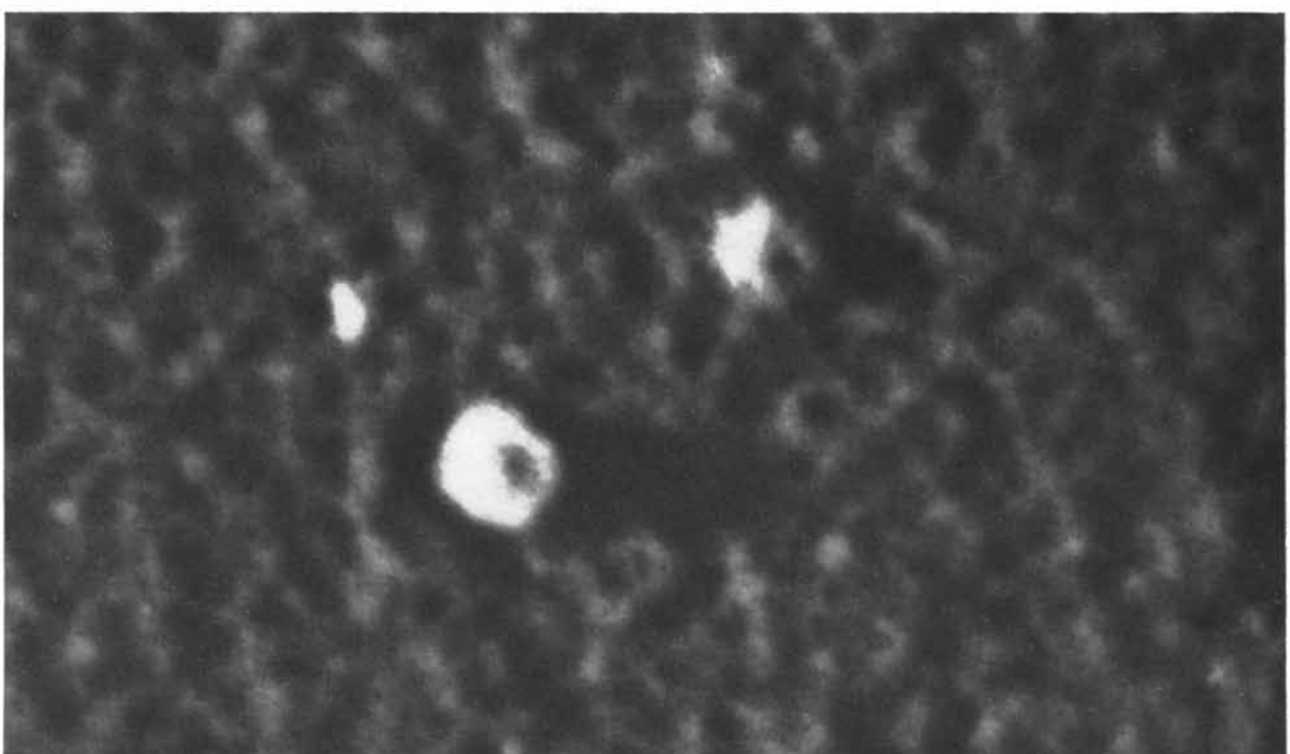
An extension of these experiments provided most convincing evidence that the recombination of protein and nucleic acid actually generated active virus particles. This new test was immunological. When an animal receives an injection of a foreign protein, it generally produces specific antibodies against that substance. Thus injection of tobacco mosaic virus into a rabbit will cause the rabbit to generate antibodies which specifically neutralize the virus's protein. If, for example, we inject the common strain of the virus, the antibodies formed are specific for that protein; if we inject the HR strain, the resulting antibodies are different—they attack the HR protein but are much less potent against common TMV.

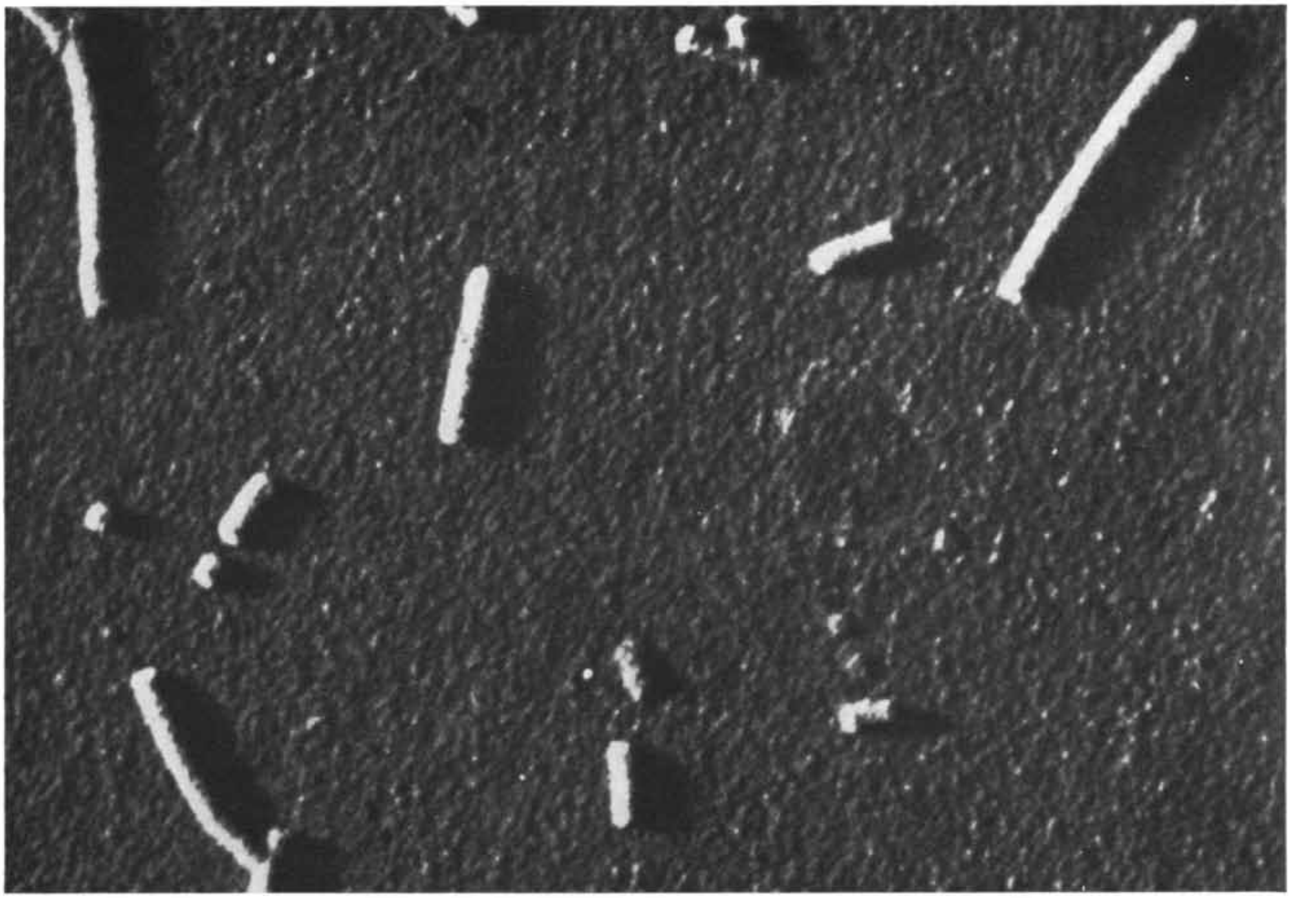
Suppose then, that we take some HR virus, separate its protein and nucleic acid components and then mix the HR nucleic acid with common TMV protein. The mixture will produce hybrid particles with an HR nucleic acid core and a TMV protein coat. Now we add antibody against the HR virus and apply the material to a tobacco plant. If this preparation succeeds in infecting the plant

ENTIRE PARTICLE of tobacco mosaic virus is a helix of protein with a strand of nucleic acid running down the middle. There are 130 turns of two-layered protein in the helix. Its length is some 3000 Angstrom units, or roughly one 100,000th of an inch.

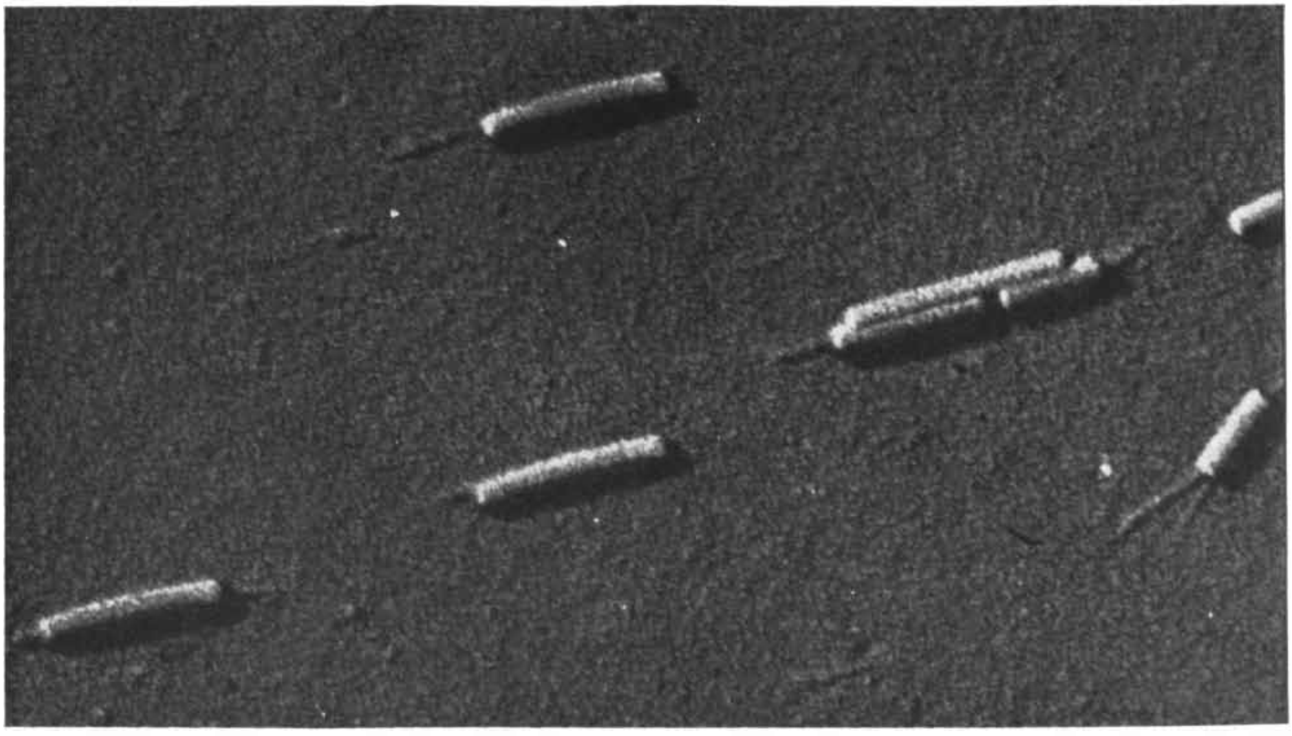


ELECTRON MICROGRAPHS made by Robley C. Williams of the University of California show disks of protein that are found in a solution of tobacco mosaic viruses which have been broken down by chemical treatment. The reproduction above enlarges the disks 130,000 diameters; the reproduction below enlarges two of the disks 650,000 diameters. Each disk has a hole in the middle.





RECONSTITUTED VIRUS PARTICLES are enlarged 150,000 diameters in this electron micrograph made by Williams. Their protein and nucleic acid had been separated, and then allowed to recombine. The longer structures are typical of the original particles.



DEGRADED VIRUS PARTICLES are enlarged the same amount in this micrograph by Roger Hart of the University of California. The particles were broken down by treatment with detergent. The thin threads emerging from some of the rods are nucleic acid.

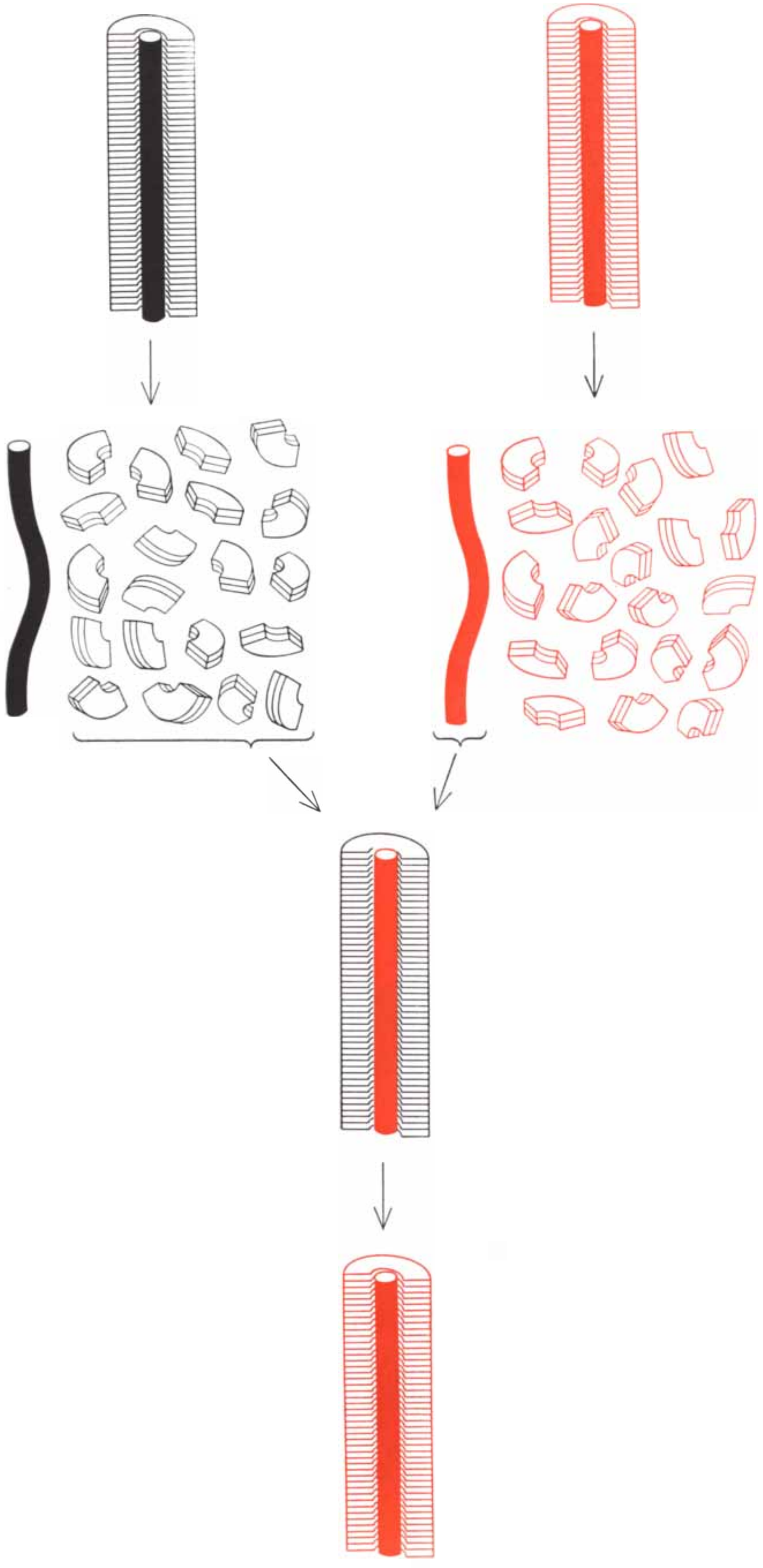
with disease, we know that the infection must be due to newly formed particles, for if any of the original HR virus survived the chemical treatment and were still lurking in the preparation, it would be neutralized by the HR antibody. We can check further by introducing common TMV antibody. If it inhibits the infectivity of the solution, we have conclusive evidence that this infectivity is attributable to newly formed hybrid viruses—HR at heart but wearing TMV coats.

These experiments have been performed, and they give a clear answer. The immunity tests show that the infectious particles do indeed wear TMV coats. On the other hand, they produce the HR disease symptoms in plants, showing that the particles have a core of HR nucleic acid.

The next exciting question is: What kind of particles will these hybrids produce when they multiply in the plant cells? In other words, what will the progeny of the hybrid viruses be like? We already have a good hint in the fact that the plant cells invaded by the spreading viruses show the HR symptoms. Chemical analysis of these descendants shows that their protein coats are in fact of the HR type. The protein contains the two amino acids—histidine and methionine—which are present in HR viruses but absent from common TMV. This proves that the nucleic acid plays the dominant part in determining the character of the progeny, providing a blueprint which gives them HR coats to match their HR nucleic acid core.

However, there seem to be some slight quantitative differences between the protein of the progeny and that of the original HR virus. This suggests that the TMV protein may contribute something to the genetic blueprint, bringing about modifications of the descendants' protein coat. If so, what we would have is an artificially produced mutation. That possibility suggests a possible method of producing new strains of viruses. It opens up the attractive prospect of forming tailor-made hybrid viruses which might serve as vaccines against virus diseases. These are only speculations, however, for much work will have to be done to determine the facts about the apparent changes in the virus hybrids.

What we can conclude safely is that the work with these viruses has launched a new chemical approach to studies of virus disease, of the organization of biologically active matter, and of the mechanism of inheritance.



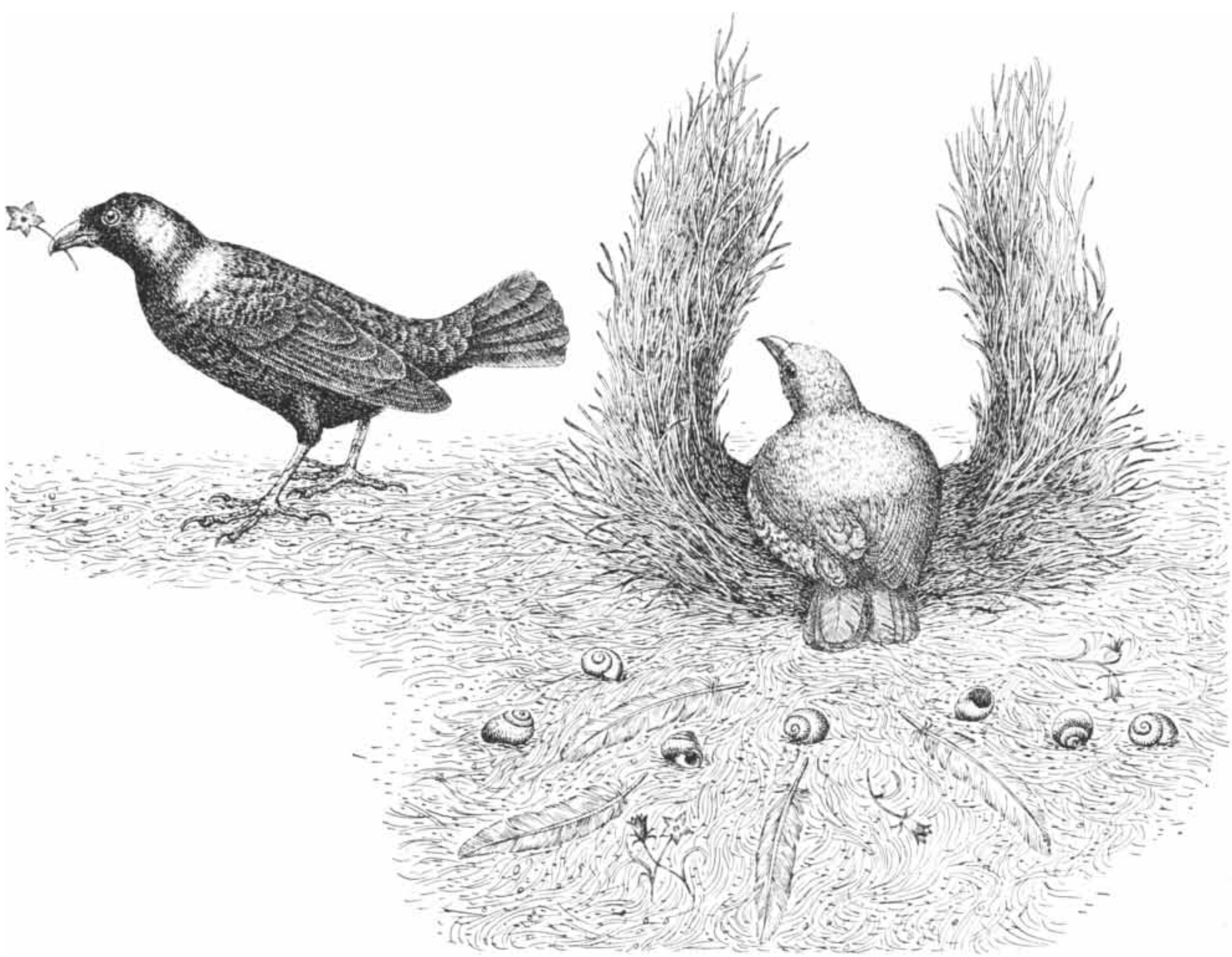
TWO STRAINS of virus (*shortened cross sections in top row*) were broken down (*second row*), and the protein of one allowed to recombine with the nucleic acid of the other (*third*). The progeny of this hybrid had the protein originally associated with their nucleic acid.

Bower Birds

The males of these species found in Australia and New Guinea build elaborate bowers decorated with, among other things, pebbles, flowers, sea shells, beer-bottle tops, car keys and charcoal mixed with saliva

by A. J. Marshall

In the 1840s, when much of the Australian continent was still unexplored, a Captain J. Lort Stokes came upon a peculiar object in the wild bush of western Australia. It was a neat structure consisting of two parallel walls of sticks stuck in the earth, forming a little avenue. The avenue and its entrances were paved with a scattering of white shells. The adventurous captain found "matter for conjecture" in this phenomenon and, not surprisingly, decided that it had been built by some aboriginal Australian mother to amuse her child. When, a little later in his voyage, he stopped at a settlement on the north coast of Australia, the settlers showed him another "playhouse" like the one he had seen. This one was occupied by its builder and owner—a gray, pink-crested male bird about the size of a small pigeon.



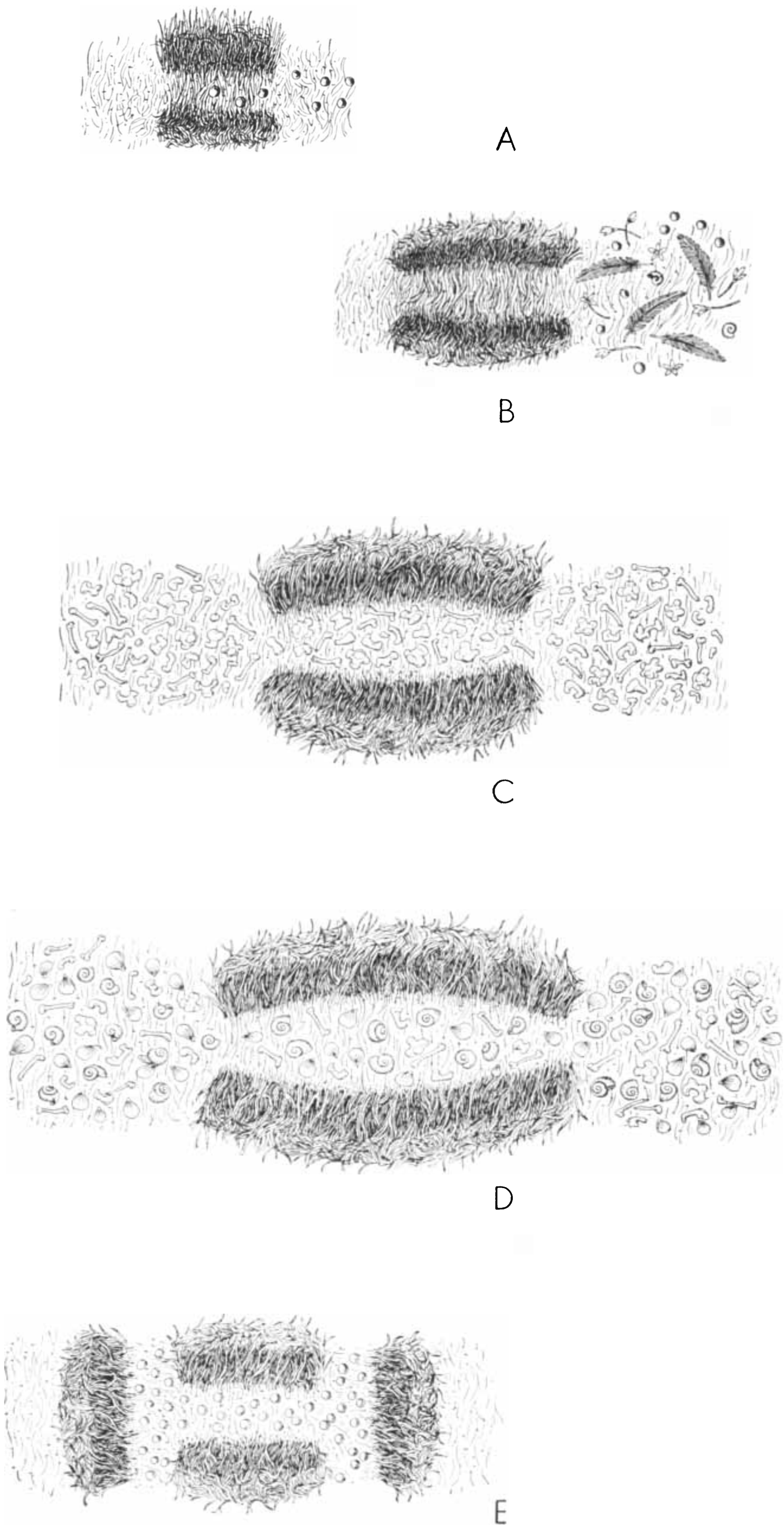
MALE SATIN BOWER BIRD (*left*) parades in its bower with a blue flower in its beak. Just before copulation the female crouches in the central avenue of the bower (*right*). The ground in front of the avenue entrance is decorated with shells, feathers and flowers.

Captain Stokes's report on the incident was one of the first accounts of a phenomenon that has continued to perplex scientists to this day. The bower-building birds attracted the interest of many of the leading naturalists of the 19th century. John Gould, the famous English ornithologist, is believed to have coined the name "bower bird." Charles Darwin, who visited Australia in the voyage of the *Beagle*, speculated about the strange behavior of these creatures, and Thomas Henry Huxley, a member of the celebrated voyage of the *Rattlesnake*, observed the discovery of a remarkable species of bower bird in Australia. (The official naturalist of this voyage carefully described a shipwrecked Scotswoman found living with the aborigines, but not the new bower bird—a thing I have never been able to understand.)

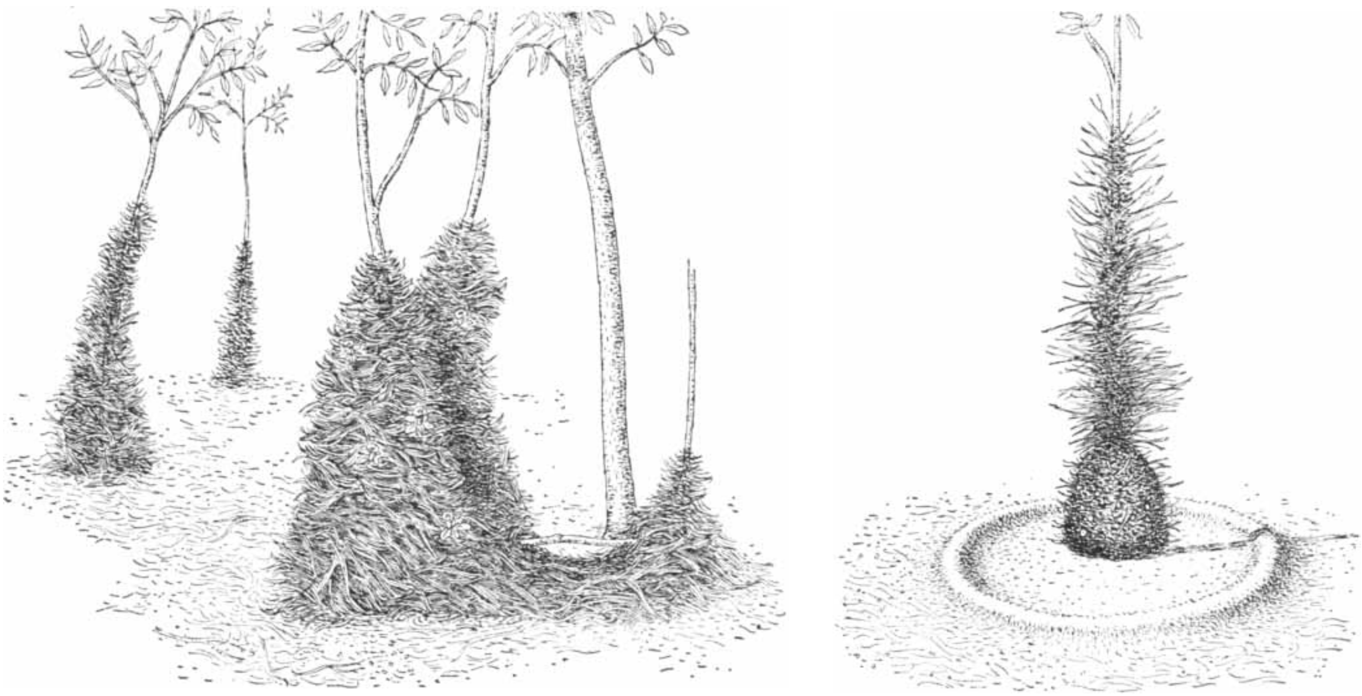
The species Captain Stokes had seen became known as the great gray bower bird. As Australia was populated, bower birds gained a fabulous reputation for their collecting proclivities: their bowers were found strewn not only with shells, pebbles, bones, bits of precious opal and pieces of quartz but also with such objects as teaspoons, coins, bits of broken glass, nails, beer-bottle tops and brass cartridge cases. An otherwise undistinguished gentleman named Edward Delaney acquired celebrity in the literature of zoology when his stolen spectacles were found in the bower of a great gray bower bird. Descriptions of the bowers and their decorations caught the imagination of the Victorian public, and "bower bird" became a household expression applied to people, especially little girls, who collect odds and ends of colorful rubbish.

The satin bower bird of eastern Australia, a glossy blue-black species, was found to have a predilection for blue objects. This urge is so powerful that it has been known to fly into laundries through the open windows to steal bags of bluing. It will purloin delphiniums, petunias, hyacinths and other blue flowers almost from under the noses of gardeners. The spotted bower bird of Australia gathers principally pale objects—bleached bones, shells, broken glass, bits of tin, thimbles, screws, spoons, forks, coins and the like. It will hop through an open window onto a dressing table to steal jewelry. A spotted bower bird once stole the keys from a parked automobile; the aggrieved owner was shrewd enough to hunt up the nearest bower and retrieve them. Another bird stole the glass eye of a bushman from the night table beside his bed!

The bowers themselves are even more



AVENUE-BUILDING BOWER BIRDS make these structures shown semidiagrammatically from above. Bower A is made by the regent bower bird; B, by the satin bower bird; C, by the spotted bower bird; D, by the great gray bower bird; E, by the yellow-breasted bower bird.



MAYPOLE-BUILDING BOWER BIRDS make much more elaborate structures than the avenue builders. At the left is the bower of the Queensland gardener bower bird, which builds a pyramid as much as nine feet high. Second from the left is the bower of the

remarkable than the objects the birds collect to decorate them. The species I have described so far build simple avenues of sticks [*see preceding page*]. But in 1878 the celebrated Italian traveling botanist Odoardo Beccari brought back from New Guinea a report of a greater curiosity. In a jungle so thick that "scarcely a ray of sunshine penetrated," he came upon a "conical hut or bower close to a small meadow enameled with flowers." The meadow was artificially made of transplanted green moss with freshly picked flowers, fruit and fungi of vivid colors strewn over it. The bird that had planted this garden had built its hut around a slender sapling as the center pole. Around the base of the pole it had packed a cone of plant fibers; the walls and roof of the hut consisted of transplanted stems of climbing orchids that formed a watertight mat [*see drawings above*].

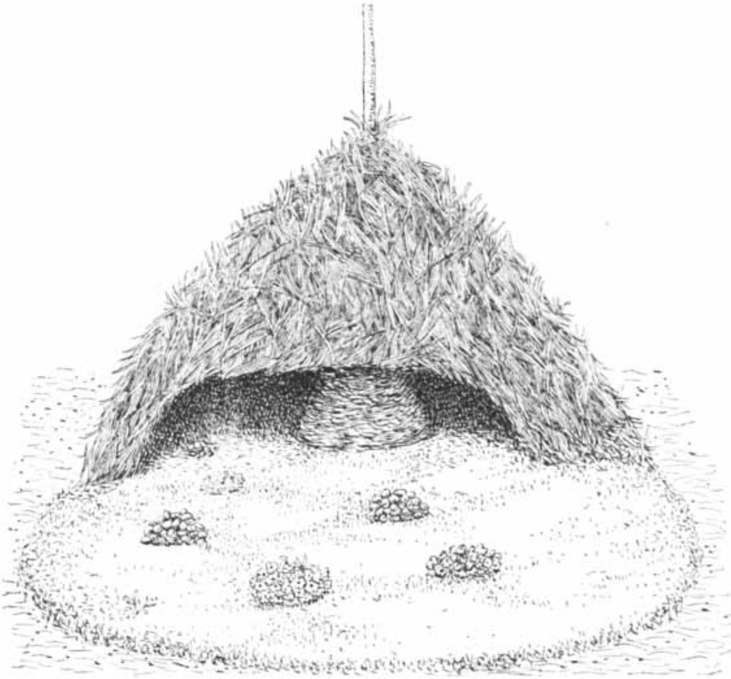
Beccari named the builder of this bower the gardener bower bird. He had discovered the first of a group of birds that I call the maypole builders, to distinguish them from the avenue builders. On the Owen Stanley Range of New Guinea lives an orange-crested gardener which builds a hemispherical hut around a central maypole. A low stockade in front of the building encloses a garden containing a variety of flowers, fruits and seed pods. The bird also adorns the cone around the base of the maypole with flowers, berries, leaves and beetles' wings of various hues. In the same region a yellow-crested gardener constructs a maypole bower consisting of a basal cone of fiber covered with web material and debris produced by wood-boring insects and topped by a further packing of green moss with pale sticks projecting outward like jets of water from a fountain—the whole surrounded by a "circus ring" which in turn is enclosed by a raised parapet of green, transplanted moss.

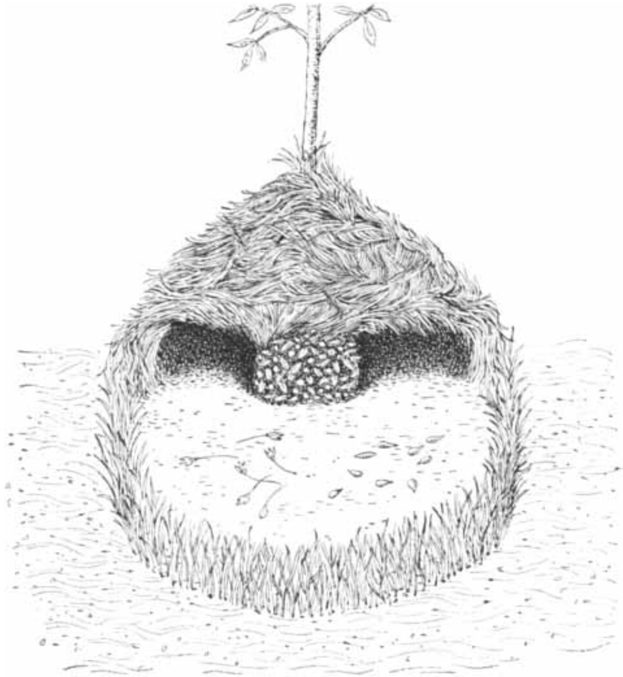
In the remote mountain rain forests of northeastern Australia the golden Queensland gardener, which is only about the size of a thrush, sometimes erects a pyramid of fabric nine feet high around its central maypole. On this pyramid it plants seed pods, lichens, moss and orchids. Beneath its hanging garden the golden male bird perches on a special display stick, where it exhibits its golden fantail, small erectile crest and wings.

Within the last couple of years a third type of bower has been discovered: it is neither an avenue nor a maypole but a simple clearing. Its builder is the so-called black bower bird of New Guinea, a dusky black species with a flaring double crest of gold. Its display ground is a bare patch of earth, about five by four feet, strewn with dead fern fronds, shells and beetles' wings.

Now what function do these bowers serve? When they were first discovered, Gould, Darwin and other scientists quite naturally supposed that they were simply arenas where the male displayed himself and courted the female. But as time went on, naturalists who observed them closely decided that they must be something more than mere places of courtship. The male birds often build their bowers and display themselves there outside the mating season. What is even more curious, some of the bower birds actually paint the inside walls of their bowers!

The blue-black satin bower bird, for example, paints the inner twigs of its avenue bower sometimes with fruit chewed to a pulp, sometimes with charcoal. Its charcoal painting is a ritual of fascinating complexity in which it uses a tool of its own making. The bird first collects some charcoal—of which there is plenty available in a country periodically swept by forest fires—and grinds it up in





yellow-crested gardener, which is surrounded by a low parapet of transplanted moss. Third from the left is the bower of the brown gardener, which builds a conical hut. Fourth is the bower of the orange-crested gardener, which builds a hut with a low stockade.

its beak to a sticky black paste. Then it selects a fragment of bark and fashions a tiny oval wad. Some observers have supposed that this implement serves as a paint brush, but in actual fact the bird uses it as a stopper which keeps its beak slightly open and allows the charcoal stain to ooze from the sides of the beak. The bird vigorously smears the stain on the twigs of its bower, repeating the job several times a day, until the twigs are painted with a thick plaster of sooty black. All this has been observed and photographed, and the bird can be heard to crunch the charcoal in its beak as it prepares for painting. Other bower birds plaster the inner twigs of the bower with fruit or grass mixed with saliva.

When this behavior was first seen in the 1920s, one observer exclaimed: "Is there any reasonable limit to the skill or the intelligence of the Australian bower birds?" Some went so far as to credit the satin bower bird with the power of deductive reasoning, on the ground that it consciously experimented with various painting materials and, acting on experience, made a selection. Soon there arose a hypothesis that bower birds built and decorated their bowers largely for recreation purposes—as a hobby. It was held that only such a theory could explain the bizarre and seemingly thoughtful activities of bower birds.

Nearly 20 years ago I began a series of physiological studies of bower birds to try to find a reasonable explanation of their behavior. The first step toward cracking the puzzle was, it seemed to me, to determine what prompted the male bird to build a bower "out of season." Male satin birds, for example, have been observed to build bowers in every month of the year, although the female normally ovulates only in October and November (the spring season in Australia). To attack this problem I examined the annual rhythm of functioning of male birds' testes.

By the end of spring or summer, the bird's interstitial gland (which produces the male sex hormone) is exhausted. At the same time its sperm-producing tubules change [see "Birds as Flying Machines," by Carl Welty; Scientific American, March, 1955]. However, the bird soon proceeds to generate some fresh interstitial cells, which appear to secrete hormones to at least a limited degree. This renewal of hormone supply apparently is responsible for the autumn resurgence of singing by male birds, and also for the fact that many species in various parts of the world stake out territories and exhibit other sexual behavior at that time.

It seems reasonable to suppose, therefore, that the hormone refreshment stimulates the out-of-season display of bower birds. Let us follow them through the annual cycle of activities. At the end of the breeding season, when the young have left their mother's nest, the mother and father satin birds foregather with their young at the bower. After a short time, during which the parents display ("dance") a little, the family flies off, joins other family groups, and the birds roam the fruit-filled forest in noisy communal flocks of up to 100 strong. But after the male's interstitial gland recovers and begins producing hormones again, he is urged back to visit the bower site from time to time and rebuilds or renovates his bower. I found that by merely scattering fragments of blue grass under a tree in which blue satin males were feeding I could stimulate impromptu displays: the males would fly down, lay a few twigs on the ground and begin to posture and give their characteristic whirring cries.

The bird soon deserts the new bower he has started and rejoins the flock. From time to time through the late summer, autumn and early winter he revisits the bower site—the focal point of his sexual territory—and rebuilds the structure, but not until midwinter does he settle down to the main seasonal display. He now builds a more elaborate bower and this time does not allow it to fall into disrepair. The male displays vigorously in an endeavor to attract a mate to his bower. Some photographs of the satin bower bird's magnificent glossy blue plumage flashing in the sun suggest a black and white magpie.

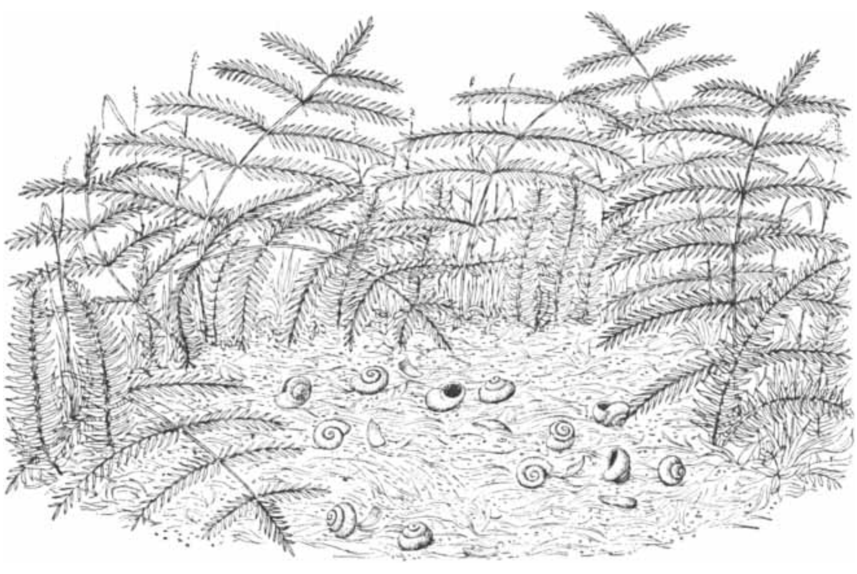
During this winter season a female that may be attracted near the bower stands by impassively; often she becomes bored with the display and goes away. The male calls her back with a special note, and if she does not respond, he follows her into the forest. A virile, mature, glossy blue-black male will generally succeed in attracting the female back again. As the season advances, the bond becomes firmer and the female spends more and more time at the bower. But she remains passively watchful, apparently unmoved, near the bower for weeks or even months, while her ovaries develop. Then, when summer comes, copulation occurs and she goes away into the forest, builds her nest and incubates and rears her young without masculine assistance. The blue male stays on alone at his bower, gyrating noisily.

How are we to explain this cycle of behavior, particularly the prolonged courtship? I believe that the answer is as follows. It is advantageous for the male to stake out his territory early. Consequently long before the arrival of the season for reproduction he begins his noisy, flashing, even violent displays to keep rivals away and hold an eligible female within his sphere of influence, so to speak. When the eastern Australian forests become full of a harvest of insect food in the late spring, the female is finally ready to accept the male. Exactly how she signals her readiness and diverts the attention of the male from his bower and posturings to herself I was never able to discover, but recently another investigator, E. McNamara, learned the answer. He saw a female suddenly enter a bower and assume a squatting position. The male began to display with high-level intensity. He circled the bower excitedly and then entered and copulated with his mate. Whatever the factors may be that trigger the female's readiness, they cause reproduction to occur at the time of the year that is most propitious for the survival of the young.

We do not know why bower birds have developed so bizarre a pattern of sexual behavior—any more than we understand why birds of paradise have developed gloriously colored and filamentous trailing plumes for their sexual displays. So far as population numbers are concerned, these spectacular and peculiar methods of courtship seem to have conferred no special advantage, for the inconspicuous flycatchers and scrub robins in the same region are just as abundant. In any case, we are reasonably sure that neither intelligence nor conscious estheticism is involved in the bower birds' behavior. The bower bird is not sufficiently intelligent to scratch aside a piece of bark to look for a beetle it has knocked down in a cage. The bird's selection and placement of decorations in its bower is purely mechanical. A species that habitually chooses blue and yellow never changes to red and white, or even to very pale blue and gold.

I see the bower birds' construction of bowers as a form of displaced nest-building. This activity on the part of the males (which do not assist females in building the nests for the young) seems to be under the influence of sex hormones, for a castrated bower bird does not build a bower. The construction may be a displaced expression of aggression against rivals. Experiments have shown that the male satin bower bird chooses decorations in the image of competitors of its own species: the blue flowers and feathers that it tosses about so ferociously match the eye color of its rivals, while the lemon-yellow objects it selects match the color of the adult male's beak tip. The savage intensity with which the bower owner displays these objects effectively keeps marauding rivals away from his bower and from his female as long as he remains strong and healthy. The aggressive "bower dance," similarly, is probably a displaced threat drive.

The mysterious painting ritual of some of the bower birds can be explained in the same way. It is probably a displacement of a common feeding practice of birds. Many birds feed one another by passing chewed food from beak to beak, particularly during courtship. The avenue-building bower birds apparently have projected this activity onto the bower, transferring chewed material to the twigs. During the many weeks when the male is secreting hormones and waiting for the unready female, the bower occupies the male's sexual attention. This fact offers the best explanation we can produce at the moment for the weird specializations of the avenue-building birds that have been studied. (The behavior of the maypole-builders, buried deep in the tropical rain forests of New Guinea and northern Australia, is still not known in detail.) The important clue seems to be that while the female is ignoring the male, awaiting stimuli from the environment that will herald the arrival of the appropriate season for reproduction, the sexually stimulated male has ample leisure, and a variety of activities focusing on the bower has evolved.



THIRD TYPE OF BOWER has recently been discovered in New Guinea. Built by the black bower bird, it is a bare patch of earth strewn with fern fronds, shells and beetles' wings.

Kodak reports to laboratories on:

filters to match your color film to your photomicrographic light source . . . bloody business at Fall River . . . the low cost of acquiring an addiction to photocopying

What the brain discounts

Color perception is something personal and indescribable that goes on inside your head. A ripe tomato, a lump of carnotite, or the eyes of a flaxen-haired girl look just as meetly and respectively red, yellow, or blue whether seen by candlelight or under a cold north sky. Between the flame and the sky there is a vast difference in the constitution of the light that these things reflect into the eye of the beholder, yet his brain discounts the physical difference and sets all to rights.

Now just because you happen to find yourself past the middle of the sixth decade of the twentieth century, you expect to feel these and all other possible color-feelings through the agency of varying amounts of three factory-standardized dyes on a piece of film. And, marvel to tell, you can come pretty close.

