SCIENTIFIC AMERICAN

MAGNETIC OXIDE

FIFTY CENTS

June 1960

—as used to make better seats and valves at Central Rubber Company, Belvidere, Ill., and Henry Pratt Company, Inc., Chicago, Ill., respectively

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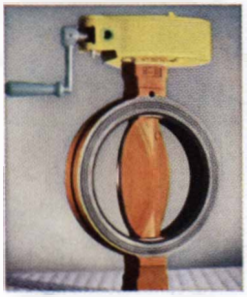

Quite new in concept is the "butterfly" valve pictured here. It quickly and surely controls the flow of highly corrosive liquids at pressures up to 150 pounds and, in tests, easily survives 10,000 cycles — the equivalent of 20 years' service.

Much of the valve's success stems from the use of CHEMIGUM in its integrally molded seat. CHEMIGUM was chosen because of its easier processing, better bonding and excellent resistance to petroleum products, chemicals, water and wear.

How can CHEMIGUM help your product take a turn for the better? Full details are yours by writing Goodyear, Chemical Division, Dept. R-9457, Akron 16, Ohio.

Chemigum—T. M. The Goodyear Tire & Rubber Company, Akron, Ohio

GOODYEAR

CHEMICAL DIVISION

WHO MAKES FINE MOTORS THIS SMALL?

Globe Industries makes motors this small to make **your** design more compact, reliable and salable. If you make miniature instrument packages for space exploration — if you build airborne and ground support equipment — if you want to design smaller typewriters, computers, recorders or other products, look at these 3 motors:

TYPE VS—The smallest, most powerful precision miniature d.c. motor for its size. Only 7/16" flat, four VS motors fit in a regular cigarette pack with room to spare. It has the power to lift its own weight to the top of the Empire State Building in 1 minute! Typical continuous torque—.25 oz. in.; typical intermittent torque—.5 oz. ins. We can design gear units, governors and brakes to meet MIL specs also.

TYPE SS — Only 7/8" in diameter, Type SS d.c. motors typically produce continuous duty torques of .3 oz. in.; intermittent torques to .6 oz. ins. With the basic Type SS motor you can specify any of 21 planetary gear speed reducers or 28 spur gear speed reducers. Governors and brakes are available also. Designed to meet MIL specs.

TYPE MM — The most widely used precision 1¼" d.c. motor in the world, MM motors typically produce .5 oz. in. in continuous duty applications — 1.0 oz. in. intermittent duty. Choose from 101 ratios of planetary gear speed reductions. Brakes, governors and clutches can be included. MIL specs are invited.

For details about these motors request Bulletin VSM. Globe Industries, Inc., 1784 Stanley Ave., Dayton 4, Ohio.

GLOBE INDUSTRIES, INC.

PRECISION MINIATURE A.C. & D.C. MOTORS. ACTUATORS. TIMERS. GYROS. STEPPERS. BLOWERS. MOTORIZED DEVICES

GLOBE

Basic as bread... is the role of electronic instrumentation in human progress. And often, as close to home ● Here, a food processor relies upon a Beckman oxygen analyzer to guarantee the freshness and flavor of orange juice. There, using ultracentrifuge, electrophoresis apparatus and chromatograph, immunochemists isolate ragweed allergens in the fight to control hay fever. Farther afield, a Beckman high temperature ceramic potentiometer helps launch and guide a missile ● Everywhere, in the pursuit of quality, the quest for a cure, the maintenance of leadership—Beckman is part of the plan. And wherever they are—in the laboratory, in the factory or in space—Beckman components, instruments and systems are basic ● They are the things on which Beckman builds its success...upon which users of Beckman products build theirs.

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Established 1845 **SCIENTIFIC AMERICAN** June, 1960 Volume 202 Number 6

ARTICLES

DEPARTMENTS

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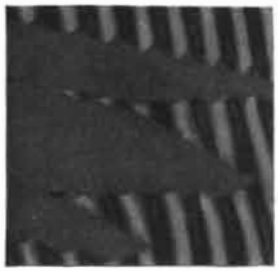

THE COVER

The photomicrograph on the cover shows magnetic domains in a thin single crystal of yttrium iron garnet, magnified 330 diameters. This magnetic oxide, a new relative of the ferrites [*see page 92*], shows the general properties of these materials: it is strongly magnetic and at the same time an electrical insulator. The photograph was made by transmitted light, with the crystal placed between nearly crossed polarizers. Polarized light interacts with the magnetization in such a way that the separate domains—regions where all the individual atomic magnets are aligned in the same direction—appear in different colors. In the dark green areas the magnetization is pointing up out of the paper; in the yellow areas it is pointing down into the paper; in the red areas it lies in the plane of the paper. Because of their high electrical resistivity some magnetic oxides can be penetrated by high-frequency alternating magnetic fields. Frequencies up to about 100 megacycles per second cause the walls between the domains to move, as the magnetization tries to follow the changing direction of the field. At higher frequencies the field and the magnetization interact in different ways. Garnet crystals transmit electromagnetic radiation at frequencies as high as those of visible light. The photograph was made at Bell Telephone Laboratories under the direction of J. F. Dillon, Jr., who discovered the transparency of garnet crystals and studied domain structure in them.

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Cover photograph by William Vandivert

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YOU'D BE SURPRISED...

...at the number and variety of general products assignments currently "in the works" at Vertol. Many companies have learned that Vertol's extensive know-how and experience in aircraft materials, structures, powerplants, instrumentation and systems — coupled with a new kind of "shirt-sleeve" ingenuity — offer a unique capability for getting things done.

Take antennas, for example. Vertol has mechanically designed, fabricated, tested and transported antennas in many shapes and materials — from a small reinforced plastic dish to the complete 105 ft. FPS-28 system including bearings, drive mechanism and tower.

Why not find out how this new combination of know-how and ingenuity can efficiently and economically deliver the goods for you. Write General Products Department

VERTOL DIVISION
MORTON PENNSYLVANIA
BOEING

After 31 years of continuous growth and

We're changing

The Bendix

To reflect our dynamic growth in such fields as electronics, missiles and space, automotive, weapons systems, computers, machine tools, instrumentation, nuclear technology, hydraulics, meteorology, electrical, marine and others, we are dropping "Aviation" from our corporate name on June 1, 1960. We do not wish to convey the impression that our products and skills are limited to the field of aviation alone, although aviation products accounted for billings of $388,700,000 in 1959.

Today Bendix—through 25 divisions and 16 subsidiary and affiliate companies around the world—serves many fields.

Our success in the rapidly expanding age of aviation has long obscured the fact that the Bendix® automobile starter drive was the company's first major product. Bendix introduced the type of four-wheel brakes that over the years has been used on most makes of cars. Bendix also pioneered automotive power brakes and power steering. Our automotive business in 1959 totaled $114,300,000.

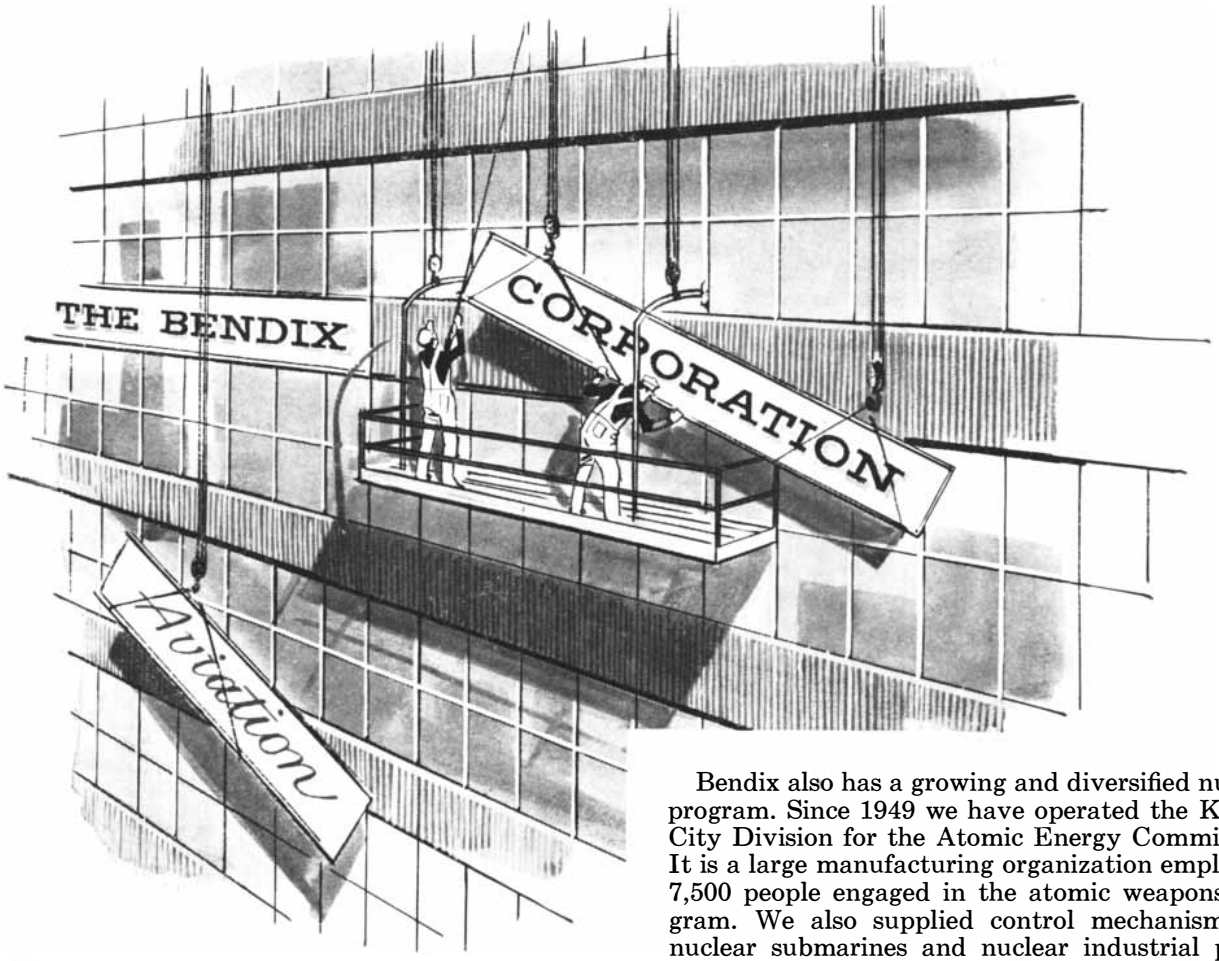
A notable trend in Bendix' recent history is the utilization of electronics in many of our major fields of activity. These range from automobile radios to aircraft and industrial communications and automatic flight controls . . . from electronic computers and data processing to numerical tape control systems for machine tools . . . and from transistors and ship-to-shore telephones to sonic cleaning and undersea sonar detection equipment. Approximately 40% of Bendix products are electronic, including air defense radar which today guards 25 million square miles of the earth's surface.

Missile and space equipment accounted for $103,000,000 of our total business of $689,692,312 in 1959. In addition to being the prime contractor for two important missiles, Talos and Eagle, we are also a supplier of components and sub-systems

diversification as Bendix Aviation Corporation . . .

our name to

Corporation



for most U. S. missiles. Bendix is likewise taking an active part in Project Mercury and in satellite communications. The first is the program to put a man into space. The second will mark a new era in communications by using a satellite in orbit as a relay station for global radio messages between earth stations and aircraft.

Bendix also has a growing and diversified nuclear program. Since 1949 we have operated the Kansas City Division for the Atomic Energy Commission. It is a large manufacturing organization employing 7,500 people engaged in the atomic weapons program. We also supplied control mechanisms for nuclear submarines and nuclear industrial power plants, and we are playing a part in developing the newest U. S. atomic power plants for aircraft, missiles and space vehicles.

Thus, as we drop "Aviation" from our corporate name, but not from our programs, we face a tomorrow where the range of our opportunities is broadening at a breathtaking rate.

THE Bendix
CORPORATION
Fisher Bldg., Detroit 2, Mich.

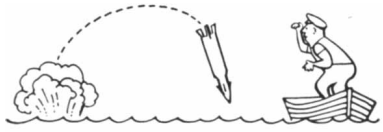
A thousand diversified products

ANALOG COMPUTERS

—How You Can Use Them

It's no secret that people who make analog computers spend a lot of time talking to each other. Pity the chap who's trying to figure out how all this palaver applies to him. He's in a semantic jungle.

First, let's define what kind of computers we're talking about. At Donner, we're concerned with two types—general purpose and fixed purpose. Quickly, general purpose analog computers solve equations describing lumped parameter, dynamic systems expressed in linear or non-linear differential equations, or transformed (La Place) equations. They are used to directly simulate systems described by these equations. They are also used to analyze sections of these systems. In other words, this type of computer gives you freedom and flexibility limited only by your imagination.



THE FIXED PURPOSE COMPUTER

Actually, there's not much difference between general purpose and fixed purpose computers. The point is that fixed purpose computers fit neatly into your system to do a specific job. You don't have to worry about programming—that's built in. All you do is turn the knobs. It may interest you to know that 80 to 90 per cent of analog computing equipment sold is fixed purpose. At Donner, fixed purpose gear is one of our big specialties. It comes in a wide variety of sizes. Typical of lightweight devices is the solid state "think" device developed by Donner for the Polaris missile which monitors flight performance. If, for example, in the initial portion of the flight, the missile does not achieve sufficient velocity by a predetermined time, the Donner system aborts the flight. The missile gets the go-ahead only as programmed.

Another fixed purpose computer is the on-line wind tunnel data reduction computer recently built by Donner for the National Research Council of Canada. This computer receives, processes, and analyzes signals from force transducers mounted on a scale model. Such coefficients as lift and drag are continuously and simultaneously studied.

COMPUTERS FOR ANALYSIS ARE OFTEN USED

Fixed purpose analog computers are used in linear and non-linear programming. Here, they solve problems of gasoline blending, game theory, logistics, military tactics, and operations research.

Other fixed purpose analog computers are used to study spectral density and variation coefficients. The spectral density computer is used to make vibration, noise and system transmissibility studies. Statistical evaluation of non-continuous or discrete process can be performed with variation coefficient computers. In this application, achieved values are put in and average value, standard deviation, and variation coefficient instantly computed out.

COMPUTERS FOR INFORMATION CONTROL, SIGNAL CONDITIONING, AND PROCESSING

Three other examples of fixed purpose analog computers in use are a missile tracking computer, signal conditioning computer, and process control computer.

The missile tracking computer receives distance and angular displacement information from tracking radars. From this information, the computer provides a continuous plot of the missile's position in cartesian coordinates.

Signal conditioning computers modify frequency, phase or amplitude to restore or control signal characteristics. They are used for hybrid computer links, preamplification of low level transducer signals, spectrum segmentation with active filters, or automatic control of dynamic range.

Process control computers receive signals from transducers, linearize the signals, compare them with set points both fixed and variable, and provide control signals with rate, reset, and proportional adjustments.

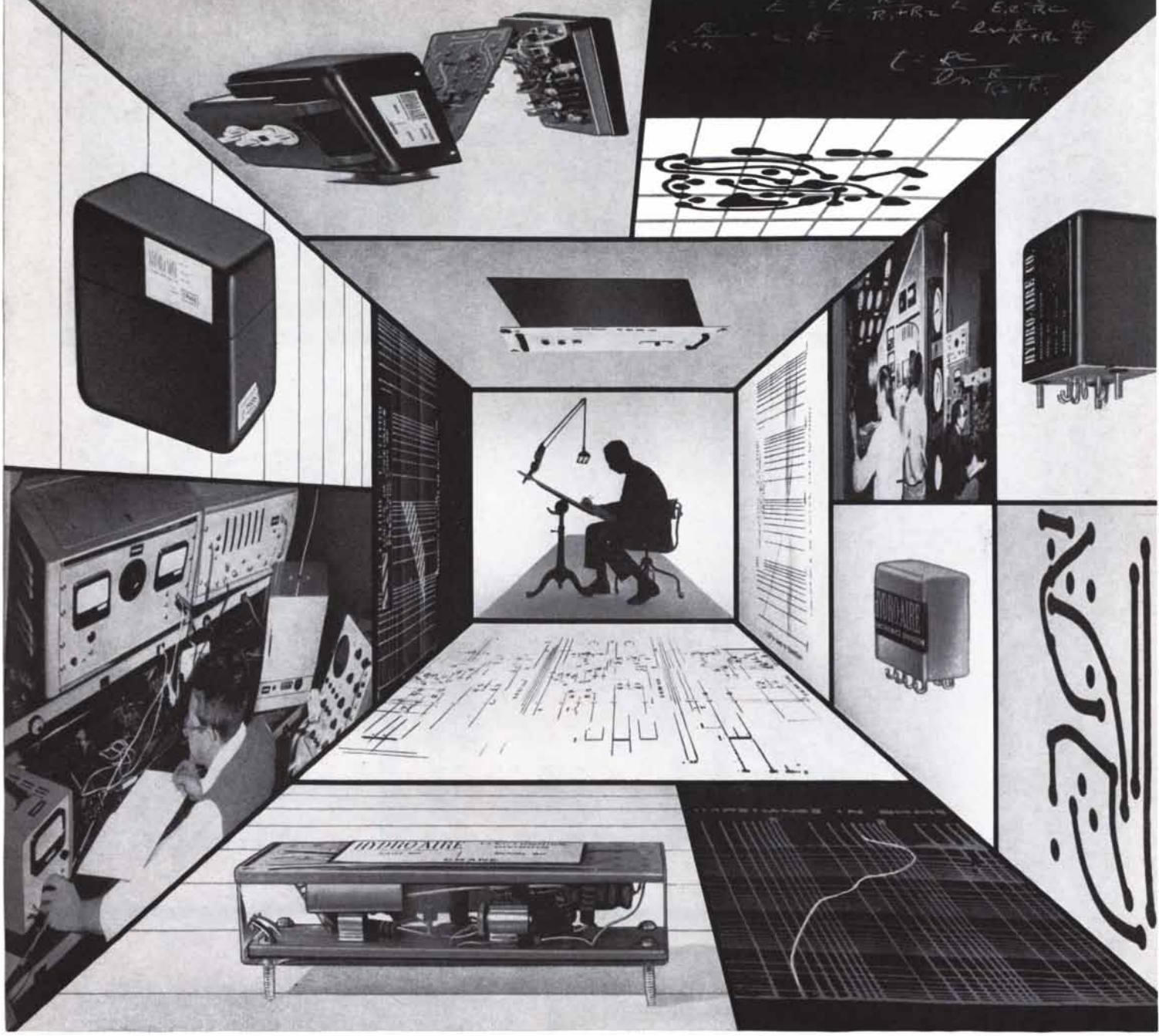
LET'S HEAR FROM YOU

Enough talk. We've given you a rough idea what Donner has done for other people. Let's find out how this applies to you. Send us a brief description of your problem; a paragraph or two will do. We'll write back telling how Donner can help and send you a Tech Note if it applies. If writing's a chore, our engineering rep will be happy to discuss methods of solving your problem with Donner's computer systems. Just contact us for his name. Either way, you'll get information that applies to your particular problem. Please address Dept. 99.

DONNER SCIENTIFIC COMPANY

CONCORD, CALIFORNIA

26



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For a prompt answer to your inquiry, write Electronics Division, Hydro-Aire, 3000 Winona Avenue, Burbank. A note on your letterhead brings your copy of our new Electronics Brochure.

Qualified Electronics Engineers are invited to investigate opportunities at Hydro-Aire by contacting Mr. Harold Giesecke.

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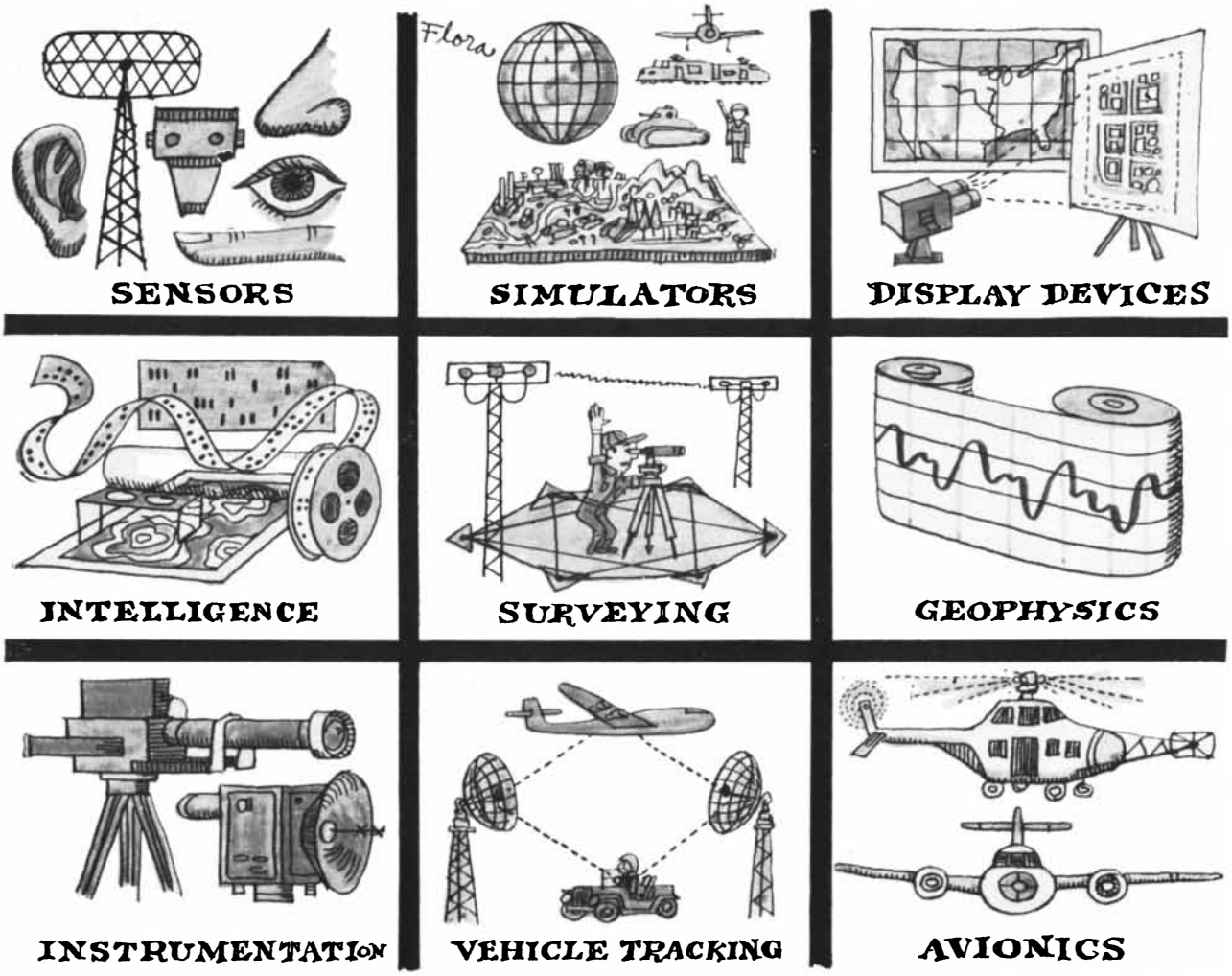
Solid-state devices include time delay devices, voltage regulators, power supplies, inverters.



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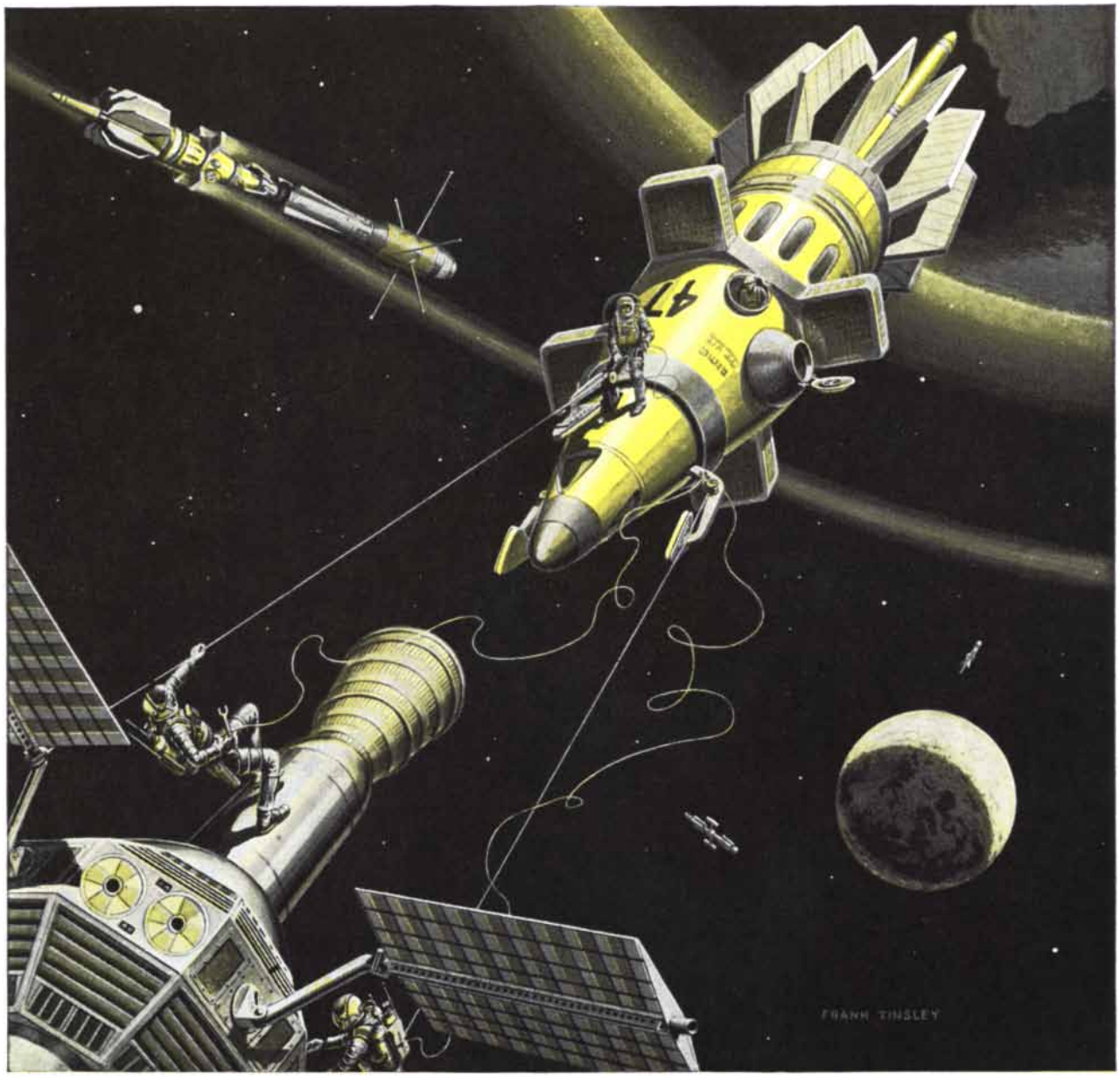


STEPS IN THE RACE TO OUTER SPACE

Breaking a Space Traffic Jam

By 1970 our solar system will be filled with expended satellites—whirling aimlessly in space with dead batteries and electronic equipment, their missions long since completed.

As space traffic increases, these derelicts will have to be captured and broken out of orbit to keep flight paths clear. For this task, special towboats will be designed and crews trained.

Here, step by step, is an account of such satellite capture and destruction:

1. The towboat, driven by electro-particle propulsion, rockets into space at speeds reaching 25,000 m.p.h. Its reversible engines enable it to slow as it approaches the radar-located satellite, and match the derelict's speed as it moves into orbit behind it.

2. Crewmen attach lines to the satellite (as in illustration). Then they haul the towboat forward and its nose cone is clamped to the satellite's rocket nozzle.

3. The towboat's engines are then switched to full reverse and the linked machines gradually lose momentum, nosing into a spiral path toward the Earth below.

4. When a safe point is reached, the towboat automatically releases the satellite and it is consumed by friction as it plunges into the heavier atmosphere. The towboat, regaining its speed, moves on to its next assignment—breaking a traffic jam in some other congested point in space.

ARMA, now providing the inertial guidance system for the ATLAS ICBM and engaged in advanced research and development, is in the vanguard of the race to outer space. For this effort, ***ARMA*** needs scientists and engineers experienced in astronautics. ***ARMA***, Garden City, New York. A Division of American Bosch Arma Corporation.

AMERICAN BOSCH ARMA CORPORATION

DOW

NEWS ABOUT PRODUCT DESIGN AND MATERIALS

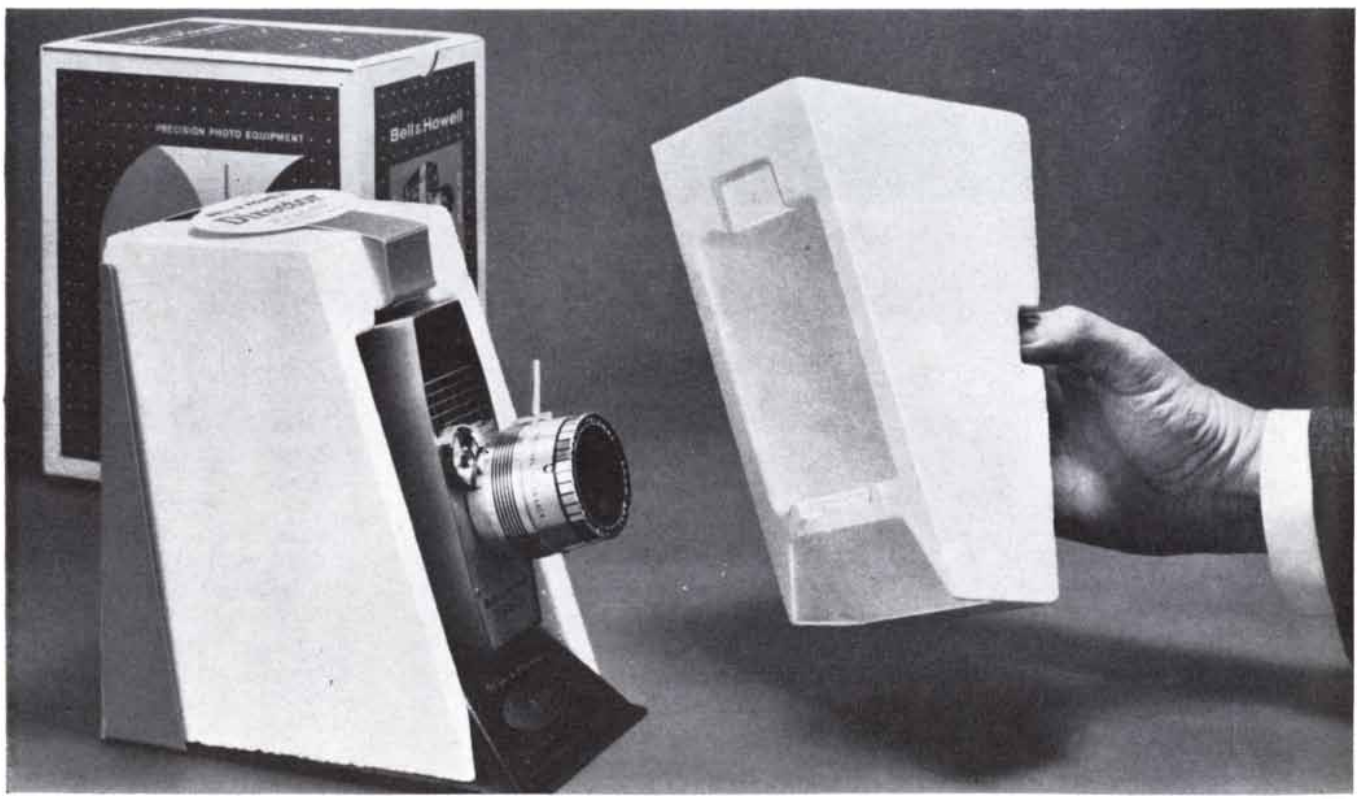
As the use of plastics materials increases, more and more new product ideas are sparked in designers' minds. The result is new sales for the manufacturer and new convenience for the buyer. Just as often, these plastics materials are used to bring old products up to date—to give them longer life, more attractive appearance, greatly improved utility. Here are some examples of how Dow plastics do these jobs well . . .

PLASTICS STAR IN NEW PRODUCT DESIGN . . . CAMERA CRADLES TO BABY BATHS!

Four members of Dow's plastics family play starring roles more and more in design and production of new products of all kinds. For example, the newest of these plastics—Pelaspan®—provides an ideal solution to the problem of safely cradling fragile objects, such as delicate instruments and cameras, during shipment.

A major manufacturer of camera equipment faced a problem of preventing damage to expensive movie cameras during shipment. Usual packaging materials had the costly disadvantage of passing a high degree of shock on to the camera inside, rather than absorbing it. They found that form-fitting Pelaspan completely protects cameras, however, because it is so shock-absorbent. Even when these packages are dropped, there is no damaging "rebound" of the contents. Pelaspan is composed of expandable polystyrene beads which, under moderate heat—steam or hot water—expand up to 40 times their original volume to form a smooth-surfaced foam. In a mold, Pelaspan expands and fuses, taking the precise shape of the mold, even to matching intricate convolutions and contours.

In addition to making a truly form-fitting package, a major design advantage of Pelaspan is its property of variable energy absorption, which varies as the density of the foam. During expansion, density can be varied from



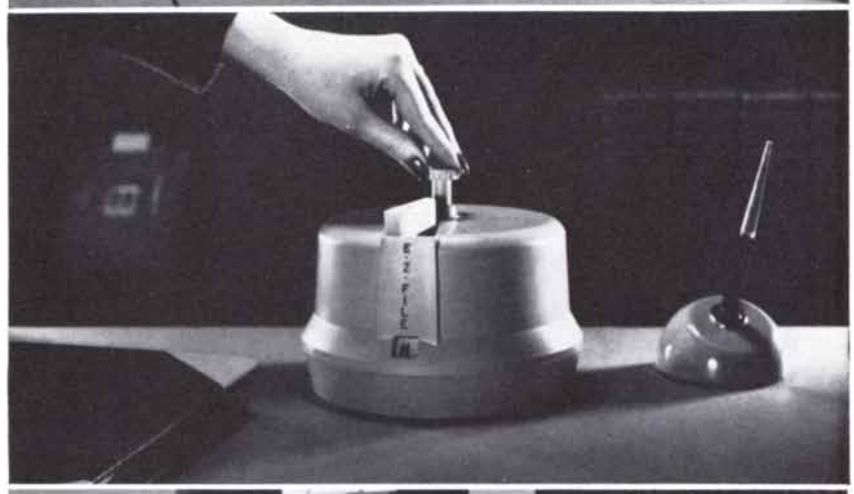
one pound to 10 pounds per cubic foot, making it easy to produce a shipping package having the exact degree of shock absorption needed.

This camera producer also gained a plus-factor in the improved appearance of the new package. The smooth surface of clean, white Pelaspan makes it an attractive point-of-sale display package!

Another of Dow's modern plastics family is Tyril®. This tough molding material is right at home in the kitchen . . . and in the dining room, too . . . thanks to good looks. Among the great number of things being made from Tyril are hot dog cookers and beverage sets. Fruit and food acids won't affect it, and Tyril is virtually unbreakable! Tyril has the production virtues of excellent flow and good moldability.

Dow's newest high-impact thermoplastic formulation is Styron® 440. A good example of the new products it makes possible is the rotary card file at right. Styron 440 gives this newly designed file extra impact strength. It won't warp, nor will rough treatment affect the appearance of the tough, lustrous shell. Inside, ribbed separators keep the cards in order . . . ribs that can be formed accurately, thanks to the excellent moldability of Styron 440.

Sheet extruded from Styron 475 is the most widely used of all Dow thermoplastics. This versatile, economical vacuum-forming material will easily take almost any shape and detail. For example, the new child's night light makes good use of the formability of Styron 475 sheet to produce a life-like, three-dimensional scene on the back-lit translucent facing. And in the baby bath shown here, Styron 475 sheet gives lasting strength to resist chipping and damage, as well as good looks that soap and oil won't harm. Won't dent, rust or scratch a table top, either.



HOW ABOUT YOUR PRODUCTS? Have you considered how modern Dow plastics materials might increase the sales appeal of your products? So wide is the range of Dow materials and formulations that there's almost sure to be some which can not only improve your present products, but which may inspire new items for your line. There are literally dozens to choose from, each backed by specialized Dow assistance and counsel . . . from color styling to production, on up to marketing help if you need it. For more information, write to THE DOW CHEMICAL COMPANY, Midland, Michigan, Plastics Merchandising Department 1755EQ6.

THE DOW CHEMICAL COMPANY

MIDLAND, MICHIGAN

DOW

LETTERS

Sirs:

Immunoelectrophoresis, which was the subject of the interesting article by Curtis A. Williams, Jr. [SCIENTIFIC AMERICAN, March], is an important daughter technique of the general method of immunochemical analysis of antigen mixtures by diffusion in gels. The importance of the latter, as a method of research, is great enough to make a more precise statement of its early history and successive stages desirable.

Antigen-antibody precipitation in gels was first performed in 1905 by H. Bechhold with the aim of studying Liesegang rings. The multiple zones of precipitation, observed in tubes, were considered in fact to be Liesegang rings, as though they were due to only one antigen. No other interpretation was offered for 40 years, though reactions in gels were sometimes used in plates for the purpose of bacterial identification (*e.g.*, by G. F. Petrie and D. Steabben in 1943).

While looking for a method of analyzing mixtures of antigens, I had the idea of using diffusion in gels for this purpose and described this method in a paper of January, 1946. In these experiments the solutions of antigens and antibodies were in contact with each other in tubes; a technique involving diffusion of antigen and antibody toward each other through a pure gel was also suggested. In this study a single antigen gave a single precipitation zone; multiple zones were demonstrated to be due to the reaction of multiple antigens. Some two years later, Orjan Ouchterlony and S. D. Elek reported separately and almost simultaneously studies using precipitation in agar plates for the purpose of identifying toxicogenic bacteria. The multiple zones which they observed were not considered then to be Liesegang rings, but rather the effect of multiple antigens. These two authors developed techniques of immunochemical analysis using diffusion of antigens and antibodies through a pure gel, in agar plates. Other techniques have been devised since that time.

The association of electrophoresis with immunochemical analysis in two steps (later called immunoelectrophoresis) was first performed in 1952 by M. D. Poulik, who used electrophoresis on paper (and more recently on starch gel). In 1953 Williams and Pierre Grabar combined immunochemical analysis with agar electrophoresis in a technique more advantageous than Poulik's earlier one using paper. However, it seems, according to recent papers by J. Kohn, that the association of electrophoresis and diffusion, both performed on cellulose acetate paper, is very promising.

I can hardly agree with Williams's opinion that "the plates are more useful in the study of complex systems" than the tubes. If it were so, how could it be that the greatest number of antigenic components, listed to date, of human serum and its fractions have been described in a work using neither plates nor immunoelectrophoresis, but the first described tube technique? In addition, the latter technique is the only one, so far as I know, that has permitted quantitative determination of these antigens.

JACQUES OUDIN

Institut Pasteur
Paris

Sirs:

I am indebted to Dr. Oudin for his interesting account of the early history of gel-diffusion methods in immunochemical studies. Dr. Oudin, through his development of gel-diffusion in tubes and his quantitative investigations with this technique, has contributed more to our understanding of these phenomena than perhaps any other person.

The early work of Dr. Poulik did not come to our attention until he published an account of agar-gel diffusion associated with starch-gel electrophoresis in June, 1959. In 1952, when Dr. Grabar

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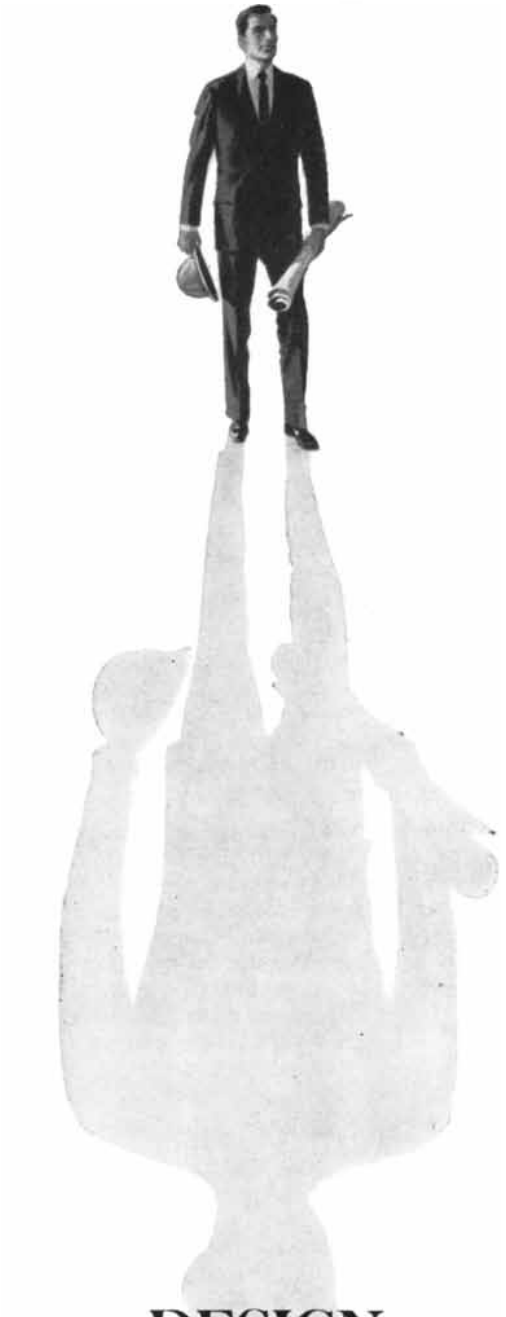

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It's the man that makes the difference in building a new plant. Men—not companies—design, engineer and construct facilities. And the key to a successful job is the right man.

Did you know that Vitro has designed and engineered over two billion dollars worth of new facilities. These projects include nuclear and chemical process production units throughout the world. In addition, Vitro has built several hundred million dollars in petroleum plants. All of these projects, large and small, had one thing in common—men who were trained and experienced in the application of new techniques. Another example of why Vitro means more than atomic energy... **facilities engineering.**

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and I began our studies, we also considered relying upon paper electrophoresis, but rejected it forthwith as inconvenient, imprecise and difficult to control. It seems appropriate to mention at this point that immunochemical analysis of electrophoretically separated fractions of serum and other protein mixtures had been a subject of investigation in several laboratories prior to 1952. Electrophoresis of all descriptions, and immunochemical analyses of a wide variety, including gel-diffusion, were employed. We gave our method the one-word name immunoelectrophoresis because the two experimental operations were performed in a single supporting medium, the entire procedure being carried out with a minimum of laboratory manipulation. Without dwelling too long on this subject, I hope (and I know that I can speak for Dr. Grabar) that immunoelectrophoresis neither as a word nor as a method will be expanded in definition to include all possible combinations of electrophoresis and immunochemical analysis.

It is also our common hope that in the not-too-distant future immunoelectrophoretic studies will be empowered with precise quantitative determinations. Whoever is responsible for this will have to rely heavily on the elegant work of Dr. Oudin and those who have taken direction from his lead.

CURTIS A. WILLIAMS, JR.

The Rockefeller Institute
New York, N. Y.

Sirs:

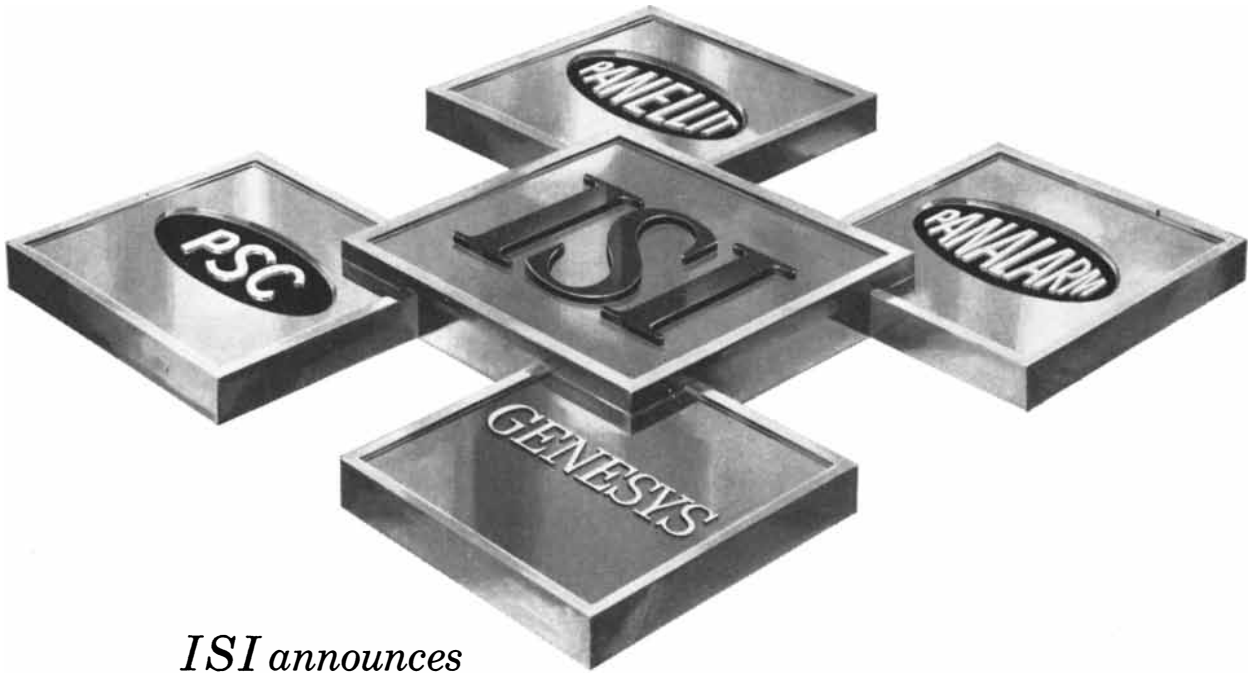
Apparently rheologists do not spend much time in the kitchen. In "The Flow of Matter" [SCIENTIFIC AMERICAN; December, 1959] Marcus Reiner reports that Karl Weissenberg's assistant "could hardly believe his eyes" when he observed a viscous liquid climbing up the stirring rod.

Anyone who has done a lot of baking cannot help but be familiar with this phenomenon. In beating certain cookie batters or bread dough (some bread recipes call for one minute of beating) the batter climbs up the electric beater so industriously that the cook has a fine time getting it back in the bowl. Dr. Weissenberg is a dear friend of ours, and I am well aware that his contribution in this field is in the explanation of the effect, not in its discovery.

MRS. H. E. SECRIST

Dedham, Mass.

Today's big news in automatic control



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The recent combination of Information Systems Incorporated (I.S.I.), all the Panellit operations, and the Genesys Corporation is made to order for your control requirements. I.S.I. now offers an exceptionally broad and well integrated service with the unique advantage of experienced engineering and proven hardware designed for reliable, economical control systems.

The expanded family of advanced I.S.I. and Genesys Digital Control Computers is now teamed with Panellit's wide experience in control instrumentation. Equally important, the conscientious policy of "small company" custom service has not been sacrificed by this corporate growth.

FROM THE SMALLEST TO THE LARGEST PROJECTS

If you need a single $200 Annunciator, or a fully automated Computer Control System, I.S.I. delivers optimum reliability backed by the coordinated capabilities of a major company in the automation field. *No other source can match this single service or turnkey flexibility.*

FOR MANAGEMENT FACED WITH THE PROBLEMS OF EXPANDING AUTOMATION—The new I.S.I. Facilities Brochure will help you evaluate I.S.I.'s control engineering, electro-mechanical and electronic capabilities. Please write the President...

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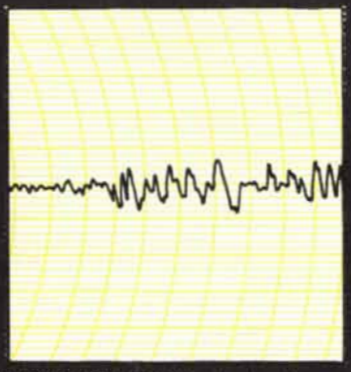
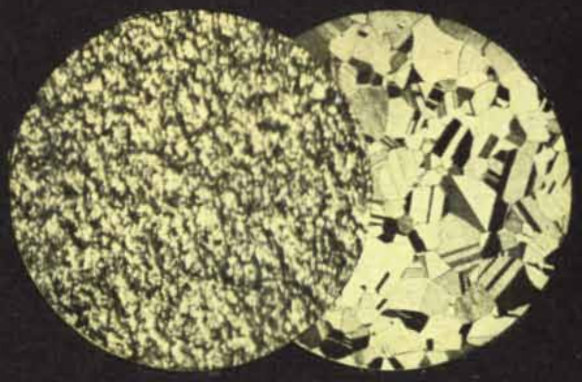
THESE SURFACE TRACES

prove that you can cut polishing costs with Formbrite, Anaconda's superfine-grain drawing brass.

STANDARD DRAWING BRASS
(grain size, .045 mm) — after 40% elongation

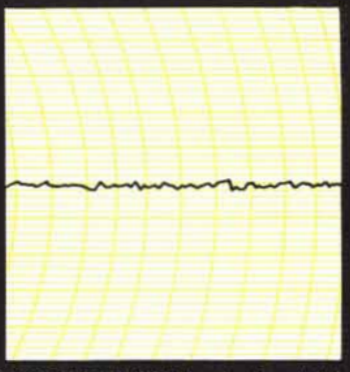


ENLARGED SURFACE TRACE showing the roughness that causes "orange-peel" effect in the working of standard drawing brass. Smoothing such mountains down to the valleys takes considerable cutting. For small deep-drawn products, up to five polishing wheels might be needed. Polishing compound costs run high; production rates, low. Bottlenecks hamstring operations.

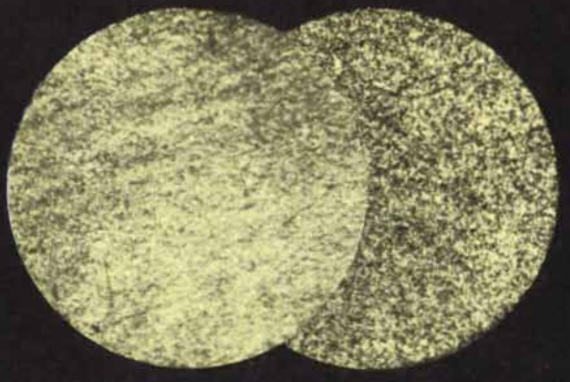


THE STRETCHED SAMPLE of standard drawing brass looks like this (left, above) when seen in oblique illumination and magnified 20x. Its microstructure is shown 75x at right. This is the kind of drawing brass that's been used for decades for stamped or drawn brass products and the micrographs show in another way why polishing costs have been high.

FORMBRITE DRAWING BRASS
(grain size, .005 mm) — after 40% elongation



ENLARGED SURFACE TRACE showing Formbrite's smoothness even after deformation, the test of polishing characteristics of a drawing brass. It is relatively easy to level these little hills on the surface of Formbrite. In many cases, users find they elliminate cutting operations altogether, need only a simple color buff. Finishing savings run up to 50%.



WHEN SEEN IN OBLIQUE ILLUMINATION and magnified 20x by the microscope, the stretched Formbrite surface looks like this (at left, above). Its microstructure is shown 75x at the right. This uniform superfine-grain structure is produced by special procedures of rolling and annealing developed by The American Brass Company.

FORMBRITE is springier, harder, more scratch resistant than the usual drawing brasses in the same standard tempers. Yet it retains remarkable ductility for forming and drawing—even such deep-drawn products as pen barrels. And Formbrite costs no more than ordinary drawing brass, despite its superiority. Get full details from your Anaconda representative or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

6048

FORMBRITE®

Superfine-Grain Drawing Brass an

ANACONDA®

product made by The American Brass Company

hp 160B

Presented proudly

The hp 160B—a new 15 MC oscilloscope built to exacting MIL specifications; most versatile oscilloscope ever offered.

Here are some of the outstanding features:

New plug-in versatility

Horizontal plug-ins. New 166 series horizontal (time axis) plug-ins add a whole new dimension of flexibility to the basic oscilloscope. First two of the series are: ℌ **166C Display Scanner** making the 160B the world's first major scope with an *X-Y recorder output. This output covers the full scope bandwidth and makes possible large, high resolution, permanent X-Y records of repetitive waveforms.* ℌ **166D Sweep Delay Generator** establishing new convenience for conventional sweep delay measurements. A unique mixed sweep feature permits detailed analysis of one pulse in a wavetrain while retaining a display (on a slower time scale) of the entire wave preceding the pulse of interest. Thus, you view the exact pulse or segment desired while still retaining presentation of the earlier display. Extremely high magnifications are possible with appropriate settings of sweep controls.

Vertical amplifier plug-ins. New 162 series plug-ins will include new amplifiers permitting scope operation under many different input conditions. Typical plug-in is ℌ 162A Dual Trace Amplifier, 20 mv/cm unit permitting simultaneous viewing of two phenomena or differential amplification of signals dc to 14 MC.

Military quality

— Using premium components throughout, the 160B is designed to meet the highest standards of ruggedness, accuracy and dependability. It follows MIL-E-16400B for shock, vibration, humidity and temperature. Premium features include high stability tube-transistor circuits, regulated dc filament voltages, power transistors in efficient heat sinks, circuits on translucent epoxy-glass, simplified layout.

Easy to operate

— Model 160B control array is traditional and logical. No special training is required to operate the 160B. Your set-up time and measurements are simplified with improved *preset triggering* and an *automatic beam-finder*. The first means that one preset adjustment insures optimum triggering for almost all conditions (even signals down to 2 mm deflection). The second means that with the press of one button the beam is instantly located and "held" until you center your trace.

SPECIFICATIONS

SWEEP GENERATOR:
Internal Sweep: 24 ranges, 0.1 μsec/cm to 5 sec/cm; vernier to 15 sec/cm
Magnification: 7 ranges, to 0.02 μsec/cm
Triggering: 2 mm minimum, internal, power line or vertical input signal. External 0.5 v peak to peak
Trigger Point: Going voltage, −30 to +30 v
Sawtooth Output: −50 to +50 v
Gate Output: 50 v pulse

HORIZONTAL AMPLIFIER:
Bandwidth: dc to 1 MC
Sensitivity: 7 ranges, 0.1 v/cm to 10 v/cm; vernier to 25 v/cm
Input Impedance: 1 megohm, 30 pf shunt

CALIBRATOR:
Type: 1,000 cycle square wave, 1 μsec rise, decay time
Voltage: 9 ranges ± 3%, 0.2 mv to 100 v peak to peak
Current: 5 ma peak to peak, ± 3%

CATHODE RAY TUBE:
Type: 5AMP mono-accelerator, flat face, P1, P2, P7, P11 screen; 5,000 v accelerating potential
Deflection Sensitivity: 20 v approx.; intensity modulation 20 v pulse to blank
PRICE: ℌ 160B Oscilloscope, $1,850.00

ℌ 162A PLUG-IN AMPLIFIER

Sensitivity Range: (Each channel) 0.2 v/cm to 50 v/cm, 10 ranges; 0.02 v/cm to 20 v/cm. Accuracy ± 5%
Pass Band: Dc coupled, dc to 14 MC, 0.025 μsec rise time
Ac coupled, 2 cps to 14 MC
Differential Input: Both attenuators may be switched to one channel and adjusted separately. Common Mode Rejection at least 40 db at max sens.; at least 30 db with attenuators
PRICE: ℌ 162A Plug-In Amplifier, $350.00

Data subject to change without notice. Prices f.o.b. factory.

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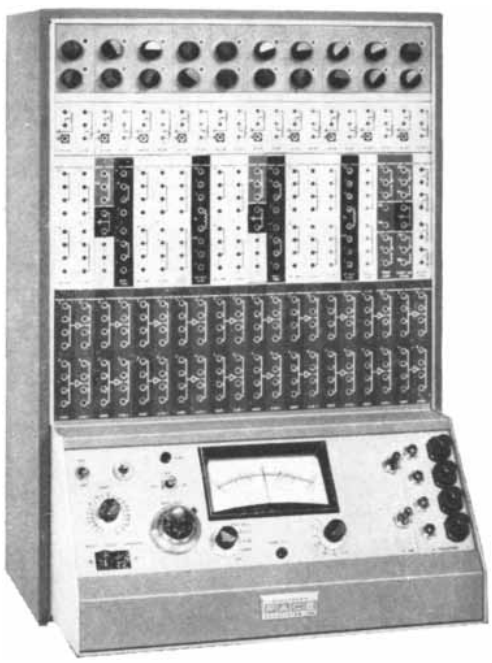
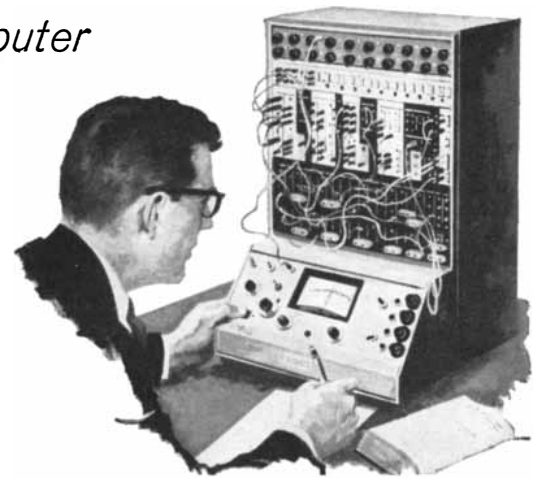
6038

EAI *Transistorized Analog Computer*

A WIDE RANGE OF SOLUTIONS AT DESIGN ENGINEERS' FINGERTIPS . . .

PACE® TR-10, the first all transistorized desktop analog computer, puts proven high-speed computation right where it's needed – on the desks of busy engineers. With this easy-to-use simulator, you can quickly solve many problems without waiting for scheduled access to large-computing systems. Though compact in size, the TR-10 is a full-fledged analog computer capable of providing solutions to a wide range of design problems. Up to 20 amplifiers, plus linear and non-linear computing components are contained in one compact cabinet with no external racks. The TR-10 permits rapid evaluation of different design approaches. It demonstrates the performance of a conceptual or drawing-board design prior to construction. Thus it saves time and money normally required for multiple test models with cut-and-try engineering.





Here's How The TR-10 Saves Engineering Time

The TR-10 is especially useful in solving problems in such diverse areas as servo-system design, heat flow, chemical reaction analyses, suspension systems studies and many other problems involving dynamic conditions. Fast answers to problems posed by new design ideas immediately determine feasibility of projects. With the TR-10, engineers can explore new ideas as they occur – concentrate valuable time on the most promising area of study.

(Applications notes are available describing typical problem solutions.)

How Do You Use The TR-10?

First—Represent in equation form the physical system to be studied.

Second—Select through a simple computer diagram the computing components required to perform the calculation (programming).

Third—Interconnect these components on the computer (problem patching) and set problem parameters with adjustable controls.

Fourth—Run the problem with results presented graphically on an accessory recorder or oscilloscope.

You now have an electronic analog *model* of the physical system under study. You can manipulate design parameters quickly, running comparative solutions without becoming involved in repeated calculations. With the TR-10 you can rapidly develop truly optimum designs.

For complete details of TR-10, write for free copy of Bulletin AC 934–AA.

PACE TR-10 Analog Computer, including components for addition, subtraction, multiplication, division, integration and generation of powers, roots, logs, antilogs and arbitrary functions.

EAI ELECTRONIC ASSOCIATES, INC. *Long Branch, New Jersey*

METALGRAMS

UNION CARBIDE METALS

. . . news about metals and metal chemicals

JUNE - JULY, 1960

99.97% Metallic Chromium -- Alert to the special problems of the alloy industry, UCM has developed a grade of chromium metal which contains very low carbon, nitrogen, and metallic impurities. Called ELCHROME LG, the product is especially well-suited for addition to alloys, such as some nickel- and cobalt-base alloys, which require minimum amounts of these impurities. ELCHROME LG is commercially available in flake and powder forms. Typical analysis of flake: 0.015% iron, 0.001% carbon, 0.001% nitrogen, 0.025% sulfur, 0.001% lead, and less than 0.01% copper. For additional data request CR2-S7.

* * *

Wear-Resistant Coating for Service up to 1800°F -- Union Carbide Metals' chromium carbide is being used in a wear-resistant coating developed by the Speedway Laboratories of Linde Company, Division of Union Carbide Corporation. Designated as LC-1A, the chromium-carbide-base coating is applied using Flame-Plating techniques. In one application, the coating is being evaluated for wear problems encountered in jet engines at service temperatures up to 1800°F.

Bulletin CC1-S7 gives data on chromium carbide. For information on LC-1A, contact Linde Company, Flame-Plating Sales Department, Indianapolis 24, Indiana.

* * *

Cold Reductions of More than 95% -- Excellent cold-working characteristics mean wider utility for vanadium metal in the form of thin strip or foil. In cold rolling 16-in. wide sheets reductions of more than 95% are possible without excessive work hardening. The need for intermediate process anneals is thereby decreased. Possible applications for vanadium strip and foil include X-ray tube parts, as well as several uses in the atomic energy field. Bulletin VM2-S7 gives general data on vanadium.

* * *

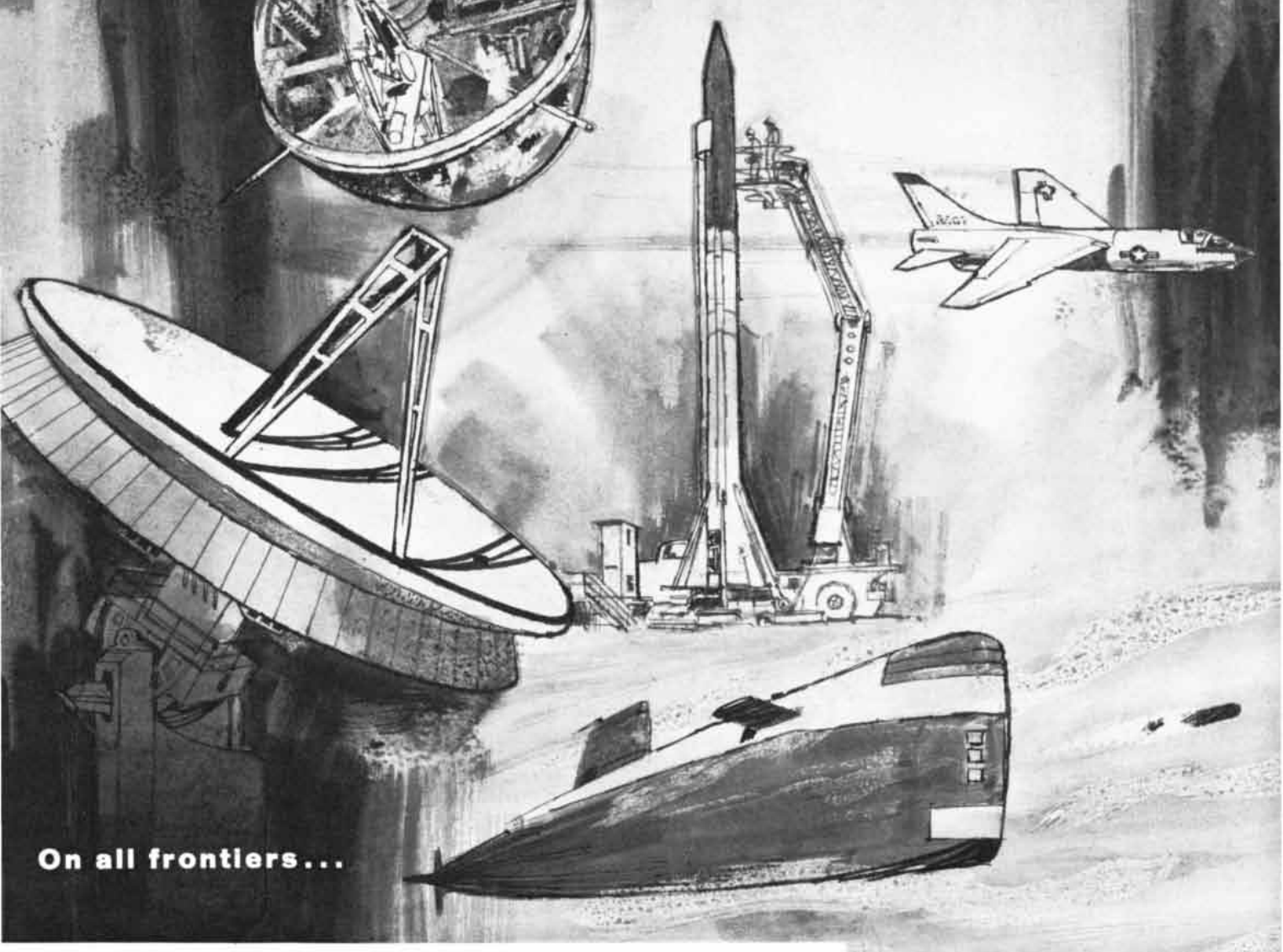
Columbium-Base Alloys in Nuclear Age Metallurgy -- Two new columbium-base alloys are suggested for possible nuclear reactor applications. These alloys contain additions of titanium and zirconium (Cb-65) or aluminum and vanadium (Cb-22). The alloy additions help achieve higher strength and better oxidation resistance than in pure columbium, while maintaining essentially the same low neutron cross section. Arrangements are being made whereby one or both of these alloys will be available in the near future for field testing. Request Bulletin CBA3-S7 for general information on columbium-base alloys Cb-22 and Cb-65.

* * *

New Uses for Aluminum Carbide -- Long known as a source material for methane gas, aluminum carbide is finding newer uses as a chemical intermediate and catalyst. It is now employed, for example, as a catalyst in the manufacture of terephthalic acid. Research has also been done on aluminum carbide as the starting material for new organic chemical syntheses. And in radiochemistry, it can be used to prepare tritinated methane for measurement of tritium. UCM supplies aluminum carbide in development quantities, 1 in. by D. Data sheet ALC1-S7 gives properties and analysis.

* * *

Union Carbide Metals Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Limited, Toronto.



Philco pioneers in advanced electronics...

In space and in the air, on land, on sea, and in the ocean depths—wherever advanced electronics plays its part—you will find dramatic proof of Philco leadership in technology, capacity and versatility. For here is an organization fully staffed and fully equipped to pioneer and contribute in every phase of the art . . . to solve the most complex problems . . . to create totally new devices . . . to manufacture the finest electronic products and systems.

Philco leadership in the field of advanced electronics is recognized throughout the world. And Philco stands ready to serve. Look to the leader . . . look to Philco.