It's just that in the manufacture of a reversal-type color film, a commitment must be made as to light source. If the light source used differs from the one assumed, the physical parameters (they're the only kind available) must be manipulated to meet the psychophysical necessities. The manipulation can be done with dyed gelatin filters placed somewhere along the line. Here, for example, are our recommendations for some light sources common in photomicrography:

Light source	**Correction filters for*		
	Kodak Ektachrome Film, Type B (sheet only)	Kodak Ektachrome Film, Type F	Kodachrome Professional Film, Type A
6-v ribbon or coil filament	82A	82A and 82C	82C
300 to 750-w coil filament	match!	82 and 82C	82A
zirconium arc	2B	82, 82C, and 2B	82A and 2B
carbon arc (4.5 amp)	81D and 2B	82 and 2B	81C and 2B

As for the choice to make in 35mm, look at it this way: If you seek comfort in knowing that your color film is capable of the highest resolving power and acutance that the market currently affords, pick the new *Kodachrome Professional Film, Type A*. Pick *Kodak Ektachrome Film, Type F*, if you want the results at once.

Still another choice might have to be made when the only all-night drug store in the neighborhood has no other 35mm color material than *Kodachrome Film, Type F*. This gives just as good definition as the *Kodachrome Professional*, but, like *Type F Ektachrome*, is balanced for the amateur's flash bulbs and therefore requires the same correction with photomicrographic light sources. The filtering cuts the speed down somewhat lower than that of the other two 35mm choices.

**"82," "82A," "82C," "81C," and "81D" are all* Kodak Light Balancing Filters; *"2B" is a* Kodak Wratten Filter, *which absorbs ultraviolet. The Kodak dealer can fix you up. If you want the filters in 33-mm very thin glass mounts for insertion in the filter receptacle below the substage diaphragm, he'll probably have to write in to us. He won't mind at all, particularly if you have accustomed him to minister to your needs.*

Truly blood

John D. MacPhail likes *p,p'-Benzylidenebis(N, N-dimethylaniline)* (Eastman 3620) better than the classic benzidine for the identification of bloodstains because he finds it more specific. Doing business as Forensic Science Service (144 Third Street, Fall River, Mass.), Mr. MacPhail knows how to keep legal evidence intact. He moistens a filter paper with 0.1N saline and merely presses it against an edge of an old stain suspected as blood. Then he touches the paper (not the stain) with one glass rod dipped in a 1:240 solution of Eastman 3620 in 40% acetic acid. A second time he touches it with another glass rod dipped in an 11:30 solution of sodium perborate in 40% acetic acid. If the paper turns blue-green after the second touch, Mr. MacPhail knows the spot is truly blood. Such colored oxidants as potassium permanganate turn the reagent blue-green *before* contact with sodium perborate. Perhaps something in the bloodstain releases from the sodium perborate the oxygen to oxidize our compound to its far better known form, malachite green, a common dyestuff named for its color resemblance to the brilliant copper mineral malachite.

The first supply of our *leuco*-malachite green that Mr. MacPhail laid in worked fine down to the last grain; presto, twenty years of human violence had gone by and it was time to reorder. (The price is $2.20 for 5 g.) The second lot we supplied worried Mr. MacPhail. It was green enough in the stock solution to invite sarcastic questions from lawyers. Our man who signed the papers to manufacture the first batch is still on the job, however. He suggested that Mr. MacPhail add a little sodium bisulfite to redress the redox balance *leuco*wards. Now Mr. MacPhail reports he is all set again.

Yes, and if you want the balance the other way we can supply Malachite Green Oxalate (*Eastman 1264*). *Among 3500-odd organics, the chance of finding what you want is encouraging. All from Distillation Products Industries, Rochester 3, N. Y.* (*Division of Eastman Kodak Company*).

Beware!

Damsel's job here is to lure the eye to the new *Verifax Signet Copier*. Reduces to $148 the cost of acquiring an addiction to the Verifax habit. Addicts make photocopies of laboratory notes and documents that might otherwise be manually copied. They are then forced to find more productive means of making the day go by. Even the rationalization that permanent copies are needed for the files is denied them. For archival storage, the Verifax kind of photocopies requires no more solicitude than do typed originals.

Write "Where?" on the back of a postcard. Be sure your name and address are on it. Mail it to Eastman Kodak Company, Business Photo Methods Division, Rochester 4, N. Y. We'll know.

Prices quoted are subject to change without notice.

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

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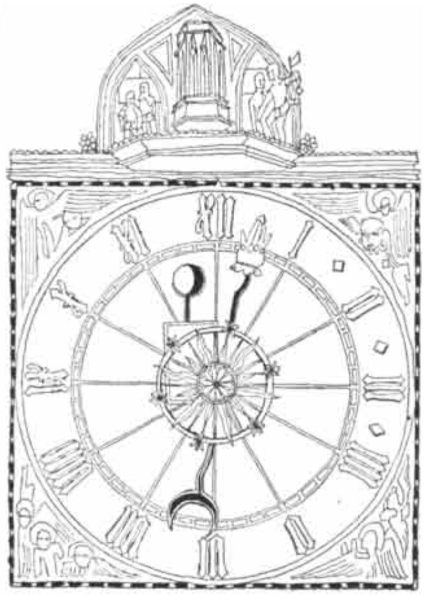
SCIENCE AND



Biology Meeting

Some 7,000 biologists, covering the entire spectrum of the life sciences, gathered in Atlantic City in April for the annual meeting of the Federation of American Societies for Experimental Biology. Among the highlights of the meeting were the following reports:

Wendell M. Stanley of the University of California announced that his laboratory had prepared what might be called the first synthetic virus. Its core, like that of natural plant viruses, consists of ribonucleic acid (RNA). This material was furnished by Severo Ochoa of the New York University College of Medicine, who had made it by exposing certain organic phosphate compounds to an enzyme extracted from bacteria. To the RNA the California chemists added a protein [see article "Rebuilding a Virus" on page 42 of this issue]. When they examined the result with an electron microscope, they found tiny rods looking exactly like plant viruses and presumably with a similar construction: a core of RNA coated with protein. As yet Stanley and his co-workers have not found a plant that their creation can infect. They call it "a virus in search of a host." The announcement was made at the 50th anniversary meeting of the American Society of Biological Chemists, one of the six organizations that are members of the Federation.

At a session of the American Society of Experimental Pathology two investigators from the Brookhaven National Laboratory's medical department reported an apparent relation between fondness for table salt and high blood pressure. They had polled 1,346 employees of the Laboratory and found: of 135 who never salted their food, only one had high blood pressure; of 630 who sometimes added salt, 43 had hypertension; of the remaining 581, who automatically reached for the salt shaker before tasting, 61 were afflicted.

At one of the best-attended sessions of the American Physiological Society a report entitled "Physiological Responses During Coitus in the Human" was made by Roscoe G. Bartlett of the National Institutes of Health. He told how he and a colleague at an unnamed university had measured the heart and breathing rates of three married couples, who had volunteered for the research, during sexual intercourse. The measurements were made by attaching wires to the subjects and recording their responses in another room. The heart rates of the subjects rose from about 70 beats per minute to about 170, and their breathing rates tripled. Electrocardiograms showed many abnormal heartbeats, particularly during orgasm. The pioneer study by Bartlett and his colleagues may help physicians advise patients who have suffered strokes or coronary attacks.

Chemical Psychoses

Chemistry was the outstanding topic of the annual meeting of the American Psychiatric Association in Chicago last month. In addition to general discussions of the connection between body chemistry and mental disorders, two groups of investigators reported experiments linking psychoses to specific substances.

Robert D. Heath and three associates at Tulane University have found that the blood of schizophrenics contains a protein which produces a temporary psychosis when injected into human subjects. They tested it on two volunteers, prisoners in a Louisiana penitentiary. Soon after the injection one lapsed into a catatonic state and had hallucinations. The other became paranoid, suspecting that everyone was talking about him. Both subjects returned to normal after about two hours.

Heath explained that the experiment was designed to test a hypothesis that a genetically determined disturbance of metabolism is the cause of schizophrenia. He suggested that the disorder may be

THE CITIZEN

linked with adrenalin metabolism. The blood protein responsible for the disturbance has not yet been identified.

Howard D. Fabing of Christ Hospital in Cincinnati reported that a drug extracted from a poisonous mushroom also produced mental disturbances. The mushroom is the one that Viking warriors a thousand years ago are supposed to have made a practice of eating before battle. Legends relate that the eater was excited to a frenzy in which he howled like a wolf and bit the edge of his shield.

Fabing isolated the active principle of the mushroom, the drug bufotenine, and found it similar to mescaline and lysergic acid, which also produce symptoms of mental disorder. Bufotenine evoked in subjects a reaction "striking in its similarity to the famous rage of the Viking hoodlums."

Wired for Joy

Electrical stimulation of certain areas in the brain of an experimental animal evokes sensations of extreme pleasure which have recently attracted the attention of a number of neurophysiologists. The investigation, which is expected to lead to important new findings about the brain, was described to a Senate appropriations subcommittee by Robert H. Felix, director of the National Institute of Mental Health.

The technique was originated by James Olds of the University of California at Los Angeles Medical School, who is expected soon to publish some results of his work. Felix told of experiments by John Lilly, a neurophysiologist at the Institute. He inserted slender wire electrodes into a brain area called the fornix, between the two halves of the brain. When an alternating current was turned on, the animals apparently experienced pure delight.

Describing experiments with rats, Felix said: "They put a little pedal in the room which the rat can press, and when he presses it he gets this electric stimulation. The stimulation apparently causes such exquisite pleasant sensations that he will push this pedal days on end, and, with food and water in his cage, he will not stop to take food and water. But he will continue to press this pedal until he falls exhausted or dead." Felix added: "I am almost frightened to say what I think might come of this in terms of the treatment of the mentally ill."

Humanities for Engineers

Engineering students should get more training in the humanities and social sciences, according to a report just released by the American Society for Engineering Education. A three-year survey financed by the Carnegie Corporation of New York showed that the average engineering student spends less than 17 per cent of his study time on subjects not directly connected with his professional education. The committee that conducted the study recommended that the proportion be increased to at least 20 per cent.

"To meet his growing responsibilities and to realize his capacities as a human being," said the engineering group, "the engineer needs both professional competence and a broad understanding of himself and of the world in which he lives. . . . Leading engineering schools have

FOUR STRANGE FIGURES appeared on the cover of a recent issue of the *Bulletin* of the Chicago Natural History Museum. They result from a remark made by the late Harvard anthropologist Earnest A. Hooton, who said that if fossil man were dressed in contemporary clothing, he might be passed on the street without attracting attention. This stimulated artist Gustaf Dalstrom of the Museum's department of anthropology to make a drawing of four fossil men dressed in top hats and opera capes. At lower left is *Pithecanthropus erectus;* at lower right, *Sinanthropus Pekinensis;* at upper left, Neanderthal man; at upper right, Cro-Magnon man. The drawing of Sinanthropus is based on a reconstruction made by the late Franz Weidenreich of New York's American Museum of Natural History; the other drawings, on reconstructions made by J. H. McGregor of Columbia University.

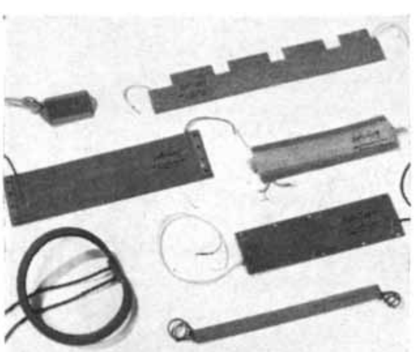
New Materials Stretch Profits

● Silicone rubber cuts aircraft warm-up time; opens new markets.

● Rolling mill production increased 30% with silicone insulated induction heaters.

● Beauty industry uncorks wide variety of silicone-based cosmetics.

• **Faster Take-offs**—Need for minimum warm-up time in aircraft led to development of heating elements that can quickly reach and safely hold temperatures of 400 to 500 F. Safeway Heat Elements, Inc., of Middletown, Conn. answers that need with woven resistance wire sandwiched between layers of Dow Corning's Silastic* R Tape. Also used to give maximum life and reliability to diesel electric traction motors, this silicone rubber tape is the only resilient insullating material that can withstand such temperatures.
Void-free, moistureproof insulating jacket has maximum flexibility, minimum thickness, high thermal conductivity, excellent dielectric properties. Safeway heaters may be immersed in fluids that must be heated or maintained at optimum temperatures. Other aircraft applications for the heaters include gyros, bearings, cameras, valves, hose, pitot tubes. Large industrial market is indicated. No. 22



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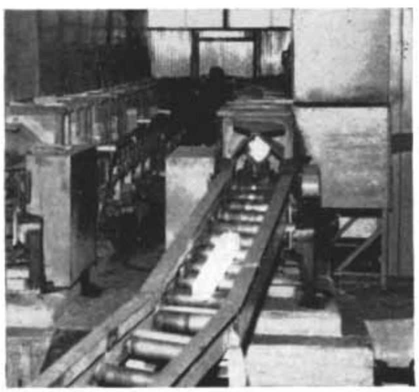
• **Fish Foam** — Trout churn up troublesome foam in tanks carrying them from hatcheries to your favorite fishing hole. Here, as in thousands of industrial applications, a little Dow Corning silicone defoamer kills foam; saves cleaning scum from tank walls; makes everybody happier—including the fish. No. 23

• **No Siestas for Induction Heaters** Vancouver Rolling Mills of Canada cut steel ingot heating time 75%; reduced fuel costs $200 per day; stepped up production 30% with induction heating coils insulated with Dow Corning silicones. Cold ingots are heated to 2300 F and converted to bar stock in 10 minutes. Rated production is 20 tons an hour. With heating coils cheek by jowl with white-hot ingots, only silicone insulation can prevent coil failure. Same's



true in any hard working or space and weight saving electrical or electronic equipment. No. 24

• **Self-bailing Boats** — "Bail-a-matic" pumps in Scott-Atwater's new outboard motors start bailing the first time out after winter hibernation, thanks to a few drops of Dow Corning 200 Fluid as nongumming lubricant for rubber impellers. No. 25

• **Grease Cuts Labor Cost**—Relubricated every 8 hours with high temperature organic grease, injector valves on Cooper-Bessemer engines in a gas field compressor station still required frequent cleaning and replacement. Relubrication cost 1600 man-hours a year plus materials. Dow Corning 41 silicone grease, used since 1953, cuts relubrication schedule from 3 times a day to 3 times a year; minimizes down-time and replacement costs. Comparable savings reported for heat-stable silicone lubricants in hard-working motors, textile machines, oven conveyors. No. 26

• **Lasting Beauty**—A few years ago, silicone-based cosmetics were total strangers to drug store shelves and beauty salons. Now, they're big business and growing like Jack's bean stalk. Latest count found over 60 cosmetic manufacturers making new or improved products through use of silicone fluids. List includes protective hand creams, sun-tan oils, nail polishes, after-shave lotions. Anatomy-wise, applications range from baby bottoms to hair dressings.

How come? With properties unlike those found in conventional ingredients, silicone fluids developed by Dow Corning give cosmetic industry new selling features. Durably water repellent, nonvolatile and harmless physiologically, silicones help cosmetic chemists create new and better products. Also important is rapidly growing sales appeal born of major contributions made to every day living and to the industrial economy by silicones. No. 27

• **Competitive Advantage** — often hinges on materials engineering. That's why design, production and maintenance men need handy new Reference Guide to Dow Corning Silicone Products. No. 28

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demonstrated that carefully planned programs provide a sound introduction to the humanities and social sciences while simultaneously reinforcing students' engineering training."

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World Atom Agency

A charter for a United Nations atoms-for-peace agency was approved by 12 nations after a two-month conference in Washington. The conferees laid plans for a second meeting to be held in September at United Nations headquarters in New York. At this meeting the charter will be submitted for ratification by all UN member nations.

The agency will operate like semi-independent groups such as the World Health Organization and the Food and Agriculture Organization. It will not be directly responsible to the Security Council but will submit reports to it, to the General Assembly and to the Economic and Social Council.

The 22 or 23 governors of the new group will be chosen according to the following formula. Five will represent the leading nuclear powers: U. S., U.S.S.R., Great Britain, France and Canada. Three will be from countries having large resources of thorium or uranium. Five more will represent major geographical regions of the world. And nine or 10 seats will be reserved for countries which have made little progress in atomic energy.

The nations taking part in the Washington talks were Australia, Belgium, Canada, Brazil, Czechoslovakia, France, India, Portugal, the Union of South Africa, the U.S.S.R., the United Kingdom and the U. S.

U.S.S.R. Fusion Research

During the recent visit to Britain by U.S.S.R. leaders, physicists of the British atomic energy establishment at Harwell got a firsthand report of Soviet progress toward the control of thermonuclear energy. A physicist in the Soviet party, Igor Kurchatov, said that his colleagues have discharged short bursts of extremely large electric current through tubes containing hydrogen isotopes and have thus heated the gas to about a million degrees centigrade, the threshold of fusion reactions. In the course of these experiments the Soviet physicists

detected neutrons, which might be interpreted as a sign that fusion had taken place. But careful investigation showed that the neutrons had resulted from another kind of reaction. Kurchatov said that plans call for tests with even stronger currents to produce higher temperatures.

B. J. F. Schonland, deputy director of Harwell, said that he was impressed by the quality of Soviet thermonuclear research and also with the willingness of Kurchatov to answer questions.

Rebirth of Genetics

Trofim Lysenko's personal rule over U.S.S.R. genetics came to an end in April with his resignation as head of the All-Union Academy of Agricultural Sciences. The event is interpreted to mean that after 15 years during which "Mendelian" genetics was a politically discredited branch of science in the Soviet Union, it is once again acceptable.

Hybrid corn, which is incompatible with Lysenko's theories of acquired characteristics, is now being planted on Soviet farms. The week before Lysenko retired from prominence there was an announcement from Moscow that the scientific works of Nikolai Vavilov were about to be published. Vavilov, a world-famous geneticist, opposed Lysenko's rise, and in 1942 died in exile in Siberia.

In the opinion of H. J. Muller, the Indiana University geneticist who worked in Moscow from 1933 to 1937, the passing of Lysenko and the rebirth of genetics indicate that the Soviet government may be relaxing its control of science.

Evolution of Elements

The widely accepted belief that a cosmic explosion 4.5 billion years ago created the chemical elements that now exist in the universe is challenged by recent findings at the California Institute of Technology. William A. Fowler and Jesse L. Greenstein propose instead that all but the lightest elements have been built up by stars formed in part from matter cast off by very old stars. This process of heavy element building is apparently still going on, they report in *Proceedings of the National Academy of Sciences.* According to their theory, the heavy elements in the earth and sun were created about 500 million years after the "beginning" of the universe.

Although no star made entirely of hydrogen has yet been discovered, the cool, ancient subdwarf stars contain very little

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metal. On the other hand, such vigorous youngsters as the red giants are rich in carbon, which is presumably the starting point for reactions that build up still heavier elements through the addition of neutrons. The most convincing evidence of element-building, the authors say, is the presence of technetium in the stars. This unstable element decays so rapidly that it could not be detected by spectroscopes unless it were freshly made.

Stellar temperatures and nuclear composition can account for all elements up to the atomic weight of lead, but the still heavier radioactive elements require more energy. Fowler and Greenstein believe that these are made by intense stellar magnetic fields which behave like powerful particle accelerators.

Test Printer

An electromagnetic printing machine which could reproduce *Gone with the Wind* in about 15 minutes has been developed by the General Electric Company. It already prints 2,500 lines a minute, and could be stepped up to "several hundred lines a second," G.E. engineer Robert D. McComb told the Rochester section of the Photographic Society of America.

The new machine is not designed, however, to compete with printing presses: it is intended to open up a bottleneck in the operation of modern computers which need ever faster printers to keep pace with their output of answers.

The printer is about the size of a shoe box. It consists mainly of a horizontal metal cylinder on which are outlined numbers, letters and other symbols. As the cylinder revolves rapidly, the output from the computer temporarily magnetizes various symbols. These pick up tiny black magnetic particles and then deposit them in the symbol forms on a roll of hot waxed paper. As the paper cools, the black particles sink into its surface like ink.

Heat Rectifier

A strange liquid that conducts heat in only one direction is helping Duke University physicists reach temperatures close to absolute zero. The liquid is a mixture of the helium isotopes 3 (rare) and 4 (ordinary). Helium 4 is a good conductor of heat and helium 3 a poor one. The rectifier-like behavior of the mixture stems from the peculiar tendency of helium 3 to concentrate at the coldest part of a container.

The Duke physicists put the mixture

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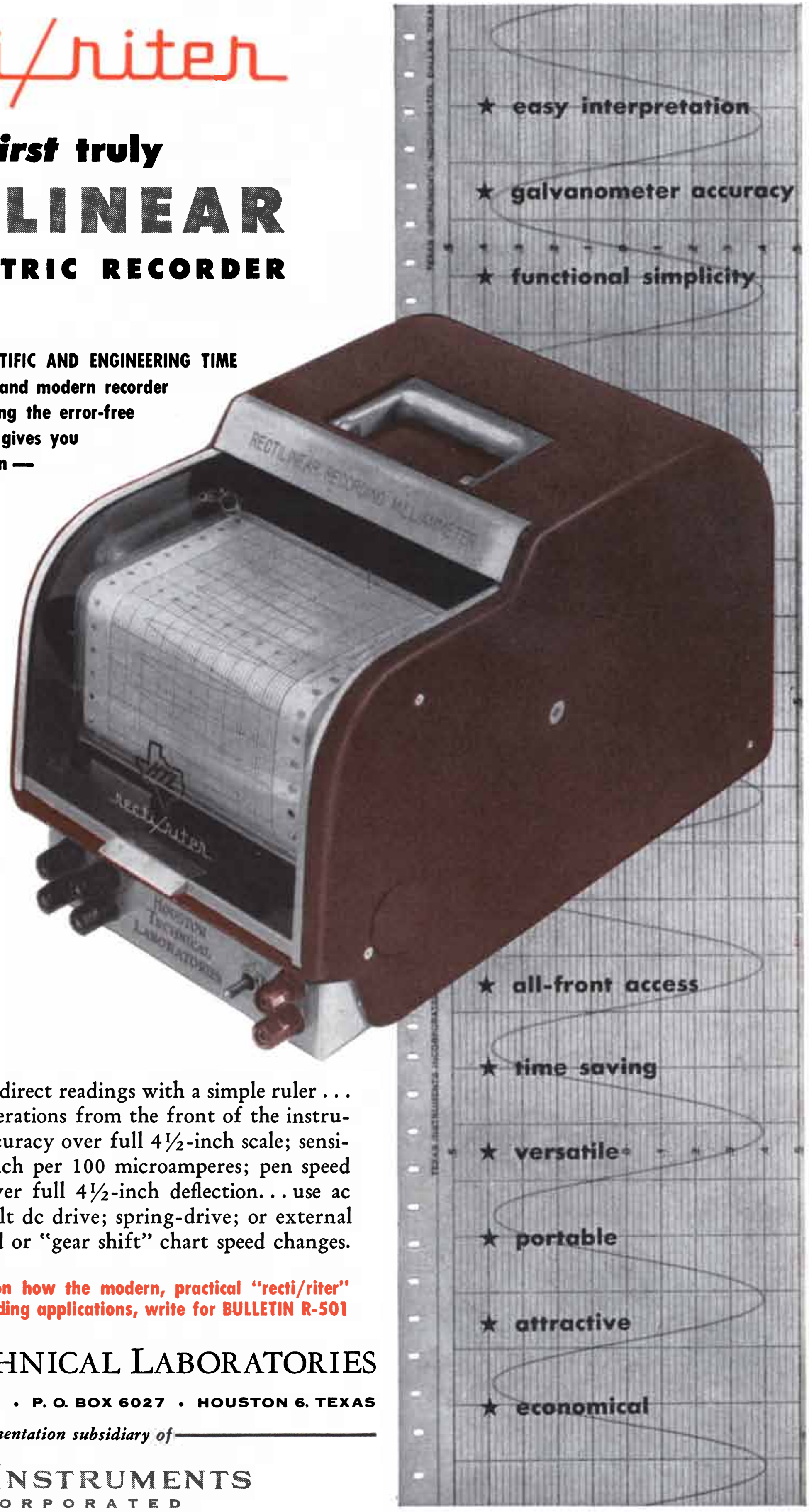

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of liquefied helium in a slender vertical tube a few inches high. At the upper end they fasten an insulated package of magnetic salt. The lower end is immersed in a cold bath of liquid helium. When they switch on a powerful electromagnet, the salt becomes appreciably warmer than its surroundings, and heat flows from it down the tube and into the cold bath. Then they turn off the magnet; the temperature of the salt quickly drops; and helium 3, collecting next to the cool salt, prevents heat from flowing into it from the warmer tube. By repeatedly switching the magnet on and off, they drain off a little more heat at each cycle.

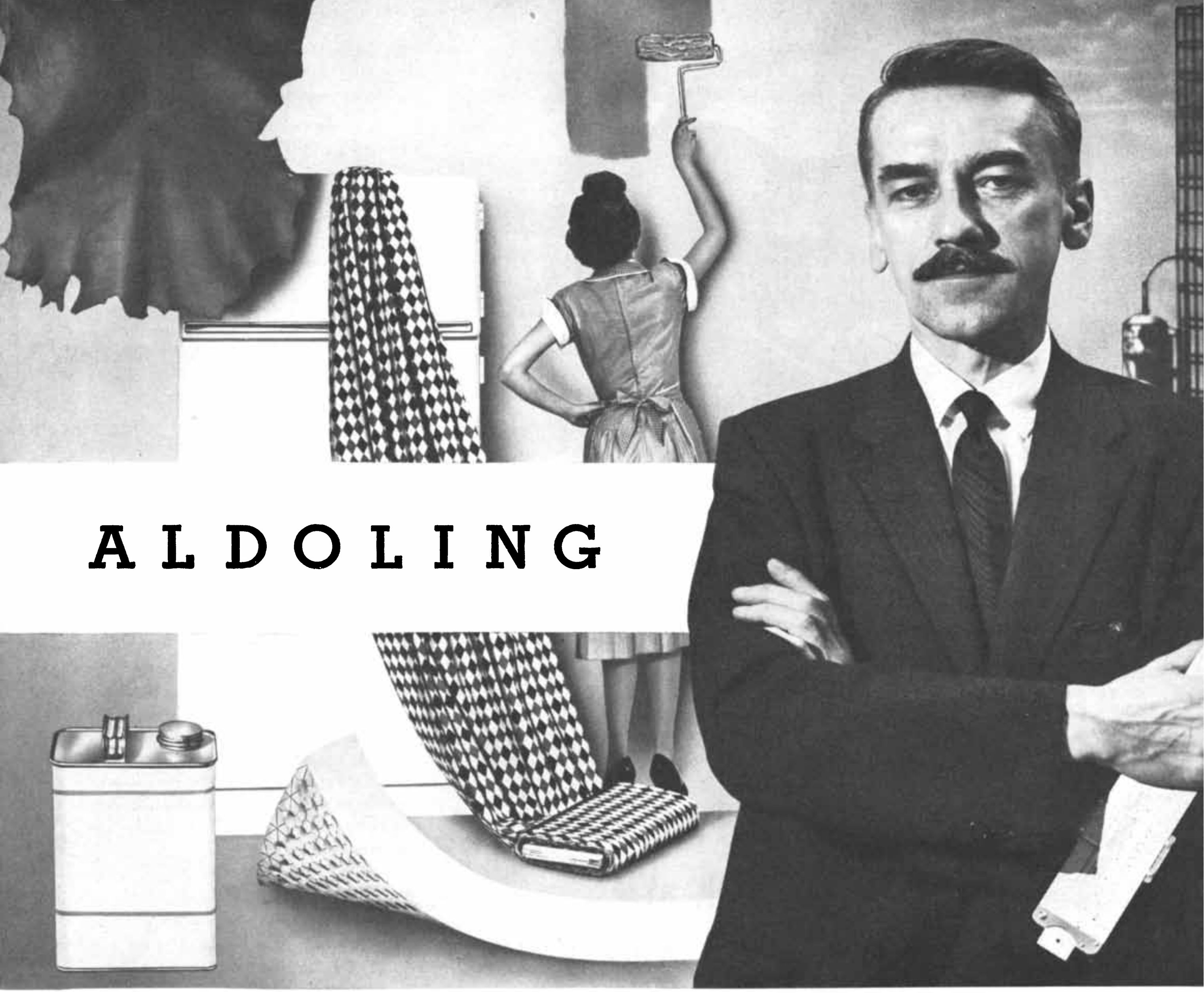
Reporting their discovery to the recent Washington meeting of the American Physical Society, W. M. Fairbank, C. D. Fulton and C. F. Hwang said they were trying out their heat rectifiers in so-called "magnetic refrigerators," consisting of a chain of magnetic-salt containers linked by tubes of mixed helium. They hope to reach temperatures only a few millionths of a degree above absolute zero.

Cryotron

Superconductivity, the strange property of metals at temperatures near absolute zero, can be eliminated by a fairly weak magnetic field. Physicists in the Lincoln Laboratory at the Massachusetts Institute of Technology are now utilizing this fact to develop a new computer element comparable with transistors in size and power requirements.

The device is a slender inch-long rod of tantalum with a single layer of wire coiled around it. When immersed in liquid helium, the tantalum becomes superconductive. But when current passes through the surrounding wire, creating a magnetic field, the tantalum regains its normal resistance. Thus current in the wire controls current in the tantalum rod, just as in a simple vacuum tube the grid current controls the flow of electricity from cathode to anode.

In the current issue of *Proceedings of the Institute of Radio Engineers* D. A. Buck of the Lincoln Laboratory foresees a brilliant future for the "cryotron," as the new element is called. It is easy to make and inexpensive. And because it operates in an extremely cold and inert atmosphere, it should have a long life. It is not as fast as vacuum tubes or transistors, but faster than electrical relays. Its chief advantage is its inherent compactness. A large-scale digital computer based on cryotron circuits should



CELANESE REFINES A CHEMICAL PROCESS AND CREATES A RICH NEW SOURCE FOR PRODUCT IMPROVEMENTS

Synthesizing organic chemicals by aldol condensation is a standard processing method. But now through the refinements introduced by Celanese, Aldol Production has suddenly taken on new meaning for manufacturers in many fields.

Celanese Aldoling has the efficiency, economy, and capacity of compactness. In place of single aldol units, there is one consolidated aldol installation which utilizes specially developed techniques and depends only upon Celanese-produced aldehydes and ketones. A typical end product is trimethylolpropane.

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Similarly released by Celanese Aldoling for full commercial development: methyl isopropenyl ketone and 3-methoxy butanol. Other high potential chemicals are in the development stage.

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occupy only one cubic foot, exclusive of refrigerating devices, and should draw no more than half a watt of power.

Free-Piston Engine

Last month the General Motors Corporation exhibited a new experimental automobile powered by a free-piston engine, similar to some that have been used for the last 30 years in Europe for ships, locomotives and power plants.

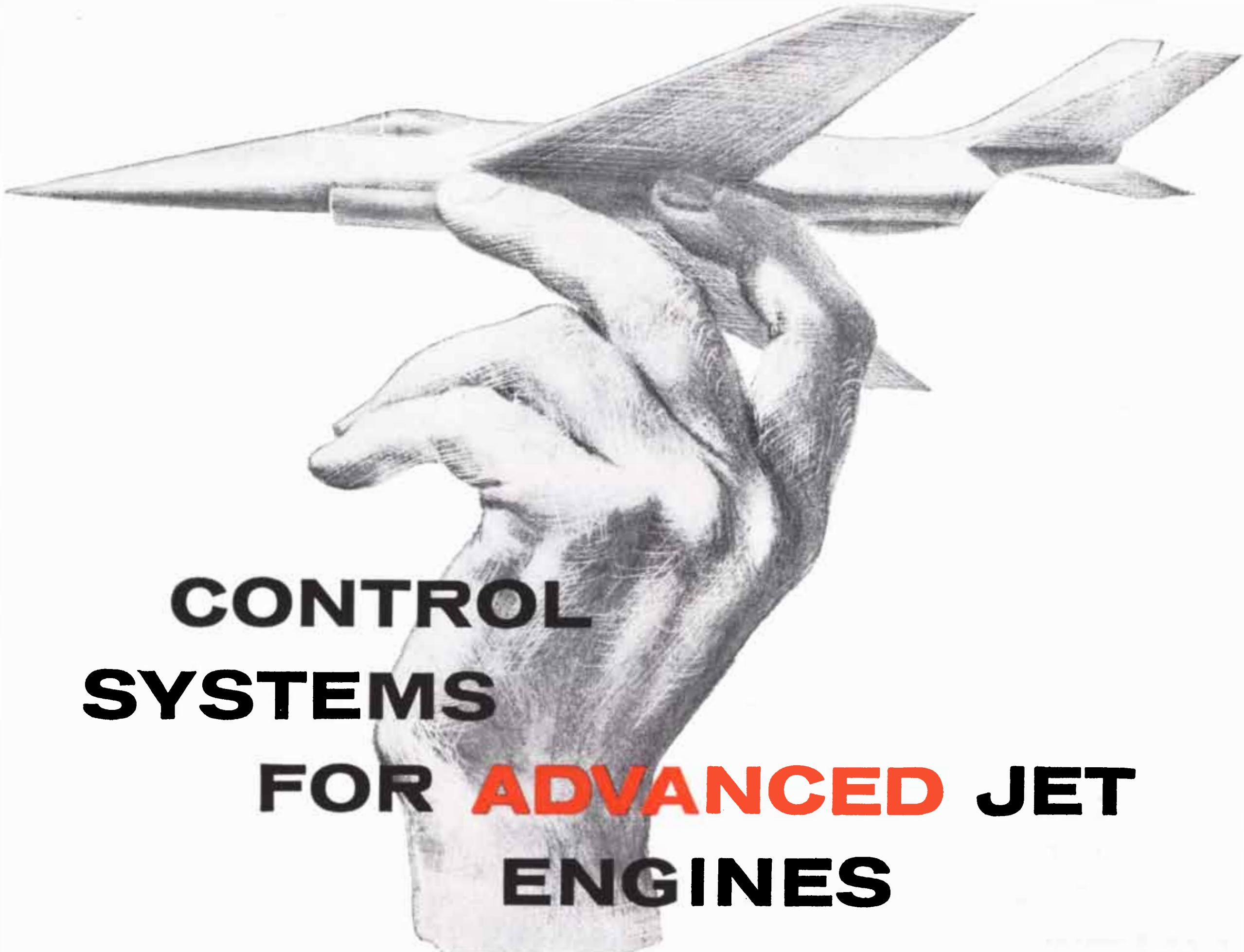
The combustion chamber of this engine is a cylinder containing two opposed pistons. At each cycle the exploding fuel drives both pistons outward, until they bounce back from a resilient cushion of air at either end of the cylinder. On the return stroke the pistons compress a fresh fuel mixture. There is no crankshaft. Instead, hot exhaust gases flow directly to a turbine that turns the car's wheels.

The free-piston design has several advantages over conventional automobile engines and gas turbines. It needs few high-precision parts, and its simplicity largely eliminates the wear of rubbing metals. It is inherently so well balanced that it operates with very little vibration. Because the exhaust gases reaching the turbine are relatively cool (about 900 degrees Fahrenheit) turbine blades need not be made of critical materials. And the engine can run on virtually any clean-burning fuel.

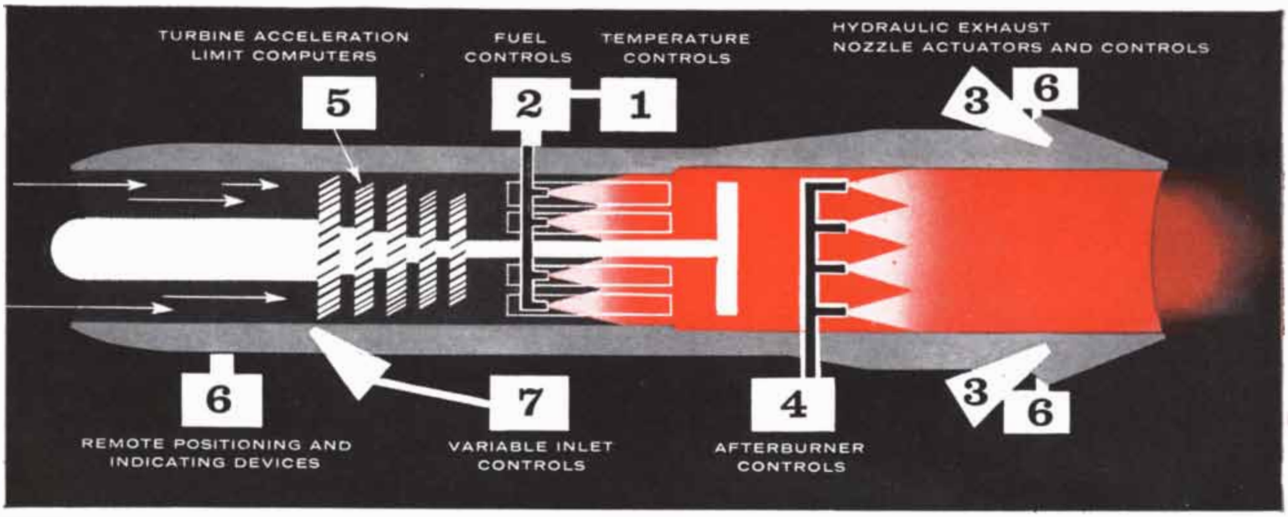
Elephant's Memory

If the saying "An elephant never forgets" is questionable, at least it has a better memory than most animals. So reports Bernhard Rensch of the West German University of Münster in *The American Naturalist.*

Rensch and a colleague trained a young Indian elephant to discriminate "right" from "wrong" plaques among 40 painted with different colors and patterns. Despite the fact that some of the patterns were only subtly different (for example, broad stripes compared with narrow stripes), the elephant learned to touch with her trunk almost unerringly the one "right" pattern in any group of four. Rensch also taught similar lessons to mice and rats and to small chickens and large chickens. From these experiments he concluded that among kindred animals, the larger species learn more and remember better than smaller ones. He attributes the difference to the big animals' larger brains, containing larger nerve cells capable of performing more complex switching operations.



CONTROL SYSTEMS FOR ADVANCED JET ENGINES



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DATA REDUCIBLE TO ANY FORM — The FR-100's output is usable in numerous forms: visual records by oscillograph or pen recorder; visual study by oscilloscope; automatic computation by data conversion devices or computers; and regulation or activation of mechanisms by electrical controls.

GÖDEL'S PROOF

Although little known, it is a landmark of 20th-century thought. The proof brought to light certain astonishing limitations which have always been inherent in mathematics and mathematical logic

by Ernest Nagel and James R. Newman

In 1931 a young mathematician of 25 named Kurt Gödel published in a German scientific periodical a paper which was read only by a few mathematicians. It bore the forbidding title: "On Formally Undecidable Propositions of *Principia Mathematica* and Related Systems." It dealt with a subject that has never attracted more than a small group of investigators, and its reasoning was so novel and complex that it was unintelligible even to most mathematicians. But Gödel's paper has become a landmark of science in the 20th century. As "Gödel's proof," its general conclusions have become known to many scientists, and appreciated to be of revolutionary importance. Gödel's achievement has been recognized by many honors; not long after his paper appeared the young man was invited from Vienna to join the Institute for Advanced Study at Princeton, and he has been a permanent member of the Institute since 1938. When Harvard University awarded him an honorary degree in 1952, the citation described his proof as one of the most important advances in logic in modern times.

Gödel attacked a central problem in the foundations of mathematics. The axiomatic method invented by the Greeks has always been regarded as the strongest foundation for erecting systems of mathematical thinking. This method, as every student of logic knows, consists in assuming certain propositions or axioms (*e.g.*, if equals be added to equals, the wholes are equal) and deriving other propositions or theorems from the axioms. Until recent times the only branch of mathematics that was considered by most students to be established on sound axiomatic foundations was geometry. But within the past two centuries powerful and rigorous systems of axioms have been developed for other branches of mathematics, including the familiar arithmetic of whole numbers. Mathematicians came to hope and believe that the whole realm of mathematical reasoning could be brought into order by way of the axiomatic method.

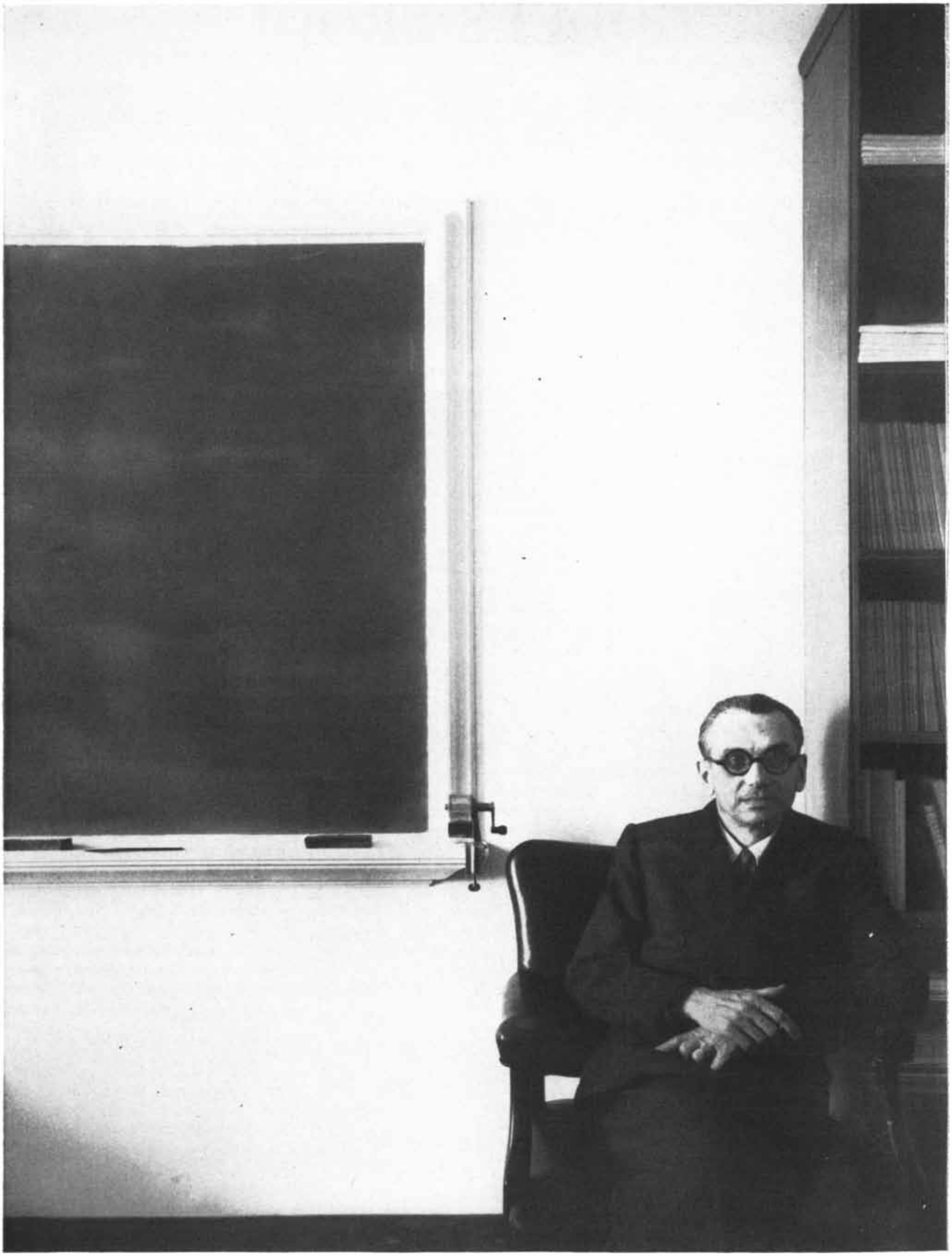
Gödel's paper put an end to this hope. He confronted mathematicians with proof that the axiomatic method has certain inherent limitations which rule out any possibility that even the ordinary arithmetic of whole numbers can ever be fully systematized by its means. What is more, his proofs brought the astounding and melancholy revelation that it is impossible to establish the logical consistency of any complex deductive system except by assuming principles of reasoning whose own internal consistency is as open to question as that of the system itself.

Gödel's paper was not, however, altogether negative. It introduced into the foundations of mathematics a new technique of analysis which is comparable in fertility with René Descartes's historic introduction of the algebraic method into geometry. Gödel's work initiated whole new branches of study in mathematical logic. It provoked a reappraisal of mathematical philosophies, and indeed of philosophies of knowledge in general.

His epoch-making paper is still not widely known, and its detailed demonstrations are too complex to be followed by a nonmathematician, but the main outlines of his argument and conclusions can be understood. This article will recount the background of the problem and the substance of Gödel's findings.

The New Mathematics

The 19th century witnessed a tremendous surge forward in mathematical research. Many fundamental problems that had long resisted solution were solved; new areas of mathematical study were created; foundations were newly built or rebuilt for various branches of the discipline. The most revolutionary development was the construction of new geometries by replacing certain of Euclid's axioms with different ones. In particular the modification of Euclid's parallel axiom led to immensely fruitful results [see "The Straight Line," by Morris Kline; SCIENTIFIC AMERICAN, March]. It was this successful departure that stimulated the development of an axiomatic basis for other branches of mathematics which had been cultivated in a more or less intuitive manner. One important conclusion that emerged from this critical examination of the foundations of mathematics was that the traditional conception of mathematics as the "science of quantity" was inadequate and misleading. For it became evident that mathematics was most essentially concerned with drawing necessary conclusions from a given set of axioms (or postulates). It was thus recognized to be much more "abstract" and "formal" than had been traditionally supposed: more "abstract" because mathematical statements can be construed to be about anything whatsoever, not merely about some inherently circumscribed set of objects or traits of objects; more "formal" because the validity of a mathematical demonstration is grounded in the structure of statements rather than in the nature of a particular subject matter. The postulates of any branch of demonstrative mathematics are not inherently about space, quantity, apples, angles or budgets, and any special meaning that may be associated with the postulates' descriptive terms plays no essential role in the process of deriving theorems. The question that confronts a pure mathematician (as distinct from the scientist who



KURT GÖDEL was photographed in his office at the Institute for Advanced Study by Arnold Newman. Gödel was born in Czechoslovakia in 1906. He received his doctorate from the University of Vienna in 1930 and served on its faculty until he came to the U. S.

employs mathematics in investigating a special subject matter) is not whether the postulates he assumes or the conclusions he deduces from them are true, but only whether the alleged conclusions are in fact the necessary logical consequences of the initial assumptions. This approach recalls Bertrand Russell's famous epigram: Pure mathematics is the subject in which we do not know what we are talking about, nor whether what we are saying is true.

A land of rigorous abstraction, empty of all familiar landmarks, is certainly not easy to get around in. But it offers compensations in the form of a new freedom of movement and fresh vistas. As mathematics became more abstract, men's minds were emancipated from habitual connotations of language and could construct novel systems of postulates. Formalization led in fact to a great variety of systems of considerable mathematical interest and value. Some of these systems, it must be admitted, did not lend themselves to interpretations as obviously intuitive ("common sense") as those of Euclidean geometry or arithmetic, but this fact caused no alarm. Intuition, for one thing, is an elastic faculty. Our children will have no difficulty in accepting as intuitively obvious the paradoxes of relativity, just as we do not boggle at ideas which were regarded as wholly unintuitive a couple of generations ago. Moreover intuition, as we all know, is not a safe guide: it cannot be used safely as a criterion of either truth or fruitfulness in scientific explorations.

However, the increased abstractness of mathematics also raised a more serious problem. When a set of axioms is taken to be about a definite and familiar domain of objects, it is usually possible to ascertain whether the axioms are indeed true of these objects, and if they are true, they must also be mutually consistent. But the abstract non-Euclidean axioms appeared to be plainly false as descriptions of space, and, for that matter, doubtfully true of anything. Thus the problem of establishing the internal consistency of non-Euclidean systems was formidable. In Riemannian geometry, for example, the famous parallel postulate of Euclid is replaced by the assumption that through a given point outside a line *no* parallel to the line can be drawn in the same plane. Now suppose the question: Is the Riemannian set of postulates consistent? They are apparently not true of the ordinary space of our experience. How then is their consistency to be tested? How can one prove they will not lead to contradictory theorems?

A general method for solving this problem was proposed. The underlying idea was to find a "model" for the postulates so that each postulate was converted into a true statement about the model. The procedure goes something like this. Let us take the word "class" to signify a collection of distinguishable elements, or "members." (For example, the class of prime numbers less than 10 is a collection consisting of 2, 3, 5 and 7 as members.) Suppose now we consider two purely abstract classes, K and L, concerning which these postulates are given:

1. Any two members of K are contained in just one member of L.
2. No member of K is contained in more than two members of L.
3. The members of K are not all contained in a single member of L.
4. Any two members of L contain just one member of K.
5. No member of L contains more than two members of K.

From this little set we can derive, by using customary rules of inference, certain theorems. For example, it can be shown that K contains just three members. But is the set a consistent one, so that mutually contradictory theorems can never be derived from it? This is where we invoke the help of a model, or interpretation, of the classes. Let K be the vertices of a triangle, and L its sides. Each of the five abstract postulates is then converted into a true statement: *e.g.*, the first postulate asserts that any two of the vertices are contained on just one side. In this way the set is proved to be consistent.

At first thought such a procedure may seem to suffice to establish the consistency of an abstract system such as plane Riemannian geometry. We may adopt a model embodying the Riemannian postulates in which the expression "plane" signifies the surface of a Euclidean sphere; the expression "point," a point on this surface; the expression "straight line," an arc of a great circle on this surface, and so on. Each Riemannian postulate can then be converted into a theorem of Euclid. For example, on this interpretation the Riemannian parallel postulate reads as follows: Through a point on the surface of a sphere, no arc of a great circle can be drawn parallel to a given arc of a great circle.

Unhappily this method is vulnerable to a serious objection; namely, that it attempts to solve a problem in one domain merely by shifting the problem to another (or, to put it another way, we invoke Euclid to demonstrate the consistency of a system which subverts Eu-

All gentlemen are polite.
No bankers are polite.
No gentlemen are bankers.

$$g \subset p$$
$$b \subset \overline{p}$$
$$\therefore\ g \subset \overline{b}$$

$$g\overline{p} = 0$$
$$bp = 0$$
$$gb = 0$$

SYMBOLIC LOGIC was invented in the middle of the 19th century by the English mathematician George Boole. In this illustration a syllogism is translated into his notation in two different ways. In the upper group of formulas, the symbol $\subset$ means "is contained in." Thus $g \subset p$ says that the class of gentlemen is included in the class of polite persons. In the equations below two letters together mean the class of things having both characteristics. For example, *bp* means the class of individuals who are bankers and polite. The second equation in the group says that this class has no members. A line above a letter means "not." (Not-*p*, for example, means impolite.)

clid). Riemannian geometry is proved to be consistent only if Euclidean geometry is consistent. Query, then: Is Euclidean geometry consistent? If we attempt to answer this question by invoking yet another model, we are no closer to our goal. In short, any proof obtained by this method will be only a "relative" proof of consistency, not an absolute proof.

So long as we can interpret a system by a model containing only a finite number of elements, we have no great difficulty in proving the consistency of its postulates. For example, the triangle model which we used to test the K and L class postulates is finite, and accordingly it is comparatively simple to determine by actual inspection whether the postulates are "true" and hence consistent. Unfortunately most of the postulate systems that constitute the foundations of important branches of mathematics cannot be mirrored in finite models; they can be satisfied only by non-finite ones. In a well-known set of axioms for elementary arithmetic one of the axioms asserts that every integer in the sequence of whole numbers has an immediate successor which differs from any preceding integer. Obviously any model used to test the set of postulates must mirror the infinity of elements postulated by this axiom. It follows that the truth (and so the consistency) of the set cannot be established by inspection and enumeration. Apparently we have reached an impasse.

Russell's Paradox

It may be tempting to suggest at this point that we can be sure that a set of postulates is consistent, *i.e.*, free from contradictions, if the basic notions employed are transparently "clear" and "certain." But the history of thought has not dealt kindly with the doctrine of intuitive knowledge implicit in this suggestion. In certain areas of mathematical research radical contradictions have turned up in spite of the "intuitive" clarity of the notions involved in the assumptions, and despite the seemingly consistent character of the intellectual constructions performed. Such contradictions (technically called "antinomies") have emerged, for example, in the theory of infinite numbers developed by Georg Cantor in the 19th century. His theory was built on the elementary and seemingly "clear" concept of class. Since modern systems in other branches of mathematics, particularly elementary arithmetic, have been built on the foundation of the theory of classes, it is pertinent to ask whether they, too, are not infected with contradictions.

In point of fact, Bertrand Russell constructed a contradiction within the framework of elementary logic itself. It is precisely analogous to the contradiction first developed in the Cantorian theory of infinite classes. Russell's antinomy can be stated as follows: All classes apparently may be divided into two groups: those which do not contain themselves as members, and those which do. An example of the first is the class of mathematicians, for patently the class itself is not a mathematician and is therefore not a member of itself. An example of the second is the class of all thinkable concepts, for the class of all thinkable concepts is itself a thinkable concept, and is therefore a member of itself. We shall call the first type of class "normal," and the second type "non-normal." Now let N stand for the class of all normal classes. We ask whether N itself is a normal class. If so, it is a member of itself. But in that case N is non-normal, because by definition a class which contains itself is non-normal. Yet if N is non-normal and thus a member of itself, it must be normal, because by definition all the members of N are normal. In short, N is normal if and only if N is non-normal. This fatal contradiction results from an uncritical use of the apparently pellucid notion of class.

Other paradoxes were found later, each of them constructed by means of familiar and seemingly cogent modes of reasoning. Non-finite models by their very nature involve the use of possibly inconsistent sets of postulates. Thus it became clear that, although the model method for establishing the consistency of axioms is an invaluable mathematical tool, that method does not supply a final answer to the problem it was designed to resolve.

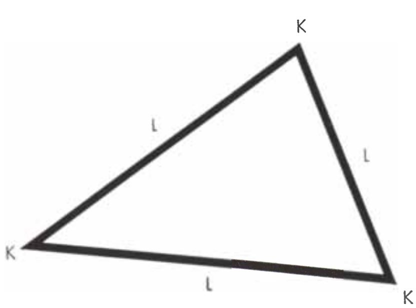
Hilbert's Meta-Mathematics

The eminent German mathematician David Hilbert then adopted the opposite approach of eschewing models and draining mathematics of any meaning whatever. In Hilbert's complete formalization, mathematical expressions are regarded simply as empty signs. The postulates and theorems constructed from the system of signs (called a calculus) are simply sequences of meaningless marks which are combined in strict agreement with explicitly stated rules. The derivation of theorems from postulates can be viewed as simply the transformation of one set of such sequences, or "strings," into another set of "strings," in accordance with precise rules of operation. In this manner Hilbert hoped to eliminate the danger of using any unavowed principles of reasoning.

Formalization is a difficult and tricky business, but it serves a valuable purpose. It reveals logical relations in naked clarity, as does a cut-away working model of a machine. One is able to see the structural patterns of various "strings" of signs: how they hang together, how they are combined, how they nest in one another, and so on. A page covered with the "meaningless" marks of such a formalized mathematics does not *assert* anything—it is simply an abstract design or a mosaic possessing a certain structure. But configurations of such a system can be described, and statements can be made about their various relations to one another. One may say that a "string" is pretty, or that it resembles another "string," or that one "string" appears to be made up of three others, and so on. Such statements will evidently be meaningful.

Now it is plain that any meaningful statements about a meaningless system do not themselves belong to that system. Hilbert assigned them to a separate realm which he called "meta-mathematics." Meta-mathematical statements are statements *about* the signs and expressions of a formalized mathematical system: about the kinds and arrangements of such signs when they are combined to form longer strings of marks called "formulas," or about the relations between formulas which may obtain as a consequence of the rules of manipulation that have been specified for them.

A few examples will illustrate Hilbert's distinction between mathematics (a system of meaningless expressions) and meta-mathematics (statements about mathematics). Consider the arithmetical expression $2+3=5$. This expression belongs to mathematics and is constructed entirely out of elementary arithmetical signs. Now we may make a statement about the displayed expression, *viz.*: " '$2+3=5$' is an arithmetical formula." The statement does not express an arithmetical fact: it belongs to meta-mathematics, because it characterizes the string of arithmetical signs. Similarly the expression $x=x$ belongs to mathematics, but the statement " 'x' is a variable" belongs to meta-mathematics. We may also make the following meta-mathematical statement: "The formula '$0=0$' is derivable from the formula '$x=x$' by substituting the numeral '0' for the variable 'x'." This statement specifies in what manner one arithmetical formula can be obtained from another formula, and thereby describes how the two formulas are related to each other. Again, we may make the meta-mathematical statement: " '$0\neq0$' is not a theorem." It says that the formula in question is not derivable from the axioms of arithmetic, or in other words, that a certain relation does not hold between the specified formulas of the system. Finally, the following statement also belongs to meta-mathematics: "Arithmetic is consistent" (*i.e.*, it is not possible to derive from the axioms of arithmetic both the formula $0=0$ and also the formula $0\neq0$).



MODEL for a set of postulates about two classes, K and L, is a triangle whose vertices are the members of K and whose sides are the members of L. The geometrical model shows that the postulates are consistent.

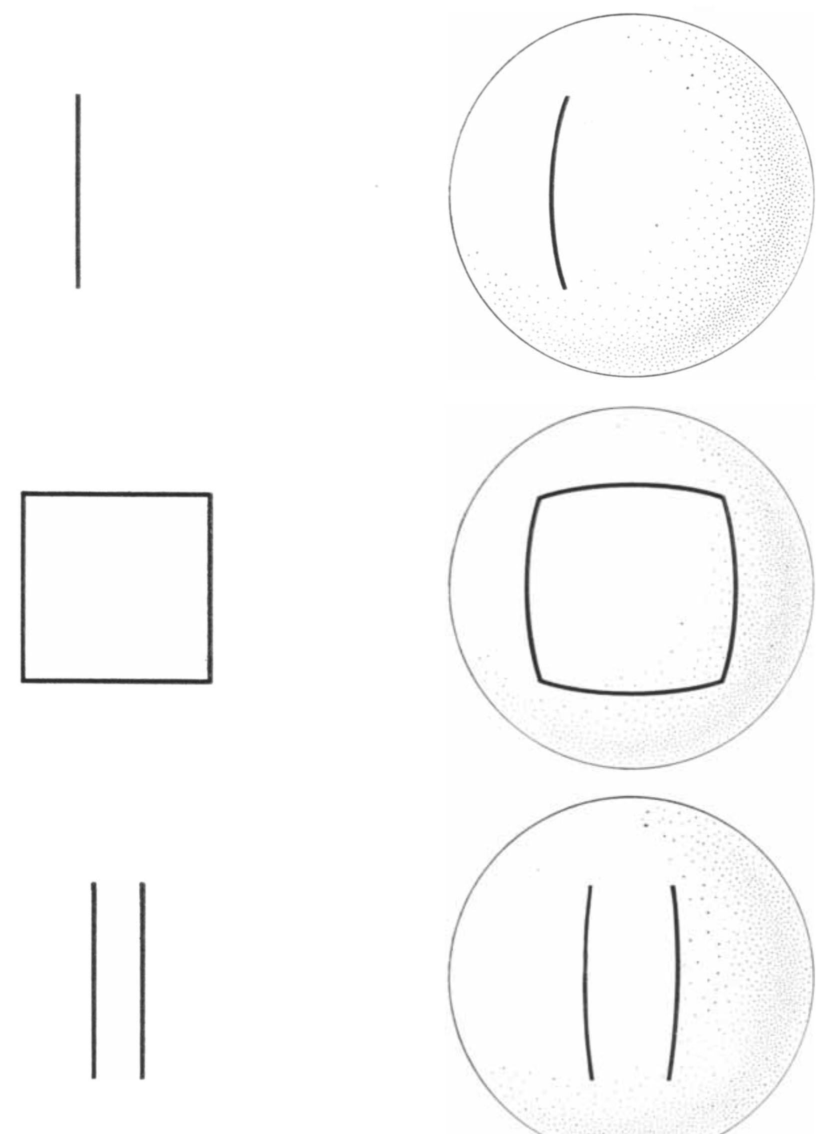
Upon this foundation—separation of meta-mathematical descriptions from mathematics itself—Hilbert attempted to build a method of "absolute" proof of the internal consistency of mathematical systems. Specifically, he sought to develop a theory of proof which would yield demonstrations of consistency by an analysis of the purely structural features of expressions in completely formalized (or "uninterpreted") calculi. Such an analysis consists exclusively of noting the kinds and arrangements of signs in formulas and determining whether a given combination of signs can be obtained from others in accordance with the explicitly stated rules of operation. An absolute proof of the consistency of arithmetic, if one could be constructed, would consist in showing by meta-mathematical procedures of a "finitistic" (non-infinite) character that two "contradictory" formulas, such as $(0=0)$ and its negation, cannot both be derived from the axioms or initial formulas by valid rules of inference.

It may be useful, by way of illustration, to compare meta-mathematics as a theory of proof with the theory of chess. Chess is played with 32 pieces of specified design on a square board containing 64 square subdivisions, where the pieces may be moved in accordance with fixed rules. Neither the pieces, nor the squares, nor the positions of the pieces on the board signify anything *outside* the game. In this sense the pieces and their configurations on the board are "meaningless." Thus the game is analogous to a formalized mathematical calculus. The pieces and the squares of the board correspond to the elementary signs of the calculus; the initial positions of the pieces correspond to the axioms or initial formulas of the calculus; their subsequent positions correspond to formulas derived from the axioms (*i.e.*, to the theorems), and the rules of the game correspond to the rules of inference for the calculus. Now, though configurations of pieces on the board are "meaningless," statements about these configurations, like meta-mathematical statements about mathematical formulas, are quite meaningful. A "meta-chess" statement may assert that there are 20 possible opening moves for White, or that, given a certain configuration of pieces on the board with White to move, Black is mate in three moves. Moreover, one can prove general "meta-chess" theorems on the basis of the finite number of permissible configurations on the board. The meta-chess theorem about the number of possible opening moves for White can be established in this way, and so can the meta-chess theorem that if White has only two Knights, it is impossible for White to mate Black. These and other "meta-chess" theorems can, in other words, be proved by finitistic methods of reasoning, consisting in the examination of each of a finite number of configurations that can occur under stated conditions. The aim of Hilbert's theory of proof, similarly, was to demonstrate by such finitistic methods the impossibility of deriving certain contradictory formulas in a calculus.

The Principia

It was Hilbert's approach, coupled with the formalization of logic itself in the famous *Principia Mathematica* by Alfred North Whitehead and Bertrand Russell, that led to the crisis to which Gödel supplied a final answer.

The grand object of *Principia*, published in 1910, was to demonstrate that mathematics is only a chapter of logic. But it made two contributions which are of particular interest to us here. First, following up work by the 19th-century pioneer George Boole, it supplied a system of symbols which permitted all statements of pure mathematics to be codified in a standard manner [see "Symbolic Logic," by John E. Pfeiffer; SCIENTIFIC AMERICAN, December, 1950]. Secondly, it stated in explicit form most of the rules of formal



NON-EUCLIDEAN GEOMETRY of Bernhard Riemann can be represented by a Euclidean model. The plane becomes the surface of a Euclidean sphere, points on the plane become points on this surface, straight lines become great circles. Thus a portion of the plane bounded by segments of straight lines is depicted as a portion of the sphere bounded by parts of great circles (*center*). Two parallel line segments are two segments of great circles (*bottom*), and these, if extended, indeed intersect, thus contradicting the parallel postulate.

logic that are employed in mathematical proofs. Thus *Principia* provided an essential instrument for investigating the entire system of arithmetic as a system of "meaningless" marks which could be operated upon in accordance with explicitly stated rules.

We turn now to the formalization of a small portion of *Principia*, namely, the elementary logic of propositions. The task is to convert this fragment into a "meaningless" calculus of uninterpreted signs and to demonstrate a method of proving that the calculus is free from contradictions.

Four steps are involved. First we must specify the complete "vocabulary" of signs to be employed in the calculus. Second, we state the "formation rules" (the rules of "grammar") which indicate the combinations of signs permissible as formulas (or "sentences"). Third, we specify the "transformation rules," which tell how formulas may be derived from others. Finally, we select certain formulas as axioms which serve as foundations for the entire system. The "theorems" of the system are all the formulas, including the axioms, that can be derived from the axioms by applying the transformation rules. A "proof" consists of a finite sequence of legitimate formulas, each of which is either an axiom or is derivable from preceding formulas in the sequence by the transformation rules.

The vocabulary for the elementary logic of propositions (often also called the "sentential calculus") is extremely simple. The "sentential" variables (which correspond to sentences or statements) are certain letters: p, q, r and so on. Then there are several connectives: $\sim$, which stands for "not"; $\vee$, which stands for "or"; $\supset$, which stands for "if . . . then," and $\cdot$, which stands for "and." Parenthesis marks are used as signs of punctuation.

Each sentential variable counts as a formula, and the signs may be combined according to the formation rules to form other formulas: *e.g.*, $p \supset q$. If a given sentence $(p \supset q)$ is a formula, so is its negation $\sim (p \supset q)$. If two sentences, S_1 and S_2, are formulas, so is the combination $(S_1) \vee (S_2)$. Similar conventions apply to the other connectives.

For transformations there are just two rules. One, the rule of substitution, says that if a sentence containing sentential variables has been assumed, any formulas may be substituted everywhere for these variables, so that the new sentence will count as a logical consequence of the original one. For example, having accepted $p \supset p$ (if p, then p), we can

1 $(p \vee p) \supset p$ If either p or p, then p	If either Henry VIII was a boor or Henry VIII was a boor, then Henry VIII was a boor.
2 $p \supset (p \vee q)$ If p, then either p or q	If psychoanalysis is valid then either psychoanalysis is valid or headache powders are better.
3 $(p \vee q) \supset (q \vee p)$ If either p or q, then either q or p	If either Immanuel Kant was punctual or Hollywood is sinful then either Hollywood is sinful or Immanuel Kant was punctual.
4 $(p \supset q) \supset [(r \vee p) \supset (r \vee q)]$ If p implies q, then (either r or p) implies (either r or q)	If ducks waddle implies that $\sqrt{2}$ is a number then (either Churchill drinks brandy or ducks waddle) implies (either Churchill drinks brandy or $\sqrt{2}$ is a number).

SENTENTIAL CALCULUS, or the elementary logic of propositions, is based on four axioms. The nonsense statements illustrate how general is the "meaning" of the symbols.

always substitute q for p, obtaining as a theorem the formula $q \supset q$; or we may substitute $(p \vee q)$ for p, obtaining $(p \vee q) \supset (p \vee q)$. The other rule, that of detachment, simply says that if the sentences S_1 and $S_1 \supset S_2$ are logically true, we may also accept as logically true the sentence S_2.

The calculus has four axioms, essentially those of *Principia*, which are given in the table at the top of this page, along with nonsensical English sentences to illustrate their independence of meaning. The clumsiness of the translations, especially in the case of the fourth axiom, will perhaps help the reader to realize the advantages of using a special symbolism.

Search for a Proof

Each of these axioms may seem "obvious" and trivial. Nevertheless it is possible to derive from them with the help of the stated transformation rules an indefinitely large class of theorems which are far from obvious or trivial. However, at this point we are interested not in deriving theorems from the axioms but in showing that this set of axioms is not contradictory. We wish to prove that, using the transformation rules, it is impossible to derive from the axioms any formula S (*i.e.*, any expression which would normally count as a sentence) together with its negation $\sim$ S.

Now it can be shown that $p \supset (\sim p \supset q)$ (if p, then if not-p then q) is a theorem in the calculus. Let us suppose, for the sake of demonstration, that a formula S and its contradictory $\sim$ S were both deducible from the axioms, and test the consequences by means of this theorem. By substituting S for p in the theorem, as permitted by the rule of substitution, we first obtain

S ⊃ (∼ S ⊃ q). From this, assuming S to be demonstrably true, we could next obtain, by the detachment rule, ∼ S ⊃ q. Finally, if we assume ∼ S also is demonstrable, by the detachment rule we would get q. Since we can substitute any formula whatsoever for q, this means that any formula whatsoever would be deducible from the axioms. Thus if both S and its contradictory ∼ S were deducible from the axioms, then *any* formula would be deducible. We arrive, then, at the conclusion that if the calculus is not consistent (*i.e.*, if both S and ∼ S are deducible) any theorem can be derived from the axioms. Accordingly, to prove the consistency of the calculus, our task is reduced to finding at least one formula which cannot be derived from the axioms.

The way this is done is to employ meta-mathematical reasoning upon the system before us. The actual procedure is elegant. It consists in finding a characteristic of formulas which satisfies the three following conditions. (1) it is common to all four axioms; (2) it is "hereditary," that is, any formula derived from the axioms (*i.e.*, any theorem) must also have the property; (3) there must be at least one formula which does not have the characteristic and is therefore not a theorem. If we succeed in this threefold task, we shall have an absolute proof of the consistency of the axioms. If we can find an array of signs that conforms to the requirements of being a formula but does not possess the specified characteristic, this formula cannot be a theorem. In other words, the finding of a single formula which is not a theorem suffices to establish the consistency of the system.

Let us choose as a characteristic of the required kind the property of being a "tautology." In common parlance a tautology is usually considered to be a redundant statement such as: "John is the father of Charles and Charles is a son of John." But in logic a tautology is defined as a statement which excludes no logical possibilities—*e.g.*, "Either it is raining or it is not raining." Another way of putting this is to say that a tautology is "true in all possible worlds." We apply this definition to formulas in the system we are considering. A formula is said to be a tautology if it is invariably true regardless of whether its elementary constituents (p, q, r and so on) are true or false. Now all four of our axioms plainly possess the property of being tautologous. For example, the first axiom, $(p \vee p) \supset p$, is true regardless of whether p is assumed to be true or is assumed to be false. The axiom says, for instance:

CONNECTIVES AND ELEMENTARY SIGNS

SIGNS	GÖDEL NUMBER	MEANING
~	1	not
v	2	or
⊃	3	If . . . then
∃	4	There is an . . .
=	5	equals
0	6	zero
S	7	The next following number
(	8	punctuation mark
)	9	punctuation mark
,	10	punctuation mark

SENTENTIAL VARIABLES (EACH DESIGNATED BY A NUMBER GREATER THAN 10 AND DIVISIBLE BY 3)

VARIABLES	GÖDEL NUMBER	SAMPLE
p	12	Henry VIII was a boor.
q	15	Headache powders are better.
r	18	Ducks waddle.
etc.		

INDIVIDUAL VARIABLES (EACH DESIGNATED BY A NUMBER GREATER THAN 10 WHICH LEAVES A REMAINDER OF 1 WHEN DIVIDED BY 3)

VARIABLES	GÖDEL NUMBER	MEANING
x	13	a numerical variable
y	16	a numerical variable
z	19	a numerical variable
etc.		

PREDICATE VARIABLES (EACH DESIGNATED BY A NUMBER GREATER THAN 10 WHICH LEAVES A REMAINDER OF 2 WHEN DIVIDED BY 3)

VARIABLES	GÖDEL NUMBER	SAMPLE
P	14	Being a boor
Q	17	Being a headache powder
R	20	Being a duck
etc.		

ELEMENTARY GÖDEL NUMBERS are assigned to every symbol used in his system of symbolic logic in accordance with the orderly scheme which is illustrated in the table above.

"If either Mount Rainier is 20,000 feet high or Mount Rainier is 20,000 feet high, then Mount Rainier is 20,000 feet high." It makes no difference whether Mount Rainier is actually 20,000 feet high or not: the statement is still true in either case. A similar demonstration can be made for the other axioms.

Next it is possible to prove that the property of being a tautology is hereditary under the transformation rules, though we shall not turn aside to give the demonstration. It follows that every formula properly derived from the axioms (*i.e.*, every theorem) must be a tautology. Having performed these two steps, we are ready to look for a formula which does not possess the characteristic of being a tautology. We do not have to look very hard. For example, $p \vee q$ fits the requirements. Clearly it is not a tautology; it is the same as saying: "Either John is a philosopher or Charles reads SCIENTIFIC AMERICAN." This is patently not a truth of logic; it is not a sentence that is true irrespective of the truth or falsity of its elementary constituents. Thus $p \vee q$, though it purports to be a gosling, is in fact a duckling; it is a formula but it is not a theorem.

We have achieved our goal. We have found at least one formula which is not a theorem, therefore the axioms must be consistent.

Gödel's Answer

The sentential calculus is an example of a mathematical system for which the objectives of Hilbert's theory of proof are fully realized. But this calculus codifies only a fragment of formal logic. The question remains: Can a formalized system embracing the whole of arithmetic be proved consistent in the sense of Hilbert's program?

This was the conundrum that Gödel answered. His paper in 1931 showed that all such efforts to prove arithmetic to be free from contradictions are doomed to failure.

His main conclusions were twofold. In the first place, he showed that it is impossible to establish a meta-mathematical proof of the consistency of a system comprehensive enough to contain the whole of arithmetic—unless, indeed, this proof itself employs rules of inference much more powerful than the transformation rules used in deriving theorems within the system. In short, one dragon is slain only to create another.

Gödel's second main conclusion was even more surprising and revolutionary, for it made evident a fundamental limitation in the power of the axiomatic method itself. Gödel showed that *Principia*, or any other system within which arithmetic can be developed, is essentially incomplete. In other words, given *any* consistent set of arithmetical axioms, there are true arithmetical statements which are not derivable from the set. A classic illustration of a mathematical "theorem" which has thwarted all attempts at proof is that of Christian Goldbach, stating that every even number is the sum of two primes. No even number has ever been found which is not the sum of two primes, yet no one has succeeded in finding a proof that the rule applies without exception to all even numbers. In reply to Gödel it might be suggested that the set of arithmetical axioms could be modified or expanded to make "underivable" statements derivable. But Gödel showed that this approach promises no final cure. That is, even if any finite number of other axioms is added, there will always be further arithmetical truths which are not formally derivable.

How did Gödel prove his conclusions? His paper is difficult. A reader must master 46 preliminary definitions, together with several important preliminary theorems, before he gets to the main results. We shall take a much easier road; nevertheless we hope at least to offer glimpses of the argument.

Gödel Numbers

Gödel first devised a method of assigning a number as a label for each elementary sign, each formula and each proof in a formalized system. To the elementary signs he attached as "Gödel numbers" the integers from 1 to 10; to the variables he assigned numbers according to certain rules [*see table at left*]. To see how a number is given to a formula of the system, let us take this formula: $(\exists x)\ (x = Sy)$, which reads literally "there is an x, such that x is the immediate successor of y" and in effect says that every number has an immediate successor. The numbers associated with the formula's 10 successive signs are, respectively, 8, 4, 13, 9, 8, 13, 5, 7, 16, 9 [*see table*]. Now these numbers are to be used as exponents, or powers, of the first 10 prime numbers (*i.e.*, 2, 3, 5 and so on). The prime numbers, raised to these powers, are multiplied together. Thus we get the number $2^8 \times 3^4 \times 5^{13} \times 7^9 \times 11^8 \times 13^{13} \times 17^5 \times 19^7 \times 23^{16} \times 29^9$. The product is the Gödel number of the formula. In the same way every formula can be represented by a single unique number.

We can assign a number to a sequence of formulas, such as may occur in some

A	100
B	4 × 25
C	$2^2 \times 5^2$
A	162
B	2 × 81
C	$2^1 \times 3^4$
D	1 ↓ ~ 4 ↓ ∃
E	~∃

GÖDEL NUMBERS of formulas are constructed by raising the prime numbers, in sequence, to powers which are the Gödel numbers of the symbols involved. Thus 100 is not a Gödel number because its factors skip the prime number 3. On the other hand, 162 is the Gödel number for "there is not."

proof, by a similar process. Let us say that we have a sequence of two formulas, the second derived from the first. For example, by substituting 0 for y in the formula given above, we derive $(\exists\, x)\ (x = S0)$, which says that 0 has an immediate successor. Now the first and second formulas are identified by Gödel numbers which we shall call m and n, respectively. To label this sequence, we use the Gödel numbers m and n as exponents and multiply the first two primes (2 and 3) raised to these powers. That is to say, the Gödel number that identifies the sequence is $2^m \times 3^n$. In like manner we can give a number to any sequence of formulas or any other expression in the system.

What has been done so far is to establish a method for completely arithmetizing a formal system. The method is essentially a set of directions for making a one-to-one correspondence between specific numbers and the various elements or combinations of elements of the system. Once an expression is given, it can be uniquely numbered. But more than that, we can retranslate any Gödel number into the expression it represents by factoring it into its component prime numbers, which can be done in only one way, as we know from a famous theorem of arithmetic [*see illustration below*]. In other words, we can take the number apart as if it were a machine, see how it was constructed and what went into it, and we can dissect an expression or a proof in the same way.

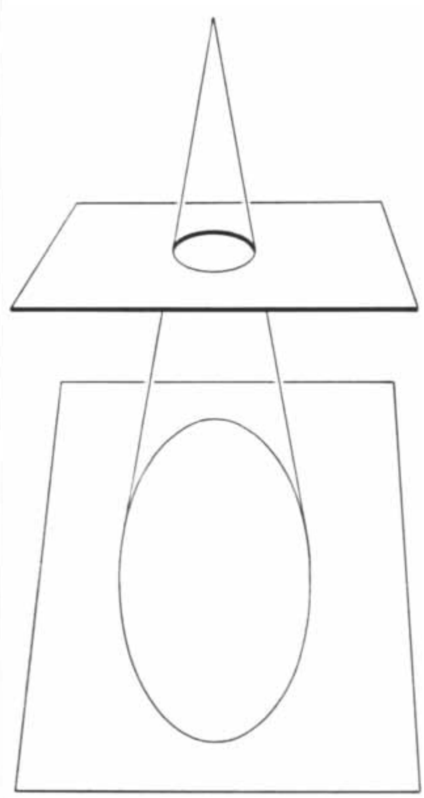
This leads to the next step. It occurred to Gödel that meta-mathematical statements can be translated into arithmetical terms by a process analogous to mapping. In geography the spatial relations between points on the spherical earth can be projected onto a flat map; in mathematical physics relations between the properties of electric currents can be mapped in terms of the flow of fluids; in mathematics itself relations in geometry can be translated into algebra. Gödel saw that if complicated meta-mathematical statements about a system could be translated into, or mirrored by, arithmetical statements within the system itself, an important gain would be achieved in clarity of expression and facility of analysis. Plainly it would be easier to deal with arithmetical counterparts of complex logical relations than with the logical relations themselves. To cite a trivial analogy: If customers in a supermarket are given tickets with numbers determining the order in which they are to be waited on, it is a simple matter to discover, merely by scrutinizing the numbers, how many persons have been served, how many are waiting, who precedes whom and by how many customers, and so on.

What Gödel aimed at was nothing less than the complete arithmetization of meta-mathematics. If each meta-mathe-

A	125,000,000
B	64 × 125 × 15,625
C	$2^6 \times 3^5 \times 5^6$
D	6 5 6 ↓ ↓ ↓ 0 = 0
E	0 = 0

ARITHMETICAL FORMULA "zero equals zero" has the Gödel number 125 million. Reading down from A to E, the illustration shows how the number is translated into the expression it represents; reading up, how the number for the formula is derived.

matical statement could be uniquely represented in the formal system by a formula expressing a relation between numbers, questions of logical dependence between meta-mathematical statements could be explored by examining the corresponding relations between integers. Gödel did in fact succeed brilliantly in mapping the meta-mathematics of arithmetic upon arithmetic itself. We need cite only one illustration of how a meta-mathematical statement can be made to correspond to a formula in the formal arithmetical system. Let us take the formula $(p \vee p) \supset p$. We may make the meta-mathematical statement that the formula $(p \vee p)$ is the initial part of this formula. Now we can represent this meta-mathematical statement by an arithmetical formula which says in effect that the Gödel number of the initial part is a factor of the Gödel number of the complete formula. Evidently this is so, for the Gödel number of $(p \vee p)$ is $2^8 \times 3^{12} \times 5^2 \times 7^{12} \times 11^9$, while the Gödel number of $(p \vee p) \supset p$ is $2^8 \times 3^{12} \times 5^2 \times 7^{12} \times 11^9 \times 13^3 \times 17^{12}$.



MAPPING of objects from one realm onto another is illustrated above. Points in the upper, horizontal plane can be uniquely mapped onto the lower plane, which slants downward from back to front, by drawing lines from a single point through the points of the upper plane and extending them until they intersect the lower plane. Thus a circle in the upper plane maps as an ellipse in the lower. Gödel mapped statements about arithmetic as expressions in arithmetic.

The Undecidable Proposition

We have now arrived at the very heart of Gödel's analysis. He showed how to construct an arithmetical formula, whose Gödel number we shall suppose is h, which corresponds to the meta-mathematical statement, *viz.*: "The formula with Gödel number h is not demonstrable." In other words, this formula (call it G) in effect asserts its own indemonstrability, though it is a legitimate formula belonging to the formal system of arithmetic. Gödel then proceeded to examine the question whether G is or is not a demonstrable formula of arithmetic. He was able to show that G is demonstrable if, and only if, its negation, $\sim$ G, also is demonstrable. But if a formula and its negation are both derivable from a set of axioms, obviously the axioms are not consistent. It follows that if arithmetic is consistent, neither G nor its negation is demonstrable. That is to say, G is an undecidable formula of arithmetic. Now from this Gödel proved the indemonstrability of the proposition that arithmetic is consistent. It can be shown that a meta-mathematical statement of arithmetic's consistency corresponds to a certain arithmetical formula, A, and that the arithmetical formula A $\supset$ G (if A, then G) is demonstrable. Thus if A were demonstrable, G would be also. But we have just seen that G is not demonstrable. It follows that A is undecidable. In short, the consistency of arithmetic is undecidable by any meta-mathematical reasoning which can be represented within the formalism of arithmetic.

Gödel's analysis does not exclude a meta-mathematical demonstration of the consistency of arithmetic; indeed, such proofs have been constructed, notably by Gerhard Gentzen, a member of the Hilbert school. But these "proofs" are in a sense pointless, because they employ rules of inference whose own internal consistency is as much open to doubt as is the formal consistency of arithmetic itself. Gentzen's proof employs a rule of inference which in effect permits a formula to be derived from an infinite class of premises. And the employment of this non-finitistic meta-mathematical notion raises once more the difficulty which Hilbert's original program was intended to resolve.

There is another surprise coming. Although the formula G is undecidable, it can be shown by meta-mathematical reasoning that G is nevertheless a *true* arith-

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2638 N. Pulaski Road, Chicago 39, Illinois metical statement and expresses a property of the arithmetical integers. The argument for this conclusion is quite simple. We need recall only that Gödel mapped meta-mathematical statements upon arithmetical formulas in such a way that every true meta-mathematical statement corresponds to a true arithmetical formula. Now G corresponds to a meta-mathematical statement ("the formula with Gödel number h is not demonstrable") which, as we have seen, is true, unless arithmetic is inconsistent. It follows that G itself must be true. We have thus established an *arithmetical* truth by a *meta-mathematical* argument.

So we come to the finale of Gödel's amazing and profound intellectual symphony. Arithmetic is incomplete, in the transparent sense that there is at least one arithmetical truth which cannot be derived from the arithmetical axioms and yet can be established by a meta-mathematical argument outside the system. Moreover, arithmetic is *essentially* incomplete, for even if the true formula G were taken as an axiom and added to the original axioms, the augmented system would still not suffice to yield formally all the truths of arithmetic: we could still construct a true formula which would not be formally demonstrable within the system. And such would be the case no matter how often we repeated the process of adding axioms to the initial set.

This remarkable conclusion makes evident an inherent limitation in the axiomatic method. Contrary to previous assumptions, the vast "continent" of arithmetical truth cannot be brought into systematic order by way of specifying once for all a fixed set of axioms from which all true arithmetical statements would be formally derivable.

Men and Calculating Machines

The far-reaching import of Gödel's conclusions has not yet been fully fathomed. They show that the hope of finding an absolute proof of consistency for any deductive system expressing the whole of arithmetic cannot be realized, if such a proof must satisfy the finitistic requirements of Hilbert's original program. They also show that there is an endless number of true arithmetical statements which cannot be formally deduced from any specified set of axioms in accordance with a closed set of rules of inference. It follows that an axiomatic approach to the theory of numbers, for example, cannot exhaust the domain of arithmetic truth. Whether an all-inclusive general definition of mathematical or logical truth can be devised, and whether, as Gödel himself appears to believe, only a thoroughgoing Platonic realism can supply such a definition, are problems still under debate.

Gödel's conclusions have a bearing on the question whether a calculating machine can be constructed that would equal the human brain in mathematical reasoning. Present calculating machines have a fixed set of directives built into them, and they operate in a step-by-step manner. But in the light of Gödel's incompleteness theorem, there is an endless set of problems in elementary number theory for which such machines are inherently incapable of supplying answers, however complex their built-in mechanisms may be and however rapid their operations. The human brain may, to be sure, have built-in limitations of its own, and there may be mathematical problems which it is incapable of solving. But even so, the human brain appears to embody a structure of rules of operation which is far more powerful than the structure of currently conceived artificial machines. There is no immediate prospect of replacing the human mind by robots.

Gödel's proof should not be construed as an invitation to despair. The discovery that there are arithmetical truths which cannot be demonstrated formally does not mean that there are truths which are forever incapable of becoming known, or that a mystic intuition must replace cogent proof. It does mean that the resources of the human intellect have not been, and cannot be, fully formalized, and that new principles of demonstration forever await invention and discovery. We have seen that mathematical propositions which cannot be established by formal deduction from a given set of axioms may nevertheless be established by "informal" meta-mathematical reasoning.

Nor does the fact that it is impossible to construct a calculating machine equivalent to the human brain necessarily mean that we cannot hope to explain living matter and human reason in physical and chemical terms. The possibility of such explanations is neither precluded nor affirmed by Gödel's incompleteness theorem. The theorem does indicate that the structure and power of the human mind are far more complex and subtle than any non-living machine yet envisaged. Gödel's own work is a remarkable example of such complexity and subtlety. It is an occasion not for discouragement but for a renewed appreciation of the powers of creative reason.

New trends and developments in designing electrical products . . .

How to determine which General Electric Alnico Permanent Magnet grade offers the optimum set of magnetic and physical properties for a particular application

The basic function of a permanent magnet is to provide a specific magnetic flux across a given air gap. The basic problem for the designer is to select a magnetic material with the optimum combination of magnetic and physical properties to fulfill this function.

Since the permanent magnet has considerable influence on the final size, cost, and efficiency of the product, it is important to know the primary characteristics of each of the seven available General Electric Alnico grades.

Each of these grades offers specific advantages in available energy, unit cost, and physical properties. No one grade excels in all of them.

In terms of energy product, cast Alnico 5 has no peer among magnetic alloys. Its 5 million minimum gauss-oersteds is 43% higher than Alnico 6.

Its demagnetization curve (Figure 1) shows that Alnico 5 has the high-

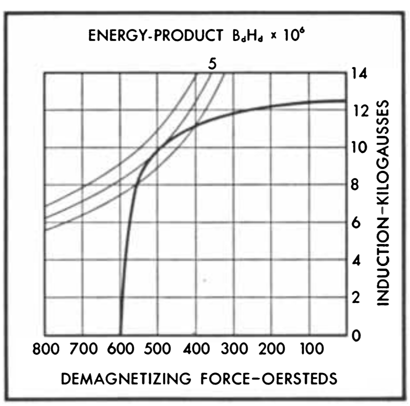

Fig. 1 — Alnico 5 Energy Product and Demagnetization Curves

est residual induction of all the Alnicos, as well as relatively high coercive force. This means that a smaller cross-sectional area and less total volume will be required to maintain a given air gap density.

Thus, where there are space restrictions, as in hearing aids, Alnico 5 has more available energy per unit volume. Where there are weight restrictions, as in airborne magnetrons, Alnico 5 offers more available energy per pound. And where there are cost considerations, as in loud speakers, Alnico 5 provides maximum external energy per dollar.

At the opposite extreme, Alnico 3 has one of the lowest energy products of the Alnicos — 1.38 million gauss-oersteds (Figure 2). About 3½ times more Alnico 3 than Alnico 5 is required to produce a given air gap field energy requirement.

However, because of its lower cost, Alnico 3 offers important savings in applications like toys and novelties, where performance and weight are not critical factors.

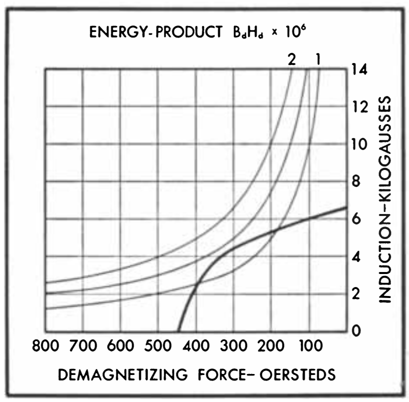

Fig. 2 — Alnico 3 Energy Product and Demagnetization Curves

Despite its relatively low energy product, Alnico 3 still provides more external energy, at lower cost, than does 37% cobalt steel — the best of all the magnet steels.

G-E Alnico 6 has an energy product of 3.5 million gauss-oersteds, ranking second only to Alnico 5. But the primary advantage of this grade lies in its flatter, more stable demagnetization curve (Figure 3, see top of next column).

Alnico 6 has ability to provide useful field energy under dynamic operating conditions. And in certain applications, Alnico 6, despite its lower energy product, will produce a higher gap flux density than Alnico 5.

For motors, generators and lifting applications, where the magnet is operating under varying demagnet-

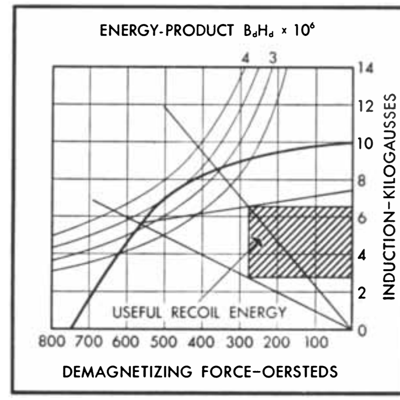

Fig. 3 — Alnico 6 Energy Product and Demagnetization Curves

izing influences, Alnico 6 offers greater stability and high useful recoil energy.

Generally speaking, permanent magnets' physical properties are seldom the primary consideration when selecting magnetic materials. However, in certain high rotary speed applications, such as rotors, physical strength is of major importance. This necessitates the use of a sintered, instead of a cast, Alnico grade. These sintered magnets have tremendously improved physical properties, with but a slight sacrifice in magnetic properties.

Sintered Alnico 2, for example, has more than 20 times the tensile strength of cast Alnico 2. And, it has 10 times the transverse rupture strength, in addition to more uniform magnetic properties. Approximately the same order of structural improvements holds true for sintered Alnicos 4 and 5.

Selecting the proper magnetic material is a crucial and complex part of the design problem. If you would like the assistance of a G-E Magnet Engineer in this, or any other, stage of your permanent magnet design, write: *Carboloy Department of General Electric Company, 11199 E. 8 Mile Ave., Detroit 32, Michigan.*

Progress Is Our Most Important Product

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"The finest steels ever developed"...

In this new ultra-modern Research Center at Monroeville, Pa. United States Steel is intensifying its activities in fundamental and applied research to better serve a changing world.*

It is safe to say that every man, woman and child living in America will in some way be benefited from the work being done in these laboratories.

For, by advancing the knowledge of steel and its related products—by better utilization of raw materials – by improving steelmaking techniques – by developing new methods of recovery and purification of coal chemicals – and by other allied research activities, from here will come not only better steels to meet the more stringent requirements of tomorrow, but a whole host of valuable products undreamed of today.

To accomplish this end, facilities at the Research Center are divided into two main groups: the Edgar C. Bain Laboratory for Fundamental Research which engages in research of a basic nature or of long-range significance—and the Applied Research Laboratory which applies basic scientific knowledge from all available sources to the improvement of processes and products and the development of new ones.

The Fundamental Research Laboratory

Broadly speaking, work in the Fundamental Research Laboratory covers four scientific fields: Physics, Physical Chemistry, Physical Metallurgy and Metallurgical Chemistry.

Specific activities of moment are concerned with fundamental studies of the chemical equilibria of interest in steelmaking and related operations, vacuum melting techniques, and the use of radioactive tracer elements in scientific investigations . . . the precise measurement of various physical, electrical and magnetic phenomena, electron microscopy and X-ray studies . . . determination of the effects of elevated temperatures on the properties of metals . . . how heat treatment affects the microstructure and properties of steel . . . the development of new or improved metallographic techniques. In short, here are accumulated scientific data of a fundamental nature that will provide an ever-broadening basis for the technology of the future.

Some of the rather unusual facilities available in this laboratory include an X-ray microanalyzer – perfected by the Fundamental Research Laboratory and, we believe, the first of its type to be used in this country. This instrument is capable of identifying microscopic particles which cannot be removed from the iron matrix.

Also designed and built at the Fundamental Research Laboratory is a unique micro-hardness tester for measuring the hardness of the individual constituents observed in the microstructure of a steel specimen.

To investigate properties of steels intended for high temperature service, the Fundamental Research Laboratory has developed apparatus which permits the measurement of hardness at temperatures up to 1500° F.