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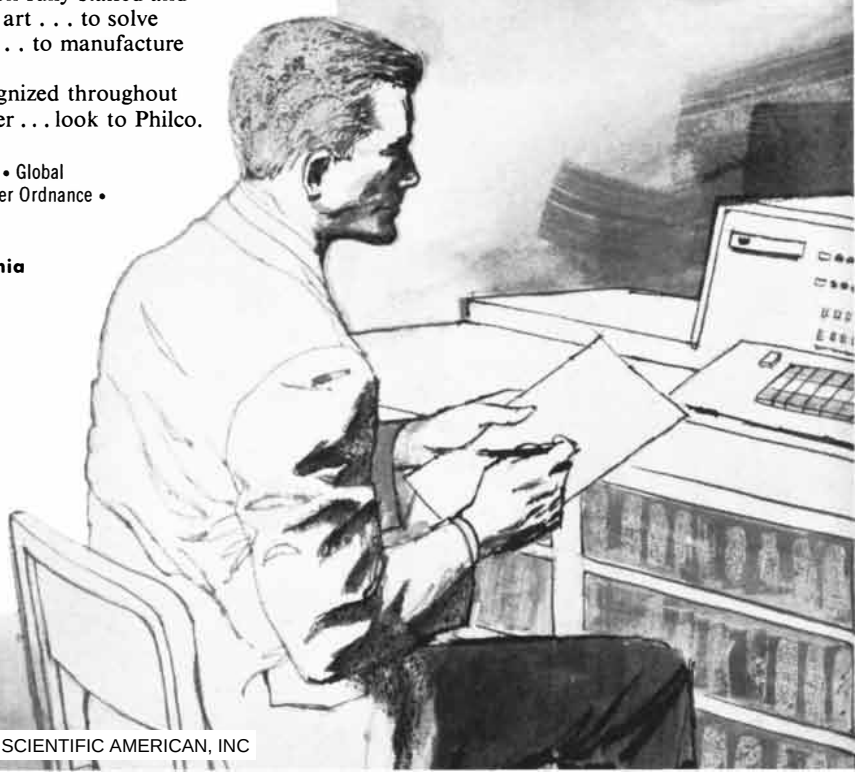
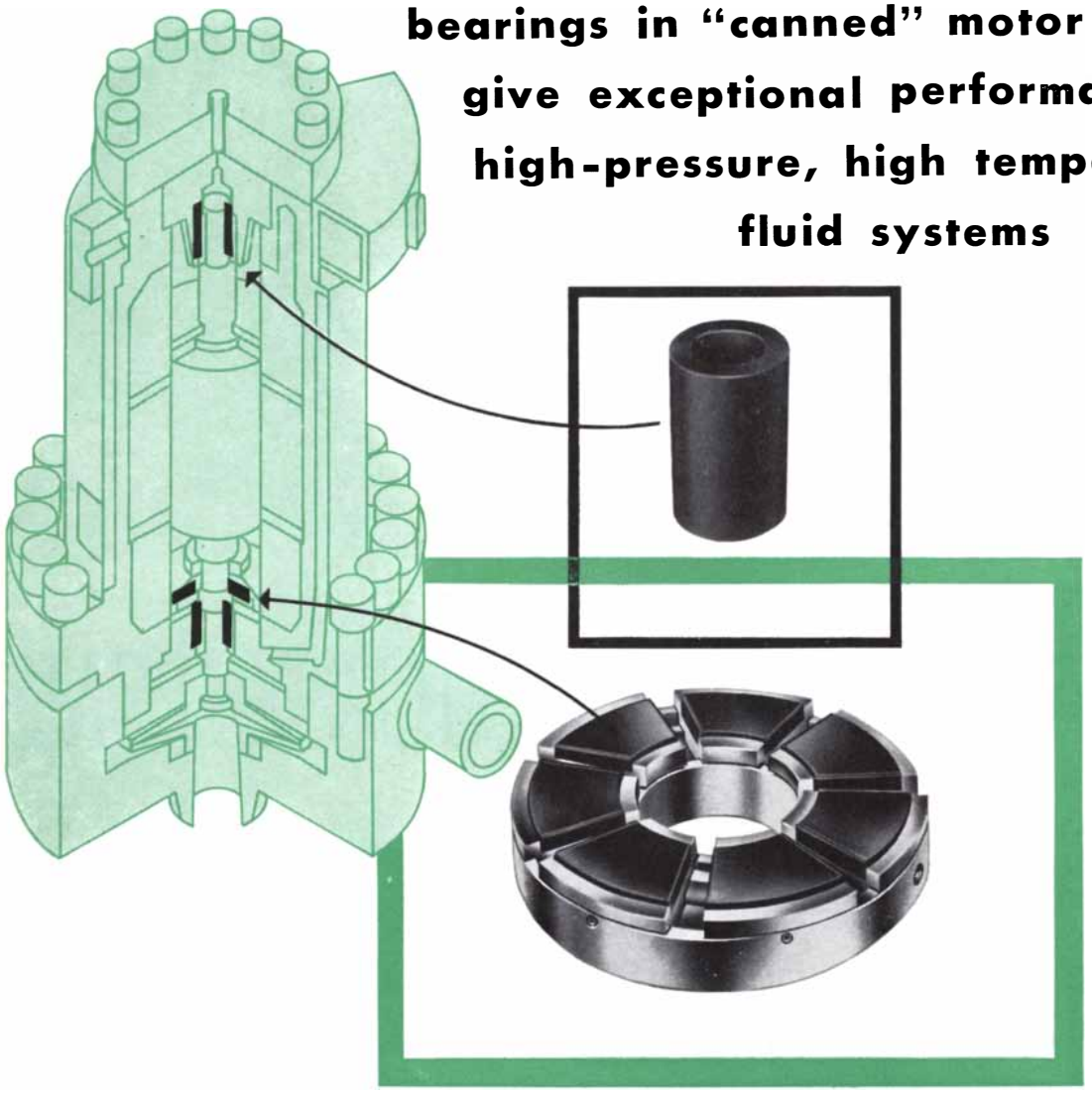
PHILCO

Famous for Quality the World Over



water-lubricated GRAPHITAR®
(CARBON-GRAPHITE)

bearings in "canned" motor pumps give exceptional performance in high-pressure, high temperature fluid systems



Special hermetically sealed motor-pumps, known also as "canned" motor pumps, were developed by Westinghouse Electric Corporation to handle radioactive water with zero leakage. These same pumps have proven a convenient means of pumping high temperature fluids for a number of nuclear reactors and other high pressure, high temperature fluid applications.

The thrust bearing utilized in the "canned" motor pump is a self-equalizing, water-lubricated, pivoted-pad bearing with inserted GRAPHITAR bearing surfaces. The radial sleeve bearings are also made of GRAPHITAR and are designed to be lubricated by the pumped fluid only . . . in the case of pumps used in nuclear reactors, only radioactive hot water is employed as lubrication.

GRAPHITAR is utilized extensively in tough applications because of its many unusual properties. It is non-metallic, resists chemical attack, has self-lubricating properties, a low coefficient of friction, is mechanically strong, hard as steel and lighter than magnesium. GRAPHITAR will not warp and shows no expansion or contraction in extreme temperature changes.

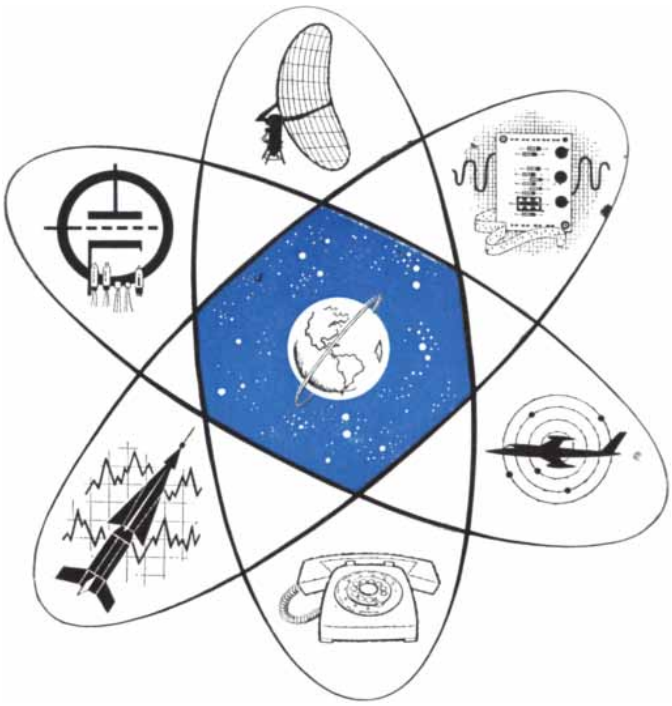
This versatile engineering material, GRAPHITAR, may well solve one of your difficult design problems. For further information on GRAPHITAR and its many applications, send for our engineering manual No. 20.

R-266-1

THE UNITED STATES GRAPHITE COMPANY

DIVISION OF THE WICKES CORPORATION, SAGINAW 6, MICHIGAN

GRAPHITAR® CARBON-GRAPHITE • GRAMIX® POWDER METALLURGY • MEXICAN® GRAPHITE PRODUCTS • USG® BRUSHES



This is

SYLVANIA ELECTRONIC SYSTEMS

now serving as Government systems managers for all subsidiaries of General Telephone & Electronics Corporation

Offering single source capabilities for integrated Communications—Data Processing—Electronic Display Systems

Now Sylvania—long experienced in the field of defense systems research, development and production—offers this far more comprehensive yet unified source of systems management and capability. Systems-oriented in concept and personnel, Sylvania Electronic Systems now integrates under one direction all the skills and facilities of one of the world's leaders in communications and electronics—General Telephone & Electronics, and its subsidiaries, including:

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HOW SYLVANIA ELECTRONIC SYSTEMS BENEFITS YOU: Sylvania Electronic Systems makes it possible to obtain complete defense systems of the highest quality, of specified performance, delivered on schedule at competitive costs. When you work with Sylvania Electronic Systems you enjoy the many advantages of:

One-Source Procurement • One-Source Authority and Responsibility
Quick-Reaction Capability • Efficiency • Financial Accountability • Experience

Communications Systems

SYLVANIA ELECTRONIC SYSTEMS offers skills and experience covering the complete electromagnetic spectrum in the media of air, space, water, ground. This integrated systems group includes the capabilities of the 32 domestic and international telephone operating companies in the General System. This group offers the most advanced equipment and development capabilities in dial telephone systems, automatic electromechanical and electronic switching systems, central office and terminal equipment, toll and exchange voice, telegraph, and data carrier transmission systems for wire, cable and radio applications, microwave relay and mobile radio systems and advanced low detectability and secure communications systems.

Data Processing and Display Systems

Sylvania leadership in digital data processing is typified by its most recent achievement: design and development of MOBIDIC. This solid state, mobile computer will give field armies real-time solutions to many intelligence and reconnaissance problems, almost instantaneous answers to operational problems involving logistics, inventory control, etc. Sylvania has also pioneered in developing electronically driven electroluminescent display equipments and systems. SYLVANIA ELECTRONIC SYSTEMS has subsystem management and development responsibility for the data processing portion of the Air Force BMEWS program, including new and advanced concepts of 3-dimensional data take-off circuitry and equipment.

Detection and Tracking Systems

SYLVANIA ELECTRONIC SYSTEMS has an advanced capability in high resolution, electronically scanned radar. Example: Sylvania has management and development responsibility for the Army's AN/MPQ-32, a mobile artillery detection, tracking and fire control system.

Intelligence and Reconnaissance Systems

In recent years, Sylvania has developed numerous types of broadband receivers, signal analyzers, and sensing devices across the entire spectrum. Advanced anti-intrusion devices are now under development. In addition, Sylvania is developing and managing several other highly classified programs in this area.

Electronic Warfare Systems

Sylvania leadership in electronic warfare is typified by its advances in countermeasures and counter-countermeasures against all known types of electromagnetic radiation. Sylvania manages the passive defense system for the B-58, and maintains a quick-reaction capability and facility for Army ground-based electronic warfare activities.

FOR FULL INFORMATION on how Sylvania Electronic Systems might be of special service to you, please call or write Sylvania Electronic Systems, a Division of Sylvania Electric Products Inc., Waltham, Massachusetts.

SYLVANIA **ELECTRONIC SYSTEMS**
Government Systems Management
for **GENERAL TELEPHONE & ELECTRONICS**

GENERAL SYSTEM

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JUNE, 1910: "The action of Congress in passing a bill making a preliminary appropriation for the work of raising the wreck of the *Maine* is for several reasons highly commendable. Chief among these is the opportunity to give decent burial to the unfortunate men who were carried down in the wreck of the ship and have remained entombed for the past 12 years. Second are those which affect the sensibilities and honor of a European power with whom we are at present, and hope ever to be, on terms of friendly understanding; for it is a fact that the Spanish Government felt very keenly the implication that the destruction of the *Maine* was brought about by Spanish agency. The raising of the *Maine* will be well worth all the trouble and cost if it brings to light clear evidence that the explosion was due to internal causes, that is to say, to the spontaneous and therefore accidental combustion of the explosives contained in the forward magazines."

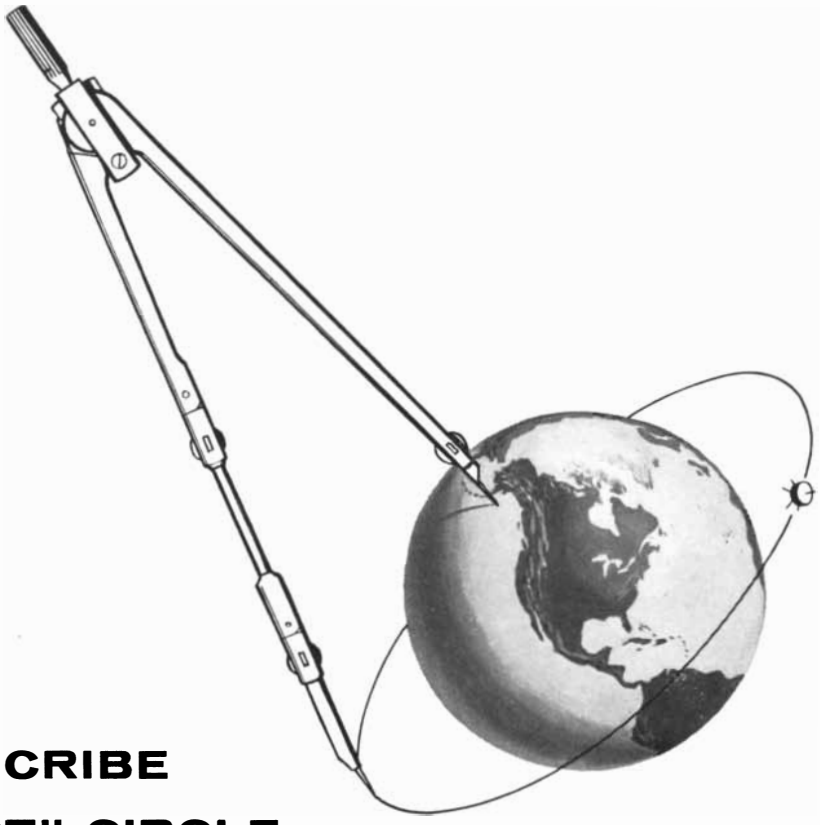
"Prof. Fritz Haber claims to have solved the problem of the direct synthesis of ammonia from its elements, nitrogen and hydrogen. If the process is as practical and economical as its inventor claims, its introduction will quickly cause a revolution in a comparatively new but already important branch of industry: the manufacture of artificial nitrates. Prof. Haber states that the combination of hydrogen and nitrogen is effected at a temperature of about 1,000 deg. F., and a pressure of 200 atmospheres. The presence of a catalyzer is required to accelerate the combination. For this purpose Prof. Haber employs uranium, but the rarity of this element appears incompatible with its employment on a commercial scale."

"A spur to the development of the art of flying has been afforded by the phenomenal achievement of Glenn H. Curtiss in making his recent flight from Albany to New York at the unprecedented speed of over 50 miles an hour. Apart from the fact that so great a distance was covered at so high a speed, there are other considerations which largely account for the powerful hold which this flight has taken upon the public imagination; such, for instance, as the altogether untried nature of the course, the almost complete absence of suitable landing places and the absolute composure with which, when an emergency landing had to be made, the aviator circled in his path, and swooped down, birdlike, upon a small open clearing above the rocky cliffs. When the news of his accomplishment was flashed throughout the country, its effect was positively electric. The last doubt as to the practicability of long-distance, cross-country flying vanished."

"Dr. Robert Koch, the father of preventive medicine, died on May 27th. Lister and Pasteur developed the germ theory of disease; Koch made of this theory the science of bacteriology. Pasteur declared it to be within human power to banish all parasitic diseases from the face of the earth; Koch clearly demonstrated how this business was to be gone about. In 1882 came his truly epochal isolation of the tubercle bacillus, the essential cause of tuberculosis. Upon this foundation preventive measures were intelligently formulated. Koch elaborated various tuberculins diagnostic of tuberculosis; their curative properties have proved disappointing, yet they were the basis of the wonderfully effective antitoxins of diphtheria, tetanus, meningitis, pneumonia and other dreadful infections. And Koch's achievements in tuberculosis were only a part of his service to mankind. In 1883 he discovered the cholera bacillus, which is responsible for the disease. In the investigation of other world scourges—cancer, bubonic plague, blood poisoning, trypanosomiasis cattle plague, anthrax, malaria—Koch's part has been most vital, either as discoverer or as originator or developer of prophylaxis and curative methods."

"Prof. E. E. Barnard informs us that on June 6th he obtained a very good photograph of Halley's comet. The plate showed the tail drifting off into space, and a new one forming in a different direction."

"In dissolving the injunction granted in favor of the Wright brothers against Curtiss by Judge Hazel, and the similar injunction granted by Judge Hand against Louis Paulhan, the Circuit Court of Appeals has followed a long-established precedent in patent law. Rarely is infringement so clearly established that



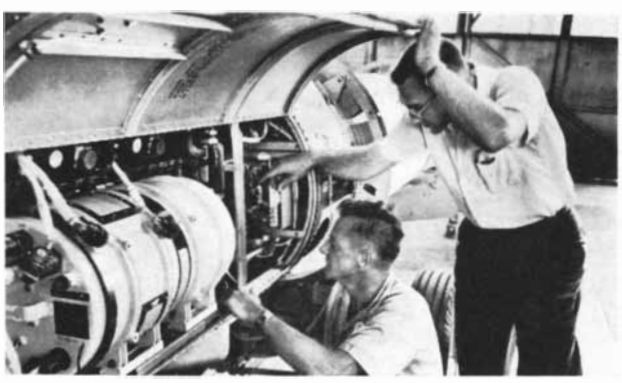
HOW TO SCRIBE A "PERFECT" CIRCLE IN OUTER SPACE

Bell Laboratories guidance system achieves unprecedented accuracy in steering Tiros weather satellite into orbit

Equipped with TV cameras, tape recorders, solar cells and antennas, the world's most advanced weather satellite, the NASA Tiros I, had to be placed in a precisely circular orbit at a specified altitude to do its job well.

The "shot" was a virtual bull's-eye. The mean altitude was within *one mile* of that planned. And the deviation from this mean was less than ½ per cent, making it the most-nearly-perfect circular orbit ever achieved with a space vehicle by either the United States or Russia.

Two Bell Laboratories engineers, T. J. Grieser and D. R. Hagner, look over the second-stage section of the Air Force Thor-Able missile used to launch the NASA Tiros weather satellite.



The dependability and accuracy of Bell Laboratories' ground-controlled Command Guidance System has been proven before—in the successful test flights of the Air Force Titan intercontinental ballistic missile, and in last year's Air Force Thor-Able re-entry test shots from which the first nose-cone recoveries were made at ICBM distance. Now, with Tiros, the system contributes to a dramatic *non*-military project. Other uses are in the offing.

This achievement in precise guidance again illustrates the versatility of Bell Laboratories' research and development capabilities—directed primarily toward improving your Bell Telephone service.

BELL TELEPHONE LABORATORIES

World center of communications research and development

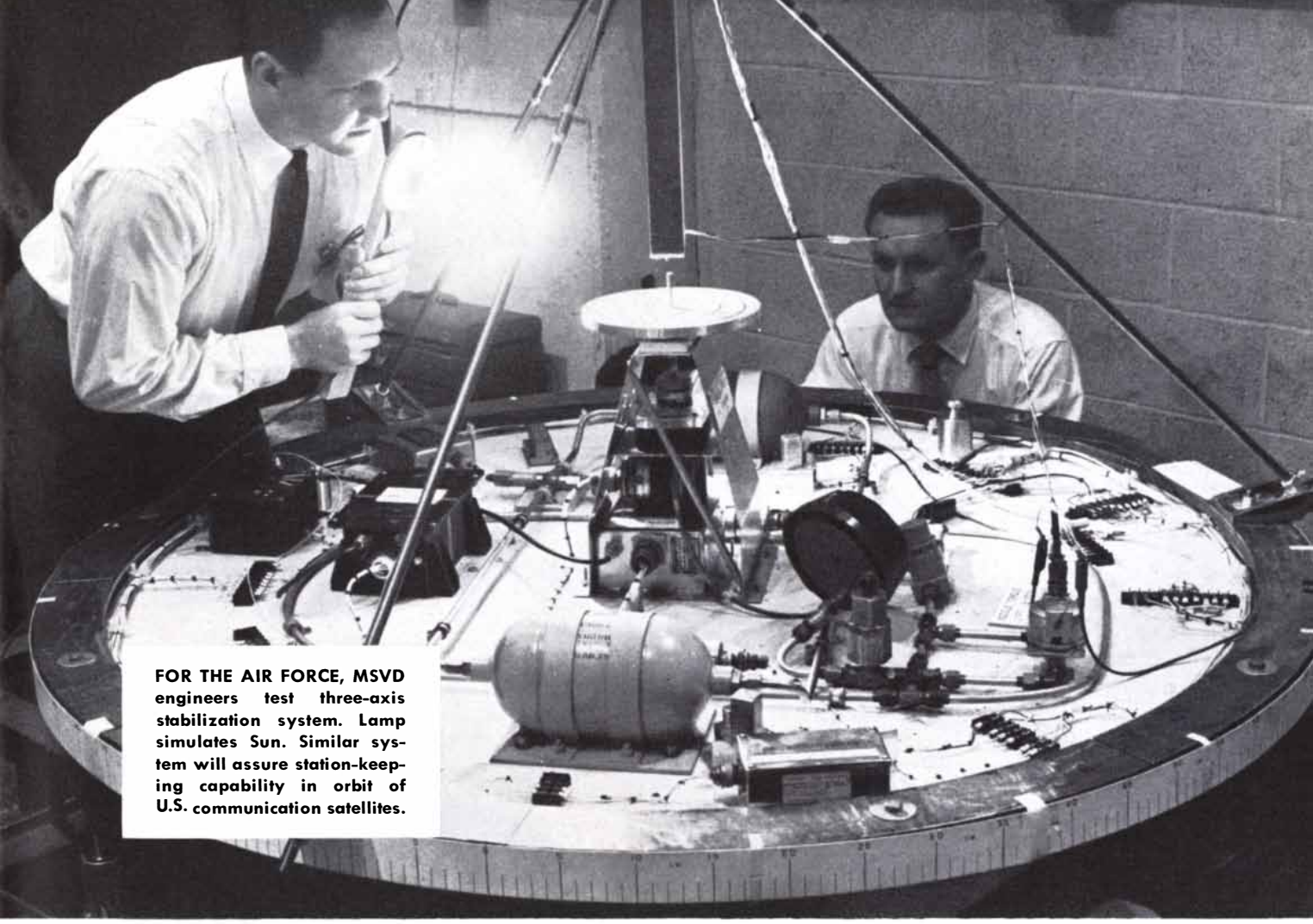
a court is justified in restraining the manufacture and use of an invention before the question of patent validity is decided. As a result of the interlocutory decrees of Judges Hand and Hazel the Wright brothers have controlled flying in this country for the last six months. Unless he filed a bond with the court, no aviator who used a machine equipped with ailerons, or wing-warping devices, operated in conjunction with a vertical rudder could make, sell, or fly his apparatus in this country. With the reversal of the decision of the lower court by the Circuit Court of Appeals, the development of aviation in this country is now unhampered."

Scientific American.

JUNE, 1860: "The population of the world is now estimated at 1,279,000,000, viz.: Asia, 755,000,000; Europe, 272,000,000; Africa, 200,000,000; America, 50,000,000; Australia, 2,000,000."

"The Suez Canal, to unite the Red Sea with the Mediterranean, has been commenced at Port Said, where two large moles, running out nearly a mile into the sea, are being constructed. About 1,700 European workmen and several thousand natives are employed on the works."

"The advent of the Japanese Embassy, and the interest in this but partially known people, has induced us to give some account of their achievements in the agricultural and mechanical departments. Being compelled to make the most of their not very extensive and rather poor soil, they have arrived at a very high state of perfection in the arts of agriculture. Where the land is inaccessible to the plow, it is cultivated by manual labor. Like the Chinese, they pay great attention to manuring and to irrigation. The short time the Embassy has already been with us shows how eager they are to profit by the experience of foreigners, and to imitate their useful arts. The inhabitants of Japan are already supplied with microscopes, telescopes, clocks, watches, knives, spoons, &c., made by themselves from European models. They manufacture Colt revolvers and Sharps rifles, and it is said that they have made improvements upon them. At Nagasaki works have been erected for the manufacture of steam-engines without European assistance."



FOR THE AIR FORCE, MSVD engineers test three-axis stabilization system. Lamp simulates Sun. Similar system will assure station-keeping capability in orbit of U.S. communication satellites.

MISSILE AND SPACE VEHICLE DEPARTMENT

...center for missile and space technology research and development at General Electric

Progress in space vehicle navigation

As space vehicles probe further and further away from the Earth, and as their missions become more and more complex, the need for accurate, high-precision space navigation and control becomes increasingly vital.

General Electric Missile and Space Vehicle Department engineers are now developing and testing space vehicle control equipment for the 24-hour-orbit communication satellite program. They have already designed and flight-tested on space vehicles a three-axis stabilization system as well as orbit computation and correction techniques. Using the Earth and Sun as reference points, this MSVD three-axis system successfully controlled the attitude in space of U.S.A.F. *Atlas* and *Thor* re-entry vehicles during a major portion of their ballistic flights. The control accuracy attained on these flights could be duplicated on flights further into space, using other planets and stars as check-points.

For more information about MSVD's space navigation and control work for the Air Force and its other contributions to U.S. space technology progress, write to Section 160–73A, General Electric Missile and Space Vehicle Department, Philadelphia 4, Pennsylvania.

GENERAL ELECTRIC

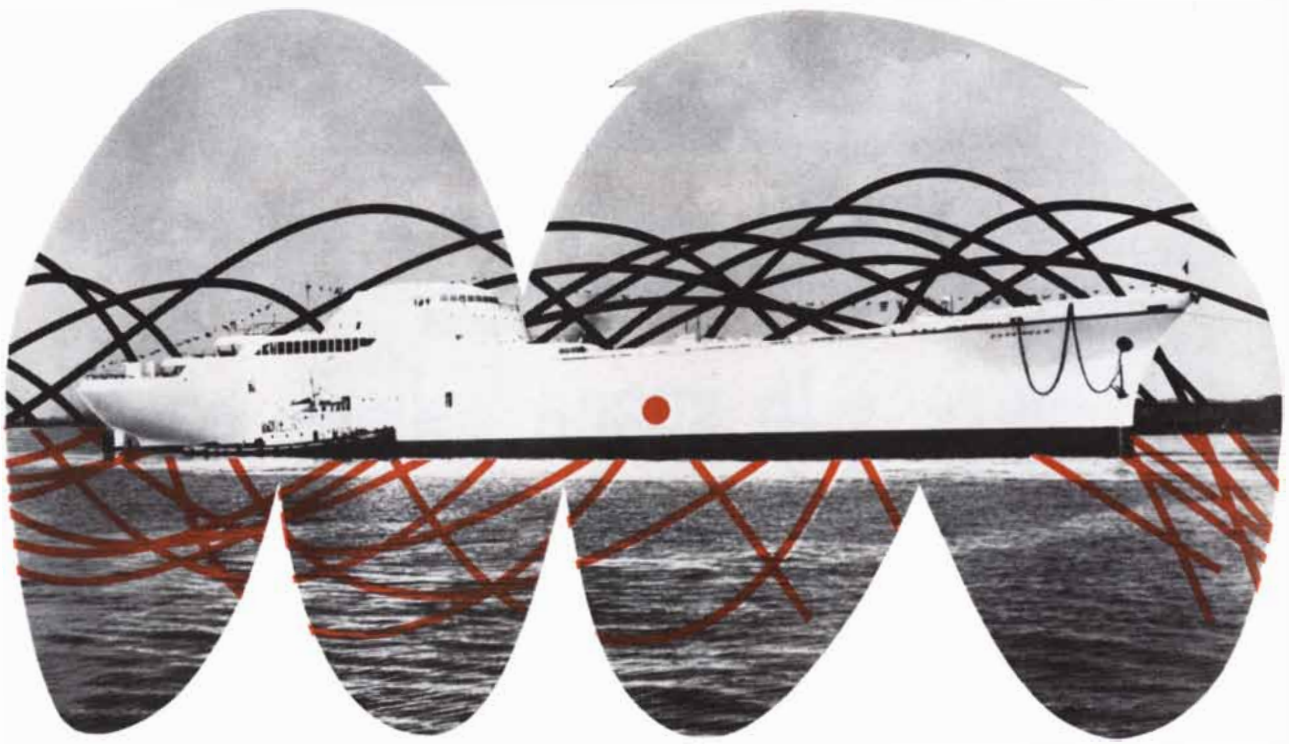
MISSILE AND SPACE VEHICLE DEPARTMENT

A Department of the Defense Electronics Division

Scientists and Engineers interested in career opportunities in Space Technology, contact Mr. T. H. Sebring, MSVD

For the Babcock & Wilcox Company:

a Burroughs 205 computer backed the
team that introduced
atomic power to the merchant fleet...



another Burroughs computer is helping build one of the world's largest steam boilers...

and still another is speeding a vast research and development program

History has already earmarked July 21, 1959, in remembrance of launching the N. S. Savannah—the world's first nuclear merchant ship. This graceful queen of the seas may well be the precursor of a vast atomic merchant fleet—ships operating quietly and efficiently on nuclear engines.

Yet months before touching water, the Savannah's nuclear propulsion system was obtaining hundreds of "trial runs" on a Burroughs 205 computer at The Babcock & Wilcox Company's Atomic Energy Division in Lynchburg, Virginia.

Long before the vessel was launched these computer runs predicted changes that were to take place in the heart of the nuclear reactor. With the aid of these data, decisions were made as to the optimum size of the reactor, the lifetime of the fuel elements, amount of fuel needed, approximate costs and myriad other specifications.

Of course, a simulated run could have been made with a desk calculator—but it would have taken one year to complete a single run. The 205 has completed the same job in just a few hours.

This is the latest installment in a success story that started in November, 1955—the installation date of the Burroughs 205 at the Atomic Energy Division. Aside from the N. S. Savannah project, the same computer contributed immeasurably to other reactor designs, and other engineering work involving stress and thermal calculations, plus cost accounting data processing.

A recognized pioneer in the application of electronic data processing equipment, B&W was one of the first companies to develop its own automatic programming system. The effect of this powerful programming aid—called DUMBO—is to extend the capabilities of the 205 to hundreds of engineers without special knowledge of computer characteristics and techniques.

B&W engineers at Lynchburg are now able to write a plan for the computer to follow; DUMBO then automatically translates the plan into 205 language for electronic data processing.

With valuable 205 experience on design problems of a different nature, B&W's Boiler division (at Barberton, Ohio) has now installed a larger Burroughs 220 computer system to handle its increasing activities. Now in the design stage, with the aid of the 220, is one of the largest steam boilers ever conceived. When finally erected, the new steam boiler will stand as high as a 22-story skyscraper, produce 4,900,000 pounds of steam per hour, and generate sufficient power to light a city of 5,000,000 population.

Whether designing mammoth power equipment or a small industrial boiler, the Burroughs 220 has become a vital tool from initial bid through final design. The Burroughs 220 is helping to win orders with fast-but-realistic proposals, slashing costs and lead time at every possible opportunity.

B&W, whose product range includes tubular products, refractories, and marine boilers, as well as stationary steam generators, is also spearheading the development and construction of nuclear stationary and marine propulsion power plants. In all these programs, B&W depends upon the most modern analytical processing equipment.

At the company's Research and Development Center based in Alliance, Ohio, a third Burroughs computer has recently gone "on the air." This Burroughs 205 was purchased to process data for a variety of research experiments in the fields of heat transfer, fluid flow, stress analysis, and thermodynamics. Its immediate impact has been to free creative engineering talent from routine calculations and to reapply valuable human resources to the pursuit of new sources of economical energy. This 205 has already developed research data otherwise inaccessible.

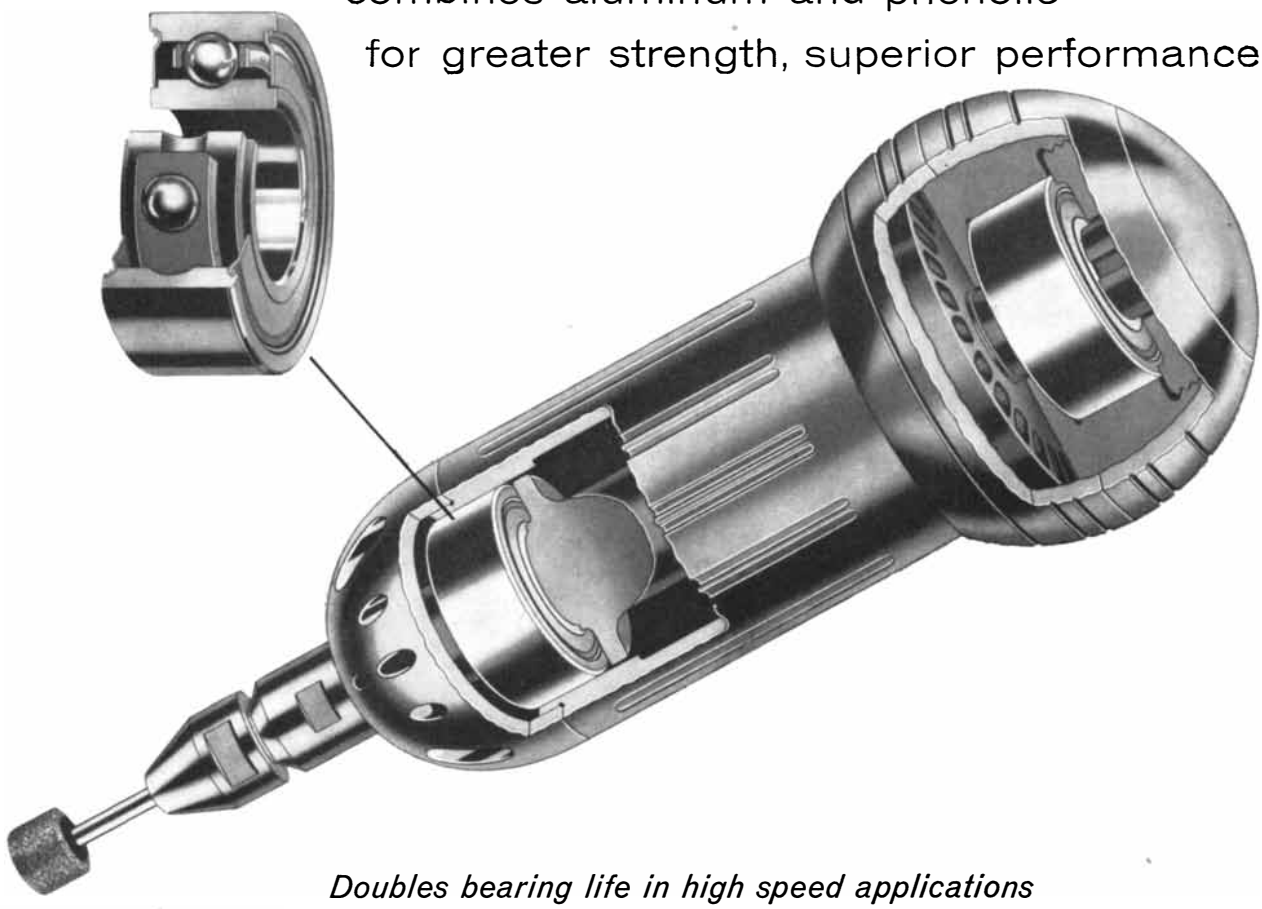
All three Burroughs computers are helping B&W to meet a wide range of the nation's power requirements in the most efficient and economical way possible. Hundreds of other industrial and commercial users are confirming similar experiences.

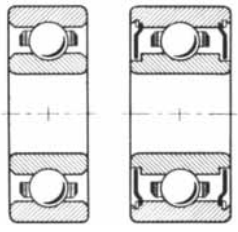
Burroughs' complete line of electronic data processing equipment is backed by a coast-to-coast team of computer specialists, able to advise on how Burroughs can help you in your business. For additional information, write General Manager, Data Processing Systems Group, Detroit, Michigan.

Burroughs Corporation

"NEW DIMENSIONS/in electronics and data processing systems"

BARDEN "T" retainer combines aluminum and phenolic for greater strength, superior performance





"T" retainer bearings are available in chrome or stainless steel, open or shielded, from .5000" O.D. to 3.3465" O.D. in standard widths. Also available: extra-wide shielded sizes with increased lubricant space for still longer life. For complete technical information write for Engineering Data Sheet T-1.

Doubles bearing life in high speed applications

Power tools, gyro rotors, aircraft and missile accessories and other high speed applications require bearings that combine high load capacity and endurance at speed. To meet these exacting demands, Barden developed the "T" ball retainer which combines the advantages of phenolic with the strength of aluminum.

The two-piece "T" retainer has laminated phenolic center sections bonded to high-strength aluminum alloy side plates. It is securely joined by body-bound rivets tightly headed against metal at both ends. The retainer's thin cross section permits maximum exposure of balls and raceways to lubricant. Outer ring piloting provides optimum lubricant circulation.

These features, together with high load capacity, result in longer, trouble-free bearing life. For example, double shielded, grease lubricated "T" retainer bearings have operated continuously in textile spindles for more than 18,000 hours at 30,000 RPM.

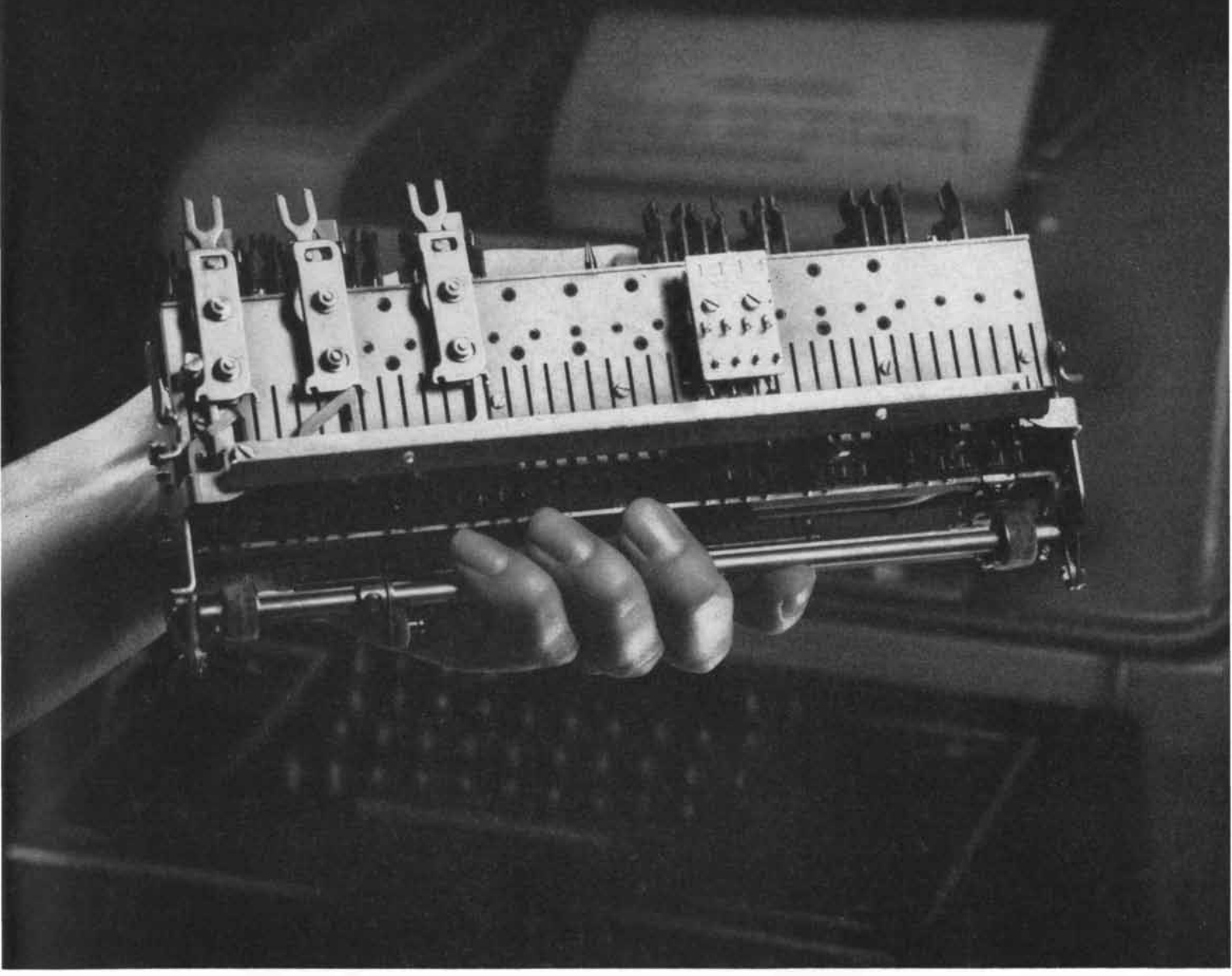
Like other Barden advances in engineering and manufacturing, "T" retainer bearings solve a specific performance problem. Other Barden Precision ball bearings satisfy such extreme demands as:

- High temperatures (to above 400° F.)
- High speeds (to over 300,000 RPM)
- Low torque (to 10 dyne-cm. for 2 lb. load)
- Concentric rotation (to .00005" max. T.I.R.)

The complete Barden line includes sizes from .0469" bore to over 3" O.D., all manufactured to Barden Precision standards of dimensional accuracy, uniformity and reliability. Refer to Sweet's Product Design File (8h/Ba) for Barden catalog and bearing selection guide.

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

THE BARDEN CORPORATION, 216 Park Avenue, Danbury, Connecticut
Western office: 3850 Wilshire Boulevard, Los Angeles 5, California



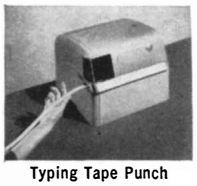
Stunt Box—your Big Plus with Teletype printers

Built into Teletype Model 28 page printers is a control device called the Stunt Box. The function of this unique component is to provide extra control facilities for both local and remote operations. Thus—in addition to transmitting, receiving and recording messages and data—the page printer can be used for a variety of switching, remote control and selective calling tasks.

The Stunt Box reduces costs by simplifying equipment needs and systems arrangements. It is the Big Plus—the extra value in Teletype Model 28 page printers and automatic send-receive sets.

Teletype Corporation manufactures this equipment for the Bell System and others who require the finest in data communications equipment.

Write for free 20-page brochure, "The Teletype 28 Stunt Box," to Teletype Corporation, Dept. 18F, 4100 Fullerton Avenue, Chicago 39, Ill.



Typing Tape Punch

Tape Reader

Send-Receive Page Printer

Automatic Send-Receive Set

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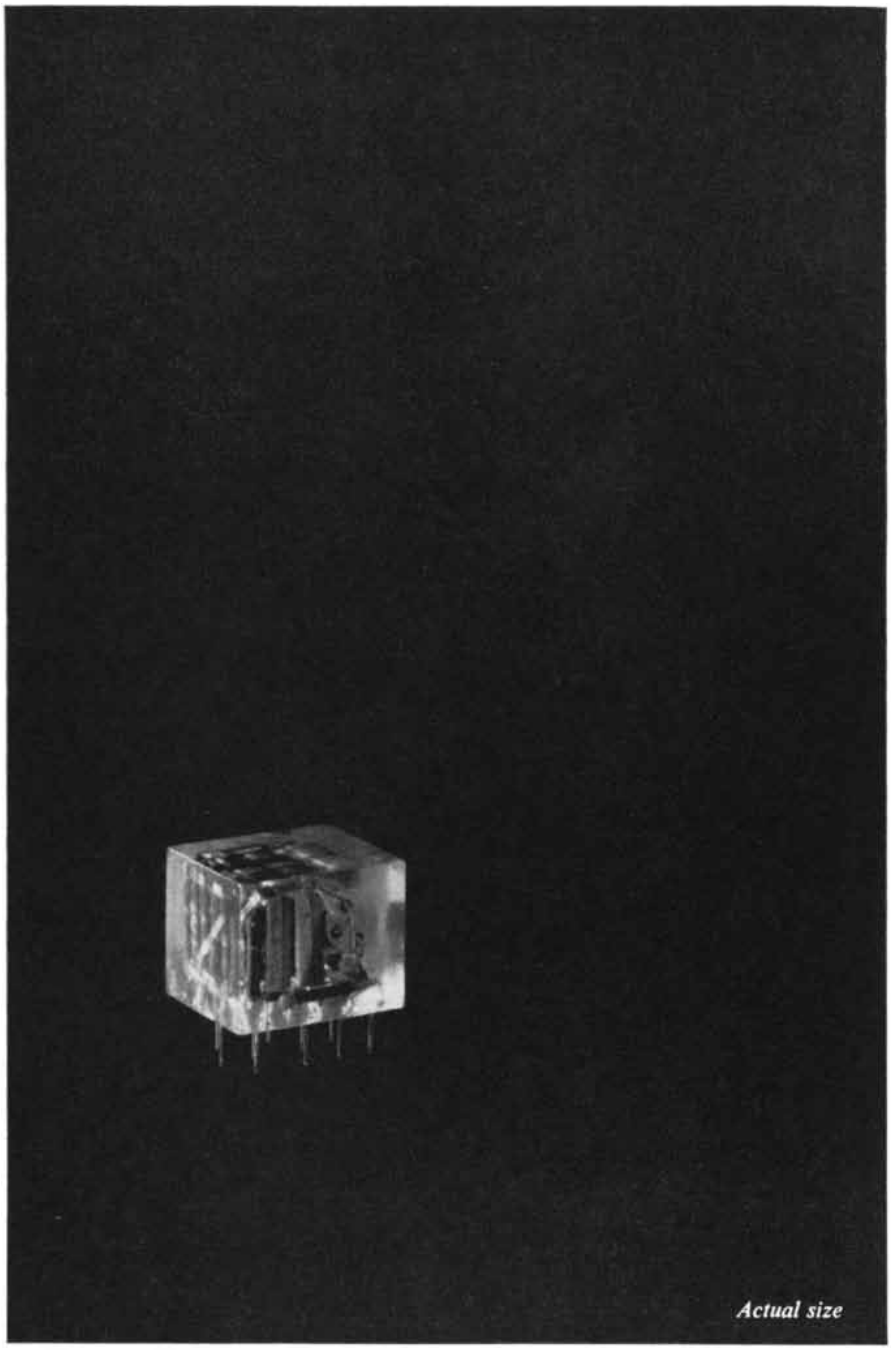


FROM DELCO RADIO NEW IDEAS FOR DEFENSE

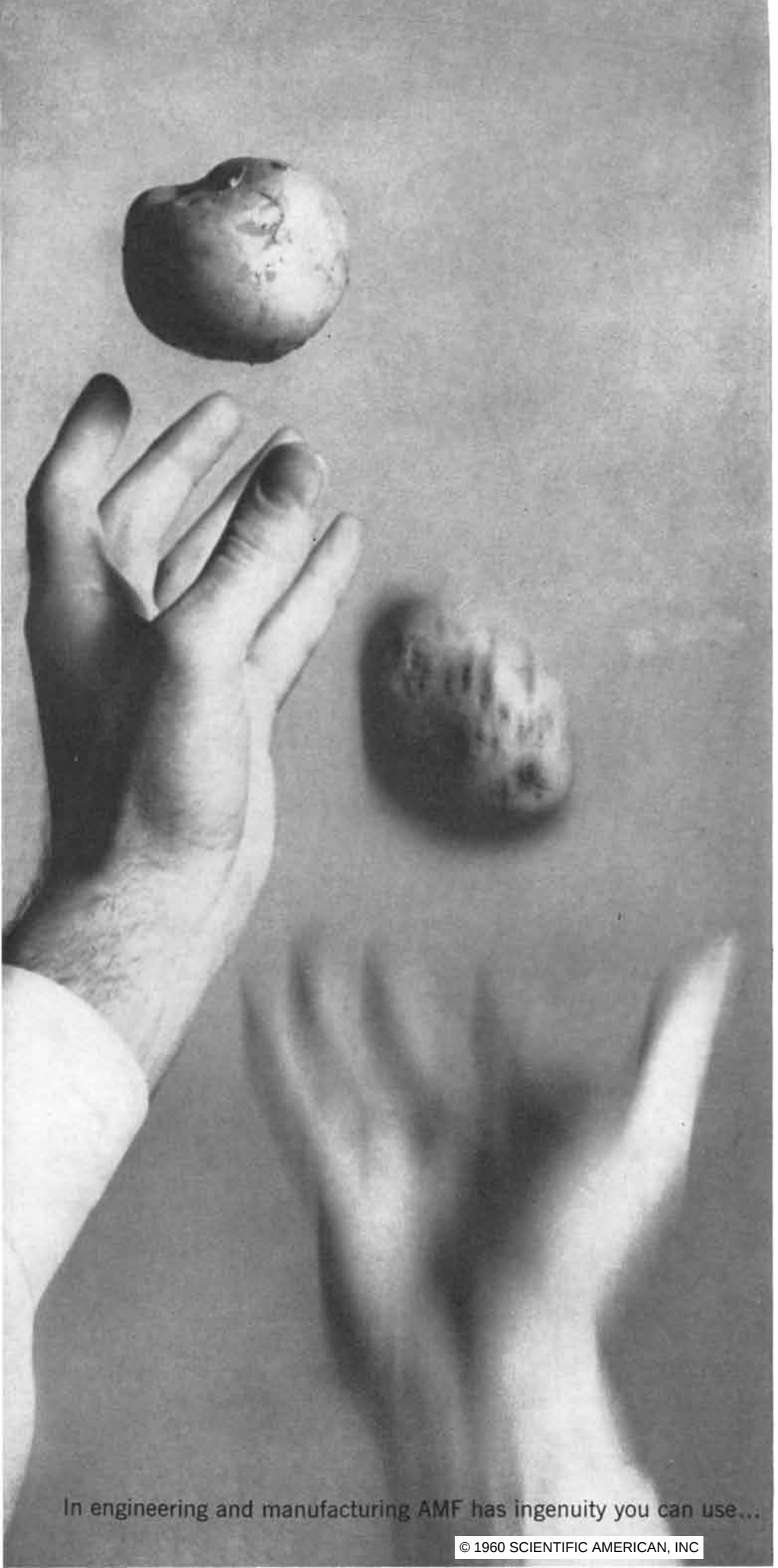
MINIATURE MODULES WITH STANDARD COMPONENTS

They are *building block modules*. They are a product of Delco Radio's newly developed, three-dimensional packaging technique. They are used to build light, compact, reliable airborne and special purpose digital computers for missile control. Each module, vacuum encapsulated with epoxy resin, contains up to 35 standard components per cubic inch—averaging more than 50,000 per cubic foot. The modules perform all the standard logic functions. They meet or exceed all MIL-E-5272D (ASG) environmental requirements and will operate over a temperature range of −55°C to +71°C. They can be assembled in groups on printed circuit boards. There are 10 basic types and 15 variations of Delco Building Block Modules. With them, Delco Radio can quickly and easily build a compact, reliable computer for airborne guidance or any other military application. For complete details, write to our Sales Department. *Physicists and electronic engineers: Join Delco Radio's search for new and better products through Solid State Physics.*

PIONEERING PRECISION PRODUCTS THROUGH SOLID STATE PHYSICS

DELCO RADIO
DEPENDABILITY
RELIABILITY

Division of General Motors • Kokomo, Indiana



He juggled the hottest potatoes in the Seawolf

...the fuel elements for its nuclear power plant.

Periodically, spent elements must be removed and replaced with fresh ones. The problem—utterly original and fiendishly difficult—was to do the job safely, quickly, and, above all, surely.

This AMF engineer designed the refueling system that did the job. One of his major problems was the fuel elements' liquid sodium environment. Sodium burns fiercely when brought in contact with either air or water. Yet, it had to be exposed during element transfer. Solution: an inert helium blanket to isolate the sodium.

Though awesomely intricate, the refueling machinery had to be designed to work in cramped quarters. The high radioactivity of the environment made the handling problem still more difficult.

That's why, though remotely controlled, all apparatus is *manually* operated. It removes the element and transfers it to a disposal container with complete safety, accuracy, and a degree of reliability that approaches the supernatural.

Single Command Concept

The solution of this first-time-in-history problem is one more example of AMF's resourcefulness.

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

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

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AMF

In engineering and manufacturing AMF has ingenuity you can use...

AMERICAN MACHINE & FOUNDRY COMPANY

"Music's most glorious voice"...perfected by Hammond Organ Company

Where no metal but Palladium

In any keyboard musical instrument easy operation and precise response to the artist's "touch" is all-important.

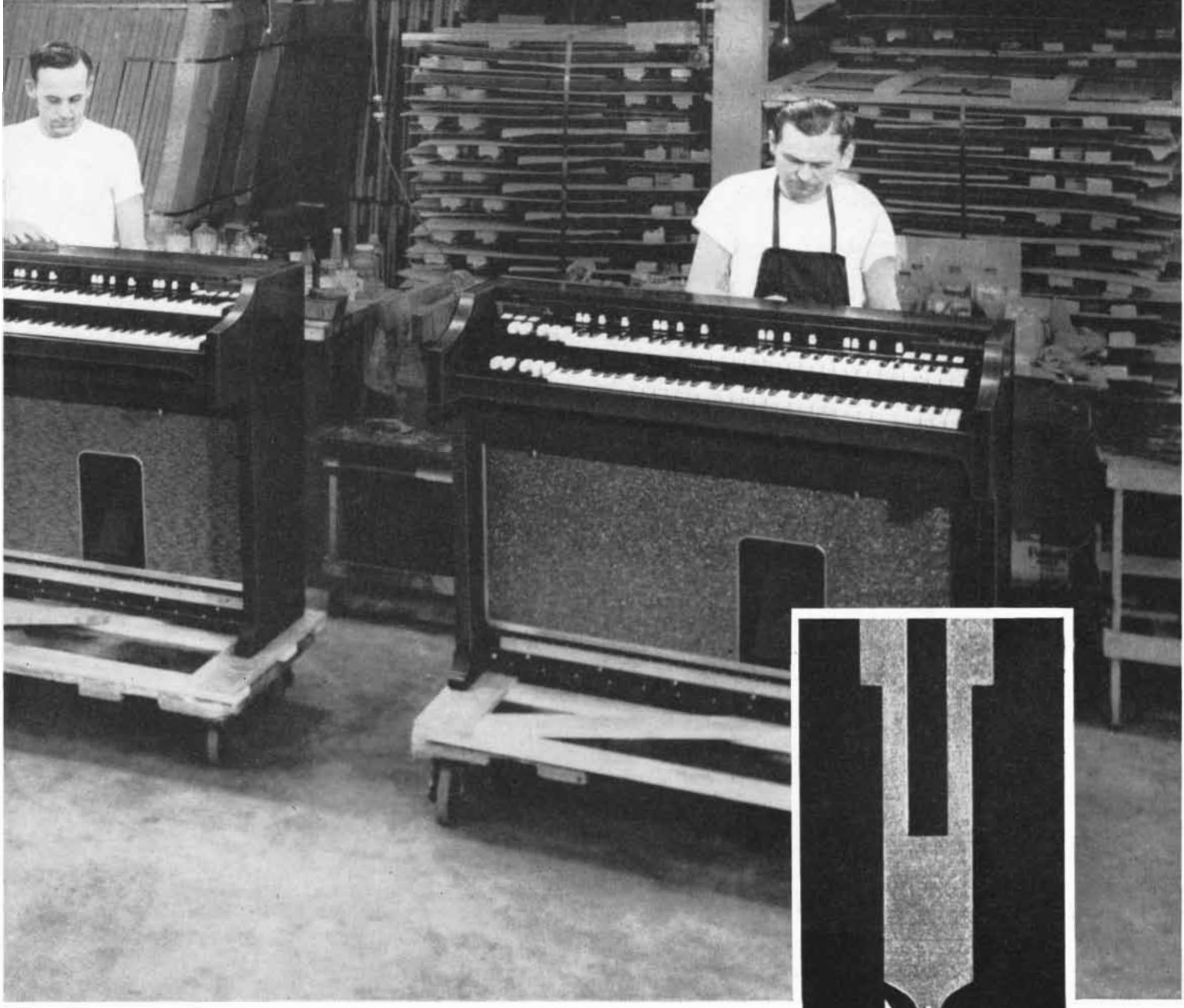
Palladium, in the form of 1296 small cross-wire electrical contacts in the standard Hammond two-manual organ, faithfully and reliably transmits the artist's touch. As the key is depressed nine lightly loaded spring finger contacts select the harmonics and the musical interpretation is instantly carried to electronic equipment which, in a blending of art and science, produces "music's most glorious voice".

Hammond uses pure palladium as a wire face on nine bus bars that extend the entire length of the keyboard. An alloy of palladium and ruthenium is used on the contact spring fingers to insure trouble-free operation. The non-tarnishing and wear-resisting palladium contacts produce high fidelity response, even with a low operating voltage and a feather-touch. No other metal has been found to do this as economically.

In accelerated tests of contacts using this combination of pure and alloyed palladium, a lifetime of music was produced without a failure—forty million perfect notes without a distorted one.

It could pay you to use a platinum metal

Your problem might be readily and economically solved with platinum metals—where reliable make and break electrical contact is indicated, such as in low noise, high fidelity transmission ...where wear-resisting, non-tarnishing surfaces are required, such as for printed electrical circuits...where a combination of severe corrosion and erosion must be met, as in the case of spinnerettes for rayon production...where peak catalytic efficiency is required as in the refining of high octane gasoline...where underwater hull protection is a problem...or where product purity must be retained despite high temperatures, as in the



Only a platinum metal does it. Individual contact fingers (this illustration shows one, enlarged) are fitted with 1/8 inch lengths of 0.005 inch diameter palladium alloy wire. These fingers work against pure palladium wire-faced bus bars which extend the length of the keyboard. An important supplier of wire and other forms of the platinum metals is Engelhard Industries, Inc., Newark, N. J.

will do the job as well...

case of lens glasses... the platinum metals have proved to be the most economical for certain critical equipment.

Industry is going to higher temperatures and higher pressures. Perhaps your own progress has been blocked by the limitations of materials to withstand such severe conditions. The platinum metals have removed many barriers. Have you considered them for your problems?

Platinum, palladium, rhodium, ruthenium and iridium have unique potentials, well worth your attention. Specialists are prepared to work closely with you in evaluating these metals for new commercial and scientific uses.

As a first step, write us for additional data on the outstanding characteristics and successful applications of the six platinum metals and their alloys—indicating your field of interest or how we might be of assistance.

Can these properties of the Platinum Metals help you?

Superior Wear Resistance
Exceptional Chemical Inertness
High Temperature Stability
Peak Catalytic Activity
Low Vapor Pressure

The six platinum metals are:

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PALLADIUM
RHODIUM
RUTHENIUM
IRIDIUM
OSMIUM

INCO PLATINUM METALS DIVISION

The International Nickel Company, Inc., 67 Wall Street. New York 5, N. Y.

THE AUTHORS

JAMES COOKE BROWN ("Loglan") is a social psychologist on the faculty of the University of Florida. He was born in 1921 in the Philippine Islands. His college career was interrupted by service in the Air Force in England during World War II, and he took his B.A. in philosophy and mathematics in 1945 at the University of Minnesota. He remained there to take his Ph.D. in sociology in 1952. After that he taught at Wayne University and Indiana University, and then engaged in commercial research for two years. In 1955 Brown went to Florida, where he has been doing research in the structure of interpersonal relations. He has published science fiction, worked on a Utopian novel which, he reports, "doesn't quite jell," and invented the game of "Careers." As for Loglan, he says: "My interest in it is almost as old as I am. I studied Esperanto and similar languages as a boy and had designed three unworkable schemes before leaving college." Brown's Loglan project began to take form when he came across the work of Benjamin Lee Whorf, and, he says, "between Whorf and the logicians and my own conviction that human life is largely the result of deliberate invention, the Loglan project was born." The work in Loglan, according to Brown, has been helped a great deal by the Basic English studies of Charles K. Ogden and his associates in England, and by the word-frequency studies of the principal European languages conducted by Edward A. Thorndike and his students in the U. S. The syntactical studies of the Danish philologist Otto Jespersen and the analyses of conversational language published by Hans Reichenbach have been especially helpful to Brown. Finally, he reports that his wife, an anthropologist, has contributed directly to the project, for she is "the world's champion Loglan word-maker."

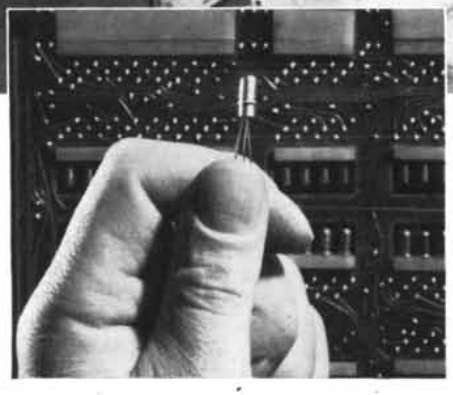
KINSEY A. ANDERSON ("Solar Particles and Cosmic Rays"), a cosmic-ray physicist, currently holds a Guggenheim Fellowship and is spending a year at the Royal Institute of Technology in Stockholm. He was born in 1926 in Preston, Minn., served in the Navy in 1945 and 1946 and took his B.A. in physics at Carleton College in 1949. He acquired his Ph.D. in 1955 at the University of Minnesota, where John R. Winckler taught him the value of the balloon technique for studies such as those described in his article. Anderson went from Minnesota to the State University of Iowa, where he became assistant professor of physics in 1958. He has sent up more than 50 instrumented balloons in remote arctic and auroral-zone locations, and reports that "during the I.G.Y., balloons rivaled satellites as a means of obtaining scientific information, and they continue to be extremely useful."

JOHN S. EDWARDS ("Insect Assassins") works on aphid physiology in the School of Agriculture at the University of Cambridge. A native of Auckland, New Zealand, he was born in 1931 and acquired his B.S. and honors M.S. degrees at the University of Auckland. In 1956 he took a research studentship at Cambridge and worked under V. B. Wigglesworth, studying assassin-bug physiology for his Ph.D. Before his M.S. studies on a cerambycid beetle, he had been interested in ecology—principally alpine, forest and soil communities. The beetle work converted him to insect physiology and biochemistry, which he reports has the one drawback of providing him with no real excuse to get out into the open.

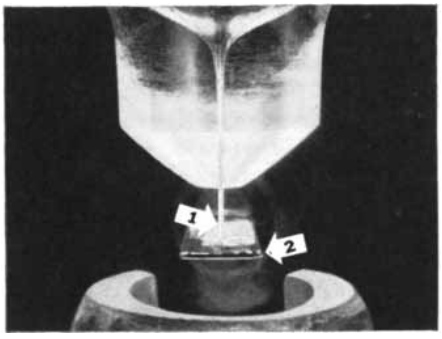
C. LESTER HOGAN ("Ferrites") is vice president of Motorola Semiconductor Products, Inc., and was formerly Gordon McKay Professor of Applied Physics at Harvard University. He was born 40 years ago in Great Falls, Mont., and earned his B.S. in chemical engineering at Montana State College in 1942. After working for a year as a research engineer at the Anaconda Copper Mining Company in Great Falls, he spent three years in the Navy and then took his M.S. in physics at Lehigh University. He stayed on the faculty there for three years and took his Ph.D. in 1950, specializing in the solid state and electromagnetic theory. From 1950 to 1953 he did research at the Bell Telephone Laboratories. In January, 1952, he published a basic paper entitled "The Ferromagnetic Faraday Effect at Microwave Frequencies and Its Applications." He joined the Harvard faculty in 1953 and went to Motorola in June, 1958.

L. PEARCE WILLIAMS ("Humphry Davy"), assistant professor of the history of science at Cornell University, is now in Oxford, England, working on a biography of Michael Faraday to be published in England by Chapman and Hall. Williams was born in 1927 in Harmon, N. Y., and entered Cornell in 1944. After service in the Navy, he returned to Cor-

Inventory of 500,000 items updated in 20 minutes!



THE HEART OF THE COMPUTER is this circuit board containing Philco Transistors. In a single large-scale computer there are 800 similar circuits, using over 50,000 Philco Precision-Etch Transistors.



EXCLUSIVE PHILCO PRECISION-ETCH PROCESS in operation on world's first automatic transistor production lines, designed and built by Philco. Electrochemical jet stream (1) etches tiny depression on surface of germanium blank (2) with tolerance controlled by infrared rays to 1/150 the thickness of a human hair.

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lead the way to faster data processing

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SPECIFY PHILCO Transistors in all electronic equipment you buy . . . or build.
CONSULT PHILCO for information or assistance in transistorizing your product.

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nell, where he received his Ph.D. in 1952. He set out to study chemical engineering, and along with other engineering students was required to take Henry A. Guerlac's course in the history of science. The combination of science and the humanities found in the history of science made him an ardent convert to that field. He wrote his doctoral dissertation on science and the French Revolution, and then taught at Yale University and the University of Delaware before joining the faculty at Cornell.

JOHN R. PLATT ("How We See Straight Lines") is a professor of physics at the University of Chicago who says he is "interested in the interactions between light and matter all the way from interstellar dust to the kind of matter that has arms and legs." He took up the study of visual organization when he began to wonder what happens to light-energy and signals after they are absorbed by the pigments of the retina. He was particularly intrigued when he learned that this problem had baffled the great 19th-century physicist and physiologist Hermann von Helmholtz. "It is a pity," Platt says, "that physicists today have so completely forgotten about these basic puzzles of perception of the external world." Most of Platt's publications have been in the field of electronic theories of chemistry and of the spectra of organic molecules, especially biological compounds and pigments. He was born in Jacksonville, Fla., in 1918, and took his B.S. at Northwestern University at the age of 18. He earned his Ph.D. at the University of Michigan when he was 23 years old. He has been at the University of Chicago for the past 15 years. In 1951 and 1952 he held a Guggenheim Fellowship at the University of London.

ROBERT F. ACKER and S. E. HARTSELL ("Fleming's Lysozyme") are, respectively, assistant chief of the cancer chemotherapy department at Microbiological Associates, Inc., in Bethesda, Md., and professor of bacteriology at Purdue University. Acker was born in Chicago in 1920, took his B.A. in chemistry at Indiana University in 1942 and his M.A. there in bacteriology in 1948. He studied under Selman A. Waksman at Rutgers University from 1950 until he acquired his Ph.D. in microbiology in 1953. At Rutgers he worked on antifungal antibiotics. He then went to Purdue, where he studied mold metabolism. In 1954 he became assistant professor of bacteriology at Iowa State College, where he investigated cell walls and lysozyme. He took up his present position last summer, and he is now studying antitumor agents in mice, mouse tumor-cell genetics and the long-term preservation of tissue cultures. Hartsell, a native of Benton Harbor, Mich., acquired his B.S. in bacteriology at Michigan State College in 1927. He earned his M.S. in 1929 at Yale University and acquired his Ph.D. there in 1933. He was on the research staff of the department of animal diseases at the Connecticut State College until he joined the Purdue faculty in 1936. While studying the spoilage of powdered eggs for the armed forces in 1944 and 1945, he became interested in lysozyme; he has since studied all aspects of the effect of this enzyme upon bacteria.