High-speed motion-picture photography, using a camera which operates at speeds up to 3000 frames per second, is being employed to record, for example, what happens in a welding arc, in the combustion zone in front of a blast furnace tuyere, in steel pouring and teeming streams and during the breaking of mechanical test specimens.

As an aid in developing steels with improved properties through the reduction of gaseous impurities, a furnace for the melting and casting of small, experimental heats in vacuum or under special atmospheres is available. (A similar vacuum furnace of 300 pounds capacity is available in the Applied Research Laboratory.)

The Applied Research Laboratory

The Applied Research Laboratory directs its efforts largely to specific, definable problems, the solutions for which are usually in immediate demand.

* *Important research is also carried out by several of the Operating Divisions and Associated Companies of United States Steel. For example, the Oliver Iron Mining Division operates a unique laboratory at Duluth, Minnesota, for studies on the mining and beneficiation of iron ore. Other laboratories are operated by the National Tube Division in Pittsburgh, Pa., the American Steel and Wire Division in Cleveland, Ohio, and the Universal Atlas Cement Company in Buffington, Indiana, for carrying out research directly relating to their respective operations and products.*

may well have their beginnings here

Of vital importance, if the country is to be assured of an uninterrupted supply of steel in the future, is optimum utilization of raw materials. This involves research on the recovery and beneficiation of lower grade iron ores (the so-called "taconites") and their utilization in the blast furnace . . . studies for evaluating various methods of agglomerating ore concentrates, such as sintering, nodulizing or pelletizing. A specially designed, experimental sintering machine makes it possible to study sintering characteristics of various raw materials as well as the sintering operation itself.

Paralleling this program are studies to develop an increasing use of low grade coals . . . to increase recovery of coal from coal washery plants . . . to improve coke quality through better selection and blending of coals. The Laboratory has complete facilities for preparing and blending coals, for closely controlled, experimental coking operations and for exhaustive testing of the experimental cokes produced.

Now being greatly extended is a research program for the continued improvement in quality of the chemicals recovered from coke oven gases—benzene, toluene, xylene, naphthalene, pyridine, phenol, etc. The work in this field not only has resulted in chemicals of higher purity but has greatly increased their availability for the final products made from them—plastics, resins, dyes, pharmaceuticals and a host of others.

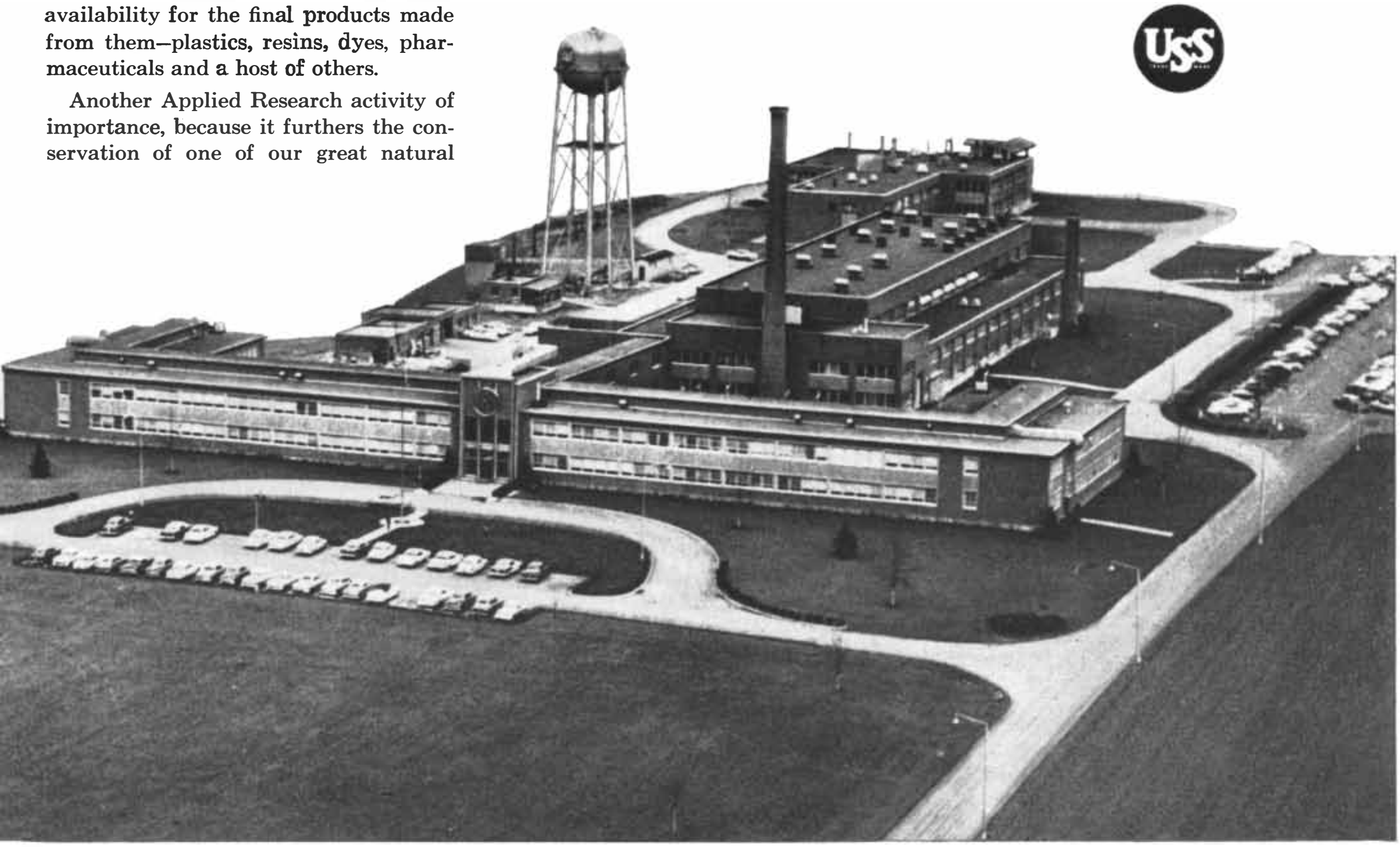
Another Applied Research activity of importance, because it furthers the conservation of one of our great natural resources, wood, comprises extensive studies of the use of coal-tar creosote . . . improved methods of application . . . factors influencing permanence . . . toxicity to wood-destroying organisms and so forth. Other investigations which are being actively pursued concern the recovery and utilization of the lesser known compounds not presently recovered from coal tar.

United States Steel has pioneered in the field of coated steel products, particularly electrolytic tin plate, and is continuing to make significant contributions on this subject. These studies have had a profound influence on the manufacture of tin plate throughout the world, resulting in more efficient utilization of available supplies of tin, and the development of such entirely new products as differentially coated tin plate.

Directly attributable to the work done in the Applied Research Laboratory is the development of new and improved alloy, stainless and other special steels. For example, the now familiar high strength, low alloy steels having superior resistance to atmospheric corrosion, of which "COR-TEN" Steel is the prototype . . . "T-1" Constructional Alloy Steel, a low carbon alloy steel which, furnished in the heat treated condition, provides high strength and toughness plus excellent weldability . . . ultra-high strength steels for aircraft landing gears and other critical aircraft parts requiring maximum strength and reliability with minimum weight . . . age-hardening austenitic steels . . . steels for television picture tubes . . . stainless steels resistant to sulphuric acid. And for the chemical industry, for steam and gas turbines and jet propelled aircraft, steels with improved corrosion resistance and high temperature properties. These problems, and many more, engage the attention of Applied Research.

Personnel

Now something about the men and women who staff this new Research Center of United States Steel. More than 500 in number, they include many of the leading research scientists in the steel industry. These outstanding metallurgists, physicists, chemists and highly skilled technicians operate as research teams to continually advance the frontiers of steel technology. Working with the ultra-modern facilities available in these splendid laboratories, their aim is to make certain that the familiar phrase "Only Steel can do so many jobs so well" will be as true in the years ahead as it is today. United States Steel Corporation, Pittsburgh 30, Pennsylvania.



CORNING GLASS

BULLETIN FOR PEOPLE WHO MAKE THINGS

CORNING GLASS WORKS, 49-6 Crystal Street, Corning, New York

Please send me the following material:

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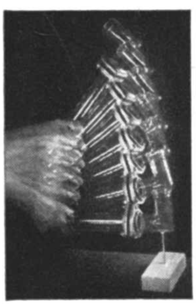
A lot of our customers, to their continuing delight and profit (we hope), have discovered that glass is sort of platypus-like in that it, too, can be made to combine many useful characteristics.

Take, for example, PYREX brand pipe. Here you see a man using a piece of it to drive a one-inch nail in a pine block. This is essentially an extra-curricular activity for glass pipe, which is more at home conveying metal-eating acids around chemical plants, but it's a way of showing just how tough glass can be when it's *made* that way.

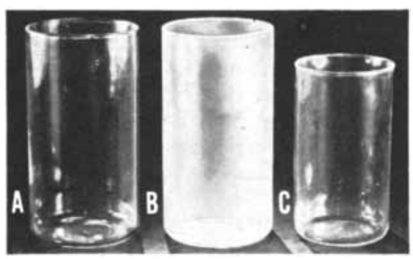


All of which may serve to illustrate for you how we can arrange the optical, chemical, thermal, mechanical, and electrical properties of glass in different combinations to match a considerable variety of end-use requirements. In fact, we've worked up some 50,000 different formulas for glass in our years of helping customers solve specific design and processing problems.

If platypus-like glass is a novel idea to you, if you've never given glass a second thought as a highly adaptable design and construction material, we suggest your reading a pocket-size volume entitled "Glass and You." It tells in a few words and many pictures how glass contributes to profit and pleasure and we'd be delighted to send you a copy. Or, if you're more concerned with putting glass to work for you than in learning what it's doing for others, there's a slightly more technical bulletin called, "Glass—its increasing importance in product design." We'll be glad to send you either—or both.

Most remarkable glass

In 1952 Philadelphia's Franklin Institute presented the John Price Wetherill Medal to Corning's Dr. Martin E. Nordberg and Harrison P. Hood for inventing the most fabulous of glasses—VYCOR brand 96 per cent silica glasses.



Evolution of a VYCOR jar: A—formed by conventional glass blowing; B—"thirsty glass"; C—finished product.

These two scientists discovered a composition that appeared to be a combination of two distinct types of glasses. One type could be dissolved out, leaving a skeleton of 96 per cent or more of silica filled with so many millions of holes that a one-inch cube contained some 60,000 square feet of hole surface.

This new child of research was dubbed "thirsty glass" because, just sitting around, it absorbed moisture right out of the air. But our researchers were on the trail of something even more exciting. They heated their "thirsty glass" and it shrank to two-thirds its original size. The millions of little holes vanished and left a vacuum-tight glass that looked like any other—except that you could take this new glass white-hot from a blazing furnace and plunge it into ice water without the slightest injury. It was a glass as ideal as fused quartz, but different since it could be melted, mass produced, and worked in its original state like ordinary glass.

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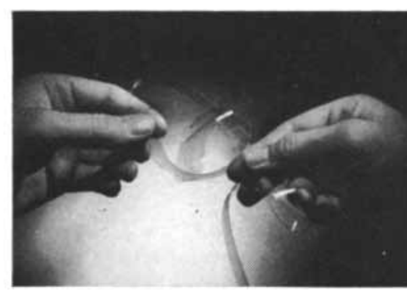
Ribbon glass by the yard

Here's a glass that's a thousandth of an inch thin and in small widths it's flexible as—well, a ribbon. You can twist it, roll it, wrap it around your arm without cracking it. It comes in any length you want—inches, yards, miles.

Actually ribbon glass isn't a single glass. We can make it of several different compositions according to what you need it for. Originally we developed it to take the place of mica in electronic capacitors of which there are several in your radio and TV sets and in any other piece of electronic equipment you can name. As mica is formed in layers, it is subject to cleavage in the plane parallel to lamination; ribbon glass being homogenous is easily workable. This is just one advantage of this glass in capacitors.



Medical scientists have found a quite different use for ribbon glass—as microscope slide covers. These are the wafer-like pieces of glass that are used to cover blood smears and the like for examination under the microscope. In this case ribbon glass can be made clearer, flatter and more free of bubbles and striae than previously made glasses.

Seems as if this unique stuff should be good for a *lot* of things, but *what* (other than electrical and laboratorial) probably lies in the laps of imaginative designers. Would you like us to send you a little strip to play with? *Customer* ideas and problems that really bring out the best in glass. So, even if what's on your mind seems unrelated to any item this page discusses, glass may still be its fulfillment. We'd like to hear from you.

CORNING GLASS WORKS

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Corning means research in Glass

Oreopithecus: Homunculus or Monkey?

This fossil primate has recently been described as manlike, which calls attention to a classical argument as to whether the primitive ancestors of man resembled little men or apes

by Loren C. Eiseley

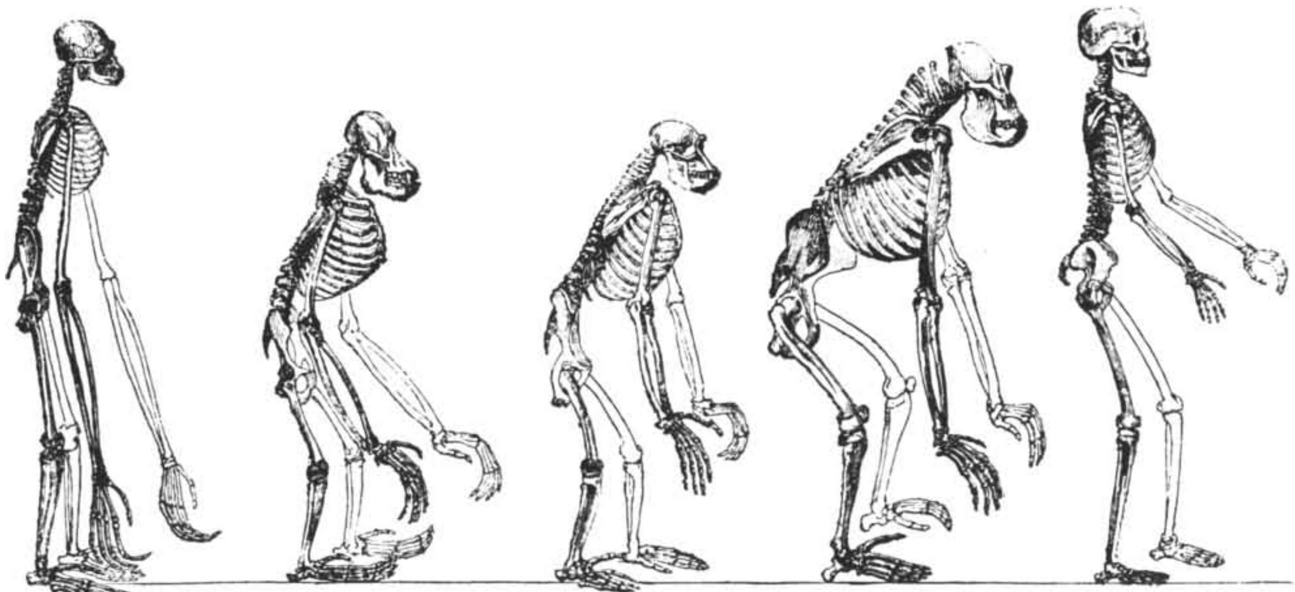
Three months ago a curious anthropological argument flamed suddenly for a few days in the newspapers. It was touched off by the arrival in New York City of a paleontologist from Switzerland bearing the bones of a small primate long known to science as Oreopithecus. Johannes Hurzeler of Basel presented to a group of scholars gathered at the Wenner-Gren Foundation for Anthropological Research his view that the bones of Oreopithecus showed human rather than anthropoid affinities. Since these bones are estimated to be 10 million years older than the earliest known fossil men, his announcement made headlines.

"Fossil Research Questions Darwin Evolution Theory," the New York *Times* announced. The *Herald Tribune* editorialized: "No Missing Link?" Specialists on fossil man were besieged by telephone calls from reporters and by faintly derisive queries from anti-evolutionists whose interest had already been whetted by the Piltdown hoax. Perhaps this new contradiction would mark the final exit of the man-monkey and of the anthropologists along with it.

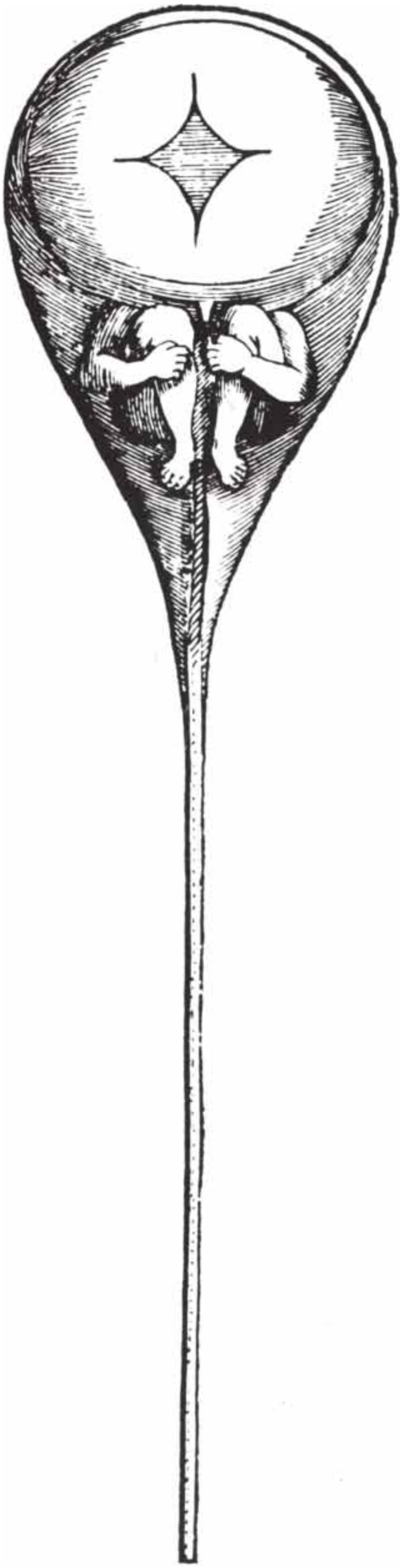
By the time scientists had begun to respond, the press had passed on to other things, leaving in the mind of the public a confused vision of a sort of "little man" who, so the newspapers said, had been found in a coal mine in Tuscany. Like most such episodes, that of Oreopithecus has a history, and the argument over it is of the same general nature as two similar controversies fought within the memory of men now living.

This episode has served to draw attention to a long-existing debate among anthropologists which has occasionally waxed acrimonious. The partisans divide basically into two schools: the school of the "little men" and that of the "ape-men." The former pursue the figure of man backward until, upon some far wall in time, it appears as a dwarfed, big-headed little shadow; the latter see our earliest ancestor shambling into the light like some great shaggy anthropoid. The argument recalls the ancient dispute between the preformationists, who saw in the human sperm cell a preformed homunculus, or little man, which had only to grow to adult size, and the epigenesists, who judged correctly that each embryo acquires the characteristics of a human being only through development.

Some anthropologists search for human characters—vertical front teeth, a



ONE 19TH-CENTURY VIEW of human evolution, by stressing the similarities between living apes and man, suggested that the remote ancestors of man resembled living apes. This picture from T. H. Huxley's *Evidence as to Man's Place in Nature* compares the skeleton of man (*right*) with those of the gibbon, orang, chimpanzee and gorilla (*left to right*). All except the gibbon are drawn to scale.



A 17TH-CENTURY VIEW of human embryonic origins is reflected by this woodcut in Nicholas Hartsoeker's *Essai de Dioptrique*. Hartsoeker believed that the human spermatozoon contained a little man, or homunculus. The hole in its head represented the open sutures in the infant skull.

shortened face, an expanded brain case—early in the human line of descent. They seek, in other words, for something dangerously close to the homunculus of the preformationists. They "prove" evolution by finding, as St. George Jackson Mivart said in 1874, "an ancestral form so like man [that] we have the virtual pre-existence of man's body supposed, in order to account for the actual first appearance of that body as we know it."

The more thoroughgoing evolutionists, in contrast, have looked for forms which contained only the *possibility* of development into man. Such students have generally regarded man as a relatively recent emergent from a group of primates which also gave rise to the modern great apes; in other words, the comparison of man with the anthropoids of today has been based on the assumption that they and we had ancestors in common.

Charles Darwin was not the first to notice our likeness to the monkeys and apes. Such observations extend into antiquity, and by the 18th and early 19th centuries philosophers were arranging the primates in an order of complexity. As voyagers began to come into contact with primitive peoples, these were often placed on the scale as grades between the anthropoids and civilized European man. The Hottentots of the Cape of Good Hope particularly appealed to the Western mind as candidates for such a place; it was said that their language was only a step above the chatter of apes.

Thus notions of the "missing link" were in existence long before Darwin and long before the appearance of a truly evolutionary philosophy. Darwin himself cautiously refrained from attempting to trace man's precise relationship to the apes. But some of his followers, notably T. H. Huxley, tackled the problem head on. Huxley was provoked to his excursion into man's past by events at the famous meeting of the British Association for the Advancement of Science at Oxford in 1860. He had borne the brunt of the conservatives' attacks on evolution. At this meeting Richard Owen, England's foremost comparative anatomist and a mortal enemy of Darwin and his followers, attempted to maintain man's unique position in the animal world by placing him in a distinct subclass of the mammals for which he proposed the name "Archencephala." This classification was based upon brain characters which Owen maintained did not occur in the lower primates. Huxley, his ire aroused, set out to demonstrate

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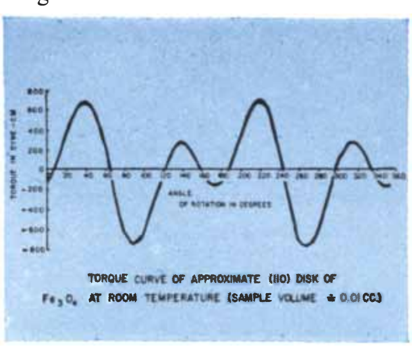
Merry-go-round

Adding "memory" to machines is no longer a scientist's fancy. It is a fact. Actually, this ability to "remember" is the ability to "recall" information previously entered into the machine. One of the latest and best ways of storing information utilizes the now familiar small, rugged, reliable magnetic cores. Each letter or numeral is stored in a kind of a "Morse code," where a dash is represented by one direction of magnetization and a dot by the other. But, to employ cores more effectively, the IBM Research people are studying a number of very basic things having to do with ferrites. One of these is magnetic anisotropy—which involves the continual measurement of the minute torque exerted in a magnetic crystal by a rotating external magnetic field.



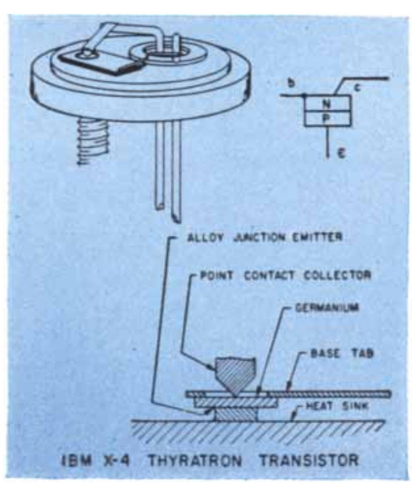
To increase the speed and accuracy of measurement of this property, Ralph Penoyer, of our Ferrite Materials Research Group, has developed an automatic magnetic torque balance that is accurate to 0.0006 inch-ounce, and allows the direction of the magnetic field to change through a 360° arc in one minute. Obtaining and plotting such data was, by standard methods, a laborious, time-consuming process.

Full details describing the device, circuit diagrams, method of operation, calibration and accuracy are available in IBM Bulletin No. 100. Write for your copy.

Trigger Happy Transistor

Everybody is talking about transistors. But, certain problems are not readily solvable by the use of conventional transistors. A typical problem is that of picking up a relay with a transistor controlled by microsecond pulses. So Richard Rutz, of our Semi-Conductor Devices Research Group, took a long look at transistor possibilities in this case. The result: The IBM X-4 Transistor. This new type permits high-speed switching of large currents by low-power electrical pulses. It operates with a turn-on time of two ten-millionths of a second and a turn-off time of one-millionth of a second; experimental models have been made to switch currents as high as 15 amperes.

You can find full scientific data on the X-4, its construction, electrical characteristics, and circuit applications in IBM Bulletin No. 101.



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Dirt, dust and moisture are death to delicate electrical devices. In our experimental component assembly room—which we call the Very Clean Room—at our Poughkeepsie Research Laboratory, we've eliminated the scourges. How do we keep the Very Clean Room clean?

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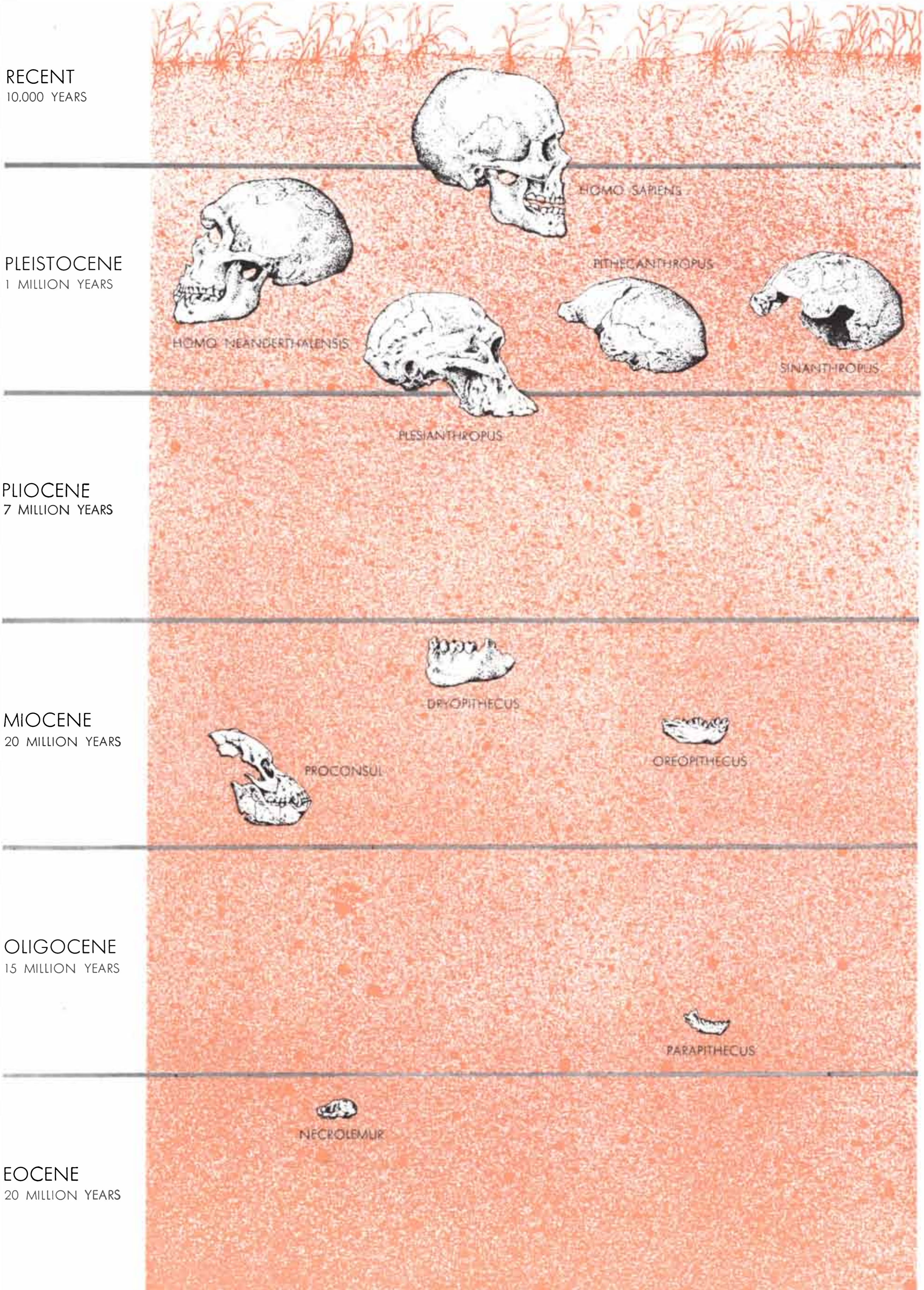
RECENT
10,000 YEARS
HOMO SAPIENS
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OREOPITHECUS
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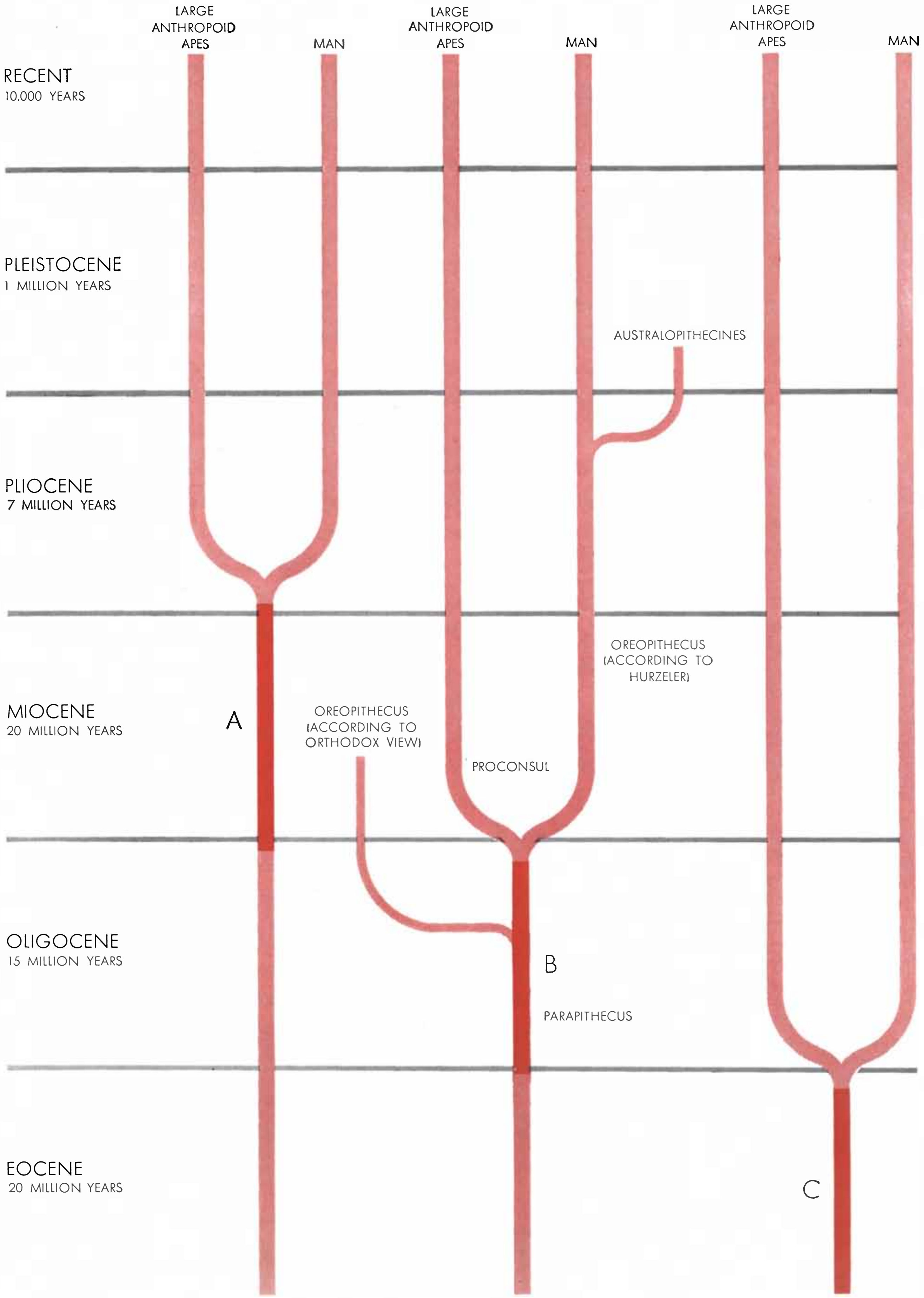
that Owen was wrong, that man was closely related to the other primates. He composed a series of lectures which were published in 1863 under the title *Evidence as to Man's Place in Nature.*

In this work, which more or less set the pattern for much that followed, Huxley thoroughly demolished Owen's position. He took the view that "the surface of the brain of a monkey exhibits a sort of skeleton map of man's, and in the manlike apes the details become more and more filled in, until it is only in minor characters . . . that the chimpanzee's or the orang's brain can be structurally distinguished from man's." Huxley was quite willing to admit that man's own origin was obscure and might go back millions of years to a common ancestor, but he insisted that the modern apes were our closest surviving relatives. If Huxley dwelt too heavily and too emotionally upon anatomical correspondence between ourselves and the great apes, it must be remembered that at the time he wrote the evolutionists were fighting primarily for a principle, against the orthodox "special creationists." Furthermore, it must also be remembered that very few human fossils had been discovered, and these were fragmentary. Our living relatives in the trees could be seen at the zoo, and it was inevitable that they should dominate man's imagination. Serious scholars even came to believe that microcephalic idiots were throwbacks to some remote period of the human past.

By the beginning of the 20th century the ape origins of modern man seemed pretty well established. The Pithecanthropus skull cap had bolstered this view. Many felt that from a form something like that of a chimpanzee it was an easy step to the Java man and thence on to Neanderthal and modern man. But at the turn of the century there came a new revolt against the ape.

The attention of anatomists was attracted to a small, tree-living creature in southeast Asia possessing definite characters of a primate. The tarsier (*Tarsius spectrum*), an animal with enormous eyes and about the size of a small kitten, has a brain and other characteristics

TEN PRIMATE FOSSILS are located in time by the chart on the opposite page. The time scale is at left. The depth of each epoch is not proportional to its length. Plesianthropus is one of the Australopithecines, or South African man-apes. Despite its name, Necrolemur is not a lemur but a tarsioid.


LARGE ANTHROPOID APES
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AUSTRALOPITHECINES
PLIOCENE
7 MILLION YEARS
OREOPITHECUS (ACCORDING TO HURZELER)
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OREOPITHECUS (ACCORDING TO ORTHODOX VIEW)
PROCONSUL
OLIGOCENE
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B
PARAPITHECUS
EOCENE
20 MILLION YEARS
C

which ally it to the lower monkeys. In 1918 F. Wood Jones, a distinguished English anatomist, first expressed the heretical view, which he has maintained and developed since, that man arose from a tarsioid rather than from an anthropoid ancestry.

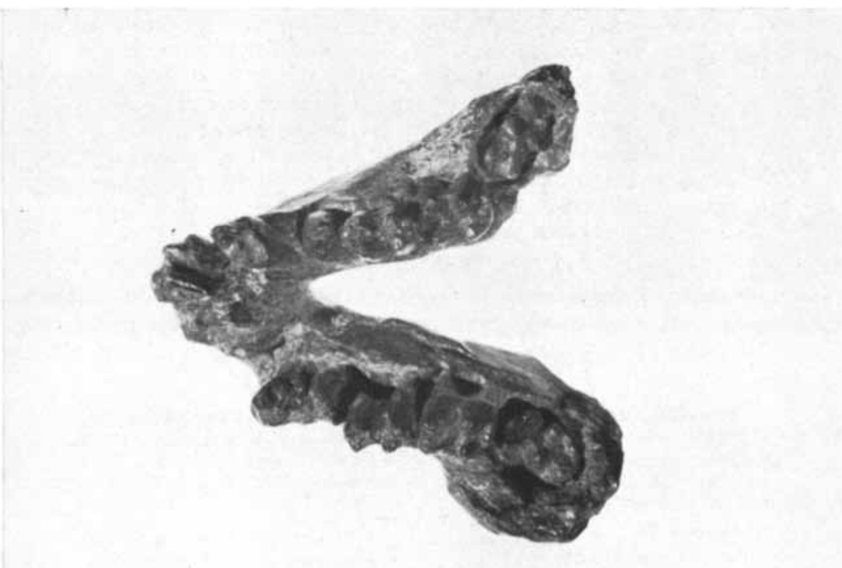
Wood Jones insists that the human line is very ancient, going back to a past tens of millions of years old in the Tertiary Period. He predicts that man's immediate ancestors, if ever discovered, "will be utterly unlike the slouching, hairy 'ape-men' of which some have dreamed . . . and will be found in geological strata antedating the heyday of the great apes." The ancestors of man, he says, were "small, active animals" already endowed with legs longer than their arms, small jaws without protruding teeth, and enlarged craniums. They were not swingers in trees: the human hand and foot, he contends, are too specialized to have been made over rapidly from an arboreal ancestor's. The present-day tarsiers in the trees, according to his view, evolved their tree-living specializations later, but our early tarsioid ancestor walked on the ground.

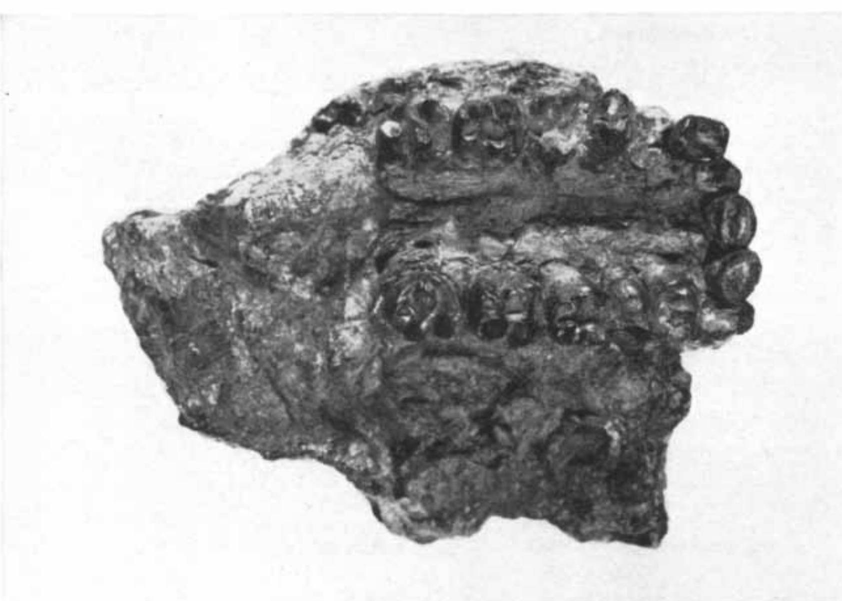
Wood Jones's proto-man thus sounds like a homunculus. When he first advocated his views, he found very few followers. Henry Fairfield Osborn, the late paleontologist, though not a Wood Jones follower, inclined toward a homuncular dawn man going back to early Tertiary times many millions of years ago. "I predict," he said, "that even in Upper Oligocene time we shall find pro-men, and that they will have pro-human limbs."

Wood Jones and Osborn were vigorously refuted by primatologists who championed the orthodox view that man

THREE THEORIES on the common ancestry of man and the large anthropoid apes are depicted on the opposite page. The theory illustrated at left supposes that in the Miocene Period man and the anthropoid apes had a common ancestry of dryopithecoid apes (A). The theory illustrated in the center suggests that in the Oligocene Period they had a common ancestry of unspecialized Old World primates in which both monkey and anthropoid ape traits were intermingled (B). On this theory the Swiss scholar Johannes Hurzeler believes that Oreopithecus is a direct ancestor of man. The orthodox view is that this primate was a separate offshoot of the common stock. The theory illustrated at right proposes that in the Eocene Period man and the anthropoid apes had a common ancestry of Old World tarsioids (C). All three lines are simplified and do not purport to represent all branches of the primate family tree.

was a "made-over ape." They insisted that man's immediate forerunners could not be so ancient as Wood Jones and Osborn said. "It seems anachronistic," wrote William King Gregory, "to attribute to the very remote Tertiary ancestors of man the long legs, long thumbs, big brain, short face, small canines, etc., which are now diagnostic characters." But by the 1940s the "made-over ape" point of view had moderated. The most important factor in this change was the discovery in South Africa of the fossil *Proconsul africanus*—a creature of the early Miocene (the period immediately after the Oligocene) which combined characters of early Old World monkeys and great apes. William L. Straus, Jr., of the Johns Hopkins University, voiced a suspicion that man's immediate ancestors might have been "more monkey-like than anthropoid-like." Straus, who takes a very sane and cautious position on this lengthy controversy over the human ancestry, feels that the anthropoid ape theory is weakest in its failure to account for anatomical traits which man shares with the monkeys and lemurs. More recently W. C. Osman Hill, the well-known English primatologist, has come to believe that man branched off the primate stock below the great ape line. He even suggests that Straus's view might be reconciled with Wood Jones's tarsioid hypothesis if some early Oligocene monkey of tarsioid affinities were admitted on the line leading to man—a form, say, like Parapithecus.





FRAGMENTARY FOSSILS of *Oreopithecus bambolii* Gervais were found in Italian coal deposits. These fragments are mandibles photographed from above the crowns of the teeth.

Thus before Hurzeler's recent announcement a slow shift of thought or widening of possible horizons had been under way in the study of human evolution. The theory that man came down late out of the trees has been dropped in some quarters and is less explosively defended in others. There is a greater willingness to reserve judgment and wait upon new evidence. It was in this receptive atmosphere that Hurzeler presented his new study of Oreopithecus.

The fossil has been known since 1872, when it was described by the French paleontologist Paul Gervais, who regarded it as an Old World monkey. Hurzeler, after studying the original fossil and later finds, has become convinced that Oreopithecus is the first manlike form discovered in the Tertiary Period—it is believed to date from the Miocene. He apparently bases this view upon certain technical features of the teeth, including the nonprojecting canines, the vertical bite and the shortened face. It must be noted, however, that only parts of the skull have been found, and its full shape cannot be reconstructed.

Oreopithecus is a lower "monkey," in popular terms. It is not a "man" in the sense that many reporters assumed it to be, in spite of "no tooth gaps, no apelike protruding jaw," and so on. There are fossil and still-living primates which would have no trouble in answering that description, yet I am sure no one would call them men.

So the substance of the story is that Hurzeler has revived interest in a problematical bit of bone we have long been fingering. For the successful reconstruction of the evolution of the horse in the Tertiary Period, paleontologists had thousands of fossil bones to study. Primatologists may therefore be forgiven their fumblings over great gaps of millions of years from which we do not possess a single complete monkey skeleton, let alone the skeleton of a human forerunner. For the whole Tertiary Period, which involves something like 60 to 80 million years, we have to read the story of primate evolution from a few handfuls of broken bones and teeth. Those fossils, moreover, are from places thousands of miles apart on the Old World land mass.

If we were able to follow every step of man's history backward into time, we would see him divested, rag by rag and stitch by stitch, of every vestige of his human garment. That divestment, however, would not occur all at one place. If we accept the evidence of evolution,

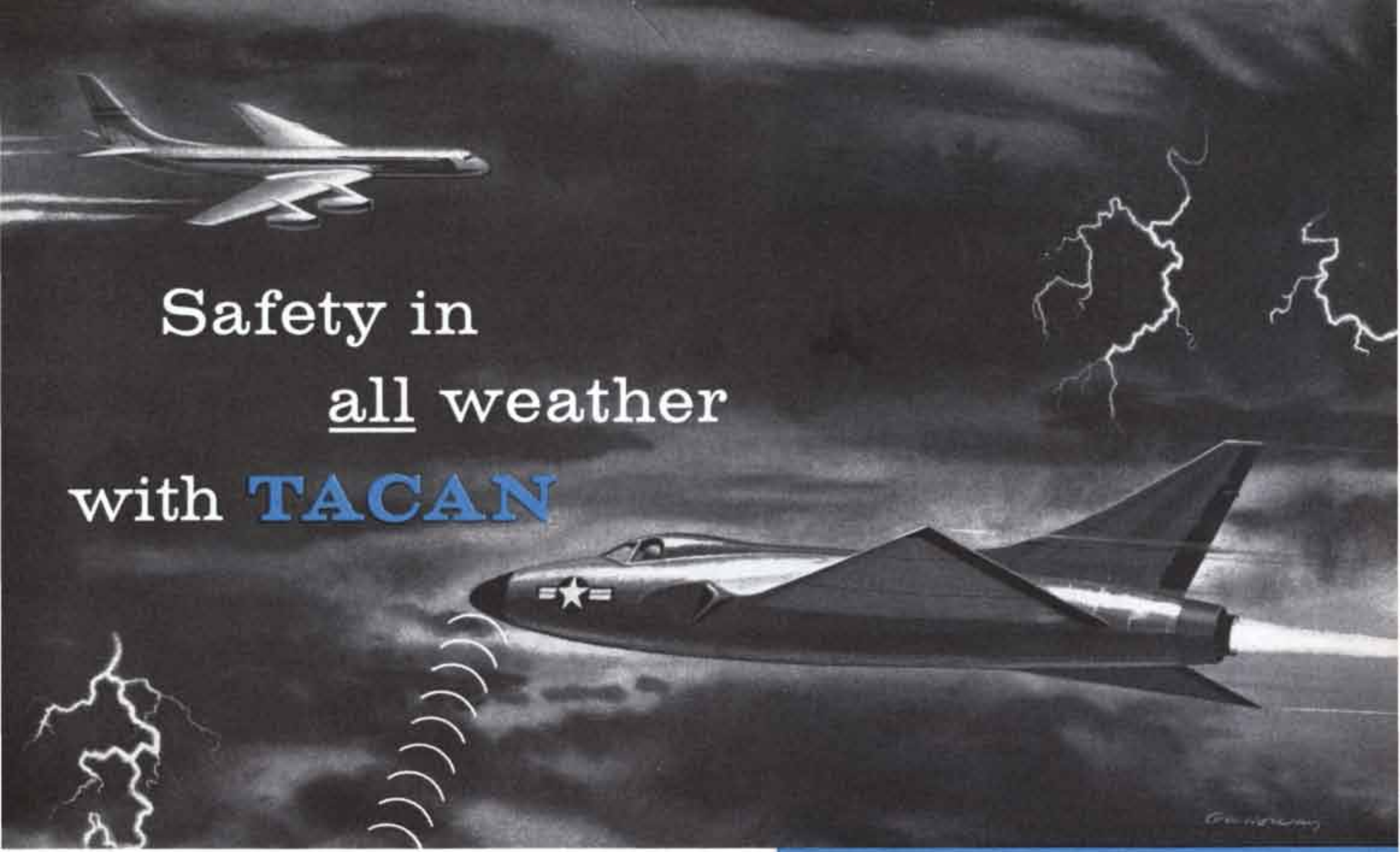
we must assume that man became man by degrees, that he emerged out of the animal world by the slow accumulation of human characters over long ages.

Our knowledge at present is not sufficient to establish precisely what anatomical traits are peculiarly human. As the British anatomist Solly Zuckerman has very aptly pointed out: "It is this general lack of structural specialization that makes the study of primate phylogeny so difficult." Some traits may have been paralleled in primate lines of evolution which did not lead to man; some traits called human may represent old generalized characters which have survived in man and been lost in some of his modern specialized relatives.

To continue our writing of the story of human evolution we are totally dependent upon finding additional fossils. Until further discoveries accumulate, each student will perhaps inevitably read a little of his own temperament into the record. Some, as Hurzeler has done, will dwell upon short faces, vertical front teeth and little rounded chins. They will catch glimpses of an elfin human figure which mocks us from a remote glade in the forest of time. Others, just as competent, will say that this elusive homuncular elf is a dream spun from our disguised human longing for an ancestor like ourselves. They will say that in the living primate world around us there are lemurs with short faces and vertical teeth, that there are monkeys which have the genuine faces of elves and the capacious craniums of little men.

In the end we may shake our heads, baffled, and have to admit that many lines of seeming relatives, rather than merely one, lead to man. It is as though we stood at the heart of a maze and no longer remembered how we had come there.

TARSIER was believed by the English anatomist F. Wood Jones to be a highly specialized descendant of the Eocene tarsioids, a group which he believed had also given rise to the human line. This specimen was brought from the Philippines to the Philadelphia Zoo.



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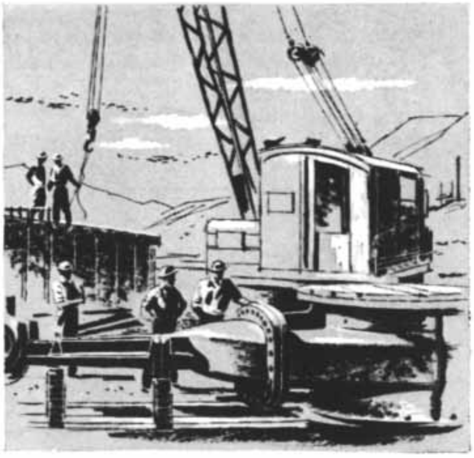

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The Freezing of Living Cells

Human blood and cattle sperm can now be stored at low temperature for more than a year. It has also been shown that a whole hamster can be frozen for an hour and thawed out none the worse for wear

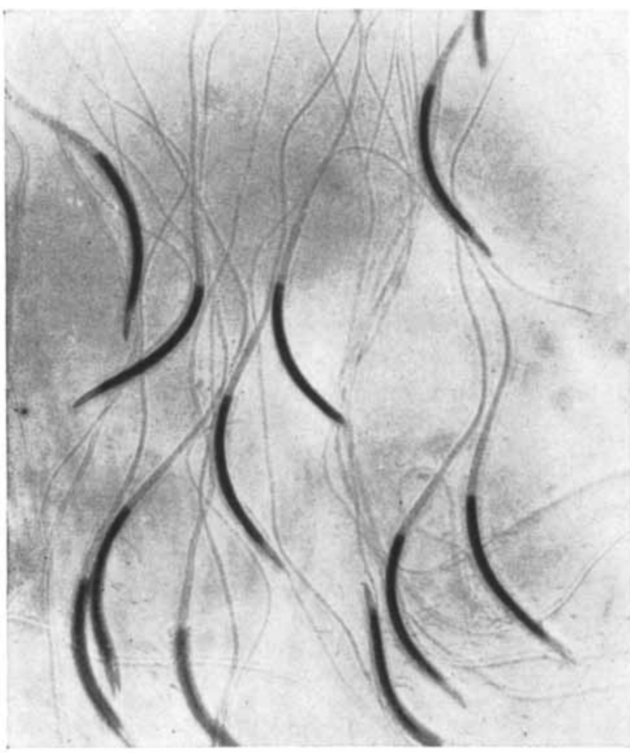
by A. S. Parkes

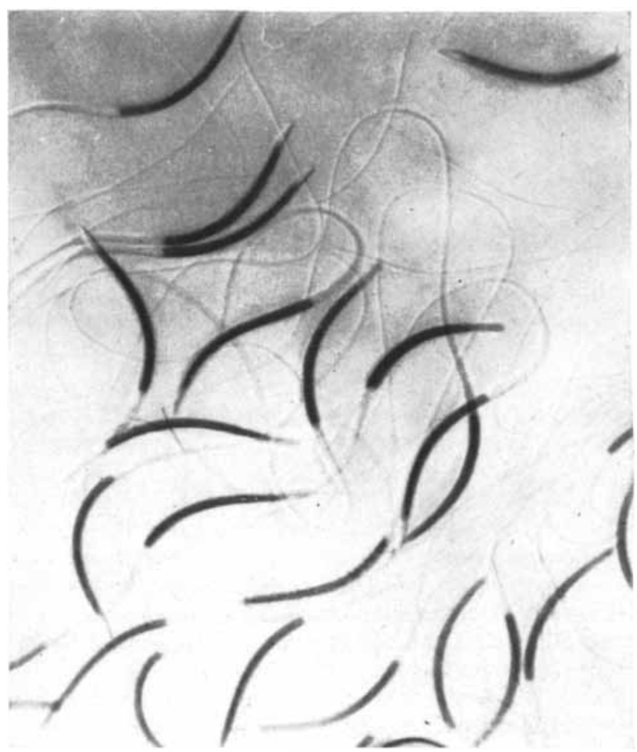
Suspended animation in the frozen state—conferring potential immortality—has often figured in legend and literature, but it is less known as a theme of laboratory experiment. Indeed, it is only within the last two or three centuries that any accurate study of the effects of cold on living organisms has been possible. In 1683 the chemist Robert Boyle, writing of his observations on the subject, remarked:

"It may to most men appear a work of needless Curiosity, or superfluous diligence, to examine sollicitously by what Criterion or way of estimate the Coldness of Bodies and the degrees of it are to be judg'd; Since Coldness being a Tactile Quality, it seems impertinent to seek for any other judges of It than the Organs of that sense, whose proper object it is."

When, in 1714, Gabriel Fahrenheit invented the first accurate thermometer, objective measurement of the "coldness of bodies" became not only pertinent but a subject of interest to biologists. They turned eagerly to testing the effects of low temperatures upon plants and animals. Outstanding among these early students was Lazzaro Spallanzani, the 18th-century Italian naturalist, who performed many experiments on cells and tissues and made some remarkably shrewd and penetrating observations. In our own century there has been a great extension of such investigations. With the aid of liquefied gases (*e.g.*, air) living cells and tissues have been subjected to temperatures far below those ever recorded in nature.

Scientists engaged in this kind of work no doubt have been activated in part by "needless curiosity," but the work also has a practical side: namely, the hope of finding ways to preserve cells and tissues (*e.g.*, blood) for long periods. Progress was not very rapid until less than a decade ago. Experimenters





FOWL SPERM are photographed under the microscope before and after freezing. After the photomicrograph at left had been made, glycerol was added to the sperm and their temperature lowered to −79 degrees centigrade. At right they are shown after thawing.

WHOLE BLOOD is stored in a deep-freeze unit in the laboratory of Henry A. Sloviter in the Harrison Department of Surgical Research at the University of Pennsylvania School of Medicine. After glycerol solution is added, the blood is stored at –20 degrees C.

had some success in freezing and reviving lower organisms, but the cells of vertebrates, including mammals, were found to be very sensitive to freezing and thawing. It was thought that they were irreparably damaged by the formation of ice crystals during freezing. Hoping to avoid this damage, some investigators, notably B. J. Luyet and his co-workers at the St. Louis University Institute of Biophysics, experimented with stratagems such as partial dehydration of the cells and ultrarapid freezing. The drying method gave encouraging results. For example, some experimenters found that the spermatozoa of fowl occasionally survived freezing and thawing when they were treated with a strong sugar solution as a dehydrating agent. However, the treatment succeeded in protecting only a very small proportion of the sperm. Much of this early work is summarized in the classic monograph, *Life and Death at Low Temperatures*, published by Luyet and his associate P. M. Gehenio in 1940.

In the fall of 1948 a curious chance discovery made possible a fresh onslaught on the whole matter. At the National Institute for Medical Research in London, Audrey U. Smith and Christopher Polge were re-investigating the sugar dehydration technique. They used solutions of levulose, the fruit sugar, and froze fowl sperm with dry ice to minus 79 degrees centigrade (112 degrees below zero Fahrenheit). The experiments were unsuccessful: hardly any of the sperm survived after thawing. Pending some new inspiration, the experimenters put away some of their levulose solution in the refrigerator. Some months later they went back to the experiment, using what they took to be the stored levulose solution. This time the solution proved to be almost completely successful in protecting frozen fowl sperm: the sperm

Local boy makes good

WHEN THE LATE Ebenezer Hubbard, a patriotic Concord man, left a bequest for a local statue, there luckily happened to be a real sculptor close at hand.

Even more luckily, young Dan French had never yet sculped a whole statue—had, in fact, recently started by whittling on turnips. So he'd take the job for expenses, and glad to get it.

Two years later, Daniel Chester French's first statue went up. And Mr. Emerson, a neighbor, gladly obliged with a little verse to go under it, ending—

"Here once the embattled farmers stood,
And fired the shot heard round the world."

Now, during his great lifetime, Daniel French was to make many more statues, but his fame needs only two to rest secure. One is the massive, brooding figure in the Lincoln Memorial. The other is his first: the big, bold, living bronze of the Minuteman of Concord.

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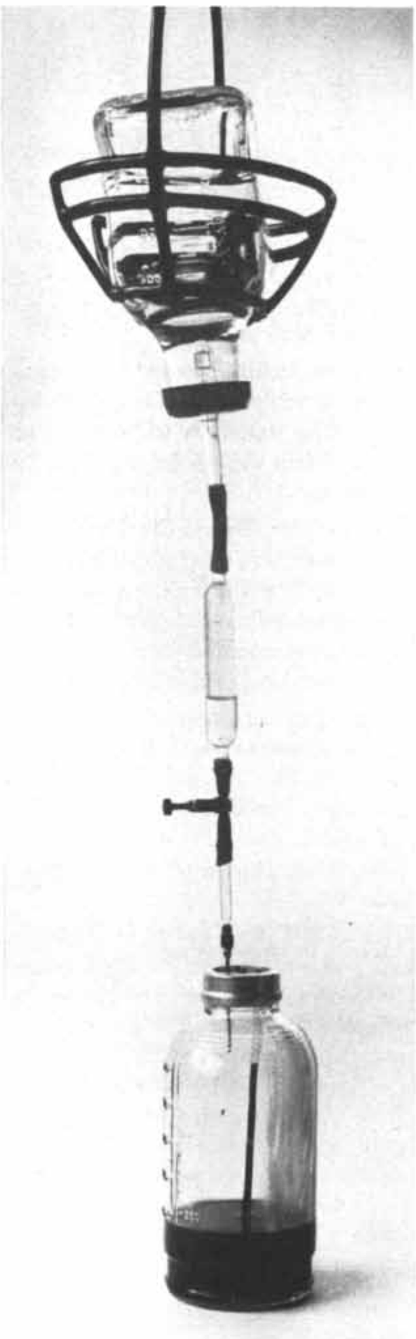
not only regained motility after thawing, but what was more, at least some also retained fertilizing power.

This very curious change in the solution's effect naturally aroused our keenest interest. The miraculous solution was analyzed, and it was then discovered that what had been taken from the refrigerator shelf was not the levulose solution but a mislabeled bottle of Mayer's albumen—a mixture of albumen (egg white) and glycerol (or glycerin)!

Tests soon showed that the albumen had nothing to do with the protection of frozen sperm, and our attention therefore focused on the glycerol—a syrupy, sweetish alcohol. It was only after our chance observation of glycerol's protective effect that we learned of an important earlier observation along the same lines. In 1946 Jean Rostand of Paris had observed that frog spermatozoa survived a slight degree of freezing when he added glycerol to the medium.

I record this story in some detail partly to add it to the literature of chance discoveries, partly to provide an authoritative account of the incident, and partly to correct any notion that our work with glycerol was based—without acknowledgment—on Rostand's observation, of which we had no knowledge at the time.



GLYCEROL SOLUTION is held in a vessel suspended above the blood bottle. The solution is added to the blood through a needle inserted into the cap of the bottle.

It was fortunate that the accident of the switched bottles occurred while fowl spermatozoa were being investigated. Glycerol would not have protected spermatozoa of mammals under the procedures we were using at the time, which included rapid freezing. Even with the fowl sperm, one snag after another cropped up. In the first place, it was found that the glycerol treatment, even without freezing, deprived most of the sperm of their fertilizing power. Considerably later we realized that this was probably due to the fact that the glycerol caused osmotic damage to the sperm after they were transferred to a normal environment in the oviduct of the hen. Experiments then established that the sperm would recover their normal fertilizing power if the glycerol was removed from the sperm suspension by a gradual process before the insemination.

The clues leading to this discovery stemmed from work by Smith on human red blood cells. She found that the red cells, like fowl sperm, would resist freezing and thawing without destruction if they were immersed in a saline solution with 15 per cent of glycerol. However, they disintegrated when they were returned to a normal medium—in this case the blood. Examination under the microscope showed that when the red cells were immersed in the glycerol solution, they first shrank, as water was drawn out of them by the glycerol, and then swelled back to their normal size and shape as glycerol slowly infiltrated the cell. When the thawed cells were returned to serum, they burst, because water passed into them more rapidly than glycerol passed out.

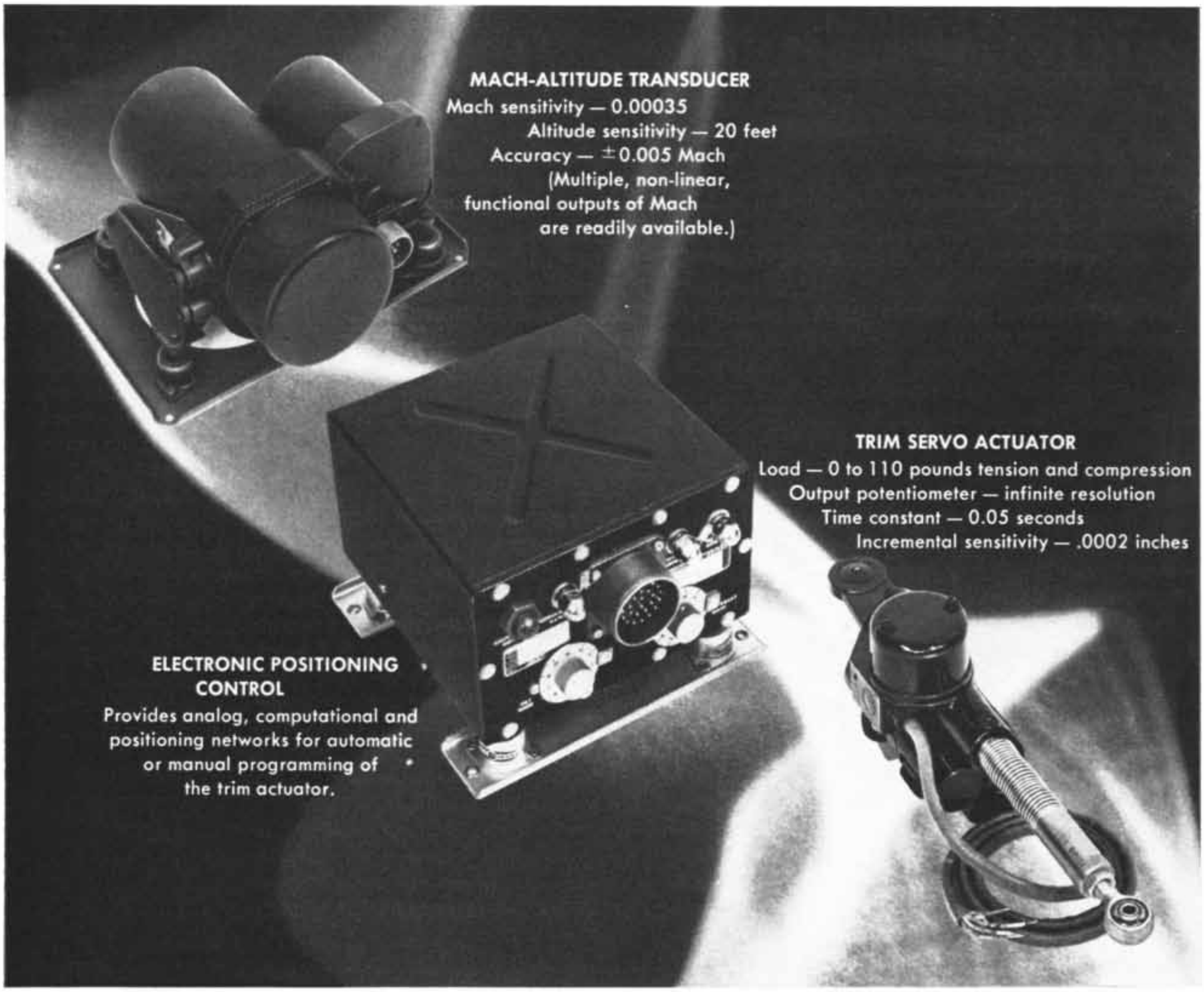
It was Henry A. Sloviter of the University of Pennsylvania School of Medicine, a visiting worker in our laboratory, who developed the technique for gradual removal of glycerol from cell suspensions; he used the process known as dialysis. Red cells so treated survived for their normal lifetime when they were returned to the bloodstream.

A second snag in the protection of frozen sperm was even more illuminating and reorientated the whole course of our freezing research. It had been tacitly assumed that cells kept at minus 79 degrees C. would not deteriorate and might be held in a state of suspended animation indefinitely. Work with the frozen fowl spermatozoa showed that this assumption was fallacious. When the cells were kept at minus 79 degrees, most of them lost their ability to recover motility within a few weeks. The recovery rate declined even when the sperm were held at the extremely low temperature of minus 190 degrees C. in liquefied air. Since it could not be supposed that biochemical processes were going on at this temperature, we had to conclude that the cells were damaged in some way by physical causes. At this stage our team was joined by a physical chemist, J. E. Lovelock. He was able to show that the losses during storage were greatly influenced by the nature of the medium in which the cells were frozen.

Red blood cells, like fowl sperm, deteriorated at minus 79 degrees C., but more slowly. Lovelock proceeded to develop a modification of the glycerol-saline medium in which red cells could be preserved for a year or more with negligible loss. The cells apparently do not age during storage, for P. L. Mollison and his co-workers found that such cells have a normal lifetime after later transfusion.

This work has made possible the long-term storage of blood. So far the method has been used in blood banks only for preservation of rare types of blood, because of the expense and complication of removing the glycerol before use, but it is applicable on a large scale if necessary. The fact that studies of frozen fowl spermatozoa, prompted in part by "needless curiosity," led directly to a new and potentially important method of storing human blood is a good example of the value of basic research.

We turned next to experiments in freezing the sperm of cattle. The first results were disconcerting: bull sperm, when treated by the technique that had been successful with fowl sperm, failed to revive after thawing. We then realized that the reason for the failure might be the fact that we were



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There's no secret to the development of a fine aircraft air data system. Required are superior components, compatible and reliable, that produce the desired stimulus-response pattern with minimum weight and size and maximum efficiency.

The simple elevator trim servo system illustrated is only one of many integrated systems produced by AiResearch to meet customer requirements. Thousands of AiResearch transducers and actuators of the highest sensitivity and performance are now in service. New ones to even more exacting requirements are constantly being developed.

A few of the fields in which we have extensive experience are temperature and flight controls, instrumentation, air data, ballistics computations and positioning and sensing systems. Let an AiResearch engineering team study your problem and formulate a solution.

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Designers and manufacturers of aircraft systems and components: REFRIGERATION SYSTEMS • PNEUMATIC VALVES AND CONTROLS • TEMPERATURE CONTROLS • CABIN AIR COMPRESSORS • TURBINE MOTORS • GAS TURBINE ENGINES • CABIN PRESSURE CONTROLS • HEAT TRANSFER EQUIPMENT • ELECTRO-MECHANICAL EQUIPMENT • ELECTRONIC COMPUTERS AND CONTROLS using the method of rapid cooling. Mammalian spermatozoa are subject to shock when cooled suddenly. A more gradual cooling method was therefore adopted. The bull semen was cooled slowly, at the rate of one degree centigrade per minute, down to minus 15 degrees C., and then more rapidly to minus 79 degrees. This change made a great difference, and with other improvements in technique we were able to raise the survival rate of the bull sperm to about 70 per cent. Moreover, it appeared that in the case of bull sperm it was unnecessary to remove the glycerol after thawing: the glycerolized sperm survived return to a normal medium without damage.

We moved on at once to field tests in which cows were inseminated with bull semen that had been glycerolized, frozen and thawed. The first season's tests failed, but in the second season, after a slight modification of technique, preserved semen produced as high a rate of pregnancies as does normal fresh semen. Frozen bull semen has now been stored successfully without deterioration for several years. A bull that has been dead nearly three years is still getting cows in calf. In cattle, at least, telegenesis in time as well as space has arrived.

Experiments with other kinds of cells, including human sperm, naturally followed. Successful human pregnancies from sperm preserved by freezing have been reported. Varieties of herring that spawn at different times of year (spring and autumn) have been crossed for the first time by the use of sperm kept in cold storage. And there have been promising results with mammalian eggs, protozoa and various other types of cells.

Further, the work has now gone beyond single cells to tissues and whole organs. Substantial success has been achieved in preserving for long periods the adrenals and gonads of rats, the skin of rabbits and the uterus of the guinea pig. Long-term storage of human tissue for grafting is an obvious possible development. It has already been achieved with the cornea of the eye, for which storage banks kept at minus 79 degrees C. are being established. The technique should be useful for other tissues which, like the cornea, can be transplanted from one person to another. It will be most intriguing to see to what extent the provision of spare parts for human surgery can be developed.

Inevitably we were drawn to a still more fascinating question: Could a whole animal survive freezing? There are, of course, many stories of fish and frogs reviving after being found frozen solid in blocks of ice, but these stories must be apocryphal. Any that revived must have been frozen only on the surface, for no vertebrate, even of the cold-blooded variety, will survive conversion of all its body water to ice under any conditions so far known.

A warm-blooded animal is, of course, vulnerable to cooling of its body temperature at levels far short of freezing. In the rat, for example, the heartbeat and breathing stop when the internal temperature falls to about 15 degrees C. (59 degrees F.). Hibernating animals may maintain the heartbeat and other vital functions, at a reduced rate, at a body temperature as low as 2.5 degrees

BOTTLES OF BLOOD are shown before (*left*) and after (*right*) freezing. After the blood is thawed out, and before it can be used for transfusion, it must be treated to dilute or remove the glycerol. The red blood cells apparently do not age during cold storage.

When research into cyanoethylation began many years ago, its future was unknown.

Its real future is still unknown today. But chemists are intensifying their investigation to discover new derivatives that may be obtained with acrylonitrile.

The challenge is pressing, since almost any material containing a labile hydrogen atom is reactive with acrylonitrile. Lignin, for example, with its phenolic hydrogen and other reactive centers is susceptible to cyanoethylation. But the question of what properties might be developed from the altered molecular structure containing a reactive nitrile group opens a broad new field for study.

Some day the answers to thousands of questions like these will be known. Perhaps from your laboratories will come some of the answers that will result in new and profitable products.

Technical Literature on acrylonitrile and laboratory-size samples are available. Write on your letterhead to Monsanto Chemical Company, Plastics Division, Room 966, Springfield 2, Massachusetts.

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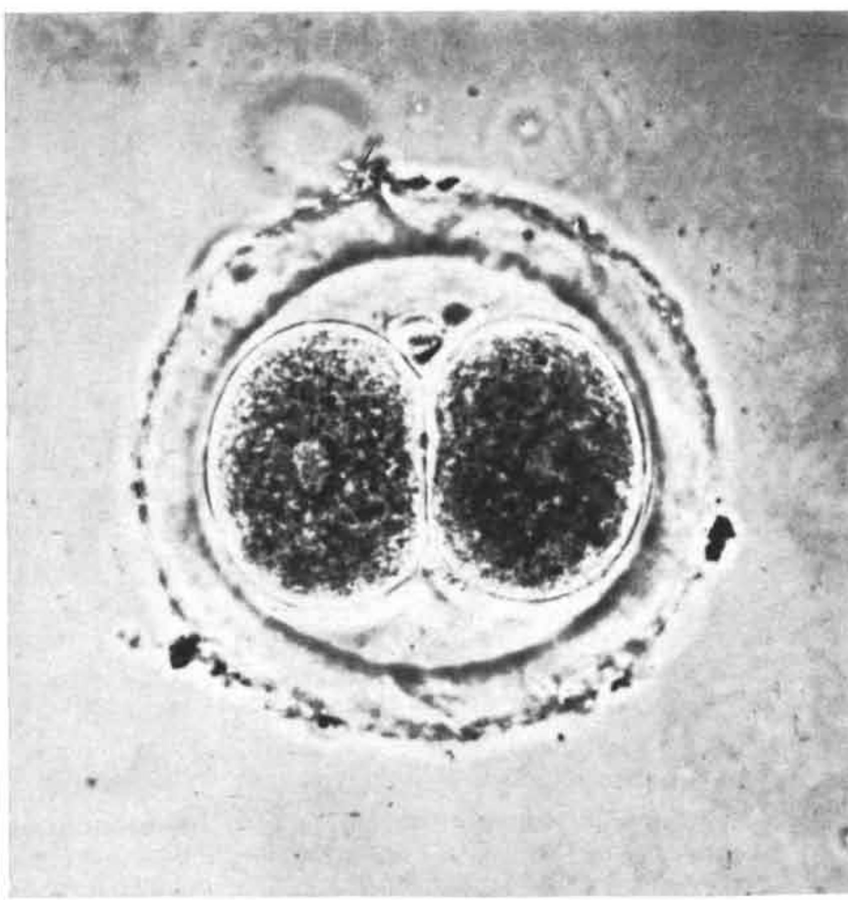
Where creative chemistry works wonders for you

C., but what would happen if the body temperature fell below zero?

In short, the reduction of a whole mammal to a state of suspended animation by freezing seemed an unpromising project. In considering the matter we saw at least two major problems: firstly, how to stop the heartbeat and breathing in such a way that they could be restored by rewarming, and secondly, how to avoid damage to the animal from freezing of its body water. At this point in our cogitations we were fortunate in making contact with Radoslav Andjus of the University of Belgrade, who seemed to have solved the first of our two problems. Andjus had succeeded in reanimating rats after chilling them almost to freezing temperature. He first placed the rats in cold air in a closed vessel, where they rebreathed their own expired air so that the proportion of oxygen decreased and that of carbon dioxide increased. When their body temperature fell to about 15 degrees C., he put the animals in iced water. Their respiration and heartbeat soon stopped, and their body temperature dropped to about one degree above freezing. Andjus found that he could revive some of the rats so treated by placing a hot spatula over the heart and giving artificial respiration.

Andjus came to our laboratory as a visiting worker, and his method was developed further so that rats were revived in almost every case after the body temperature had been reduced nearly to the freezing point of water. The way was thus cleared to study the cooling of mammals below zero. For this purpose it was decided to use the golden hamster, which in nature is a hibernating animal.

Audrey Smith of our group first cooled the hamster to about 3 degrees C. by Andjus' method. At this point, when its heartbeat and breathing were about to cease, the animal was transferred to a very cold bath kept liquid by an antifreeze solution of 50 per cent propylene glycol. It was kept at about 5 degrees below zero centigrade in a deep-freeze cabinet. The hamster's deep body temperature, as measured by a thermocouple inserted into the colon, soon went below zero. At this stage one of two things happened. The animal might start to freeze, at first on the outside and then in the deeper layers of the body. If taken out within one hour, when about 50 per cent of its total body water had been

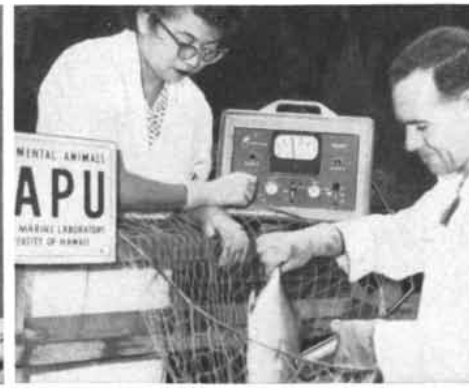


NEWLY FERTILIZED RABBIT EGG divides in laboratory culture after having been treated with glycerol, cooled to –190 degrees C. and kept frozen for 20 hours before thawing.

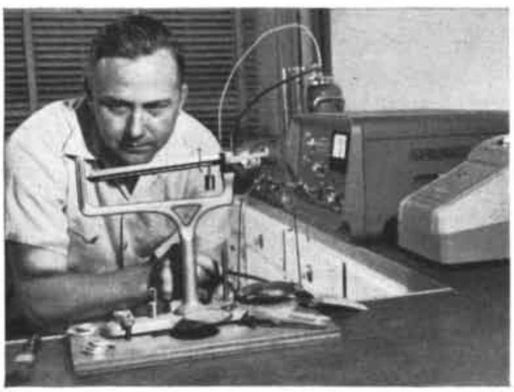
SCIENTISTS IN MANY FIELDS, THE WORLD OVER, DEPEND ON RADIOACTIVITY MEASURING INSTRUMENTS BY NUCLEAR-CHICAGO

Uranium Ore Assay—Ontario, Canada.
Uranium ore producers use Nuclear-Chicago scaling units in assaying various ore samples to determine uranium content.

Medical Diagnosis—Detroit, Michigan.
Nuclear-Chicago Isotope Scanner makes it possible for physicians to have "picture" of radioisotope distribution in organs of patient.



Metabolic Research—Coconut Island, Hawaii.
Marine biologists use Nuclear-Chicago instruments for metabolic research, monitoring fish forced-fed radioactive strontium.



Petroleum Research—Pasadena, California.
Petroleum geologists determine radioactivity of oil well cuttings—use resultant "profile" to expand and develop oil fields.

Industrial Research—New York, N. Y.
Laboratory uses radioactive "dirt" and Nuclear-Chicago instruments to test washing machines, improve soil-removal techniques.

Diagnosis of Thyroid Function—La Crosse, Wis.
Nuclear-Chicago "Mediac" determines uptake of radioiodine by thyroid gland, helps physicians diagnose thyroid dysfunction.

Biological Chemistry—College Station, Texas.
Pea plants grown on a liquid radiosulfur diet and Nuclear-Chicago instruments help biochemists determine how plants produce amino acids.

Uranium Exploration—Wallace, Idaho.
Uranium prospectors use an ultra-sensitive Nuclear-Chicago airborne scintillation system to survey vast areas quickly.

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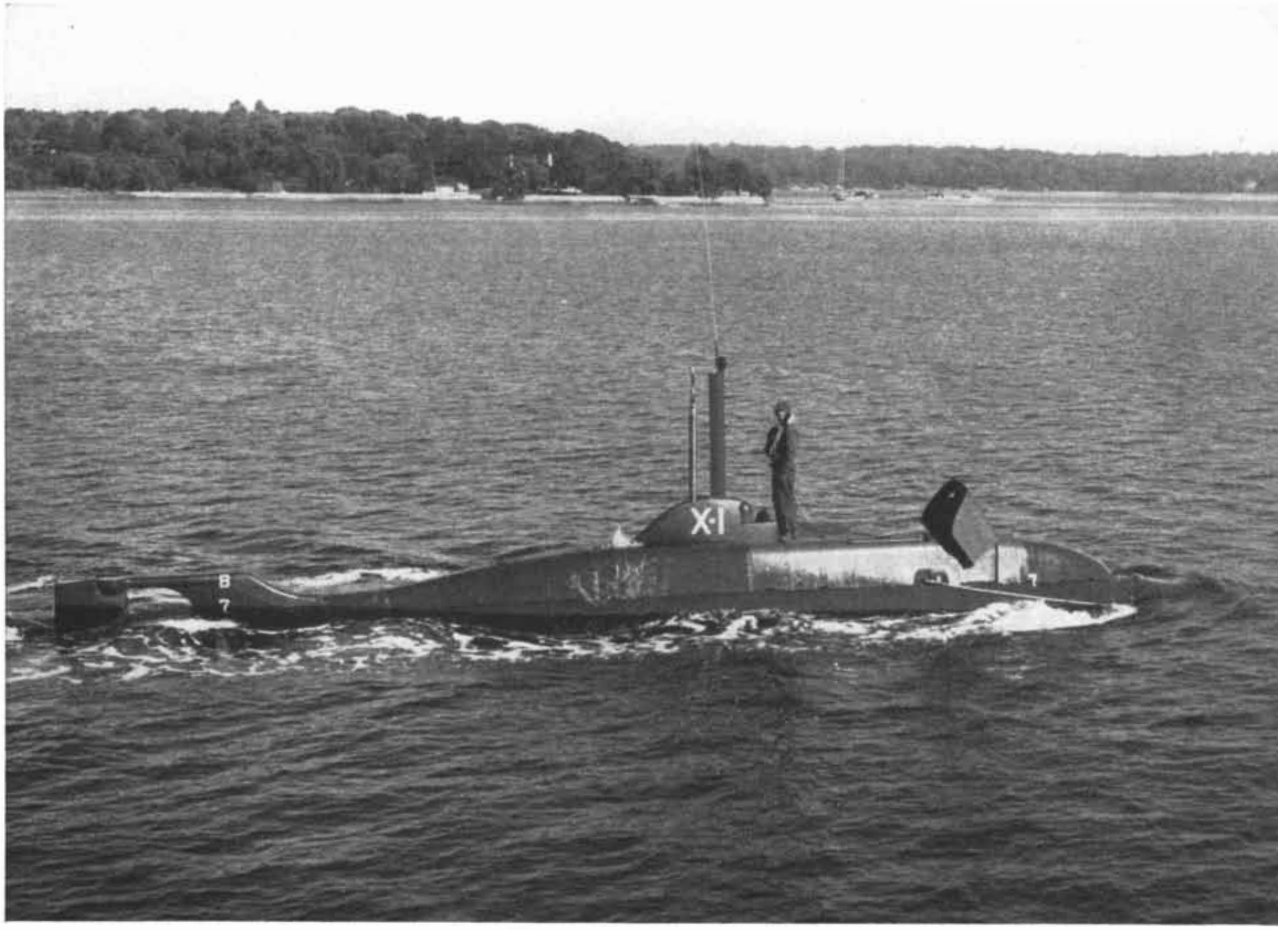
converted to ice, the hamster could be revived by rewarming and artificial respiration, and it recovered completely. On the other hand, many hamsters did not freeze when their body temperature fell below zero. These "supercooled" animals remained quite limp at internal temperatures as low as 6 degrees below zero C. Rewarming from this state resulted in complete recovery of the animal.

A remarkable finding of these experiments was the rarity of cold injury to the surface parts of the animal that had been frozen stiff. Even extremities, such as the ears, very rarely showed signs of frostbite unless manipulated while frozen—a relationship discovered when a group of distinguished visitors to whom the experiments were being demonstrated yielded to the temptation to try to bend the frozen extremities.

At zero temperature the hamster has every appearance of being dead. All of its obvious vital functions have ceased. No doubt less obvious functions, such as enzyme activity, also are arrested or slowed down. However, the animal's many and various processes are certainly not slowed to a uniform degree, and it must be in a biochemically unbalanced and therefore unstable condition. Consequently no prolonged survival can be expected at this temperature. For long-term preservation in the frozen state much lower temperatures will be necessary, presumably not less than those already known to be required for individual cells and tissues. The induction of suspended animation at minus 80 degrees C. will no doubt necessitate the pretreatment of the mammal with some such substance as glycerol at a concentration which according to present knowledge is highly toxic to the whole animal. In other words, the biologist is not yet in sight of achieving suspended animation of a warm-blooded animal at a temperature likely to result in a stable state.

When biologists arrive at this achievement, they will find, of course, that novelists have been there before them and that the icy Valhalla already has several charter members. Among them is Edmond About's *L'homme à l'oreille cassée*. "The Man with the Broken Ear" was one of Napoleon's soldiers, who was frozen stiff during the retreat from Moscow. His body was retrieved and dried from the frozen state by an enterprising scientist, and years later was reconstituted and reanimated by another genius—at no greater cost than the accidental breaking off of one dried ear.



"Rigged for diving", the Navy's new 4-man experimental submarine, USS X-1, heads for deep water. Built by Fairchild Engine Division, Deer Park, New York, many vital parts of this boat are made of corrosion-resisting Inco Nickel Alloys.

Undersea "*ferret*"

for close-in attacks on harbors and shipping

You are looking at the Navy's new 4-man midget submarine, USS X-1.

It is only 50 feet long. Diameter 7 feet. Displacement 25 tons. A unique and nimble offensive weapon for testing U. S. harbor defense and performing missions larger subs simply cannot do.

But its very compactness posed a perplexing problem. Major alterations and repairs were bound to come up on this experimental boat. How were they to install or remove equipment that was too large to pass through the hatch?

A unique solution occurred to Fairchild engineers: build the pressure hull in sections and bolt them together. Then the hull could be easily disassembled for alterations, repairs, or even shipment over land.

But this led to a second problem: what alloy to use for the bolts. It had to be corrosion-resisting, of course. But more than that, it had to be strong enough to hold the pressure hull tightly together even when the boat was submerged.

They found the answer in "K" Monel age-hardenable nickel-copper alloy. It is outstandingly resistant to marine corrosion. And it can be age-hardened to a tensile strength of 130,000 to 200,000 psi.

Because of the Navy's previous successful experience with Monel and Nickel, in resisting corrosion by salt water, these alloys are used in many other parts on this submarine. Grease fittings. Plumbing. Pumps and pump parts. Diving gear, including universal joints. Exhaust valves. Engine accessory apparatus. Rings. Springs.

Do you need a strong metal that will resist corrosion? Wear? High temperatures? Or provide some unusual electrical property? Then write for our handy guide to more than 20 alloys developed specifically to give longer, better service under destructive conditions. Called "Standard Alloys for Special Problems," this 16-page booklet is yours for the asking.

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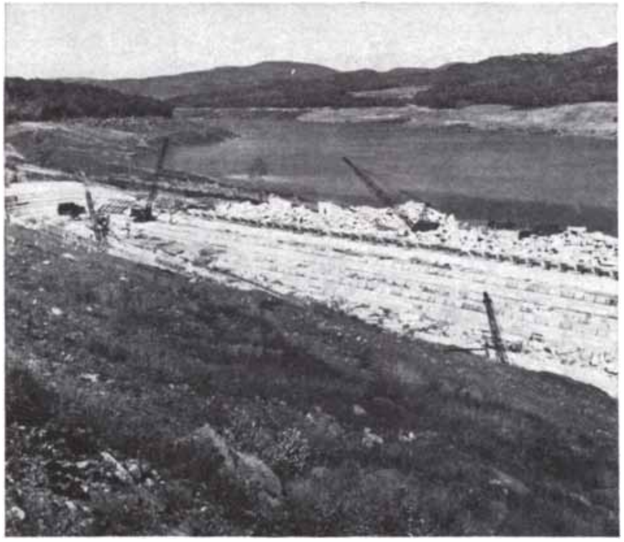
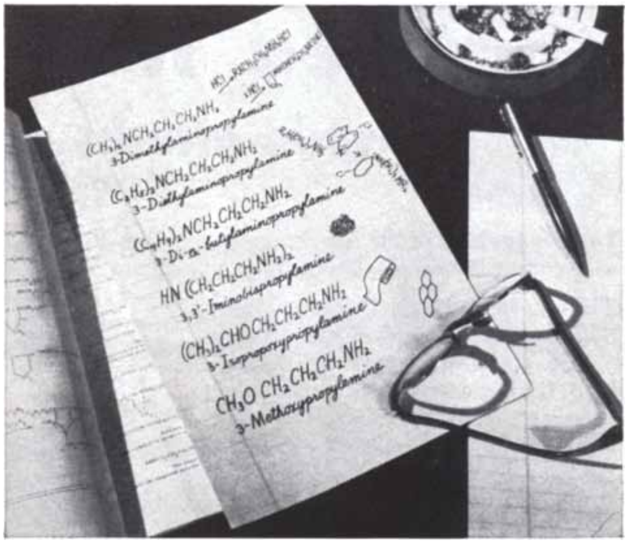
Life on the Chemical Newsfront

SILVER COMES CLEAN AS A WHISTLE with one quick dip in a properly formulated acidified thiourea solution, an ideal work-saving, silver-saving instant cleaner. The thiourea solution dissolves silver sulfide tarnish without the rubbing required by abrasive polishes and without loss of metallic silver other than that contained in the dissolved tarnish. Cyanamid's thiourea, a sulfur analog of urea, is a highly reactive intermediate also used in making black and white reproduction papers, liquid glues, fumaric acid, hair-waving lotions, pharmaceuticals, and in the treatment of nylon fiber and silvering of mirrors. **(Organic Chemicals Division)**



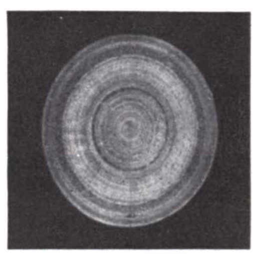
NEW WATER RESOURCES like the one above must be developed on an unprecedented scale to take care of growing municipal and industrial needs. A 90% increase in demand is forecast over the next twenty years, with industry taking the lion's share. To help quench this tremendous thirst, chemical means for purifying water also must be expanded. Cyanamid, a major producer of alum, widely used in water treatment and papermaking, is building a new liquid alum plant in Plymouth, N. C., to meet the growing need for this chemical in the South. Alum, an efficient coagulant, is used in water treatment and pH adjustment, and as a precipitant for rosin size. In liquid form, it can be handled with greater efficiency and economy. **(Industrial Chemicals Division, Dept. A)**

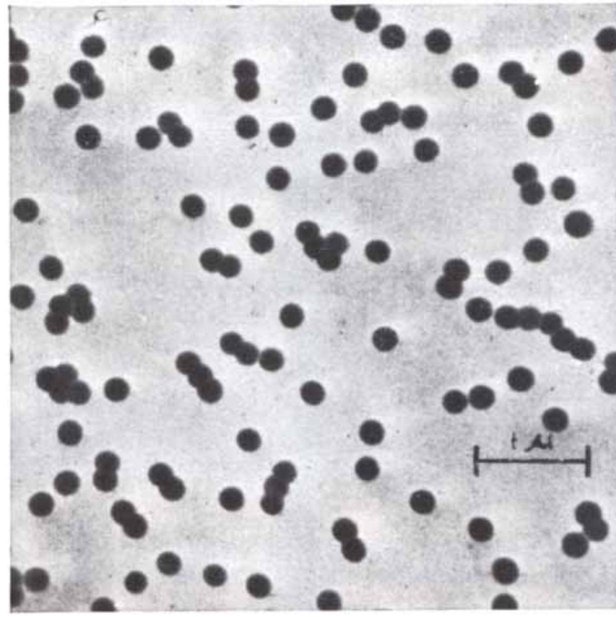


INTERESTING NEW PRODUCT POSSIBILITIES are offered by these six amines, derived from Cyanamid's acrylonitrile. Each has a propylamine group, but varies in the other substituent with corresponding changes in physical properties. As the substituent increases in each series, vapor pressure decreases, solubility in non-polar solvents increases, and activity in specific reactions varies. For example, dimethylaminopropylamine provides rapid cure for epoxy resins, while higher substituents offer greater pot life. Surface active agents produced by reaction with fatty acids make useful emulsifying agents for waxes and flotation agents. Possibilities also include use as intermediates for germicides, pharmaceuticals and dyestuffs. **(New Product Development, Dept. A)**

A NEW PIGMENT MAKES THE GRADE in exterior weathering exposures on Cyanamid's test fence. This time it's Cyan Green Toner 15-3100, a phthalocyanine green with high strength and excellent stability to light and weathering in exterior finishes. Recommended for paints, lacquers, automotive enamels, printing inks, plastics, floor coverings, synthetic textiles and roofing granules, Cyan Green Toner 15-3100 has excellent working properties. It disperses readily in coating formulations and is free from bodying. It is essentially non-bleeding in organic solvents, highly stable in both acid and alkaline media and does not migrate in organic media. (Pigments Division)

FIGHTING ENGINE WEAR. Most new cars today are delivered with "break-in" oil containing zinc dithiophosphate. Major automotive manufacturers consider it the most effective wear-inhibiting additive, particularly in the valve-train mechanisms of modern V-8 high-compression engines. Notice the excellent condition of the test valve lifter (above) protected by oil containing AEROLUBE® 93-C Zinc Dithiophosphate, recently modified to give superior antiwear characteristics. The badly pitted valve lifter (below) received ordinary lubrication. AEROLUBE 93-C also controls oil oxidation and checks formation of corrosive peroxides and organic acids, extending bearing life and reducing engine maintenance. (Industrial Chemicals Division, Dept. A)

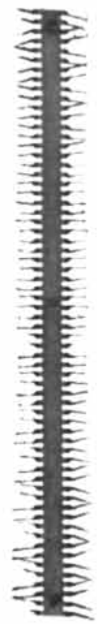




BETTER QUALITY CONTROL in the commercial production of rubbers, plastics and other polymers is one of the many benefits secured by selection of the proper surfactant for emulsion polymerization. AEROSOL® Surface Active Agents have shown excellent results as emulsifiers in producing uniform particle size, as shown above in an electron micograph of a styrene-butadiene latex, magnified 15,000×. The latex particles are very uniform in size and shape, ranging in diameter from 0.21-0.24 microns. The AEROSOLS also increase the rate of polymerization, stabilize dispersions during reaction and secure good heat, color and rub stability in the latex film. The versatility of AEROSOL Surface Active Agents has been demonstrated by their use in a variety of emulsion polymerization reactions. Since they vary considerably in ratio of polar to non-polar constituents, a selection is available for specific applications. (Industrial Chemicals Division, Dept. A)

Additional information may be obtained by writing on your letterhead to the Division of American Cyanamid Company indicated in the captions.

Building for the Future Through Chemistry



TITANIUM's Rating in Etching Solutions

Special purpose racks, with a nonconductive protective coating can effectively be used in many electroplating or etching solutions.

Etching Solution	Rating
H_3PO_4-CrO_3 at 180°F	Excellent
Alcoa R5 Bright Dip at 190°F	Good
H_2SO_4-CrO_3 at 180°F	Good
50% HNO_3 at Room Temp.	Fair

how TITANIUM cuts costs of anodized aluminum

Racks used for anodizing aluminum parts lead a rugged life. Sulphuric acid, and other highly corrosive solutions in which they're used, quickly eat up racks of ordinary materials . . . and production and labor costs go up.

But, made of TITANIUM, these same racks last *indefinitely*. For TITANIUM is not affected by any of the solutions used in anodizing — *is exceptionally resistant to most forms of corrosive attack*. And TITANIUM's high strength helps cut rack maintenance to practically zero.