H. G. BACHMANN ("The Origin of Ores") is engaged in research at the Mineral and Crystallographic Institute of the University of Göttingen. He was born at Remscheid in Germany in 1928, and became interested in chemistry and rock-collecting at the age of 10. He defines a mineralogist as "one who lacks the experimental skill to become a chemist, who is not fond enough of hiking to become a geologist and who finds mathematics too high an obstacle to becoming a physicist," but his mineralogical experience belies this definition. He took his Ph.D. at the University of Bonn in 1953 and then spent two years in the service of the Turkish Government, "criss-crossing Asia Minor by jeep, on foot and on mule and horseback." Says Bachmann: "I covered more than 20,000 dusty miles in search of ceramic raw materials and other mineral deposits." The antiquities of Turkey whetted his appetite for archaeology, and in 1956 he obtained a post as geological advisor to the U. S.-German team excavating sites of the ancient kingdom of Kommagene in southeastern Turkey (see "The Tomb of Antiochus I," by Theresa Goell and Friedrich Karl Doerner; SCIENTIFIC AMERICAN, July, 1956). Then he received a fellowship with the National Research Council of Canada to study the crystal chemistry of vanadium compounds. He became a "rock-hound" again, touring mining sites in the U. S. and Canada. He returned to Germany in 1958.

HERBERT DINGLE, who in this issue reviews the symposium *Measurement: Definitions and Theories,* edited by C. West Churchman and Philburn Ratoosh, is professor emeritus of the history and philosophy of science at University College London.

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Color is a facet of function. Color identifies . . . emphasizes . . . warns . . . attracts or repels.

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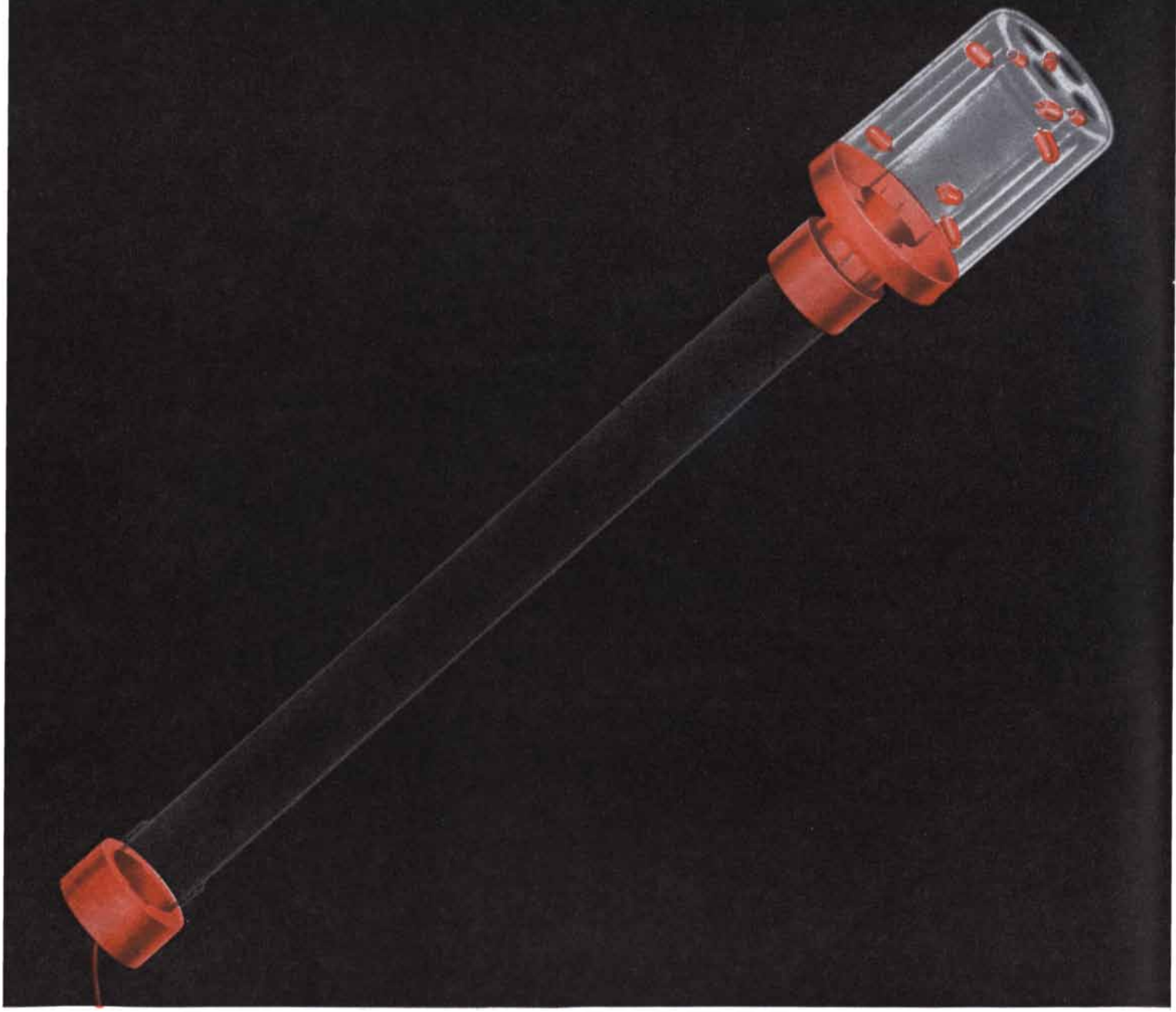

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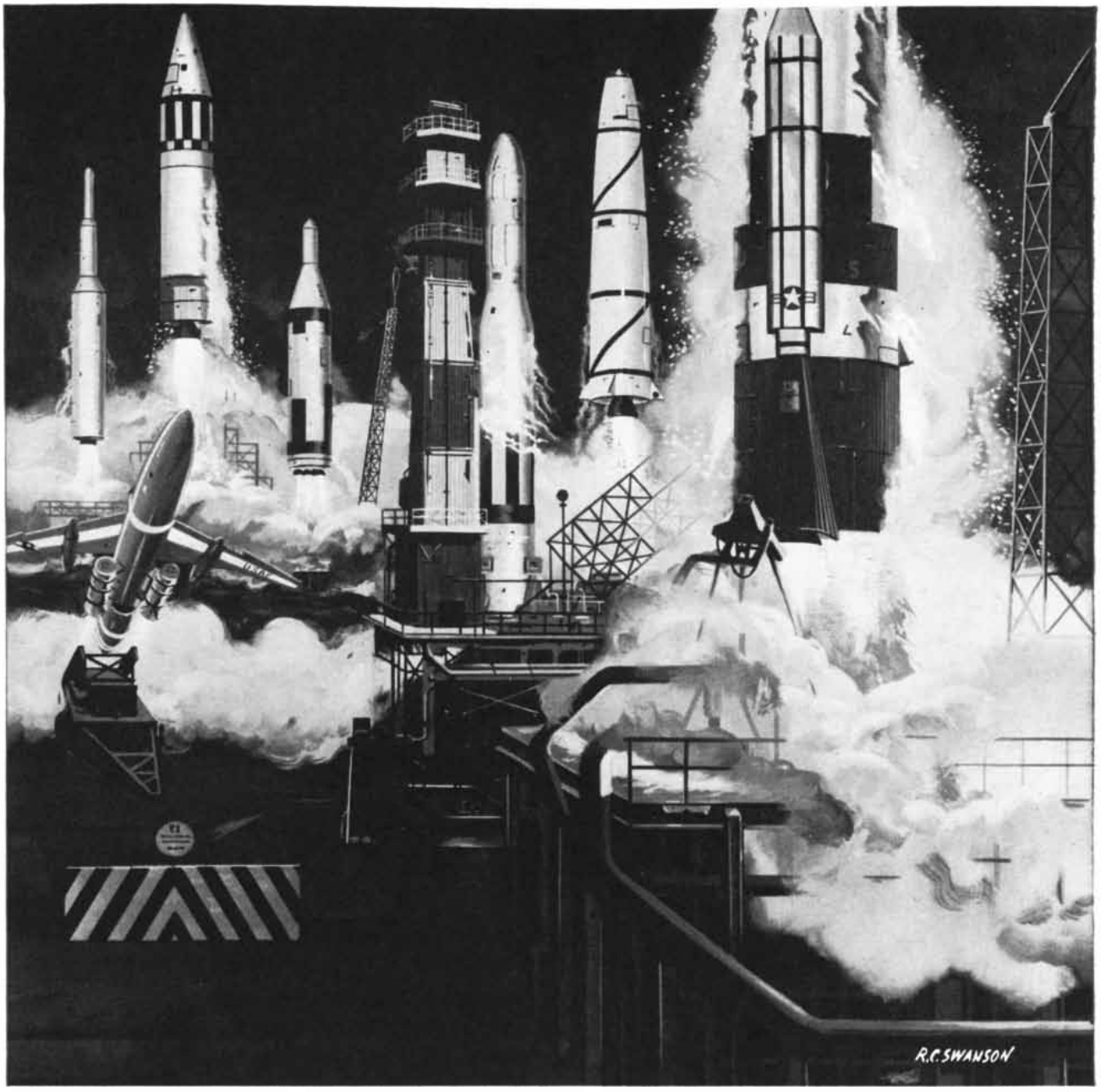

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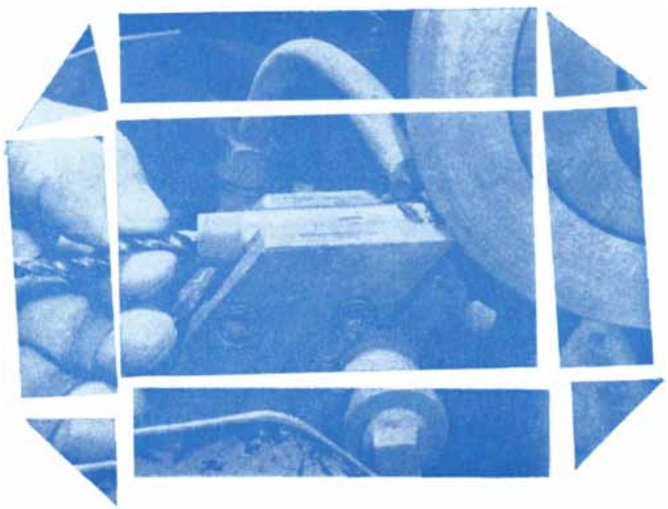

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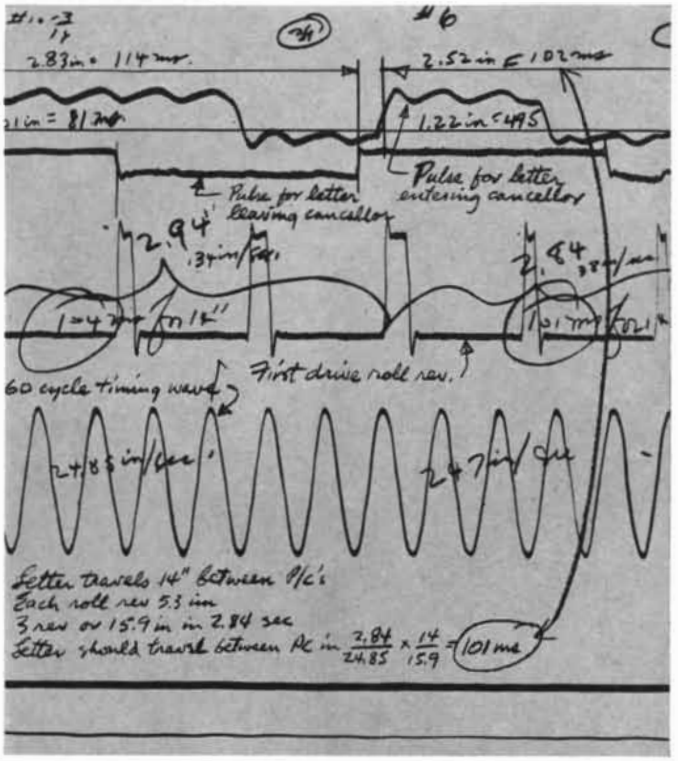

these are records of leadership

In production...

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

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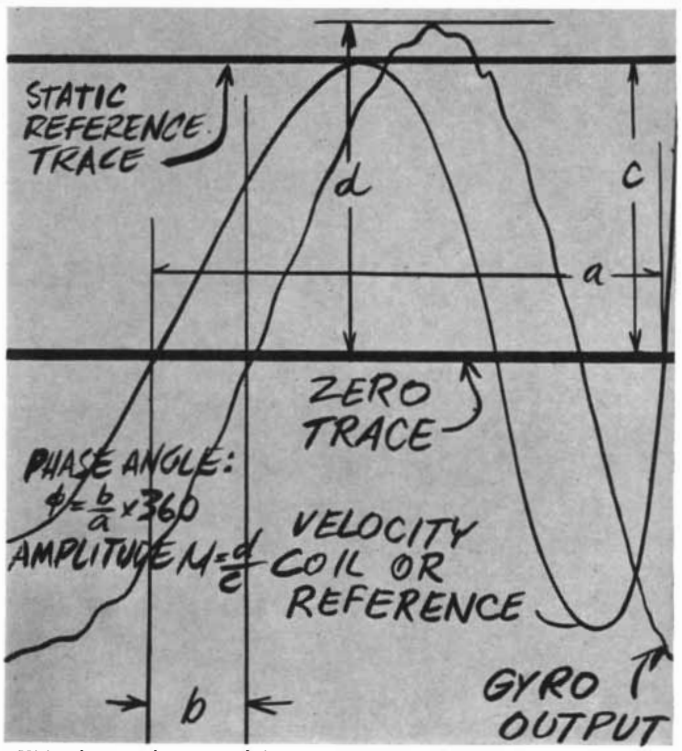

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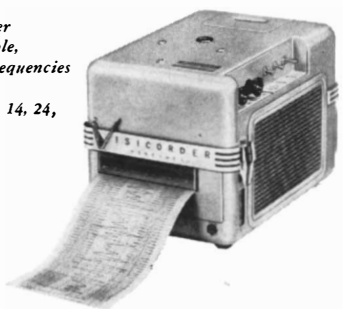
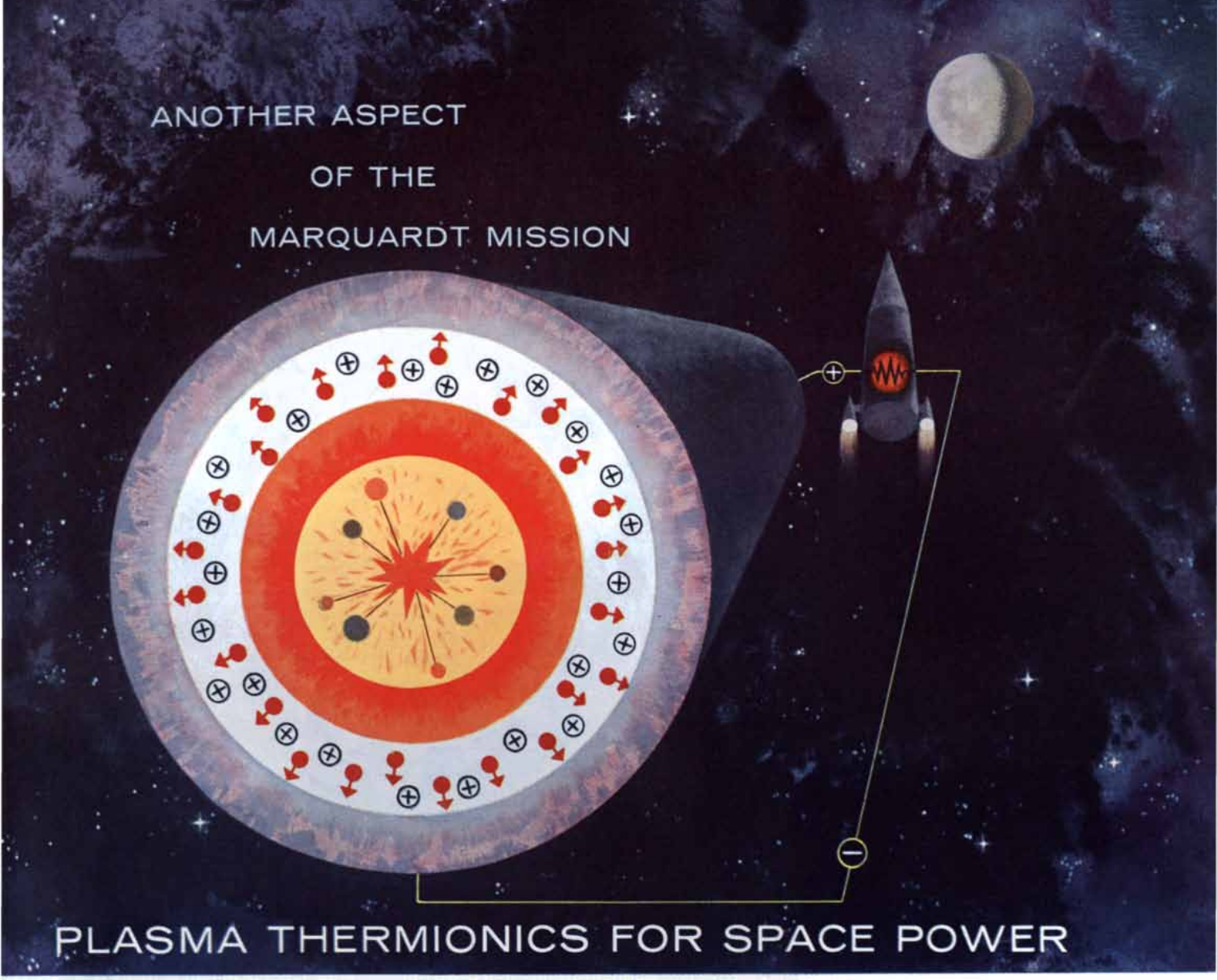


Honeywell

Industrial Products Group

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

Minneapolis-Honeywell Regulator Co., Industrial Products Group, Heiland Division, 5200 E. Evans Ave., Denver 22, Colorado



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ASTRO's plasma thermionic power studies typify but one aspect of The Marquardt Mission.

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power a light bulb...power a rocket

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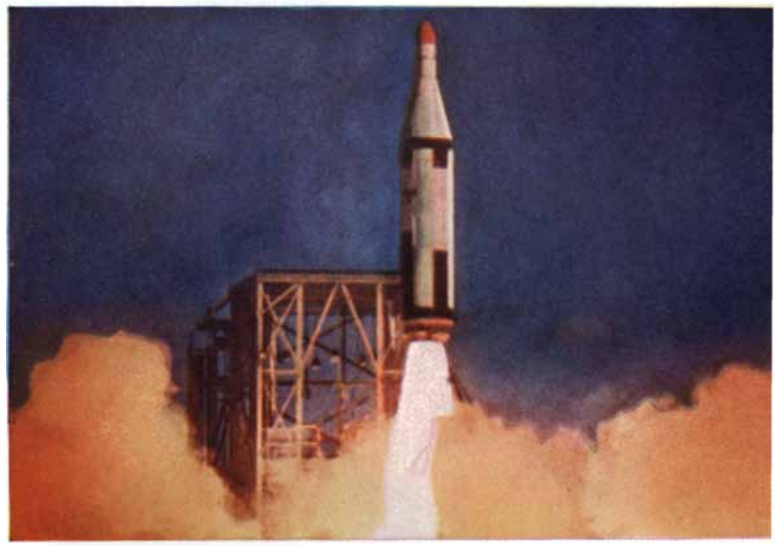

One of the intriguing new developments of this rocket age is solid fuel. And one of the magically versatile Reynolds Aluminums plays a big role in these exotic missile propellants. A Reynolds Aluminum—an atomized aluminum powder—helps provide thrust powerful enough to drive a missile into outer space. Aluminum powders can provide dramatic effect in fireworks, destruction in bombs, or protective finishes in industrial paints and coatings. Other Reynolds Aluminums—sheet, plate, and extrusions—are used in missile air frames and skin, and ground support equipment.

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*** Reynolds Aluminum: the singular metal that is very plural indeed**

Tobias Dantzig...on mathematicians

"The mathematician may be compared to a designer of garments, who is utterly oblivious of the creatures whom his garments may fit. To be sure, his art originated in the necessity for clothing such creatures, but this was long ago; to this day a shape will occasionally appear which will fit into the garment as if the garment had been made for it. Then there is no end of surprise and of delight!

"There have been quite a few such delightful surprises. The conic sections, invented in an attempt to solve the problem of doubling the altar of an oracle, ended by becoming the orbits followed by the planets in their courses about the sun. The imaginary magnitudes invented by Cardan and Bombelli describe in some strange way the characteristic features of alternating currents. The absolute differential calculus, which originated as a fantasy of Riemann, became the mathematical vehicle for the theory of Relativity. And the matrices which were a complete abstraction in the days of Cayley and Sylvester appear admirably adapted to the exotic situation exhibited by the quantum theory of the atom."

—*Number, The Language of Science, 1930*

Established 1845 SCIENTIFIC AMERICAN June, 1960 Volume 202 Number 6

Loglan

This logical language is now being synthesized on modern linguistic principles, largely to examine the hypothesis that the world view of the members of a culture is determined by the structure of their language

by James Cooke Brown

In the closing decades of the 17th century the philosopher-mathematician Gottfried Wilhelm von Leibniz proposed the development of a "universal symbolism" that would speed the growth of scientific thought in the same dramatic way that the development of mathematics was then advancing the art of scientific computation. As a mathematician, Leibniz was doubtless aware that mathematical methods are limited to tracing the deductive consequences of quantitatively stated premises. As a philosopher, he was certainly aware that scientific thinking consists of more than deduction alone. He knew that inductive, or generalizing, operations are also involved, and he would have argued that hypothesis formation, or "creative imagination," is decisive in the development of science. Thus Leibniz intended his universal symbolism to embrace mathematics and imitate its "ratiocinative power," but he meant it to go far beyond mathematics, to encompass the whole of scientific, indeed of all rational, thought. By this means, he predicted, the rational powers of man would be marvelously extended.

In the intervening centuries little progress has been made toward the realization of Leibniz's vision. It is true that the period has seen the development of modern logic, and the extension of mathematics itself in non-numerical domains. The theory of games and of statistical inference appear to have broadened the scope of formal reasoning in precisely the direction anticipated by Leibniz's proposal. But the universal symbolism, in the sense of an all-encompassing scientific language, has yet to come. The Western scientist, like the man in the street, still does his reasoning largely in the familiar Indo-European languages, and so within the confines of the grammatical rules and metaphysical categories they carry over from the past. If ratiocinative power has increased, it has not been in the universal sense that Leibniz proposed.

The central notion underlying Leibniz's vision may be stated in a question. Is it true that the "rational power" of the human animal is in any significant measure determined by the formal properties of the linguistic game it has been taught to play? A whole school of anthropologically oriented linguists, following the late Benjamin Lee Whorf of Hartford, Conn., believe they have found compelling evidence that the answer to this question is yes. These investigators, arguing largely from the astonishing differences to be found among the grammars and lexicons of preliterate peoples, and between these languages and our own, believe that the structure of the language spoken by a people determines their world view; that is, it sets limits beyond which that world view cannot go. Thus the native speaker of any language is fated to see reality, and to think about it, exclusively on the terms and by the rules laid down for him by that language—unless he learns a new one.

Other linguists and psychologists have found reason to doubt the Whorfian thesis of linguistic determinism. They feel that, in principle at least, all languages are mutually intertranslatable; that they can all be most fruitfully regarded as dealing with the same "reality"; that "thought," scientific or otherwise, is somehow independent of the specific character of the linguistic machinery in which it is expressed. The biologically oriented psychologist would argue further that any such attribute as "intelligence," "rationality," "problem-solving ability" and so on is a property of the behavior of the individual organism, resulting from its hereditary endowment on the one hand and its particular history of reinforcement on the other.

But Whorf's doctrine, that human thought is largely determined by the formal properties of the pre-existent social forms embedded in the structure of language, is slowly gaining experimental attention. Whorf does not explicitly embrace Leibniz's program of a universal symbolism. Yet implicit in his view of the nature of language is just this possibility. For if language is a human artifact, the power of the human mind need not be restrained by existing languages; the possibility that the inventive human animal will create still more powerful linguistic instruments is certainly

	21 LOGLAN PHONEMES	ENGLISH	CHINESE	HINDI	RUSSIAN	SPANISH	JAPANESE	FRENCH	GERMAN
5 VOWELS	**A** F**A**THER	√	√	√	√	√	√	√	√
	E M**E**T	√	√	√	√	√	√	√	√
	I MACHINE; ALSO, BEFORE VOWELS, **Y** AS IN **Y**ET	√	√	√	√	√	√	√	√
	O N**O**TE; ALSO, BEFORE R, **O** AS IN **O**R	√	√	√	**O** ONLY	√	√	√	√
	U L**U**TE; ALSO, BEFORE VOWELS, **W** AS IN **W**OE	√	√	√	√	√	√	√	√
16 CONSONANTS	**B** **B**OY	√	√	√	√	√	√	√	√
	C **SH**E	√	√	√	√	IN **TC** ONLY	√	√	√
	D **D**OG	√	√	√	√	√	√	√	√
	F **F**AT	√	√	√	√	√	√	√	√
	G **G**O	√	√	√	√	√	√	√	√
	J A**Z**URE [FRENCH **J**EAN]	√	IN **DJ** ONLY	IN **DJ** ONLY	√	IN **DJ** ONLY	IN **DJ** ONLY	√	√
	K **C**OAL	√	√	√	√	√	√	√	√
	L **L**ATE; AB**LE**	√	√	√	√	√	NO	√	√
	M **M**AN	√	√	√	√	√	√	√	√
	N **N**O	√	√	√	√	√	√	√	√
	P **P**ET	√	√	√	√	√	√	√	√
	R **R**AIN; BROTH**ER**	√	√	√	√	√	√	√	√
	S **S**EW	√	√	√	√	√	√	√	√
	T **T**ON	√	√	√	√	√	√	√	√
	V **V**ERY	√	NO	√	√	√	NO	√	√
	Z **Z**EPHYR	√	√	√	√	NO	√	√	√

LOGLAN SPEECH SOUNDS comprise the five vowels and 16 consonants most widely distributed among the eight languages spoken by the 1,700 million people of the "target population." A check mark indicates that some similar version of the Loglan sound occurs in the natural language. Only *l*, *v* and *z* are not common to all eight languages. In some languages *c* ("sh") and *j* ("zh") occur only in the combinations *tc* ("ch" of "chum") and *dj* ("j" of "jam"), obliging a speaker of one of those languages to separate the Loglan sound out of the psychologically unitary native sound. Loglan words are spelled phonetically with these letters.

very real. In this sense we may speak of the new linguistic doctrine and the older philosophical hope as expressions of the same hypothesis. That hypothesis has apparently been similarly presupposed in an engaging activity of Western philologists: the construction of international auxiliary tongues.

Until recently, however, a thoroughgoing empirical test of what we will now call the Leibniz-Whorf hypothesis has not been possible. The necessary experimental apparatus has simply not existed. The languages (and their speakers) available to the linguistic experimenter are either the natural languages, with their vast traditions and structural irregularities, or artificial languages such as Esperanto, Interlingua and Novial, which have been created primarily in the interests of international communication. Unfortunately these artificial languages are all modeled so closely on the European plan that they offer little advantage to the experimenter over the natural languages themselves. In either case, the formal properties of these linguistic systems are not, and cannot be, deliberately controlled.

It was to supply an instrument for experimental investigation of the Leibniz-Whorf hypothesis that we undertook our work on Loglan in 1955. Loglan was to be an artificial language, but one especially designed to test the thesis that the structure of language determines the forms of thought. It was to have a small, easily learned vocabulary derived from the word stock of as many of the major natural languages as proved feasible (though it was not intended to be an auxiliary international language). Its rules of grammar and syntax were to be as few and regular as possible. It was to utilize a short list of speech sounds (phonemes) common to the natural languages [*see table on opposite page*], and it was to be phonetically spelled.

But most important, Loglan was to incorporate as many of the notational devices of modern logic and mathematics as could be adapted to its use. Our Whorfian assumption here was that these powerful calculi carry in their structures precisely those psychosocial devices that give their human practitioners their rational power; our only problem was to tease them out. Lacking the very knowledge needed to assess the "power" of a symbolic device, we have invoked insight and speculative hypothesis to pack the structure of Loglan with the formal properties that seemed most suitable to its experimental purpose. We cannot be sure that this imitative borrowing from mathematics and logic has maximized Loglan's "ratiocinative power." But we have at least succeeded in achieving a high degree of imitation. It would be surprising if, with such formidable models, Loglan were not superior to any of the natural languages in its ability to facilitate thought, if indeed thought is liable to such facilitation.

Of the many criteria that guided us in the construction of Loglan, the easiest to satisfy was that of the "learnability" of its vocabulary. We do not yet know if the language as a whole will prove learnable with satisfactory speed under experimental conditions. But the vocabulary at least should prove remarkably easy to master, whether the subject's native language is English or Chinese. One of our objectives was to provide an instrument that would be useful in experiments with subjects of different language backgrounds. It would not do, for example, to allow the vocabulary to imitate the English lexicon exclusively. Not only would this limit the range of any cross-cultural investigations we might later wish to make, but we could never be sure that it was Loglan and not English that was producing our experimental results. We have therefore taken great pains to construct a vocabulary that is international in both its concepts and its roots.

To satisfy this requirement we happily hit upon a simple word-finding process. Well over two thirds of the world's present inhabitants speak one or more of just eight of its several hundred natural languages, either as a native or as a second tongue. Counting both their native speakers and secondary speakers who are not native speakers of any of the other seven, these eight languages, in the approximate descending order of the number of their speakers, are: English, Mandarin Chinese, Hindi, Russian, Spanish, Japanese, French and German. The ninth language is Arabic, but the addition of languages below the rank of eight geometrically increases the etymological labor of finding common roots, and only negligibly increases the total population. Now if one regards the 1,700 million speakers of the eight major languages as the target population of Loglan research, the relative statistical importance of each of them may be defined as the proportion of their speakers in the whole. On this basis the relative importance of English is approximately .28; Chinese, .25; Hindi, .11; Russian, .10; and so on down through German, with .05. If these figures are even approximately correct, English and Chinese are over-

BLANU	ALL OF ENGLISH BLUE [**BLU**]	1 × .28 = .28
B**LAN**U	ALL OF CHINESE **LAN**	1 × .25 = .25
B**LA**NU	1/2 OF HINDI NI**LA**	.5 × .11 = .06
BL**ANU**	2/7 OF RUSSIAN G**ALU**BOI	.3 × .10 = .03
BL**ANU**	1/2 OF SPANISH AZUL [**ASU**L]	.5 × .09 = .05
BLANU	NO COUNTABLE PORTION OF JAPANESE AO OR KON	0 × .06 = .00
BLANU	2/3 OF FRENCH BLEU [**BL**Ü]	.7 × .06 = .04
BLANU	ALL OF GERMAN **BLAU**	1 × .05 = .05
		TOTAL LEARNABILITY SCORE = .76

THE WORD FOR "BLUE" in Loglan is *blanu*. In the "finding" of this word, words of corresponding meaning from the eight natural languages were respelled in Loglan phonemics. Trial words (including *blula* and *lablu* as well as *blanu*) were then assembled from the phonemes in these words, and each was scored according to the system illustrated here. Only the phonemes common to and occurring in the same order in both the Loglan and the natural word are counted. Since *blanu* incorporates all of English "blu," it is given the maximum rating of 1 (*top right*); since 28 per cent of the target population speaks English, *blanu* receives a score of .28 on the English line. Addition of the scores for all eight languages gave *blanu* the highest "total learnability" score of .76. This expresses the probability that a person will learn the word from association with a familiar natural word.

whelmingly the most "important" modern languages; their speakers constitute 53 per cent of the target population.

We then make a simplifying assumption. We assume that the probability of learning a new word in a second language on first, or very few, exposures is well approximated by the proportion of the phonemes in the corresponding native word that one finds in it. This is, of course, an extension of the familiar practice of studying "cognate roots" in second-language learning. The problem of finding the most learnable Loglan word —and Loglan words are found, not made —is thus reduced to finding a permissible sequence of Loglan phonemes that maximizes the proportion of the target population who will find matching phoneme sequences in related words of their native tongues. Thus the Loglan word *blanu* (English: blue), on the basis of its phoneme-match to words for blue in the eight major languages, has a learnability of .76. The score of .76 is obtained for *blanu* in the following way. The proportion of the phonemes in *blanu* that matches the phonemes in the most similar natural word of corresponding meaning is first computed for each language [*see table on preceding page*]. This proportion we assume to be a best estimate of the ease with which the speakers of that language will learn the word *blanu*. We then multiply that proportion by the proportion of speakers in the target population who speak that language. The product of these two proportions is nothing but the joint probability of two events: first, that a subject drawn at random will be a Frenchman, say; and second, that he will recognize his own word *bleu* in the Loglan *blanu*. The probability of the first event is only .06; of the second, by our assumption, .67; and of their joint occurrence, therefore, .04. The sum of the resulting probabilities over all eight languages is the probability that some one of these eight alternative joint events will happen: that a subject drawn at random will either be a Frenchman and learn *blanu* through *bleu*, or that he will be a German and learn it through *blau*, or that he will be a Hindi-speaking Indian and learn it through *nila*, or that he will be a Japanese and not learn it (immediately) at all, and so on. Thus the probability that anyone in this vast polyglot population will (easily) learn *blanu* is .76. The nearest competitor for the job of representing the concept "blue" is *blula*; a somewhat handsomer word from the standpoint of the English-trained ear. But the learnability score of *blula* is only .67. Since no other word obtains a score equal to or greater than .76, *blanu* is the Loglan word.

Many Loglan words score 1 in at least one language; that is, they contain all the phonemes for the corresponding word in that language [*see top table at right*]. These words, however, had to survive the test of learnability in other languages and achieve a high total learnability. Loglan distributes such favors impartially, giving the speakers of each of the languages, in proportion to their numbers, easy cognate routes into its polyglot vocabulary [*see bottom table at right*].

We have discovered over 1,000 Loglan words by this means. They comprise the most frequent empirical terms (words for phenomena, say) in any language, and the ones least likely to be affected by direct interlanguage borrowing. Yet the average of their learnability scores is surprisingly high; about half of them have scores above .5, and the range of scores is from about .3 to .9. These figures indicate that our technique is not entirely arbitrary, and preliminary tests on English-speaking subjects suggest that the theoretical ratings tend, if anything, to underestimate the real learnability of the Loglan vocabulary. The figures also suggest that there is more phonetic similarity among the world's languages, even historically divergent ones, than is commonly supposed. The possibility of a universal human tongue may not be so remote after all.

Another feature of the Loglan vocabulary that should make it easy to learn is that each part of speech has its own phonetic form or forms. It is no accident that words like *blanu*, as in the tables at right, are all five-letter words. They all possess, in fact, either of two similar consonant-vowel patterns. *Blanu* has the *ccv'cv*-form (that is, "consonant—consonant—stressed-vowel—consonant—vowel"). Words like *bakso* and *cabro* (pronounced "bahk'-soh" and "shah'-broh"), on the other hand, exhibit the pattern *cv'ccv*. These two five-letter forms are the only permissable forms of what we have called the simple Loglan predicate, a grammatical category that roughly corresponds to the combined class of English common nouns, adjectives and verbs [*see table on page 58*]. Loglan makes no fixed distinctions between these well-defined Indo-European categories. By avoiding them it also avoids making the metaphysical distinctions between "processes" and "things" and between "substances" and "attri-

ENGLISH-CONTAINING WORDS			
BAKSO	[*BAHK'SOH*]	**BAKS**O	BOX
BATLA	[*BAHT'LAH*]	**BATL**A	BOTTLE
CLIFE	[*SHLEE'FEH*]	**CLIF**E	LEAF
DZEGO	[*DZEH'GOH*]	DZ**EG**O	EGG
FORMA	[*FOR'MAH*]	**FORM**A	FORM
GROCA	[*GROH'SHAH*]	**GRO**CA	GROW
GRUPA	[*GROO'PAH*]	**GRUP**A	GROUP
KAPRE	[*KAHP'REH*]	**KAPR**E	COPPER
KETLI	[*KET'LEE*]	**KETL**I	KETTLE
LAKSO	[*LAHK'SOH*]	**LAKS**O	LOCK
KRUMA	[*KROO'MAH*]	K**RUM**A	ROOM
NARMI	[*NAR'MEE*]	N**ARMI**	ARMY
NIGRO	[*NEEG'ROH*]	**NIGRO**	NEGRO/BLACK
PROZA	[*PROH'ZAH*]	**PROZ**A	PROSE
RIZNU	[*REEZ'NOO*]	**RIZNU**	REASON
SAZNO	[*SAHZ'NOH*]	SAZ**NO**	KNOW
SEDBO	[*SED'BOH*]	**SEDB**O	SAID/SAY
TRATI	[*TRAH'TEE*]	**TRAT**I	TRY
TRUCI	[*TROO'SHEE*]	**TRU**CI	TRUE
TITCA	[*TEET'SHA*]	**TITC**A	TEACH

LEARNABLE WORDS in Loglan for speakers of three of the eight languages of the target population incorporate all of the phonemes of the corresponding word in the natural language and in the same order

LOGLAN	ENGLISH .28
MATMA [*MOTHER*]	MOM **MAM**
SUPTA [*SOUP*]	SOUP **SUP**
BLANU [*BLUE*]	BLUE **BLU**
RISMI [*RICE*]	RICE **RAIS**
DERTU [*EARTH, SOIL*]	DIRT **DRT**
TRELU [*RAIL*]	RAIL **RĒL**
VITCU [*SEE*]	VIEW **VIU**
PLUCI [*PLEASE*]	PLEASE **PLIZ**
FORLI [*STRONG*]	FORT **FORT**
SORLU [*EAR*]	AURAL **ORL**
KLESI [*CLASS*]	CLASS **KLĀS**
GRODA [*BIG*]	GROSS **GROS**

MOST-LEARNABLE WORDS in Loglan have high "total learnability" scores measured in terms of the phonemes that compose the corresponding words in all of the eight natural languages. Each natural word

FRENCH-CONTAINING WORDS			
BOSNI	[*BOHS'NEE*]	**BOS**NI	OS [*BONE*]
BRIKI	[*BREE'KEE*]	**BRIK**I	BRIQUE [*BRICK*]
CEFLI	[*SHEF'LEE*]	**CEF**LI	CHEF [*CHIEF*]
FLAMI	[*FLAH'MEE*]	**FLAM**I	FLAMME [*FLAME*]
GLIDA	[*GLEE'DAH*]	**GLID**A	GUIDE [*GUIDE*]
FEKTO	[*FEK'TOH*]	**FEKTO**	FAIT [*FACT*]
GRISI	[*GREE'SEE*]	**GRI**SI	GRIS [*GRAY*]
GUSTO	[*GOOST'OH*]	**GUST**O	GOUT[ER] [*TASTE*]
KORLO	[*KOR'LOH*]	**KOR**LO	CORPS [*BODY*]
KROKU	[*KROH'KOO*]	**KRO**KU	CROC [*HOOK*]
LAVDO	[*LAHV'DOH*]	**LAV**DO	LAV[ER] [*WASH*]
MLEKO	[*MLEH'KOH*]	M**LE**KO	LAIT [*MILK*]
MORTI	[*MOR'TEE*]	**MOR**TI	MORT [*DEAD*]
PORKO	[*POR'KOH*]	**POR**KO	PORC [*HOG*]
PUDRU	[*POOD'ROO*]	**PUDR**U	POUDRE [*POWDER*]
SLIVI	[*SLEE'VEE*]	SLI**VI**	VIE [*LIFE*]
TABLI	[*TAHB'LEE*]	**TABL**I	TABLE [*TABLE*]
TCELA	[*CHEH'LAH*]	TC**EL**A	AILE [*WING*]
TCENA	[*CHEH'NAH*]	T**CEN**A	CHAÎNE [*CHAIN*]
VEGRI	[*VEG'REE*]	**VE**GRI	VERT [*GREEN*]

CHINESE-CONTAINING WORDS			
CABRO	[*SHAH'BROH*]	**CA**BR**O**	SHAO [*BURN*]
DUNZO	[*DOON'ZOH*]	**DUNZO**	DZO [*DO*]
DZORU	[*DZOH'ROO*]	**DZOR**U	DZOU [*WALK*]
FLETI	[*FLEH'TEE*]	**FLETI**	LEI [*TIRED*]
DJILE	[*JEE'LEH*]	**DJILE**	JIE [NOUN *RING*]
DJORI	[*JOH'REE*]	**DJ**O**RI**	JI [*ORDER*]
LALDO	[*LAHL'DOH*]	**LALDO**	LAO [*OLD*]
LILFA	[*LEEL'FAH*]	LIL**FA**	FA [*LAW, LEGAL*]
MANDU	[*MAHN'DOO*]	**MAN**DU	MAN [*DECEIVE*]
MATCI	[*MAHT'SHEE*]	MA**TCI**	CHI [*MACHINE*]
METRI	[*MET'REE*]	**METRI**	MEI [*SISTER*]
MUBRE	[*MOO'BREH*]	**MU**BRE	MU [*WOOD*]
NUMCU	[*NOOM'SHOO*]	NUM**CU**	SHU [*NUMBER*]
PETRI	[*PET'REE*]	**PETRI**	PEI [*DISTRIBUTE*]
PRANO	[*PRAH'NOH*]	**PRANO**	PAO [*RUN*]
RETCA	[*RET'SHAH*]	**RETCA**	CHA [*DIFFERENT*]
SANRE	[*SAHN'REH*]	**SAN**RE	SAN [*UMBRELLA*]
STISI	[*STEE'SEE*]	**STISI**	TI I [*SENTENCE*]
TIRNE	[*TEER'NEH*]	**TIRNE**	TIE [*IRON*]
TOSKU	[*TOH'SKOO*]	**TO**SK**U**	TOU [*HEAD*]

in which they occur in that word. Thus, according to the assumptions of the Loglan word-finding system, the 20 words at left should prove to be immediately learnable by speakers of English. The Loglan words appear in the first column; their pronunciations in English phonetics, in the second column; the phonemes common to the Loglan and the English word, in bold-face type in the third column. But these words had to score in other languages as well to be accepted in the Loglan lexicon. Similar lists can be drawn up for other major languages and represent the Loglan words that their speakers would learn most easily.

CHINESE .25	HINDI .11	RUSSIAN .10	SPANISH .09	JAPANESE .06	FRENCH .06	GERMAN .05	SCORE 1.00
MA **MA**	MATA **MATA**	MAT **MAT**	MAMA **MAMA**	OKOSAMA OKOSA**MA**	MAMAN **MAMĀ**	MUTTER **MUTR**	.94
TANG **TAN**			SOPA **SOPA**	SUPU **SUPU**	SOUPE **SUP**	SUPPE **ZUPĀ**	.76
LAN **LAN**	NILA NI**LA**	GALUBOI GA**LU**BOI	AZUL **ASUL**		BLEU **BLÜ**	BLAU **BLAU**	.76
MI **MI**		RIS **RIS**	ARROZ A**RO**S		RIZ **RIS**	REIS **RAIS**	.71
TU **TU**	DHARTI **DART**I		TIERRA TI**ER**A		TERRE **TER**	ERDE **ERD**Ă	.71
TIE LU **TIELU**	REL **REL**	RIELS **RIEL**S	BARRERA BA**RER**A	RERU **RERU**	RALE **RAL**	RELING **REL**IN	.71
CHOU **TCOU**		VID[IET] **VID**-	VI **VI**		VISION **VI**ZIŌ		.67
SHI **CI**	KHUSH K**UC**		PLAC[ER] **PLA**S-	TANOSHIMI TANO**CI**MI	PLAI[RE] **PLE**-	LUST **LU**ST	.65
LI **LI**			FORTE **FOR**TE		FORT **FOR**	FORT **FOR**	.65
RH GU **RGU**		SLUH **SLU**	OREJA **ORE**HA		OREILLE **ORE**I	OHR **OR**	.65
LEI **LEI**		KLASS **KLAS**	CLASE **KLAS**E		CLASSE **KLAS**		.65
DA **DA**		SHCHI- ROK[IOI] CTCI**RO**K-	GRAND[E] **GRA**ND-		GROS **GRO**	GROSS **GRO**S	.65

is respelled in letters representing Loglan speech sounds, with the letters in bold face indicating the speech sounds shared with the Loglan word. As this table indicates, the common features of English, Spanish, French and German, which are spoken by 52 per cent of the target population, predominate in the determination of these high-scoring Loglan words. Because of its great number of speakers and its typically short words, Chinese also makes a contribution. Russian and Japanese show up with the smallest frequency. Hindi, with its short, consonant-rich words, is intermediate despite its slight similarity to the other Indo-European languages.

butes" that have long troubled Western thought. It turns out that these distinctions are nonessential in a logical grammar. We wish to impose as little metaphysics as possible upon the speakers of Loglan; therefore we have avoided them.

Not all Loglan predicates are of this five-letter form. Complex terms may be compounded of two or more elementary roots; for example, the word *rizdonsu* means "to reason" (literally "give reasons"), from *rizna* (reason) and *donsu* (give). Such terms have characteristic eight- or 11-letter forms. This arrangement conforms to the mechanism found in natural languages which interrelates the frequency of use of any word, its length and the number of other words of that length in the vocabulary. The late George Kingsley Zipf of Harvard University and other investigators have shown not only that the most frequently used words in any natural vocabulary are the shortest words, but also that there are much fewer short words than long ones. Conversely, the infrequently used words of a language tend not only to be numerous but also to be long. This empirical finding has been carefully worked into the formal structure of the Loglan vocabulary. Whether they be simple five-letter or complex eight- and even 11-letter terms, all of the Loglan predicates are instantly identifiable by their phonetic forms.

The other classes of Loglan words, as shown in the table at the right, have correspondingly recognizable phonetic forms, and they equally reflect the results of modern logical analysis of grammar. In collapsing the conventional European categories of noun, verb, adverb and adjective, the Loglan predicate embodies the realization that all such words may be treated alike for logical purposes. They share the distinguishing property of extralinguistic reference. They are the descriptive terms for the multitude of empirically distinguishable objects, actions, qualities and so on with which any language must deal. But formally considered, they are the interchangeable counters of the linguistic transactions with which logic is concerned. Ignoring the distinctions between nouns, verbs, adjectives and adverbs, Loglan draws other distinctions that conventional grammar either does not draw or draws faintly. Thus all the emotive or attitudinal elements of Loglan speech form a single phonetically distinct class. Such elements are called indicators. They do not refer; they only indicate the attitude of the speaker toward what he says, and form a category that embraces such expressions as "yes," "no," "please," "hello," "ouch" and diverse others. Similarly, all the logical elements of speech are formally distinguished in Loglan. These are the words, or parts of words, in any language that relate other words to one another. Their reference is intralinguistic; in short, they impart to speech its structure. In Loglan these logical elements occupy several phonetic categories: most numerous are the operators, of which there are several subtypes; then there are the five connectives, the conjunctions of ordinary grammar.

The phonetic distinctions among the form-classes both transcend and reinforce the logico-grammatical distinctions among them. No matter how Loglan words are combined into sentences, their distinctive character remains. Thus all predicates, and only predicates, have adjacent multiple consonants; all indicators and sentential operators, and only these words, contain vowel diphthongs. On the other hand, all Loglan words except proper nouns end in vowels.

These regularities not only serve the purposes of grammatical distinction; they lead to a second interesting result. No matter how words of any of these classes are ordered in the flow of speech, their lexical separateness and their grammatical identity may be rapidly resolved [*see table on page 61*]. The reader is challenged to find a combination of permissible word-forms that does not resolve. This remarkable property of Loglan contributes in turn to what may ultimately be one of its most useful characteristics: its audiovisual isomorphism. But more of this important matter later.

We have said that logic and mathematics were our models. Therefore one might expect Loglan to be terse, explicit and symbolically compact, and that the logical structure of its sentences would be plainly apparent. In large measure the formal separation of empirical content from logical structure achieves this result. Thus the logically manipulable aspect of any statement in Loglan is expressed by its 90 operators and connectives together with a handful of attitude indicators. These 112 tiny words [*see table on page 60*] carry the entire burden of Loglan grammar and syntax, and are always immediately recognizable for what they are. Many of them are represented by distinctive symbols in the written form. In consequence we expect the thinker in Loglan to find it easy to concentrate on the formal structure of his ideas, because the grammatical apparatus of the language will always leave that structure starkly revealed.

This is not all. Loglan not only separates the logical from the empirical and attitudinal components of speech, but Loglan grammar itself is nothing but a linguistic extension of symbolic logic. Under logical analysis the English sen-

LOGLAN WORD-CLASS		PHONETIC FORM[S]
CONNECTIVES		.V
INDICATORS		V'V
OPERATORS	SIMPLE OPERATORS	CV
	SENTENTIAL OPERATORS	CV'V
	COMPOUND OPERATORS	CV'CV
PREDICATES	SIMPLE PREDICATES	CV'C/CV OR CCV'/CV
	COMPLEX PREDICATES [TWO-TERM]	CV'C / CCV' /CV'C/CV CV'C / CCV' /CCV'/CV
	COMPLEX PREDICATES [THREE-TERM]	CV'C / CCV' /CV'C, CV'C / CCV' /CCV' } /CV'C/CV CV'C / CCV' /CV'C, CV'C / CCV' /CCV' } /CCV'/CV
PROPER NAMES		LU —C

LOGLAN WORD-CLASSES reflect the syntactical concepts incorporated in the grammar of the language from symbolic logic and are readily identified by their characteristic phonetic forms (*second column from left*). Thus any one-letter word is a logical "connective" and is recognizable as

tence "He is a man" comes apart into two elements: the so-called propositional function "is a man," written *f( )*; and the variable "he," written *x*. The complete scheme for this kind of sentence may then be written *f(x)*. The corresponding Loglan sentence form is *xP*, where *x* is any variable and *P* is any predicate. Thus "He is a man" would be written "*da mreni*" in Loglan, for no coupling operation between variable and predicate is necessary. Consequently Loglan predicates turn out to be nothing more nor less than the propositional functions of symbolic logic. The predicate *mreni* does not really have the same meaning as the English noun "man"; it carries with it the force of an assertion ". . . is a man" or ". . . is manlike" and so corresponds to *f( )*. (So also the meaning of *blanu* is best captured by the expression ". . . is blue" or ". . . is a blue object"). Similarly the five free Loglan pronouns (*da, de, di, do, du*) are precisely equivalent to the variables of logic; they do not really correspond to English pronouns, with their limiting inflections of number, gender and case, but are more appropriately interpreted as the *x*, *y* and *z* of the mathematician.

The English sentence "All men are rational" may serve to illustrate the logical function of other crucial little words in Loglan. The sentence in Loglan reads: "*Radaku da mreni u da rizdonsu.*" Here the operation of quantification ("all") is performed by the special expression "*radaku,*" which may be rendered "for any *x*. . . . " The little word *u* performs

EXAMPLE	ENGLISH WORD-CLASSES REPRESENTED	MAXIMUM SIZE OF CLASS	PROBABLE SIZE OF CLASS	PROBABLE FREQUENCY RANGE
I [*EE*] AND	THE MAJOR CONJUNCTIONS	5	5	WITHIN FIRST 500
IA [*YAH*] YES	EXPLETIVES, MANY ATTITUDINAL EXPRESSIONS	25	22	
DA [*DAH*] HE, SHE, IT	ALL PRONOUNS, NUMBERS, TENSE FLEXIONS, MINOR CONJUNCTIONS, MATHEMATICAL SYMBOLS, NAMES OF LETTERS, PUNCTUATION MARKS; MOST ADVERBS AND SOME PREPOSITIONS	80	80	WITHIN FIRST 1,000
SOI [*SOY*] SO, THEREFORE		550	100	
FACI [*FAH'/SHEE*] SOON		6,400	20	
BORSI [*BOR'/SEE*] BOY GROCA [*GRO'/SHAH*] GROW	ALL COMMON NOUNS, ADJECTIVES, AND VERBS; SOME ADVERBS AND MOST PREPOSITIONS	86,400	8,000	WITHIN FIRST 10,000
GROMAKSO [*GRO'/MAHK/SO*] CULTIVATE FROM GROCA = GROW, MAKSO = MAKE		103,296,000	?	?
GROMAKSENSI [*GRO'/MAHK/SEN/SEE*] AGRONOMY FROM GROCA = GROW, MAKSO = MAKE, SENSI = SCIENCE		VERY LARGE	?	?
LU TAM [*LOO TAHM*] = TOM LU MISISIPIS [*LOO MEESEESEEPEES*] = THE MISSISSIPPI	ALL PROPER NOUNS	VERY LARGE	?	ENTIRE FREQUENCY RANGE

a vowel preceded by a glottal stop (.v). Any vowel diphthong (v'v) is an "indicator" of the attitude of the speaker toward what he says. Any open monosyllable, that is, a consonant followed by a vowel or diphthong (cv or cv'v), or series of such syllables (cv'cv) is an "operator," a formal logical, mathematical or grammatical element of the statement in which it occurs. Any five-, eight- or 11-letter word containing a multiple consonant and ending in a vowel is a "predicate," a class of words that takes in the nouns, adjectives, verbs and adverbs of familiar grammars. Proper names may have any length and consonant-vowel pattern, but they must be preceded by the name operator *lu*, must end in a consonant and must not include *lu* preceded by a consonant. As the columns at right indicate, the use (frequency range) of these words is roughly proportional to their length and is inverse to the number in each class.

the logical operation of implication (If . . . , then . . .) and is one of the five connectives that express the principal logical relations between propositions [*see tables below and on next page*]. The Loglan sentence thus corresponds faithfully to the symbolic form of the statement: $(x)\,[f(x)\,g(x)]$, which may be read "For any x, if x is a man, then x is rational."

Multi-place predicates are handled in Loglan precisely as they are in symbolic logic, that is, by arranging the predicates in meaningful sequence. For example, the direct and indirect objects of the verb "to give" in "x gives y to z" are written in logic as $g(x,y,z)$ and in Loglan *da donsu de di*. Loglan uses no prepositions, but establishes the meaning of the places in its multi-place predicates by

SOUNDS	SIGNS	APPROXIMATE ENGLISH EQUIVALENTS
	5 CONNECTIVES	
A E I O U	↔ . ... o →	MEANS, AND, [FULL STOP], OR, IMPLIES
	77 OPERATORS	
DA DE DI DO DU MI MA MU TU TI TA	X Y W H Q	IT_1, IT_2, . . . , IT_5 [*ALSO* HE, HIM, SHE, HER, ETC.] I, WE [HE AND I], WE [YOU AND I], YOU THIS, THAT
LE LI LA LU VI VA VU		THE-, THIS-, THAT-, THE ONE NAMED- HERE, THERE, FAR AWAY
PA NA FA GA CI CA		BEFORE, NOW, AFTER, DURING NEAR [TIME], FAR [TIME]
NO NU [NIU]	~ ← [←]	NON- [*ALSO* NOT], UN- [*ALSO* PASSIVE VOICE OF TWO-PLACE PREDICATES]
PE PO PU		OF, -ING [*ALSO* TO-], -NESS
RA RE RI RO RU SU BO SO CO JO LO GO		ALL, MOST, MANY, SOME, FEW, ENOUGH BECAUSE, SO THAT, FOR, WITH [*ALSO* BY], LIKE, ACCORDING TO
NI NE TO TE FO FE SI SE VO VE MO	0 1 2 3 4 5 6 7 8 9 Ø	ZERO [*ALSO* NO], ONE [*ALSO* A/AN], TWO, THREE, FOUR- FIVE, SIX, SEVEN, EIGHT, NINE, -THOUSAND
ZA ZE ZI ZO ZU BI FI FU SA PI CE CU BE BA BU	× ' − + / = < > . . , √ ! ( )	TIMES, TO THE -TH POWER, MINUS, PLUS, OVER EQUALS, IS LESS THAN, IS GREATER THAN -TH, POINT, SUB-, THE -TH ROOT OF FACTORIAL, PARENTHESIS, CLOSE PARENTHESIS
KA KE KI KO KU JA JE JI JU	" , : —	QUOTE, WHO/WHICH, [COMMA], THAT [*ALSO* COLON], [DASH] [CAPITALIZE], [INDENT], [UNDERLINE], [CENTER LINE]
	22 INDICATORS	
IO IU		HELLO, GOODBYE
IA IE II AI AE AO		CERTAINLY, PROBABLY, MAYBE I WILL, I WANT, I HOPE
EA EI EO EU OA OE OI OU		WHAT? IS THAT SO? PLEASE. SUPPOSE. MUST, SHOULD, MAY, IT DOESN'T MATTER.
UA UE UI UO UU AU		WHAT! WELL! HOW NICE! THANKS! SORRY! OUCH!
	9 SENTENTIAL OPERATORS	
TUI TUE TAI KAI NIE NIO PIU SOI NIU		IN GENERAL, MOREOVER, ABOVE ALL, SUMMING UP HOWEVER, IN ANY CASE, IN PARTICULAR, THEREFORE UN- [*ALSO* PASSIVE VOICE OF THREE-PLACE PREDICATES]

ONE HUNDRED TWELVE "LITTLE" WORDS carry the whole burden of Loglan logic and grammar. Once these words have been learned, the student will have acquired mastery over the entire grammatical apparatus of the language, together with the many logical and mathematical devices which have been built into that grammar. The words as sounded, or spelled, are listed in the column at left. The logically more significant words have formal "signs," shown in the middle column, which adapt them for written manipulation in the algebra of symbolic logic. Some of these signed words correspond to punctuation marks, which are spoken as well as written in Loglan. The English equivalents of all the words are approximated in the column at right. There are four classes of these "little" words. Each class is identified by its characteristic phonetic pattern. The connectives are the five vowel sounds; they include not only the familiar connectives "or" and "and" but the specialized logical concepts of equivalence and implication. The operators are all consonant-vowel words. This large class includes concepts represented in familiar languages by numbers, pronouns, prepositions, verb endings, the most common adjectives and adverbs, mathematical signs and of course punctuation marks. Nonetheless all the operators have a common function: to facilitate inference, cross reference, manipulation and transformation within the flow of speech. They may be joined together to express compound operations; for example, *rada* ("all of these"). The indicators are vowel diphthongs, and relate the attitude of the speaker to what he says. The sentential operators are all composed of a consonant followed by a vowel diphthong; they serve various rhetorical functions in the context of sustained speech.

syntactical rules. Many problems of conventional grammar are solved at one stroke by this device. Thus the comparative adjective "shorter than" is rendered without confusion in Loglan by the same word as the absolute adjective "short." Thus, *da cortu* (pronounced "short too") means "He is short," while the same word *cortu* means "is shorter than" in the context of *da cortu de*. Similarly, *da farfu* ("He is a father") employs the same predicate in one-place form that is used with two places in *da farfu de* ("*X* is the father of *y*").

From its logical syntax Loglan gains great simplicity and rigor; yet it is still capable of reproducing—if one insists—all of the conventional grammatical distinctions. Unmodified, the predicate *prano* means "runs" or, alternatively, "is a runner," and so serves as a verb or a

a

THE CHIEF OF THE GROUP OF ARMY GUIDES SAID THAT HE WAS PLEASED TO SAY THAT HE HAD KNOWN THE FACTS FOR A LONG TIME. "THEY CERTAINLY DID NOT DECEIVE ME," HE SAID FORCEFULLY, "EVEN THOUGH THEY TRIED"; AND ORDERED SEVEN HUNDRED OF THEM LOCKED UP IN THEIR ROOMS.

b

LE NARMI GLIDA GRUPA CEFLI PA SEDBO KOKO DA PA NU PLUCI PO SEDBO KO DA PAPACA SAZNO LE RI FEKTO . . . KA IA NO DE MANDU MI KA DA PA FORLI SEDBO KA NU NIE DE PA TRATI KA E PA DJORI SENINI DE NU LAKSO VI LE RU KRUMA PE DE

c

LENA'RMIGLI'DAGRU'PACE'FLI.PASE'DBOKOKO.DAPANU PLU'CI.POSE'DBOKO.DAPAPACASA'ZNO.LERIFE'KTO.IKA IA'NODEMA'NDUMI.KADAPAFO'RLISE'DBO.KANUNIE. DEPATRA'TIKA.EPADJO'RISE'NINIDE.NULA'KSOVILE RUKRU'MAPEDE

d

CVCV'CCVCCV'CVCCV'CVCV'CCV.CVCV'CCVCVCV.CVCVCV CCV'CV.CVCV'CCVCV.CVCVCVCVCV'CCV.CVCVCV'CCV.VCV ɣV'CVCVCV'CCVCV.CVCVCVCV'CCVCV'CCV.CVCVCɣV. CVCVCCV'CVCV.VCVCCV'CVCV'CVCVCV.CVCV'CCVCVCV CVCCV'CVCVCV

e

CVCV'**CC**V**CC**V'CV**CC**V'CVCV'**CC**V.CVCV'**CC**VCVCV.CVCVCV **CC**V'CV.CVCV'**CC**VCV.CVCVCVCVCV'**CC**V.CVCVCV'**CC**V.VCV ɣV'CVCVCV'**CC**VCV.CVCVCVCV'**CC**VCV'**CC**V.CVCVCɣV. CVCV**CC**V'CVCV.VCV**CC**V'CVCV'CVCVCV.CVCV'**CC**VCVCV CV**CC**V'CVCVCV

f

CV **CVCCV CCVCV CCVCV CVCCV** CV **CVCCV** CVCV.CVCVCV **CCVCV** CV **CVCCV** CV.CVCVCVCV **CVCCV** CVCV **CVCCV** VCV ɣV'CVCV **CVCCV** CV.CVCVCV **CVCCV CVCCV** CVCVCɣV. CVCV **CCVCV** CV.VCV **CCVCV** CV'CVCVCV.CV **CVCCV** CVCV CV **CCVCV** CVCV

g

CV CVCCV CCVCV CCVCV CVCCV CV CVCCV CV CV CV CV CV CCVCV CV CVCCV CV CV CV CV CV CVCCV CV CV CVCCV VCV ɣV'CVCV **CVCCV CV CV CV CV CVCCV CVCCV** CVCVCɣV. CVCV **CCVCV** CV.VCV **CCVCV CV CV CV CV CV CVCCV CV CV CV CCVCV CV CV**

h

. . . . . .
. . . . . **V CV**
ɣV **CV CV** . . . . . **CV CV CV**ɣV
CV CV . . . . . **CV V CV** . . . . . .
. . . . . .

i

LE NARMI GLIDA GRUPA CEFLI PA SEDBO KO KO DA PA NU PLUCI PO SEDBO KO DA PA PA CA SAZNO LE RI FEKTO I KA IA NO DE MANDU MI KA DA PA FORLI SEDBO KA NU NIE DE PA TRATI KA E PA DJORI SE NI NI DE NU LAKSO VI LE RU KRUMA PE DE

j

LE NARMI GLIDA GRUPA CEFLI PA SEDBO KOKO DA PA NU PLUCI PO SEDBO KO DA PAPACA SAZNO LE RI FEKTO . . . KA IA NO DE MANDU MI KA DA PA FORLI SEDBO KA NU NIE DE PA TRATI KA E PA DJORI SENINI DE NU LAKSO VI LE RU KRUMA PE DE

k

LE NARMI GLIDA GRUPA CEFLI PA SEDBO: : X PA ←PLUCI PO SEDBO: X PAPACA SAZNO LE RI FEKTO . . ."IA⌐ Y MANDU MI" X PA FORLI SEDBO "←NIE Y PA TRATI" · PA DJORI 700Y ←LAKSO VI LE RU KRUMA PE Y

l

LE **NGG**R**C** P**S**: ; X P←**P** PO **S**: X PP**C**S**A** LE RI **F** . . ."IA⌐ Y **M** MI" X P**F**O**S** "←NIE Y P**T**" · P**D** 700Y ←**L** VI LE RU **K** PE Y

WRITTEN AND SPOKEN LOGLAN may be resolved easily into each other and reduced to purely symbolic expression. In *a* at upper left is an English sentence constructed of words whose Loglan equivalents are shown in other tables. The passage is translated into written Loglan in *b*, and in *c* is transcribed as it might sound if read rapidly with word identity lost but with a natural pattern of stresses (') and pauses (.). The spoken transcript is then resolved in *d* into its consonant-vowel (cv) pattern, with stresses and pauses and the occurrence of semivowels (ɣ) noted. The adjacent consonants that identify predicates appear in boldface in *e*. Since pairs of consonants preceding a stressed vowel (ccv') always begin a predicate, and pairs of consonants that follow a stressed vowel (v'cc) always occur in the middle of a predicate, and since predicates have only limited numbers of phonemes, the predicates may be resolved as in *f*. Most of the unresolved sequences consist of consonant-vowel alternations; these can only be operators, and they are resolved in *g*. The remainder of the passage is now easily resolved (*h*) into connectives (vowels preceded by a glottal stop, or .v), indicators (diphthongs, or ɣv) and sentential operators (cɣv). With the spoken passage thus resolved into words, it is restored to full phonemic form (*i*), and the compound operators and full-stop are identified in *j* to restore the passage to original written form. The punctuation may be carried a step further (*k*) with translation of the connectives and certain operators into their conventional signs as shown in the chart on opposite page. The passage may then be completely mathematized, with predicates reduced to abbreviations and most operators represented by signs, to expose its logical structure (*l*).

"VERB" FORMS

DA DONSU	HE GIVES.
DA DONSU DE	HE GIVES IT.
DA DONSU DE DI	HE_1 GIVES IT TO HIM_2.
DA NU DONSU	IT IS A GIFT.
ETC.	
DA NIU DONSU	HE IS A RECIPIENT.
ETC.	
DA NA DONSU	HE NOW GIVES.
DA PA DONSU	HE GAVE.
DA FA DONSU	HE WILL GIVE.
DA PAPA DONSU	HE HAD GIVEN.
DA PANA DONSU	HE HAS GIVEN.
DA PAFA DONSU	HE WILL HAVE GIVEN.
ETC.	
DA NAGA DONSU	HE IS NOW GIVING.
ETC.	
DA PAGANA DONSU	HE HAS BEEN GIVING.
ETC.	

"ADVERB" FORMS

DA RANA DONSU	HE ALWAYS GIVES.
DA RENA DONSU	HE USUALLY GIVES.
DA RINA DONSU	HE OFTEN GIVES.
ETC.	
DA PACI DONSU	HE RECENTLY GAVE.
DA PACA DONSU	HE GAVE LONG AGO.
DA FACI DONSU	HE WILL SOON GIVE.
ETC.	
DA VI DONSU	HE GIVES HERE.
DA VA DONSU	HE GIVES THERE.
DA VU DONOSU	HE GIVES FAR AWAY.
DA RAVI DONSU	HE GIVES EVERYWHERE.
ETC.	
DA PACAGAVI FACI DONSU	SOON HE WILL HAVE BEEN
ETC.	GIVING HERE FOR A LONG TIME.

NEGATIVES

DA NO DONSU	HE IS A NON-GIVER.
NO DA DONSU	HE DOES NOT GIVE.
NI DA DONSU	NONE OF THEM GIVES.

"NOUN" FORMS

LE MRENI	THE MAN
LI MRENI	THIS MAN
LA MRENI	THAT MAN
RA MRENI	ALL MEN
RE MRENI	MOST MEN
RI MRENI	MANY MEN
ETC.	
NI MRENI	NO MEN
NE MRENI	A MAN, ONE MAN
TO MRENI	TWO MEN
ETC.	
LE TE MRENI	THE THREE MEN
RA LE TE MRENI	ALL OF THE THREE MEN
ETC.	

ABSTRACT "NOUNS"

LE PO DONSU	THE GIVING
LE PO PRANO	THE RUN
LE PU DONSU	THE GENEROSITY
LE PU MRENI	THE MANLINESS

"ADJECTIVE" FORMS

NE LALDO MRENI	AN OLD MAN
NE DONSU MRENI	A GENEROUS MAN
NE LALDO DONSU MRENI	A TRADITIONALLY [?] GENEROUS MAN
NE DONSU LALDO MRENI	A GENEROUSLY [?] OLD MAN
NE MRENI KE LALDO	A MAN WHO IS OLD
NE MRENI KE DONSU	A MAN WHO IS GENEROUS
NE MRENI KE DONSU E LALDO	A MAN WHO IS GENEROUS AND OLD
NE MRENI KE DONSU DE	A MAN WHO GIVES IT
NE MRENI KE DONSU DE DI	A MAN WHO GIVES IT TO HIM
LE LALDO MRENI KE PA DONSU TE DA LI SE PRANO	THE OLD MAN WHO GAVE THREE OF THEM TO THESE SEVEN RUNNERS
ETC.	

IDENTITIES

DA BI LU DJAN	HE IS JOHN.
DA BI LE MRENI	HE IS THE MAN.
DA BI LE LALDO MRENI KE PA DONSU TE DE LI SE PRANO	HE IS THE OLD MAN WHO GAVE THREE OF THEM TO THESE SEVEN RUNNERS.
ETC.	

COMPOUND FORMS

DA PRANO O DZORU	HE RUNS OR WALKS.
DA PRANO E DZORU	HE RUNS AND WALKS.
ETC.	
DA O DE PRANO	HE_1 OR HE_2 RUNS.
DA E DE PRANO	HE_1 AND HE_2 RUNS.
ETC.	
DA PRANO O DE DZORU	HE_1 RUNS OR HE_2 WALKS.
DA PRANO I DE DZORU	HE_1 RUNS AND HE_2 WALKS.
DA PRANO U DE DZORU	IF HE_1 RUNS THEN HE_2 WALKS.
DA PRANO A DE DZORU	HE_1 RUNS IF AND ONLY IF HE_2 WALKS.
DA PRANO BO DE DZORU	HE_1 RUNS BECAUSE HE_2 WALKS.
DA PRANO LO DE DZORU	HE_1 RUNS LIKE HE_2 WALKS.
ETC.	
BO DE DZORU KI DA PRANO	BECAUSE HE_2 WALKS, HE_1 RUNS.
ETC.	
DA PRANO NA DE DZORU	HE_1 RUNS WHEN HE_2 WALKS.
DA PRANO PA DE DZORU	HE_1 RUNS AFTER HE_2 WALKS.
DA PRANO VI DE DZORU	HE_1 RUNS WHERE HE_2 WALKS.
ETC.	
NA DE DZORU KI DA PRANO	WHEN HE_2 WALKS HE_1 RUNS.
ETC.	

UNIVERSALS

RADAKU DA PRANO U DZORU	ANYONE WHO RUNS CAN WALK.
RANAKU DA PRANO NA DE DZORU	HE_1 RUNS WHENEVER HE_2 WALKS.
RAVIKU DA PRANO VI DE DZORU	HE_1 RUNS WHEREVER HE_2 WALKS.
RADARODEKU DA DONSU U DA DONSU DE	EVERYONE WHO GIVES GIVES SOMETHING.

ATTITUDINAL FORMS

UA DA PRANO	WHAT! HE RUNS? [ANGER]
UE DA PRANO	WELL! SO HE RUNS. [SURPRISE]
UI DA PRANO	HOW NICE THAT HE RUNS! [PLEASURE]
ETC.	
EI DA PRANO	DOES HE RUN?
EA DA PRANO	WHO RUNS?
DA PRANO EA DE	WHERE DOES HE RUN?
ETC.	
IA DA PRANO	YES; HE RUNS.
IE DA PRANO	HE PROBABLY RUNS.
II DA PRANO	PERHAPS HE RUNS.
IA NO DA PRANO	NO; HE DOESN'T RUN.
ETC.	
AI MI FA PRANO	YES; I WILL RUN.
AE MI FA PRANO	I WANT TO RUN.
AO MI FA PRANO	I HOPE TO RUN.
AI NO MI FA PRANO	NO; I WON'T RUN.
ETC.	
OA MI FA PRANO	I MUST RUN.
ETC.	

LOGLAN GRAMMAR derives great flexibility and variety from manipulation of the 112 "little words" that do all of its work. These words are defined and their functions explained in the table on page 60. As demonstrated here, it is the little words that determine whether a predicate—a term of extralinguistic reference, such as *donsu* and *prano*—is to serve in a given statement as a noun, verb, adjective or adverb, as in more familiar grammars. Thus *pa* (before), *na* (now) and *fa* (after) give the predicate *donsu* (give) the function of a verb (*upper left*) and "conjugate" it through the future, present and past tense. Compound forms of these operators yield the compound tenses; for example, *papa* (before-before) indicates the pluperfect tense. In such combinations they not only duplicate all of the familiar grammatical forms but go far beyond to express relationships that can be only clumsily approximated in the natural languages, as is indicated by the translation of the compound operator *pacagavi faci* at center left. The flexibility of the system is suggested further by the transformations of *donsu* (in this table "give," "giver," "gift," "generous," "generously," "generosity," and so on) in accord with its association with operators and connectives or its place in a multiple predicate.

noun [*see table on opposite page*]. But should anyone wish explicitly to differentiate these meanings, it can easily be done. Thus *da na prano* means "He is now running," for *na* is the tense-operator of present time. This expression clearly communicates the sense of verbal action, and leaves the simpler expression *da prano* ("He is a runner") with the categorical, timeless sense of the predicate which we would associate with the English noun. Similarly "He talked" is *da pa takla*, for *pa* is the operator of past time. In exactly the same way predicates that we would consider adjectives can be given time specification. Thus *da pa blanu* means "It was blue" and *da fa blanu* means "It will be blue" in senses that now involve explicit use of the English verb, while *da na blanu* expresses the clearly verbal property of being only temporarily blue, as might be said of a flashing light.

The three tense-operators *pa*, *na* and *fa* constitute the elements out of which the whole system of Loglan verb tenses is constructed. Here again word order plays a decisive role. Thus *da panu kamla* means "He has come" (literally "He before-now comes"), *da papa kamla* means "He had come" ("He before-before comes") and *da pafa kamla* means "He will have come" ("He before-after comes"). On the other hand, *da fapa kamla* ("He after-before comes") precisely expresses a compound tense only approximately suggested by the past progressive "He was going to come".

Loglan is, of course, an analytical language. Its predicates are never inflected, and are free to be combined in any order. Thus the serial predicate *venri cortu mreni* means ". . . is a very short man." Each modifier qualifies the meaning of the immediately subsequent word exactly as in English. But unlike the corresponding English words—one of which is an adverb, the other an adjective and the third a noun—it is possible to recombine the Loglan words in any order without doing violence to their essential meanings. Thus *da venri mreni cortu* means "X is a very manlike shortthing," in which *venri* modifies *mreni*, and *mreni* modifies *cortu*. *Da mreni cortu venri*, on the other hand, means "X is a masculinely short extreme thing," and *da cortu venri mreni* means "X is a shortly extreme man." These clumsy English sentences only approximately convey the three quite different perceptions that are expressed by simple rearrangement of the serial predicate in Loglan. With the free range of imaginative permutation available in its permissive syntax, we expect Loglan to be a metaphor-rich language, more similar to Chinese in this respect than to the structurally more confining European tongues. The formal property of metaphor facilitation has a service to render to the exercise of "creative imagination," whether in science or poetry.

Another feature of Loglan that we hope will interest linguists and psychologists—and perhaps computer engineers as well—is that the spoken and written forms of the language are isomorphic. That is, each element of the spoken utterance stands in one-to-one correspondence with some element in the written form. This is saying a good deal more than that Loglan is written phonetically; in addition, all the "punctuation marks" of Loglan are spoken, and even the spaces between its written words, its paragraphing, indentation, italicizing and the like have formal analogs in the structure of the spoken form [*see tables on pages 60 and 61*]. No other symbolism of which we know has this audiovisual isomorphism; no natural language approaches it, and the symbolisms of mathematics and logic do not even attempt it (as is indicated by the almost total lack of parallelism between the way logical expressions are written and the way they are read). Perhaps the most nearly isomorphic of existing symbolic systems is the notation of musical composition: a symbolism that is not meant to be rendered into human speech at all. In this sense Loglan's isomorphism is a unique linguistic property that we think will have some interesting experimental consequences.

It is a surprising feature of the history of the natural languages that the forms of speech and the forms of writing have had little effect on each other until comparatively recent times. Speech is an activity shared by all members of any society; writing, when it exists at all, by the few. As a consequence the forms of writing tend to be remote from the forms of "vulgar" speech. It is only recently, in our own highly literate societies, that writing has come to adopt the forms of audible speech. Even "literary" sentences are now shorter; dialogue in the hands of modern writers tends more and more clearly to imitate audible forms. But a process of reciprocal influence also seems to be well under way. Speakers are more and more often heard to use devices that formerly belonged exclusively to the written form. Consider the still somewhat slangy use of the spoken word "period" to indicate the unqualified nature of an assertion, or the even more frequent use of the spoken words "quote" and "unquote" in precise speech. Thus as writing and reading approach speaking and listening as universal arts, we should expect their forms to grow more similar if not actually to coalesce.

Loglan experimentally pushes this historical tendency to its extreme. In Loglan the formal structure of writing is identical with that of speech. This formal property in no way guarantees, however, strict isomorphism of behavior. It should be interesting to observe its effects upon the actual speaking and writing of the learners of the Loglan game. It is especially tempting to consider how children might respond; the growth of capacity to read and write might closely parallel that of speech itself, with interesting consequences for the early development of the rational powers. Finally, the audiovisual isomorphism of Loglan should permit its spoken form to be mechanically and correctly recorded in writing and conversely should permit its written form to be reproduced mechanically in intelligible speech. In short, the isomorphism of Loglan, while unprecedented and therefore ungaugeable, may yet prove to be one of its most fruitful properties.

At present Loglan has a tested grammar; a core vocabulary of nearly 1,000 elementary terms has been constructed, and complex terms based on these elements are rapidly accumulating. Our object is to test the adequacy of this list of elementary predicates by constructing from them the first 4,000 most frequent concepts of the European languages before publishing a dictionary. If so much can be demonstrated, it is our hope that the remainder of a vocabulary of any desirable size and specificity can be easily generated in use. The model language is thus very nearly finished. While there are as yet no speakers, we are hopeful that Loglan primers and laboratory manuals will soon be available.

Loglan is already "alive," however, in the interesting sense that those of us who have been closely associated with it have begun to sense the parsimony of its metaphysics, its liberating style of metaphor, its incisive modes of thought. We are by no means certain yet that Loglan is a thinkable language, let alone a thought-facilitating one. But there is some prospect that this instrument will facilitate experimental investigation into the distinguishing human faculty of symbolic communication.

Solar Particles and Cosmic Rays

Magnetic fields in the galaxy may constitute an "accelerator" for cosmic rays. Recent studies have examined the question of whether the sun and similar stars inject particles into this accelerator

by Kinsey A. Anderson

Throughout the past 35 years investigators concerned with the origin of the enormously energetic particles called cosmic rays have been assured of progress along at least one line. Each time they have contrived experiments to detect more energetic cosmic rays they have found them. With each upward step in energy, however, it has become more difficult to imagine where cosmic rays come from or to conceive of a process by which they acquire such enormous energies. It is true that the sun showers the earth not only with electromagnetic radiation but also with particles; during periods of high sunspot activity gusts of energetic solar particles frequently rush into the earth's atmosphere along the lines of force of the earth's magnetic field. But almost all of these particles enter the upper atmosphere at much smaller velocities than do cosmic rays. The great majority of cosmic rays arrive with energies above 500 million electron volts, some with energies of millions of billions of electron volts and a few with energies of more than a billion billion electron volts. Such energies are sufficient to overwhelm the deflecting force of the magnetic field and plunge the particles deep into the atmosphere, setting off cascades of secondary particles and electromagnetic radiation that reach the surface of the earth at all latitudes.

The best guess is that cosmic rays come from distant reaches of our galaxy. As messengers from those regions they have much to tell about processes that go on there. But even though cosmic rays may be remote in origin and truly cosmic in significance, the investigator must seek the clues to their meaning in the nearer regions of the universe. Thus one of the most hopeful theories about the genesis of cosmic rays bears similarities to purely terrestrial experience with the design of the great accelerators by which men have learned to invest atomic particles with energies in the cosmic-ray range. Thanks to the recent advances in man's knowledge of the sun, notably during the International Geophysical Year, that theory can now be subjected to further observational test.

It was the late Enrico Fermi who suggested that a "galactic accelerator" might push the cosmic rays up to their immense energies. He postulated that particles ejected from stars might wander into the weak magnetic fields associated with the clouds of dust and gas in the spiral arms of the Milky Way. Because the particles—the nuclei of hydrogen, helium and other elements in the stellar substance—are electrically charged, they would receive a tiny bump at each encounter with a magnetic field. Correspondingly, in a laboratory accelerator particles are bumped over and over again by electric fields to higher and higher energies. In the galactic accelerator, after millions of years and many such encounters, the particles would acquire the high energies of cosmic rays. If this process is to work, however, the particles must be shot from their sources with an energy above a certain critical minimum. The most powerful laboratory accelerators employ analogous injection systems. In the huge alternating-gradient synchrotron now being completed at the Brookhaven National Laboratory, for example, a voltage multiplier will bring protons (hydrogen nuclei) up to 750,000 electron volts, and a linear accelerator will push them to 50 million electron volts for injection into the synchrotron proper. There they will be accelerated to 30 billion electron volts.

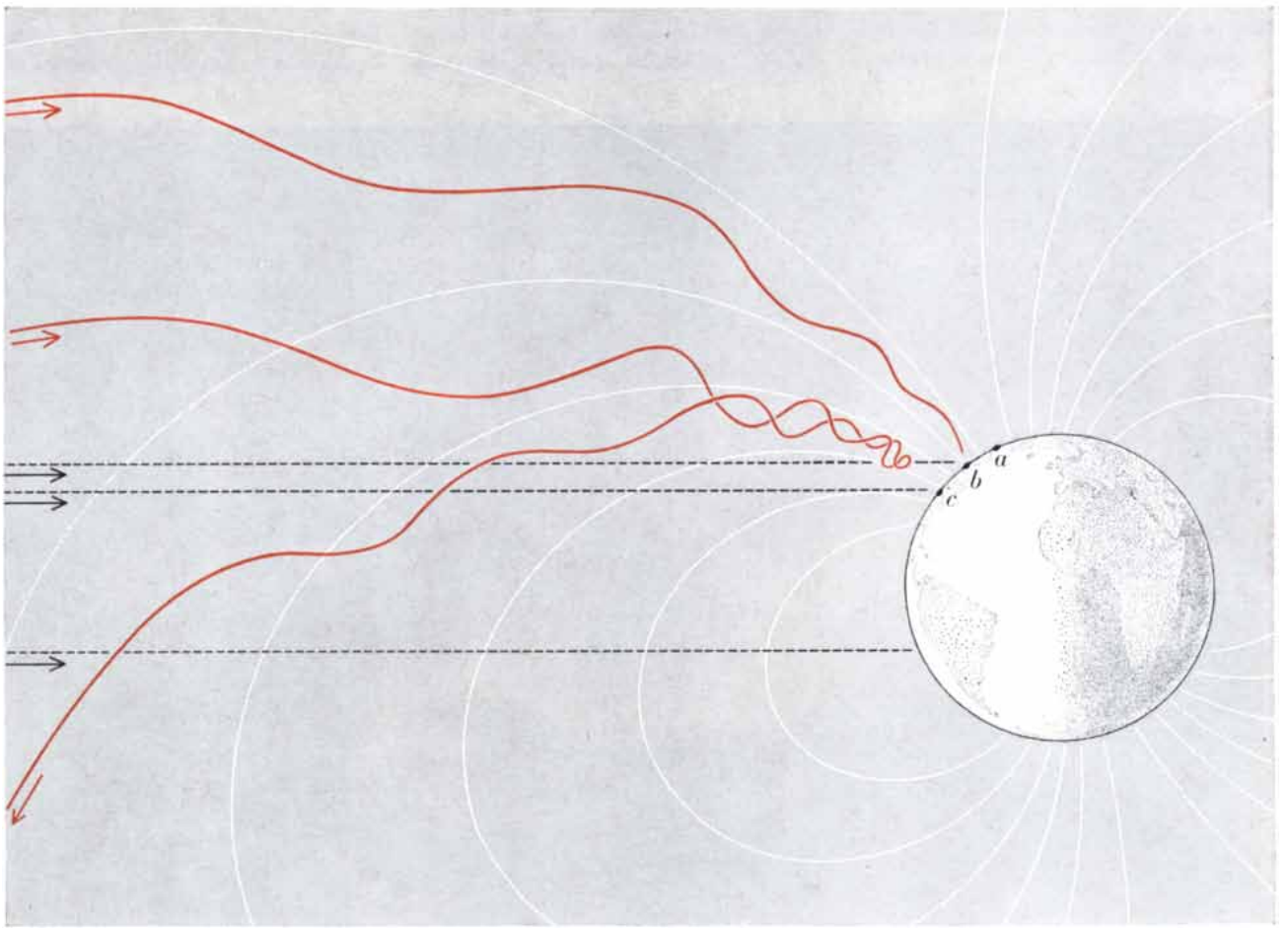
The question to be settled by solar observation, therefore, was whether the sun and stars like it furnish an adequate injection system. The most likely mechanism is the solar flare, the most violent activity on the face of the sun. Great flares that fired streams of particles into space with energies of several billion electron volts were observed on five occasions between 1942 and 1956. Prior to the I.G.Y., however, the infrequency and unpredictability of these events made it difficult to bring them under observation with the instruments then available. During the I.G.Y., with the sun under coordinated 24-hour surveillance by instruments on the ground, in high-altitude balloons and in artificial satellites, it was found that flares operate 15 per cent of the time to eject particles with energies somewhat lower than 500 million electron volts. Study of these relatively frequent events has continued for the past three years and has begun to supply data on which investigators can base tentative conclusions about the role of our sun in the production of embryonic cosmic rays.

The story of the I.G.Y. solar-flare investigations actually begins on February 23, 1956, more than a year before the I.G.Y. was formally inaugurated. On that date a great flare suddenly appeared in the midst of a group of sunspots. Shortly after the onset of the flare, solar particles with energies of several billion electron volts began plunging into the ionosphere. In fact, some of these particles were so energetic that they penetrated the earth's magnetic field and dense lower atmosphere and produced large effects in radiation counters at sea level even at the Equator. By stripping electrons from the neutral atoms in the upper atmosphere, the inrushing particles increased the number of ions in the ionosphere and thereby disrupted radio communications on earth, especially in the polar regions. Moreover, receivers measuring the level of radio noise from the

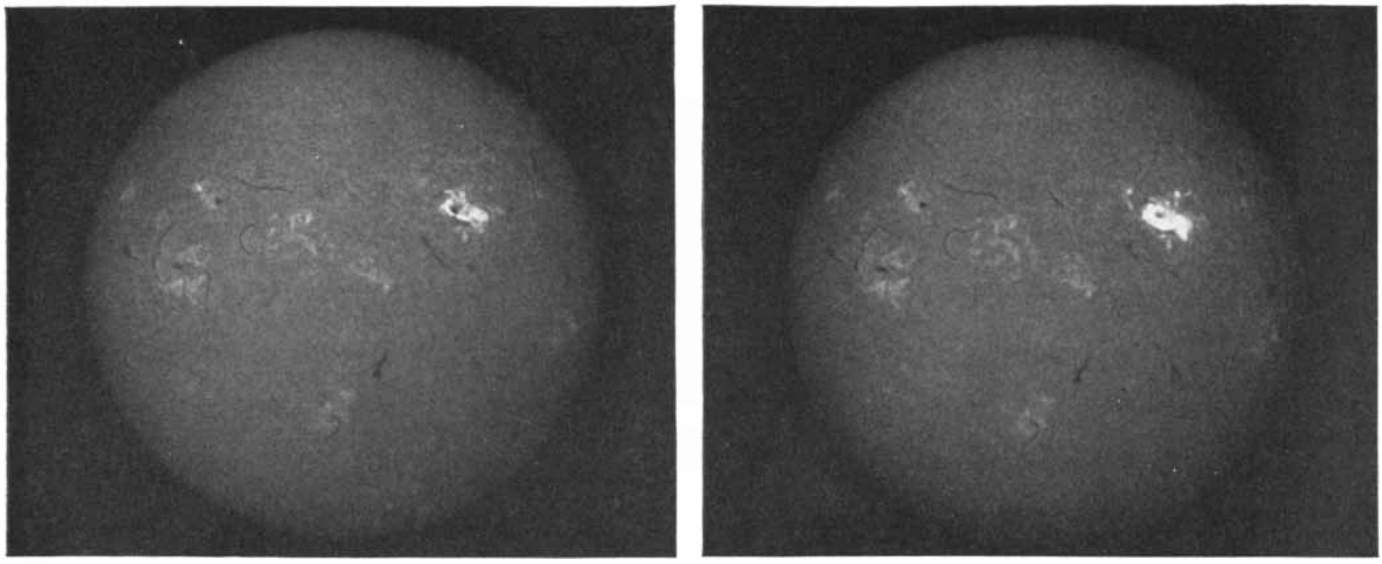
galaxy suddenly became quiet, because the ionizing particles had abruptly closed the atmospheric "window" through which these radio waves reach the earth. The great flare showed that there is a solar mechanism that can produce particles with energies above the minimum required for injection into a galactic accelerator. But investigators were forced to conclude that if most of the other stars inject particles as infrequently as the sun does, the stars would not supply nearly enough particles to account for the observed number of cosmic rays.

To monitor the ionization of the upper atmosphere, I.G.Y. workers in 1956 and 1957 set up a world-wide network of sensitive radio receivers that has since kept a continuous record of the level of cosmic radio-noise. By measuring the varying opacity of the atmospheric radio window, these receivers furnish a reliable index to the ionization of the atmosphere. They are called relative ionospheric opacity meters, or riometers. Since the sun was then entering the most active phase of its 11-year sunspot cycle, the riometers were soon responding to flare activity. Investigators were impressed to find the response coming in three phases [*see illustration on page 68*]. The first, which began just as a large flare erupted, was a sudden drop in the cosmic radio-noise level over the entire side of the earth facing the sun. The opacity lasted until shortly after the decline of the flare. The ionization responsible for this effect is caused by electromagnetic waves in the form of ultraviolet radiation and soft X-rays, emitted by the flare along with visible light, and traveling at the speed of light. Such radiation carries no electric charge, and so is not deflected by the earth's magnetic field. Another type of opacity started about a day after the flare and occurred only over the areas where auroras were appearing. Presumably this effect was due to the particles that caused the auroras.

The most interesting type of ionospheric opacity started about an hour after the peak of a large flare. Inhabitants of the Arctic were familiar with its effects, but they came as something of a surprise to the physicists who were watching the riometers. Cosmic radio-noise and terrestrial radio transmissions near the North Magnetic Pole and throughout the Far North were blacked out for several days [*see illustrations at top of pages 70 and 71*]. The ionosphere became markedly opaque north of the auroral zone, but south of that zone it remained virtually unaffected. Studies of the ionosphere showed that the agent responsible for this effect must be more energetic than the particles that produce auroras, because the ionization reached more deeply into the earth's atmosphere. Although radiation counters on the ground had not registered any increase in particles, investigators in Canada, Sweden and the U. S. put forward the hypothesis that during and after many large flares protons with an average energy of at least 10 million electron volts were entering the earth's atmosphere. Unfortunately, these proposals did not come to the attention of cosmic-ray physicists until early in 1959; if they had, they might



EARTH'S LINES OF MAGNETIC FORCE (*white curves*) **virtually guide protons** (*colored lines*) **in over Fort Churchill** (*b*), **which is 1,000 miles south of North Magnetic Pole** (*a*). **Over Minneapolis** (*c*) **solar protons are not energetic enough to cross lines of force and enter atmosphere. Neutrons** (*broken lines*), **on the other hand, carry no electric charge and can penetrate magnetic field at all latitudes, including magnetic equatorial regions. The atmosphere is the only obstacle to an influx of neutrons from the sun.**

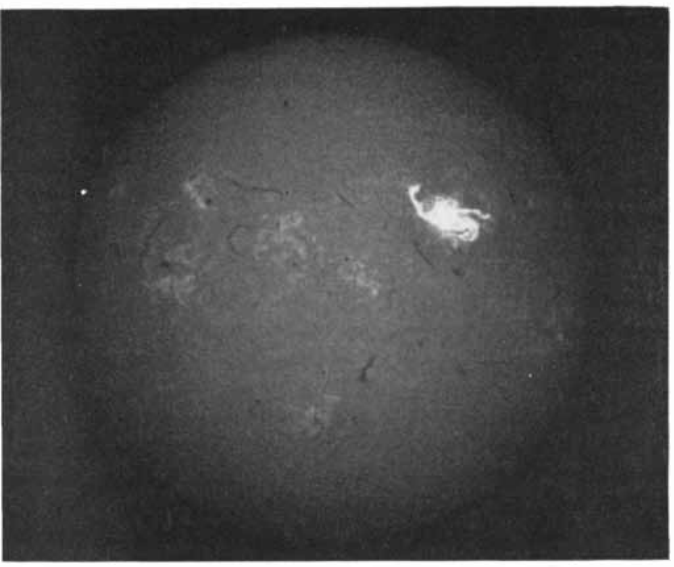


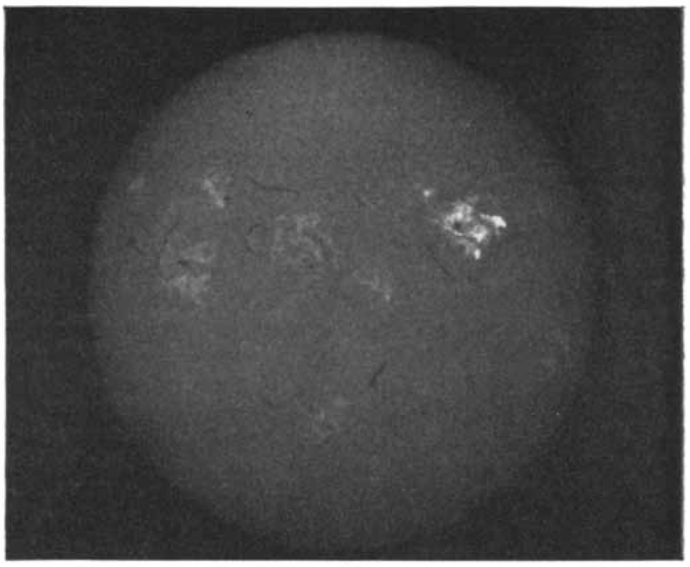
GREAT SOLAR FLARE of July 16, 1959, is shown in these photographs, made on 16-millimeter film with a refracting telescope having an aperture of five inches and a focal length of five feet. Flare appears as bright spot in the photograph at left. Second photo-

have suggested the direct study of the particles with instruments carried aloft in balloons.

In August, 1958, a large, complex group of sunspots was crossing the solar disk. I was at Fort Churchill in Canada with a group of students from the State University of Iowa, and we were launching balloons with the general idea that flares appearing in the sunspot regions might be emitting high-energy radiation. We released a balloon late on August 21 which reached its maximum height of 20 miles at 10 p.m. and remained at that height until 5 p.m. the next day. During the night of August 21 and 22, detectors carried by the balloon showed only the normal level of radiation caused by the steady influx of cosmic rays. At 9:30 the next morning, however, the radiation suddenly began irregularly to increase, and finally jumped to 10 times normal. Four or five hours later the radiation began to decrease slowly, but even when

DETAILED VIEWS OF GREAT FLARE of July 16, 1959, were made with solar telescope of 40-foot focal length having a mirror 16 inches in diameter. Photograph at left was taken 11 minutes after first picture in series at top of pages, and shows flare near



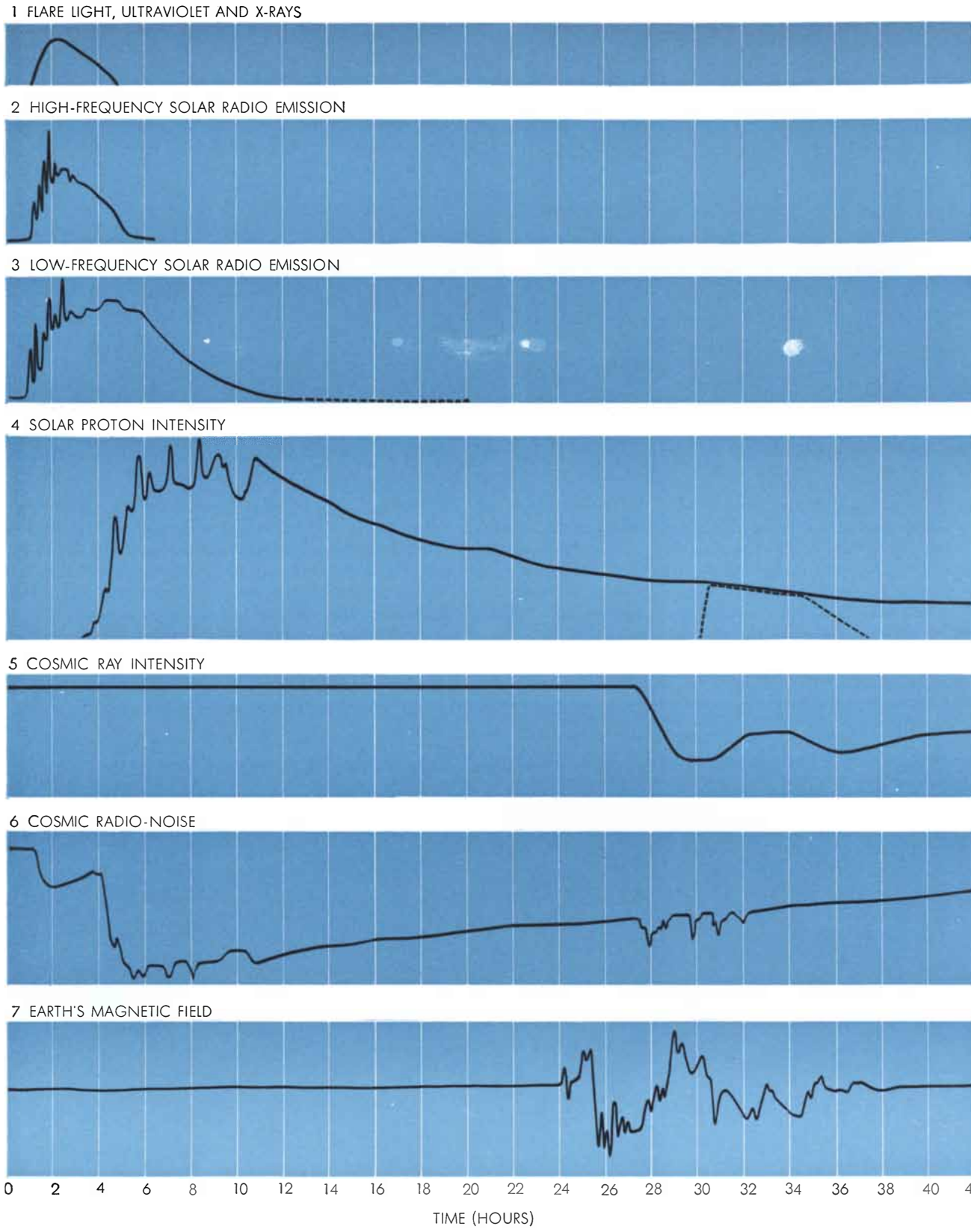


graph was made four minutes later. In third photograph, made 28 minutes after second, flare is very intense. At far right, 71 minutes later, it is fading away. The pictures on these two pages were made at the McMath-Hulbert Observatory of the University of Michigan.

the flight ended at 5 p.m., the level of radiation remained abnormally high. Meanwhile, starting at 8:15 a.m., equipment on the ground at Fort Churchill had been registering intense outbursts of radio noise from the sun. Late in the day we learned that a large flare had blazed up on the sun about 75 minutes before our balloon had detected the increase in radiation.

The effects registered by our detectors could have been caused only by protons with an average energy of 150 million electron volts. Although the balloon was above 99 per cent of the atmosphere, particles with an energy of less than 100 million electron volts could not have penetrated to the balloon. Thus we felt sure that only the most energetic of the protons had reached our detectors. Data from detectors aboard the satellite *Explorer IV*, analyzed later by Pamela Rothwell of the State University of Iowa, showed that at this time, 300 miles up

maximum intensity. Photograph at right was made 33 minutes later and depicts flare covering maximum area. All the photographs on these two pages were made through a filter that passes only the red light of the hydrogen-alpha line of the spectrum.



FLARE THAT EMITS PARTICLES lasts up to four hours, as shown by curve at top (1). High-frequency solar radio emissions accompany it (2), while low-frequency emissions (3) go on longer, perhaps for days, as indicated by broken line. In Far North protons from sun arrive for days after a flare (4). Broken curve starting at 30 hours (4) indicates protons arriving over Minneapolis and other normally "forbidden" latitudes; these particles were detected by workers from the University of Minnesota. The particles penetrate as a result of disturbances in the earth's magnetic field (7) caused by late-arriving cloud of low-energy electrons and protons that also produces auroras. Same magnetic disturbance disrupts steady influx of cosmic rays over entire earth (5). Radio noise from galaxy, as detected in Far North (6), drops suddenly as flare starts, due to ultraviolet and X-rays, recovers a bit, then falls nearly to zero when high-energy protons arrive. Protons continue to depress cosmic radio-noise for hours and days after the flare.

and essentially outside the atmosphere, solar particles of less than 100 million electron volts were about 100 times as numerous as those at the level of our balloon.

By a fortunate coincidence a group headed by Edward P. Ney, John R. Winckler and Phyllis Freier of the University of Minnesota had launched a balloon on August 21 near Minneapolis, 1,000 miles due south of Fort Churchill. On the morning of August 22 their balloon, like ours, was 20 miles up. But while our detectors were recording the large increase in radiation over Fort Churchill, identical detectors registered absolutely no increase over Minneapolis. It was to be expected that detectors over Minnesota would not register protons; at that latitude the lines of force in the earth's magnetic field tend to deflect charged particles before they reach low altitudes. The Minnesota balloon, however, recorded a far more significant negative observation, bearing upon the process that ejects protons from the sun. The detectors did not register any neutrons. Because neutrons have no electric charge, they are not affected by the earth's magnetic field, and would surely have appeared over Minneapolis if the flare had emitted them [*see illustration on page 65*]. It is thought that a flare is produced when the magnetic field above a sunspot collapses; such a field could accelerate protons, but not neutrons. On the other hand, thermonuclear explosions and "plasma pinches" on the sun could accelerate both neutrons and protons. The fact that neutrons did not appear over Minnesota indicates that the protons we observed over Fort Churchill were not accelerated by such processes.

Solar protons continue to arrive at the earth for several days after a large flare, and they sometimes have a devastating effect upon radio communications in the Arctic. After a large flare on July 10, 1959, for example, radio communications in the Arctic were blacked out at nearly all wavelengths. Four days later, when communications had returned almost to normal, another intense solar outburst extended the black-out for several more days. At that time a group of us were waiting at Fort Churchill to fly into Resolute Bay, 1,000 miles north and near the North Magnetic Pole, in order to send up balloons. Ironically the very particles we wanted to study delayed us for two days, because we could not receive information on landing conditions.

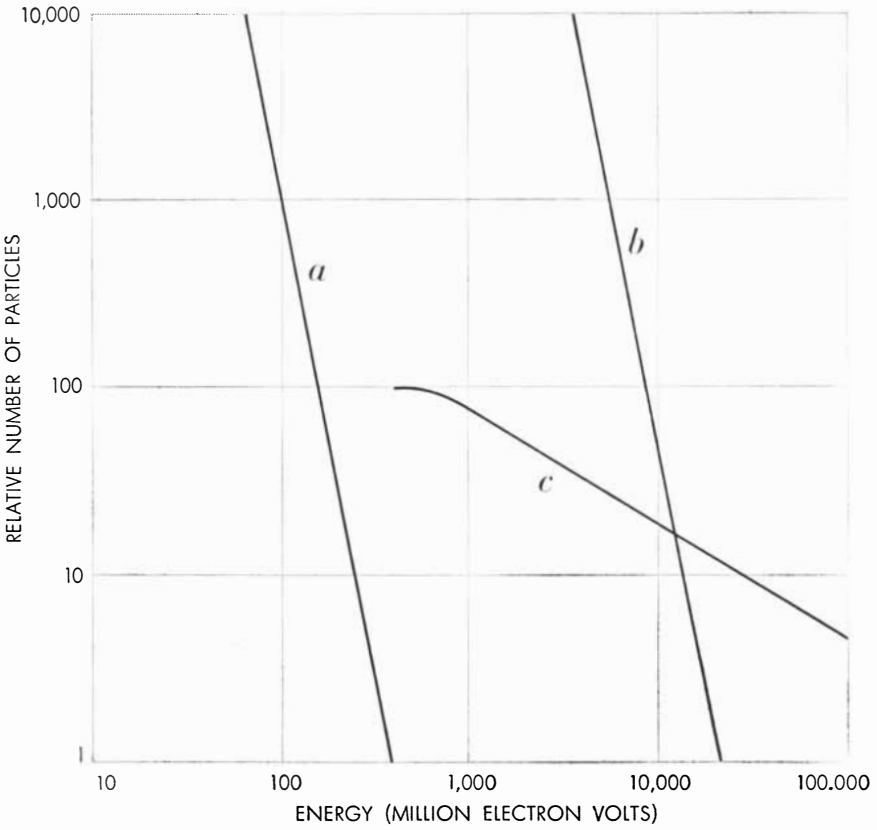
Although the protons continue streaming toward the earth for days, many workers believe they are accelerated only during the first few minutes that a flare is active. It is therefore deduced that the ejected protons are "stored" in magnetic fields and gradually leak away from them. A clue to the location of such reservoirs comes from the radio-noise outburst that follows a flare. Radio astronomers have attributed solar radio-noise to the motion of electrons ejected by the flare and trapped in magnetic fields above the sunspot region. We have postulated that the protons are trapped in the same field, but leak away because they have higher energies than do the electrons.

The observations of August 22, 1958, and subsequent investigations of solar flares, made with riometers, balloons and satellites, have produced reliable correlations between direct measurements of solar protons and ionospheric opacity. As a result riometers on the ground can now be used to "count" the solar protons reaching the earth from a flare. The riometers also alert physicists to the appearance of high-energy solar protons that merit study by balloon-borne instruments. The group at Minnesota and our group at Iowa, for example, followed up riometer measurements by launching balloons during the intense radiation outbursts in May and July of last year.

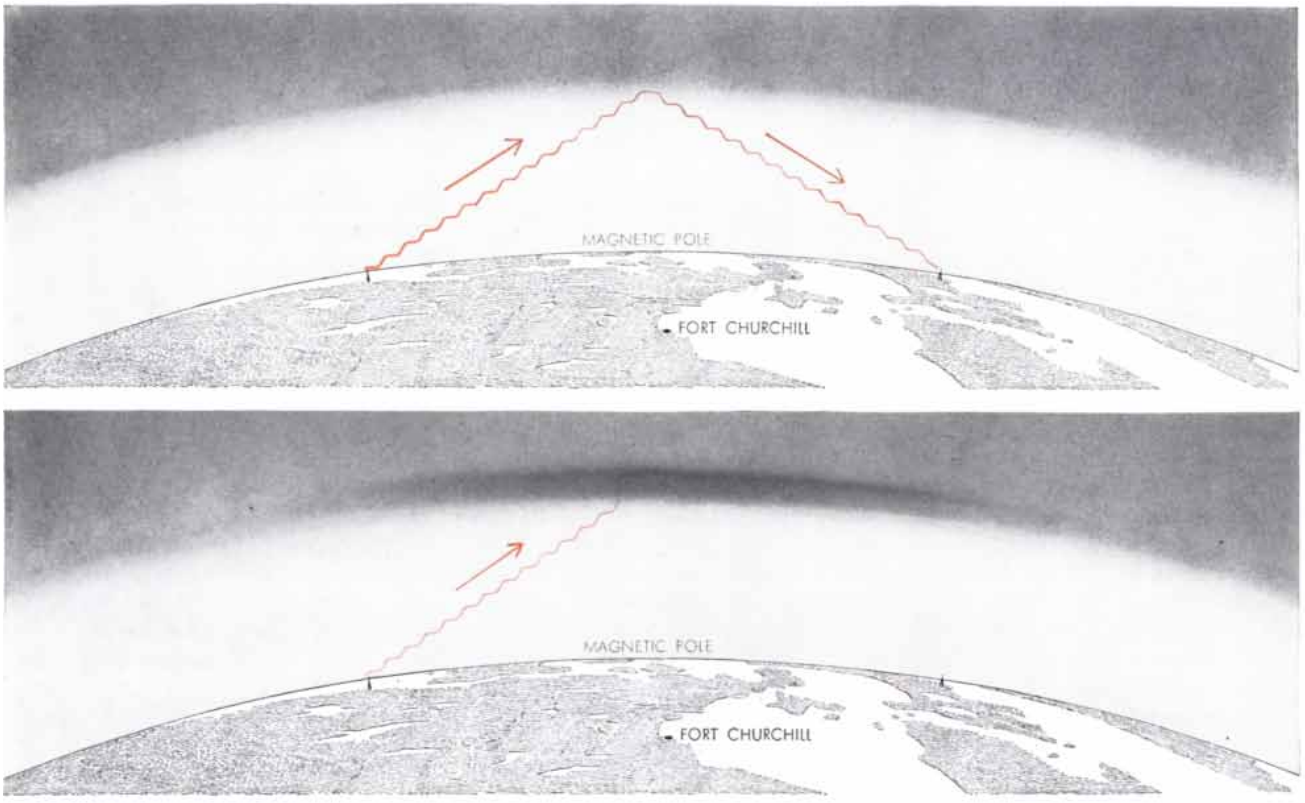
These and later studies have established that output of protons from the solar-injection system is much greater than was hitherto suspected. If these rays could penetrate the atmosphere to the ground, they would have significant biological effects. The frequent bursts of solar protons will still be a hazard to space travelers, but most of the particles can be stopped by fairly light shielding.

What can be said, on the basis of the I.G.Y. investigations, about the sun as a source of embryonic cosmic rays? Are the particles ejected by the sun destined to enter the galactic accelerator and, over millions of years, to acquire the enormous energy that characterizes cosmic rays? Or do the solar protons simply wander out of our planetary system and lose their energy in collisions with other particles and with magnetic fields, finally joining the clouds of gas that make the vacuum of interstellar space a little less perfect? Unfortunately no conclusive answer can yet be given, but the I.G.Y. studies have led to some tentative judgments.

For one thing, if other stars produce as many particles as the sun does, the Fermi acceleration process could keep the galaxy well supplied with cosmic rays. However, the particles have rather



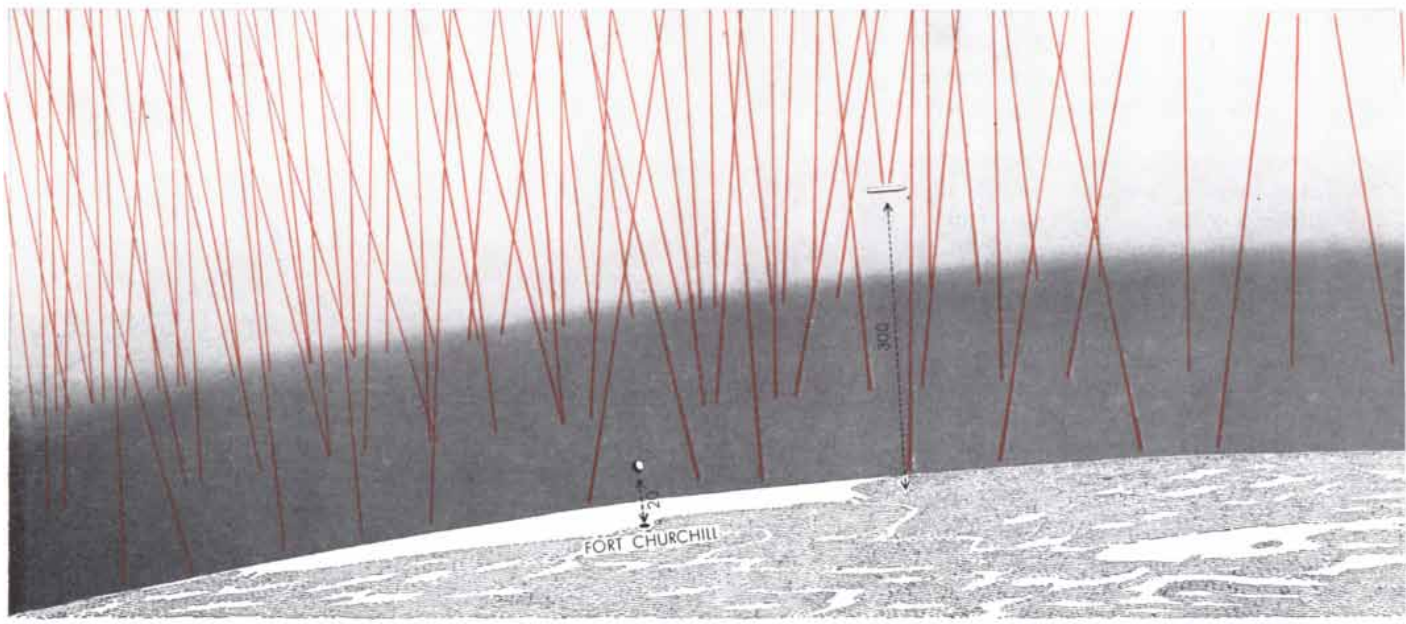
ENERGY SPECTRA OF PARTICLES (the relative number of particles at various energies) are shown by these curves. Particles from the great solar flare of August 22, 1958 (*a*) had less energy than those from the large flare of February 23, 1956 (*b*). The spectrum of cosmic rays from the galaxy (*c*) is not nearly so steep as the solar-particle spectrum.



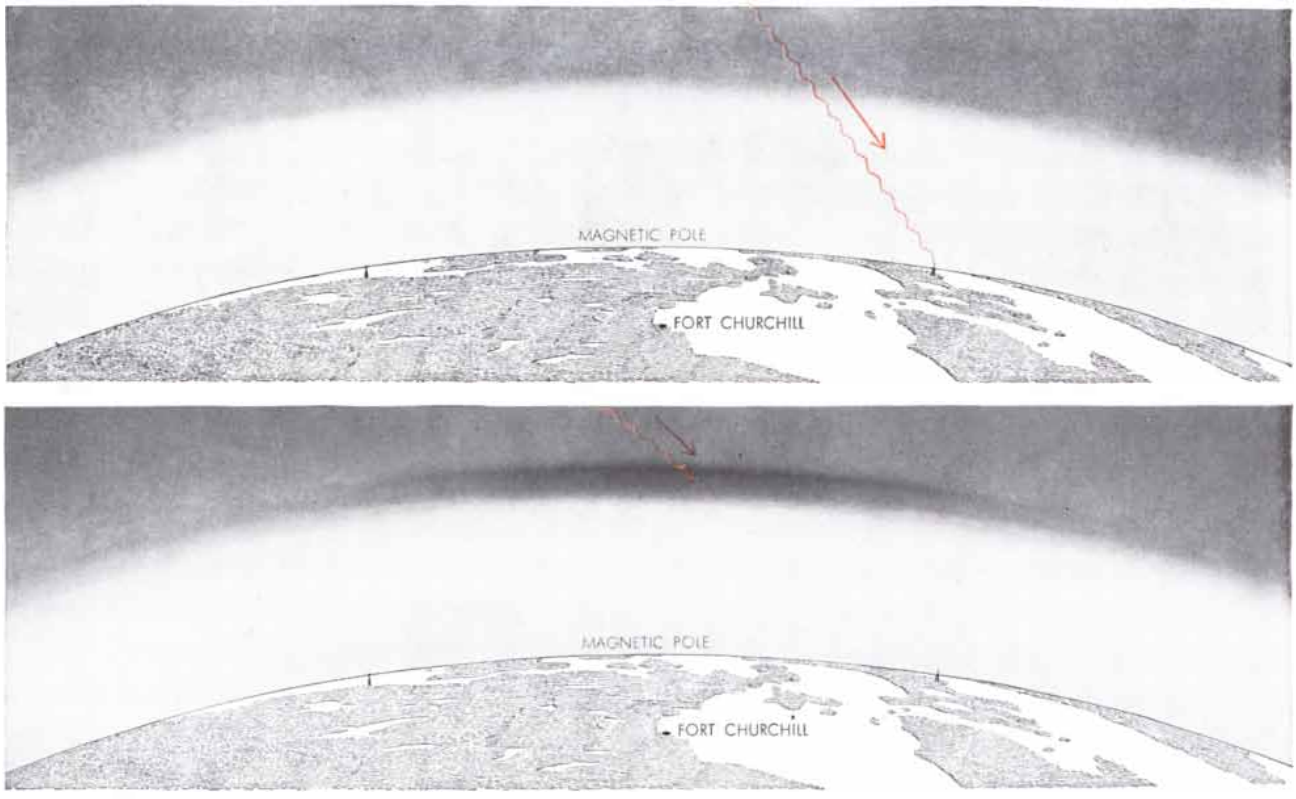
IONOSPHERE OVER FAR NORTH normally reflects terrestrial radio transmissions, as shown in drawing at top. High-energy particles from solar flare, however, make ionosphere absorb radio waves, indicated by darkened reflecting layer in lower drawing.

low energies, as the balloon flights have indicated. These flights have revealed that the energy spectrum of the solar particles is very steep: the number of particles decreases rapidly with the increase of energy. This is in marked contrast to the spectrum of cosmic rays, in which the number of particles decreases rather slowly with the increase of energy [*see illustration on preceding page*]. The Fermi process would need several millions of years to convert the steep solar spectrum into the much flatter cosmic-ray spectrum. On the astronomical timescale such a "growing-up" period would not be unreasonably long.

But one factor weighs seriously against the sun and similar stars as a significant source of cosmic-ray particles. Solar particles seem to consist almost exclusively of protons, with only a minute admixture of alpha particles (helium nuclei); such particles have only recently been detected in photographic emulsions sent up in balloons by the Minnesota group. Cosmic rays, on the other hand, are some 13 per cent alpha particles. Even though the solar atmosphere appears to contain only a small amount of helium, it could be argued that the



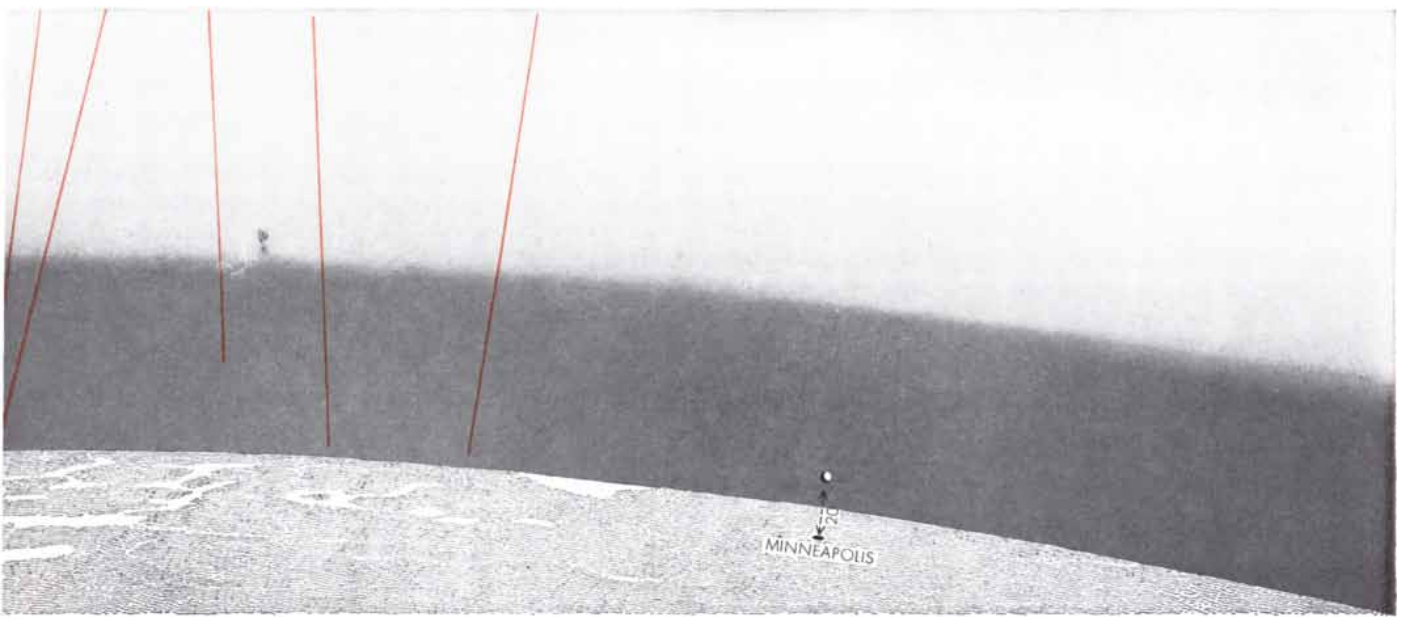
SOLAR PROTONS reaching earth on August 22, 1958, are represented in this schematic drawing. Varying lengths of proton "tracks" (*colored lines*) indicate energy differences. The most energetic particles penetrate atmosphere (*shading above earth*) to



RADIO NOISE FROM THE GALAXY normally penetrates the ionosphere (*top drawing*) and reaches receivers on earth. Protons ejected by a large flare abruptly close this radio "window" over Far North, as indicated by darkened layer in the lower drawing.

sun does emit a great many undetected alpha particles. They do not have sufficient energy to penetrate to balloons 20 miles above the earth, however, and the dust and gas in interstellar space would stop them long before they became cosmic rays. On the basis of the I.G.Y. evidence it seems that our sun does not qualify as a source of embryonic cosmic-ray particles.

It will nonetheless be worthwhile to continue investigating solar flares as a possible source of cosmic-ray particles. The mechanism by which the flare accelerates protons is not yet understood. When the process is determined, it might explain how other stars could inject particles of the proper elemental distribution into the galactic accelerator. If the normal life processes of stars, such as flares, do not provide an adequate injection system, it may be that we will have to accept the other leading hypothesis of the origin of cosmic rays: that they spring full-blown from supernovae. These vast explosions, which are thought to be the death-throes of stars, may expel from helium-rich stellar interiors the large numbers of alpha particles that are found in cosmic rays.



balloon 20 miles above Fort Churchill. Less energetic protons reach *Explorer IV* satellite, 300 miles high. No particles strike balloon 20 miles above Minneapolis because earth's magnetic field at that latitude deflects charged particles far above surface.

INSECT ASSASSINS

The assassin bug injects other insects with a venomous saliva that paralyzes them and dissolves their tissues. The assassin then drinks its predigested meal and may live on it for weeks

by John S. Edwards

Catch 'em alive! Gentlemen, I've
Here such a dose as no fly can survive.

With this bit of doggerel a Victorian poet described the perfect way to administer a perfect insecticide. The procedure is clearly impractical in human efforts to control insects, but it is used quite effectively by the insects themselves. The insect order Hemiptera includes a family of some of the most efficient predators in the animal kingdom. They are the Reduviidae, or assassin bugs, which literally catch their victims alive and administer a dose they cannot survive.

There are some 2,500 species of assassin bug, and they are distributed throughout the world. One large and particularly venomous species, *Platymeris rhadamanthus,* lives in Zanzibar, where it feeds on the rhinoceros beetle, a pest of coconut plantations. Platymeris assassinates its victim with remarkable precision. It grasps the beetle firmly, places its beak against the beetle's body and pushes a set of sharp, hollow stylets out of the beak and into the beetle's body cavity. Through this hypodermic syringe Platymeris injects a squirt of venomous saliva that first paralyzes the beetle and then breaks down its cells. Thereafter the assassin bug drinks the liquefied tissues through its beak.

It was the cell-destroying action of the venom that excited my own interest in assassin bugs, and for my research Platymeris proved to be an unusually valuable species. Platymeris is a singularly unpleasant insect to work with: its inch-and-a-half-long body, jet black with a blood-red spot on each wing, has a menacing air. Platymeris also has the nasty habit of spitting a jet of venom when it is disturbed. The venom can cause considerable pain when it strikes the eye or nose tissue of a vertebrate—as I have found to my cost. This behavior provides the assassin bug with a defense against insectivorous vertebrates; it also provided me with a copious source of venom. Platymeris proved to be an adaptable laboratory organism. Transferred from its home in the coconut plantations in Zanzibar, it soon adjusted to life in culture jars at the University of Cambridge, and it readily exchanged its regular fare of beetles for a diet of cockroaches.

All Hemiptera, including the assassin bugs, live on a liquid diet. Some, such as the water boatmen and the water scorpions, live in fresh water. The toe biter, another aquatic bug, sometimes grows to a length of four and a half inches, a size that enables it to capture small fish and to suck from them the nutriment it needs. Among the land-dwelling Hemiptera there are vegetarian species that pierce the tissues of plants and suck their sap; this behavior is not only destructive in itself, but also spreads virus diseases among crop plants. Still other Hemiptera have adopted a diet of warm blood. The Triatomas, close relatives of the assassin bugs, spread the trypanosome of Chagas' disease, a serious affliction of man in South America. Following an encounter with a Triatoma, Charles Darwin wrote in his *Journal of a Naturalist:* "It was quite disgusting to feel the soft wingless insects about an inch long crawling over one's body." He mightwell have felt more than mere revulsion; it has recently been suggested that the undiagnosed disease which troubled him in later life was the result of this episode.

Some Hemiptera, like the Cimicidae, or bedbugs, are familiar pests; others spring into sudden and short-lived notoriety. In 1899 a woman in Washington, D.C., received a painful bite on the lip from an assassin bug. By the time the newspapers had thoroughly covered the matter, a "kissing-bug plague" was sweeping the eastern U. S.; even mosquito bites were attributed to the bug. In testimony to the excitement of the episode assassin bugs are still widely known as kissing bugs.

Assassin bugs have long engaged the interest of biologists, and the bizarre behavior of many species has been described. The tactics employed by the different species to capture their prey vary widely: some use guile, some stealth, others agility. The tactics of most of the species fall into two general categories: the smash-and-grab and the sit-and-wait. Platymeris belongs to the smash-and-grab group. When a prey insect comes within the field of its large compound eyes, Platymeris turns to face it, and steadily adjusts its position to keep its victim in view. It then advances with quick, nervous dashes, and when it is within leaping range, it pounces.

Fast-moving insects do not always succumb easily: they struggle violently and seek to slip out of the assassin bug's grasp. At such times Platymeris and other assassin bugs make good use of remarkable adhesive pads on their lower legs. These pads, which are similar to those that enable a fly to walk on a ceiling, are flexible, velvety structures. When they are examined under the microscope, it is apparent that they are composed of minute hairs; each pad of Platymeris consists of 70,000 to 80,000 such hairs. Each hair is a hollow tube about .05 millimeter long that has a flattened, fanned end. The British biologists J. D. Gillett and V. B. Wigglesworth examined the mechanism by which this type of adhesive pad works;

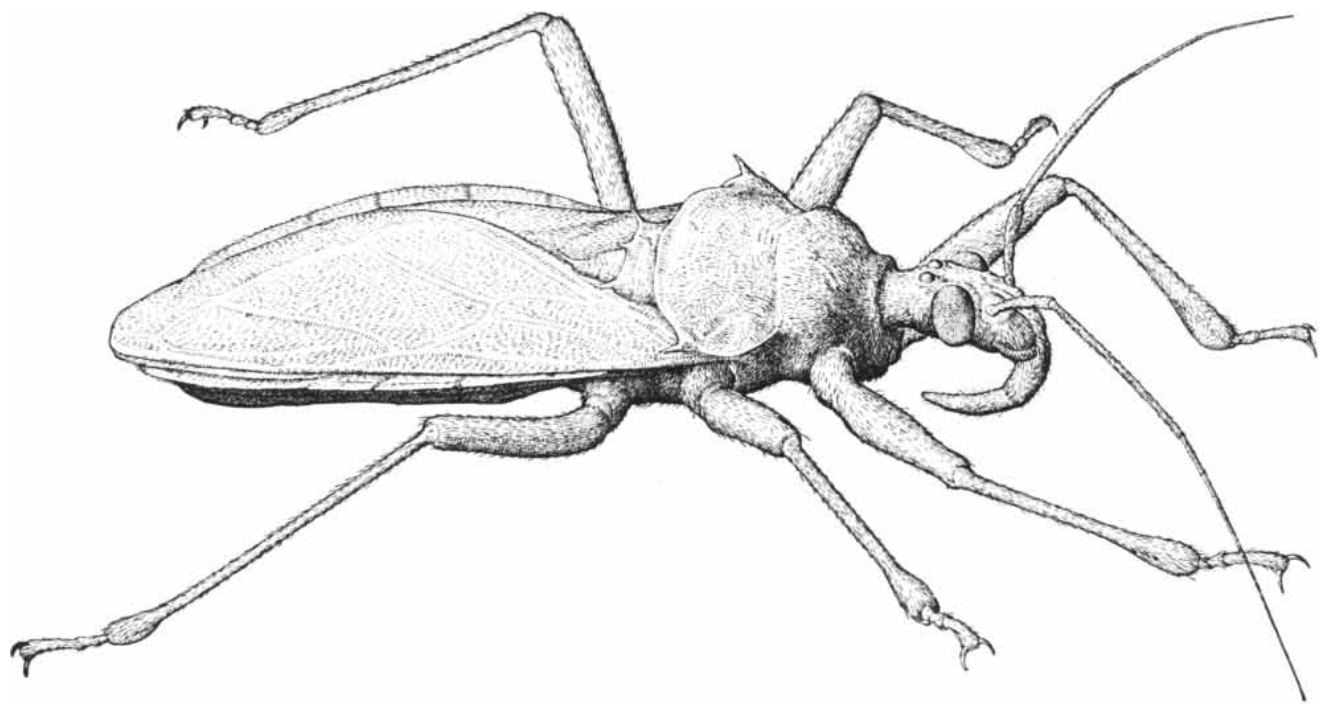
they concluded that it could be explained by the action of a thin film of oil between the end of the hair and the surface on which it rests. So effective is this mechanism that my Platymeris specimens were able to resist a steady pull of 65 to 70 grams as they clung to polished glass, or, more pertinently, to the cuticle of a rhinoceros beetle.

Assassin bugs of the sit-and-wait group stand guard at a chosen station, perhaps on a flower or near an abandoned spider web, and wait until a prey insect comes within striking distance. Several tropical species vary the sit-and-wait strategy. They plunge their forelegs into the resin of a coniferous tree and hold them aloft until some small insect blunders into them and gets stuck. The bee assassins, the Apiomerinae, have clublike front legs that are covered with stout hairs, an arrangement that is well adapted to capturing the hirsute bee. Their technique is not unlike catching a hedgehog between a pair of brushes.

Perhaps the most subtle technique of all is that of an East Indian assassin bug (*Ptiloceros ochraceus*). From glands on its undersurface Ptiloceros secretes a fluid that is highly attractive to ants; it is even said that ants are intoxicated by it. Ptiloceros takes up its stand beside an ant run and raises its forelegs to display the source of the attractive fluid. When an ant accepts the invitation and approaches, Ptiloceros stands quite still. As the ant proceeds to drink, the assassin bug unhurriedly closes its forelegs on the ant's head and thorax. It does not strike, but waits until the numbing secretion has done its work. Only then does Ptiloceros turn its hypodermic proboscis down and pierce the neck membrane of its prey.

Whatever the tactics of the assassin bug, its prey is dead within a few seconds. The secret of the assassin bug's success lies in the specialized organs of its head and thorax, the forepart of its body. In the assassin's thorax are the greater part of the salivary glands that produce and store its powerful venom, in its head are a pump to force the venom through its beak into its prey's body, another pump to suck in the liquefied tissue of the prey and the beak itself—the hypodermic needle. The needle is a highly specialized version of the mouth parts found in related insects. The jaws of the assassin bug have been modified into long stylets. There are two pairs of stylets: the two outer, or mandibular, stylets have barbed tips and flank the two inner, or maxillary stylets. The maxillary stylets, which move in and out between the mandibular ones, each have two longitudinal grooves on their inner surface and are faced together in register so that the complementary pairs of grooves form two tubular channels. Thus they comprise a two-way hypodermic needle. In most Hemiptera one channel discharges saliva into the prey, and the other takes the prey's juices up into the gut. The assassin bug, however, must inject its prey with a great quantity of saliva very quickly, and so needs a large-caliber channel. Accordingly one channel is greatly enlarged at the expense of the other, and performs both the injecting and sucking functions. The stylets are sheathed by the assassin bug's lower lip, which has evolved to form a protective beak, or rostrum.

The stylets form the needle of the hypodermic, but what of the syringe? Cutting away the tough side-wall of the assassin bug's head reveals a most elegant pump. All sucking bugs have such a salivary pump, but because the assassin bug must deliver a large volume of saliva in a short time, its pump is highly developed. Securely fixed to the forward end of the insect's head wall is a cone of stiff cuticle. Inside and concentric with this stiff cone, and joined with it rim to rim, is a plunger cone composed of more elastic cuticle. The apex of the inner cone is stiffer than the rest of the cone, and extending backward from it is a shaft to which are attached retractor muscles that radiate in two bundles to the back wall of the head. When the muscles retract, they pull the arm and draw the inner cone back like a piston within the outer cone. The action sucks saliva from the salivary glands through



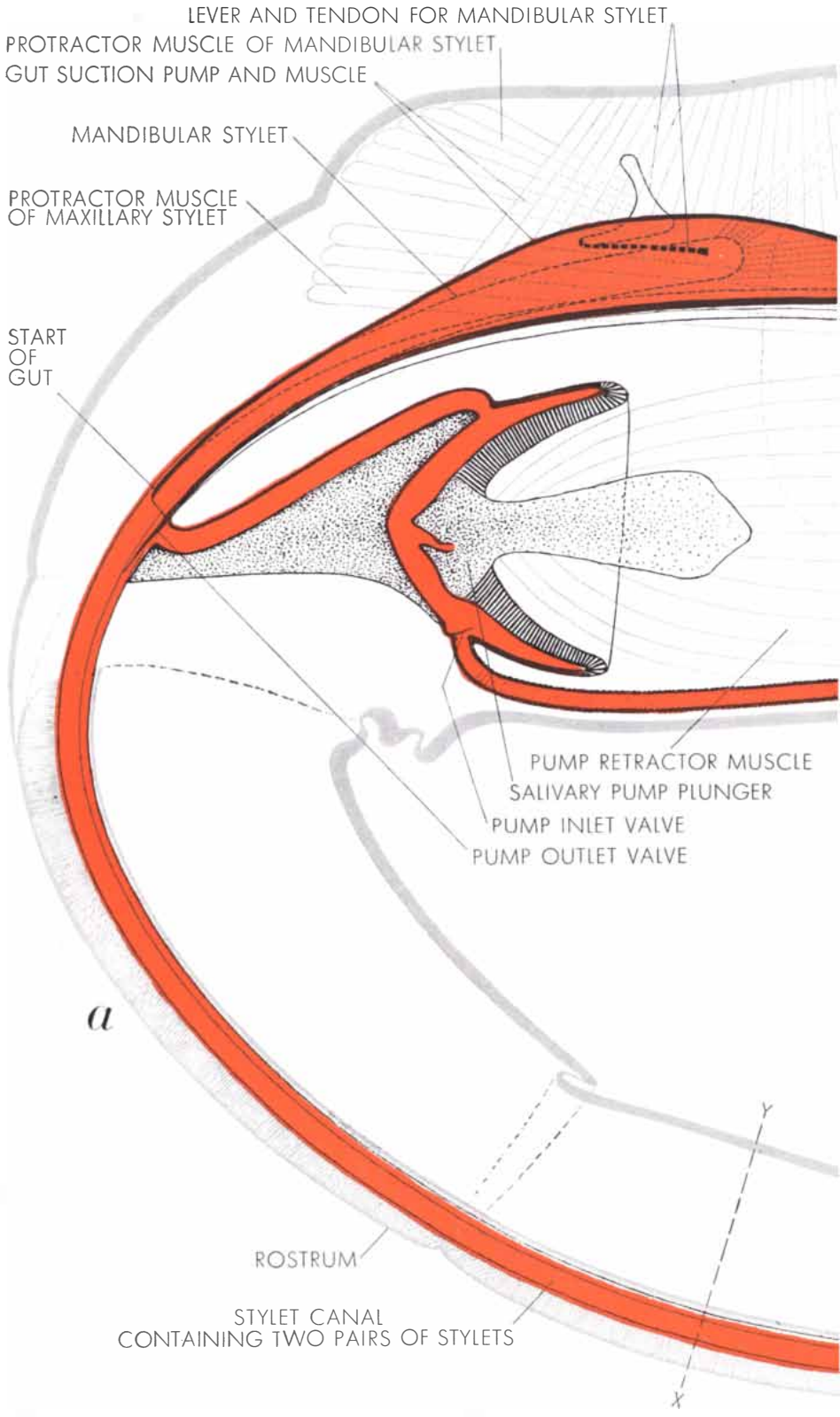
ASSASSIN BUG *Platymeris rhadamanthus* is an inch and a half long. It lives in Zanzibar, where it feeds on the rhinoceros beetle. The curved structure below the bug's head is its rostrum, or beak, from which slide the stylets that inject its venom into its prey.

a flap valve on the undersurface of the pump, thus filling the cavity between the cones. When the assassin bug injects saliva into its prey, it merely relaxes the retractor muscle, allowing the inner cone to spring forward to its resting position. The motion forces a jet of saliva through an outlet duct in the upper wall of the pump, down the salivary canal of the stylets and into the prey.