For example, the anodizing racks shown here were designed and made by Omega, Inc., Litchfield, Connecticut. Joseph Reed, Jr., Omega's president, sums up TITANIUM's advantages this way: "True, the TITANIUM rack costs approximately three times as much as a conventional rack, but for any production run which will demand three or more sets of special purpose aluminum racks, TITANIUM is definitely the choice. After such runs, TITANIUM racks are still in good condition for future use."

This is no isolated example of how TITANIUM is cutting production costs. If you have an application calling for a metal that's *strong* (TITANIUM is as strong as steel, but weighs only half as much), *corrosion resistant*, and *easily formed* by normal shop methods, then TITANIUM may be for you, too. Your REM-CRU representative will be glad to help you make the best use of this versatile metal.

To keep abreast of the latest developments on this vital metal, write to Dept. S-6 for the Rem-Cru Review — a free periodical presenting the latest technical data on titanium alloys.

REM-CRU TITANIUM

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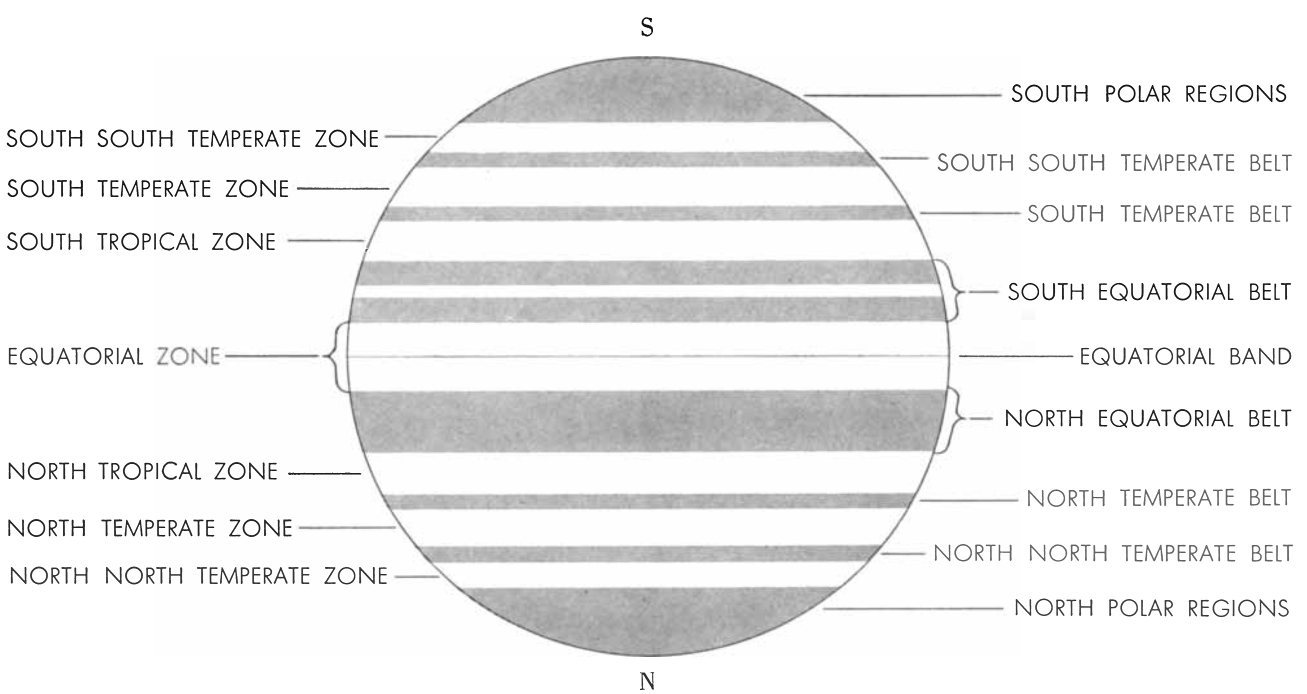
THE CHEMISTRY OF JUPITER

The big planet's varicolored markings are an old astronomical puzzle. The author now suggests that the colors may be due to free radicals, frozen solid in the very cold Jovian atmosphere

by Francis Owen Rice

The planets of the solar system (omitting Pluto, about which little is known) fall into two natural groups: (1) the terrestrial planets—Mercury, Venus, Earth and Mars—and (2) the major planets—Jupiter, Saturn, Uranus and Neptune. We can make informed estimates of the composition of the terrestrial planets because they are all somewhat like our own. But the chemistry of the larger planets has always been something of a mystery. They are much less dense than the Earth and are enveloped in huge atmospheres several thousand miles deep. These atmospheres are quite evidently very different from ours. Jupiter, which is the nearest to us and has been most thoroughly studied, wears a Joseph's coat of many colors, suggesting that its atmosphere is made up of a varied and unusual array of compounds. My chief purpose in writing this article is to present a new chemical explanation of the markings on Jupiter.

Through a telescope we can see that Jupiter is encircled by bands of rich yellow, brown and orange, alternating with darker strips, roughly parallel to its equator. In addition there are olive green and bluish patches on its surface. If we fix on a distinctive spot in a band and follow its movement, it appears to make a complete circuit of the planet in somewhat less than 10 hours. But this does not mean that the planet itself is rotating at that speed. The markings seem to be floating at various speeds in an atmospheric ocean. Those near the poles circle the planet in a somewhat shorter time than those traveling around the equator, and one band may drift as much as 200 miles per hour faster than the next. Some of the markings are transient; others may last for weeks or even months. The members of the Jupiter section of the British Astronomical Association watch the planet constantly and



SURFACE CURRENTS in Jupiter's atmosphere, moving at different speeds, produce sharp bands of light and dark. The dark bands are conventionally called belts; the bright bands, zones. The planet is shown inverted, as it appears in an astronomical telescope.

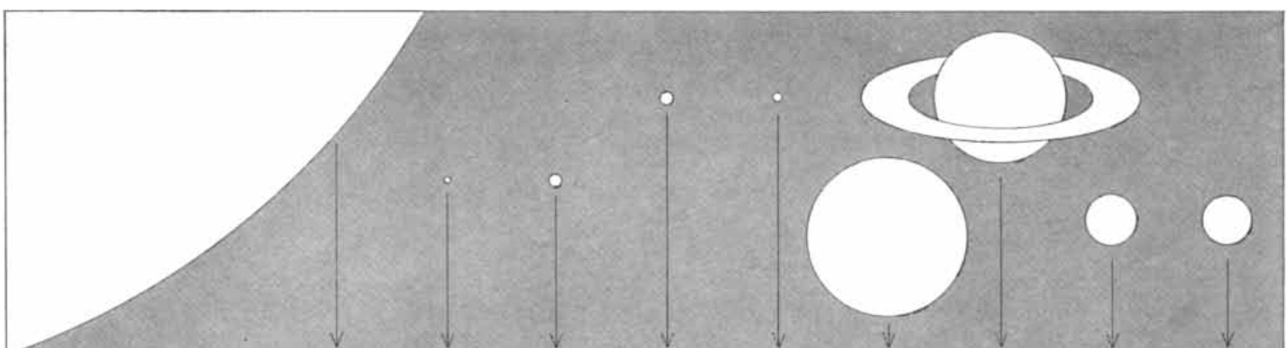
have made a systematic study of its more conspicuous markings, following their life history and keeping meticulous records of their period of rotation, duration, intensity, color changes and so forth. But over the many years that Jupiter has been under inspection, observers have seen hardly any regularities of pattern, except that there appears to be a cycle of coloring in the equatorial belt which repeats at intervals of 11.8 years—the period of Jupiter's revolution around the sun.

Of the few comparatively permanent markings on Jupiter, the most remarkable is the Great Red Spot. Robert Hooke described in 1664 what is probably the same Red Spot we see today. It has been observed continuously for the past 100 years. Its appearance changes from time to time. A marked increase in its intensity during the latter half of the 19th century caused great excitement among astronomers. At other times it loses its color and appears to fade until it can scarcely be seen. Situated in Jupiter's southern hemisphere, the Red Spot is normally oval in shape, about 30,000 miles long and 7,000 miles wide. Its period of rotation varies so irregularly that the spot must be drifting in the atmosphere.

Until fairly recent years many astronomers thought that Jupiter was red hot and the bands and spots were glowing vapors. But the fact that Jupiter's moons cast shadows on the planet makes this doubtful, for if Jupiter emitted its own light, the shadows of the moons should not be visible. The belief now is that the markings are simply reflections of sunlight from distinctive formations in Jupiter's atmosphere. This belief has been confirmed by recent measurements of the atmosphere's temperature. Determining the temperature is not easy, because one needs a sensitive instrument to detect and measure the feeble radiation from the planet and must make various corrections for such matters as absorption of light from Jupiter by the atmosphere of our own planet. However, careful experimental work has established that the temperature of the outer layer of Jupiter ranges between 130 and 180 degrees below zero centigrade. Theoretical calculations based on the energy received by Jupiter from the sun give about the same figures.

Many years ago spectral analysis of the light reflected from Jupiter showed that its atmosphere absorbed certain wavelengths of the sun's light, particularly the extreme red and the infrared portions of the spectrum. The pattern of absorption was peculiar: it had never been observed in any laboratory analysis of compounds. Eventually it was discovered that exactly the same absorption spectrum appeared when light passed through ammonia and methane gas for a considerable distance. Thus both of these gases were identified as components of the Jovian atmosphere. It seems probable that free hydrogen and perhaps helium are abundant in the atmosphere of Jupiter, but no definite evidence of their presence has yet been obtained.

We may imagine that Jupiter has a relatively small core of rock and metal, that this is covered with a thick layer of ice and frozen ammonia, that a huge



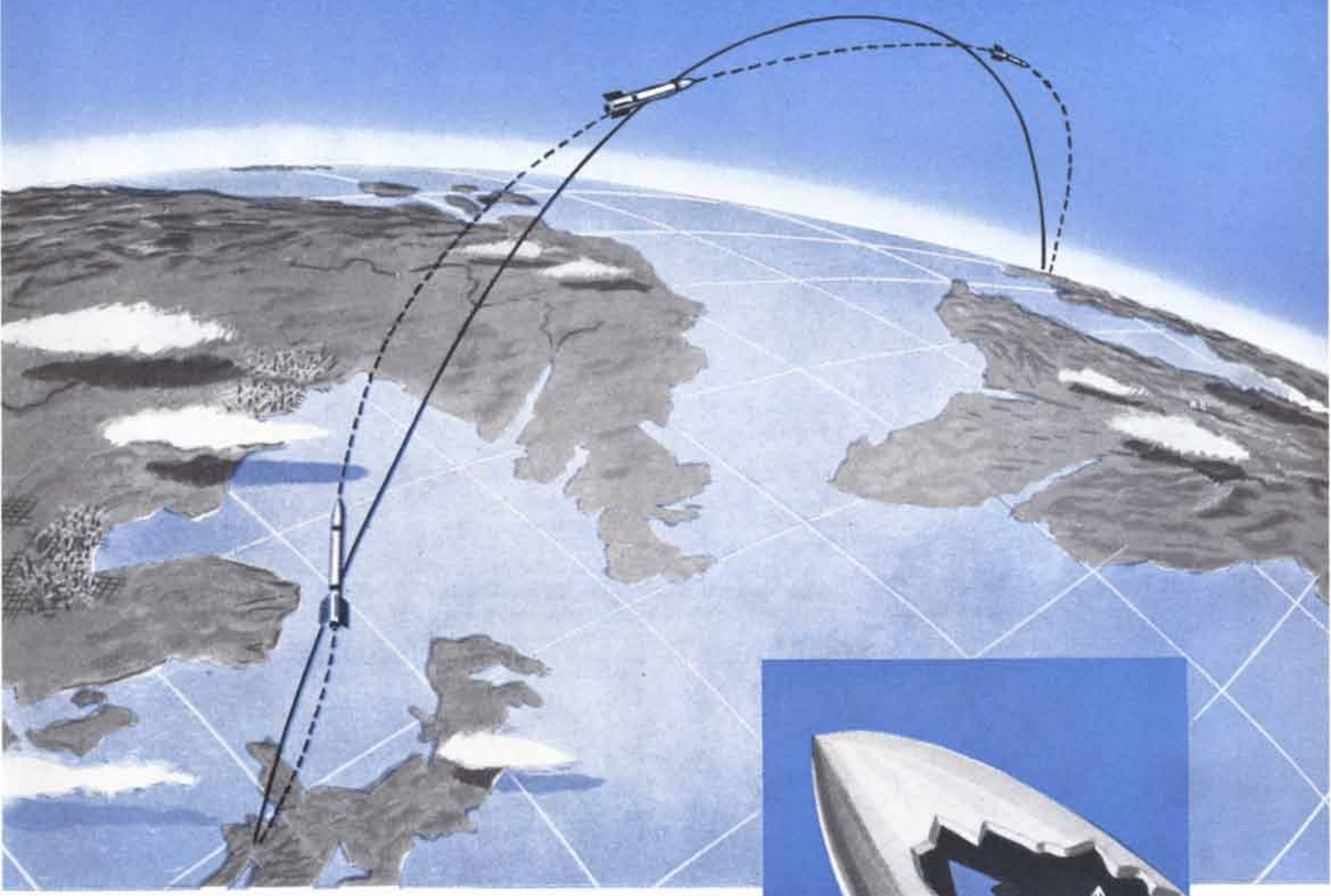
	SUN	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN	URANUS	NEPTUNE
DISTANCE FROM SUN (MILLIONS OF MILES)		36	67	93	140	480	890	1800	2800
DIAMETER (THOUSANDS OF MILES)	865	3	7.6	7.9	4.2	87	71	29	27
MASS (EARTH = 1)	300,000	.05	.8	1	.1	320	95	15	17
NUMBER OF MOONS				1		12	9	5	2
DENSITY (WATER = 1)	1.4	4.9	4.9	5.5	4.2	1.3	7	1.1	1.6
ROTATION PERIOD (DAYS)	26	88	100	1	1	.4	.4	.4	.6
ROTATION AROUND SUN (YEARS)		.24	.6	1	1.9	12	29	84	165
REFLECTED SUNLIGHT (PER CENT)		7	60	45	15	50	60	60	70
AVERAGE TEMPERATURE (DEGREES C.)	6,000		-44	-27	-56	-171	-197	-224	-231

SOLAR SYSTEM comprises the sun and nine planets plus an enormous number of smaller bodies. The planet Pluto is not included in the table because very little is known about it. Average temperatures are those at top of atmosphere of each of the bodies.

FAIRCHILD GUIDED MISSILES DIVISION PIONEERS

the application of

INERTIAL NAVIGATION



After years of experience in the application of inertial navigation, Fairchild Guided Missiles Division is now participating in the development of many new systems of this type.

The particular direction being taken by our talented engineering and scientific staff is of course secret, but the importance of inertial guidance to America's defense is not. The missile that incorporates true inertial guidance is virtually non-deterrable, because it is totally self-contained, depending only upon its own "brains" to pinpoint its target.

Developing such projects as these demands the greatest knowledge, experience and inventiveness. You'll find them all at Fairchild Guided Missiles Division, currently being applied as well to many other new, advanced concepts in this vital field of defense.

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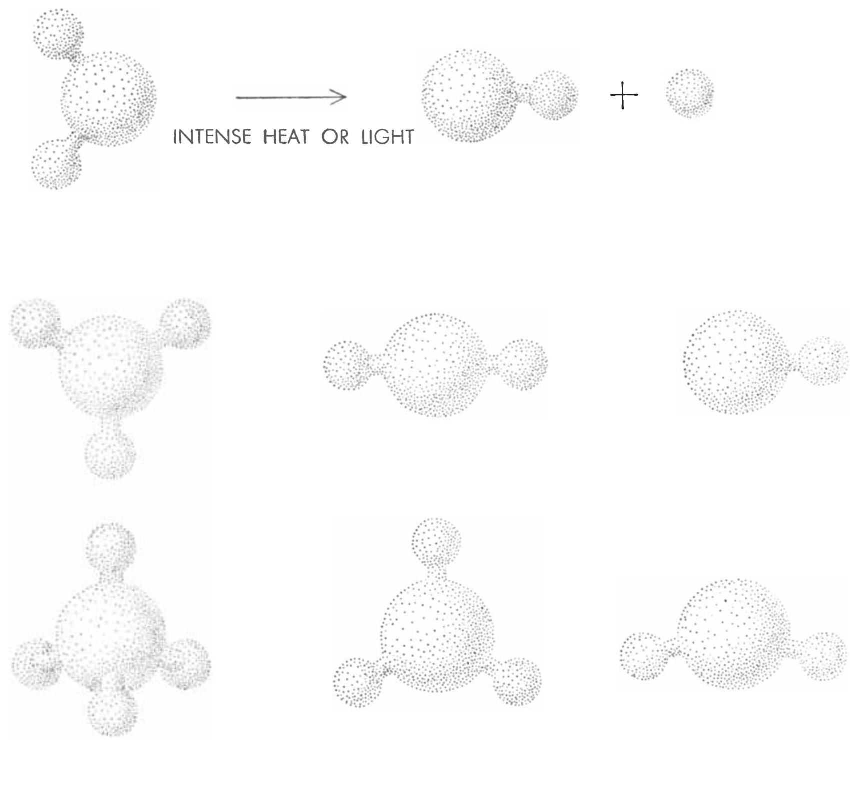
WHERE THE FUTURE IS MEASURED IN LIGHT-YEARS!



FREE RADICALS are formed when molecules of ordinary substances are decomposed by exposure to intense heat or to light of appropriate wavelength. At the top, a molecule of water (*large sphere represents an oxygen atom; small spheres, hydrogen atoms*) is schematically shown breaking up into a hydroxyl radical, OH, and a hydrogen atom. The middle row shows an ammonia molecule, NH_3 (*large sphere is nitrogen, small spheres are hydrogens*), an amine radical, NH_2, and an imine radical, NH. At the bottom is a molecule of methane, CH_4 (*the large sphere is now a carbon atom*), a methyl radical, CH_3 and a methylene radical, CH_2. Under ordinary conditions free radicals disappear almost as soon as they are formed. They react among themselves, or with other molecules, to form new substances.

sea of liquid methane overlies the ice and that finally the planet is enveloped in an atmosphere of hydrogen, helium and vapors of ammonia and methane. But the only thing we know positively is that ammonia and methane are present in the outermost layer.

The first clue to understanding the extraordinary activity and fascinating color changes in Jupiter's atmosphere is the rotation of the planet itself. A point on the surface of Jupiter moves at a speed of about 30,000 miles per hour—about 30 times as fast as on Earth. It is exposed to the sun for five hours and then is in the shadow of night for the same period. Because of this rather rapid heating and cooling, and the fact that the atmospheric bands move with different speeds, Jupiter probably has wind and electrical storms far surpassing any on the Earth. The tremendous cyclones may whirl clouds of colored material from the planet's surface into the upper atmosphere. The red material we see may be cuprene, a polymer of acetylene, which is known to be formed when methane is illuminated with light of very short wavelength. The blues and grays may well be due to the presence of sodium, for this metal gives such colors when it is dissolved in liquid ammonia, the color depending on the temperature.

The new hypothesis I shall discuss is that Jupiter's colors may be accounted for in part by free radicals—the transitory chemical compounds which on Earth are detectable only as fleeting intermediate products of chemical reactions [see "Free Radicals," by Paul D. Bartlett; Scientific American, December, 1953]. For example, if we take a hydrogen atom away from the water molecule, we are left with the hydroxyl radical, OH. If we take away the second hydrogen atom, we are left with just one atom (of oxygen)—the simplest type of radical. Similarly, if we take a hydrogen atom from ammonia, NH_3, we obtain the amine radical, NH_2; removal of a second hydrogen atom gives the imine

It has to be better to reach

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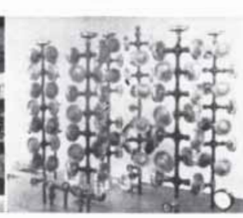
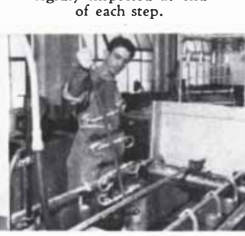
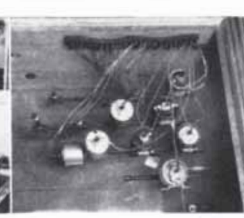


Sensing elements are cycled to the proof pressure 1,000 times. Cycling relieves any stresses left in metals. Any small leaks are detected in this test.



Since sensing elements might be corroded by the atmosphere, this photo shows how they are plated to prevent corrosion.



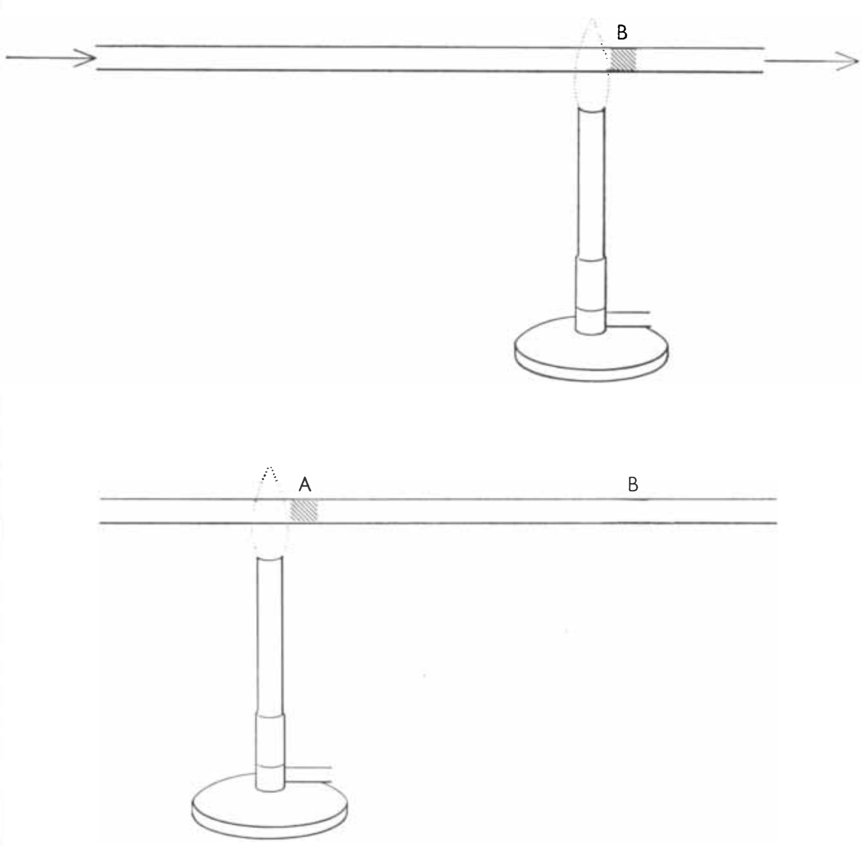
Pressure switches may be required to work in high altitudes, dry climates, high humidity or over rough terrain. These switches are being tested in a high temperature.

In final test calibration, special Meletron developed equipment operates every switch several hundred cycles; then each switch is individually inspected.

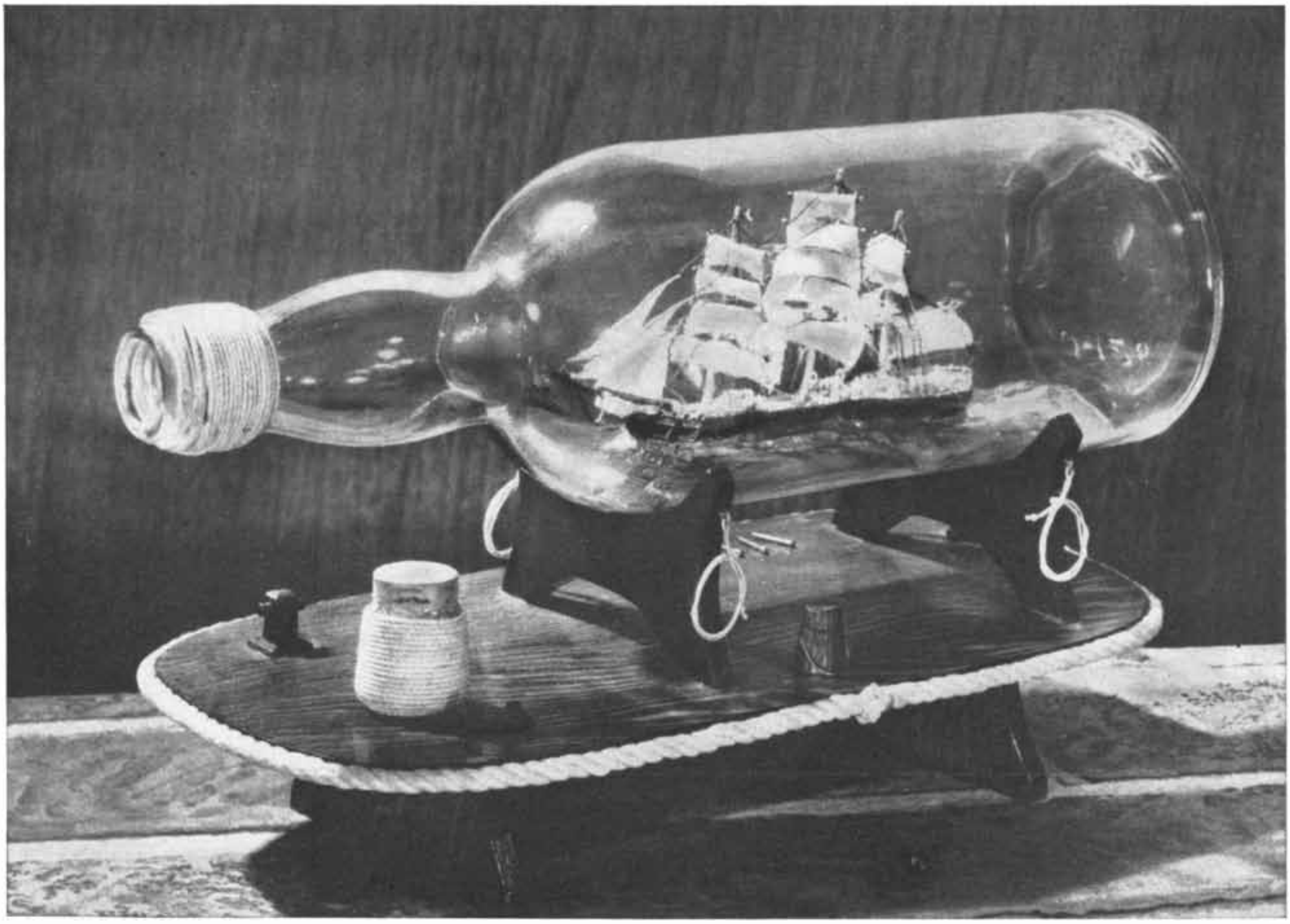
radical, NH, and removal of the third hydrogen atom leaves a nitrogen atom. In the same way we can obtain from methane, CH_4, the methyl radical, CH_3, the methylene radical, CH_2, and so on.

Under ordinary conditions radicals have only a fugitive existence in the free state because they react very rapidly, either with themselves or with other molecules. It is only recently that methods have been discovered for studying their chemical behavior. The favorite method is to generate and trap them in a tube in which, as soon as the radicals are formed, they are swept away from the source material by a stream of inert gas, such as nitrogen. If, for example, the vapor of tetraethyl lead (the antiknock compound) is heated in such a tube, the compound decomposes into lead and the ethyl radical (C_2H_5). The lead is deposited on the tube wall, and the freed radicals are swept rapidly down the tube by the current of nitrogen. Their presence can be detected by trapping them on a cold "mirror" of lead or some other metal, where they combine with the metal to form a volatile compound. The radicals in the stream also react with themselves to form ordinary molecules. Their lifetime as free radicals in the tube lasts only a few thousandths of a second.

While this technique has been useful for studying hydrocarbon radicals, it is not adaptable to noncarbon radicals (such as OH or NH_2), which do not react with "mirrors" of lead or any other known material. However, a method of detecting such radicals was discovered through a chance happening in our laboratory at the Catholic University of America. One of my graduate students accidentally spilled some liquid nitrogen on a tube through which a stream of radicals was passing. A colored deposit immediately appeared on the walls of the tube. The radicals, it seems, were



EXISTENCE OF FREE RADICALS can be demonstrated by the experiment diagrammed here. Through the tube, from left to right, is pumped a stream of nitrogen gas containing a small amount of tetramethyl or tetraethyl lead vapor. The tube is first heated near point B, as in the upper drawing. The lead compound decomposes and a lead mirror forms at B. This deposit is then cooled and the tube is heated at point A, as in the lower drawing. A new mirror forms at A, but as it develops the one at B grows thinner and finally disappears. This shows that the radicals generated at A have passed down the tube and combined with the lead at B to form a volatile compound which is then carried away by the moving gas.



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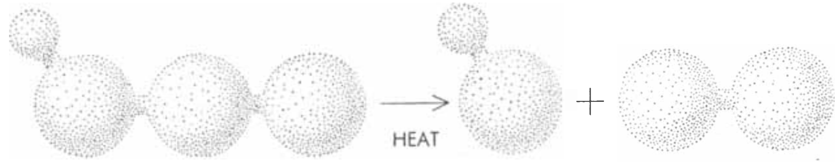


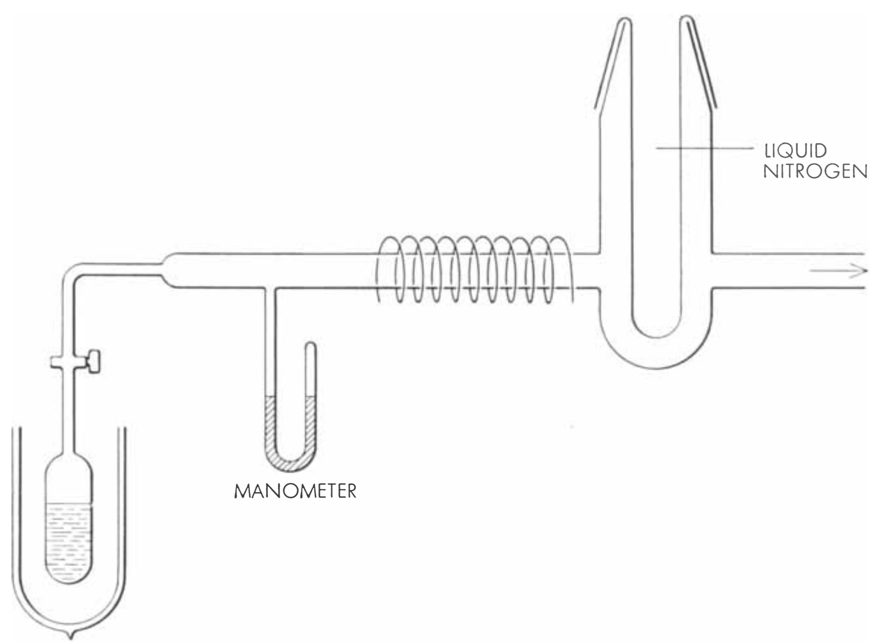
NONCARBON RADICAL is formed when hydrazoic acid, HN_3 (*left*), is decomposed by heat. The reaction yields an imine radical, NH (*center*), and a molecule of the very stable N_2 (*right*). The large spheres in the drawings are nitrogen atoms; small sphere is hydrogen.

frozen out of the stream onto the suddenly chilled walls.

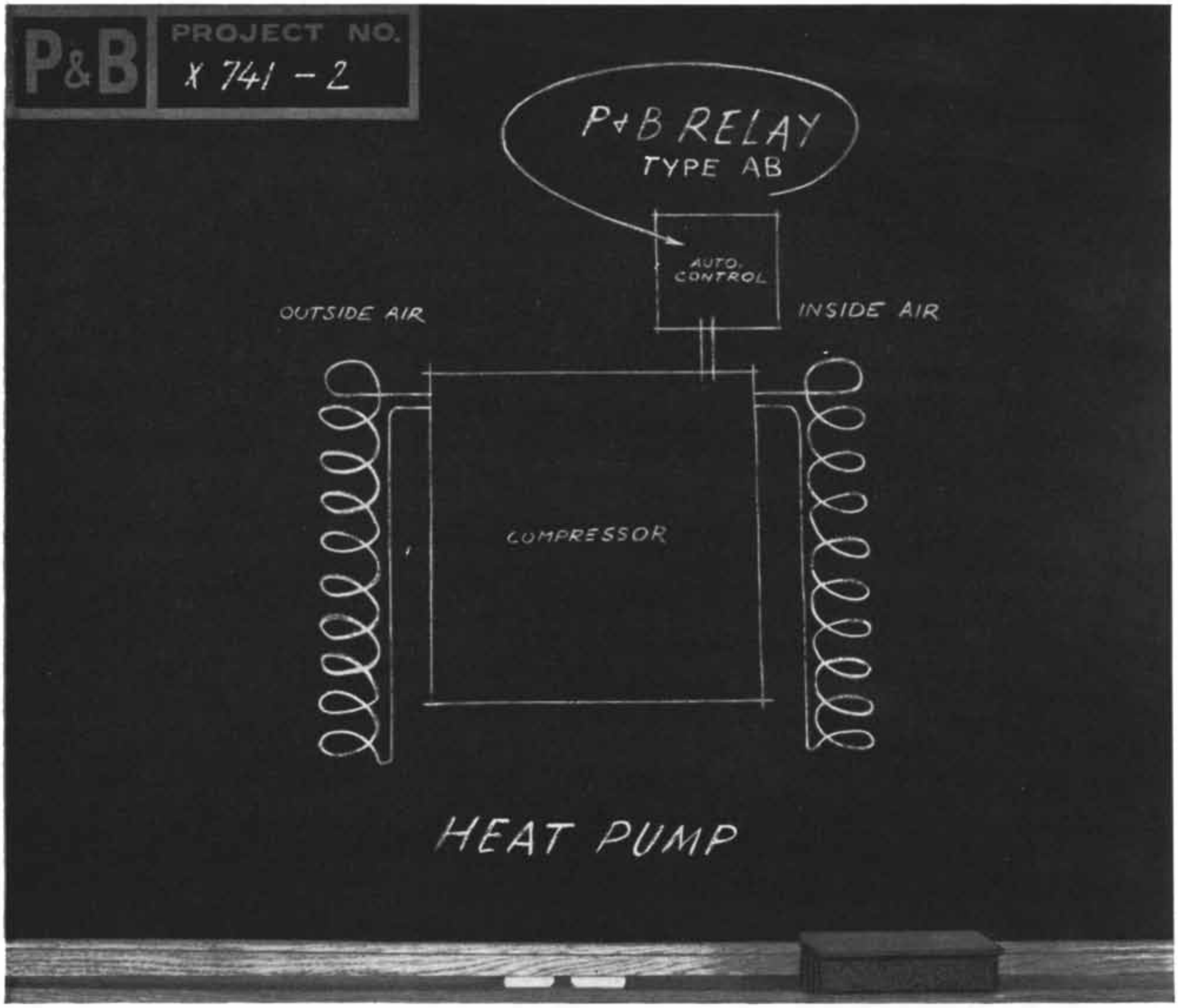
We are now using the following apparatus to study noncarbon radicals. A low-pressure volume of, say, hydrazoic acid is swept rapidly through a quartz tube heated to a high temperature. Under these conditions hydrazoic acid should decompose into the very stable nitrogen molecule, N_2, and the imine radical, NH. The stream of N_2 and NH encounters a pyrex glass finger which is filled with liquid nitrogen at a temperature of 195 degrees below zero C. When NH strikes the surface of the cold finger, it condenses as a beautiful blue solid. At liquid-nitrogen temperatures the solid is chemically stable in the free state. It also possesses the extraordinary property of being attracted by a magnet. This "paramagnetism" is due to the fact that a free radical has an unpaired electron.

When the blue solid is warmed, as soon as its temperature rises to 125 degrees below zero it suddenly turns white and gives off heat. The white substance turns out to be ammonium azide, NH_4N_3, formed by the combination of four NH radicals.

When the compound hydrazine, N_2H_4, is decomposed in the same apparatus, a yellow substance freezes out on the cold finger. This solid also is stable indefinitely at minus 195 degrees, but when warmed to minus 178 degrees, it suddenly becomes white and gives off free nitrogen. The substance may well be the hydrazine radical, NH_2NH. We have no conclusive evidence that either the blue or the yellow solid produced in



FROZEN FREE RADICALS can be obtained in the apparatus shown above. To prepare solid imine the flask in the thermos bottle is filled with a solution of sodium azide in sulfuric acid. This generates hydrazoic acid. The hydrazoic acid is conducted through the heating coils of an electric furnace where it is heated to a temperature of 800 to 1,000 degrees centigrade. There the compound decomposes into imine and nitrogen. On this cold surface the imine radicals crystallize out as a blue solid. The material, which has the property of being attracted by magnets, is stable if it is kept cooler than —125 degrees C.



"Standard" relay solves special problem

A leading manufacturer of heat pumps, modern devices to heat and cool the home, had this problem. Improperly applied relays in the automatic control unit were failing in service.

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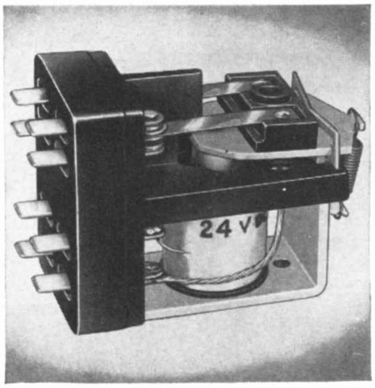
Whether your problem requires engineering a new electro-mechanical device, or merely the intelligent application of a "standard" relay, you can be certain the solution lies with P&B.

P&B series AB relay, specifically designed for those appliance applications where long, dependable life is a requirement. Has stationary, pure-silver contacts, integrated with a sturdy, one-piece molded base, plug-in terminals for rapid installation.



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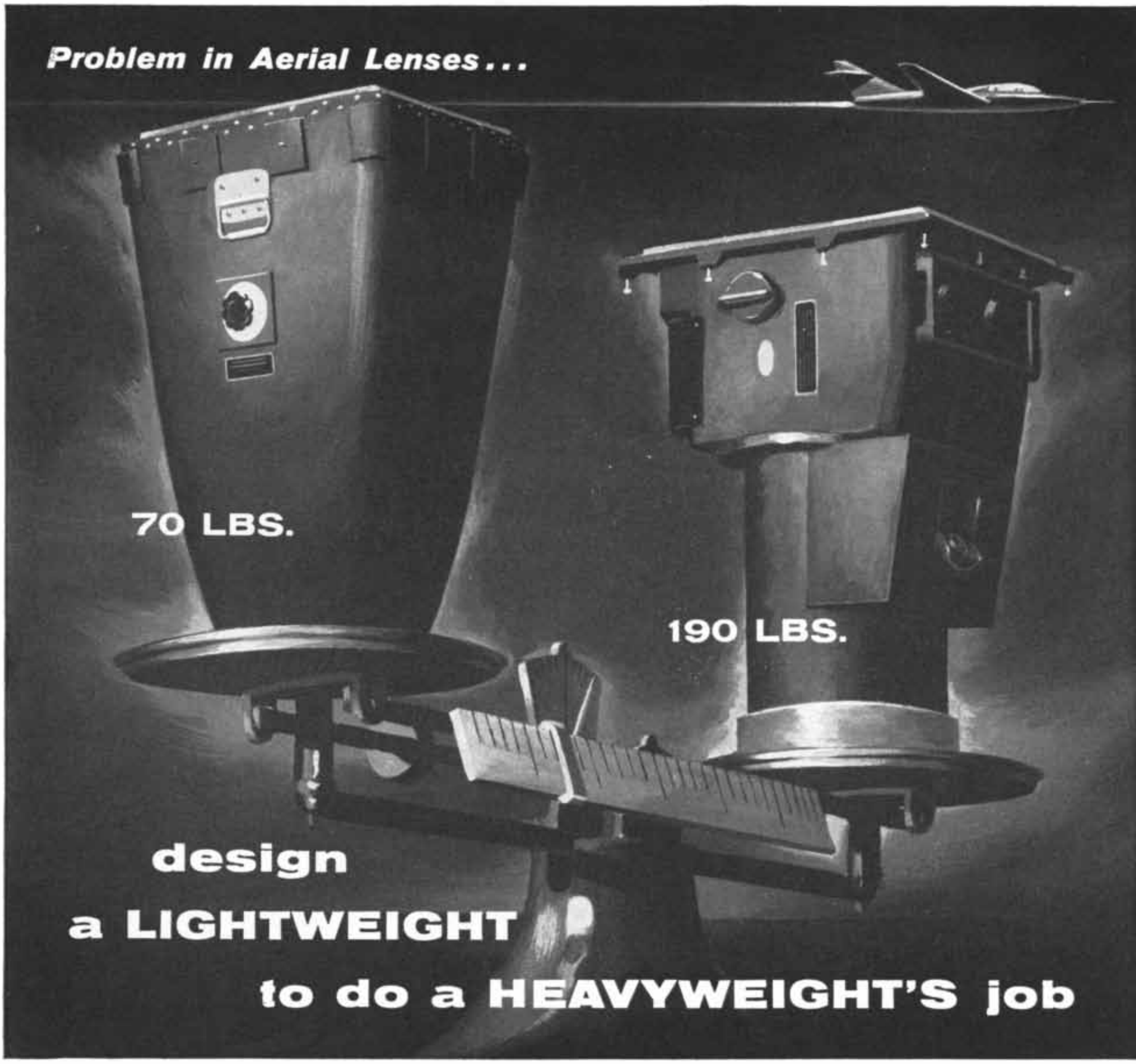
these experiments is actually a free radical rather than a composite molecule, but the nature of the experiment suggests that they are radicals.

Now the blue and the yellow are like the colors observed on Jupiter. It seems almost certain that sunlight shining on Jupiter continuously generates free radicals in its outer atmosphere. On the basis of laboratory experience we can say that absorption of sunlight by the planet's methane and ammonia should liberate radicals such as CH_3, CH_2, NH_2, NH, NH_2NH and so on. Swept down rapidly to the colder depths of the planet's atmosphere by its great winds, the free radicals would be preserved there, for as we have seen, some of them at least are stable at low temperatures. This storing of sunlight in the form of high energy radicals deep in Jupiter's atmosphere would be analogous to the storage of sunlight in the form of coal in the Earth (through the photosynthesis of ancient plants).

It is difficult to avoid the conclusion that the generation of free radicals by absorption of light and their stabilization under conditions of intense cold occur in Jupiter's atmosphere. Since the process has been occurring throughout the ages, the accumulation of colored materials may be sufficiently great to account, at least in part, for the colors observed.

A program of research is now under way to test our hypothesis. To decompose compounds into radicals we have substituted intense ultraviolet light for the electric furnace we were using, and we are studying the absorption spectra of the substances deposited on the cold finger, with a view to comparing the spectrum of light reflected from them with that of the sunlight reflected from Jupiter itself. This should give unequivocal evidence as to whether or not free radicals are present on Jupiter.

If free radicals are indeed stored in considerable amounts in the lower parts of Jupiter's atmosphere, we can amuse ourselves by speculating that a space ship traveling to that planet would find an abundant supply of rocket fuel *par excellence* to refuel for the return journey to Earth. This might give Jupiter priority over Mars as the first target of man's interplanetary travel, except for the unfortunate facts that at a speed of 1,000 miles per hour a space ship from the Earth would take about 40 years to reach Jupiter, and the big planet's mass is such that a 180-pound man would weigh almost a quarter of a ton there.



As part of its never-ending war on weight the Air Force handed Perkin-Elmer this problem: find a way to trim the fat off bulky aerial telephoto lenses — without impairing their optical performance.

Drawing on the experience of a staff that has designed and built some of the world's most complex optical and electro-mechanical equipment, P-E came up with a definitive report on lightweight lens techniques. Using these new techniques, P-E took a large lens system weighing 190 pounds, remanufactured it down to a cool 70 pounds — with no loss in optical performance!

Even more dramatic weight reductions are in the offing. P-E has recently developed a method for mass-producing aspheric lenses. This new method will make possible lens systems with greatly simplified optical elements. Here again, the answer was found by a P-E staff whose experience went far beyond mere specialization.

Other projects that testify to Perkin-Elmer's ability to take a systems problem and "see it whole":

- ROTI Mark I (Recording Optical Tracking Instrument) for tracking the flight of guided missiles.
- Airborne infrared detection systems for military use.
- The Y-4 bombing periscope for the B-47.
- Prototype optical and radar bombing and navigation system now designated MA-2 for use on the B-52.
- Most of the large aerial photographic lenses in use today by the Air Force.
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Pneumatic Buildings

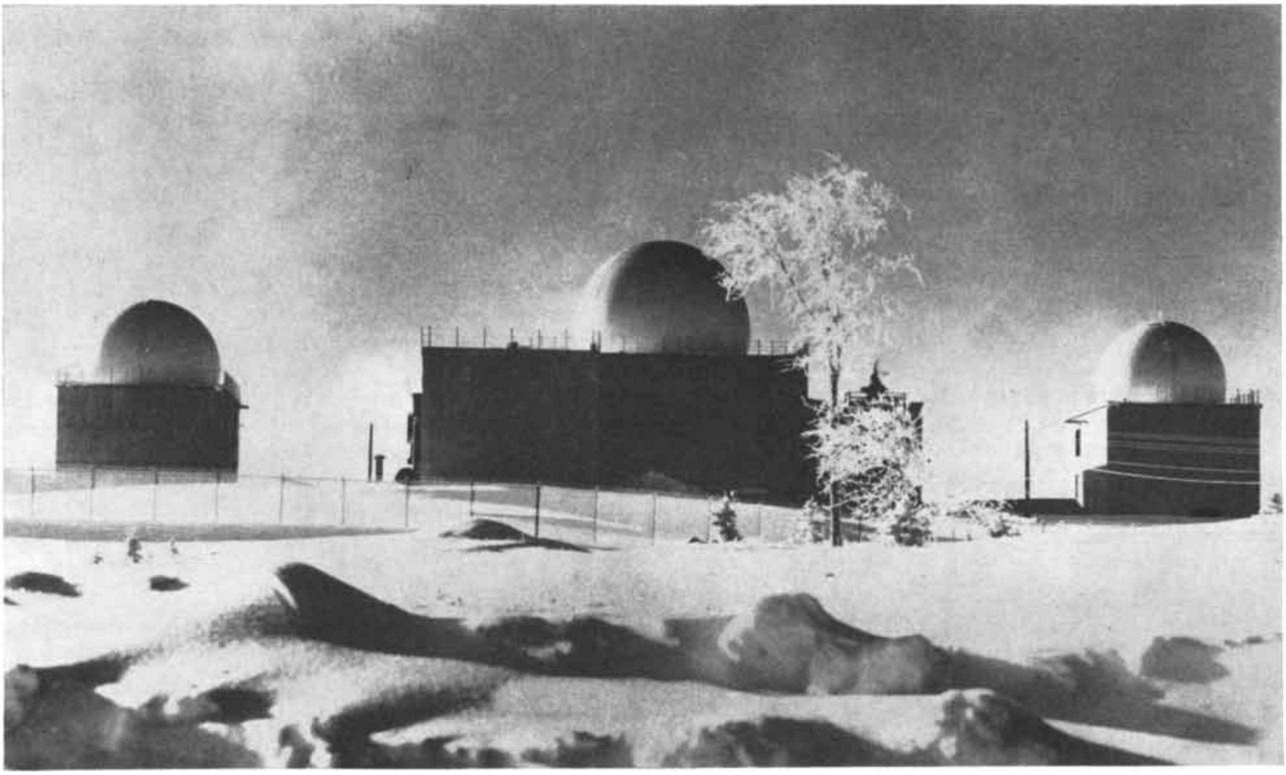
Supported only by thin air, these balloon-like fabric structures now house radar installations. Eventually they may also be used to roof over exhibition halls, hangars and other large buildings

by Murray Kamrass

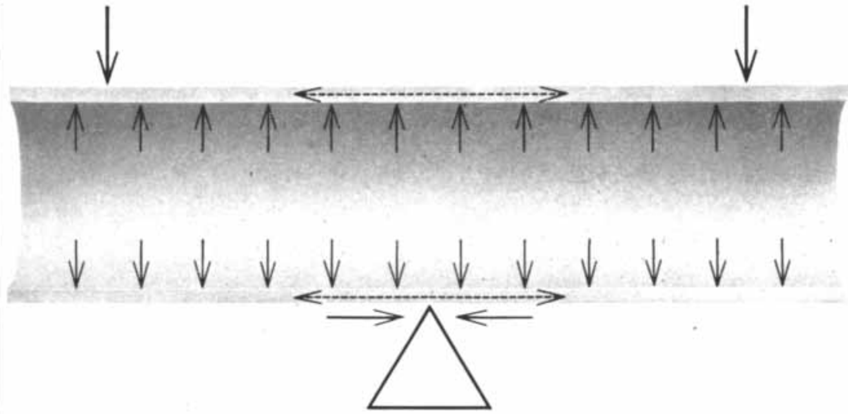
One day in June, 1948, visitors at the airport in Buffalo, N. Y., watched curiously as an immense balloon was slowly inflated on the ground beside the field. No doubt many of them expected the balloon, huge as it was, to take off. But when it was fully inflated, the big bag turned out to be a building. What the spectators saw was the erection of the world's first completely pneumatic structure. It had no girders, poles, struts, ribs or any other support but the air pressure inside the dome.