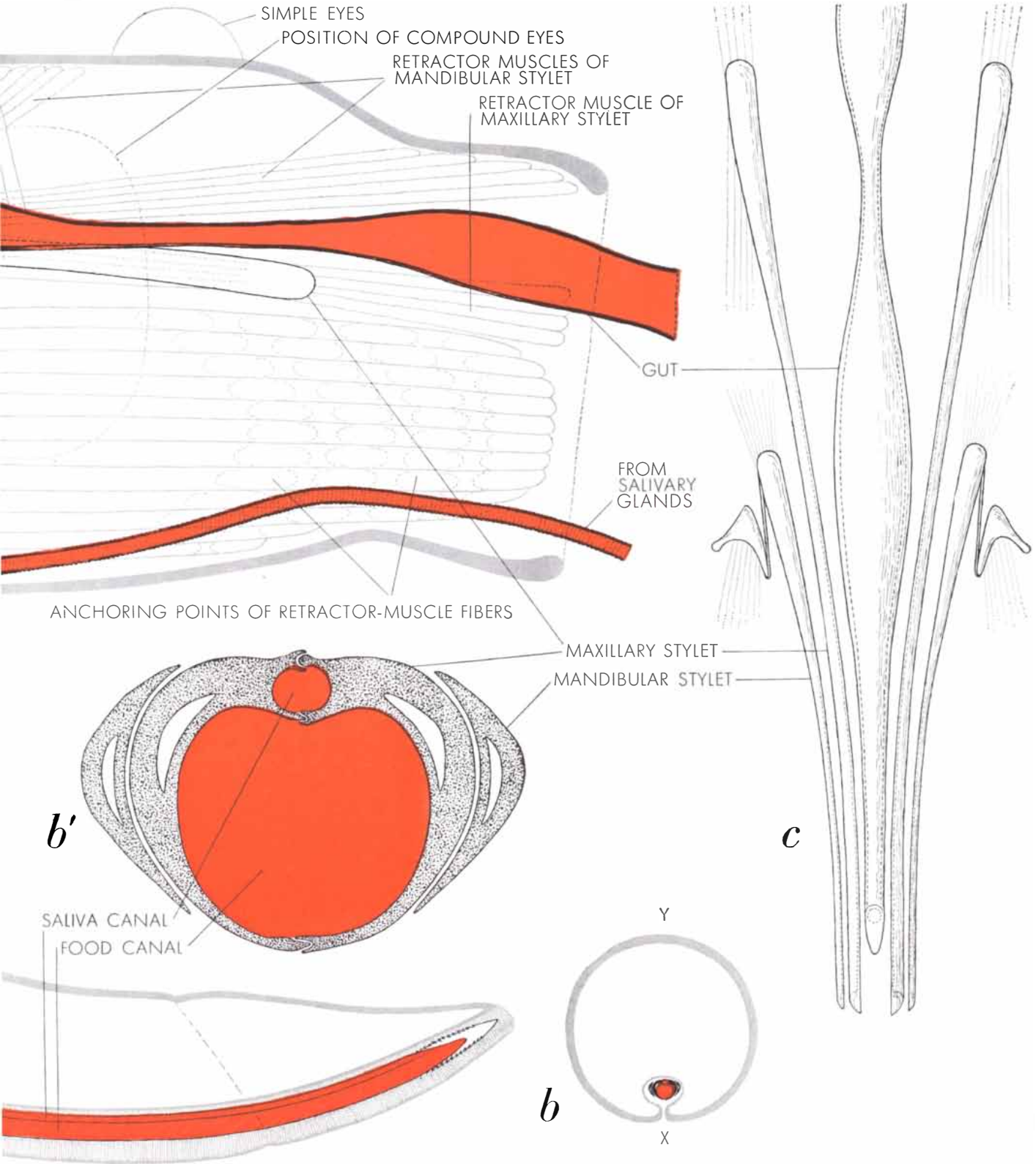
The glands that secrete the venomous saliva are large and complex; of their several lobes, two secrete a clear and viscid toxic material that the assassin bug can store indefinitely in a saclike lobe of the gland. Another lobe produces a watery nontoxic secretion that apparently acts to dilute the active components of the saliva, and perhaps serves also as a mouthwash that flushes the ducts of the stylets after an injection has been completed.

How the assassin bug can store its extremely venomous saliva indefinitely without harm to itself is still a mystery that other sucking bugs do not present. Although most sucking bugs produce a saliva that contains such digestive enzymes as protease, which attacks protein without itself being altered, it is only the predatory species that secrete a toxic saliva. A simple experiment gave me some notion of the extreme toxicity of assassin-bug venom. I diluted one part of venom in a million parts of saline solution, and with a fine pipette dropped some of the preparation on the isolated heart of a cockroach. Almost immediately the heart contracted violently and stopped beating. When I repeated the experiment with the saliva of plant-feeding bugs, there was no such dramatic effect; the heart continued to beat for quite some time.

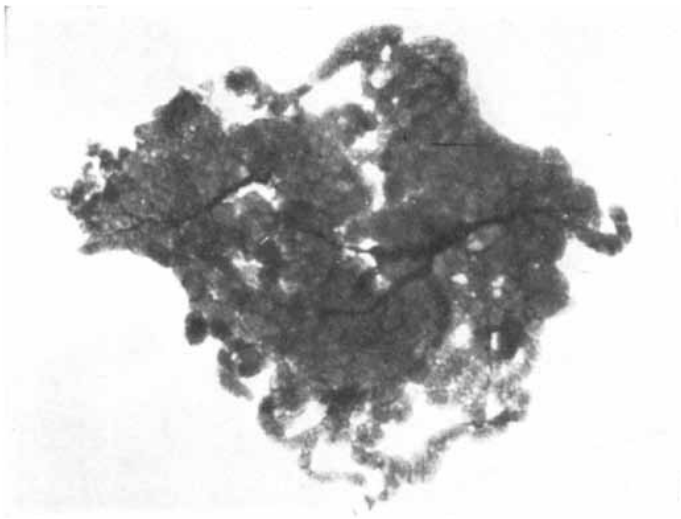
Although the needle-like proboscis of the assassin bug is a most efficient instrument, its very form restricts the assassin to a liquid diet: the bug must digest its food externally before it can drink it. In this respect the assassin bug resembles the snake, whose venom accelerates the breakdown of its prey's tissues. The rapid sequence of events that follows upon the snake's biting a mammal and leads to the breakdown of the mammal's tissues is fairly well understood. Enzymes in the venom attack the tissues, especially the red blood-cells, and liberate the pharmacologically powerful compound histamine. The histamine dilates the capillary blood vessels, thus lowering the blood pressure and inducing shock. But here the correspondence between

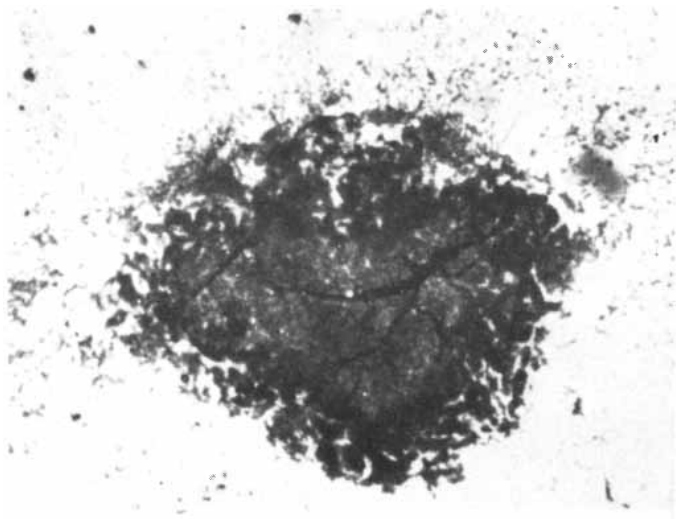


ARMAMENT OF PLATYMERIS, shown in schematic vertical section, includes two major systems (*colored areas*): the food system (*top*) and the salivary system (*middle*), both of which terminate in the stylets (*bottom*). When it attacks, the assassin bug straightens its rostrum (*a*) and, by means of the lever, tendon and muscles shown at upper left, telescopes its stylets out of the rostrum and forces them into the body of its prey. By simultaneously



drawing back the salivary-pump plunger, it sucks saliva into the salivary pump. To inject the venomous saliva, it relaxes the pump-retractor muscles, allowing the plunger to move forward and thus force the saliva through the pump outlet-valve and down the stylets. The bug takes in its food by means of its gut suction-pump (*upper left*). The exploded detail of the gut pump and stylets shown at right (*c*) relates to the colored area at top of drawing *a*. Illustration *b* is a cross section of the rostrum and stylets as they appear at the broken line X-Y (*bottom, left of center*). Details of the colored area of illustration *b* are shown in illustration *b'*.





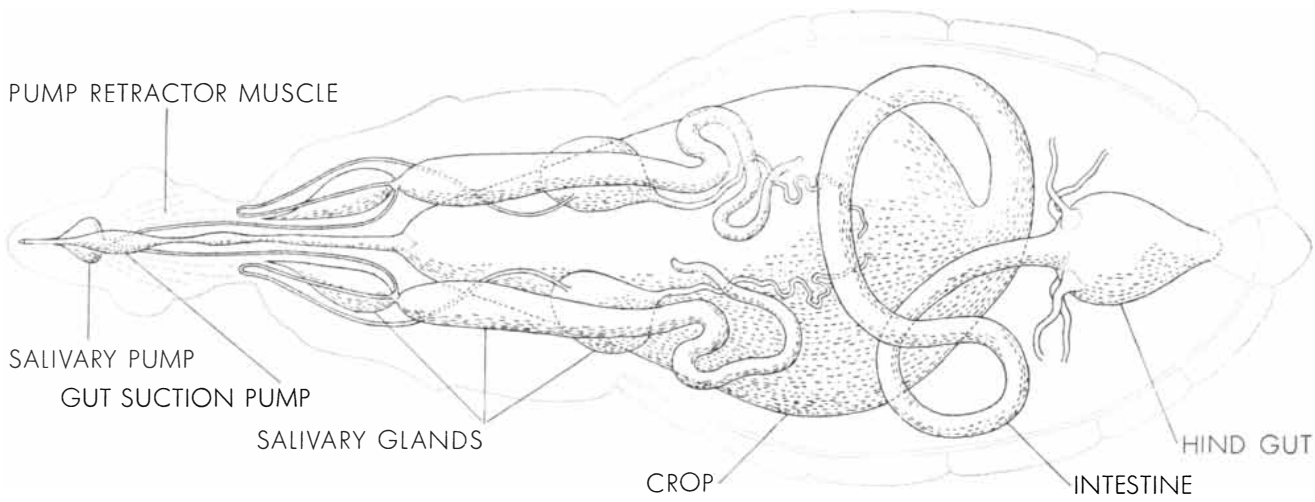
EFFECT OF ASSASSIN-BUG VENOM is shown in this sequence of photomicrographs. At left is normal fat-tissue freshly excised from a fly. The second photomicrograph shows effects on tissue after five minutes' immersion in a solution of venom. Third photomicro-

the action of snake venom and of assassin-bug venom ends.

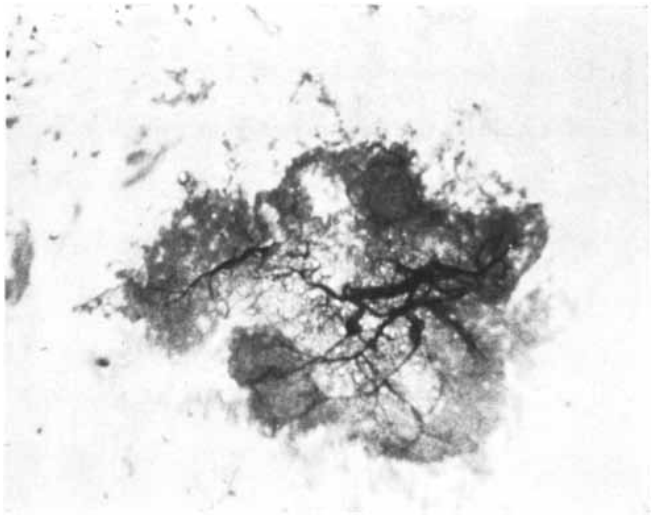
The capacity of assassin-bug saliva to bring the insect heart rapidly to a standstill is not especially significant, because the insect can get along quite well with its heart not beating. Moreover, since the circulatory system of an insect differs from that of a mammal in having no red blood-cells and neither arteries nor veins in the mammalian sense, very different mechanisms must be at work. Finally, where histamine so violently affects the tissue of vertebrates, it has virtually no effect on insect tissue. Immersed in a 2-per-cent histamine solution, a cockroach heart continues to beat for several hours. Thus the mechanisms by which snake and assassin-bug venoms work must be quite different.

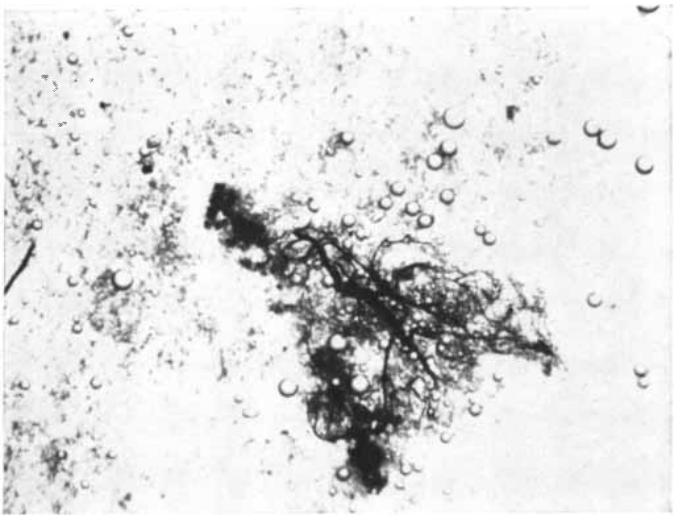
In the prey's tissues the assassin-bug venom brings about the same kind of cell breakdown, or lysis, that occurs when the insect dies of "natural causes." Under the action of the venom the process is much more rapid. The venom rapidly penetrates the protective layers of fatty membrane that surround the central nervous system, and breaks down the walls of the nerve cells. There is good reason to believe that this is due to an enzyme that acts specifically upon the lipid (fatty) constituents of the cell wall. With the help of stains that react with the lipid portion of the tissue, it can be seen that, within a very short time after the venom has arrived, the fatty layers of the cell walls have broken up, and in their place hangs a great number of disconnected droplets of oil.

Along with its corrosive attack on the prey's nervous system, the assassin bug's venom attacks the other cells of the prey's body. One of the first visible effects is the breakdown of the body fat and the release of the close-packed oil droplets they contain. Less obviously, but no less swiftly, the muscle tissue degenerates into a structureless paste. Within half an hour the prey's internal tissues are reduced to a thick, reddish soup: an emulsion of oil droplets suspended in a mixture of digested muscle and nerve. Only the cuticular parts of



THORAX AND ABDOMEN OF PLATYMERIS, shown here schematically, contain the complex salivary glands, which make and store the bug's venomous saliva; and its large, saclike crop, in which it is able to store sufficient food to last for several weeks.



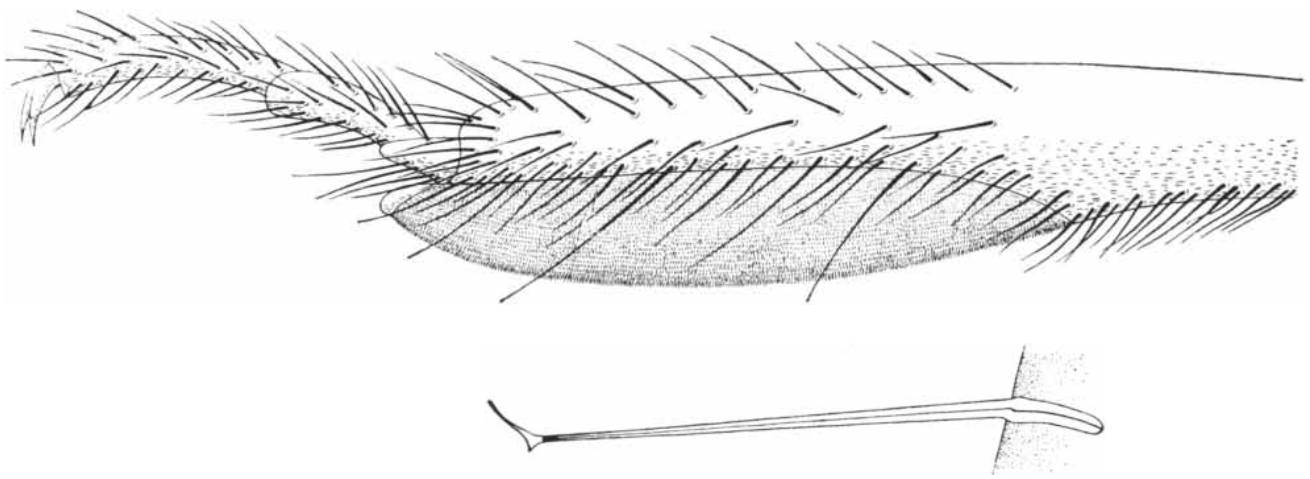


graph shows effect of 10 minutes' immersion. The photomicrograph at right shows fat globules released from digested tissue after 15 minutes of immersion. The thick, dark structure remaining is indigestible cuticle. These photomicrographs were made by the author.

the body wall, of the trachea and of the lining of the gut remain intact. The assassin bug sucks its meal up through the feeding channel of its stylets to a large storage chamber, or crop, in its abdomen. With the meal completed, it retracts the stylets into the rostrum, and the hollow shell of the prey falls to the ground. If the prey is especially large, the assassin may more than double its weight and live off the contents of its crop for days or weeks and show no interest in passing prey until the crop is nearly empty.

In this sucking process the salivary pump plays no part; a second pump formed by the upper end of the gut attends to that. At this end the gut has a U-shaped section; muscles reach from the inside of the U to the wall of the head. With an action similar to that of the salivary pump, the muscles expand the pump and the elastic cuticular walls compress it, thus sucking the liquid up and forcing it back through the gut and into the storage crop.

Against the tactics and lethal armament of the assassin bug, the struggles of even a powerful insect are unavailing. In the laboratory Platymeris was always successful in subduing the cockroach. After pouncing upon a cockroach, Platymeris holds the struggling insect firmly and runs the sensitive tip of its rostrum over the cockroach's body, seeking a chink in its armor. The flexible membrane at the neck or in the crotch of a leg joint does nicely, because these are close to the centers that coordinate movement. The assassin bug presses its rostrum firmly against the vulnerable spot and forces the bundle of stylets from the end of the supporting rostrum into the body of the victim. A shot of saliva is then administered. The effect on the cockroach is immediate: it goes into violent convulsions and falls limp and paralyzed. Its heart stops beating and its gut contracts. One of its limbs may quiver, its mouth parts may chew aimlessly for a few moments, but within 10 seconds the body of the cockroach hangs helpless from the assassin bug's rostrum. By the

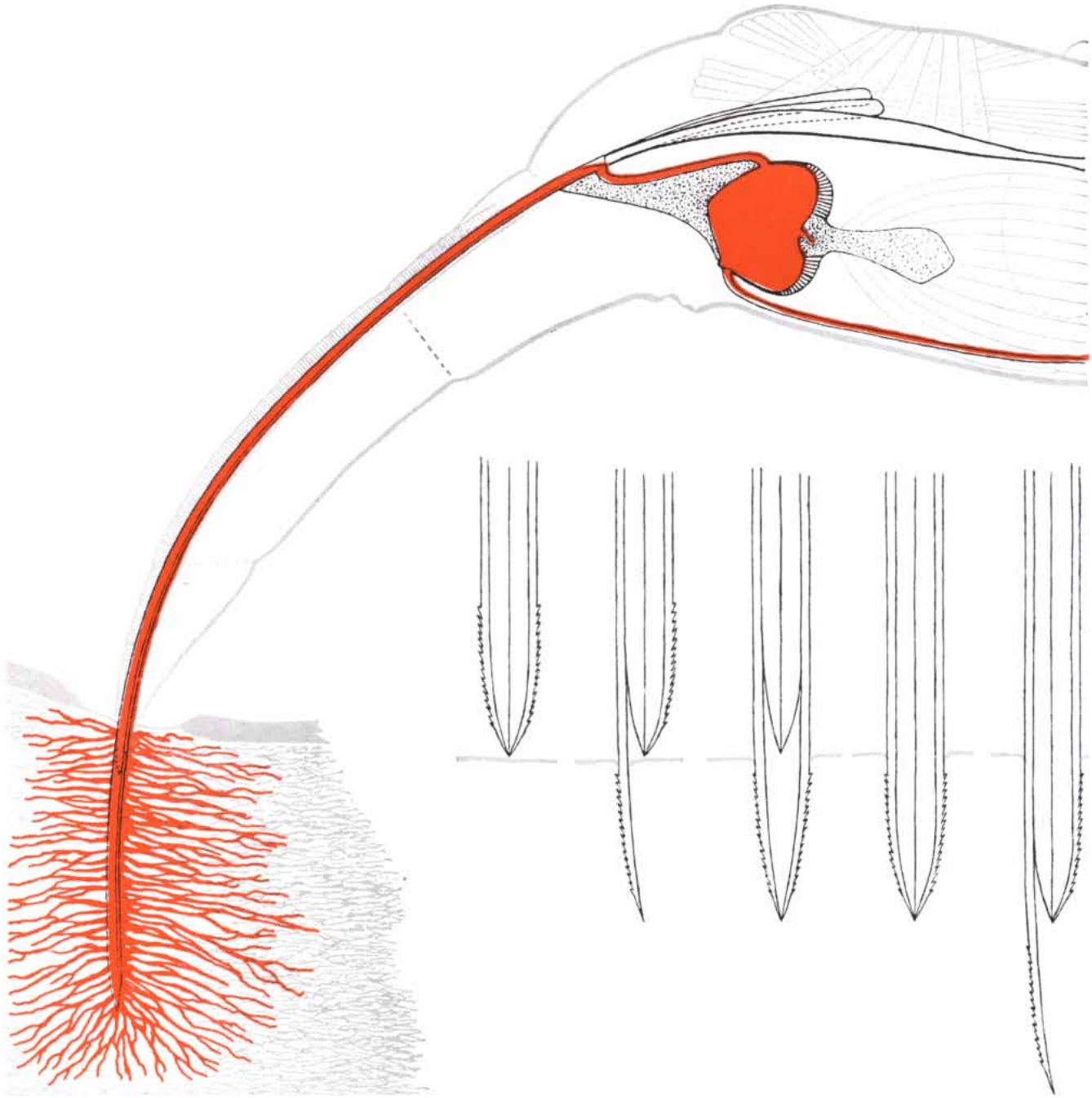


ADHESIVE PAD (*top*) on lower segment of assassin bug's leg enables it to grip struggling prey. The pad may have as many as 80,000 hairs, each about .05 millimeter long (*bottom*). Fanned end of the hair has a film of oil which helps it to adhere to surfaces.

time the cockroach makes its last feeble flickers of movement, Platymeris will have pumped at least 10 milligrams of saliva into it. The barbed outer stylets, which have held the rostrum and hypodermic needle firmly in place during the initial struggle, now hold the prey as the assassin bug releases the grip of its legs and carries the victim off to a quiet corner where it can drink its meal without too much risk of having to share it.

During their life span the assassin bugs and their predatory relatives among the Hemiptera consume large numbers of other insects. A single female black-kneed capsid (*Blepharidopterus angulatus*), a valued predator of an orchard pest, the red spider mite, can account for as many as 4,000 mites. The value of insect predators has been made all too clear when the use of insecticides has wiped out the predators without completely extinguishing the pest upon which they prey, and for which the treatment was intended. The dramatic growth in the pest population that has followed shows that, although the predators may not wipe out their prey, they are effective agents for controlling them.

There is no doubting the potency of assassin-bug venom; only the assassin bugs themselves are immune to its lethal effects. The question inevitably arises: Has the venom possibilities for use by man as an insecticide? The answer is yes, but the problem is to get the poison to where it acts, within the body cavity of the insect pest. The only way to do that is to leave the venom where it belongs: in the assassin bug, which, with its hypodermic syringe, is the perfect applicator for the perfect insecticide.



BARBED OUTER STYLETS puncture food tissue and form a passageway for insertion of the assassin bug's inner, venom-carrying stylets. The action of the stylets depicted here (*bottom right*) is that of plant-feeding Hemiptera; the action of assassin-bug stylets is probably similar. The illustration at top and left shows the course the venom (*color*) follows as it flows through the salivary pump, down the salivary stylets and into the prey, where it diffuses into the prey's tissues. Barbs hold the stylets in place.

Kodak reports on:

a substrate that doesn't split by itself . . . increasing the peak value of informational sensitivity . . . sooty things with a lot of physics in them . . . color lore that might have bored Goethe to death

Suggestion from East Berlin

Let us issue the large, round declaration that enzymes are the most important subject on earth. Does not their interplay govern all activity in the biosphere, including that in the cerebra of men of business and science? Of course.

Permit us now to narrow the scope to one class of enzymes, the lipases. They split fats. Lipases occur in certain animal organs and plant tissues. The lipase content of the blood serum is very low unless the duct of the pancreas is closed off.

To demonstrate and estimate a lipase, one gives it something (designated a substrate) to split under fixed conditions and one compares the amount of split product against a blank. Olive oil has been the standard substrate for lipase. The fatty acids released are titrated against sodium hydroxide. The measurement offers difficulties when the serum lipase level is normally low. It becomes a poor subject for wit when some foul derangement in the human machine raises the level to a point easy to measure.

The subway from East Berlin has brought out of Humboldt University there the suggestion (*Clin. Chim. Acta. 4*, 221) that phenyl laurate nicely liberates phenol in colorimetrically measurable quantity when acted upon by serum lipase. Soon after the news reached us, we prepared this compound for sale because it has good shelf life, where other proposed substrates all too soon split by themselves untouched by lipase. Then we took a different subway to Brooklyn, N. Y., to chat with a biochemist who told us of a considerable improvement in the phenyl laurate procedure.

Whoever will write name and address and the last three words of the preceding sentence on a postcard to Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), will receive an abstract of the Brooklyn procedure as soon as it is published.

Nice sharp pictures

We must not lose our sense of proportion. We must recognize that some people take so little technical interest in photography that they have never even heard of *Kodak Tri-X Pan Film*. Others who do use it have noticed that since that "Improved Type" has appeared on the carton, results have somehow improved. Most of these folk will be content with a bland assertion that the recently added notation signifies a major advance in reduction of graininess and improvement in picture sharpness. A single congenial luncheon table could probably accommodate all who would press us to explain that what we have really done is to increase the peak value of the informational sensitivity I of *Kodak Tri-X Pan Film* from .0016 to .0036

where $I = \frac{g}{a_s} \cdot \frac{1}{\sigma_s(D)}$

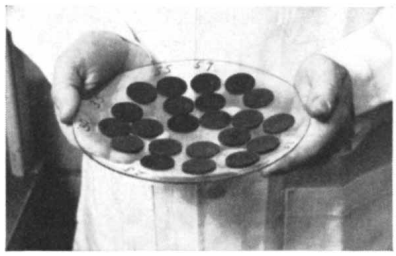
g = gradient of the linearized characteristic curve

a_s = area of the spread function

$\sigma_s(D)$ = standard deviation of the granularity trace for a scanning aperture having the size of the spread function

If you want to talk like that you should first consult Journal of the Optical Society of America, 48, *926, but if you just want very sharp pictures from very fast film, ask the Kodak dealer for Kodak Tri-X Pan Film, Improved Type.*

Adjustable boundary for the infrared



These sooty things have a lot of physics in them. The physics is of the old-fashioned type, not very clear, but not nearly so opaque as the little wonders themselves look when held to the light. Yet they transmit to 30μ in the very far infrared. Their utility lies in the easy adjustability of the spectral position of the transition from opacity to clarity. The opacity is achieved not by absorption and not by interference but by marvelously selective and effective scattering. What interference there is, in fact, operates on the side of clarity by beating down Fresnel reflection losses.

These *Kodak Far Infrared Filters* have turned into a hotter item than we dared hope when we first taught ourselves how to take silver chloride and convert its surface to silver sulfide in a manner as tunable as a fiddle string. Now the infrared trade—military and analytical—has grown to where it needs cut-on filters worse than it needed them ever before. And we are ready—even with a warning that these filters require precautions to protect them from harsh military environments and that silver chloride in the presence of water vapor still corrodes metal just as it always has. Of course, they can be mounted in plastic. The corrosion we can forestall if, at the expense of inserting a few absorption bands, we can be permitted to overcoat with polystyrene.

The pitch for the business is made by a collection of mimeographed sheets entitled "Kodak Far Infrared Filters," obtainable from Eastman Kodak Company, Special Products Sales, Rochester 4, N. Y. Here are given sizes, prices, and the code for specifying the cut-on wavelength wherever wanted from 1 to 5μ.

Gelatin responsibly dyed

A rich legacy of heuristic nonsense has been accumulating for generations in the next region of the electromagnetic spectrum over from the infrared, where the eye reigns supreme as the receptor and has qualified every seeing, thinking man to hold opinions. Even the mighty Johann Wolfgang Goethe, author not only of "Faust" but also of "Die Farbenlehre," put in his *zweipfennig* worth.

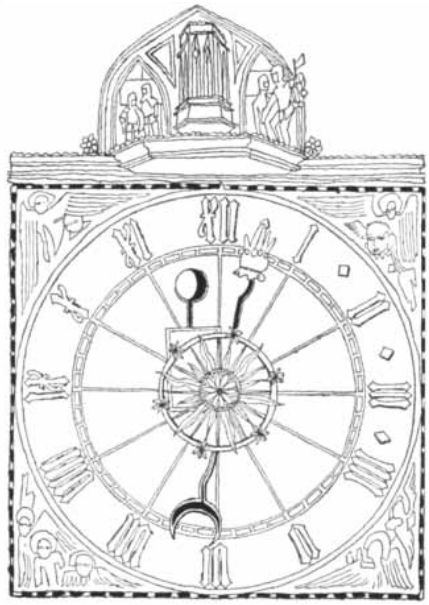
Amid rampant intellectuality, it has behooved us to tread lightly and confine our thinking to such *farbenlehre* as will fit us the better to flood the earth with color photography, myriad-colored Tenite plastics, color-locked Chromspun fibers, and Eastman textile dyes. Plus another field of dye art, tiny in economic comparison and disproportionately demanding in technical patience but important to those who, whatever their theories or purposes, wish to modify spectral distribution or overall intensity of light in systematic, quantitative, reproducible, simple, and inexpensive fashion. We refer to the celebrated little marvel of precision dye chemistry, the *Kodak Wratten Filter* of uniform gelatin, with or without glass mounting.

The reason we refer to it is that the new 20th edition of "Kodak Wratten Filters for Scientific and Technical Use," containing 81 pages of curves, data, and other useful information, is now obtainable from well-stocked photographic stores for 75¢ or from Eastman Kodak Company, Sales Service Division, Rochester 4, N.Y.

Price quoted is subject to change without notice.

Kodak
TRADE MARK

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



The Test Ban and "the Hole"

When President Eisenhower was queried at a recent press conference about the "driving force" behind his determination to reach an agreement outlawing nuclear weapons tests, he replied: "The driving force behind me is the belief that we should try to stop the spreading of this, what you might say, the size of the club. . . . As of now, I assure you, the power that exists in the arsenals, certainly of our own, and we know of Russia's, is such a tremendous thing that I don't think that testing will necessarily make destruction more likely, I mean of your enemy or of yourself. I don't mean enemy; I mean of anyone, any nation, or this one. . . . If we continue to do that [test], others are going to test in the fields we have already covered, you see, and finally there will be any number of nations that have it, and I think it ought to be stopped."

The President had just issued a joint statement with British Prime Minister Macmillan declaring their readiness to "institute a voluntary moratorium of agreed duration" on small underground tests if two conditions are met: (1) that a treaty be concluded with the U.S.S.R. to ban surface and large underground explosions and to provide for "an adequate quota of on-site inspections"; (2) that arrangements be made "for the purpose of progressively improving control methods for events below a seismic magnitude of 4.75" (equivalent to an unmuffled underground explosion of about 19 kilotons of TNT).

In the following weeks it became apparent that official U. S. opinion is not unanimous on the subjects of suspension and control. "Many responsible officials in the U. S. Government—particularly in the Atomic Energy Commission and in the Defense Department—view the decision [of the President and Prime Minister] with pessimism and alarm for several reasons," reported *The New York Times*. Joseph Alsop in the *New York Herald Tribune* quoted A.E.C. chairman John A. McCone as saying: "If their word is good, then our position of nuclear superiority is secure. If the Soviet's word is not good, the past 18 months will have given them time to catch up in nuclear weapons development. Another two or three years would place them well ahead of us." As to the advances in weapons that can be expected from further testing, they "are second only to the historic advance from the atomic to the hydrogen bomb."

The Joint Congressional Committee on Atomic Energy conducted hearings to air "the available facts" as to "various technical problems that may or may not exist in the operations of an adequate control and detection system." More than 20 scientific witnesses presented their views. Summarizing the hearings, the Committee declared: "It appears from the testimony that for the next several years at least it will not be possible to identify underground events whose seismic signals record the equivalent of a nonmuffled explosion of 20,000 tons or less, although they may be detected. Further, it appears that for this same time period it will not be possible to detect muffled tests of 100,000 tons or more set off deep underground in large cavities. Therefore, it seems that for the next several years onward there could be a race between improved means of detection and identification as against improved means of concealing and muffling nuclear tests."

Newspaper reports of the testimony emphasized that both Edward Teller, who has opposed the cessation of testing, and Hans A. Bethe, who has favored it, agreed that the original network of 180 seismic stations, proposed by an experts' conference in 1958, is now inadequate. Bethe was said to have "advocated" a 600-station network in the U.S.S.R. alone (as compared with 21 stations contemplated in the original scheme).

After the hearings an expanded U. S. program of research on seismic detection methods, known as Project Vela,

was announced by the White House. During this year and next about $76 million will be spent on "increased basic research in seismology, procurement of instruments for a world-wide seismic research program, development of improved seismic instruments, construction and operation of prototype seismic detection stations, and an experimental program of underground detonations encompassing both high-explosive and, where necessary, nuclear explosions." The nuclear explosions will "produce no radioactive fallout."

In a speech before the Philosophical Society of Washington, Bethe, who is professor of physics at Cornell University and a former member of the President's Science Advisory Committee, reviewed the detection problem. He pointed out some of the practical questions raised by the large cavity: the only "reasonable" way to make it is by washing out a salt dome; this would take two and a half years and cost $10 million for a hole big enough to hide a 20-kiloton explosion; the washed-out salt could be detected in any river into which it is dumped; salt domes, especially ones accessible to rivers or oceans are not very common, and so on. Bethe concluded: "So I really think that the big hole is not quite as easy as it sometimes is represented to be."

As to his "advocacy" of a 600-station net in the U.S.S.R., he had mentioned it "only in order to show that the detection system is technically—technically, not politically—capable of dealing even with the newly decoupled shots." Such a net "would be able not only to detect but to identify explosions of 20 kilotons carried out under the extreme decoupling."

However, Bethe added, "I really think that we are all behaving like a bunch of lunatics to take any such thing as the big hole seriously. . . . The opponents of a test-cessation agreement have forced us into considering more and more, and smaller and smaller, technical details which become more and more absurd. . . . I think the problem is not a technical problem; [it is] a political problem."

At present, Bethe continued, the U. S. has "nuclear weapons of all sizes and shapes: heavy ones and particularly light ones. There is, in my opinion, very little of military value that we do not have." The U.S.S.R., being less advanced in nuclear-weapons technology, has more to

gain than the U. S. from a continuation of testing. If the U.S.S.R. wished to develop small, tactical weapons, it would be better advised to accept the U. S. proposal to allow small tests rather than to undertake the necessary long series of tests clandestinely. In fact, Bethe believes, if negotiations break down, the Russians will not test small weapons but large thermonuclear weapons. "These are the ones which threaten our homeland."

The supremely important goal is to reach agreement on limitation of armaments. A test ban would constitute a first step. "We have the Russians in a frame of mind now where they are quite willing to talk about such matters. . . . But how can we expect the Russians to be willing to negotiate, or to agree to other measures of disarmament which might be more far-reaching and might be more important for the peace of the world than this one, if already in this little one, where we risk so very little, we are as sticky as we have been?"

Atoms for Peace Awards

The Atoms for Peace awards for 1959 and 1960 were presented last month to four U. S. physicists for their contributions to the development of the nuclear reactor. Leo Szilard and Eugene P. Wigner received the 1959 award, and Walter H. Zinn and Alvin M. Weinberg the award for 1960. Each received $37,500 and a gold medal.

Together with the late Enrico Fermi, Szilard, now professor of biophysics at the University of Chicago, received a patent on the first atomic pile. Wigner, a former director of the Oak Ridge National Laboratory, is professor of physics at Princeton University. Weinberg is now director of the Oak Ridge National Laboratory, and Zinn, who formerly directed the Argonne National Laboratory, is vice president of Combustion Engineering, Inc.

Stunt Man in Space

"Putting a man in space is a stunt: the man can do no more than an instrument, in fact can do less." So said Vannevar Bush, chairman of the Board of Governors of the Massachusetts Institute of Technology, in a statement to the House Committee on Science and Astronautics. "There are far more serious things to do than to indulge in stunts. As yet the American people do not understand the distinctions, and we in this country are prone to rush, for a time, at any new thing. I do not discard completely the value of demonstrating to the world our skills. Nor do I undervalue the effect on morale of the spectacular. But the present hullabaloo on the propaganda aspects of the program leaves me entirely cool."

In general Bush believes that "we are overemphasizing" space research as compared with "other possible programs which might be carried on at the same cost, and at the same utilization of our all-too-limited scientific and engineering talents." He observed that of "all the vast sums" the U. S. spends on research only 6 to 8 per cent are put into basic investigations "upon which our prosperity and stature in the next generation may indeed depend."

CHEM Study

Following the lead of their colleagues in physics and mathematics, U. S. chemists have now set up a large-scale project to revise high-school chemistry teaching. The program, known as the Chemical Education Materials Study (CHEM) gets under way this month with a meeting of 20 to 30 high school and college teachers at Harvey Mudd College in Claremont, Calif. The group will spend six weeks preparing new text and experimental material for presentation to some 30 high-school teachers in August. If this material is deemed satisfactory, it will be released to selected schools throughout the country for a trial during the 1960-61 school year. Later the group will also prepare instructional films and monographs on selected topics.

The CHEM study is a joint project of the University of California and Harvey Mudd College. Glenn T. Seaborg, Nobel laureate in chemistry and chancellor of the University of California, is general chairman of the program's steering committee. J. A. Campbell, head of the chemistry department at Harvey Mudd College, will direct the study. It is being financed by a grant from the National Science Foundation.

Organic Semiconductors

Transistors and other semiconductor devices may shortly be made of plastics, according to a report in *Materials in Design Engineering*. Although most organic materials are ordinarily insulators, writes Walter Brenner of New York University, some of them can be made semiconductive when their atomic structure is altered by heat treatment or ionizing radiation.

By irradiating the polymer of acrylonitrile with gamma rays and then heating

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This Air Force program involves system analysis, equipment evaluation, computer design, human factors, and operations research. The results of the investigations are being used as a basis for planning future Air Force programs. It is typical of advanced systems programs being carried out by the Bendix Systems Division. Better engineers and scientists interested in pioneering systems of the future are invited to join this growing team.

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THE Bendix CORPORATION

"Sun gas" returns to stay

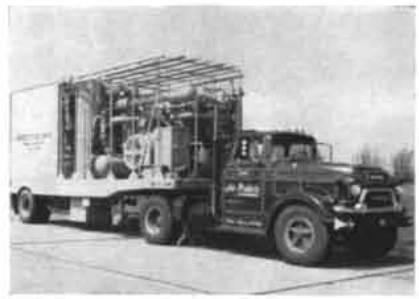
Helium today is making a dramatic comeback for a gas that was once considered down for the count. Reasons for its resurgence—vital jobs that helium, and only helium, can perform in a variety of fast-moving fields . . . and the successful development of new processes and equipment that make it readily available by the ton.

Discovered on the sun in 1868, on earth in 1895, helium was still a low-quantity item in the 1940's, though it had gained some prominence as a nonflammable lifting agent for U.S. dirigibles and blimps. Then metal fabricators discovered in helium an ideal atmosphere for arc-welding magnesium, incendiary when welded in air. Today helium helps weld many lightweight, high-strength metals, including aluminum and titanium. Taking a cue from the welders, manufacturers use corrosion- and oxidation-resistant helium atmospheres in making semiconductors, processing zirconium and titanium, degassing metals. Our liquid-fuel space rockets take advantage of helium's light weight (about ⅛ that of oxygen) to get effective fuel tank pressurization and carry higher payloads. But helium's inertness and light weight are today among its more prosaic properties.

Heat-loving cold maker

Helium is remarkably eager to absorb heat, and is a superior transfer agent. Add its stubbornness against contamination by radioactive particles and you get a superior coolant for nuclear reactors. *Liquefy it and you have the coldest cold man knows—just seven degrees* (F) *shy of absolute zero.* Helium's cold is even now opening new doors in electronics, by cooling solid state devices and superconductors to the point of peak performance. And in the lab, helium is helping to slow molecular motion down to a crawl, giving us our first looks at free radicals, chemical reactions and physical phenomena.

Helium is uncommonly apt at penetrating things. Its viscosity of 1.24 micropoises (about 8,000 times less than water) and its small molecular size get it through holes you can't see without a microscope, makes it a dependable leak detector for nuclear reactors, high-vacuum and high-pressure vessels. (It even goes through glass.) And researchers are seeking new ways to take advantage of all these properties *plus* helium's high heat- and sound-conductivity (among gases excelled only by hydrogen) . . . its very low ionization potential . . . and its low, unexcelled refractive index.



Production doubled in one year

Late in 1959, under a crash program for the Bureau of Mines, a high-efficiency plant that extracts (from natural gas) and purifies a million cubic feet of helium daily was designed, built and placed in operation at Keyes, Okla., doubling U.S. capacity to keep pace with greatly increased demand. Ultra high-speed turbo expanders, providing efficient refrigeration at —320°F, were the keys to success of the new process. With helium gas supply boosted, the next challenge—actually a refrigeration problem of the highest order—was commercial-scale liquefaction. A few seconds with a Carnot cycle work curve show that helium liquefaction demands over 5 times the refrigeration it takes to liquefy hydrogen (no mean feat itself), 30 times that required for oxygen. And equipment design is ultra-critical, for helium's low latent heat of 39.6 BTU per lb-mol (only 10% that of hydrogen, 1.35% that of oxygen) means that excessive heat leakage would make liquefaction impossible.

We recently completed for the Navy a mobile liquefier (shown above) that is now turning out more than 35,000 cubic feet per day . . . built another unit that we operate ourselves. These pave the way for larger units, and for research on transportation and storage . . . open new frontiers for ultra-low-temperature exploration. The "sun gas", at last, has found its place in the sun. Air Products, Inc., Allentown, Pa.

it, workers in the U.S.S.R. claim to have developed a semiconductor that can operate at much higher temperatures than germanium can. At Bell Telephone Laboratories the heat treatment of polystyrene and other substances has yielded semiconductors with similar thermal stability. Some of the materials offer the further advantage, for certain applications, that they are transparent.

Some organic semiconductors have additional valuable properties. Charge-transfer complexes (substances formed by the loose coupling of electron-donating and electron-accepting molecules) generate a voltage when heated. In one of them the effect is roughly seven times stronger than in bismuth telluride, which is presently used in many thermoelectric devices. Crystalline organic compounds such as naphthalene produce a voltage in response to light, and thus may find applications in detecting-devices and in solar batteries. Biologists are also interested in light-sensitive organic semiconductors. Evidence is accumulating that both chlorophyll and proteins are such materials, and that semiconduction plays an important role in photosynthesis and protein chemistry.

Galactic Gas

Recent observations by astronomers at Mount Wilson and Palomar Observatories on the inner part of the Milky Way may furnish new insight into the forces that rotate galaxies. Guido and Luis Münch report in *The Astrophysical Journal* that they have measured the speed of rotation of 18 stars lying 13,000 to 20,000 light-years from the center of our galaxy. The stars apparently move at different speeds from those of gas clouds in the region. Heretofore it had been thought that the gas and stars rotate together. At 20,000 light-years from the center, stars move faster than the hydrogen clouds near them; at 13,000 light-years they move more slowly. Since stellar motions are controlled by gravitational forces and gas motions by both gravitational and magnetic forces, comparative studies of rotation should provide a better understanding of galactic dynamics.

Further details of gas motion have been discovered in the Great Nebula in Andromeda. In this spiral galaxy Guido Münch has found huge, lumpy clouds that stream outward from the center of the galaxy at about 150,000 miles per hour along the plane of the galactic disk. These movements are strikingly similar to those of hydrogen clouds near the nucleus of the Milky Way, detected in radio

AT RAYTHEON—

Scientific imagination focuses on

HIGH-TEMPERATURE SEMICONDUCTORS

Silicon carbide, long employed as a refractory for furnaces, shows promise as a material for semiconductor operation at temperatures up to 1,000° C. Substances presently used as semiconductors—silicon and germanium—fail at 300° C. and 150° C., respectively. At these temperatures, the thermal energies of their electron carriers are too high for satisfactory semiconductor operation. In silicon carbide, the carriers have a broader energy gap to bridge in reaching conductivity and thus permit semiconductor characteristics at high temperatures.

Crystals of this man-made compound have a cubic *(beta)* or hexagonal *(alpha)* lattice structure. The highly ordered *beta* phase appears to have more desirable characteristics, including greater mobility and lifetime of electron carriers. Raytheon scientists have been investigating crystal growth of the *beta* phase by gaseous reaction and from solution. Because crystals for semiconductive devices must be of extreme purity, production techniques are far more sophisticated than those called for in producing silicon carbide for commercial applications.

Raytheon scientists responsible for these efforts are R. C. Ellis, Jr. and Dr. A. H. Smith, who are contributing to fundamental knowledge of the morphology and growth mechanisms of high-temperature semiconductors.

Excellence in Electronics RAYTHEON **RAYTHEON COMPANY, Waltham, Mass.**

*A branch of study concerned with the observation and classification of facts.—Webster

observations by the Dutch astronomers G. W. Rougoor and Jan H. Oort. Münch and Oort suggest that the outrushing streams are fed by gas pouring in from the corona—a ball of tenuous hydrogen that seems to envelop a galaxy—along magnetic lines of force.

Coming in out of the Radiation

Although it is commonly supposed that high-energy radiation cannot be felt, a few individuals have reported tingling or burning sensations during exposure to large doses of radiation. Now two workers at the National Cancer Institute have demonstrated that mice apparently feel and shun a high-energy X-ray beam. When the animals were placed in a cage that was shielded on one side and open to the X-ray beam on the other, they exhibited a strong preference for the sheltered area. The mice usually began avoiding the open side after receiving a dose of 300 to 400 roentgens, the rapidity of their response increasing with the rate at which the radiation was delivered.

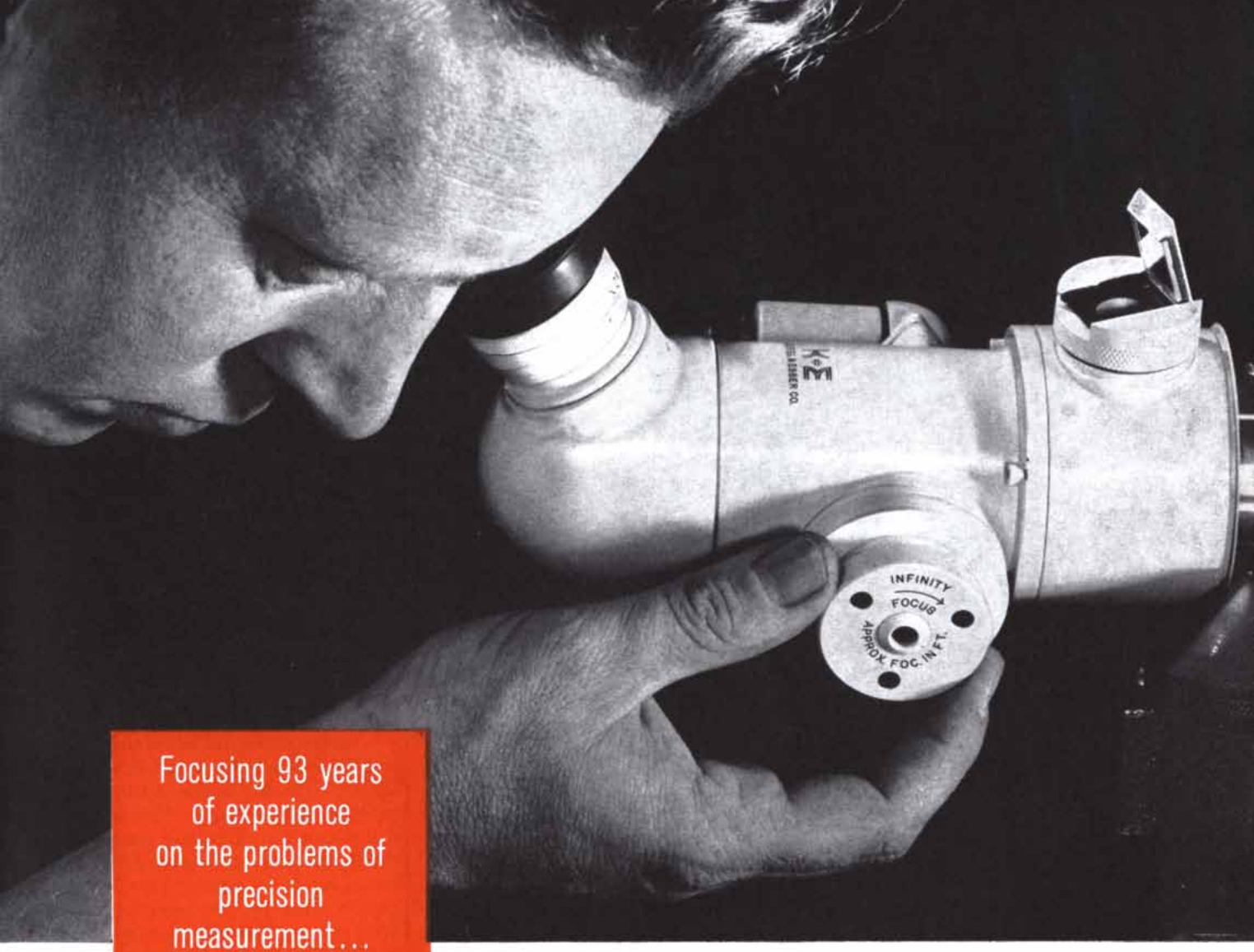
Describing the experiments in *Proceedings of the Society for Experimental Biology and Medicine,* Howard L. Andrews and Louis M. Cameron say they do not know how the mice detect X-rays. The experiments were designed to rule out radiation-induced fluorescence or gas products as sensory cues.

Lunar Organic Chemistry

Although it is highly unlikely that there is life on the moon, the nearest target of space explorers probably does contain a layer of organic molecules, formed in its early atmosphere and now buried in dust roughly 10 meters below the surface, according to calculations by Carl Sagan of the Yerkes Observatory. Contamination of this material with microorganisms or organic matter carried by rockets, he writes in the *Proceedings of the National Academy of Sciences,* "would represent an unparalleled scientific disaster."

The author suggests that the early moon, like the early earth, probably had an atmosphere of methane, ammonia and water vapor. The composition may have persisted for 10 to 100 million years, nourished by gas leaking out from the interior. Thus there would have been ample time for ultraviolet light and electrical discharges to convert some of the mixture to organic molecules, including amino acids.

Sagan calculates that enough of this



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material fell to the lunar surface to make up a layer as dense as 10 grams per square centimeter. If the molecules had not later been buried by dust created by meteorite impacts, radiation from the sun and space would have destroyed them; but first it would have caused some of them to link together in large, organic molecules such as polypeptides. These too may now lie buried along with the smaller molecules.

Study of lunar organic matter should throw light on such problems as the early history of the solar system, the chemical composition of matter in the remote past, the origin of life on earth and the possibility of extraterrestrial life. But only if the stuff is not devoured by terrestrial organisms or hopelessly mingled with nonliving terrestrial material. "Because of the moon's unique situation as a large, unweathered body at an intermediate distance from the sun, scientific opportunities lost on the moon may not be recoupable elsewhere," Sagan points out.

Journalistic Flood

At a recent conference in London scientific editors, publishers and librarians debated how to protect themselves against a growing deluge of journals. A report of the meeting in *Nature* stated that the number of journals received by the British Science Museum Library is increasing at the rate of about 700 per year, or almost two new journals per day. With new research institutions spawning in China, Japan and elsewhere, the figure will probably go up to 1,000 per year.

The flood was variously blamed on irresponsible publishers, on an increase in research and on small institutions that hope to acquire good journals free, in exchange for their often almost-worthless publications. But the greatest share of the blame fell on the scientists themselves, and particularly on "the habit of some workers of publishing the same material several times, . . . first in a preliminary communication, then in various papers in national and international journals and again, with minor modifications, in congress reports and symposium volumes."

Apparently the increase in publications has not led to a corresponding increase in reading. A survey was cited indicating that few scientists regularly read more than three or four journals. One delegate wondered whether science would suffer if workers were licensed to publish only one paper and one preliminary report per year.

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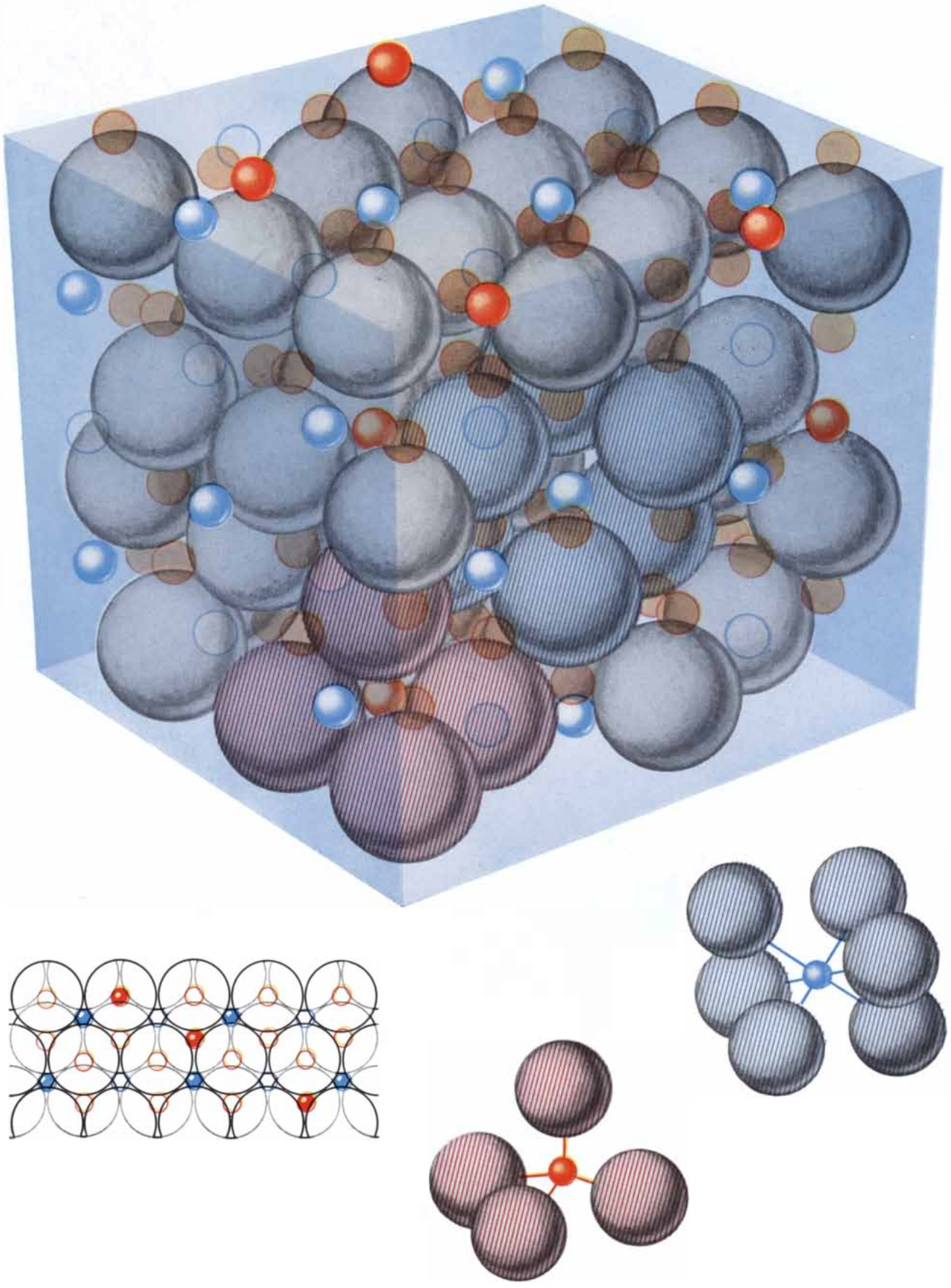
MARTIN



FERRITE CRYSTAL-LATTICE is shown in three dimensions at top. Large spheres represent oxygen atoms; small shaded red circles, so-called A sites; blue circles, B sites. (Colored spheres represent metal atoms in the sites.) Below is a typical group of four oxygen atoms around an A site (*middle*) and of six oxygen atoms around a B site (*right*). Corresponding groups in the cubical lattice are hatched and tinted. At lower left the lattice is seen edgeon. The circles outlined in gray are behind those outlined in black.

FERRITES

These iron oxide materials combine substantial magnetic strength with extremely high electrical resistance. Electrical engineers are using them in the design of revolutionary microwave devices

by C. Lester Hogan

The first magnetic material known to man appears to have been lodestone. It was with this iron oxide mineral (now commonly called magnetite) that the Greek philosopher Thales made the earliest recorded observations on magnetism in about 600 B.C. Thereafter lodestone remained a curiosity. Much stronger magnets could be made of certain metals: iron, nickel and cobalt and their alloys.

In the past decade, however, magnetic oxides have dramatically emerged from obscurity. These materials are in large part responsible for a postwar revolution in electronics, particularly in the burgeoning field of microwave electronics. They have helped extend standard electronic techniques to the manipulation of higher and higher frequencies. And they make possible a group of entirely new devices that no one had ever considered possible—strange devices that seem on first consideration to violate fundamental laws of electromagnetism.

Magnetic Insulators

All these benefits arise out of one simple fact: A magnetic oxide is both a reasonably strong magnet and an electrical insulator. Why is this combination so potent? The answer is implied in the word electromagnetism, which indicates how intimately the phenomena of electricity and magnetism are associated. On the one hand, the association is responsible for almost every useful application of electricity. On the other, its very intimacy eventually sets a limit to what can be done. It is by the partial isolation of electrical and magnetic effects that the magnetic oxides have pushed back the technological limits.

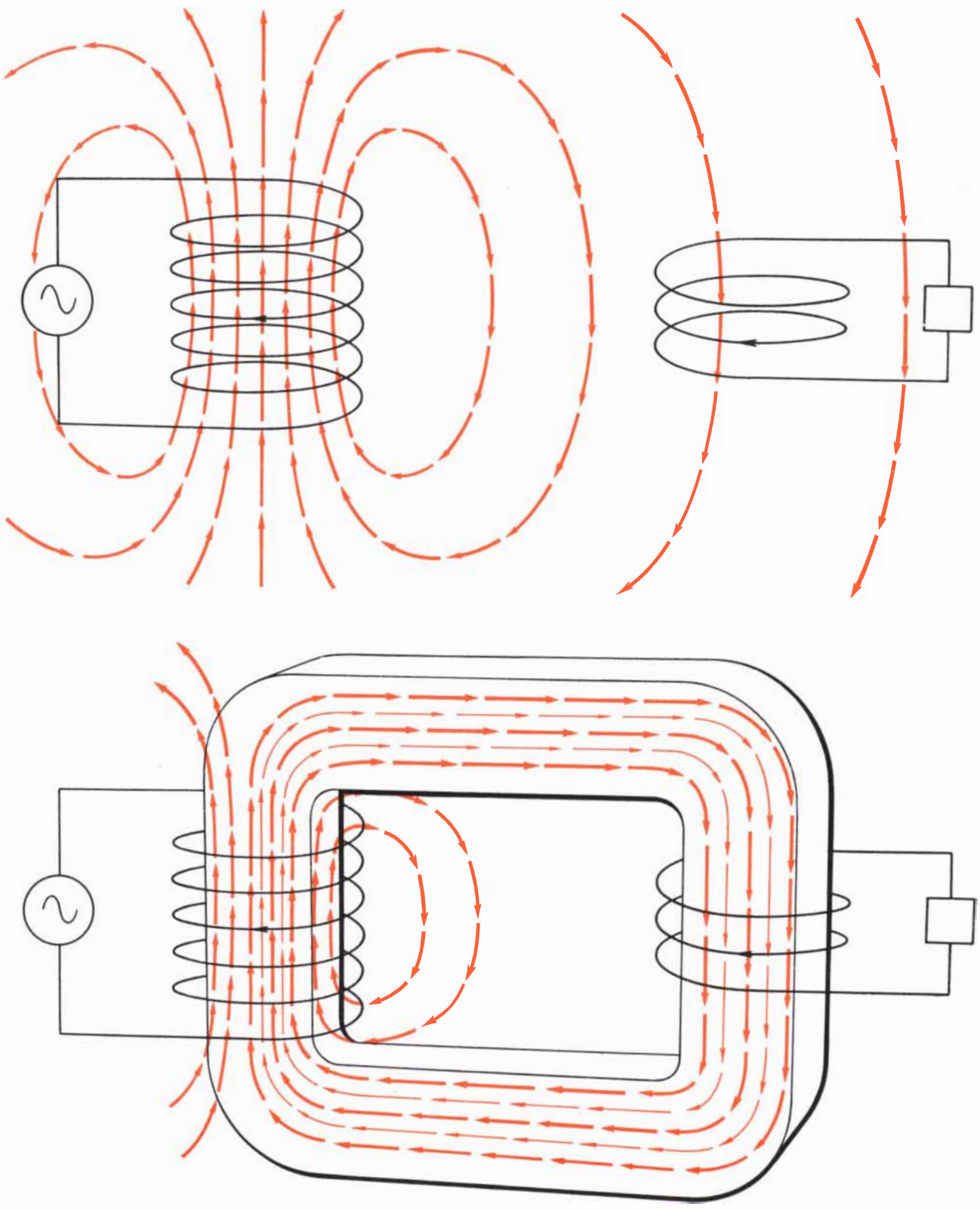
Consider the archetype of electromagnetic devices: the transformer. It consists essentially of two coils of wire, one called the primary and the other the secondary, which are separate but close together [*see illustration on next page*]. When an alternating electric current flows through the primary coil, it sets up a pulsating magnetic field, part of which passes through the secondary. (In the illustration the field is represented by imaginary lines of force. It is useful to think of the lines as actually existing. Then the number of lines in any region, or the flux density, as it is called, is an index of the strength of the field in that region.) As the lines of force enter or leave the secondary, they induce a voltage, which sends a current through the circuit connected to the coil.

The efficiency of the energy transfer depends on the number of lines of force that thread the secondary. If the coils are separated simply by air, the primary field spreads out in all directions, and comparatively few of its lines get into the secondary. But if the two coils are wound around a core of a magnetic material such as iron, the field is almost entirely concentrated in the core and is therefore within the secondary. Thus the iron acts as a magnetic conductor: lines of force pass more easily through it than through air. Added to this effect is a sort of amplifying action. The tiny atomic magnets of which the iron is composed swing parallel to the field and thereby add their lines of force to those produced by the primary coil.

The ability of iron to concentrate and reinforce magnetic fields is seriously limited, however, by the fact that it is a good conductor of electricity. The alternating primary field induces a voltage in the core, just as it does in the surrounding secondary coil. Because the iron is an electrical conductor, circular currents like those in the secondary coil also flow in the core [*see top illustration on page 95*]. Known as eddy currents, they create magnetic fields of their own. And the direction of the secondary field always tends to oppose that of the primary field, partly canceling it. To put it another way, the eddy currents tend to keep the primary field out of the iron. Furthermore, they steal energy from the primary circuit and dissipate it in useless heating of the core.

Now the size of an induced voltage depends not only on the strength of the primary field (the number of lines of force) but also on the rate at which the field ebbs and flows. This in turn depends on the frequency of alternation of the primary current. The higher the frequency, the stronger the inductive action, and hence the stronger the eddy currents. Thus as the frequency is increased, the effectiveness of iron or other metallic cores drops off.

To combat eddy currents, transformer cores are usually made of thin sections of metal joined by an insulating glue. This breaks up the electrical circuit around the core. For "low" frequencies, from the 60-cycle-per-second current in power lines to the 100,000-cycle alternations of the regular radio-broadcast band, lamination is reasonably effective. As the frequency goes up, however, eddy currents within each thin section grow so large that again the primary field is substantially canceled in the core. The maximum usable frequency can be extended further by making cores of tiny metal grains, pressed together and held by an insulating binder material. But eventually, in the range of millions of cycles (megacycles) per second, the same effect appears within the individual particles. Furthermore, the insulating glue separates the particles not only electrically, but also magnetically. This tends to prevent the individual atomic magnets from acting together to multiply the field strength. At very high frequencies a



TRANSFORMER consists essentially of two coils of wire (*black lines*). An alternating current is sent through one coil, called the primary (*left*). An alternating magnetic field (*colored arrows*) from the primary cuts the turns of the secondary coil (*right*), inducing an alternating voltage. If the coils are separated by air (*top*), the primary field spreads widely and only a small portion cuts the secondary coil. By inserting a core of magnetic material (*bottom*), the field is concentrated so that more lines of force thread the secondary. In addition, the atomic magnets in the core align themselves with the primary field, adding their own lines of force (*thin arrows*) to those set up by the primary. The stronger the field cutting the secondary, the higher the efficiency.

powdered core is hardly any better than no core at all.

A more direct attack on the problem would be to use magnetic materials that simply do not conduct electricity; in short, to use magnetic oxides. Strictly speaking, magnetic oxides are not perfect insulators; no material is. But their resistance is so high—billions or even millions of billions times higher than that of metals—that even very large voltages produce negligible currents in them.

Magnetic Crystals

The secret of the magnetic strength, as well as of the high resistance, of these materials lies in their crystal structure. Several types of magnetic compound, each having valuable new properties, have been developed in the past few years. The simplest type, and the one in widest use, is called the ferrite. Lodestone, or magnetite, is a natural iron ferrite. Its chemical formula is $Fe^{++}\ Fe_2^{+++}\ O_4^{--}$. This gives the proportions of its composition: one doubly ionized or divalent iron atom (Fe^{++}), two triply ionized or trivalent iron atoms (Fe_2^{+++}) and four doubly ionized oxygen atoms (O_4^{--}). All ferrites contain the trivalent iron ions and the oxygen ions in the ratio of two to four. The divalent ion can be of any metal whose atom is small enough to fit into the crystal lattice. Thus the general formula of a ferrite is $X^{++}\ Fe^{+++}\ O_4^{--}$, X representing an atom of such a metal as iron, nickel or zinc.

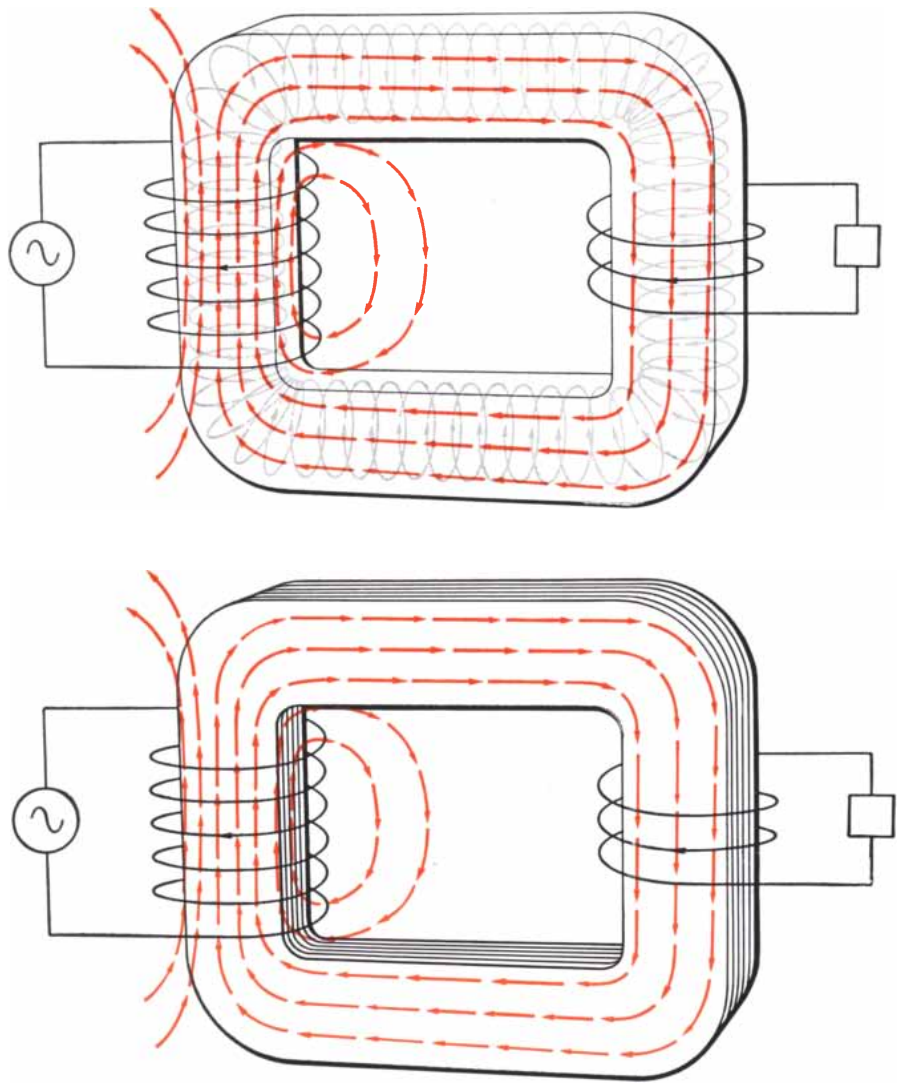
By itself the formula tells very little about the interesting properties of ferrites. It does indicate, however, why they have high resistance. This is because the crystals are ionic: the metal atoms have transferred some of their electrons to the oxygen atoms. The result of this exchange is to fill completely the lower of the energy bands in which, according to quantum theory, the electrons can lie. They have no room to move within the band, and they are separated from the next available level by a wide "forbidden" gap of energy. Very high voltages are required to lift even a few of the electrons into the conducting region.

As to magnetic strength, it arises, as always, from the magnetism of spinning electrons. Most of the electrons in any atom are grouped in pairs; the electrons in each pair spin in opposite directions and therefore cancel each other's magnetism. Some atoms, notably those of the so-called transition metals—manganese, iron, nickel, cobalt and so on—contain one or more unpaired electrons, and therefore have a net magnetism.

The effect of such atomic magnets on the properties of a crystal of which they are a part depends on the force between them. In some crystals the coupling between magnetic atoms is quite weak. At room temperature the energy of thermal vibration is sufficient to overcome the force, and the magnetic units are oriented entirely at random [*see illustration at top left on next page*]. Unless there is an external field to pull the atoms into line, these crystals exhibit no magnetism; they are said to be paramagnetic.

In other solids magnetic atoms are much more strongly coupled, and unless the temperature is too high, each atom assumes a fixed direction with respect to its neighbors. (If the temperature is raised sufficiently, thermal vibrations will eventually overcome the coupling force. The point at which this happens for any magnetic material is known as its Curie temperature.) Depending on the type of interatomic force, the neighboring atomic magnets are either parallel or antiparallel. In the first instance all the units point the same way, giving rise to a strong external magnetic effect; the material is said to be ferromagnetic. Actually all the atoms in a ferromagnetic crystal do not ordinarily point in the same direction. The crystal is usually subdivided into small "domains," each magnetized in a different direction [see "Magnetic Materials," by Richard M. Bozorth; SCIENTIFIC AMERICAN, January, 1955]. A sufficiently strong external field can pull all the domains into line, and then the ferromagnet is saturated, or as strongly magnetic as it can be.

If the coupling is of the type that aligns adjacent atoms antiparallel to each other, and if all the atoms have the same strength (the same number of un-



EDDY CURRENTS (*curved gray arrows at top*) **are set up in conducting magnet-cores by the alternating primary field. To help prevent these unwanted currents the core can be made of separate thin laminations, held together by an insulating binder** (*bottom*).

paired electrons), then their magnetism cancels; the crystal is antiferromagnetic. However, the little magnetic units may not all be of the same kind. Then they may have different strengths, and although they are oriented so as to offset one another, they give rise to a net magnetic effect. Crystals of this type are called ferrimagnetic. Ferrites and other magnetic oxides are ferrimagnets.

Clearly a ferrimagnet must be weaker than a ferromagnet containing the same kind of magnetic atoms. The strongest of the ferrites has only a third the saturation strength of pure iron. Hence ferrites are not used in devices such as power transformers, which must carry a great deal of magnetic energy. In the low-power applications to which they are suited, however, ferrimagnetism is a distinct benefit, making them much more versatile than metallic magnets.

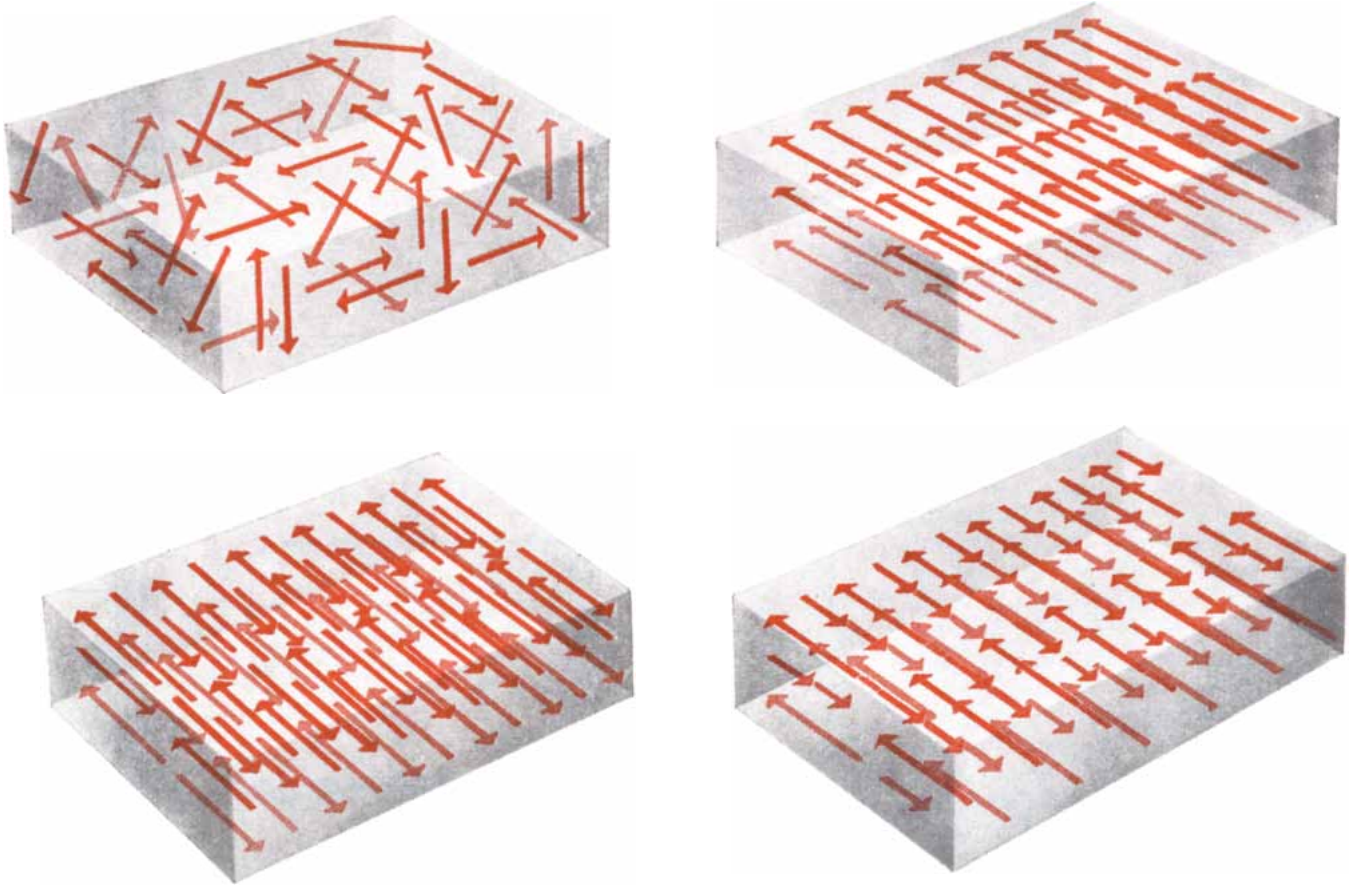
The Ferrite Lattice

To understand why this is so, one must turn to the details of the ferrite crystal. If its atoms were big enough to see, it would look like a cubical stack of cannon balls with billiard balls tucked into some of the spaces between them [*see illustration on page 92*]. The cannon balls are oxygen atoms and the billiard balls the much smaller metal atoms. There are different ways in which cannon balls can be "close packed" in a cubical box. One arrangement, known as cubic close-packing, repeats itself every other layer; that is, the balls in the third layer are directly over those in the first. This is the pattern of the ferrite crystal. (In the other most common arrangement the repeat interval is three layers high rather than two.)

As the drawings of the ferrite crystal-lattice show, there are two distinct types of pocket among its oxygen atoms. They are conventionally labeled A and B. A metal atom in an A pocket would have four oxygen atoms as its nearest neighbors: three in one layer and one in the next. In a B pocket it would have six oxygens as its nearest neighbors: three in each layer. For every 32 oxygen atoms (the basic repeating unit, or "unit cell," of the lattice) there are 64 A-pockets and 32 B-pockets; 96 pockets in all. Since there are only three metal atoms to every four oxygens, or 24 metal atoms per unit cell, the pockets are only a quarter filled. Analysis of ferrite crystals reveals that eight of the occupied sites are of type A and 16 of type B.

In view of the fact that the material contains twice as many trivalent iron ions as divalent metal ions, and twice as many occupied B sites as A sites, one might expect to find the trivalent iron in B sites and the divalent metal in the A. When the divalent metal is zinc, cadmium or manganese, this is the way the atoms are distributed [*see top of illustration on opposite page*]. It turns out, however, that in the majority of ferrites the preferred distribution is one in which the divalent metal is in the B site, and the trivalent iron is equally divided between A and B. Iron, cobalt and nickel ferrite have this pattern. Copper and magnesium ferrite tend toward it, but have some divalent ions in both sites, the exact distribution depending on the heat treatment the material has received.

The significance of these distributions is that strong coupling (which is of the



TYPES OF MAGNETISM are illustrated schematically. Colored arrows represent the direction of magnetization of individual atomic magnets. The shaded volumes are single magnetic "domains" within a material. In paramagnetic material (*top left*) the atomic magnets are weakly coupled to each other and, at room temperature, are disordered by thermal vibrations. In ferromagnetic material (*top right*) the magnets are coupled parallel to each other. In antiferromagnetic material (*bottom left*) the magnets are coupled antiparallel, and there is no net magnetism. Ferrimagnetic materials (*bottom right*) also have antiparallel coupling, but the magnets pointing one way are stronger than those pointing the opposite way, and the substance is magnetized.

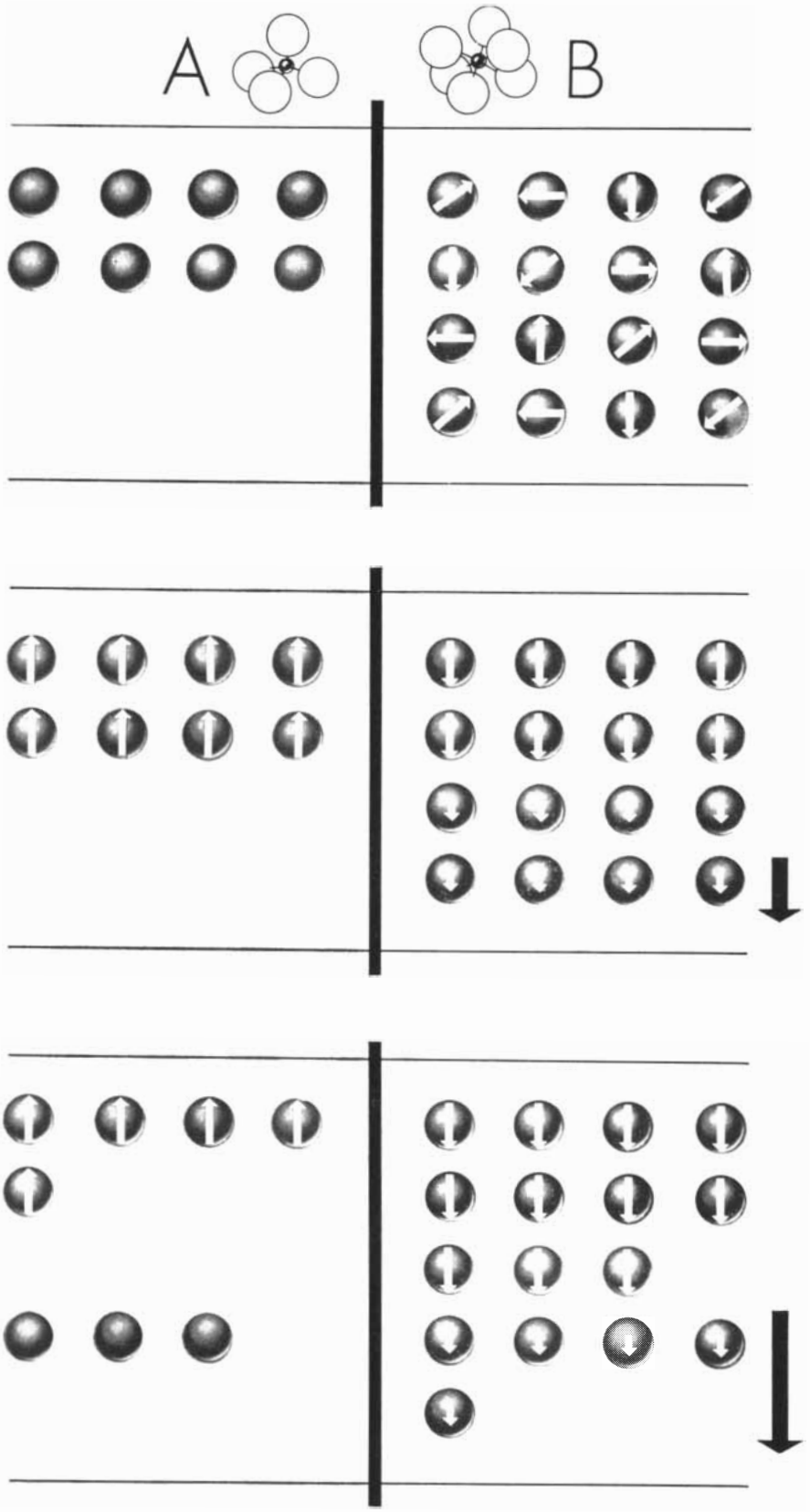
antiparallel type) exists only between atoms in different types of site: it goes from A to B but not from A to A or B to B. Thus the magnetic behavior of a ferrite depends on which of its metal atoms are where. Consider a few examples. In zinc ferrite the zinc ions are in A sites, and all the iron ions are in B sites. The zinc ion has no unpaired electrons and is not magnetic. Even though the iron ions have five unpaired electrons apiece, there are no A-site magnets against which they can align themselves. They are so weakly coupled to each other that, at any temperature above minus 269 degrees centigrade (4 degrees C. above absolute zero), thermal vibrations jumble them. Hence zinc ferrite is not ferrimagnetic but paramagnetic.

In nickel ferrite, on the other hand, the nickel is in B sites, and the iron is equally divided between A sites and B. The iron ions in the two sites, being antiparallel, cancel each other's magnetism. Therefore the total magnetic strength of nickel ferrite should come from its nickel ions, which have two unpaired electrons each. Experimental measurements agree closely with this theoretical prediction.

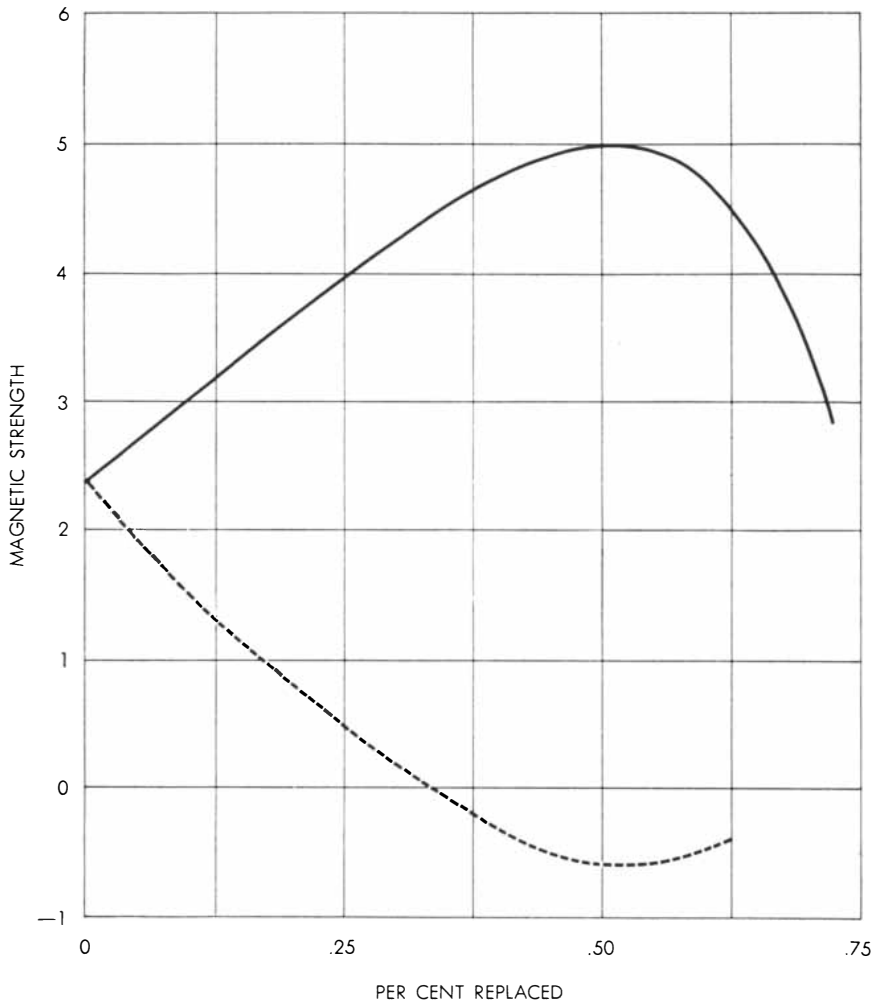
Suppose a little zinc is added to nickel ferrite, say three atoms per unit cell. This means that, of the eight divalent ions in a unit cell, only five are nickel and three are zinc. Three magnetic ions have been replaced by three that are nonmagnetic. One might suppose that the strength of the ferrite would decrease. Not at all. The zinc ions locate themselves in their preferred position: A sites [*see bottom of illustration at right*]. In doing so they displace three iron ions, which move over to the B sites, reversing their magnetic alignment. Thus the three missing nickel ions, with two unpaired electrons, have actually been replaced by three iron ions, with five. Zinc-nickel ferrite is hence a stronger ferrimagnet than is the nickel material.

Molecular Engineering

The sensitivity of ferrites to the arrangement of their atoms, and the natural preference of certain atoms for certain positions, make it possible to manipulate the properties of these materials, tailoring their crystals to the demands of specific applications. Sometimes, for example, one needs a material that retains its magnetism at high temperature, but is not too strongly magnetic (to reduce certain energy losses). Nickel ferrite has the highest Curie temperature of all the ferrites, but its magnetic strength is also high. If some trivalent aluminum ions



DISTRIBUTION OF METAL IONS in ferrite crystal takes different forms, depending on the kinds of metal. In zinc ferrite (*top*) the nonmagnetic zinc ions (*eight spheres at left*) occupy A sites, and the magnetic iron ions (*16 spheres at right*) occupy B sites. Coupling between iron ions is weak, and they are not aligned coherently. The material is paramagnetic. Nickel ferrite (*middle*) contains magnetic nickel ions in B sites (*two bottom rows*), and the iron is divided equally between A and B sites. Nickel-zinc ferrite (*bottom*) has zinc ions in A sites and nickel ions in B sites, with iron distributed between the two sites. The net magnetization (*large arrow at right*) is greater than in pure nickel ferrite.



EFFECTS OF SUBSTITUTION of metal ions in ferrites are shown in this graph. Nickel-zinc ferrite (*solid curve*) increases in magnetic strength as its nickel ions are replaced by zinc ions up to about 50 per cent. Further addition of zinc brings other effects into play that reduce the strength. Nickel-aluminum ferrite (*broken curve*) decreases in magnetic strength as aluminum ions replace iron. When about 35 per cent of iron has been replaced, net magnetization is zero. More aluminum reverses direction of magnetization.

are added to nickel ferrite, they settle in B sites, replacing an equal number of trivalent iron ions. Aluminum is nonmagnetic, so the net magnetization in the B sites is decreased, while that in the A sites unchanged. Since the preponderance of magnetic strength was in the B position, the result is to decrease the over-all magnetism. The process can be carried to the point where the A and B sites exactly offset each other, and the material becomes antiferromagnetic. Still more aluminum then shifts the preponderant strength to the A site, increasing the magnetization in the reverse direction [*see illustration above*].

This "molecular engineering" has become a highly developed art, like French cooking. Witness the following compound, which is now in general use: $Ni^{++}_{.86}\ Cu^{++}_{.1}\ Mn^{++}_{.02}\ Co^{++}_{.02}\ Al^{+++}_{.3}\ Fe^{+++}_{1.7}\ O^{--}_{4}$ The subscript numbers give the proportions of the various ions per "formula unit" of one divalent and two trivalent ions. Basically this substance is nickel-aluminum ferrite, which, as has just been shown, combines a high Curie temperature with a relatively moderate magnetic strength. The small amount of copper permits the material to be compacted, or sintered, at a lower temperature. (The high firing temperature used in preparing ferrites tends to drive oxygen out of the crystals and thus to degrade them.) Although no one has yet discovered exactly why, the little pinch of manganese substantially increases electrical resistance. Cobalt reduces the width of the magnetic-resonance line, which will be discussed later.

As a final example of the molecular subtlety of ferrites, take the case of magnetite. This earliest ferrite finds little application because its electrical resistance, although much higher than that of metal, is billions of times lower than that of other ferrites. To understand why, one must reflect again on the crystal. Recall that $Fe^{++}\ Fe_2^{+++}\ O_4^{--}$ has the same structure as nickel ferrite, with the divalent iron in B sites and the trivalent ions split between A sites and B. Now suppose an electron were to jump from an Fe^{++} to a neighboring Fe^{+++} in a B site. The net result would be to convert the divalent ion to Fe^{+++} and the trivalent ion to Fe^{++}. In short, it would be as though the two ions had simply changed position.

It has been discovered that, within the A or B sites, the distribution of ions in ferrites is random. So the interchange of a divalent and trivalent iron atom leaves the crystal essentially unchanged. Hence the interchange occurs rather easily, meaning that electrons can move through the crystal and conduct electric current. In some instances it is desirable to have a ferrite with lower resistance than usual. The addition of a little doubly charged iron does the trick.

Other Magnetic Oxides

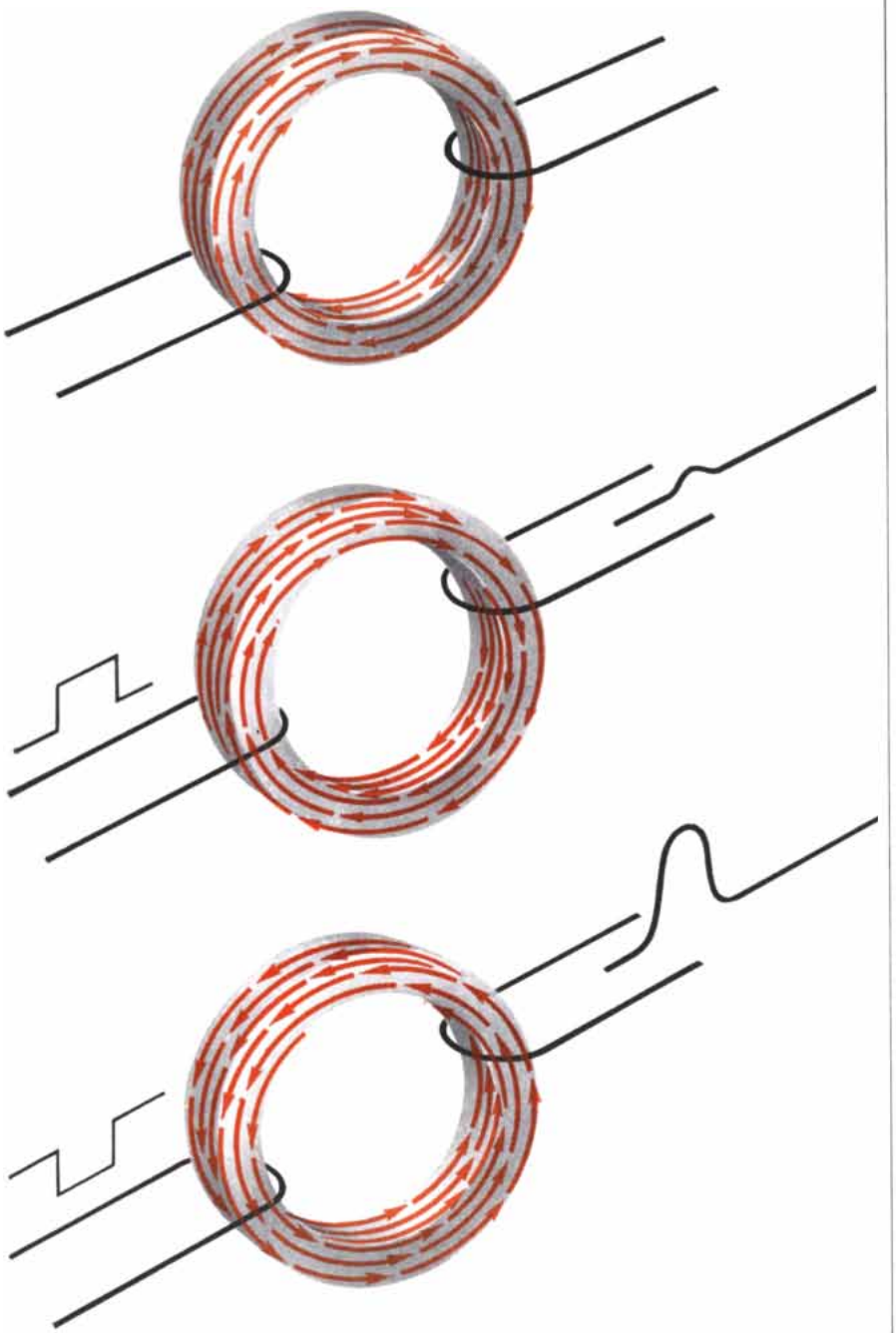
The possibilities of ferrites were demonstrated largely in the brilliant researches of J. L. Snoek of the Philips Research Laboratories in the Netherlands during World War II. As soon as his work became generally known, physicists began to think of ways to make still better materials. One obvious direction to look was at the rare-earth elements: elements 58 through 71 on the periodic table. The atoms of these 14 elements have the characteristic that an inner shell of their electron orbits is only partly filled. Moreover, some of the electrons in the shell are unpaired. Gadolinium, for instance, has seven out of the full complement of 14 electrons in one of its inner shells, all of them unpaired. If gadolinium could be substituted for nickel ions in nickel ferrite, the magnetic strength of the ferrite would be increased by a factor of three and a half.

The rare-earth atoms, however, are too large to fit into the ferrite crystal. Recently Louis Néel, the French pioneer in magnetic theory, and Alten Gilleo and his associates at the Bell Telephone Laboratories have found another oxide crystal, the garnet, which can admit the heavier rare earths starting with element 62 (samarium); it can also admit the related element yttrium. (Within each group of elements in the periodic table the heavier atoms tend to be the smaller, because the higher positive charge on

their nuclei pulls in the surrounding electron clouds more tightly.) Because of the details of their molecular arrangement, ferrimagnetic garnets are not more strongly magnetic than ferrites, but they do possess a number of other superior properties. In some applications they are beginning to displace ferrites.

The garnet crystal structure is much more complicated than is the cubic arrangement of the ferrites. A unit cell contains 24 rare-earth ions, 40 iron ions and 96 oxygen ions—160 in all! In this array there are three different types of site for metal atoms, and there is strong antiparallel coupling between the atoms. Thus the same sort of shifts that can be made in ferrite crystals are possible in garnet also.

A newer group of promising sub-



MEMORY ELEMENT for computers can be made of a ring of ferrite. The ring has two possible directions of magnetization, clockwise and counterclockwise, corresponding to the digital numbers 0 and 1. At top a ring is magnetized clockwise, and no current flows in input coil (*left*) or output coil (*right*). In the middle drawing an interrogating pulse (*square wave*) is fed into the input in the direction that produces clockwise magnetization. The magnetization of the ring does not change, and resulting output pulse is weak. At bottom an interrogating pulse reverses magnetization, producing a large output.

stances is the hexagonal compounds (so called because of their crystal architecture), developed at the Philips Laboratories. They are essentially a mixture of ferric (trivalent iron) oxide, barium oxide and many of the divalent metal oxides that go into ferrites. Among the useful characteristics of the hexagonal compounds is that they strongly prefer to be magnetized along a particular direction of the crystal. All magnetic materials exhibit such asymmetry, but it is unusually strong in the new hexagonal oxides. As we shall see, this raises their magnetic-resonance frequency.

Encouraged by the striking successes thus far, many laboratories are investigating still other ferrimagnetic materials. The field is largely unexplored, and important finds can be expected.

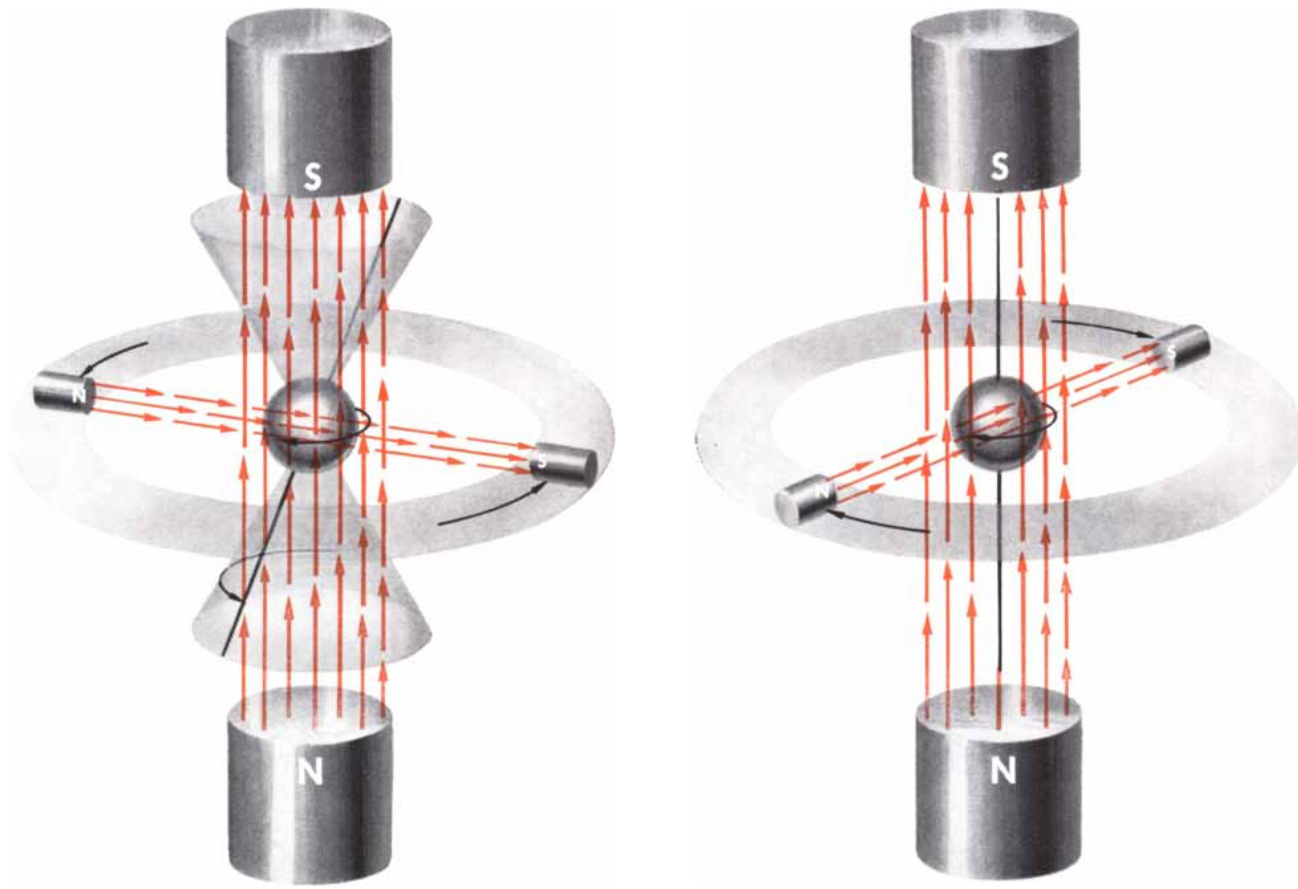
Ferrite Transformers

Let us now look briefly at some of the uses to which magnetic oxides have already been put. These uses fall into two classes. The first is typified by the transformer: magnetic oxide cores concentrate and reinforce magnetic fields that alternate at high frequencies, or in general that change rapidly. For example, a television receiver must have a "flyback" transformer to pull its electron-scanning beam back very quickly to the starting line on the picture tube after each horizontal sweep. All flyback transformers now have ferrite cores.

The small size of today's portable radios is as much a product of ferrite-cored antennas as of other miniaturization techniques. A receiving antenna can be thought of as the secondary coil of a transformer whose primary is the distant transmitting antenna. Formerly the antennas in portable receivers had to contain many turns of wire, wound in a good-sized coil to intercept enough energy. With a ferrite reinforcing the weak field from the transmitter, the antenna can be reduced to a coil no bigger than a pencil. Magnetic oxides perform similar functions in the induction coils of high-frequency communications equipment and in many other standard electronic circuits.

The oxide materials have made possible a new application of the transformer principle in digital computers. Operating on a binary system, in which all numbers are expressed in the digits 0 and 1 and all information is translated into yes-no terms, computing machines need circuit elements that have two alternative states. Any magnetic core is such an element: it can be magnetized clockwise or counterclockwise. One direction represents 0; the other, 1.

Imagine a tiny transformer core threading two coils [*see illustration on preceding page*]. A bit of information comes in from the computing circuits as a pulse of current on the primary or input coil and magnetizes the ring clockwise. Now the material retains its magnetization, "memorizing" the information. To interrogate the core later on, a second pulse is sent through the input coil. If the original pulse was in the opposite direc-



ELECTRON PRECESSES when it is aligned in a permanent magnetic field (*vertical colored arrows*), and a rotating field (*horizontal colored arrows*) is applied in its natural direction of precession (*left*). When the direction of the rotating field is reversed (*right*), the electron ignores it and does not absorb energy. The electron is represented by the gray sphere, with the sharply curved arrow showing its direction of spin. Shaded cone at left is an imaginary surface that is swept out by the precessing axis of the electron.

tion, the ring is now remagnetized counterclockwise. This reversal of the field produces a large voltage-pulse in the output, or secondary, coil, announcing the fact that the core has been switched and that the original magnetization was clockwise. If, on the other hand, the original input and the interrogating pulse are in the same direction, the magnetization does not reverse, and the field through the output coil changes very little. The weak voltage-pulse which results indicates that the core was in the counterclockwise state.

To be useful in high-speed computers the switching action must be very rapid. In metallic magnets a brief pulse generates eddy currents that keep the primary field out of the core. Only ferrites and their newer relatives can be switched quickly enough.

Memory arrays in big computers contain thousands of tiny ferrite cores. The wiring is more complicated than the two-coil system we have described, but the underlying principle is not changed. Circuits employing magnetic cores can also add and carry out other logical operations. Now under development are more sophisticated devices that combine several functions in a single unit. They consist of ferrite plates with many holes, through which various windings can be threaded. These arrangements can translate information into digital form, changing decimal to binary numbers and vice versa, and can perform many other valuable tricks.

All the applications described so far share a common element: The magnetization of the materials follows the alternations, or sharp reversals, of an input field. Magnetic oxides can do this at much higher frequencies than can other materials. The best of them can do so at several hundred megacycles per second. But eventually the limits of magnetic response are exceeded. Even though no eddy currents prevent the primary field from penetrating the material, the magnetic domains cannot swing back and forth faster than a few hundred million times a second. This represents the maximum frequency of operation for transformers with magnetic cores.

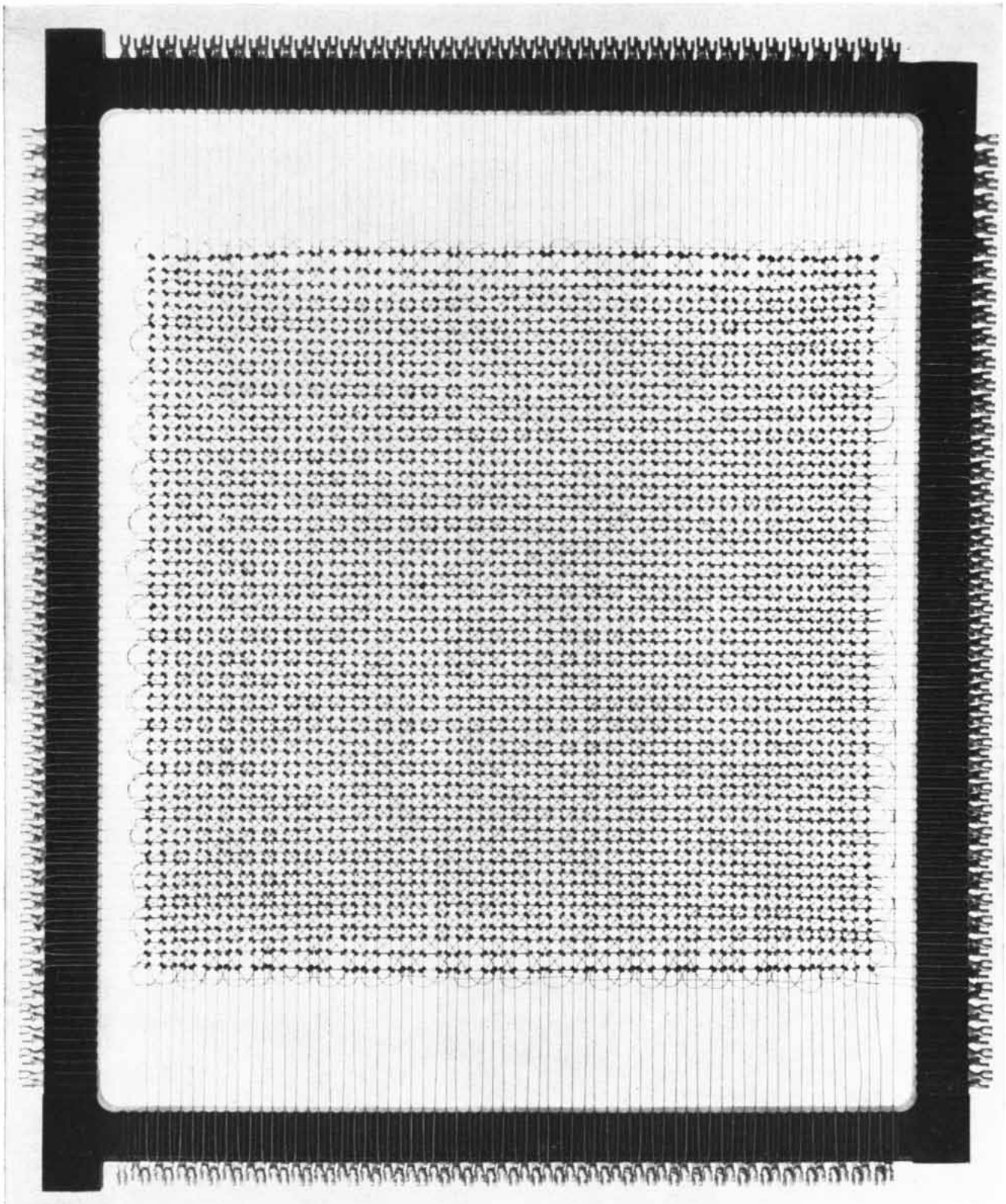
Precession

In addition to flipping back and forth, unpaired electrons can respond to magnetic fields in another way. Their spinning motion makes them magnetic gyroscopes. Just as a spinning top, when placed at an angle to the gravitational field, wobbles or precesses, so an electron

ISOLATOR is made of a section of rectangular wave guide containing a piece of ferrite (*dark gray object near top of wave guide*). Successive drawings show advance from right to left of a magnetic field pattern (*broken colored arrows*) through wave guide. Colored arrow through white dot at top left in wave guide shows direction of field at that point. Colored arrow at left edge represents "biasing" field from external coil (*not shown*).

will precess around a steady magnetic field. The field may be one that is applied from the outside, or it may be the field built into the crystal along the preferred direction of magnetization. In either case, the stronger the field, the higher the rate of precession. If the motion were completely unimpeded, the electrons would precess at the same angle indefinitely. In any actual material the presence of neighboring particles provides a sort of internal friction, which causes the axis of the precessing electron to spiral in toward the direction of the field. This is what makes it possible for atomic magnets to line up with an outside field; the process takes only about a millionth of a second.

Under certain conditions a gyroscope executes more complicated types of motion than simple precession. Suppose a



MEMORY MATRIX for a computer designed by International Business Machines Corporation consists of an array of tiny ferrite cores threaded by several wiring systems. A complete circuit is composed of many such matrices stacked above one another.

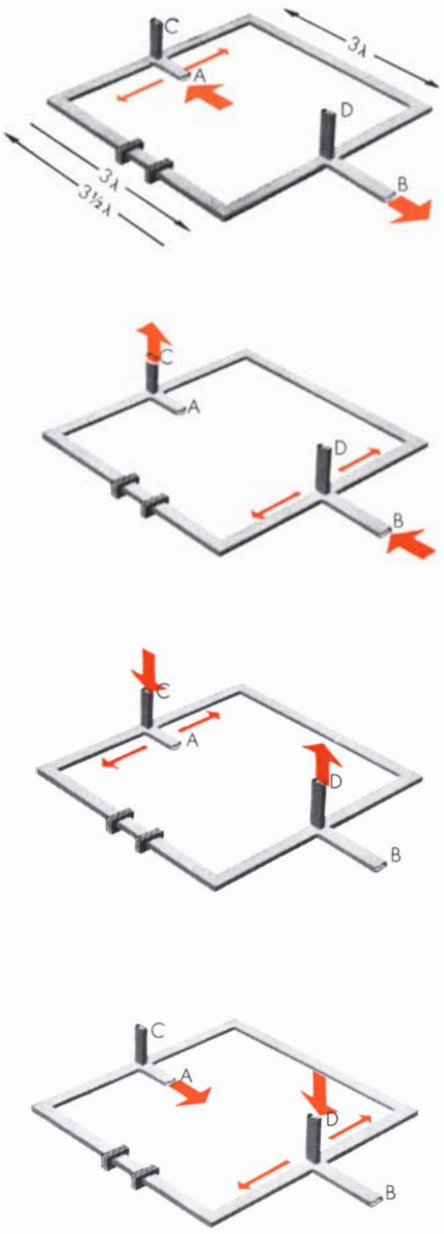
string is attached to the axis of a gyroscope rotor and pulled tight. If the axis is not in line with the string, the instrument precesses around the direction of the force, as an electron precesses around a magnetic field. A well-made gyroscope, with little friction, will rotate for a long time before spiraling into line. Eventually, however, it does align itself. Now let us take the string in our fingers and rotate it. When the rotation is in the same direction as that of the precession, the gyroscope will begin to rotate too. And if the string is moved at the natural precession-frequency, the gyroscope responds violently. If, on the other hand, the string rotates in the direction opposite to that of the precession, the gyroscope ignores the motion, and its axis stands still.

Electrons behave in the same way. The magnetic "string" can be turned by feeding in an auxiliary rotating field at right angles to the aligning field [*see illustration on page 100*]. The electron responds if the rotation is in its natural direction of precession, and ignores the auxiliary field if it is not. At the natural, or resonant, frequency of precession (which can be as high as several thousand megacycles per second, depending on the strength of the main field), the response is very large. Then the electron absorbs most or all of the energy from the auxiliary field. This property is inherent in any magnetic material, but it can be realized only in magnetic oxides. High-frequency rotating fields simply cannot get into metallic magnets.

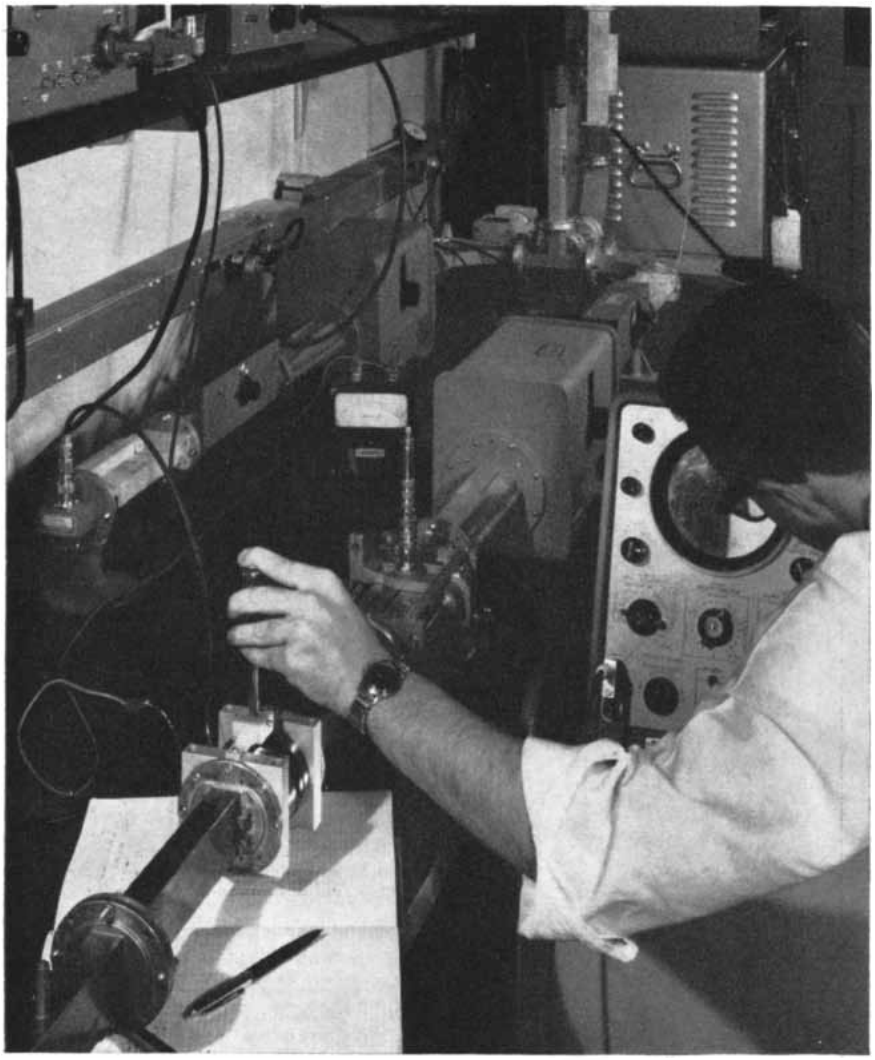
With the advent of materials that can be penetrated by such fields, an entirely new class of electronic elements has become possible. These devices violate a basic tenet of standard circuit-theory: the rule of reciprocity. One of the first laws an electrical engineer learns is that any passive circuit element—one that does not generate energy—is reversible. The resistance of a wire, for example, is the same no matter which way current passes through it. Now the lesson must be unlearned. With a little piece of ferrite we can make a microwave conductor with essentially no resistance when energy flows in one direction through the circuit, but whose resistance to an energy flow in the opposite direction can be as high as we wish.

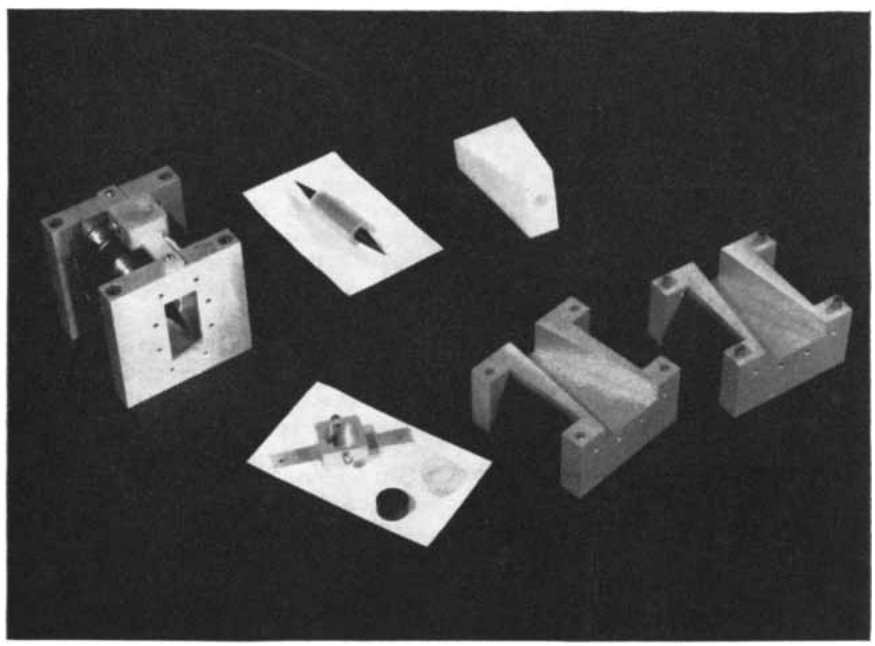
In microwave equipment energy usually travels from one place to another not as a stream of electrons, but as a coherent electromagnetic wave. The conductor, or wave guide, is a coaxial cable or simply a length of metal pipe—"plumbing" in the parlance of the radio engineer. Within the pipe the magnetic field travels in groups of closed concentric rings [*see illustration on page 101*]. As the field moves past a fixed point in the wave guide, the direction of the magnetic lines appears to rotate. The speed of the rotation depends on the size of each group of rings, which in turn depends on the frequency of the wave. And the direction of rotation reverses with the direction of travel.

Suppose a piece of ferrite is placed at the same point, and an aligning field is applied perpendicularly to the plane of the loops. If the wave is traveling one



CIRCULATOR consists of a rectangular loop of wave guide having four input or output pipes (A, B, C *and* D) and a piece of ferrite inserted in one branch. The ferrite offers a path that differs by one-half wavelength (λ) for energy traveling in opposite directions. Phase relationships of waves traveling in two branches cause energy to follow the paths shown by colored arrows.





FERRITE SWITCH in microwave equipment at Bell Telephone Laboratories can be seen in top photograph directly below the hand of the experimenter. At bottom left is a close-up of the assembled switch; at right are its component parts. Ferrite (*double-pointed object*) fits into plastic holder to its right, which is enclosed between sections at bottom center and right. Small disk at bottom left is a magnet that can be positioned to adjust magnetic field-strength. When current is sent through coils around switch, and small magnet is adjusted, energy flows through wave guides. With no current, energy is blocked.

way through the pipe, its field rotates in the direction of precession of the electrons in the ferrite. Then they go into oscillation, absorbing energy from the wave. If the wave travels the other way, the electrons do not precess, and the energy passes through unimpeded. By adjusting the strength of the aligning field, the precession frequency can be tuned to the frequency of the wave. In that case a ferrite slab a few inches long can completely absorb a wave traveling in one direction, but ignores a wave moving the other way. Thus the length of wave guide containing the ferrite serves as an "isolator." Such a device has many uses. To mention just one, it will conduct energy from a radar transmitter to the antenna while blocking the unwanted waves that bounce back from the antenna.

In some cases it is more desirable to divert energy than to absorb it. This can be accomplished by adjusting the aligning field so that the precession frequency does not agree with the frequency of the waves. Now the ferrite will still ignore energy traveling one way, and will not absorb energy going the other way, but will merely change its velocity, and hence its wavelength. Taking advantage of this property we can build a surprising device called a circulator. It consists of a rectangular loop of wave guide with a ferrite in one branch and with four pipes that can serve as either input or output sections. Because of the difference in wavelength of energy traveling in opposite directions through the branch containing the ferrite, a wave entering the circulator through pipe A will leave through pipe B, one entering B leaves through C, one entering C leaves through D and one entering D leaves through A [*see illustration on preceding page*]. With the help of a circulator it is possible, for example, to use the same antenna for transmitting and receiving. The transmitted wave travels from A to B and out to the antenna. An incoming wave moves from the antenna into B and emerges at C, which feeds it into the receiver.

High-frequency fields can interact with magnetic materials in still more complicated ways than those we have described. Designers are hard at work finding ways to capitalize on these effects. Among the more promising ideas is one for a low-noise, high-frequency amplifier that will duplicate the performance of the so-called maser, but much more simply and cheaply. The field is still so new and so fertile that we can merely guess at the harvest it may eventually yield.

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

The Nature of Oxidation: Studies In The High-Temperature Oxidation of Alloys

Under high temperatures, oxidation is accelerated. While some pure metals deteriorate rapidly, certain of their alloys oxidize much more slowly. Accurate prediction of alloy oxidation rates, however, awaits development of a reliable mathematical model. At Honeywell Research, new techniques have produced data that make a start toward a universally applicable theory.

With the single exception of gold, oxidation limits the use of all metals at high temperatures. This is true because the products of corrosion do not have the properties of the parent metal. In addition, corrosive products occupy more space than the parent metal they replace, affecting dimensions and tolerances.

Corrosion is greatly accelerated by high temperatures, putting serious limitations on progress in heat generating equipment such as internal combustion engines, rockets, nuclear reactors and electrical contacts.

At the present time the accepted method of inhibiting corrosion is to apply a protective coating to the metal to prevent the migration of oxygen atoms to the surface of the material. This, however, is expensive and in many cases not practical.

We know that when an oxide free surface is exposed to ordinary air at room temperature the upper layers of the metal combine with the oxygen atoms to form a thin film or scale (oxide). For further oxidation to occur the thin oxide film must be penetrated by either oxygen atoms migrating down to the fresh metal surface or by metal atoms migrating outward to the air. In most cases, one of these reactions predominates.

For about 40 years metallurgists have worked with several classical equations that predict the rate of oxidation. However, these equations apply rigorously only under idealized conditions. They do not fully equate the mechanical and microstructural features of a multi-layer oxide or the dislocations and stresses that affect the oxidation process. For example: Is the oxide film ductile or brittle? A change of temperature puts thermal stress on the oxide and if it is brittle it will probably break off. These properties modify the classical theory. All of these problems multiply and each influence is changed when an alloy is introduced.

Honeywell scientists hope to learn more about these altering influences in order to extend the classical equations. They are analyzing multi-layer oxide scales with a number of different laboratory methods to build support for new, predictable behavior.

Multi-layer scales are caused by the ability of metals to have multiple valences. The balance between these layers is controlled by temperature. When a multi-layer scale exists, oxides are often unable to relax the stresses that occur. These stresses are caused by the differences in specific volume and the differences in thermal coefficients of expansion between the oxide and the metal. When they cannot be relaxed, stresses may build up and affect the rate of oxidation. Also, if external stresses are applied to the material the rate of oxidation may be affected.

The approach to this study quickly becomes a mixture of metallurgy and physical chemistry. One technique in studying rate of growth of the scale has been to measure the weight gain of alloys during oxidation. Reliable data on oxidation has been obtained in this manner.

To determine the direction of the migration of ions and also measure the growth of individual layers, Honeywell scientists are welding thin platinum wires to a specimen prior to heating. These marker wires give a point of reference to the original surface. If oxygen ions are moving inward, the wire remains outside the surface. If cations are moving outward, the marker wire will be under the surface. This method has yielded valuable new information on the formation of oxides.

Microscopic examination also has been helpful in identifying layers, and X-ray diffraction has given positive identification of the oxide phases.

Ideally we would like to completely inhibit even the first monatomic oxide layer. At the present state of knowledge, this seems unattainable. Our approach then is to utilize the natural oxidation process but control it. By doing this we permit the formation of a thin film but seek to make it impermeable to further ion migration.

In our experiments Honeywell scientists have effected radical changes in oxidation rates by changing the oxide microstructure through heat treatment of its alloy. For example, with an alloy of .87 Mg—.62 Cu, the oxidation rate can be retarded and the resulting oxidation reduced by a factor of ten with proper heat treatment.

We now know that in a polycrystalline structure, stress and mechanical properties affect both the rate and the mechanism of oxidation. Also we know that the mechanical properties of the oxide have a decisive effect on the tendency of the oxide to either spall or adhere.

This is a start toward the derivation of a general theory explaining the oxidation of alloys. Though our research is basic at this point in time, we expect it to yield many practical answers to assist the design engineers working on high temperature problems confronting today's nuclear and space projects.

If you are engaged in scientific work relating to oxidation of metals and would like to know more about Honeywell's research on this subject, you are invited to correspond with Dr. J. A. Sartell, Honeywell Research Center, Hopkins, Minnesota.

If you wish a recent paper, "The Role of Oxide Plasticity in the Oxidation Mechanism of Pure Copper," by Dr. Sartell, write to Honeywell Research, Minneapolis 8, Minnesota.

Humphry Davy

Widely known as the inventor of the safety lamp, he also founded modern electrochemistry, tutored Faraday and discovered sodium, potassium, calcium, barium, magnesium, strontium and chlorine

by L. Pearce Williams

In the spring of 1801 Humphry Davy gave his first public lecture at the newly created Royal Institution, and a thrill rippled through London society. To the scientists who had heard him the young Cornishman merely showed promise; to the wellborn ladies in his audience he seemed to offer a unique diversion from the accustomed round of social events. With the Continent closed by the wars that followed the French Revolution, what could be more interesting than to be told about the progress of science by a young man of 22 whose vitality and enthusiasm—not to mention his good looks—made chemistry more exciting than the latest novel? One of his auditors expressed a general sentiment when she remarked that his eyes "were made for something besides poring over crucibles."

Davy's success as a popularizer of science was to have important consequences. The original aim of the Royal Institution—to bring useful knowledge to working people—faded rapidly before the social brilliance of the audience attracted by Davy's lectures. In return the fashionable world provided the funds necessary for the pursuit of science in a well-equipped laboratory. The giant voltaic pile that Napoleon had lavished on the Ecole Polytechnique as a sign of his respect for science was matched in England by the munificence of Davy's supporters. In his fine laboratory at the Royal Institution Davy performed the pioneering experiments in electrochemistry that led him to the discovery of chlorine and the alkali metals. Here too he developed his theory of acids, invented the miner's lamp and later employed and inspired a remarkable youth named Michael Faraday.

In 1801, however, all this was far in the future; at that moment in Davy's life merely to be noticed favorably in the scientific and social circles of London represented a triumph. Unfortunately the attractions of stylish society were eventually to prove disastrous for Davy's scientific work. Although he never abandoned creative research, the sustained investigations that characterized his rise to greatness were impossible after he had scaled the social heights. But at 22, given his first glimpse of the fashionable life, Davy could contemplate with some satisfaction the distance he had come.

The eldest of five children, he was born in 1778 in Penzance, near Land's End in the southwestern extremity of England. Except for his father's tendency to spend more time in the pursuit of sport than seemed consonant with business success, the family was indistinguishable from other middle-class provincial English households. Humphry went to the local grammar school, where the quick intelligence that later led him to scientific fame was manifested only in an infinite capacity for mischief and daydreaming.

The years of childhood ended abruptly when his father died in 1794, leaving the 16-year-old Humphry with the responsibility of helping to support the family. The urgent need to find a profession or trade led ultimately to his career in science. A few weeks after the funeral he apprenticed himself to one Bingham Borlase, an apothecary and surgeon in Penzance, and at the same time set himself a rigorous course of self-instruction in the sciences and the arts. When he got around to chemistry in 1797, he was fortunate in the guides he chose: an English translation of the *Elementary Treatise on Chemistry* by the father of modern chemistry, Antoine Laurent Lavoisier; and the *Dictionary of Practical and Theoretical Chemistry* compiled by William Nicholson, who built the first voltaic pile in England. In these works Davy discovered two conflicting theories of combustion; the conflict stimulated him to undertake his first research.

Lavoisier's writings vigorously rejected the phlogiston theory of combustion put forward at the end of the 17th century by the German chemist Georg Ernst Stahl. Phlogiston was the "principle" of fire, believed to be present in everything that burned. The fact that most substances lose weight during combustion was attributed to the escape of phlogiston. Lavoisier argued that the loss of weight was due to the combination of the burning substances with oxygen to form volatile products. His demonstration that phosphorus and sulfur gained rather than lost weight when burned was a severe blow to the phlogistonists. But to explain the heat and light given off during combustion Lavoisier was forced to invent another imponderable fluid of heat, which he named "caloric."

Nicholson reported Lavoisier's views, but he also cautiously mentioned another theory which maintained that heat was not a fluid but the motion of the constituent particles of matter. Davy at once devised an experiment to decide between the two. Melting two pieces of ice by rubbing them together in the chamber of a rather inefficient and makeshift vacuum pump, he convinced himself that heat was indeed a mode of motion. To forestall the objection that the rubbing served only to pump in caloric from the outside, he surrounded two pieces of wax with ice and then rubbed the wax slabs together. If caloric were pumped in, it would melt the ice through which it passed. But only the wax melted, and Davy was triumphant. Lavoisier was wrong and he was right!

Carried away by his enthusiasm, Davy

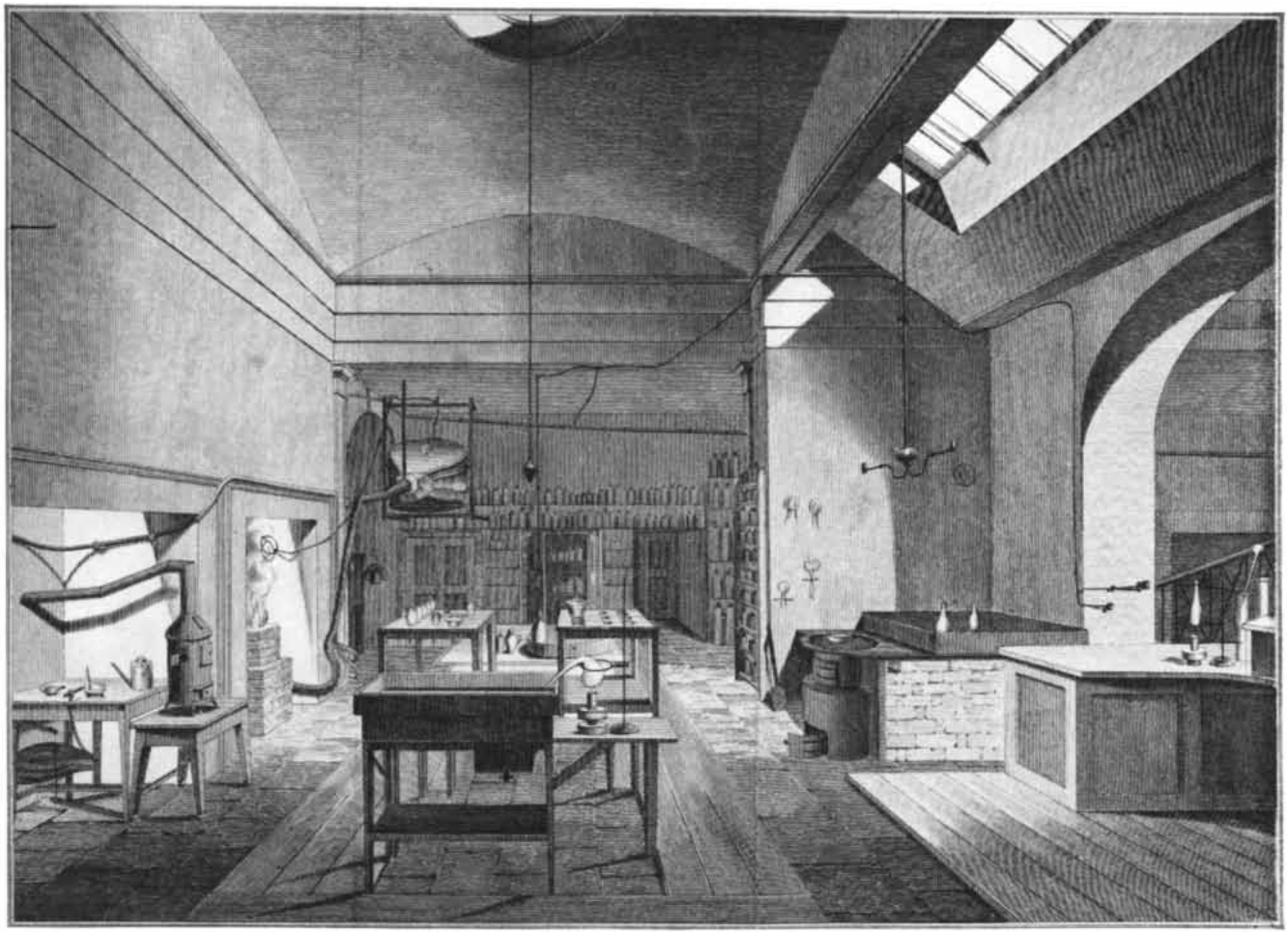
SIR HUMPHRY DAVY was born in England in 1778 and died in Geneva in 1829. This 19th-century engraving by Edward Scriven is a reproduction of a famous portrait by the painter Sir Thomas Lawrence. Lady Davy donated the original to the Royal Society.

indulged in an orgy of speculation: Since caloric did not exist, the light emitted during combustion was the important imponderable; oxygen was a combination of a ponderable base and light, which he renamed "phosoxygen." In a flight of poetic fancy he viewed the chemical relations of light as the fundamental ones of the universe. Chemistry, plant physiology, electricity and magnetism, the action of nerves, intelligence—all were due to different modes of the action of light. This mystic vision was not shared by Davy's scientific peers, and the young chemist was brought down to earth with a rude bump. His oft-cited caution and fear of hypotheses date from this time.