By now hundreds of these bulbous structures have popped up in many locations in the U. S. and Canada. They have not been seen by many people, because they are mainly in remote, out-of-the-way places where they serve as portable "radomes" for housing radar stations. But their practicality and virtues have been so successfully tested that we can expect pneumatic buildings to become common in civilian life in a variety of capacities, from sports arenas to granaries.

The idea of a pneumatic structure is not exactly new, but it was never investigated on a thoroughgoing scale until after World War II. It came into being as a result of the U. S. Air Force's need for a means of sheltering radar antennas in the far-flung radar warning system it was building around the North American continent. The shelter had to be large enough to cover a huge antenna yet light enough to be flown to remote stations, transparent to radio signals yet sturdy enough to withstand hurricane winds and weather extremes from the arctic to the tropics. To transmit and receive radio signals without loss of strength or distortion, the antenna ideally should be sheltered behind walls of



PNEUMATIC BUILDINGS are now in use as enclosures for the antennas of the radar installations which are now being set up across Canada. The fabric bubbles successfully withstand all the rigors of the Arctic climate and are transparent to radio waves.



HOSE IS STIFFENED by the pressure of water against its inside surface. This pressure, indicated by the small vertical arrows, produces tension in the hose material, as shown by the broken horizontal arrows. When the hose is pressed downward against a wedge, it will not buckle until the compressive force (*solid horizontal arrows*) exceeds the tension.

some thin, nonmetallic material without interfering supports. These specifications led the Cornell Aeronautical Laboratory, Inc., at Buffalo to propose an unconventional but practically inevitable solution—a dome supported simply by air, pumped to slightly higher pressure than the outside atmosphere.

Although the proposal met with considerable skepticism, the development center at the Griffiss Air Force Base in Rome, N. Y., sponsored a short study by the Cornell Aeronautical Laboratory of the idea's feasibility. The results were impressive enough to launch a full-scale development at the Laboratory by a team of engineers under the direction of Walter W. Bird.

As finally worked out, the airdome, an inflated sphere truncated at the bottom and tied to a foundation, seems simplicity itself. But complex theoretical and practical problems had to be solved before the idea was reduced to a workable form.

The essential principle is familiar enough. An empty water hose is limp, like a rope, but when it is filled with water under pressure, its walls become rigid and resist bending; anyone who has ever handled a fire hose knows how stiff it can be. The stiffness is explained by the fact that the hose walls have been put into tension by the internal pressure. This is the simple scheme of the airdome: its flexible fabric envelope is put under tension and made rigid by internal air pressure. How much pressure is necessary? It turned out that one tenth of a pound per square inch above the atmospheric pressure (which averages about 15 pounds per square inch) was sufficient under ordinary wind conditions. This difference amounts to about .2 inch of mercury—well within the range of daily variations of the barometer. During violent storms the airdome can be kept rigid simply by raising the pressure slightly. In a wind-tunnel test run by the author, a model radome withstood a 200-mile-per-hour wind without perceptible effect on its shape with the internal pressure only .65 of a pound per square inch higher than the ambient.

Such pressures can easily be maintained by blowers or other equipment, *e.g.*, pressure tanks or gas generators. The radomes generally have a control system which keeps the pressure at the necessary level and switches on extra blowers in an emergency, such as high winds or tears in the envelope. They have on occasion been kept inflated in spite of many punctures. In case of failure of the power supply for the blowers, it is desirable to have an auxiliary standby power system. But one of the great virtues of these structures is that a collapse of the building is not dangerous. The supporting air pressure is so little more than that outside that the air escapes slowly, and the structure settles gently. The lightness of the "roof" would be a big safety factor in a theater or sports arena of this design; in case of an earthquake or fire there would be nothing to crash on the spectators' heads. A light frame of cables could catch the collapsing envelope and prevent it from falling to the floor.

The radomes usually have simple air locks at the doors to prevent too much loss of air when people enter or leave. Revolving doors could be used for the same purpose. A person in the airdome does not notice the difference in pressure, except for momentary pressure on the ears when he goes out, like the effect in a descending airplane. To keep an air-

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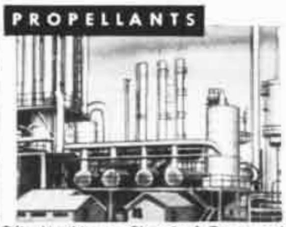

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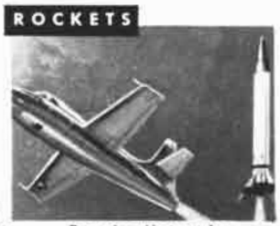
ROCKETS



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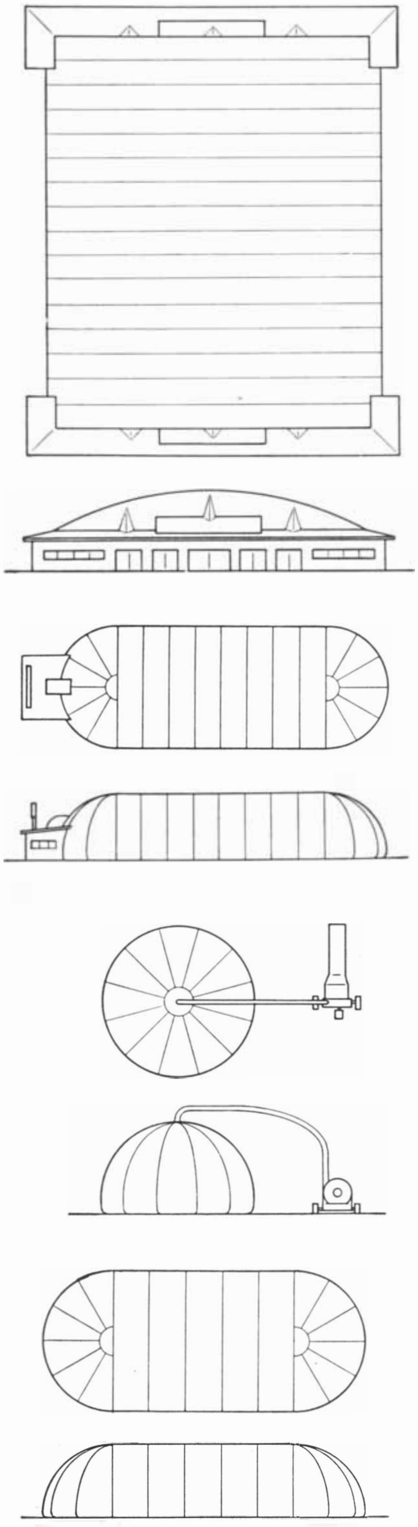
tight seal around the bottom of the envelope, many radomes are clamped to the circular foundation with a ring. The foundation is sometimes on the ground, sometimes on a building or tower 25 or 30 feet high.

One of the most interesting and important aspects of the research was the analysis of stresses on the various parts of the envelope. Wind blowing against an envelope from one side of course imposes nonuniform forces over the surface; the forces vary in strength and direction from point to point. Yet the envelope must be kept reasonably rigid at all points. If it buckles or billows in any area, it may foul up the big antenna revolving inside. If the stress is concentrated too strongly at any point, the envelope may tear. If the radome stands on a small base, a strong wind may overturn it. The cure for all these possible calamities is to maintain just enough air pressure to keep all parts of the envelope under sufficient tension to resist buckling.

The wind pressures and stress distributions over the whole envelope were measured in detail in wind-tunnel tests. It was first assumed that the envelope would not bend or give in such a way as to relieve high local stresses and distribute the load to other areas. The calculations as to the pressure needed and the loads on the fabric were made on this conservative basis. Actually it was found that the cloth envelopes studied were in fact capable of distorting to transfer stresses from the most stressed areas. This useful property allows considerable leeway in design.

Much research has been spent on finding the best materials for construction of the envelope. The design called for a fabric which was strong and weather-resistant, would not stiffen in extreme cold, would not absorb moisture, would not stretch too much yet would give when necessary, could be stored for long periods without deteriorating, and, above all, would not significantly absorb radio energy, so that radar signals could pass through the envelope freely. The principal fabrics investigated so far have been Fiberglas, nylon, Fortisan (a rayon) and Dacron. Field experience has shown that for radomes the best of these are nylon and Dacron. To improve resistance to tearing, the fabrics are used in a two-ply weave with the threads biased at a 45-degree angle; when this is punctured, it does not rip beyond the original break.

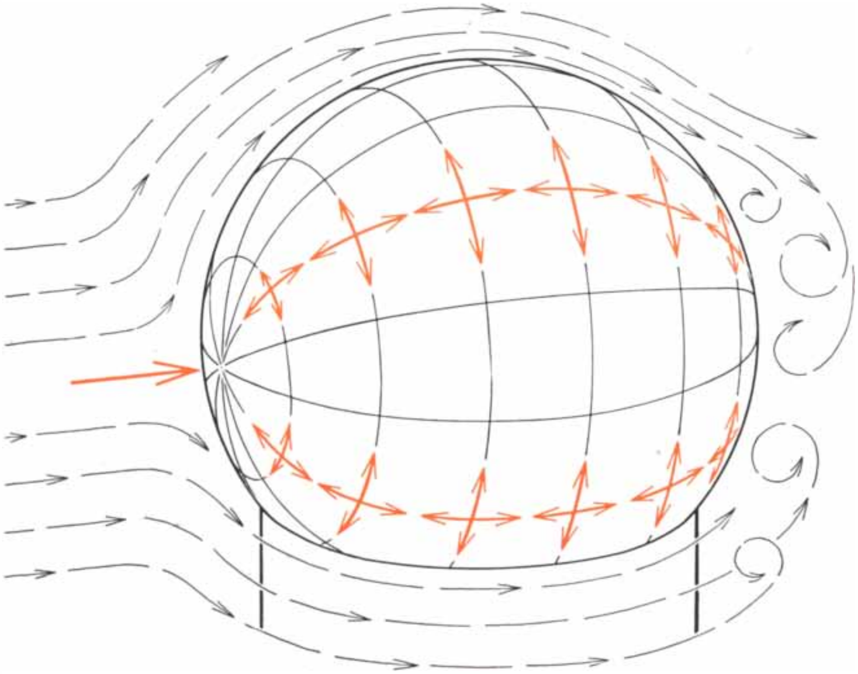
For resistance to weathering the fabric is coated with neoprene contain-

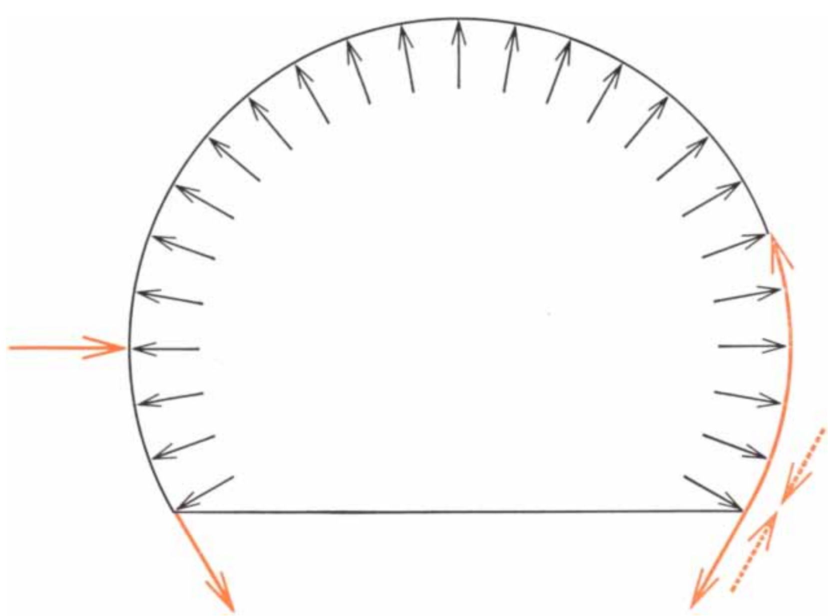


POSSIBLE COMMERCIAL USES for air-supported buildings are suggested in these drawings. The topmost pair of drawings represents a large coliseum with an air-supported roof. It is seen in plan view (*above*) and elevation (*below*). The next pair represents a portable enclosure that might serve for summer fairs or carnivals. The two lower pairs of drawings show structures that could be used for bulk storage in open fields. Attached to the upper, hemispherical enclosure is a pump to load it from the top.

ing a little carbon black. A vinyl-base white paint over this coating proved effective in improving resistance to weather and in reflecting the sun's heat, but in severe climates the radome had to be repainted as often as every year. Further development produced a paint known as Radolon (chlorosulfonated polyethylene) which has given the best service of any so far. Research is being continued to find still better fabrics and coatings which will be less costly to make.

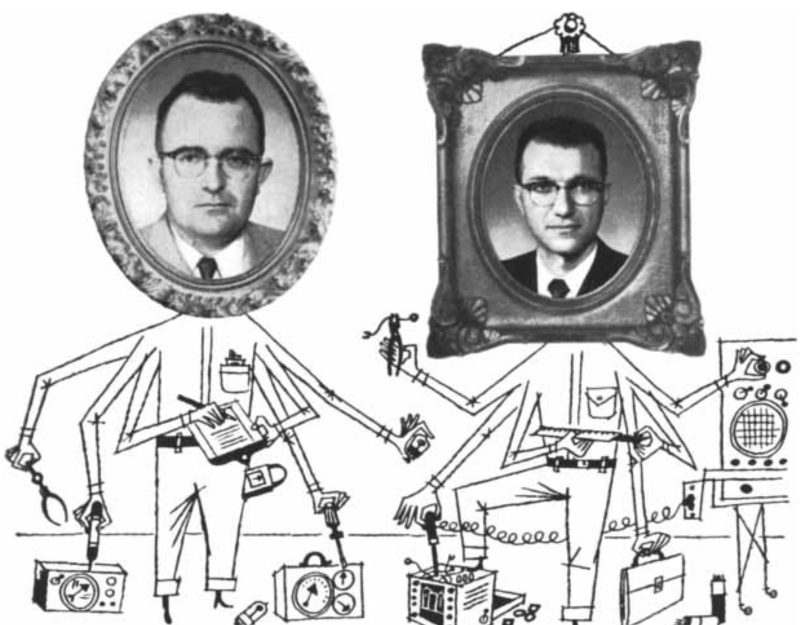
The radome is constructed of panels of the fabric, tapered to the top where they are fastened to a circular crown piece. The panels are cemented rather than sewn together, as this makes a tight seal and just as strong a joint. Usually a tape is cemented over the joint. The





DISTRIBUTION OF STRESSES on a radome is shown by the colored arrows in the upper diagram. The broken arrows around the dome represent the general direction of wind flow around it. In the lower diagram a wind force (*horizontal colored arrow*) produces a compression on the far side of the dome (*broken colored arrows*). The compression is counterbalanced by the tension (*vertical colored arrows*) due to the internal pressure.


M O N R O E
DOWN
FROM
BLUE SKY
Monroe puts AUTOMATION on these desks . . . Today
Budd THE BUDD COMPANY
DOUGLAS
J&L STEEL
Jones & Laughlin
STEEL CORPORATION
76
UNION OIL COMPANY

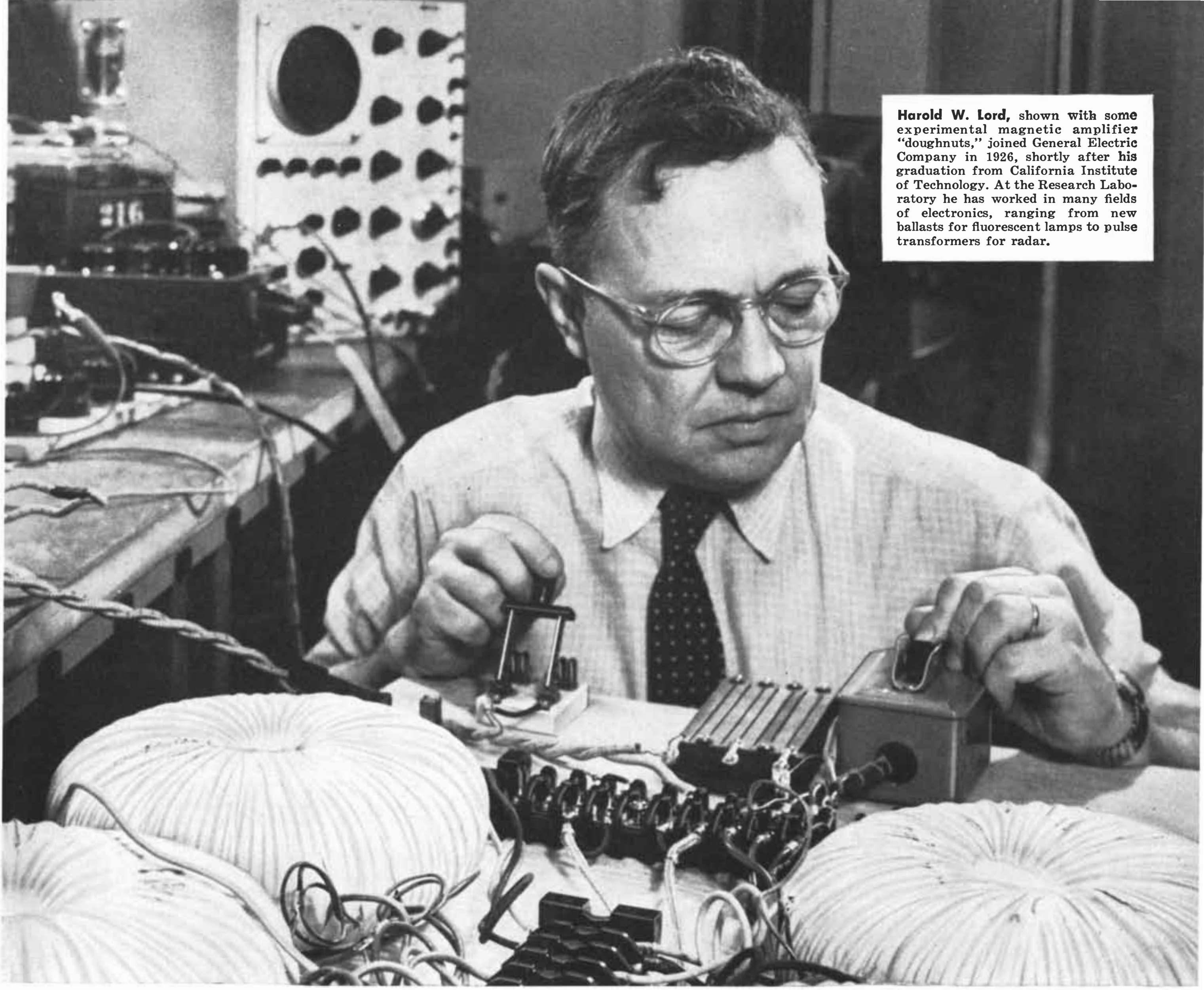


cement now used is a self-curing, air-drying product which has proved highly effective. When windows or other openings are cut in the fabric, they are reinforced with plastic or metal frames; the fabric is wrapped around the frame and bonded to it.

One of the problems in these uninsulated pneumatic buildings is condensation of moisture on the inside of the envelope in cold weather. Consequently the air has to be dehumidified, particularly in a radome, where moisture on the envelope interferes with the radar signal. This is done by means of continuous ventilation or various types of driers. Ice on the outside of the envelope also has to be dealt with. On a small radome the ice can be cracked off merely by relaxing or stretching the envelope. In large radomes heat from banks of infrared lamps is beamed on the envelope when icing conditions threaten, and these have proved adequate to prevent accumulation of ice in severe weather.

Obviously the possible uses for pneumatic buildings are almost unlimited. Circus tents, fair buildings, exposition halls, portable hangars, farm produce storage depots, sports stadiums—this is only a small part of the list of possibilities. As a temporary structure, a pneumatic building can be transported easily and erected with a minimum of labor. A small transparent envelope could be put over a swimming pool, making it available for year-round use in any climate. The envelope need not necessarily take a spherical form: it can be made cylindrical, conical or in various other shapes. An airplane with inflated wings and fuselage has already been designed and flown; its advantage, of course, is that the aircraft is collapsible when not in use. Moreover, the development work on coated fabrics has suggested applications other than for pneumatic buildings. Coated with a reflecting material, the fabric could serve as the reflecting "dish" of a large radio telescope or as a reflector of sunlight for a solar heating plant.

It is plain that one of the principal advantages of the pneumatic building is its low cost. This is particularly true when a structure with a large clear floor area is needed. A large auditorium with an air-supported roof would cost about half as much as one with the conventional trussed-roof construction. Some engineers have even had fun speculating that the pneumatic envelope may one day make possible the enclosed, climate-controlled city of which imaginative writers have long dreamed.



LOCKHEED in GEORGIA MOVES AHEAD AGAIN!

Staff of 500 Seen For A-Plane Plant

W. R. Rhoads to Head Dawsonville Project, To Be Biggest of Its Type in Nation

Lockheed Aircraft Corp., wasting no time in the development of nuclear aircraft testing facilities at Dawsonville, announced Tuesday that W. R. Rhoads will head up the Dawsonville project.

Mr. Rhoads, who lives at 120 Osner Dr., NE, is chief staff engineer at Lockheed's Marietta plant now. He has been with Lockheed since 1941.

He will direct the work of the approximately 500 scientists, engineers and service personnel who will be employed at the Dawsonville site.

LOCKHEED AND the Air Force officially announced Monday night at a dinner at Gainesville that they intend to build a 10,000-acre, multi-million-dollar nuclear aircraft test site just southwest of Dawsonville (population, 350).

And, perhaps as significantly, Lockheed's top Georgia executive hinted that the actual manufacture of a nuclear-powered plane—perhaps the world's first—might take place at Lockheed's Marietta plant.

AND

there's more that can't be published—yet

The world's largest integrated aircraft plant, at Marietta, Georgia, — where we build Lockheed C-130 Turbo-Prop Cargo planes and B-47 Jet Bombers—welcomes this new Lockheed program in Georgia.

Here are projects to challenge the very limits of imagination, vision, ability and capabilities of man!

This new atomic development and its effect on the adjacent manufacturing plant and new Engineering facility at Marietta, creates far reaching additional opportunities for Engineers and Scientists in a wide range of categories in both places.

Here is a program that is literally long range in both scope and product.

Qualified Engineers and Scientists interested in becoming associated with this progressive and rapidly expanding organization are invited to inquire for further information or personal interview.

Write to

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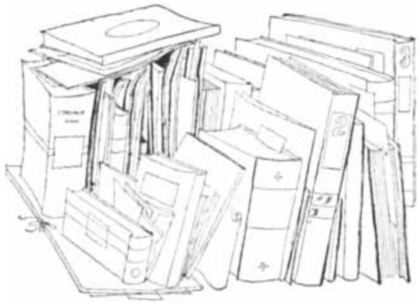


BOOKS

A British account of the hidden breakdown of the Anglo-American nuclear partnership

by James R. Newman

Atom Harvest, by Leonard Bertin. Martin Secker and Warburg Ltd. (20 shillings).

When a historian withholds important facts likely to influence the judgment of his readers, he commits a fraud, as an English statesman once remarked. When a government withholds important facts likely to influence the judgment of its people, it commits a graver fraud. Unfortunately these are offenses unknown to the law, though their effects are incalculable.

A prime example of official juggling—and of its consequences—is brought out in this book by Leonard Bertin, science correspondent of the London *Daily Telegraph*. The subject of his account is Britain's atomic energy industry. He describes its growth from small wartime beginnings to the great plants at Harwell, Capenhurst, Windscale and Calder Hall; the scientific and technological labors that made possible the expansion; the military and peaceful benefits that Britain hopes to derive from atomic energy. All this makes a readable and informative report. But the chief interest of the book for this reviewer lies in two chapters which present a timely recapitulation of a critical episode of recent history: the breakdown of the Anglo-American partnership in atomic energy.

Most of the facts, to be sure, are not new. They can be extracted from the Smyth report, the official British and Canadian atomic energy statements of August, 1945, Robert Sherwood's *Roosevelt and Hopkins*, Winston Churchill's war memoirs and various papers and documents made public in the last few years. But the material is put together here for the first time. While Bertin's is a partisan account, exaggerating the British contribution in atomic energy as others have exaggerated the U. S. contribution, it explains pretty well the nature, the causes and the results of the breach. It is a story worth pondering, more as a guide to the future than as another revelation, so fashionable in our period, of who killed Cock Robin.

To understand the culminating political fiasco it is necessary briefly to review the scientific background.

In January, 1939, Otto Hahn and Fritz Strassmann of Berlin announced their discovery that an isotope of barium was produced by the neutron bombardment of uranium. A couple of weeks earlier Hahn had imparted this information to Otto Frisch, who was spending Christmas with his aunt, Lise Meitner, in Stockholm. Frisch passed on the news to Niels Bohr at the Institute of Theoretical Physics in Copenhagen, but not before making a profound and fateful conjecture. "It looked [Frisch told Bertin] as if the absorption of the neutron had disturbed the delicate balance between the forces of attraction and the forces of repulsion inside the nucleus. It was as if the nucleus had first become elongated and then developed a waist before dividing into two more or less equal parts in just the same way that a living cell divides." From a U. S. biologist Frisch learned that the process by which bacteria and other organisms reproduce themselves is called "fission." He gave the same name to the newly discovered nuclear phenomenon.

Bohr brought the news with him to the U. S. and told his former student John A. Wheeler and others at Princeton University about it. The word spread to Enrico Fermi and his associates at Columbia University. Immediately several groups began a search for the massive pulses of ionization to be expected from the flying fragments of uranium. Within a few days the fission theory was experimentally confirmed by four laboratories in the U. S., by Frisch in Copenhagen and by Frédéric Joliot (later Joliot-Curie) in Paris. The race was on. Physicists in the U. S. and in Europe drove themselves furiously to broaden their knowledge of the subject; sensational stories began to appear in the press. When L. A. Turner of Princeton wrote an article on fission in the January, 1940, issue of *Reviews of Modern Physics*, he cited nearly 100 papers on the subject published during the preceding 12 months.

The crucial question was whether a chain reaction was possible. This turned, as Henry D. Smyth pointed out in his account, on the result of a competition among four processes: escape of neutrons before capture, non-fission capture by uranium, non-fission capture by impurities, fission capture. One of the first groups off the mark consisted of H. von Halban, Lew Kowarski and Joliot in France. They made experiments to ascertain the rate of production of neutrons, comparing the absorptive capacity of a uranium compound dissolved in water with that of a solution of a non-uranium salt. Their conclusions were basically correct though overoptimistic—for every neutron that split a uranium atom, they calculated, between three and four additional neutrons would be produced.

It was generally known by 1940 that to harness atomic energy two different processes would have to be achieved, depending on whether one wanted power or a bang. To get atomic power required a chain reaction induced by slow neutrons; to get a bomb required one induced by fast neutrons in separated uranium 235 or in plutonium. It was also known that fission neutrons had high speeds, that the neutrons had to be slowed to produce power and to convert U-238 into plutonium, and that various substances—including graphite, heavy water and beryllium—could be used as moderators to slow down fast neutrons. On the basis of this knowledge the French scientists in 1940 made designs of heavy-water reactors and graphite reactors to be used as sources of power. Lest anyone suppose that pure scientists are above sordid concerns, Bertin relates—not without relish—that the French team "hurriedly made the first application for patents of chain-reacting piles, not very different in general principle from those now operating in many parts of the world."

I need not devote time to the parallel U. S. developments during the period, because they have been often and fully described; but the British side of the story, much less widely known, merits some attention.

The importance of the Hahn-Strassmann announcement was of course not overlooked in Britain. Within a short time after the news from Germany, Sir George Thomson, son of the famous J. J. and himself a Nobel prize winner in physics, went to the Air Ministry and asked for a ton of uranium oxide. He explained that he needed it to conduct experiments on the possibilities of atomic power and atomic bombs at the Imperial College of Science and Technology in London, where he was teaching. The Air Ministry supplied the material and he began to work, but the first results were disappointing. He concluded that unless large supplies of heavy water were made available, a chain reaction in uranium oxide could not be realized. To the end of the war, fortunately (as Sir George pointed out to Bertin), the "most distinguished physicists in Germany thought the same."

But the most distinguished physicists *in* Germany were by no means the most distinguished physicists *of* Germany. Albert Einstein, Hans Bethe and Leo Szilard were in the U. S.; Lise Meitner was in Sweden; Otto Frisch was in Copenhagen; F. E. Simon and R. E. Peierls were in Britain. These and other refugees—including Fermi from Italy—were to cost the "master races" dear. Like the Egyptians, the Germans soon had cause to ask: "Why have we done this, that we have let Israel go from serving us?" In March, 1940, word came to Thomson from Peierls and Frisch (who had moved to Britain from Denmark) that a bomb made of uranium 235 was probably feasible. A committee was promptly set up under Thomson to go into the matter. The cover name selected for the group was "Maud"—by which choice hangs an amusing tale.

When the Germans overran Denmark, Bohr sent Frisch a telegram, the last part of which said: "Tell Cockcroft and Maud Ray Kent." Knowing no "Maud Ray Kent," Frisch and Cockcroft concluded the words were an anagram for "radium taken," intended to warn that the Germans had confiscated the Danish stocks of that valuable and significant commodity. At any rate, it was the telegram that suggested the name for the committee. Years later Thomson mentioned the fact to Bohr, who was astounded. It turned out that he knew a lady named Maud Ray who lived in Kent; he had wanted word sent to her that he was safe and well. Nor was this the whole of the comedy. For among civil servants who regarded themselves in the know, the name Maud was interpreted as a block of initials representing "Military Application of Uranium Detonation." These ingenious conjectures remind one of some of the hypotheses of cosmology.

Among the problems tackled by the Maud committee were the separation of U-235, the physics of neutron capture and fission, the critical mass of U-235 needed to provide an explosion, and various related chemical matters. Peierls, Simon, James Chadwick, Norman Feather and Egon Bretscher led these studies, which made promising headway.

Meanwhile a daring plan was conceived by that extraordinarily gallant and intrepid agent, the late Earl of Suffolk. As scientific attaché in Paris he had compiled a list of 150 French scientists and technicians who were to be smuggled to Britain if France fell. When the Germans tore through the Maginot Line, the plan was put into execution, with Suffolk in charge. Halban, Kowarski and Joliot were on the list—but Joliot preferred to stay in France. In the confusion after the capture of Paris only 40 of the men Suffolk had selected reached Bordeaux. There they were taken aboard a small British collier, the *Broompark*, for the hazardous voyage across the Channel. Besides Halban, Kowarski and other scientists, the cargo included several million dollars' worth of industrial diamonds and 36 gallons of heavy water, comprising most of the then existing stock in the world. Suffolk, who numbered carpentry among his array of talents, built a raft, and the heavy water and diamonds were lashed on top. A "solemn agreement" was made that if the ship was mined or bombed, the survivors were to cut loose the raft and try to make port; but in the event of a torpedoing, in which case the Germans would have seen the raft, it was to remain tied to the *Broompark* when it sank. The *Broompark* arrived safely in Falmouth, although a neighboring ship exploded on a mine. The Earl of Suffolk, afterwards killed in attempting to disarm a German bomb, had brought off another brilliant coup.

Halban and Kowarski set up shop in the Cavendish Laboratory at Cambridge and resumed their researches on reactors. According to Bertin they made notable progress, and by late 1940 had proved conclusively the feasibility of a chain-reacting, homogeneous, heavy-water reactor. If this claim is to be credited, they anticipated by more than 18 months experimental demonstrations in the U. S. that a heterogeneous, graphite-moderated pile would sustain a chain reaction. The author says that when the Frenchmen's findings were "reported to the United States . . . they were immediately pooh-poohed." They are not mentioned in the Smyth report. Bertin seems to feel that nothing less than British and French honor were impugned by our attitude, and he emphasizes the fact that when the U. S. finally did catch up with Halban and Kowarski, it was the achievement of "foreign-born scientists working in America." This is petty stuff, but it bred resentments which even now, 15 years later, are apparently not forgotten.

The British work moved steadily forward, and there were frequent interchanges of information on their progress and ours. In the summer of 1941 Maud made a high-level report on the possibility of a U-235 bomb and a pile to produce power and plutonium. Simon prepared a cost estimate for a full-scale gaseous diffusion plant; the figures frightened him and he decided he had better forward his lowest estimate lest the Cabinet itself suffer a chain reaction. After hearing the opinions of his advisers, Churchill drafted one of his classic minutes for his Chiefs of Staff:

"Although personally I am quite content with the existing explosive I feel we must not stand in the way of improvement and I therefore think that action should be taken in the sense proposed by Lord Cherwell and that the Cabinet Minister responsible should be Sir John Anderson. I shall be glad to know what the Chiefs of Staff think."

The Chiefs recommended a "maximum priority." A decision was taken to build a pilot plant for uranium in Britain and, if possible, a full-scale plant in Canada. The Department of Scientific and Industrial Research set up a new unit called the "Directorate of Tube Alloys." This cover name corresponded to our "Development of Substitute Materials Project" in the "Manhattan District" of the Corps of Engineers. Anderson hit upon "Tube Alloys" because a diffusion plant would require miles of tubing made of a special alloy to resist corrosion.

It was one thing to create the administrative machinery, quite another to erect the plant. Britain was heavily committed in manpower and resources, and the threat of invasion was ever present. Churchill therefore welcomed President Roosevelt's proposal to "coordinate or even jointly conduct" the atomic energy program. Roosevelt's letter to Churchill was sent October 11, 1941, and it was followed shortly by a visit to Britain by Harold Urey and George Pegram. The day before Pearl Harbor the U. S. Office of Scientific Research and Development announced to "S-1," its uranium section, that a vigorous program would be undertaken to make a bomb. Vannevar Bush urged the British to move the bulk of their research and development to Canadian laboratories; as a result Halban led a team to Montreal. On August 13, 1942, the Manhattan District was born. The British assumed that the cooperation already achieved would be extended. By autumn, however, it was clear that the channels of Anglo-American communication were becoming constricted. British scientists soon discovered they they could learn very little about our progress. Fermi's group in Chicago kept open a line to the Montreal group, but in general if the British were able to pick up anything at all it was only out of the corner of some amiable fellow's mouth and not through official channels. In this respect, it should be pointed out, the British were not worse off than most U. S. scientists on the project: no one was told any more than high authority thought he needed for his particular job. This practice led to certain costly blunders but was regarded as essential to security.

In due course the breakdown of communication came to the attention of the Prime Minister. It was a painful surprise. He had discussed the matter with President Roosevelt at Hyde Park in June, 1942, and had come away with the understanding, as he afterwards cabled Harry Hopkins, "that everything was on the basis of fully sharing the results as equal partners." At Casablanca in January, 1943, Churchill expressed his concern and Hopkins promised to look into the question on his return to Washington. This he failed to do, and Churchill cabled: "I should be grateful for some news about this, as at present the American War Department is asking us to keep them informed of our experiments while refusing altogether any information about theirs." Hopkins asked that Anderson "send me a full memo by pouch of what he considers is the basis of the present misunderstanding, since I gather the impression that our people feel no agreement has been breached." In a long responding cable Churchill said: "Urgent decisions about our programme both here and in Canada depend on the extent to which full collaboration between us is restored, and I must ask you to let me have a firm decision on U. S. policy in this matter very soon."

Hopkins conferred with the President, Secretary of War Stimson, Bush and James B. Conant. A memo by Bush (quoted in Sherwood's biography) stated that information would be furnished only to individuals "who need it and can use it now in furtherance of the war effort." To step beyond this policy, he said, "would be to furnish information on secret military matters to individuals who wish it either because of general interest or because of its application to nonwar or postwar matters." This would "decrease security without advancing the war effort." On the surface this seemed a sound position, but the British objection, as reported by Sherwood, was equally sound. Our policy, they said, gave us the excuse to withhold from them all the fruits of joint research, including the possible industrial uses of atomic energy after the war. In the event, this is exactly what happened. After the war Congress, grossly misled by the Executive Department as to the nature of the British contribution and the Anglo-American agreements, passed legislation which forbade the transfer of atomic energy data to any foreign country.

In the early summer of 1943 Stimson and Churchill discussed the atomic energy impasse. Stimson took the position that the British pressure to obtain information was economically motivated, and that "the Americans could not see the fun of spending billions of dollars to find out things for someone else to use in a competitive postwar world." At least this put the cards on the table. The British were deeply concerned, but further discussion was postponed until the heads of state met at Quebec a month later. There an agreement provided for the setting up of a Combined Policy Committee "to keep all sections of the project under constant review" and for a "complete interchange of information and ideas on all sections of the project between members of the Policy Committee and their immediate technical advisers." The policy of compartmentalization was to be maintained, in that exchanges at the working level were to take place only "between those in the two countries engaged in the same sections of the field." Bertin makes the point that this gave U. S. authorities the excuse to withhold information on production techniques, since the British were not engaged in this "section of the field." The facts seem at least partly to bear out this contention, for no British scientist or engineer, according to Bertin, "was ever allowed to enter the plant at Oak Ridge, and our men were not even told whether the ideas that they

had developed [on gaseous diffusion] had worked satisfactorily." It is not altogether clear why, under the terms of the Quebec agreement, the British members of the Combined Policy Committee were denied access to these data—if, indeed, that was the case.

The most important provision of the Quebec agreement related to the postwar uses of atomic energy. It stated that "in view of the heavy burden of production falling upon the U. S. as the result of a wise division of war effort, the British Government recognize that any postwar advantages of an industrial or commercial character shall be dealt with as between the U. S. and Great Britain on terms to be specified by the President of the United States to the Prime Minister of Great Britain. The Prime Minister expressly disclaims any interest in these industrial and commercial aspects beyond what may be considered by the President of the United States to be fair and just and in harmony with the economic welfare of the world."

Whether or not this was a wise provision; whether or not it demonstrated—as Bertin contends—Churchill's magnanimity, or Roosevelt's shrewdness; whether or not Congress would have approved it as a workable agreement after the war, one fact is certain: Never was a solemn treaty between heads of state more completely disregarded than this one. The agreement was made in secret and for many years was kept secret. Churchill made it public in April, 1954; Congressional leaders had been apprised of it somewhat earlier but not in time to inform their debates and decisions on the atomic energy legislation adopted in 1946.

As a participant in some of these events I am able to corroborate Bertin's statement that the McMahon Act was drafted, debated and passed by a Congress "completely unaware of the terms of the agreement with the British and Canadians." While serving as counsel to the Senate Committee on Atomic Energy, I learned by chance, as did Senator McMahon, that there had been an agreement at Quebec. Repeated attempts to discover its contents were unsuccessful. The Senator and I called upon President Truman early in 1946 to see whether he could enlighten us. We came away empty-handed. Neither the White House nor the State Department thought it advisable to share this knowledge. Senator McMahon, according to Bertin, "to his great embarrassment, was only shown the text of the Quebec agreement after he had accepted the chairmanship of the Joint Congressional Committee on Atomic Energy"—*i.e.*, in September, 1946.

It is unnecessary to read sinister motives into the decision of the Executive Branch not to make Congress privy to the facts. Disclosure would have loosed a storm on the Administration, and it is unlikely that Congress would have regarded itself as bound by President Roosevelt's more or less private and altogether vague commitment. Yet beyond question Congress had the right to know about it. Its provisions might not have been welcome to members of Congress, but at least they would have been able to act with knowledge, and the public would have been able to judge their action. Disclosure would also have countered the myth, still widely believed, that atomic energy was an exclusively American achievement and possession. Gordon Dean, in his book *Report on the Atom*, described the common misconception as follows: "Atomic energy was discovered and first developed in the U. S. in secret during World War II. Although we are still ahead in the field, the Russians, with the help of traitors, successfully stole enough of our key secrets during the war to develop a program of their own and are now hot on our heels. Our Allies, the British, because some of their scientists came over to help us with our wartime program, also know something of these matters, but are actually running a very poor third." No thoughtful person can fail to wonder to what extent the myth has made more difficult the attainment of international control of atomic energy.

One asks why the British kept quiet about the Quebec agreement in the face of legislation "which made no distinction between countries like Britain and Canada and our late enemies or those with whom at the time we were engaged in a cold war." The answer is fairly obvious. The British desperately needed our help and cooperation in the years after the war. They were in no position to risk strengthening isolationist sentiment by ventilating a secret treaty. The British therefore kept mum and built up their own establishment. And they did pretty well. Except in magnitude, their atomic energy industry is at least the equal of ours—as to weapons, atomic power and the uses of isotopes.

Atom Harvest is a valuable book. It contains errors of detail, improper emphases and doubtful inferences, but the key historical account is essentially dependable and always honest. There is no reason to criticize its occasional flashes of anger. This is how the British feel and we may as well know it. Bertin is to be congratulated as a journalist who has done his job in the best traditions of journalism.

Short Reviews

The Secret of the Hittites, by C. W. Ceram. Alfred A. Knopf ($5.00). Some 4,000 years ago a warlike Indo-European people called the Hittites invaded the mountainous peninsula which today comprises most of Turkey. The Hittites established a number of city states. Their civilization apparently flourished for several centuries, extending its influence to Egypt and its boundaries almost to Damascus. Then around 1200 B.C. the Hittite Empire collapsed and was forgotten to history. In 1834 a French traveler came upon the remarkable ruins of one of its cities. His discoveries drew other diggers, and then slowly, from the remains of great monuments and cuneiform and hieroglyphic inscriptions, was extracted the story of an empire which at its height was comparable to the Babylon of Hammurabi and the Egypt of Tutankhamen. So far as can now be determined, the Hittites were not distinguished for their art or culture or technology; they were not astronomers or great craftsmen or outstanding traders. They were, however, pre-eminent warriors and apparently were politically more advanced than other ancient nations. The Hittites had a federal state under a constitutional monarchy, a flexible social order in which even the slaves had rights, and a code of law based on "reparation" rather than retaliation. The story of their civilization, of its rediscovery by archaeologists, of the painstaking century-long task of deciphering Hittite hieroglyphs, is recounted in this book by C. W. Ceram. Unfortunately his account does not come up to the standard of his earlier book *Gods, Graves and Scholars.* He overdramatizes a chronicle whose bare facts are sufficiently dramatic: every event is described as "incredible," "unbelievable" and so on. He muddles up the Hittite chronology, which is at best a difficult muddle; he is not conspicuously clear in explaining the fascinating business of deciphering ancient scripts. But the most wearisome feature of his account is the impression he gives of telling you, and referring you back to what he has told you, without ever actually telling you.

Benjamin Henry Latrobe, by Talbot Hamlin. Oxford University Press ($15.00). Latrobe, an Englishman who came to the U. S. in 1796, was the first professional architect in this country. He designed cathedrals, private homes, banks and public buildings. His Bank of Pennsylvania originated the "Greek Revival" style in the U. S. He was appointed, through Thomas Jefferson, Surveyor of Public Buildings and was in complete charge for some years of the construction of the U. S. Capitol. He contributed to the development of canals and, with Robert Fulton and Nicholas J. Roosevelt, to the introduction of steamboats on the Ohio and the Mississippi. He built the famous Philadelphia waterworks in which steam engines were used to supply the city with water from the Schuylkill River. Latrobe was a rarely gifted and personally attractive man, but misfortune dogged him. Tragedy struck at home with the death of his first wife and his beloved son Henry. He was scandalously underpaid for his services, was frequently a victim of private feuds and legislative stinginess and caprice, and was innocently involved in ruinous financial schemes which left him holding the bag. Neither small nor large humiliations were spared him. When he submitted his plans for the Baltimore cathedral, the builder made the mistake of reading part of them upside down, which, for a few months at least, made Latrobe look like a madman. At the age of 53, having time and again miraculously eluded the bailiff's clutches, he finally became a bankrupt. Three years later, just as it seemed he was getting back on his feet, he died suddenly in New Orleans of yellow fever. Hamlin, a noted historian of architecture, has written a massive and stately life of this sympathetic man. It is a richly detailed book based largely on Latrobe's extensive journals and letters and on other first-hand sources, and it provides not only a full appraisal of its subject and his work, but many interesting sidelights upon the American scene during a time of "struggle and transition." Profusely illustrated.