Yet his very enthusiasm and exuberance recommended him to Thomas Beddoes, a physician and former Oxford professor of chemistry who was organizing a "Pneumatic Institution" in Bristol to study the medical effects of various gases. The last thing Beddoes wanted was a person who would be bound by traditional opinion. Through mutual friends Davy was suggested to him and, after a successful interview, Davy left the life of an apprentice apothecary in 1798 to become a gas chemist.

Davy's task at the Pneumatic Institution was to provide the solid scientific foundation for Beddoes's ideas. The 18th century had witnessed a prodigious increase of knowledge about gases (or "airs," as they were called), and their importance in chemistry and physiology had been demonstrated. At a time when medical theory was unable to suggest a truly rational approach to therapeutics, the only alternative was to try new substances and observe their effects. Beddoes was convinced that airs would prove to be excellent medicines, and instructed Davy to investigate their physiological properties. In 1800 Davy published his results under the title *Researches, Chemical and Philosophical, Chiefly concerning Nitrous Oxide, or Dephlogisticated Nitrous Air, and Its Respiration*. The excellence of his technique in a period when gas analysis was in its infancy established his reputation as an experimentalist. But far greater interest was aroused by his account of the peculiar sensations he experienced after breathing nitrous oxide. Among those he persuaded to join him in experiencing the effects of the gas were Samuel Taylor Coleridge and Robert Southey, two young poets with whom he shared his own attempts at poetry. (Southey once said of Davy's verse that "He had all the elements of poetry, he only wanted the art.") The breathing of "laughing gas" became such a fashionable parlor pastime in England that a visiting Frenchman described it as a national vice. The public notice attracted by his researches in gas chemistry served Davy well, for it prompted Count Rumford to bring him to the Royal Institution as a lecturer in 1801.

In the midst of his other duties there he soon found time to launch his epoch-making study of the voltaic cell and its effects. The confusion that surrounded the subject at the opening of the 19th century was extraordinary. Alessandro Volta had just announced to the Royal Society that an electric current could be generated in a pile consisting of disks of copper, zinc and paper. Soon afterward Nicholson and Anthony Carlisle showed that the current could decompose water



DAVY'S LABORATORY at the Royal Institution was one of the best equipped of its time. Here Davy carried out the electrochemical experiments that brought him fame. This engraving is from William Thomas Brande's *Manual of Chemistry*, published in 1819.

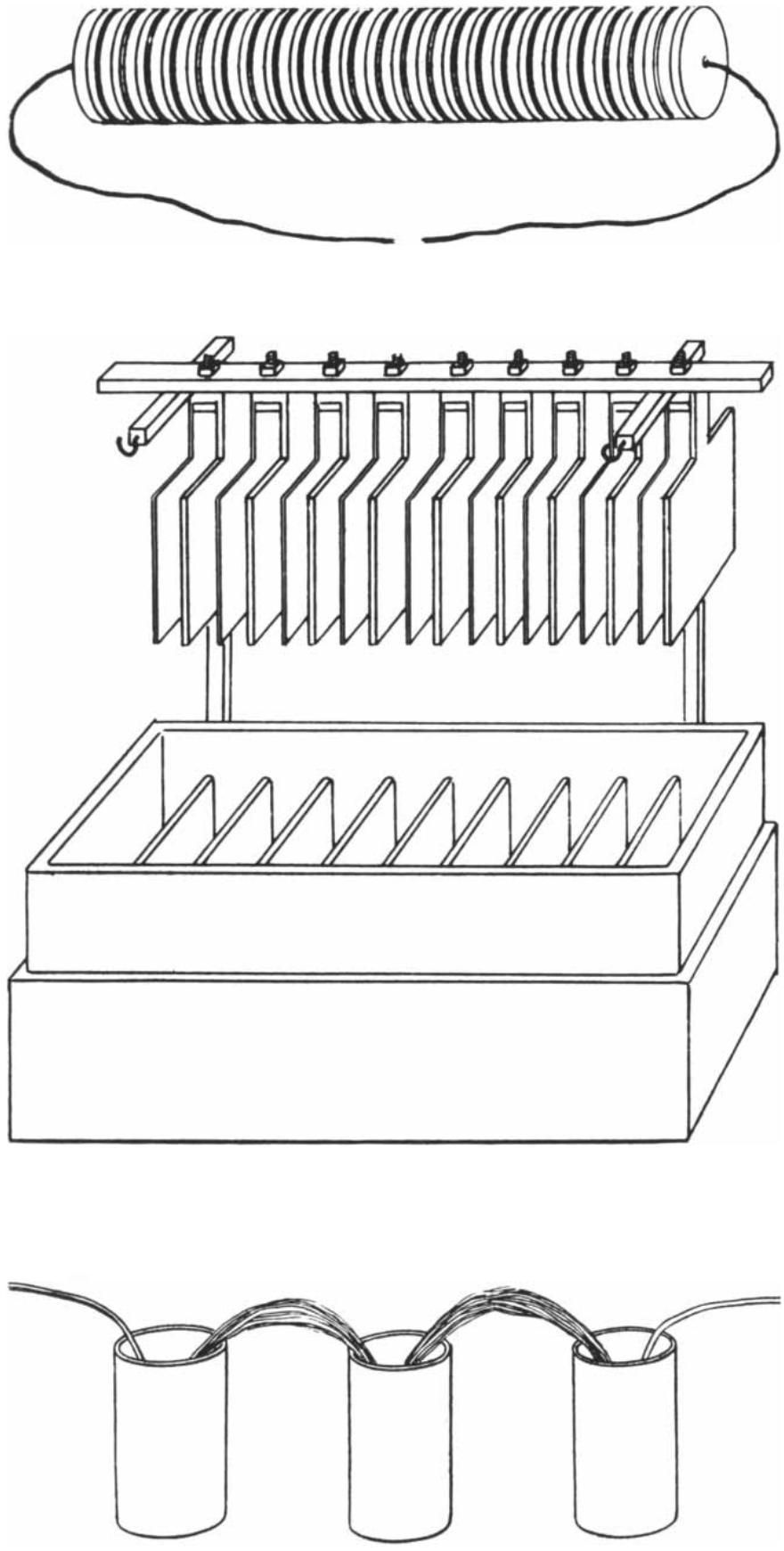
into the two gases hydrogen and oxygen, which the French school of chemistry had earlier identified as the constituents of water. This result immediately attracted the attention of chemists, because it revealed a previously unsuspected connection between chemistry and electricity.

It also raised a major problem: If electricity did tear the water particles into these two components, how account for the fact that the gases bubbled up at widely separated points? Why did the gases not appear at the center of a vessel of water rather than near the electric wires? Or to put it in modern terms, how could anyone explain the results of ionic migration when the concept of the electrically charged ion was almost a century away? There was still another problem: When the terminal wires of a voltaic battery were immersed in "pure" water, acid (generally hydrochloric) could be detected at the negative pole and alkali at the positive. How could this be reconciled with the accepted theory of the composition of water?

Speculative answers came to English scientific journals from all over Europe. It was suggested that hydrogen and oxygen were carried through the wires and deposited at the poles, where they bubbled off. Luigi Brugnatelli of Italy explained the presence of acid by "proving" that electricity itself was a new acid, and he claimed to have collected salts that he called copper electrate, zinc electrate and so on. Another Italian named Pacchiani, after announcing the production of hydrochloric acid from pure water, put forward a complicated theory about how the acid was formed. In Germany, the birthplace of the phlogiston theory, Johann Ritter even denied that water was a compound. With a few suitable modifications, he said, the moribund phlogiston theory could explain electrochemical phenomena far more completely than could the new French system.

Davy brought this bewildered speculation to an end with a classical investigation that he summed up in a single short paper. His Bakerian Lecture to the Royal Society in 1806 marked the real beginning of the science of electrochemistry. Entitled *On some Chemical Agencies of Electricity,* it is a model of the union of hypothesis and careful experiment to produce a new and immensely fertile viewpoint.

Davy's first concern was to remove the underbrush that so seriously impeded progress in the understanding of electrochemical phenomena. The starting point



EXPERIMENTAL APPARATUS used by Davy to demonstrate the migration of salts during electrolysis included an early voltaic battery (*top*), a later model (*middle*) and three vessels connected by dampened asbestos wicks (*bottom*). He placed a solution of sodium sulfate in one of the end vessels and a solution of barium nitrate in the other; when they were connected to a voltaic cell, insoluble barium sulfate precipitated in center vessel.

was clearly marked: Lavoisier and his French colleagues had provided considerable evidence to support their conclusions about the chemical composition of water. Davy, chastened by his youthful rejection of Lavoisier's theories, was not prepared to accept uncritically the ideas of Brugnatelli, Pacchiani or Ritter. Accordingly he first investigated the possibility that the anomalous ingredients which they had found in the electrolysis of water were merely contaminants. He skillfully tracked each ingredient to its source. The hydrochloric acid found at the negative pole came from small amounts of sodium chloride in the electrical connections or in the glass; the alkali at the positive pole also came from the glass. Brugnatelli's acid reaction was caused by dissolved nitrogen.

By using vessels made of agate or gold together with connecting wires of platinum, and taking care to exclude nitrogen from the water, Davy proved that the only products of the electrolysis of pure water were hydrogen and oxygen. And he demonstrated convincingly that the appearance of acid and alkali was due to the breakdown of dissolved salts. He thus refuted the phlogistonists by showing that water was not an element, and that an electric current could break down not only water but also many other compounds.

This left the mechanism of the electrolytic process as the last area of dispute. According to Ritter, the failure of bubbles to appear in the middle of the electrolytic cell indicated that the action took place at the poles: At the positive pole water gained positive electricity to become oxygen; at the negative pole it gained negative electricity to become hydrogen.

Davy was certain that electrolysis occurred within the solution. But this was difficult to prove, and it was still more difficult to suggest an alternative explanation that did not require the gases to evolve in the middle of the cell. To show that substances could migrate through a solution, Davy placed the solution in three vessels. These he connected to one another in series by asbestos wicks, and he placed the leads from the poles of a voltaic battery in the two outer vessels [*see illustration on preceding page*]. Into each vessel he dropped some powdered litmus; a change in its color would indicate the breakdown of any compounds the vessel contained. He found that if he dissolved a neutral salt in the end vessels and closed the circuit, the litmus in these vessels changed color, but the litmus in the middle one did not. Moreover, he showed that the constituents of the salt were migrating by placing a solution of sodium sulfate in one of the end vessels and a solution of barium nitrate in the other. When the circuit was closed, a precipitate of insoluble barium sulfate formed in the middle vessel, indicating the passage of the barium in one direction and the sulfate in the other.

From these results Davy worked out a theory of electrochemical action. The fact that electricity decomposed compounds led him to assume that the force of combination, or chemical affinity, was electrical and was a property of the constituent particles of matter. Chemical combination, then, was simply the union of oppositely charged particles, or particles with charges so distributed that,

CARTOON OF DAVY by a contemporary, the caricaturist James Gillray, depicts a demonstration of the effects of inhaling nitrous oxide, or "dephlogisticated nitrous air," as it was often called. Davy, holding the bellows, assists at the lecture while Count Rumford, the founder of the Royal Institution, stands near the door. The flatulent individual inhaling the gas has not been identified.

although fundamentally neutral, they were either attracted or repelled by other particles. The poles of a battery forced the particles to move in opposite directions. As each particle moved toward one of the poles, it was grasped, as in a square dance, by a particle of opposite charge moving in the other direction. Such a scheme very nicely explained all the observed results: Gases and other substances were deposited at the poles, particles migrated toward their respective attractive poles, but at any point between the poles the electronegative and electropositive particles combined with each other to render the solution electrically neutral.

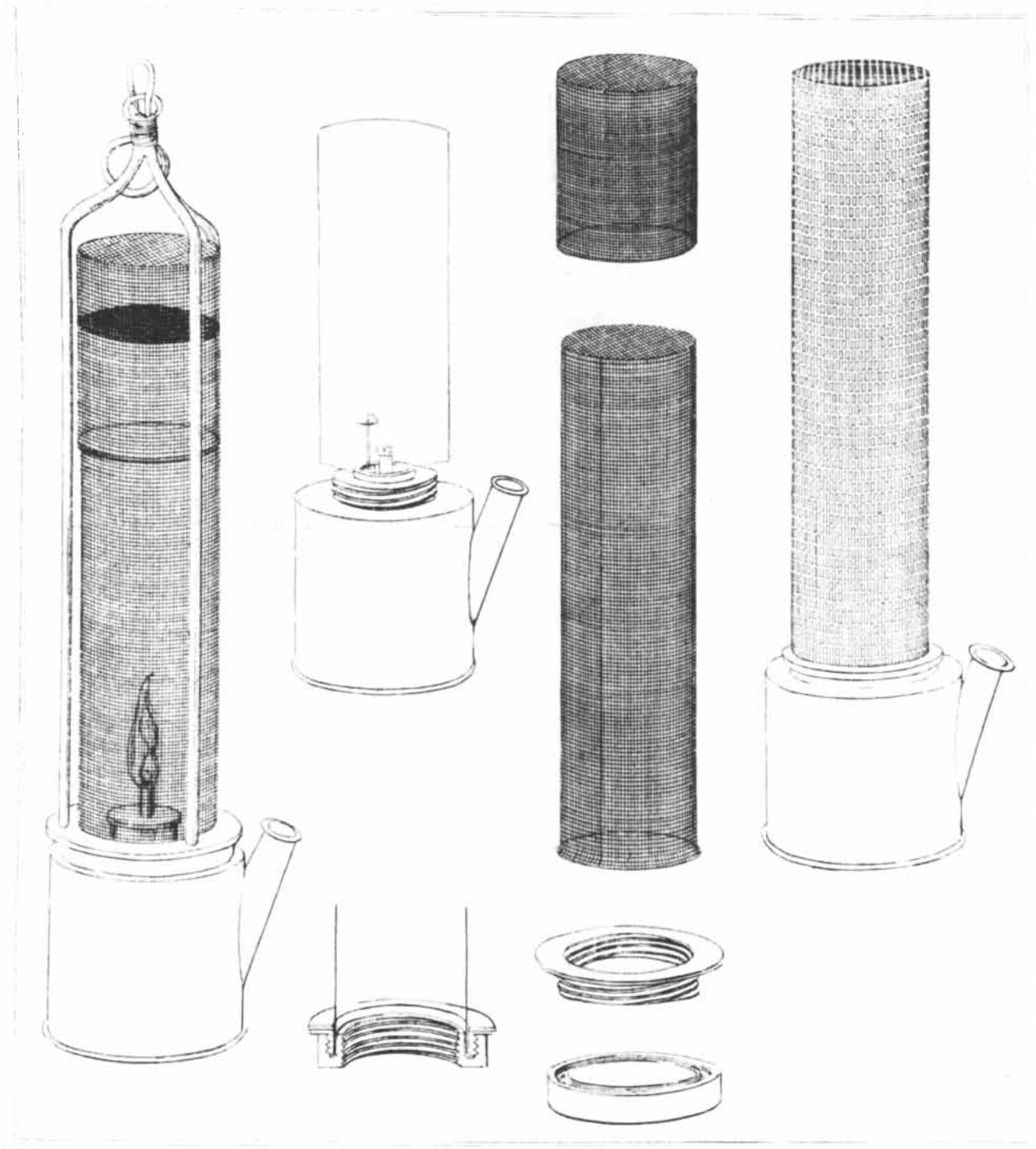
Davy's electrochemical theory not only brought order out of chaos, but also suggested rich territory for further investigation. It was no accident that in 1807 he could announce the discovery of sodium and potassium, the first alkali metals to be isolated. When a strong solution of soda (sodium carbonate) or potash (potassium carbonate) was electrolyzed, the decomposition products were hydrogen and oxygen, the constituents of water. These Davy believed to be secondary products, so he abandoned solutions and experimented with solid potash. By passing an electric current through melted potash in a vacuum he obtained small globules with a high metallic luster that burst into flame when exposed to air. Though the globules were light in weight, Davy recognized that they were metallic; he named the new substance "potasium." Davy next separated sodium, and finally, using a mercury electrode suggested to him by the Swedish chemist Jöns Jakob Berzelius, obtained amalgams of mercury and several alkaline-earth metals. He distilled the amalgams and named the substances he isolated calcium, barium, magnesium and strontium. The discovery of the new metals could hardly be bettered as a spectacular confirmation of Davy's theory.

To Davy the great value of the alkali metals lay in their power as an analytical tool. Their extraordinary affinity for oxygen provided a possible method for breaking down other oxides. One "oxide" that had previously resisted all attempts to break it down was muriatic acid, that is, hydrochloric acid. It occupied a particularly important place in the chemical controversies of the day. Lavoisier had revolutionized chemistry by rejecting metaphysical explanations. He held that attempts to explain chemical properties in terms of ultimate particles of matter and their presumed

forms were mere vaporings. An important school of 18th-century chemists, for example, had attempted to explain the properties of acids by assuming that acid particles possessed sharp points which permitted them to penetrate the pores of other materials and thereby to dissolve them. This, said Lavoisier, was nonsense; the only "principles" that could be admitted into the new chemistry were those that could be verified in the laboratory. And the "principle" of acidity that was present in all acids and endowed them with acid properties was oxygen. Thus muriatic acid was supposed to be a compound of oxygen and a hypothetical base called "murium." As the only strong mineral acid that had not been shown to be an oxide, muriatic acid was a challenge to both the proponents and opponents of the new chemistry.

The experimental breakdown of muriatic acid led Davy to challenge again the theories of the great Frenchman. This time, armed with caution and meticulous technique, he was to emerge successful.

Davy had long been interested in muriatic acid and its "oxidation" product, oxymuriatic acid, which was prepared by treating manganese dioxide and salt



EARLY SAFETY LAMPS are depicted in this illustration from *The Collected Works of Sir Humphry Davy*, published in 1839-40. The completely assembled lamp at left is shown in an exploded view at center. A semicylindrical metal mirror has been added to the base to keep the lamp cool in strong currents of fire-damp. The experimental lamp at far right is shielded by a sheet of perforated copper.

with sulfuric acid. The peculiar bleaching properties of oxymuriatic acid had caught his attention earlier, when he had propounded the primary role of light in chemical processes. Now, in 1807, he was beginning to doubt that muriatic acid contained oxygen, and that oxymuriatic acid was a higher oxide. To resolve this doubt he had at his disposal the two most powerful analytical tools of the day: the alkali metals and the new voltaic pile of the Royal Institution. After torturing the acids in every conceivable way he recognized that oxymuriatic acid was an element, which he named chlorine. He concluded further that muriatic acid was a compound of chlorine and hydrogen. The oxygen that was occasionally formed during the analysis of these substances was due to the accidental presence of water vapor.

Davy's discovery shook the chemical world. Lavoisier's theory of acids had been overthrown. Its fall seemed to threaten the entire system, and many chemists feared a return to the anarchy from which Lavoisier had rescued the science. Davy was attacked harshly; his analytical skill was questioned and his results were challenged. His response was to insist upon and to repeat his results and, when pressed, to suggest a substitute for Lavoisier's theory of acids. Acid properties, Davy said, were probably due to molecular structure rather than to the presence of any particular element. As proof of this hypothesis he cited his analysis of diamond, which demonstrated that it consisted of pure carbon. He insisted that the difference between diamond and graphite lay solely in the crystalline arrangement of their carbon particles. This appeal to molecular structure, although unheeded at the time, was to be vindicated by research in organic chemistry, where slight differences in molecular arrangement often cause marked differences in chemical and physical properties. As evidence accumulated, chemists gradually swung to Davy's side, but it was 10 years before even Berzelius accepted chlorine as an element.

The years from 1804 to 1812 were ones of almost constant triumph for Davy. Discovery followed discovery, and honors flowed in. In 1806, though France and England were at war, the French awarded his Bakerian Lecture the annual prize that had been founded by Napoleon for work in galvanism. Davy became more and more sought after in fashionable society, and he began to squeeze his research in between visits to the country and journeys abroad. In

His problem:

To extend human engineering concepts to an entire process

Name of this scientific American:

Thomas B. Douglas
Vice President, Operations
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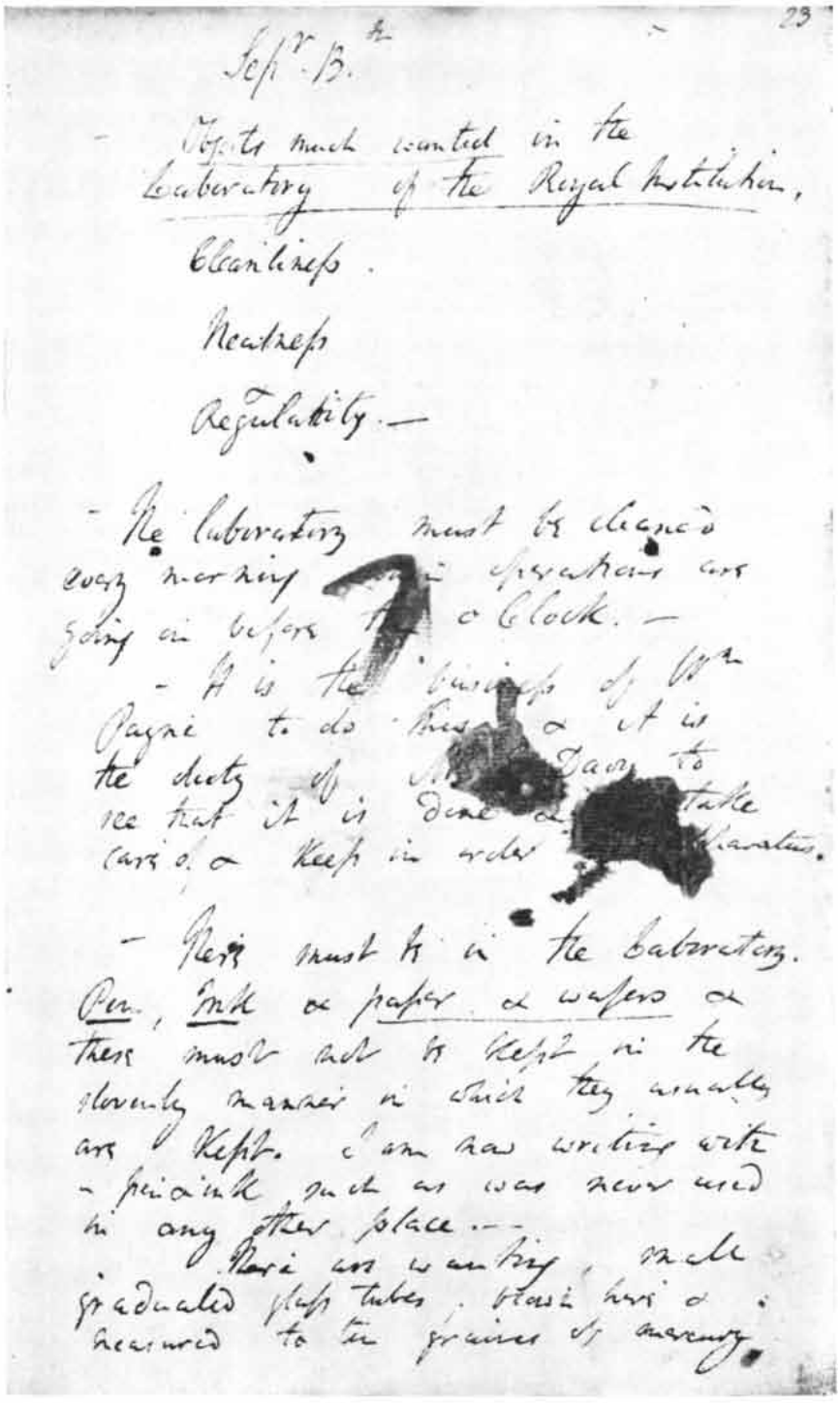
1812 he reached the peak of his career: within a week he was knighted by the Prince Regent and married a widow of wit, beauty and wealth. This year was to see the last of his sustained researches. Throughout his life he remained a pioneer, but the problems he treated were generally of small scope. In his analyses of ancient pigments and in his attempts to unroll decayed papyri at Herculaneum by chemical means, he was the first to apply chemistry to the problems of archaeology. As President of the Royal Society from 1820 to 1828 he attempted to raise the scientific level of its members, a reform that was to be accomplished only after his death.

Perhaps Davy's outstanding achievement during this period was the invention of the safety lamp, which made his name a household word throughout the world. The simplicity of this device has



DAVY'S LABORATORY NOTES, despite their demands that others practice neatness and cleanliness in the laboratory, are spattered with ink and chemicals and in places are almost illegible. His laboratory method appalled his tidier colleagues at the Royal Institution.

tended to obscure the fact that it was the result of one of the most beautiful series of experiments in the history of science.

In the summer of 1815 Davy's help was sought by a committee that had been formed to find some way of preventing disastrous explosions of mixtures of methane and air in coal mines. After a short tour of the mining districts Davy returned to London to work on the problem. He first tried to find sources of light that would not inflame an explosive mixture, but he was unsuccessful. He then studied methane thoroughly and found that it had a surprisingly high ignition temperature. When he attempted to explode a mixture of methane and air in a glass tube a quarter of an inch in diameter, he discovered that the flame passed slowly down the tube; and that when the diameter was reduced to a seventh of an inch, the mixture would not burn at all. Davy reasoned that the small-bore tubes cooled the gases to a temperature below the ignition temperature of the explosive mixture. He found that if a lantern flame was enclosed within a fine wire mesh, the escaping gases would be similarly cooled; and thus the Davy lamp was born [*see illustration on page 112*]. The whole investigation had taken him only three months. It was one of the earliest and most dramatic illustrations of the aid that science could offer to the rapidly developing industries of England.

In publishing the results of these researches Davy announced his indebtedness to his young assistant, Michael Faraday. It has often been said that Faraday was Davy's greatest discovery. Faraday was a young journeyman bookbinder when he first heard Davy lecture at the Royal Institution. He carefully copied the notes he had taken, bound them in leather and sent them to Davy with a request for employment. Davy, won by this flattery, offered Faraday a job as a laboratory assistant. Faraday always acknowledged his debt to Davy, whom he called "a mine inexhaustible of knowledge and experience." Many of the investigations that made Faraday famous were continuations of Davy's work. Faraday's discovery of compounds of chlorine and carbon, his work on the liquefaction of gases, on electrical discharges in a vacuum and on electrochemistry were all inspired by Davy and picked up where Davy left off.

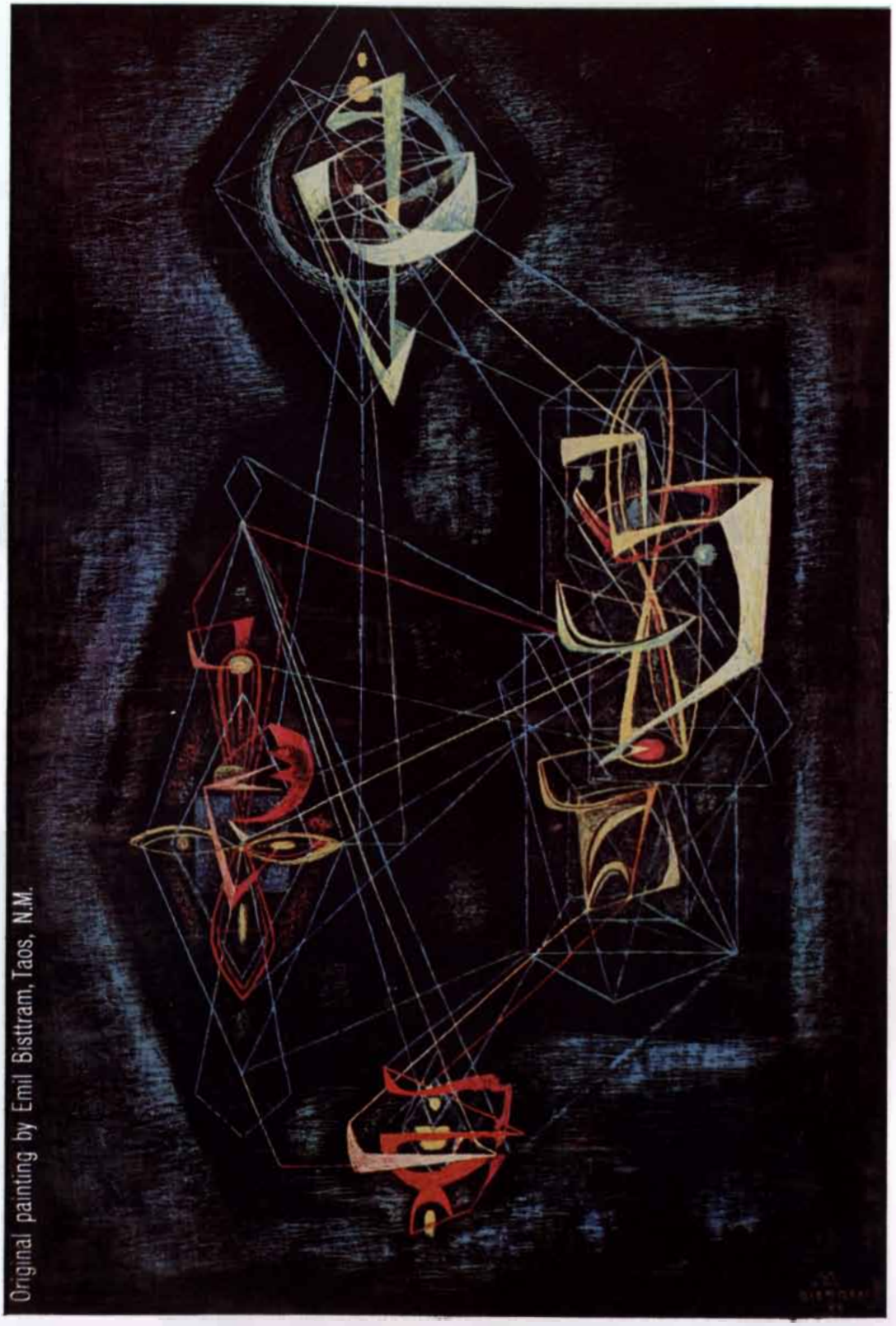
But the theoretical framework that Davy passed on to Faraday was of even greater importance. Both Davy and Faraday rejected John Dalton's atomic theory in favor of one put forward in the 18th century by the Jesuit priest Ruggiero Boscovich. Boscovich postulated that atoms were immaterial, mathematical point-centers of force surrounded by shells of attraction and repulsion. This scheme preserved all the advantages of the existing corpuscular theory of matter with none of its disadvantages. Furthermore, it was peculiarly adaptable to the chemistry of the time. It explained the specificity of chemical reactions and differences in the chemical stability of compounds in terms of the interaction of complex patterns of forces. To Davy and to the young Faraday this explanation seemed more satisfactory than the previously accepted theory that matter consisted of clumps of atoms drawn together solely by the force of gravity.

The ability of the Boscovich theory to predict as well as to explain chemical phenomena was illustrated to Faraday in 1823, when Davy suggested that he heat crystals of hydrate of chlorine in a closed glass tube. The result was the liquefaction of chlorine, in exact contradiction to the Daltonian theory (which held that heat was a repulsive principle) and in accord with Davy's prediction that heat, as a mode of motion, would force the chlorine particles into closer relation and liquefy the substance. But a satisfactory explanation of this result did not appear until J. Willard Gibbs published his classical papers on thermodynamics later in the century.

That Faraday's scientific education under Davy took place in terms of point-atoms is evident from manuscripts of Faraday's musings, as well as from many passages in his later work. If one reads Faraday with Boscovich in mind, he will discover, perhaps to his surprise, that the researches of the master experimentalist are linked by a theory of immaterial atoms.

This legacy Davy himself saw as perhaps his finest achievement. Although his relations with Faraday were often stormy, the childless dean of English science could contemplate, with almost mystic joy, the soaring of his disciple into the regions of the unknown. In 1821, eight years before his death, Davy watched a flight of eagles and wrote what might well serve as his epitaph:

The mighty birds still upward rose
In slow but constant and most steady flight,
The young ones following; and they would pause,
As if to teach them how to bear the light,
And keep the solar glory full in sight.



Original painting by Emil Bisttram, Taos, N.M.

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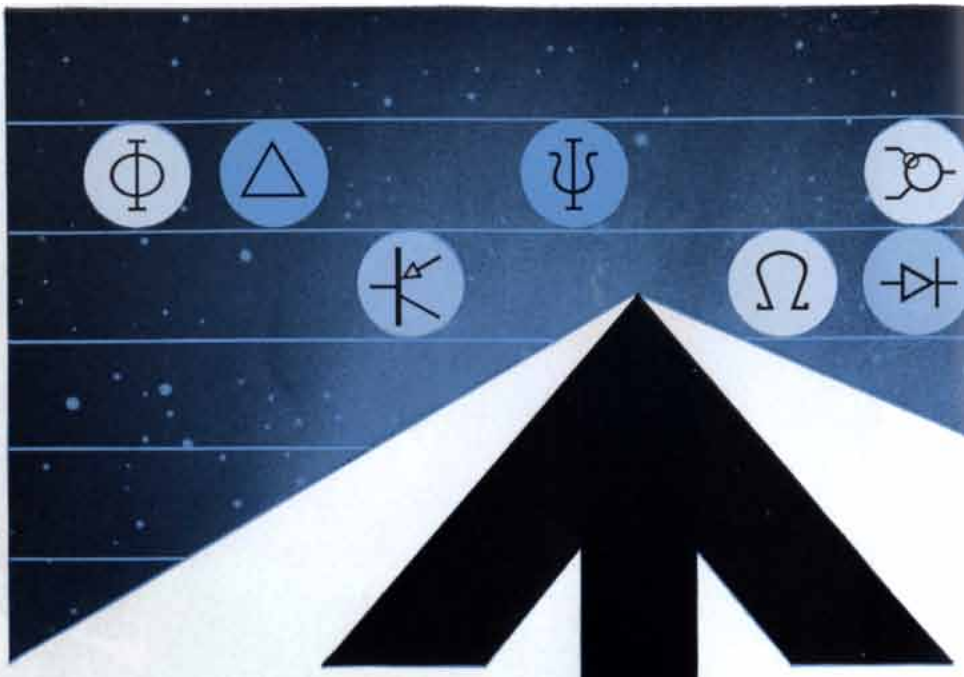

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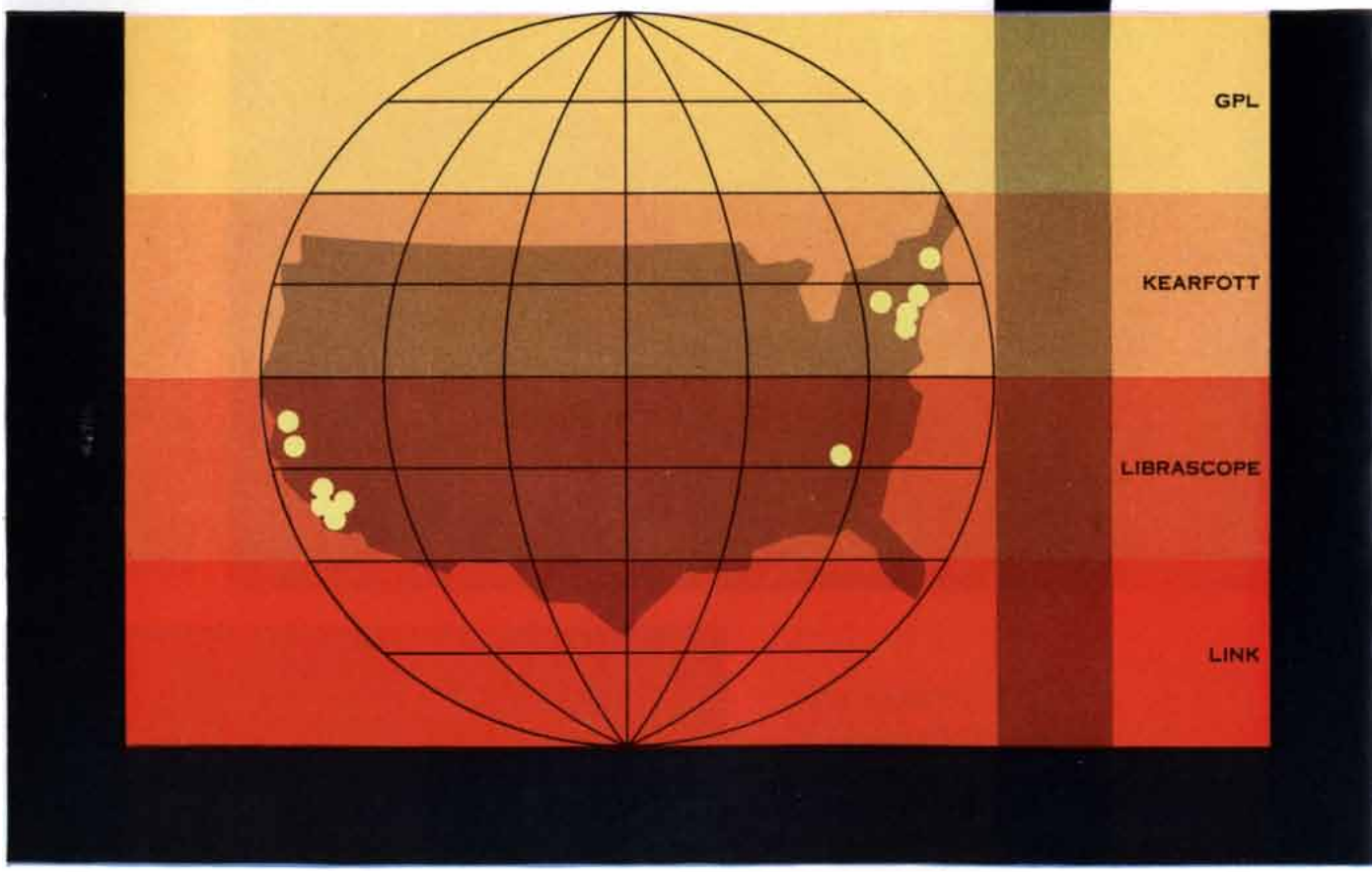

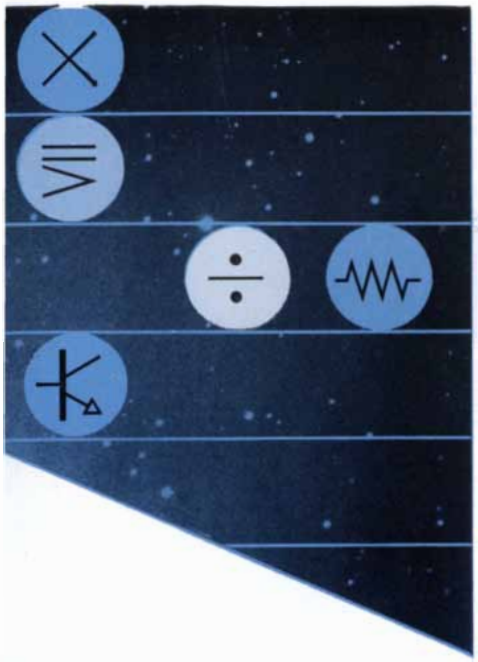

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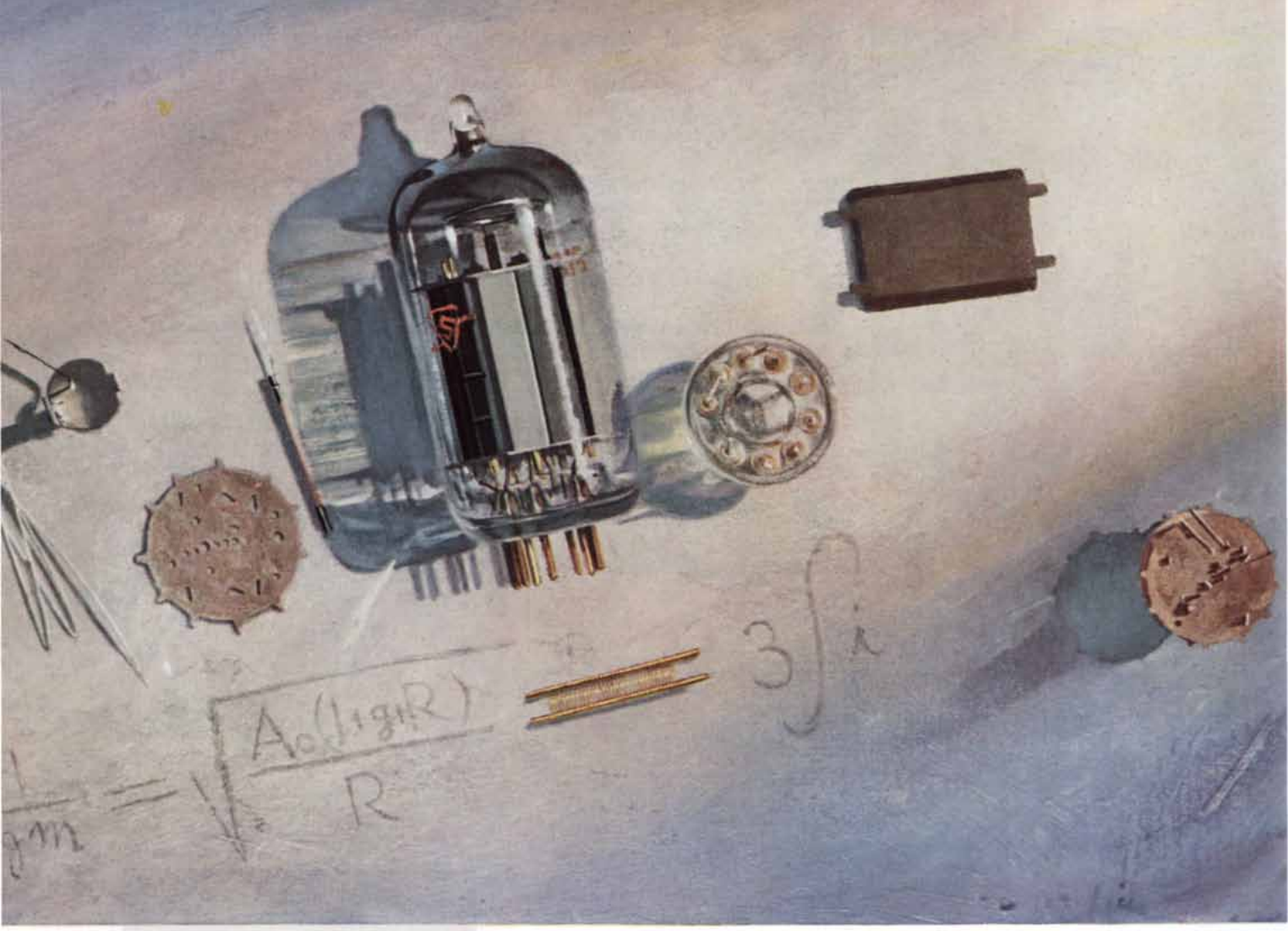

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GENERAL SYSTEM

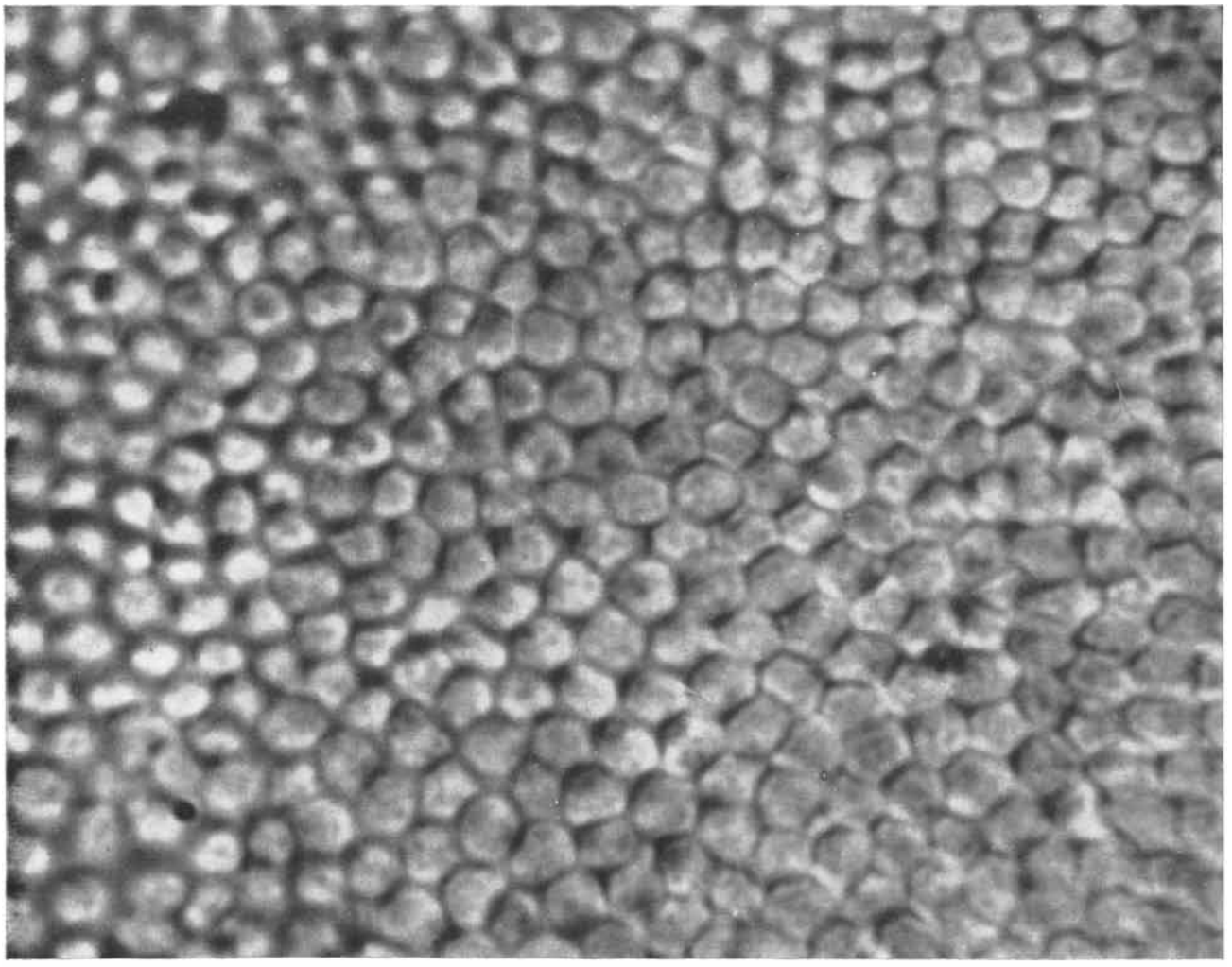
How We See Straight Lines

In looking at a straight line, the eye can detect a lateral break that forms an image only .00001 centimeter wide on the retina. A new hypothesis holds that this ability is due to rapid scanning motions

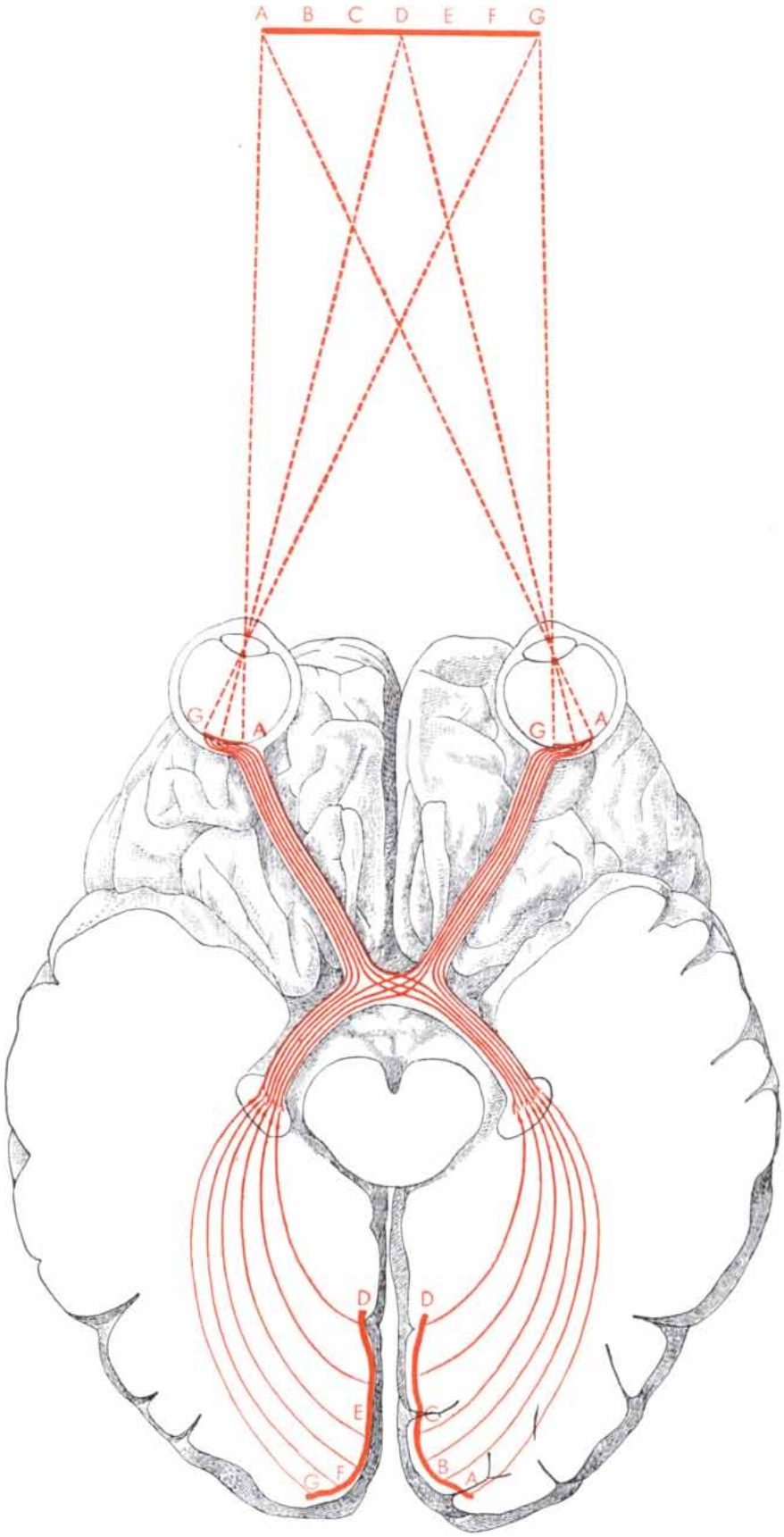
by John R. Platt

On first thought it would seem quite impossible for human beings to see whether a line is straight or not. Our visual mechanism is apparently unsuited to the task.

Consider what happens when we look at a straight line: Its image falls on the curved surface of the retina at the back of the eye. Here the light pattern stimulates the tiny receptor elements—rods and cones—that lie underneath it, and they fire off a volley of electrical signals to vaguely defined regions on both sides of the cortex of the brain. Surely the cerebral pattern is not "straight." It is often argued, however, that the brain somehow knows the location of the rods and cones whose stimulation gave rise to the sensation. If these particular rods and cones lie along an appropriate curve, the object they record is a straight line.



CELLS IN RETINA of the human eye form a mosaic pattern of light-sensitive receptors. This photomicrograph shows the cells enlarged about 3,000 diameters. It appears in *The Vertebrate Visual System*, by S. L. Polyak, published by University of Chicago Press.



VISUAL PATHWAYS of the human central nervous system (*solid colored lines*) carry stimuli from the eye (*center*) to the visual areas of the brain. This horizontal cross-section view shows how the image of a straight line (*AG*) falls on the curved surface of the retina and is projected onto convoluted areas of the visual cortex (*heavy colored lines at bottom*).

Let us examine this reasoning a little more closely. The retina is a layer of tissue about one inch square, containing something like 10 million receptor cells arranged in a closely packed mosaic. How can the brain know where each cell is? Hermann von Helmholtz, the great pioneer in the theory of vision, thought the knowledge might be provided by specific "local signs"—possibly chemical in nature—from cells at different positions. His idea has recently been confirmed in some elegant experiments performed by Jerome Y. Lettvin and his colleagues at the Massachusetts Institute of Technology. When they cut a frog's optic nerve and allowed it to regenerate, they found that the neuron from each point of the retina grew back to its proper point in the brain.

But this specificity can hardly be indefinitely fine. Seen under a microscope, the mosaic of retinal cells looks random, and, as living tissue, it has been subject to all the accidents and irregularities of biological growth. Surely the cells must be subject to some microscopic uncertainty of location. Thus a line that appears straight to one man should appear full of little wiggles to his twin brother. The amplitude of the wiggles would indicate the limits of accuracy of the genetic or local sign-specification.

Yet the fact is that we *can* tell when a line is straight, and none of us ever sees any such wiggles. Our actual precision in certain visual observations is fantastic. Our vernier acuity, or ability to detect a lateral break in a straight line, is about two seconds of arc. This corresponds to a distance of a little more than a hundred thousandth of a centimeter on the retina, about a 30th of the diameter of a cone cell! Even in mechanical construction this precision is almost impossible; a hundred thousandth of a centimeter cannot be measured in the finest machine shops except by optical methods. In a biological system such as the eye the location of every tissue cell to such an accuracy, 30 times finer than the size of the cell, is quite unbelievable.

I puzzled over this paradox for a long time, until I finally began to wonder if we were not looking at the problem in the wrong way in emphasizing the precise location of the individual cells. We were unconsciously assuming that the brain can somehow examine its associated retina, as if through an external microscope, and locate each of the rods or cones in space.

Thinking about the microscope fallacy, as it might be termed, led me to wonder whether there could not be some high-

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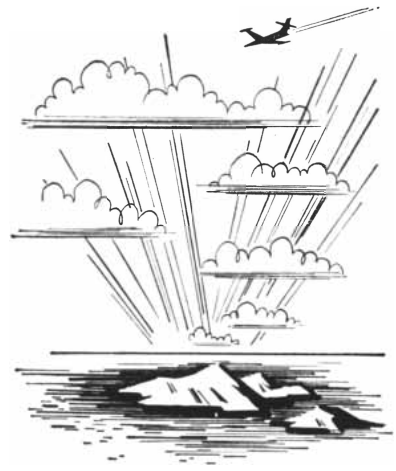

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. . . WHERE RESEARCH IS THE KEY TO TOMORROW

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PARALLEL SCANNING along a straight line (*top row*) or a curved line (*bottom row*) excites a single pattern of receptors on the surface of the retina (*large circles*). Small black circles indicate excited receptors. If eye scans a broken line (*middle row*), three different patterns of receptors are stimulated. The brain interprets this shift from one pattern to another as a lack of straightness.

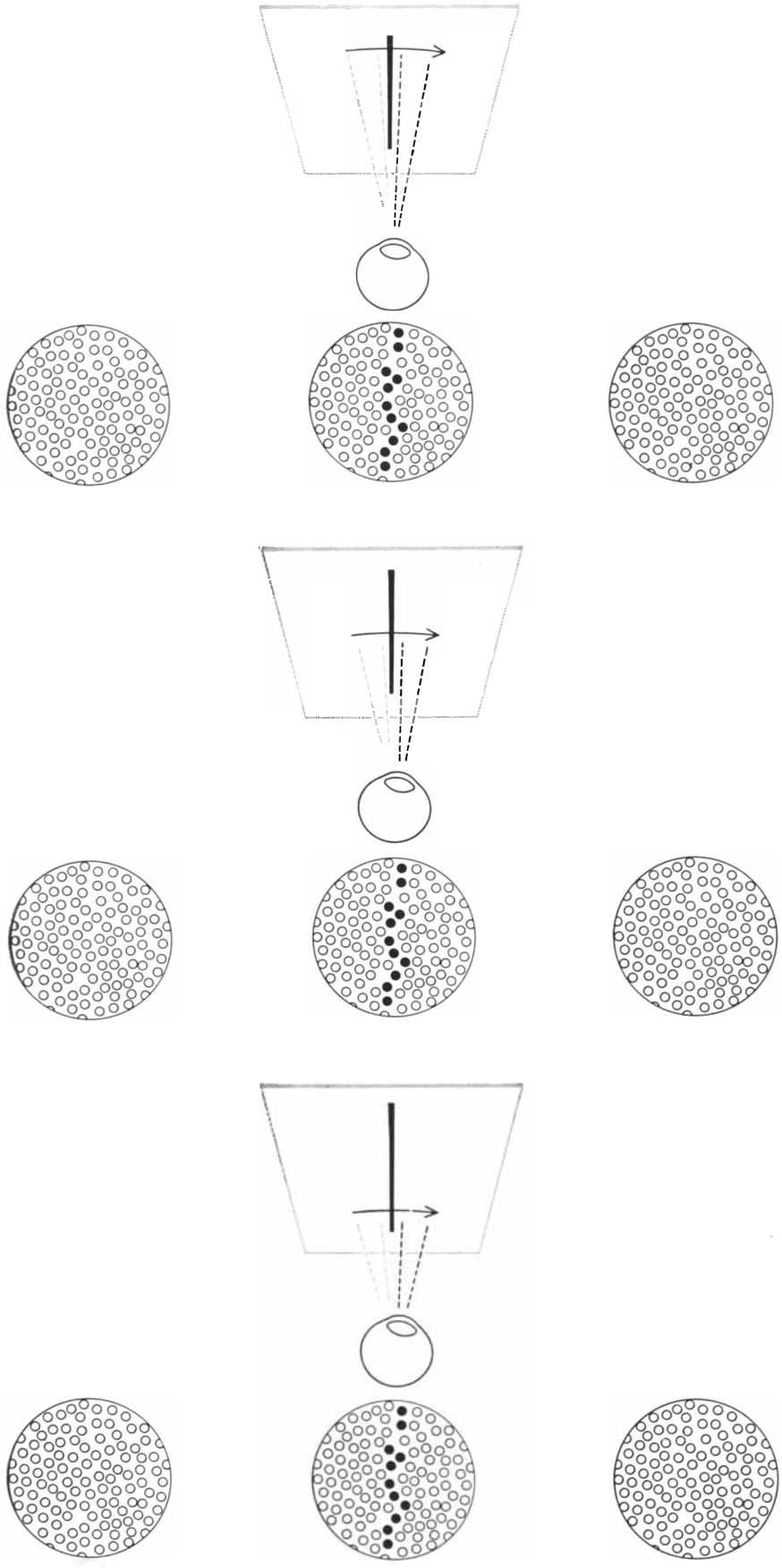
precision physical method that would enable a system consisting of 10 million elements to make acute discriminations without knowing exactly where its individual sensory elements were located. I finally found one, a method that I call functional geometry. As its name implies, the method generates spatial relations in the course of the normal functioning of the visual system rather than through the static, point-by-point location of images.

The essence of this functioning is motion, or scanning. Several years ago experimenters discovered that, in order to keep a static pattern steadily in view over even a short period of time, a person must continuously shift his eyes in tiny scanning motions. If he does not, the image fades away. I suggest that the same scanning can provide the sense of straightness.

The basic idea is as follows. Imagine the image of a scene—any scene—projected on the retina. The arrangement of light and dark areas stimulates a particular set of rod and cone cells, which then transmit a specific array of signals to the brain. If the eye scans the scene, moving so as to shift the image slightly, a somewhat different set of receptors is stimulated, and the signal array changes accordingly. But suppose the scene is a straight line, and the scanning is parallel to the line. Then the motion does not change the set of stimulated receptors, and the signal array remains constant. This constancy, or "self-congruence," after displacement is what the brain recognizes as straightness.

Evidently an ability to detect the sameness of an array is about the weakest demand one could make of a communications network, however it may operate. Moreover, the perception can be made without knowledge of where the individual receptor-cells are located. All that is necessary is an external object that is congruent to itself under a displacement such as the eye can carry out. A straight line fulfills the condition. So do parallel lines. A crooked line, or a set of nonparallel lines, does not.

One of the important features of the method is that the images of these lines on the retina or on the cortex can be as crooked as you please without destroying the self-congruence; all that is required is that the image fall on the same locus after displacement, and it makes no difference what that locus is. The discrimination is therefore for straightness or parallelism in the external field. Clearly the brain does not know—and, if it uses functional geometry, does not need to know—how the images on its



TRANSVERSE SCANNING is another method of determining the straightness of a line. By comparing the patterns produced on the surface of the retina each time the eye sweeps across the line, the brain can form a very accurate judgment of its relative straightness.

cortex would look when observed from the outside. The fact that we see self-congruence in the external field is what makes straightness (and the other self-congruent pattern properties I shall mention) matters for public discussion. We do not see objects, but relationships; and the relationships are public. This is a point of considerable importance in linguistics and in theories of knowledge.

Another important feature of the self-congruent method of perceiving patterns is that it is not affected by damage or loss of receptor cells, or by blind spots. An array of signals can be the same after displacement as before, regardless of what cells have high or low sensitivity. This means we do not have to assume uniform sensitivity in all the cells of the eye. And it is consistent with the fact that we do indeed perceive patterns as passing straight across our blind spots.

In addition to scanning back and forth along a line, our eyes may move transversely across it. By making a series of such perpendicular passes at various points along a line, and by comparing the times at which signals come from different receptors, we can also form a judgment of straightness. Here we are limited only by the time taken in observation. The longer the time, the closer the check on possible discrepancies between time-sequences at various points along the line. It is probably this mechanism by which we make visual judgments of the highest acuity.

Either type of scanning of straight lines, or of parallels, is carried out by combinations of two rotations of the eyeball: around a horizontal axis (looking up or down) and around a vertical axis (looking left or right). However, our eyes are capable of still another motion, though it is sharply limited: rotation around a longitudinal axis pointing along the line of sight [*see bottom of illustration on page 128*]. (To observe this rotation, closely examine a marking on the iris of your eye in the mirror as you tip your head from side to side.) By adding a component of this twisting motion we can scan along a curve, and, if it has constant curvature, keep the image over the same set of receptors on the retina. Thus arcs of circles exhibit the same sort of self-congruence as straight lines, and concentric arcs the same sort of self-congruence as parallels.

As a matter of fact, it is not easy to judge whether a gentle arc is curved or straight. Uniformity of curvature (including the zero curvature of a straight line) is more readily perceived than is straightness or curvedness. If the curvature is sharp enough, however, we

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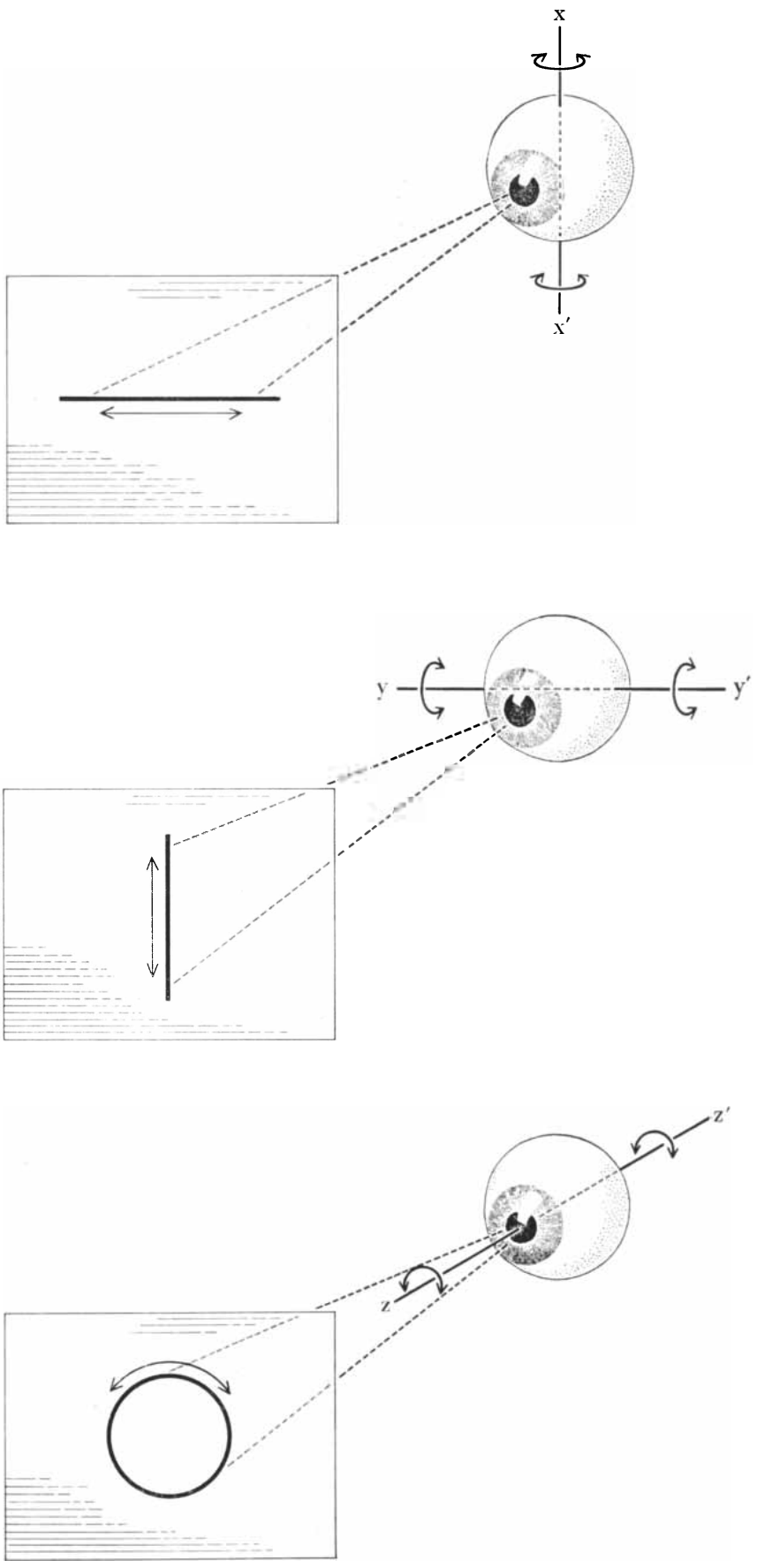


EYE ROTATES about three axes as it scans lines and geometric shapes. It can turn rather freely about the x-x′ and the y-y′ axes, but can rotate only slightly about the z-z′ axis.

probably become aware of it through muscular cues arising out of the twisting motion.