THE HISTORY OF THE TELESCOPE, by Henry C. King. Sky Publishing Corporation ($12.50). In view of the immense contribution of the telescope to man's knowledge of the universe and to philosophical speculations, it is surprising that Dr. King's book is the first comprehensive history entirely devoted to the origins and development of this marvelous instrument. The author, senior lecturer in the department of ophthalmic optics at the Northampton Polytechnic in London, spent many years collecting data for his masterly work. The story begins with the astronomical observations of antiquity and describes various early instruments such as the Egyptian merkhet, the staff of Archimedes, sundials, gnomons and clepsydras, armillary spheres, quadrants and astrolabes. The first telescope appeared around 1600, but there is still much debate as to the exact date and place of invention. Many historians favor the claim of Hans Lippershey, an obscure Dutch spectacle maker who in 1608 satisfied the States-General of the Netherlands that he could make a telescope. However, the great Dutch scientist Christiaan Huygens called Lippershey an "illiterate mechanick" who had got his idea from others, and there is an assortment of evidence that undermines his claim to priority. Leonard Digges of Oxford suggested in 1571 an instrument which might be called a reflecting telescope; Giambattista della Porta of Naples in 1589 proposed to combine a concave and convex glass so that "you will see both distant and near objects larger than they would otherwise appear and very distinct"; Jacobus Metius and Zacharias Jensen of Holland asserted, not without vestiges of proof, that they had made telescopes in the 1590s. Indeed, on the ground that "many other persons had a knowledge of the invention," the States-General refused finally to grant a patent to Lippershey. Among other landmarks of this history are the telescopes built by Galileo and the capital use he made of them in astronomical observations, Isaac Newton's invention of the reflecting telescope, advances in the making of optical glass by Pierre Guinand and Joseph Fraunhofer, the huge reflectors of Sir William Herschel, Justus von Liebig's discovery of a method for applying a thin film of silver to a glass surface, the perfecting of the application of this method to mirrormaking by Léon Foucault—culminating in the great reflecting telescopes of modern days. King describes clearly hundreds of telescopes of all sizes and types, and he supports the text with a wealth of diagrams and fine plates. An absorbing contribution to the history of science.

CARL FRIEDRICH GAUSS, by G. Waldo Dunnington. Exposition Press ($6.00). Gauss made his first mathematical discovery when he was about 10: a delightfully simple method for adding a string of numbers where there is a constant difference between any number and its successor. During his long life (he died at 77 in 1855) he so enriched his subject that one may accept Eric Temple Bell's appraisal: He lives everywhere in mathematics. His contributions include the method of least squares, the inscription of the regular polygon of 17 sides in a circle, elliptic functions, the fundamental theorem for quadratic residues and the fundamental algebraic theorem that every equation in one unknown has a root. He made major advances in higher arithmetic, functions of a complex variable, theories of surfaces, conformal mapping, topology and differential geometry. Nor were his epochal researches confined to pure mathematics; they included work in the mathematical theory of electromagnetism, capillarity, the attraction of ellipsoids, optics, the theory of attractions, geodesy, the motion of the planets, the orbits of comets, crystallography. Together with Wilhelm Weber he invented in 1833 an electric telegraph whose wires, draped over the rooftops and church steeples of Göttingen, ran to 8,000 feet. (The first words sent over it were "Michelmann kommt"—Michelmann being a servant who ran errands for Gauss and Weber.) Gauss had health as well as genius. He had many friends and delighted in social life. He was twice married and had children. He carried on practical duties for years as a surveyor, administrator and lecturer. It is hard to understand why a full-scale biography of this prodigious and interesting man has not been written before this. Dunnington's painstaking 500-page study is the first serious attempt. It is not an appealing book; in fact it is deadly. The author, a member of the faculty of Northwestern State College of Louisiana, gathered material for his study for 25 years. He diligently dug out the minutest details about Gauss here and abroad; he ran down genealogies, read extensively, interviewed scores of men and women descended from Gauss and his friends, lived in Gauss's rooms at the Göttingen library. Having swallowed this great congeries of facts, Dunnington now regurgitates them undigested. In relentless sequence the record emerges. There is not a trace of life or humor in it; the author makes no effort to explain Gauss's mathematical discoveries but merely states them. For nonmathematicians all remains as impenetrable as before. If a pile of facts is better than no monument at all, this pedestrian exertion can be said to serve Gauss's memory. And it is perhaps true that future biographers will derive advantage from Dunnington's industry.

MATHEMATICS IN RETROSPECT: THE BEQUEST OF THE GREEKS, by Tobias Dantzig. Charles Scribner's Sons ($3.95). Dantzig's latest book is the first of three volumes on the history of mathematics. The approach is selective rather than systematic. In this study he discusses certain "problems, principles and procedures which modern mathematics has inherited from Greek antiquity." He addresses himself, for example, to an attempt to identify the founders of Greek mathematics. He credits Thales with the introduction of the method of deductive reasoning, which transformed geometry from an empirical into a logical discipline. Dantzig's conjecture is based on the flimsiest kind of evidence. The argument runs more or less along this line: Since no one else is known to have made the discovery, and since Thales was highly regarded by Greek historians, it must have been he. Among other topics considered are the five regular solids and their mystical influence on the cosmological theories of Kepler; the attempts to solve the classical problems of the squaring of the circle, the duplication of the cube and the trisection of an angle; the extraordinary implications of the Pythagorean theorem, Pythagorean triples and number theory; the still unsolved problem of the crescents of Hippocrates; the vast field opened by the algorithm of Euclid; Hero's formula for the area of a triangle in terms of its perimeter; the quadratrix of Hippias and the chords of Hipparchus. Dantzig loves his subject, has thought about it deeply and is very proficient at explaining its intricacies when he is not carried away by the desire to be paradoxical and oracular. His book is in part for general readers, in part for those with more than average mathematical knowledge; there is much in it which anyone can enjoy.

The Unity of Knowledge, edited by Lewis Leary. Doubleday & Company, Inc. ($5.00). These are the lectures delivered at a Columbia University Bicentennial Conference in 1954 by a diverse group including Niels Bohr, Etienne Gilson, Julian Huxley, Sir Richard Livingstone, Archibald MacLeish, John von Neumann, Robert Penn Warren, Hermann Weyl. Despite its formidable auspices, the book is in large part diffuse and disorganized. Few of the participants seemed to know exactly what they were called upon to contribute to the vaporous theme of the conference. This is the sort of undertaking that deserves no encouragement.

The Renaissance Philosophy of Man, edited by Ernst Cassirer, Paul Oskar Kristeller and John Herman Randall, Jr. University of Chicago Press

($1.75); They Wrote on Clay, by Edward Chiera. University of Chicago Press ($1.00). These volumes are the first two publications in an attractive new series of paperback reprints called Phoenix Books. *Renaissance Philosophy* includes writings of Petrarch, Lorenzo Valla, Marsilio Ficino, Pico della Mirandola, Pietro Pomponazzi and Juan Luis Vives. The late Professor Chiera's reading of the Babylonian clay tablets, though written 18 years ago, is still superior to more recent and more pretentious popularizations. His account is simply and well told, is fully illustrated and is a first-rate introduction to an infectiously exciting branch of science.

Arctic Research, edited by Diana Rowley. The Arctic Institute of North America ($3.50). A review by some 30 experts. The scope of the studies reflects the intense interest and attention the arctic regions have attracted in recent years—more, one may suppose, for political, economic and military reasons than because of a simple quest for knowledge. Among the subjects discussed are meteorology, geology, glaciology, geophysics, oceanography, botany, archaeology and present-day life in the arctic. This is an uncommonly informative volume, well designed and illustrated.

Notes

The Fields of Group Psychotherapy, edited by S. R. Slavson. International Universities Press, Inc. ($6.00). Articles by various specialists on developments of group therapy in the last decade.

Advances in Electronics and Electron Physics, edited by L. Marton. Academic Press, Inc. ($11.50). Among the topics included in this, the seventh volume of a series, are the physics of semiconductor materials, characteristic energy losses of electrons in solids, radio astronomy, analogue computers, electrical discharge in gases.

Proceedings of the International Conference on the Peaceful Uses of Atomic Energy. Columbia University Press ($6.50). Volume 14 of the Geneva proceedings, dealing with radioisotopes.

Thermodynamics and Statistical Mechanics, by Arnold Sommerfeld. Academic Press, Inc. ($7.00). The fifth volume of Sommerfeld's noted lectures on theoretical physics. The author was

engaged in the writing of his treatise when he died of an accident. This volume was completed by F. Bopp and J. Meixner and translated by J. Kestin of Brown University.

GEOMETRY OF FOUR DIMENSIONS, by Henry Parker Manning. Dover Publications, Inc. ($3.95). This is a reissue of a clearly written introduction to the Euclidean geometry of hyperplanes, hyperspaces, hypersolids and other mathematical furniture of the fourth dimension. An excellent book for stretching the imagination, requiring no previous knowledge of higher mathematics.

THE DEAD SEA SCROLLS, by Millar Burrows. The Viking Press ($6.50). This account by the chairman of the Department of Near Eastern Languages and Literature at Yale University is clear, direct and authoritative. It includes new translations of the principal scrolls and a bibliography; it is the best book on the subject for the general reader.

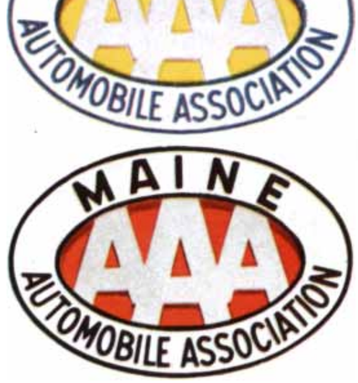
AN INTRODUCTION TO THE THEORY OF NUMBERS, by I. M. Vinogradov. Pergamon Press ($1.75). An English translation of a standard introductory monograph on the foundation of the theory of numbers by a famous Russian mathematician.

AN AUTUMN GLEANING, by Sir Henry H. Dale. Pergamon Press (21 shillings). Occasional lectures and addresses by a distinguished British physiologist and former president of the Royal Society. Included is Dale's memorable Pilgrim Trust address to the National Academy of Sciences on the freedom of science.

METALLURGICAL THERMOCHEMISTRY, by O. Kubaschewski and E. Ll. Evans. John Wiley and Sons, Inc. ($10.00). Completely revised edition of a reference work on the application of chemical thermodynamics to metallurgy.

RECENT STUDIES IN AVIAN BIOLOGY, edited by Albert Wolfson. University of Illinois Press ($7.50). Thirteen specialists contribute articles on birds, ancient and modern.

BIOCHEMISTRY OF THE DEVELOPING NERVOUS SYSTEM, edited by Heinrich Waelsch. Academic Press, Inc. ($11.50). This interesting volume comprises the proceedings of the First International Neurochemical Symposium held at Oxford in 1954.



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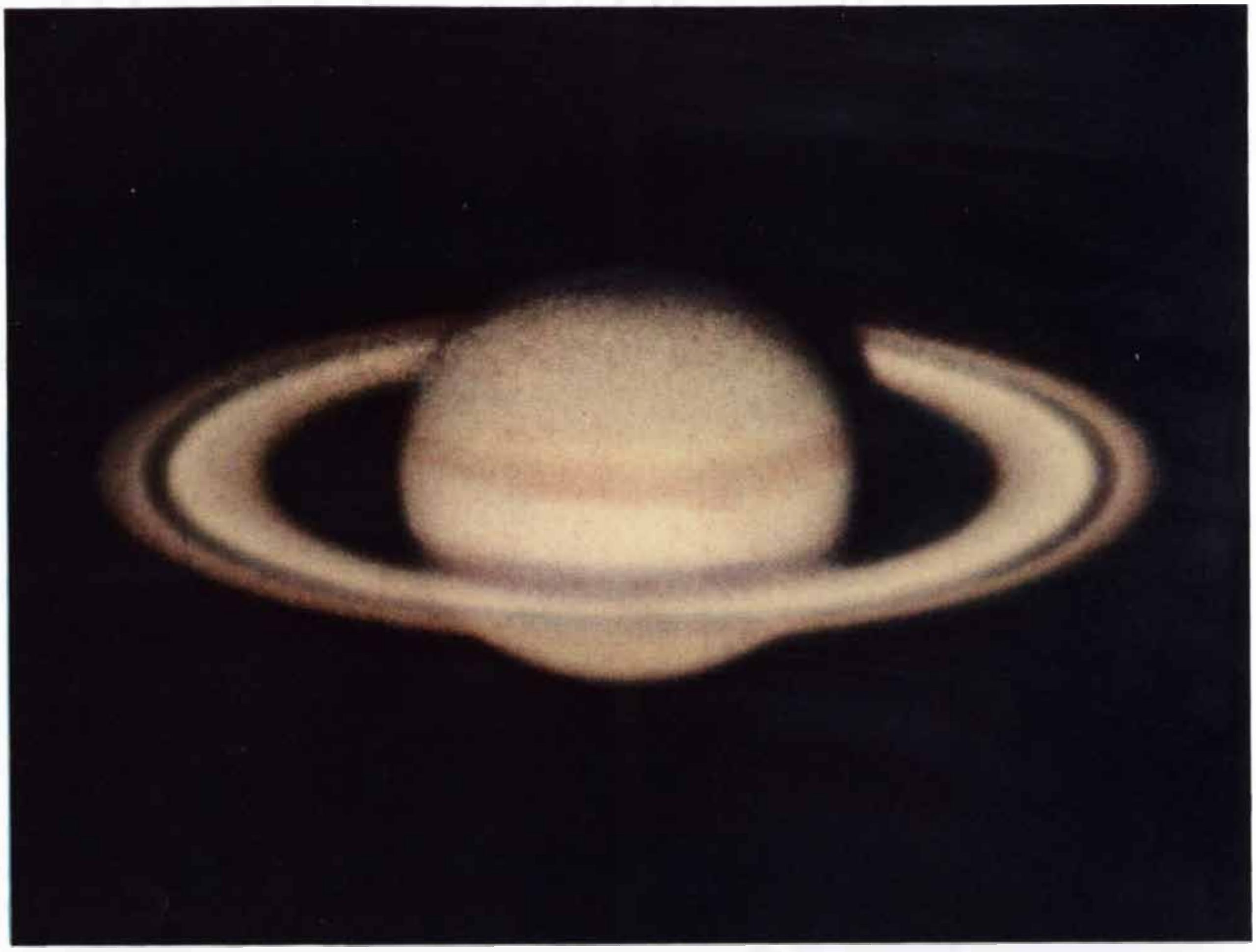


SATURN was photographed in color by Robert Leighton, physicist at the California Institute of Technology. The photograph was made on March 14, 1954, with the 60-inch reflecting telescope on Mount Wilson. It clearly shows gradations in the brightness of the planet's rings. The equatorial zone of the planet itself is conspicuously brighter than the rest of it. At the pole is a blue-green cap.

MARS was also photographed in color with the 60-inch telescope. The photograph at left was made on June 23, 1954. The south polar cap of the planet is at the top. The prominent dark markings are Syrtis Major (*lower left*) and Sabaeus Sinus (*right*). The photograph at right was made on July 17 of the same year. It shows "lakes" and "maria." The twilight edge of the planet is to the right.

THE AMATEUR SCIENTIST

Concerning the problem of making sharper photographs of the planets

The clearest color photographs of Saturn and Mars ever to reach the attention of this department appear on the opposite page. Another, of Jupiter, adorns the cover of this issue. All are the work of Robert B. Leighton, a nuclear physicist at the California Institute of Technology who insists that in the field of astronomy he is still an amateur. These remarkable pictures are the initial products of an electromechanical guiding system which Leighton designed and built. He made the photographs with a larger telescope than most amateurs ever see, much less use—the 60-inch reflector at the Mount Wilson Observatory.

Leighton is one of those fellows who is happiest when he has at least a half dozen balls in the air at once. During recent years, while becoming a young parent, he has built a modern ranch-style house with his own hands, carried a steady teaching schedule at Cal Tech, made basic contributions in the field of nuclear physics and squeezed out sufficient free time for many hours on his hobby of amateur astronomy. Just now he is finishing the construction of a rooftop observatory on his house, with a 16-inch Cassegrainian telescope controlled by a precision electronic drive.

Several years ago, while working with a cloud chamber atop Mount Wilson as part of a cosmic ray study, Leighton became restless between observations and soon found himself up to his elbows in one of astronomy's most stubborn problems: how to circumvent poor "seeing" of stars due to the turbulence of the earth's atmosphere. The swirling air above the observatory causes the image of a star or planet to twinkle and shift around on the photographic plate so that it registers as a smudge instead of a sharply defined point or disk. Making the telescope larger and more powerful only aggravates the smudging. Tourists who visit the big observatories, hopeful of a glimpse of life on Mars, often express chagrin when told that the surface of a planet or of the moon appears no clearer when viewed through the 200-inch Hale telescope than through a little 10- or 12-inch glass. "Why, then," they demand, "do you waste millions building these huge white elephants?"

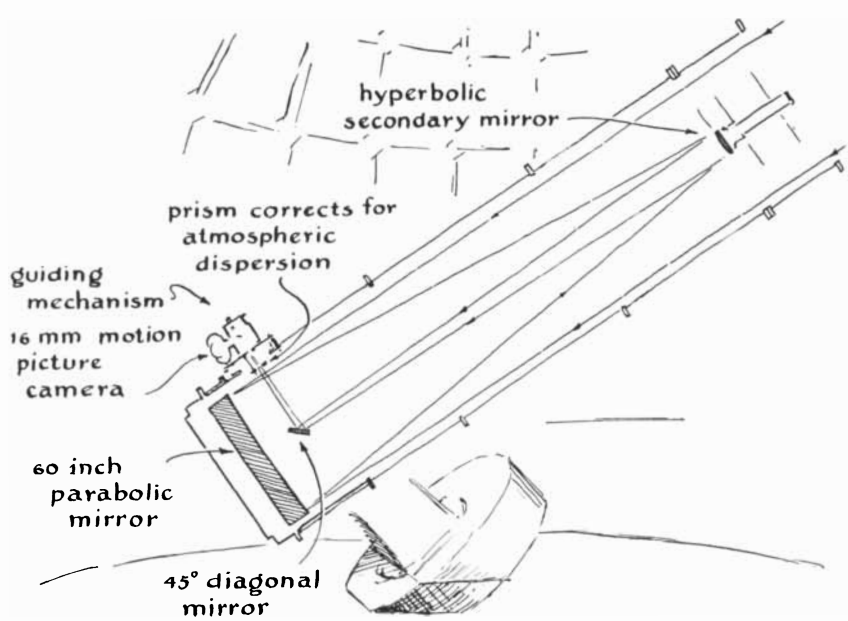
This department recently asked Leighton to answer that question, and, while he was at it, to explain how he had made his magnificently sharp pictures of the planets.

"It is a common belief," he writes, "that very large telescopes, such as the 100-inch and 200-inch reflectors of the Mount Wilson and Palomar Observatories should show fine detail of the moon and planets because the resolving power of a perfectly figured telescope lens, for objects situated at a great distance, is supposed to improve as the diameter of the objective lens is increased.

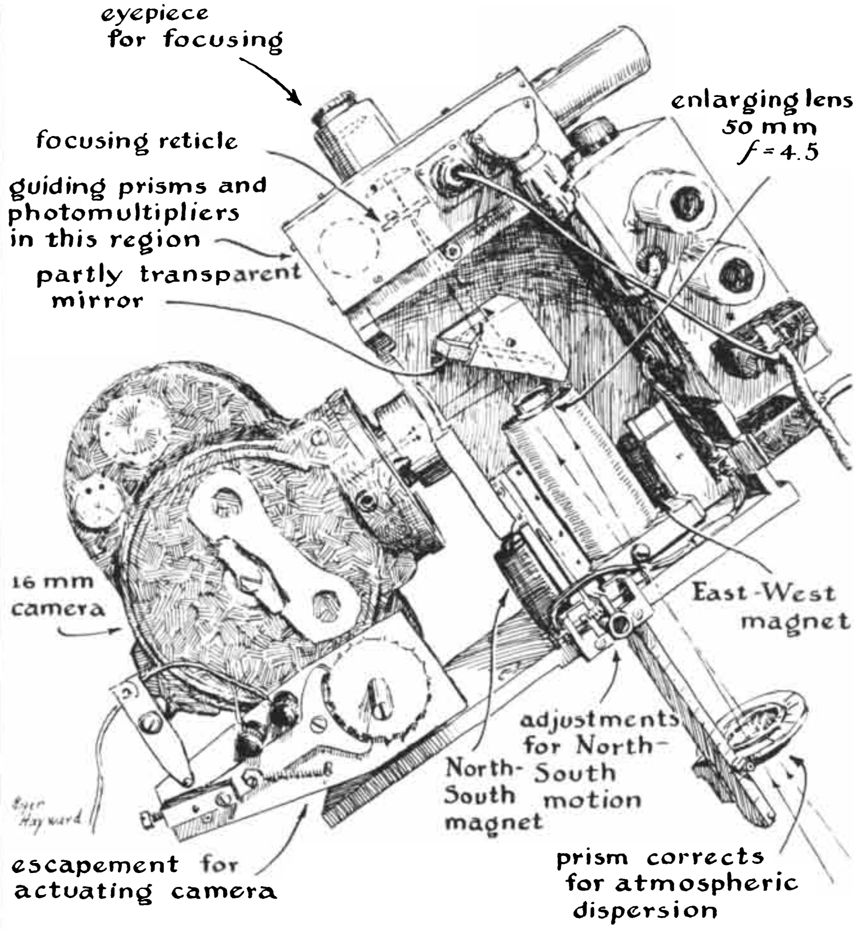
"According to the so-called Rayleigh criterion, the resolving power of a telescope is expressed numerically by dividing 4.5 by the diameter of the objective in inches. The quotient gives the smallest angular separation, in seconds of arc, at which two equally bright point sources of light can be distinguished. Any pair separated by a smaller angle will merge because of the wave nature of light and be seen as a single point. Hence if the performance of the huge telescopes were limited only by their optical quality, they would indeed give breathtaking views of the planets.

"Although the big instruments are virtually perfect in their optical and mechanical construction, and have surpassed their expected performance in the applications for which they were designed, there is very little likelihood that they will ever show planetary detail to the limit of their theoretical capabilities. In fact, there is good reason to believe that the best planetary and lunar photographs will be made with telescopes of but 30 to 40 inches aperture.

"An observer at the eyepiece of a relatively small telescope can see millions of tiny craterlets and other structures less than a thousand feet wide on the moon, but no lunar photograph has yet pictured detail less than about a mile in extent. Again, the ring system of Saturn has never been adequately photographed. Most photographs show only the two main rings and the largest division, whereas the faint crape ring is very



Leighton's guiding device is located in the optical system of the 60-inch telescope



Closeup drawing of the guiding system and camera

clear visually in small telescopes, and at least two other divisions are recognized. The canals of Mars may be a third example. Their failure to appear on any of the many thousands of photographs that have been made of this planet is the cause of a long-standing controversy regarding their existence. Many qualified observers have reported seeing them. Others, apparently equally qualified, see not a trace of them. Even a single convincing photograph could settle the question of their existence.

"These examples, particularly that of the lunar craters, clearly establish that a wide gap exists between well-substantiated visual observation and the corresponding photographic results. The fundamental cause of this discrepancy is to be found not in any lack of optical perfection of the telescope itself, but rather in the optical unsteadiness of the earth's atmosphere, which is brought about by thermal nonuniformities always present throughout it. This, coupled with the need for several seconds' exposure, leads to relatively poor photographic resolution, no matter how large or small a telescope is used.

"The degree of optical steadiness of the atmosphere is called the 'seeing.' One effect of the turbulence is visible to the naked eye as the scintillation or 'twinkling' of the stars. As the thermally inhomogeneous regions move past the observer's line of sight, they act upon the light rays passing through them, thereby producing a constantly changing deviation and phase shift. Neighboring rays interfere with one another and cause the observed color and brightness changes. In times of good seeing the atmosphere is relatively calm and thermally uniform and there is little or no naked-eye stellar scintillation. During bad seeing, on the contrary, the atmosphere is quite nonuniform thermally and a large degree of scintillation is visible.

"The atmospheric turbulence that leads to poor seeing arises from many causes. It may be created by local warm objects (such as motors, vacuum tubes or observers near the telescope itself), by a difference in temperature between the telescope tube and the surrounding air, or by nearby chimneys or factories which emit heat. More basically, the inhomogeneities are caused by large-scale convection currents which accompany cloud formation and thunderstorms, or

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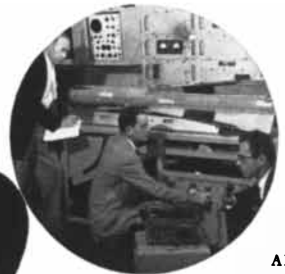

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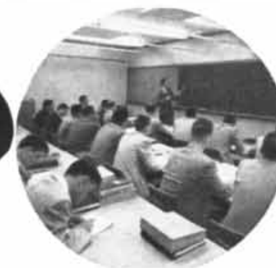

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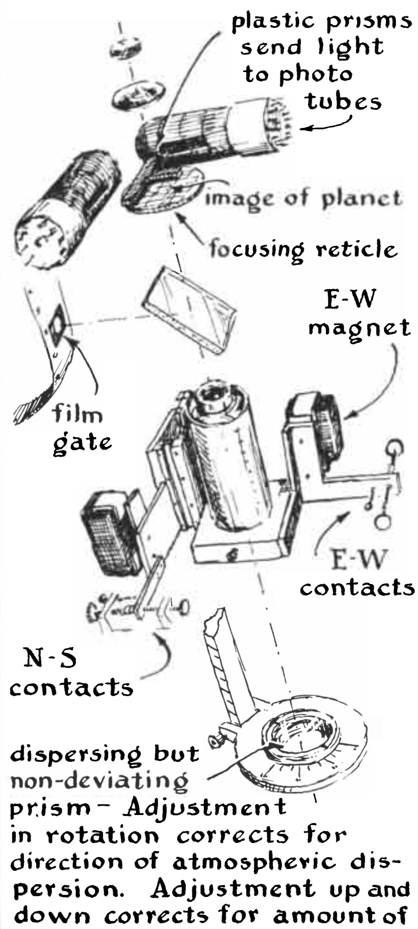
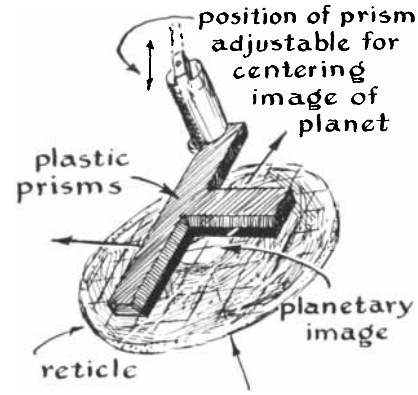
by turbulence between atmospheric layers having different temperatures and wind velocities.

"The character of the seeing can be viewed telescopically in considerable detail by observing an out-of-focus image of a bright star. The pattern you see resembles the bands and spots of sunlight on the bottom of a slightly agitated pool of water. They are in constant motion. Slow-moving patterns with sharp boundaries generally signify nearby heat sources, and these can often be tracked down by careful observation. Fast-moving patterns can usually be seen sweeping across the objective in one or more directions; these are caused by winds somewhere in the atmosphere.

"The effect of the seeing upon the quality of an image formed by a telescope depends upon the 'cell size' of the seeing. This refers to the size of the region over which the air temperature is sufficiently uniform so that a parallel light beam passing through such a region to the telescope is negligibly distorted. The part of the objective that receives such a beam forms a perfect



Optical train of the guiding system



Deflecting prisms of the system

image. If the cell size is substantially smaller than the telescope aperture, the objective will encompass several such cells, with the result that a number of separate images are formed by the telescope. These then combine to form a blurred image on which fine detail cannot be resolved. If only a few such cells cover the aperture, the separate images may be individually visible. Each star or other object is split into a small cluster. This is often the case with fine detail such as the craters of the moon or the Jovian satellites.

"At the other extreme the seeing cell-size may be much larger than the telescope aperture, so that the entire objective acts as a unit and the resultant image is clear and sharp. But the image will move irregularly about some average position. These irregular excursions are often as large as one or two seconds of arc, which is several per cent of the angular diameter of Mars or Jupiter. Under given conditions of seeing it is clearly disadvantageous to use an aperture larger than the seeing cell-size. This aperture will yield a brighter image, though it will show less detail.

"What is the best size of telescope, then, for visual observation? It ought to be large enough to take advantage of the best seeing (*i.e.*, largest cell-size) that is reasonably likely to occur. The maximum size thus depends upon the geographical location, for at each location there is a certain distribution of seeing conditions throughout the year, and on each night there is a corresponding maximum useful aperture for visual observation. On most nights, even at a favorable location, this will be less than three or four inches. On many it may be as large as 10 or 12 inches. But apertures as large as 50 or 60 inches very seldom can be used with maximum effect. The greatest telescopes, such as the 100-inch and 200-inch reflectors, will encounter

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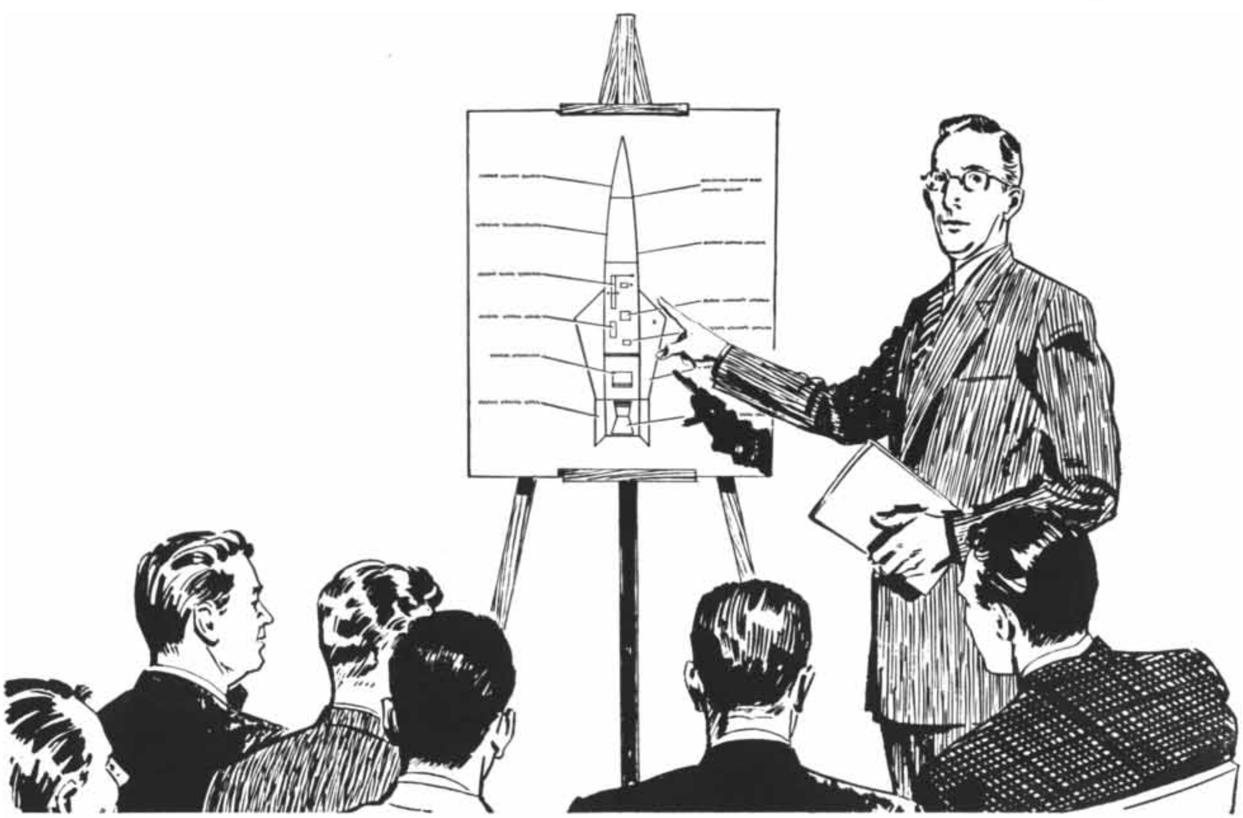


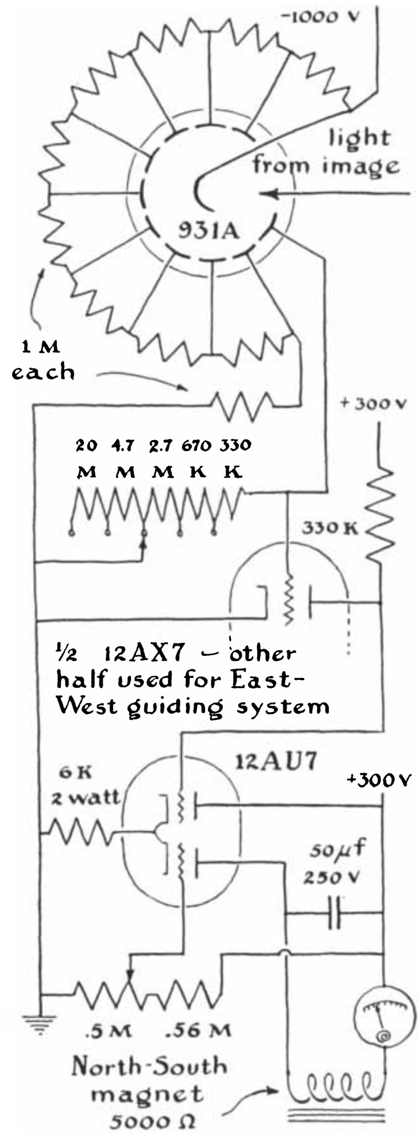
seeing conditions fully matching their apertures only once in many years. Indeed, no astronomer who has used the 200-inch Hale telescope has yet reported star images less than about three tenths of a second of arc in diameter. This size corresponds to the theoretical resolving power of a 15-inch telescope! Obviously a visual observer gains no advantage at the eyepiece of the huge telescopes.

"If we now consider the photographic situation, a new element enters the problem. This is the requirement that a sufficient exposure time be provided to yield a satisfactory photographic image. Because of this the advantage of a smaller aperture disappears, since the fainter image corresponding to the smaller aperture requires a longer exposure and will therefore move about more on the film, yielding a blurred image. Thus for photographic purposes it is almost immaterial whether a large or small aperture is used, so long as it is at least as large as the seeing conditions will permit for visual observation.

"It should now be clear why direct vision has proved superior to photography for the observation of lunar and planetary detail. For visual observation of a sufficiently bright object, it is of no great importance that the image be steady, so long as it is sharply defined, because the eye is able to follow the irregular excursions of the image that are brought about by the atmospheric instability. For photographic observation, on the contrary, it is quite necessary that the image be both sharply defined and steady for the duration of an exposure. Furthermore, a visual observer has a great advantage in being able to ignore the times when the image is distorted and to remember the moments when it is excellent, while the photographic plate indiscriminately records all the accumulated fluctuations.

"Yet in spite of the marvelous ability of the eye to catch, and the brain to retain, fleeting glimpses of extraordinarily fine detail, we cannot regard the situation as anything but unsatisfactory. The eye is not a quantitative measuring instrument, and the brain is not always objective in what it records. The accuracy, objectivity and permanence of the photographic record are as much to be desired here as in other fields of science.

"A number of possibilities exist for removing or relaxing the limitations that the turbulent atmosphere imposes on stellar photography. The most obvious of these is to try to exploit those very rare nights when a large telescope actually will perform better than a small



Circuitry of the system

one. Unfortunately this requires more than a steady atmosphere; it also requires that a suitable object be available in a favorable location to photograph. In the case of the moon, this immediately reduces the likelihood of such a coincidence by at least a factor of four, and in the case of Mars, by a factor of at least 40, not allowing for the fact that the most favorable oppositions of Mars occur when it is low in the sky for the majority of the large telescopes in the world. It would be the sheerest accident if any ordinary photograph of Mars taken with the 200-inch telescope within the next century were to show detail worthy of its tremendous resolving power!

"In contrast with the performance of the 200-inch, the chances of good seeing improve so rapidly with diminishing aperture that a telescope of 40 or 50

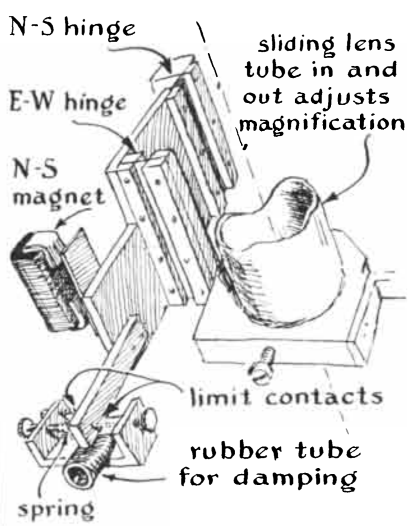
inches might be used effectively for planetary photography, provided photographs were taken almost continuously during every reasonably steady night. But this would require reserving a large portion of the observing time for such use. Such a program probably could not be justified except possibly for a limited time, such as during a very favorable opposition of Mars.

"Clearly the economic justification of the big telescope does not lie in its ability to resolve minute details of bright, relatively close objects. Rather, its immense light-gathering power is largely exploited for photographing objects too faint or remote in space for smaller instruments.

"We cannot hope to make the much-desired photograph of Mars by the mere expedient of building ever more powerful telescopes. How, then, may we approach the job?

"Although no ideal solution is known at present, several possibilities have been suggested and some have been tried with promising results. One is to remove directly the main cause of the problem: the atmosphere. This could be done by taking the telescope away from its traditional bedrock foundation and lifting it above most of the atmosphere in a rocket, a balloon or a high-altitude jet aircraft. Such a project has been seriously considered, but to my knowledge is not now in active progress. Many difficult problems would have to be solved, among them the weight and bulk of a large telescope and the need for a steady yet sensitive means of aiming it.

"A different line of attack, which shows considerable promise, involves the use of electronic image intensification [see "Electronic Photography of



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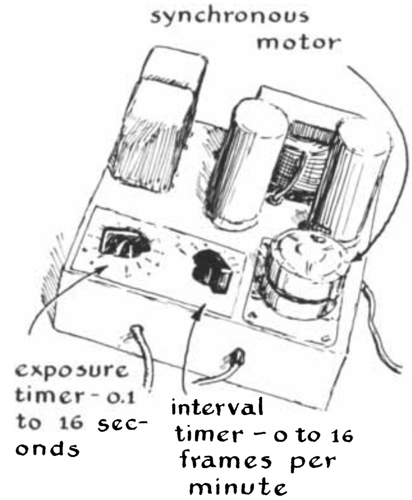
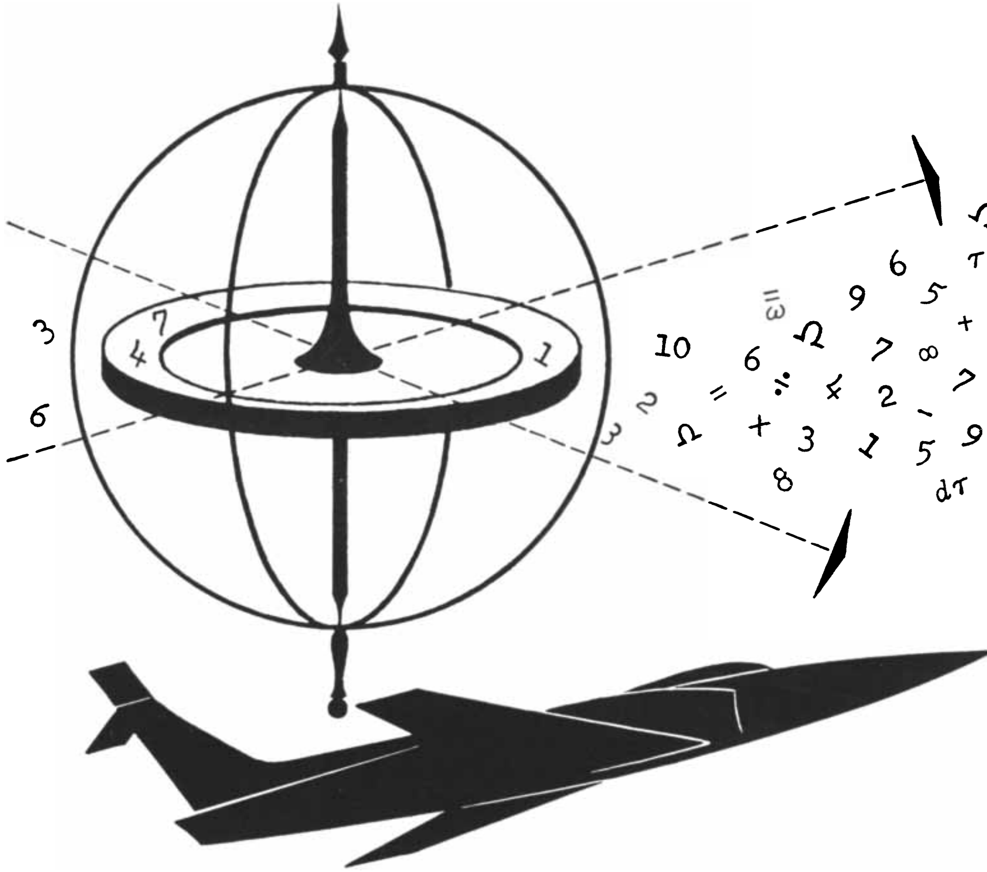


Timing device of the system

Stars," by William A. Baum; Scientific American, March]. The aim here is to reduce the required exposure time so drastically that the image from a relatively small telescope could be utilized. A system based on this principle has been tested at the Lowell Observatory at Flagstaff, Ariz. It yields enough intensification to permit a 30-fold reduction in exposure time. The image thus has less time for wandering about on the film, and smearing is reduced accordingly. This is essentially a closed-circuit television system utilizing an image-orthicon pickup tube connected through an amplifier to a picture tube. The picture tube is then photographed with a camera whose shutter is suitably synchronized with the picture. With this method the possibility also exists of detecting electronically the moments when the image is sharpest and building up a complete exposure out of many selected shorter intervals. It is too early to evaluate the capabilities of the new electronic methods, but doubtless much will be heard of them in the future.

"During the past few years I have experimented with a third approach in which an electronic guiding system is used to cancel out most of the motion of the image on the film. I observed that during good seeing the image of a planet tends to move as a whole, rather than to change in size or shape. This motion is erratic, but the image remains within one or two seconds of arc of some average position. Most important, the image moves slowly enough so that the design of an electromechanical servo system capable of following it appeared practicable.

"After the usual number of false starts, I assembled a guiding device and tested it on an artificial planet in the form of



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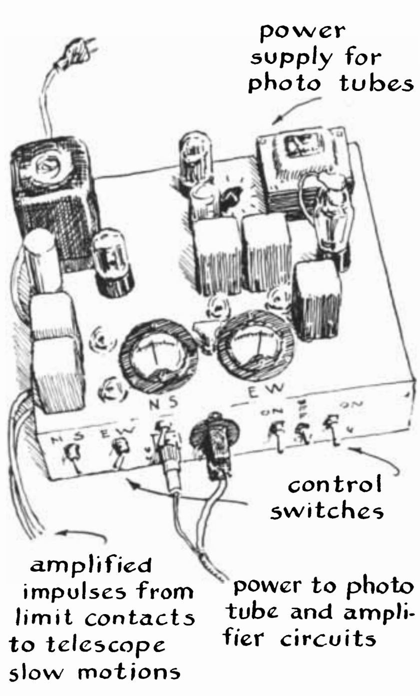
an illuminated hole two millimeters in diameter in a metal sheet. This spot of light could be moved in a pattern that simulated the image movement of a planet under average seeing conditions. The assembly was then coupled to a modified 16-millimeter motion picture camera and mounted on the tube of the 60-inch reflector on Mount Wilson [*see drawing on page 157*]. The planetary photographs accompanying this article were selected from the resulting exposures. The pictures show at least as much detail as was visible to the eye at about 750 power, with the exception that Saturn's crape ring was underexposed photographically.

"The device operates in this way. A small enlarging lens of about *f*/4.5 focal ratio is mounted on a doubly pivoted carriage [*see drawing on page 158*]. The carriage permits the lens about half a millimeter of transverse motion in any direction. The two components of this motion are governed by two small electromagnets whose pulls are balanced against springs [*bottom of page 160*]. The light from the telescope forms an image in the normal focal plane of the telescope, proceeds past this plane through the enlarging lens, reflects from a partly reflecting diagonal mirror, and comes to a new focus at the film plane of the motion picture camera. Part of the light proceeds through the partly reflecting diagonal mirror and comes to a focus on a reticle, where it can be viewed by an eyepiece. Two small reflecting prisms with sharp edges project slightly into this latter beam from two directions at the focal plane and throw a small amount of the light into each one of two photomultipliers [*drawing at top of page 160*]. The signals from these tubes are amplified in separate direct-current channels and are fed into the electromagnet coils that determine the position of the magnifying lens. The system seeks a stable condition wherein a certain amount of light is entering each photo tube [*drawing on page 162*]. If the telescope image moves by a small amount, the amount of light entering the photocells changes, and the system responds in such a way as to cancel out this motion. This negative feedback is, of course, not capable of completely canceling the erratic motion, but it reduces it by a factor of about 10. In this way seeing fluctuations, mechanical vibration and driving errors are essentially canceled out through a frequency range extending from zero vibrations per second up to approximately two vibrations per second.

"An additional feature that is a great convenience, but not a necessity, is that there are relay contacts on the lens carriage which act as limit switches to prevent the electromagnets from having to work outside their designed range [*bottom of page 164*]. If this preset range is exceeded, the corresponding slow-motion drive of the telescope is automatically applied so as to bring the electromagnet back into the center of its operating range. Thus, once adjusted, the guider will track and center a planet image for the duration of an entire observing night. Indeed, except for focusing the image on the reticle and rotating the telescope dome now and then, the entire operation is automatic, including the timing of each exposure and the advancing of the film. The timing system is shown at the top of page 164.

"Through the use of this device one of the two serious disadvantages of a long exposure is essentially removed: the relative motion of the image as a whole with respect to the film is neutralized. But it is still necessary to match the diameter of the telescope objective to the 'seeing' cell-size, so that the image will be sharply defined over the greater part of the exposure time.

"I used 16-mm. Kodachrome film with exposure times that varied from two seconds for Jupiter to 16 seconds for Saturn. Exposures were usually made at the rate of two frames per minute over a period of a few hours, and the best of the resulting images were later selected for enlargement."



Amplifier assembly of the system

INDEX OF ADVERTISERS

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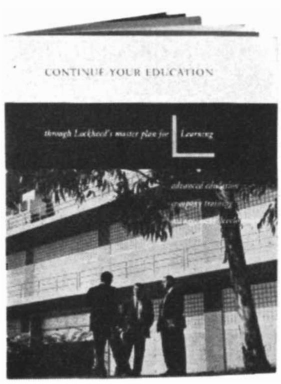

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