Both the method of self-congruence and the approach to greater accuracy through repeated trials are central concepts in high-precision optical work. Every amateur who has made his own telescope mirror knows that spherical and plane mirrors and precision screws can be brought virtually to perfection by being polished with a matching tool until they are self-congruent under lateral or rotational displacement. Within a finite time the error can be made less than any preassigned value.

In biology the principle of self-congruence generates perfectly helical elbow-joints and spherical hip-joints, and eyeballs in spherical sockets. The spheres are self-centering; they know nothing about the point centers and fixed radii of Euclidean geometry. This suggests a new approach to the study of geometry. It might be more natural to start not with points, distances, lines and coordinates, but with self-congruences, which are biologically more primitive.

Do we actually apply functional geometry to every judgment of straightness (and other patterns)? The experienced adult eye may not need to scan every new line afresh to determine its approximate straightness. Possibly certain receptors on the retina have been associated so often in past straight-line perceptions that when these elements are excited again and give off the same chorus of signals, we are satisfied of the straightness of the new object without further scanning. It is self-congruence to an old straight line, with a long time-delay. In a sense, the pattern has been learned.

If this is the mechanism of pattern perception, then we should expect to find that an infant or a visually naive adult (for example, a person who has had congenital cataracts removed) would require long scanning and study to determine the straightness of a line. Such, in fact, appears to be the case. The finding is consistent not only with the theory of perception developed here, but also with the doctrine of D. O. Hebb and his school at McGill University. They hold that perceptual organization of even such apparently primitive relationships as straightness or triangularity is acquired—learned—only through visual experience.

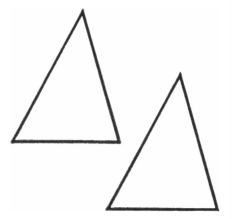
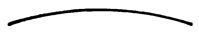
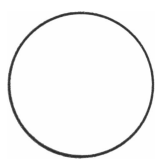
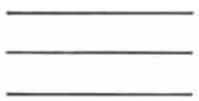
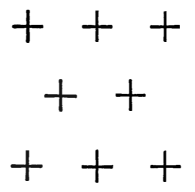
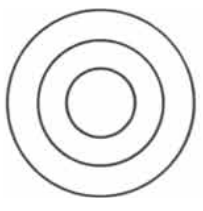
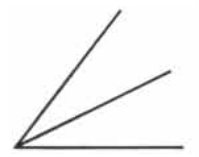
Arthropods (such as insects and spiders) can learn almost nothing, and

birds can learn only certain things. It follows that much, if not all, of their pattern-perceiving system must be prelocated and preconnected, determined by genetic information alone. Pattern-perceiving that involves learning, perhaps using methods such as functional geometry, is a way of escaping this genetic limitation. Such an escape is obviously needed for a really big brain with more inputs. This suggests that pattern-learning may be the faculty that grew most rapidly in the sudden evolutionary expansion of our own brain and cortical capacity in the last few hundred thousand years.

Perhaps the most noteworthy feature of functional geometry with a mosaic system is that it necessarily picks out certain patterns as fundamental or primitive. A mathematician of curved spaces might say that an S-curve in one curved space is a straight line in another, and that these are equally good descriptions of the line. But a functional mosaic will accept as straight only those Euclidean lines that satisfy self-congruence under displacement. Thus straightness is a primitive and unique category of perception for all mosaic systems. So is parallelism, concentricity and so on. It is interesting to note that the various relationships belong to the "synthetic *a priori*" categories of Immanuel Kant—unique categories that impose themselves on all minds regardless of particular experiences and yet cannot be learned without experiences and comparisons.

I suggest that there is only a small number of unique symmetry categories for a visual mosaic receptor, and that they are determined by the three possible rotations of the eyeball [*see table below*]. When the rotations are continuous, we get straightness, parallelism and the like. When the eye moves in discrete jumps, it perceives relationships such as equidistance, congruence and the equality of angles. On this view every visual pattern-relationship that can be perceived is some combination of the primitive elements.

It would be interesting to try to construct artificial mosaic receptors, complete with scanning motions, that might be able to make discriminations similar to those our eyes make. Evidently any such system would have to be able to learn. The receiving network would somehow have to grow or to establish new connections guided by experience. If we could design such a system, it might teach us far more than we now know about how the human eye and brain organize external information.

PATTERN OBSERVED	AXIS OF EYE MOVEMENT	PATTERN OBSERVED	AXIS OF EYE MOVEMENT
STRAIGHT LINE	xx′ AND yy′	CONGRUENCE 	xx′, yy′ AND zz′
CURVATURE OF ARC 	xx′, yy′ AND zz′		
CIRCULARITY 	zz′		
PARALLEL LINES 	xx′ AND yy	EQUIDISTANCE 	xx′ AND yy′
CONCENTRICITY OF ARCS 	xx′, yy′ AND zz′		
CONCENTRICITY OF CIRCLES 	zz′	EQUIANGULARITY 	zz′

PRIMITIVE PATTERNS are self-congruent under the types of rotation the eye can perform. Patterns at left are perceived by continuous rotations; relationships at right, by discrete rotations. Axes of rotation are listed in second and fourth columns.

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Fleming's Lysozyme

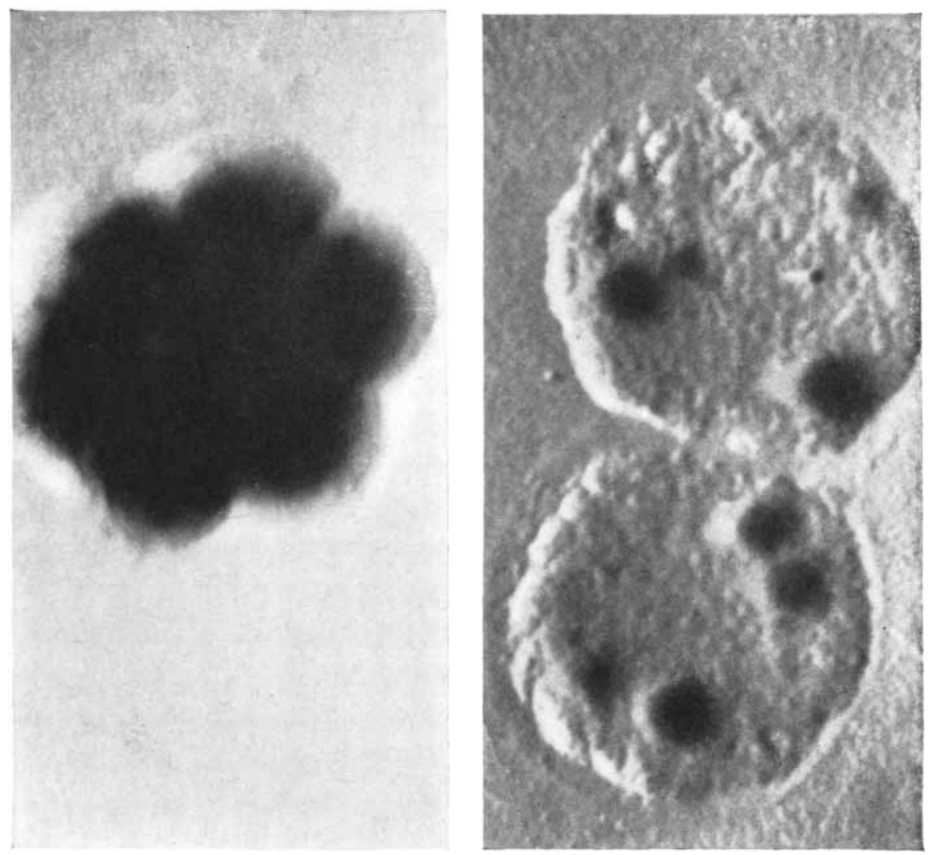
The discoverer of penicillin also found a substance that dissolves bacteria. Occurring in many human tissues and secretions, lysozyme is presently used to investigate the structure of the bacterial cell

by Robert F. Acker and S. E. Hartsell

The several major classes of bacteria have characteristic shapes: spherical, rodlike or spiral. From these shapes the bacterial classes get their names: cocci, bacilli and spirilla. Although nonbacterial cells have recognizable shapes, most of them are soft and pliable. The individual bacterial cell usually holds its shape with considerable rigidity. This feature of bacterial anatomy long ago attracted the curiosity of microbiologists. They soon discovered the reason for it: In bacteria the soft outer cell-membrane is enclosed in a tough, thick wall, which is often enclosed in turn in an even thicker gummy or slimy capsule. Together the wall and capsule may constitute as much as 45 per cent of the total mass of the cell. Plainly such an important structure must serve a purpose more significant than the conferring of rigid shapes for ready recognition by microbiologists. The cell wall, in fact, insulates bacteria from the vagaries of the environment, especially during their passage from host to host. In distilled water, for example, the osmotic pressure exerted by the bacterial cell would cause it to draw in water, swell up and burst; it has been estimated that the cell wall must in some species withstand an internal pressure of 20 atmospheres (300 pounds per square inch).

Bacterial anatomists are indebted to the late Sir Alexander Fleming for a sensitive chemical tool with which they have been studying bacteria, dissolving away the cell wall and exposing the cell body, or cytoplasm, within. In 1922 at St. Mary's Hospital in London, six years before his epochal discovery of penicillin, Fleming found "a substance present in the tissues and secretions of the body, which is capable of rapidly dissolving certain bacteria." Because of its resemblance to enzymes and its capacity to dissolve, or lyse, the cells, he called it "lysozyme." Fleming's lysozyme has not joined his penicillin in the armamentarium of medicine, but it undoubtedly renders all the service that could be expected of it as an element in the natural defenses of the body. In the hands of Fleming and his successors, moreover, lysozyme has helped to develop significant new understanding of the bacterial cell wall in its relationship to the processes that go on in the cytoplasm it otherwise protects so well.

Fleming isolated both lysozyme and the bacterium (*Micrococcus lysodeikticus*) that has been found to be most susceptible to it from the nasal secretion of a patient suffering from acute catarrh. A few simple experiments soon demonstrated the remarkable properties of the



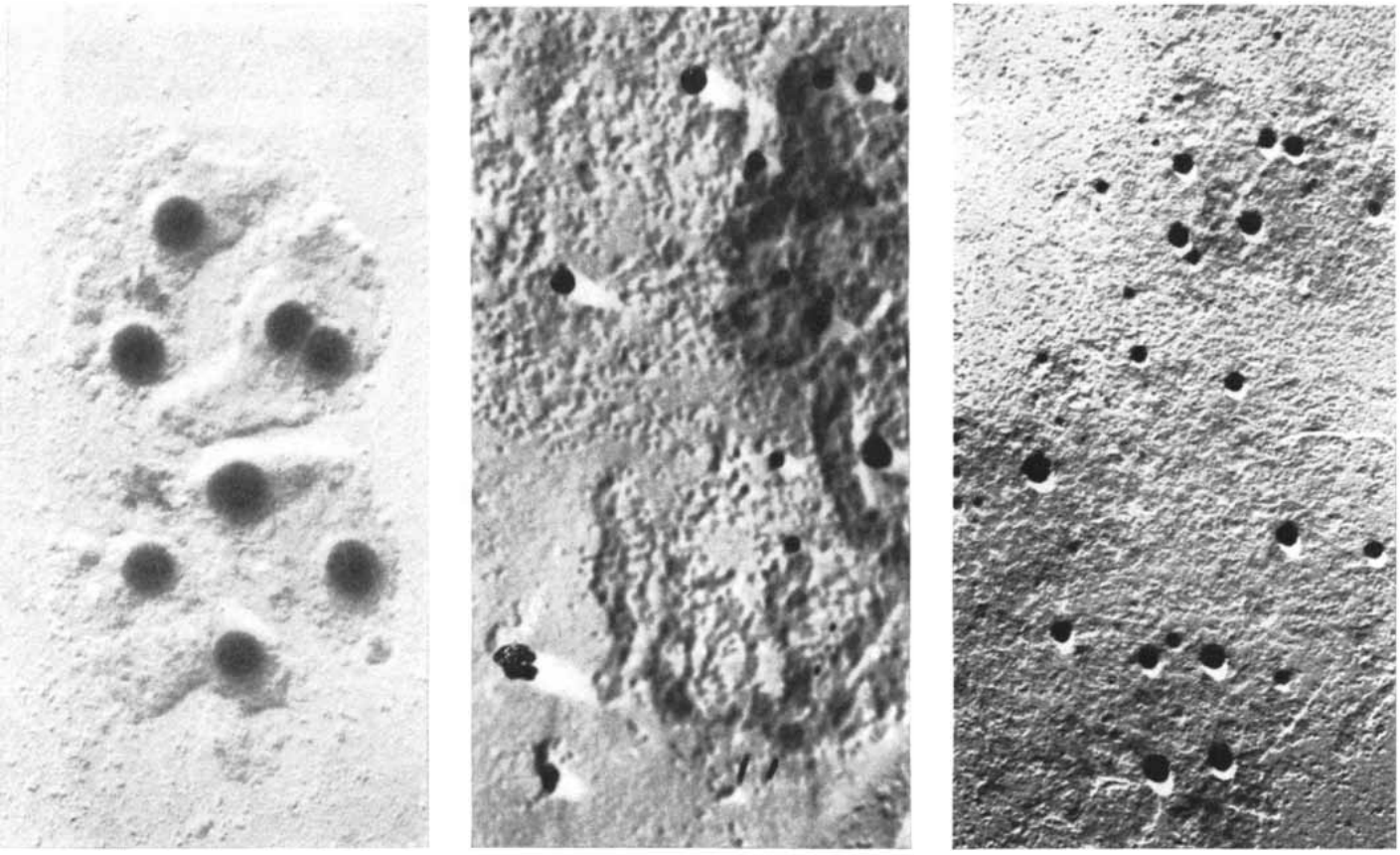
DISSOLUTION OF BACTERIAL CELLS with lysozyme treatment is shown in this series of electron micrographs. At far left is a clump of normal cells of *Micrococcus lysodeikticus*. About 15 seconds after the addition of lysozyme (*second picture*), the cell wall starts to

substance. In one experiment Fleming seeded a dish of solid culture medium with *Micrococcus lysodeikticus* and placed a droplet of mucus at the center of the dish. The bacterial cells multiplied and covered the surface with a cloudy continuous film, except in the area surrounding the mucus droplet. Here a clear zone appeared, created by the dissolution of the cells. Under the microscope Fleming observed that bacteria exposed to lysozyme undergo a series of characteristic changes. First the cells begin to swell, both spherical and cylindrical cells becoming transformed into large spheres. These soon lyse and lose their visible outline. After a time the only visible remains are a scattering of dark granules.

Lysozyme has been found in tears, nasal mucus, saliva and the exudate from infections; in extracts from the spleen, kidney, liver, lungs and lymph; and, in especially high concentration, in cartilage. It is not detectable in urine, cerebrospinal fluid or sweat. Lysozyme is not restricted, however, to tissues and fluids of animal origin; plants such as turnip, cabbage and cauliflower and even certain bacteria contain it. Egg white is the best source of lysozyme in quantity. Good yields are obtained by adding a small quantity of salt to egg white and homogenizing and acidifying it, whereupon the enzyme crystallizes out in pure form.

Chemical analysis of lysozyme has shown it to be a protein with the relatively low molecular weight of 14,700, of the same order as that of ribonuclease (13,895) and insulin (6,000), which are proteins simple enough to have yielded the principal features of their structure to investigation. The elucidation of lysozyme is not yet complete, but it is known that some 130 amino acid units, comprising 18 different amino acids, make up its structure. It is unique in that it contains very little of the amino acid tyrosine; the amino acid lysine, on the other hand, occurs characteristically at the ends of its amino acid chains. Since lysine occupies the same position in the structures of other proteins, particularly those found in wheat grains, it may be that lysozyme has a significant place in the evolution of proteins that accompanied the evolution of the organisms composed of them.

Like other enzymes, lysozyme is highly specific in its activity. In susceptible bacteria it is the capsule and cell wall that are broken down by lysozyme. The complete susceptibility of the cell wall of *Micrococcus lysodeikticus* has been demonstrated in experiments with purified preparations of its cell wall. M. R. J. Salton of the University of Manchester ruptured these cells by shaking them at high frequency in the presence of tiny glass beads, and then separated the walls from their contents by repeated centrifugation. The entire substance of this preparation was dissolved when it was mixed with lysozyme. Upon analysis, the susceptible material proved to be half polysaccharide (sugar units forming a chain) and half peptide (short amino acid chains) in composition. The polysaccharide portion breaks down into simpler sugar units such as glucose, and the peptide portion into a half dozen or so amino acids. In addition to the major components, substances classed as amino sugars have been found. As the name implies, these compounds are the result

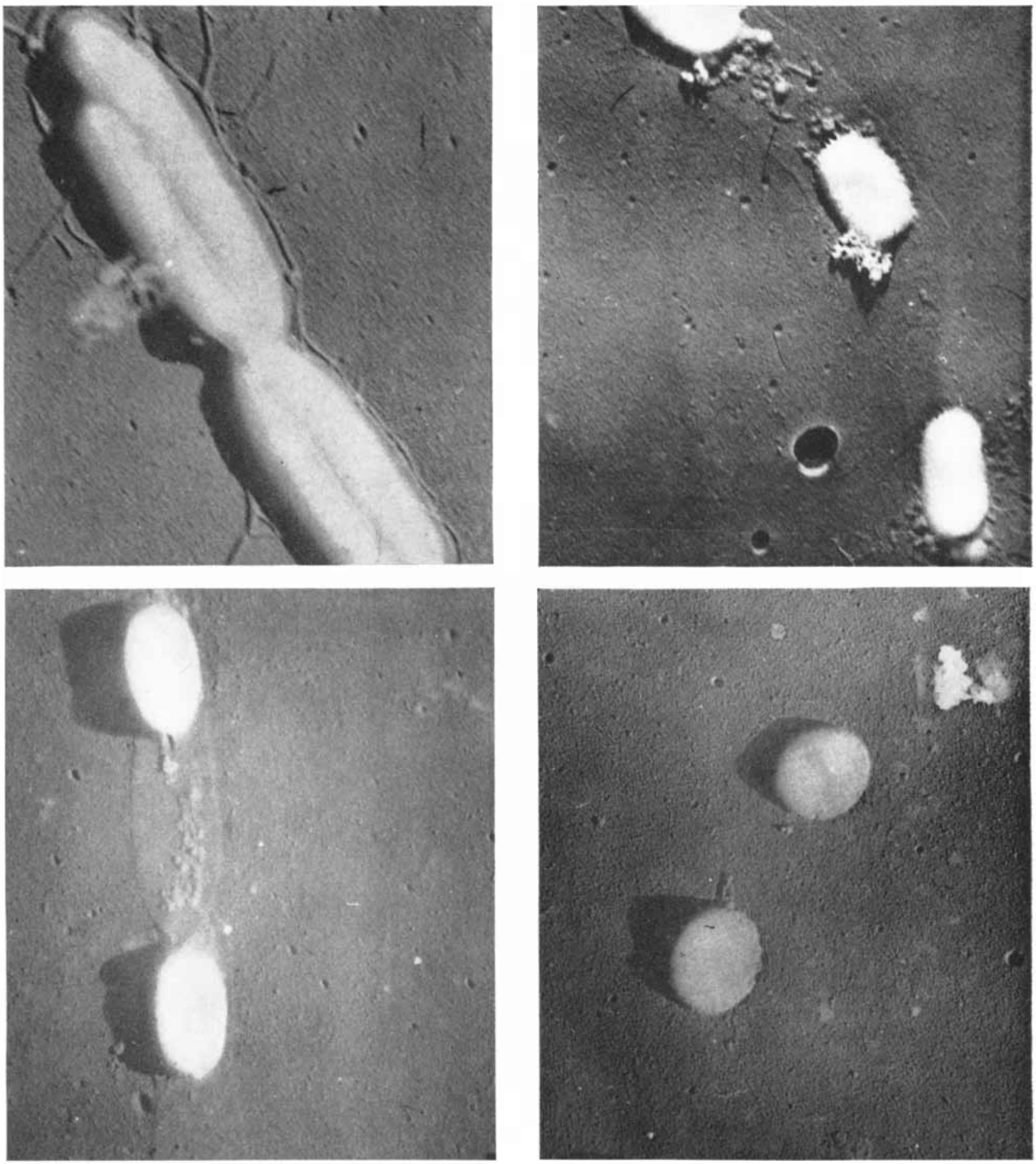


dissolve and the cell material spreads out. At 60 seconds (*third*) the cell wall disappears and at 90 seconds (*fourth*) cell organization is almost lost. At 120 seconds (*fifth*) nothing remains but granules. The granules in the last two micrographs appear to be holes because of a special shadowing technique. All these structures are enlarged 1,800 diameters. The micrographs were provided by Hartsell.

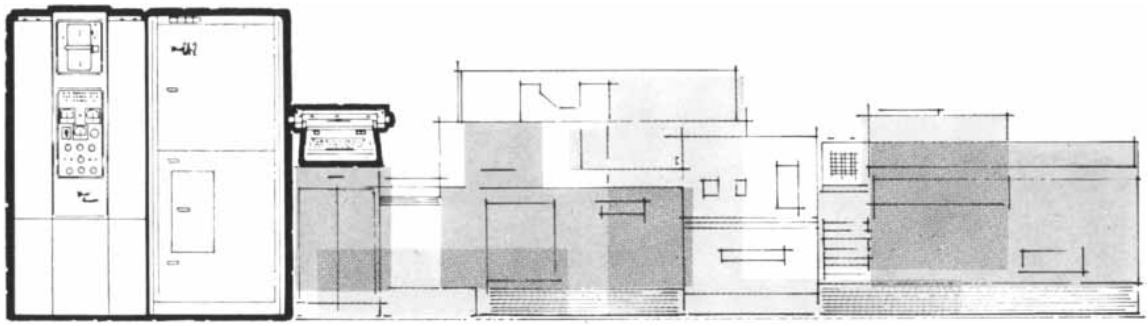
of chemical attachment of amino groups (NH_2) to sugar molecules.

The selective action of lysozyme fills a long-felt want of the microbiologist, permitting detailed study of the cell wall and a new approach to investigation of the cytoplasm. Other agents fail to segregate one from the other or tend to disrupt and destroy both together. When bacteria are placed in strong salt solution, for example, the cytoplasm shrinks away from the cell wall into rounded bodies called protoplasts. The opposite reaction, swelling of the cytoplasm, may be induced by certain toxic or growth-promoting substances. The cell wall now splits open. The protoplast may be visible momentarily as a large sphere of cytoplasm enclosed in a thin flexible membrane, but it disintegrates rapidly.

Investigators tried for many years without success to secure protoplasts in stable form in the hope of using them to



SPHERICAL FORMS OF BACTERIA, called spheroplasts or protoplasts, result from lysozyme treatment in a sucrose solution. Cells of *Bacillus subtilis*, which are normally rod-shaped (*first picture*), upon treatment gradually lose their cell walls and become rounded. The structures are enlarged some 15,000 diameters. The electron micrographs on this page and on page 142 are reproduced from an article by J. M. Wiame, R. Storck and E. Vanderwinkel that appeared in *Biochimica et Biophysica Acta,* Vol. 18, page 353.



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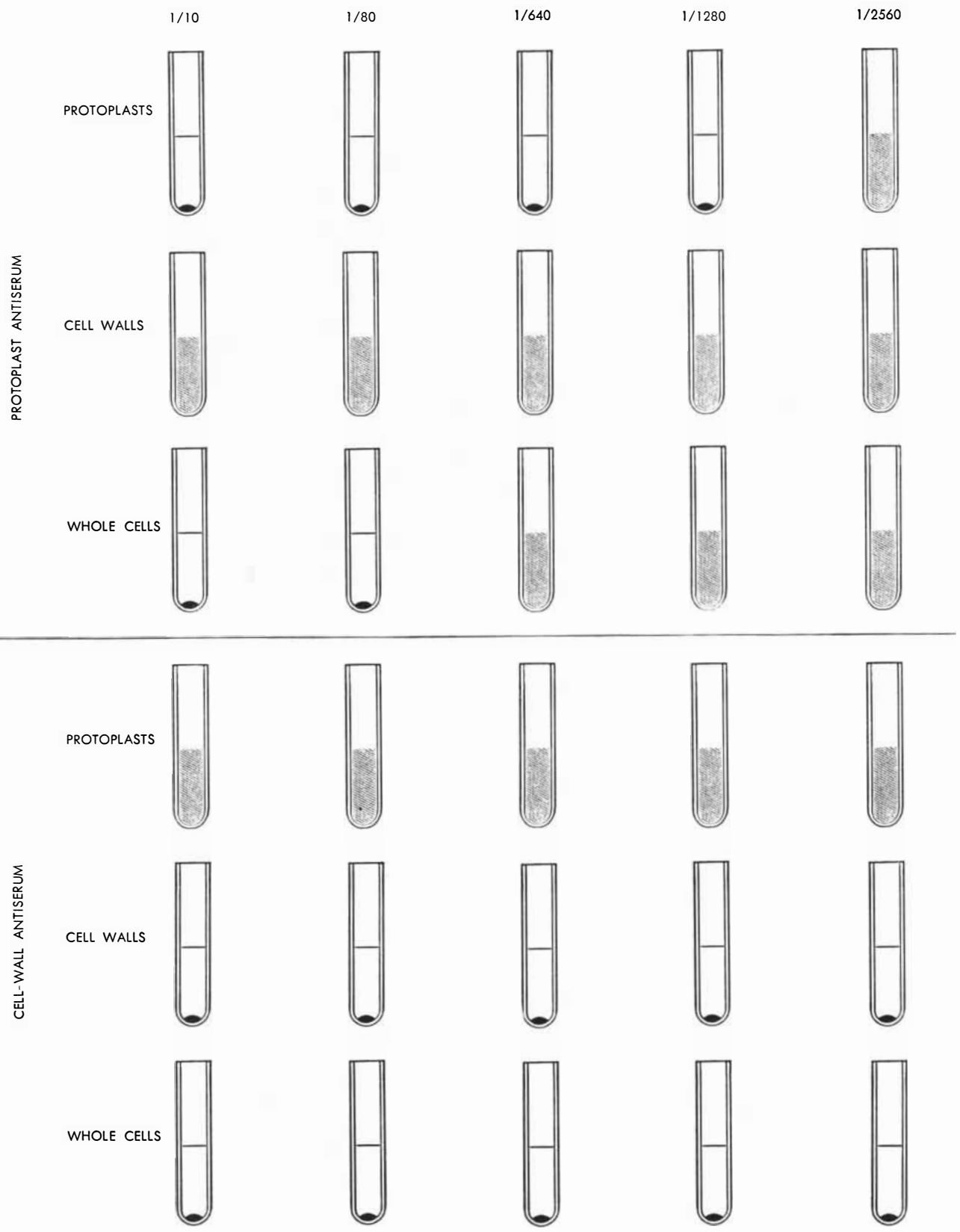


SEROLOGICAL TESTS show that protoplasts of *Bacillus megaterium* are free of cell-wall material. Serum containing antibodies to the protoplasts (*upper group*) causes the protoplasts to clump together and settle out of suspension, but does not react with isolated cell walls of the same organism. Serum containing antibodies to the cell walls (*lower group*) reacts with cell walls but not with protoplasts. Whole cells are clumped by cell-wall antiserum and, at low dilutions, by protoplast antiserum. Figures at top indicate serum dilution. Data are based on a study by John W. Vennes and Philipp Gerhardt at the University of Michigan Medical School.

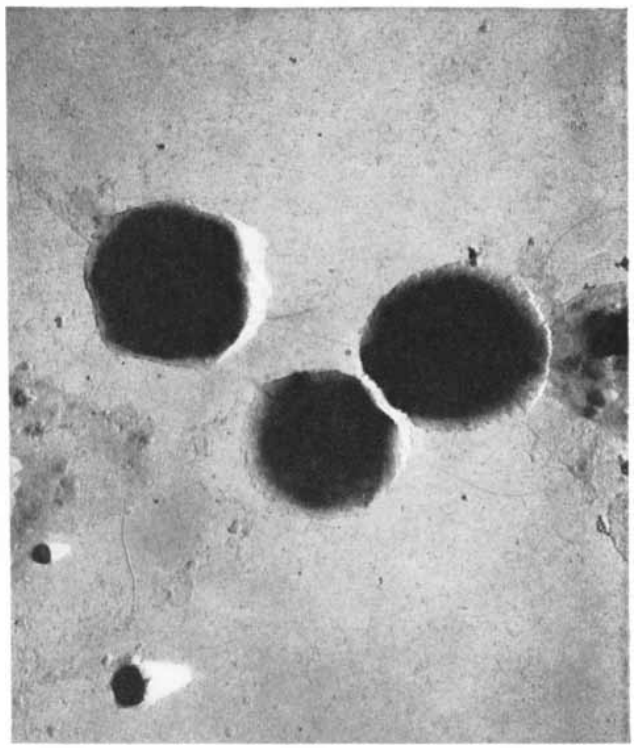
study the properties of bacterial cytoplasm. This objective was achieved in 1953 when Claes Weibull of the University of Uppsala in Sweden developed a simple technique employing lysozyme to isolate and preserve protoplasts. Weibull found that a sufficiently low concentration of lysozyme would dissolve the cell walls of the giant *Bacillus megaterium* slowly enough to permit experimental control of the process. He was able to keep the resulting protoplasts from breaking down by conducting the process in a dilute solution of sucrose, which balanced the osmotic pressure across the exposed cell membrane, and by maintaining a low level of oxygen in the medium to inhibit the metabolism of the protoplasts.

That this treatment achieves complete separation of the cell wall and protoplast has been demonstrated by serological means. Protoplasts, like other protein-containing substances, are antigenic; when they are injected into the bloodstream of an experimental animal, they induce the formation of antibodies that react with them. Blood serum taken from the animal and mixed with the same type of protoplasts will cause the protoplasts to clump together. The serum will also cause clumping of whole bacteria of the same type, but will not clump isolated cell-walls. On the other hand, antiserum prepared by injecting an animal with purified cell walls will cause whole bacteria as well as cell walls to form clumps, but will not affect the protoplasts of the same bacteria. The smallest contamination either way would blur these clear-cut results.

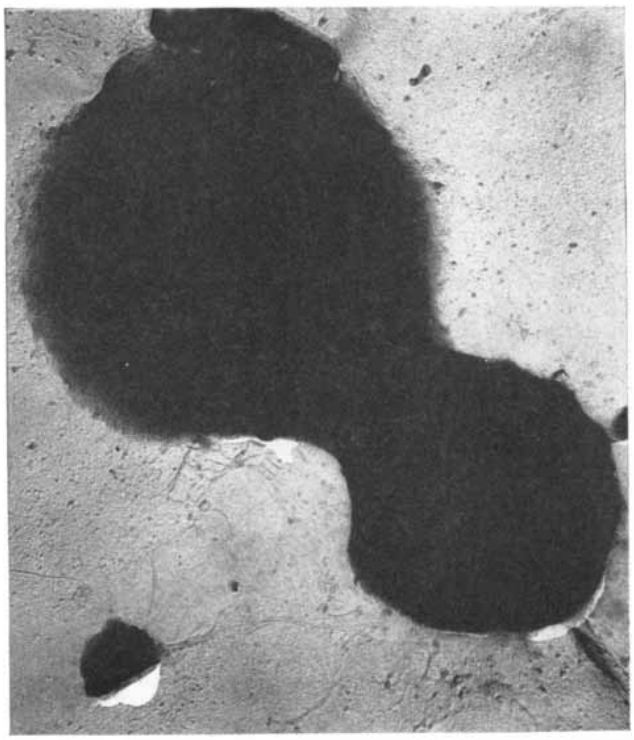
With protoplasts available in stable form for experiment, investigators have found that many activities of the cell remain unaffected when the cell wall has been stripped away. For example, the respiration rate—the intake of oxygen and elimination of carbon dioxide—appears to be much the same in protoplasts as in intact cells. This is particularly the case when the respiration rate is throttled down by culturing the cells or protoplasts in a medium devoid of energy-yielding nutrients. When nutrients are added to the medium in which cells or protoplasts are suspended, the protoplasts take up the nutrients with about 75 per cent the efficiency of whole cells. Interestingly enough, they do not assimilate certain compounds that are normal constituents of cell-wall substance, although they may incorporate their precursors. Accordingly it seems that those systems that function within the cyto-

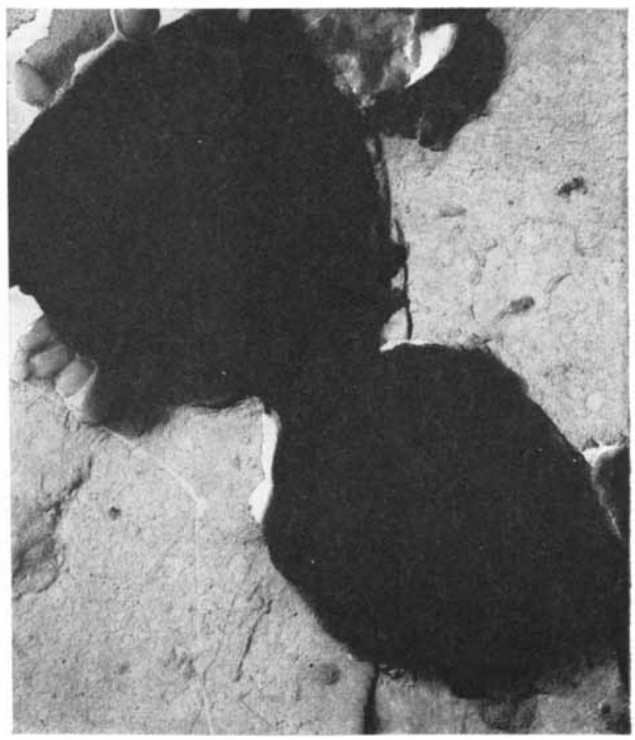
plasm of the cell do so as effectively in protoplasts as in intact cells, and so are not dependent on the presence of the cell wall.

The next question is whether protoplasts can also grow and divide like whole cells. The protoplasts of *B. megaterium* swell and increase in weight and volume, much as whole bacteria do between cell divisions. Under certain conditions they even exhibit a phenomenon suggestive of division. In the presence of glucose and selected amino acids they increase in size, produce budlike protrusions and become dumbbell-shaped. But unlike the intact cells, which undergo division at a sufficiently rapid rate to form visible colonies on a solid growth-medium, protoplasts do not succeed in carrying through the process of normal division. Though a single protoplast can



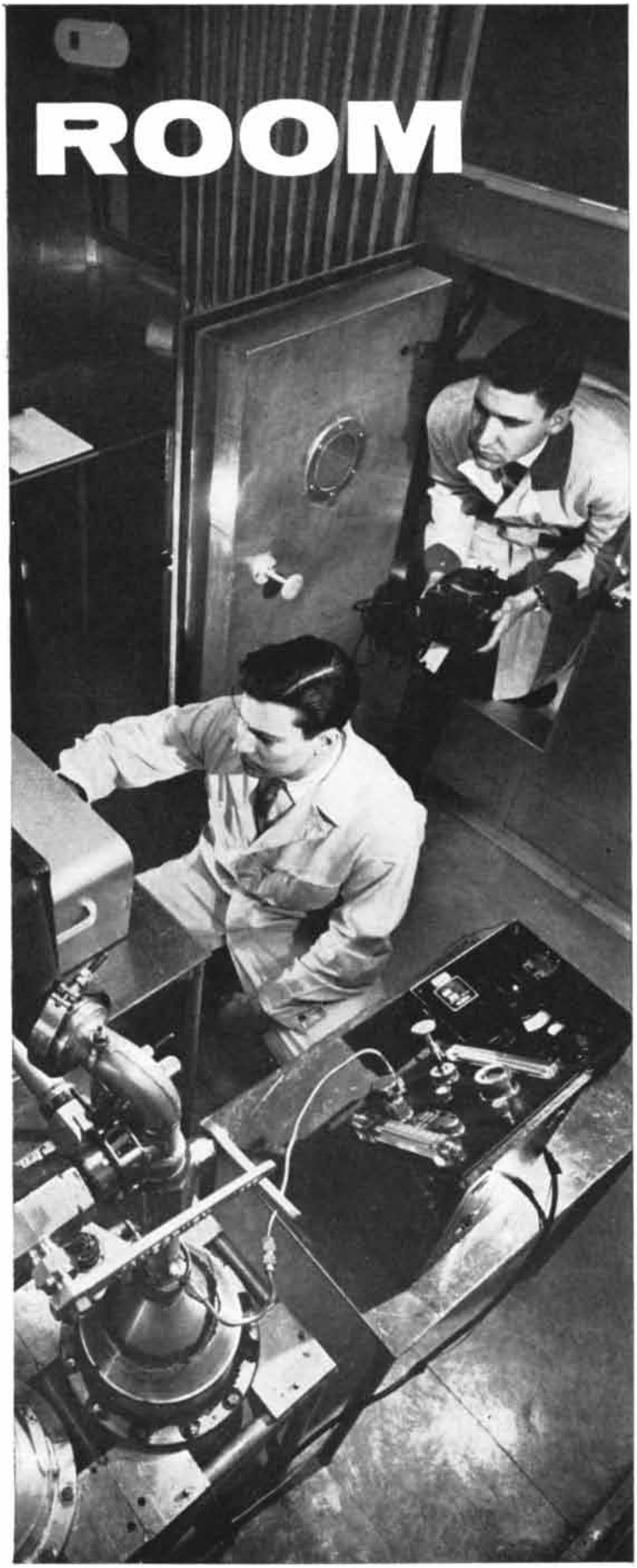
NEWLY FORMED PROTOPLASTS of *B. megaterium* at right have the same volume as the rod-shaped cells from which they came. Normal cells are shown at left. Kenneth McQuillen of the University of Cambridge provided these electron micrographs.





PROTOPLASTS AFTER NINE HOURS in a nutritive medium have increased in size and weight. Some appear to be budding (*left*) or dividing (*right*). These structures, which are enlarged about 15,000 diameters, are shown at the same scale as those at top.

MOON ROOM



Hamilton Standard environment control project seeks ways to ensure a safe air supply for man in space

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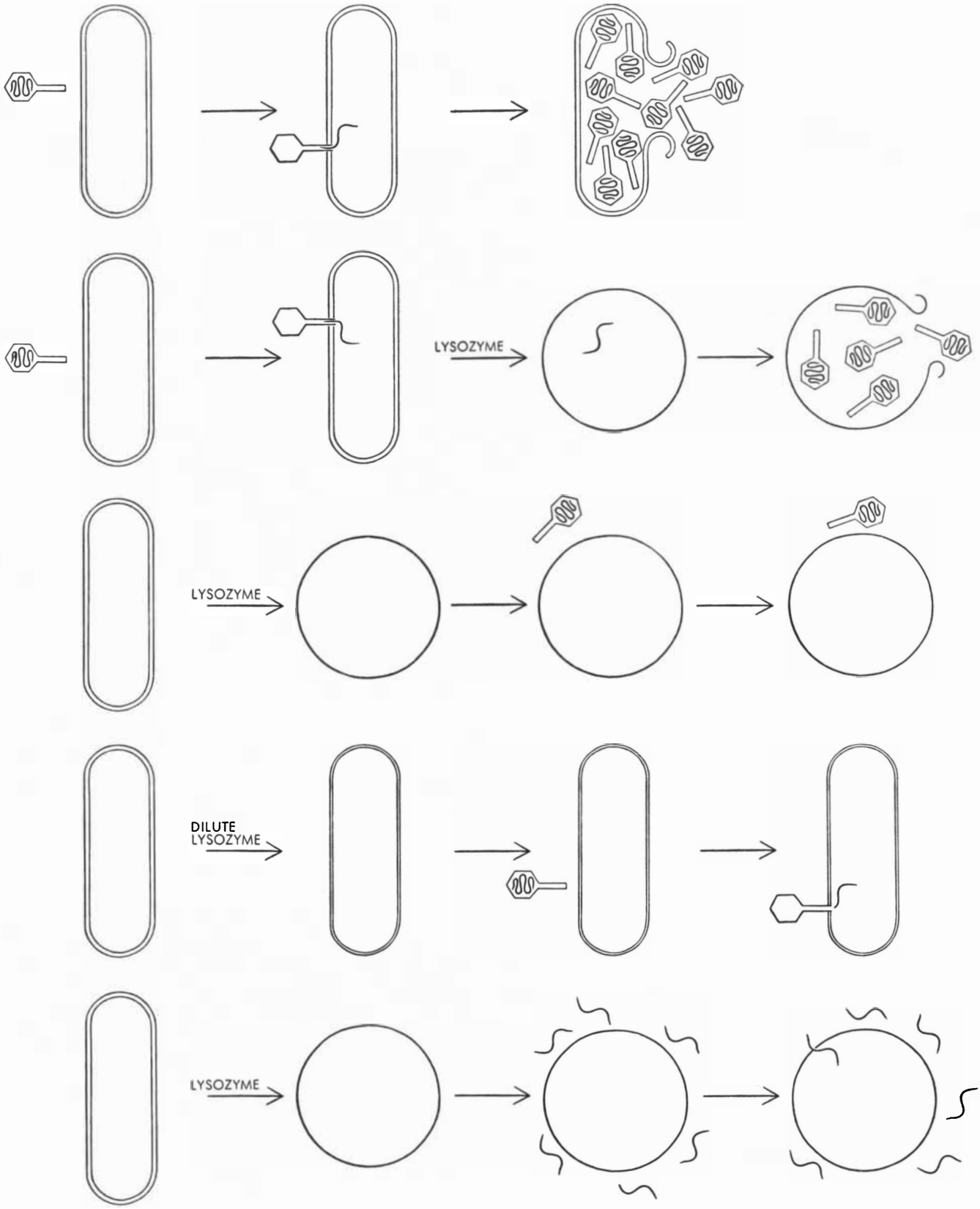


VIRUS INFECTION OF BACTERIA has been studied by means of protoplasts. Normally a virus particle attaches itself to a bacterium and injects its DNA (*thread*) into the cell; later the cell bursts to release many new virus particles (*first row*). A cell converted to a protoplast by lysozyme after it is already infected produces viruses in reduced number (*second row*). Viruses cannot attach themselves to protoplasts (*third row*), but can attach to and infect cells having some cell-wall layers remaining after mild

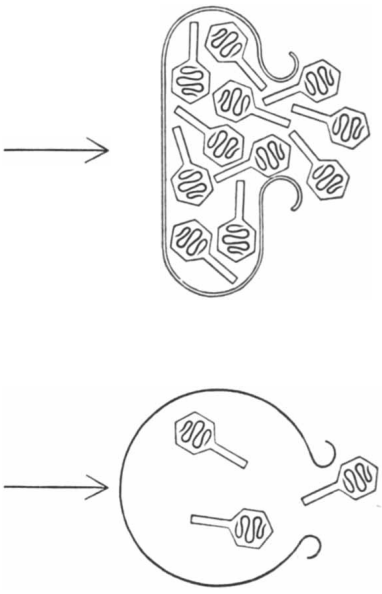
divide in two, neither it nor its offspring can form cell walls. This may be because protoplasts lack the ability to synthesize new cell-wall substance, or because they require special, and as yet undetermined, environmental conditions.

Some bacteria, such as *B. megaterium*, are equipped with whiplike appendages called flagella, the rhythmic motion of which propels the cells about when they are suspended in a fluid medium. Dissolution of the cell wall of these motile bacteria shows that the flagella are part of the cytoplasmic structure, for they remain attached to the protoplasts. The protoplasts are nevertheless incapable of motion. Probably some essential triggering mechanism associated with the cell wall is lacking. Or it may be that the protoplast structure lacks the rigidity necessary to make the thrust of the flagella effective. (An aircraft propeller would not work very well attached to a soft balloon!)

Virus infection represents one chink in the armor of the bacterial cell-wall. Investigators have found, however, that viruses which infect *B. megaterium* will not affect protoplasts of this bacterium. This supports other evidence that some chemical affinity between the virus and the cell wall makes a bacterium susceptible to infection by a particular virus. The submicroscopic, tadpole-shaped bacterial virus is known to be a quite complex structure, composed largely of virus genetic material (deoxyribonucleic acid, or DNA) enclosed in a protein coat. Ordinarily virus particles attach themselves tail-first to the cell wall, digest a hole in it and then inject their DNA into the bacterial cytoplasm. Inside the cell the virus DNA redirects the host's metabolism, causing it to produce virus material. The host cell then ruptures and frees several hundred newly formed virus particles into the surrounding medium. On the other hand, when a bacterial virus is cultured with protoplasts of a susceptible bacterium, it shows no affinity for them and does not infect them; it does, however, attach itself to the empty cell-walls of the same bacteria. Although the virus cannot attach itself to naked protoplasts, it can multiply in the protoplasts of bacteria that receive an infecting dose of viral DNA before their cell walls are removed. The process differs from that in normal whole cells only in that the protoplasts yield somewhat fewer viruses than whole cells do.

Must the entire cell-wall be present, or will the virus attach itself to cells with some layers of wall removed? A dilute solution of lysozyme, added to a suspension of *B. megaterium*, will remove small amounts of cell-wall material instead of the whole wall. When bacteria so treated are exposed to virus, they succumb to infection as readily as do intact cells. This indicates that the lower levels of cell-wall structure exposed by the lysozyme digestion are sufficiently like the surface for viruses to take hold. Either the configuration of the chemical bonds on the surface of the cell is not essential for phage attachment or it is somehow duplicated at lower levels as cell-wall material is removed. The lysozyme-treated cells produce a larger yield of virus than do normal cells, implying that the thinned-down cell wall is more readily penetrated by the virus.

The experience gained in the production and handling of protoplasts of organisms susceptible to lysozyme has encouraged investigators to extend this kind of study to other organisms and to adapt other agents, such as penicillin, to the production of protoplasts. The important and ubiquitous colon bacillus (*Escherichia coli*), extensively used in

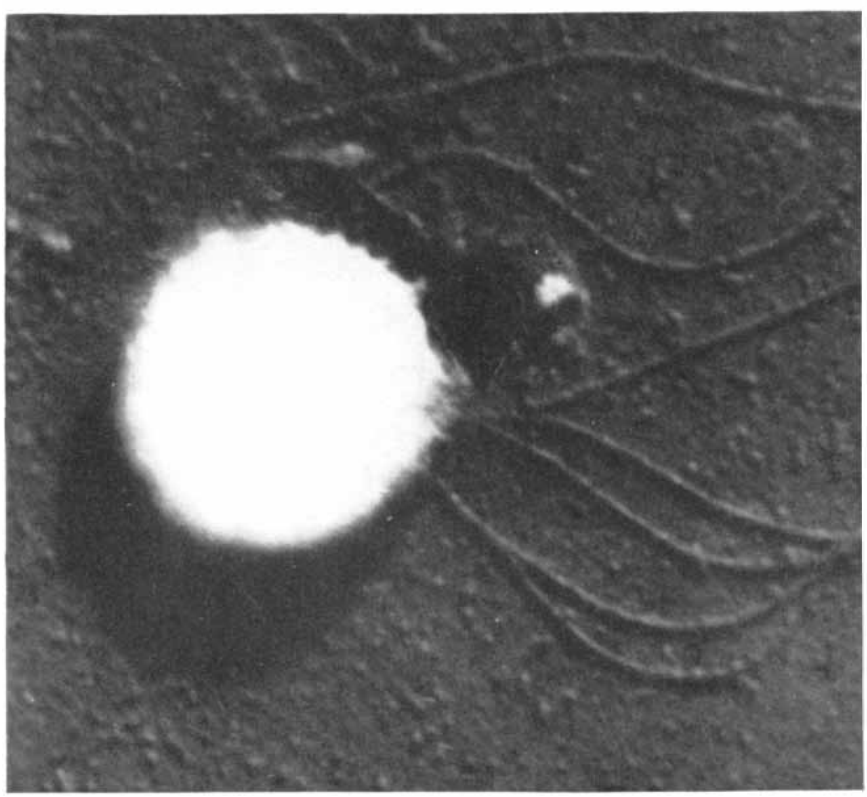


lysozyme treatment (*fourth row*). In one experiment spheroplasts, possibly still retaining some cell-wall material, were infected by free virus DNA (*fifth row*).

studies of bacterial biochemistry, bacterial genetics and virus infection, is resistant to lysozyme under the usual laboratory conditions, but is susceptible under special conditions. One of us (Hartsell) has discovered that dead cells of *E. coli* respond to lysozyme in an acid environment at high temperature to form stable protoplast-like spheres. Other workers have succeeded in removing the cell-wall material from living *E. coli* by employing lysozyme in combination with an alkaline solution or a chelating (metal-binding) agent. The cells thus treated lose their characteristic lozenge shape and form protoplast-like spheres. They can be preserved for extended periods in solutions containing sugar, salts or serum albumin in proper concentrations to balance the osmotic pressure on either side of the cell membrane. There is some question, however, whether these protoplasts are really completely free of cell-wall material, since their behavior sometimes differs from that observed in protoplasts of more sensitive strains that can be stripped of their cell walls by lysozyme alone. Pending the outcome of serological, chemical and other tests to prove the complete absence of cell-wall material, they are designated as spheroplasts.

Spheroplasts of *E. coli* have recently figured in a significant experiment involving DNA preparations from *E. coli* virus. Investigators at Indiana University and at Western Reserve University, working independently of one another, succeeded in separating most of the protein from the DNA fraction of this virus. Each group exposed a suspension of spheroplasts to their DNA preparation and secured a yield of viruses. Careful checking showed that the preparation contained no intact virus, although it was probably contaminated by a small amount of virus protein. Thus, although virus DNA by itself may not infect intact cells, the DNA in these preparations had penetrated the thin membrane enclosing the spheroplasts. The yield of virus from these experiments was small, but the findings are remarkable nevertheless. The synthesis of complete virus particles from DNA constitutes another piece of evidence that this molecule carries the important genetic properties usually associated only with intact organisms.

Fleming could not have anticipated the direction in which lysozyme would carry research in microbiology. The exploitation of lysozyme as a research tool shows how a simple discovery may open up vast new areas to investigation.



FLAGELLATED PROTOPLAST of *B. subtilis* shows that these whiplike swimming organelles are attached to the cell cytoplasm and not to the cell wall. This electron micrograph was obtained from J. M. Wiame. The structures are enlarged about 64,000 diameters.

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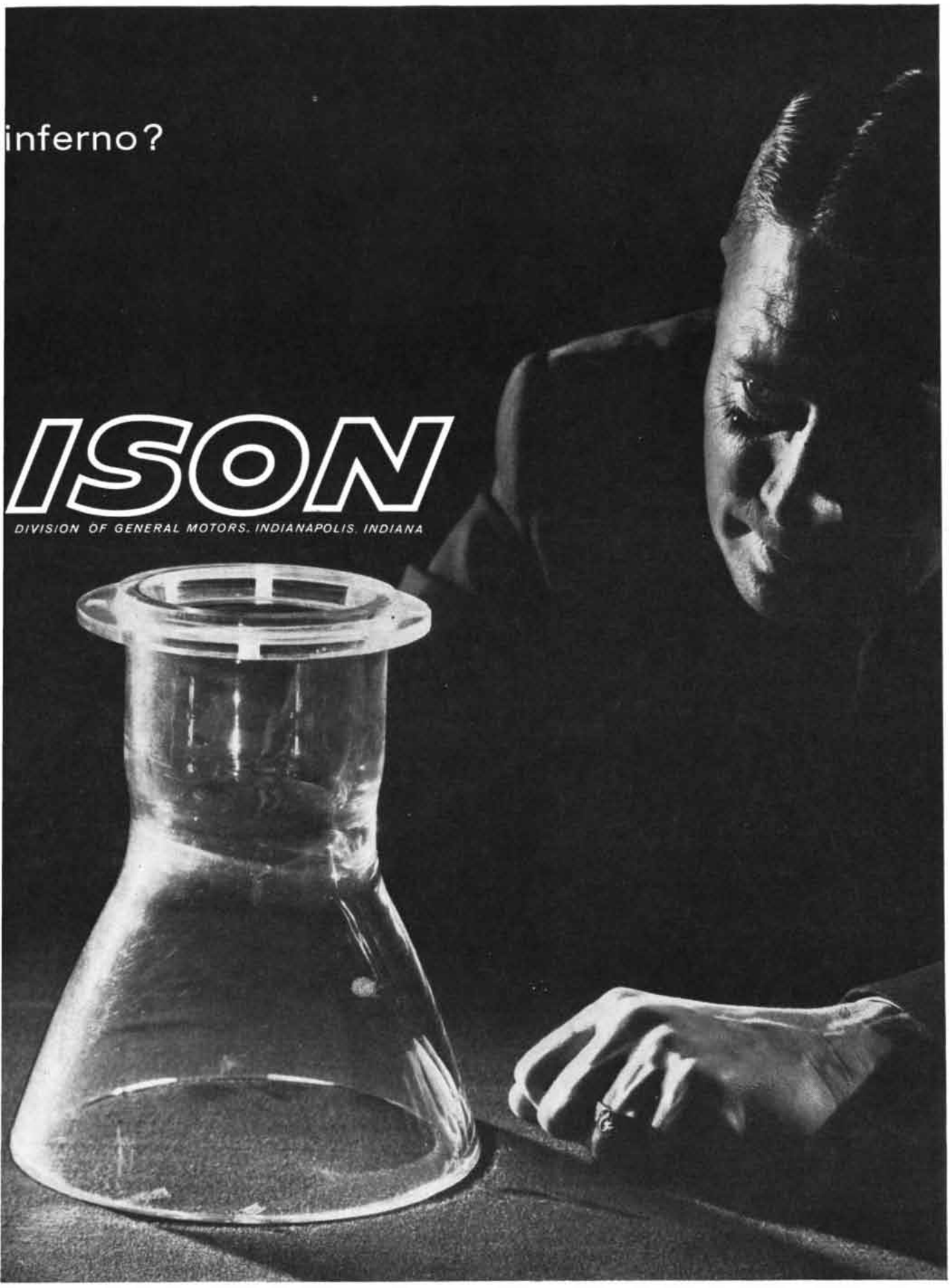


THE ORIGIN OF ORES

The metals most commonly found in the world's ores are not necessarily the most abundant. Over geologic time natural processes have concentrated some metals more than others

by H. G. Bachmann

Into ore-smelting furnaces all around the world the metals industries each year tumble hundreds of millions of tons of broken rock. Selective chemical reactions, promoted by the heat of the furnace, separate the metal from the other elements to which it is bound in the rock. The heavier molten metal gathers on the bottom of the hearth, and the slag floats to the top. Thus the smelting process, employing special stratagems for each ore and metal, segregates the metals from the more common and less useful materials contained in the ores. But civilization could scarcely base its existence upon the use of metals if the earth itself had not served, throughout a long chapter in its history, as a kind of gigantic smelting furnace, segregating the various metals in ore bodies ready at hand for the day when man would learn to use them.

All metals are relatively rare and precious. Iron, the metal that is found most abundantly "above ground" in the works of civilization, constitutes but 5 per cent of the earth's crust. Aluminum, the third most abundant element in the crust, is presently accessible only in scattered small ore-bodies, which are not nearly so workable as the larger deposits of iron. Titanium, a metal that has only recently come into industrial use, has an average abundance in the crust of 4,400 grams per ton—60 times the abundance of copper and 30 times that of zinc. Zirconium, another metal that is just now finding wide use, is as abundant as the more familiar chromium (200 grams per ton). Lead, one of the first metals to be smelted by man and still irreplaceable for numerous purposes, has an abundance of 16 grams per ton, only four times that of uranium. One might expect to find that the precious metals are rare, but not so rare as they actually are: silver has an abundance in the crust of only .1 gram per ton; gold, an abundance of .005 gram per ton.

There is thus little connection between the abundance of the metals and their economic importance. It is the local concentration of metals in ores that has determined to a large extent the order in which the metals have been taken up by man. An understanding of how these concentrations were formed has an obvious utility for the prospectors who go in search of them. In view of the mounting demand for metals of all kinds,

INJECTION AND SEDIMENTARY ORE-DEPOSITS are shown in these photographs. At left is a view from the south ramp of the Frood pit, mined by the International Nickel Company of Canada in the Sudbury district of Ontario. The ore is an injection deposit

such understanding has an increasing economic significance.

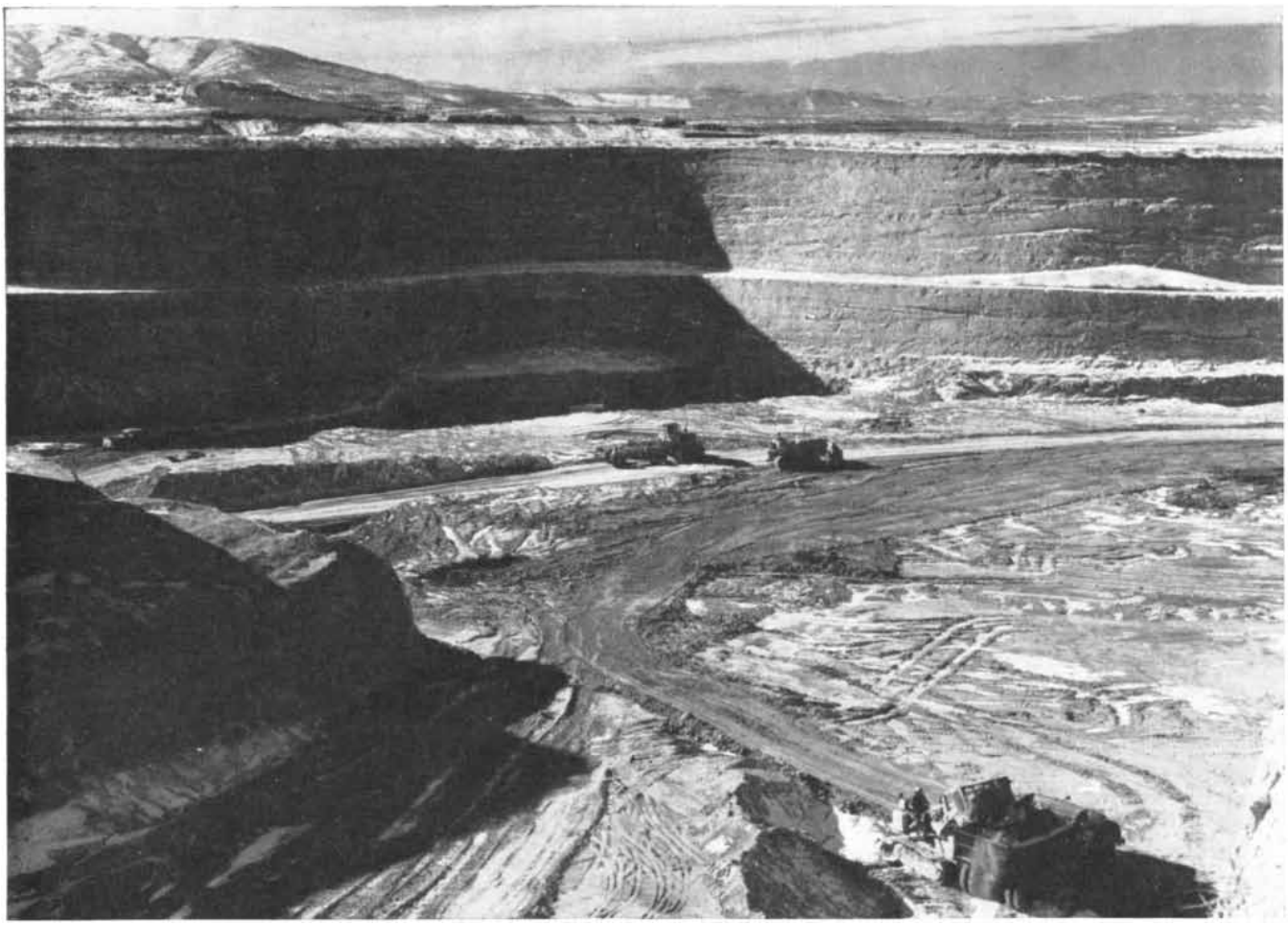
The geochemist, whose task it is to reconstruct the origin of the ores, must work like an archaeologist who seeks to read the story of an ancient civilization in clay tablets written in a language unknown to him. The language of the rocks is that of the well-established laws of physics and chemistry. But this language too often fails the geochemist when it comes to reconstructing events that happened eons ago under conditions that cannot be duplicated in the laboratory. The high temperatures and pressures of the geological furnace are not the only obstacle; the ultimate barrier is time. Compounds that cannot be synthesized within months or years may very well form in the earth's crust after thousands or millions of years.

Nonetheless the discipline of geochemistry has arrived at a well-founded explanation of the major stages in the segregation of the metals in the crust. This segregation involves not only processes that occur deep in the earth, but also the interaction of the lithosphere (the earth's crust) with the hydrosphere (the oceans, lakes and rivers), the biosphere (the sphere of living things) and the atmosphere.

A crucial piece of evidence bearing upon the first stage in the geochemical history of the earth comes from yet another sphere: the cosmos around our planet. The meteorites that survive the plunge through the atmosphere are of two general kinds: stone and iron. Believed to be fragments of a disrupted planet, they strongly support the idea that the earth has a nickel-iron core surrounded by rocky material. Assuming that the earth was molten in the early stages of its history, it must have fit very well the analogy of an ore-smelting furnace; the heavier metals, eight to 10 times as dense as water, sank toward its center, and the lighter stony "slag," with an average density of 2.8, floated upward to form the mantle and the crust. The "first geochemical differentiation of matter" thus segregated most of the earth's metal forever beyond reach in the core.

The thin shell of the crust, to which the search for useful materials is necessarily restricted, is proportionately thinner than the peel of an orange. Yet even the deepest oil wells and mine shafts barely scratch it. Direct knowledge of the structure and constituents of the crust extends no deeper than 12 miles. Even that depth would seem to involve uncertainty and conjecture, since oil wells seldom reach down farther than four miles, and the deepest mine shafts go down no more than 7,000 feet. Here and there on the surface of the earth, however, the upheaval of rock from regions near the bottom of the crust, and the erosion of overlying formations, have exposed materials once deeply hidden.

From thousands of rock samples collected all over the globe during the past half-century geochemists have worked out a reliable picture of the relative



containing nickel and copper. The gaping hole in the center foreground was left after 225,000 tons of ore had been blasted and dropped to a level 600 feet below. The open-pit mine at right is near the Union Carbide Nuclear Company's uranium mill in Maybell, Colo. The uranium here is found in sedimentary formations of unconsolidated sandstone (*at bottom left and in background*).

abundance of the elements in the crust. The names of the eminent U. S. geochemists Frank W. Clarke and Henry S. Washington are particularly associated with that tedious pioneering task. The table of abundance [*see illustration on page 152*] readily explains the low density of the crust. The lighter elements oxygen, silicon and aluminum account for nearly 90 per cent of the crust's volume. All of the other elements together constitute a small admixture; they would be scarcely noticeable—some scarcely even detectable—if they did not occur in local concentrations.

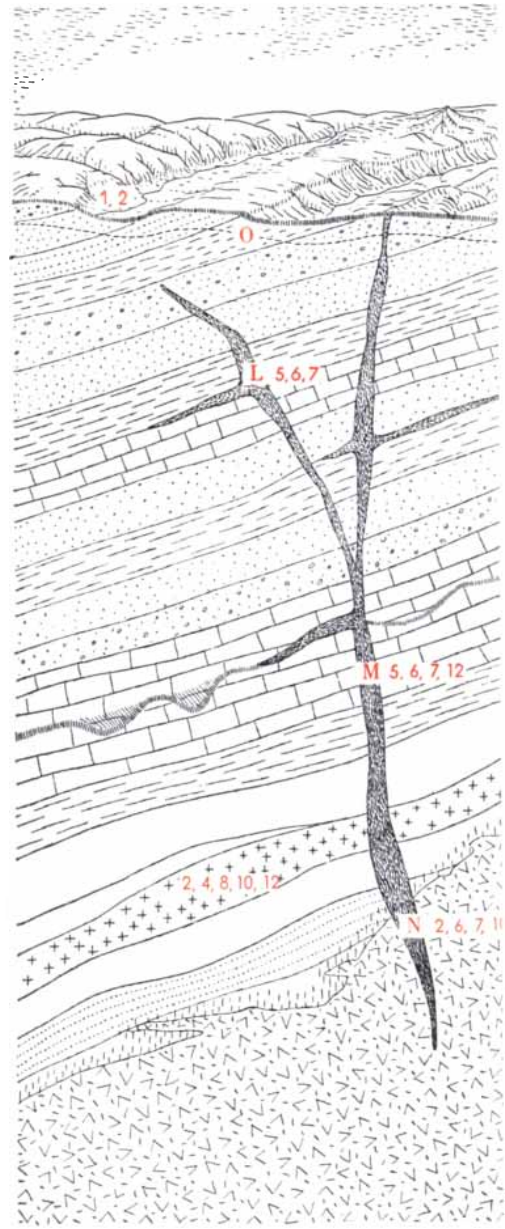
Before the crust cooled and consolidated, therefore, it was an inhomogeneous melt of silicon-oxygen compounds in which all of the other elements were thinly dispersed. Covering this melt, or magma, was a thin layer of solid material that served as a lid to contain the fluid material beneath and hold it under high temperature and pressure. In this pressurized furnace the elements in the crust entered into the "second geochemical differentiation."

The explanation of the origin of the ores begins with the manifold processes that attended this second differentiation. As Alan M. Bateman of Yale University has put it: "Magmas are the source of essentially all the ingredients of mineral deposits." From the state of low order prevailing at the outset in the melt, with the various elements randomly dispersed in solution, the atoms and molecules proceeded to sort themselves out and find appropriate partners in accord with their characteristic chemical affinities. Thus as the temperature of the magma dropped, its constituent elements formed stable compounds and entered the ordered solid state in the form of minerals of numerous varieties.

As every student of chemistry learns, the affinity of one element for another is not accidental but follows well-defined laws. Certain elements tend to combine with oxygen and form oxides; others to combine with sulfur and form sulfides, and so on. In minerals, moreover, combinations of three or more elements are not uncommon. Such affinities among the atoms of the various elements are of course dictated largely by the configuration of the electrons in their outer electron shells. The atoms of most elements have outer shells that have room for one, two or more electrons. Such elements combine most readily with elements that have a similar deficiency. Two or more atoms thus share their electron complements, and the shared electrons, circulating impartially in the outer shells of the atoms in the combination, bind them together. In the magma solution a great many of the elements are ionized; that is, they have lost one or more of their normal complement of electrons and so are positively charged, or they have picked up one or more electrons and are negatively charged. The electrical attraction of oppositely charged ions acts similarly to line up complementary partners and causes them to form equally powerful and stable bonds.

Differences in the size of atoms constitute another important factor governing the formation of compounds. The oxygen atom is relatively large, and the atoms of the heavier metals are small. Since oxygen accounts for more than 85 per cent of the volume of the crust, it is not surprising that the arrangement of the oxygen atoms in a mineral largely determines the arrangement of the metals and other elements it contains. The smaller metal atoms fit themselves into the interstices between the oxygens. Sulfur atoms, having a chemical nature closely resembling that of oxygen and an almost equally large size, form similar combinations with metal atoms. Thus as the atoms and ions join up with their partners in the cooling magma, they pack themselves together in a minimum of space, forming highly symmetrical, energetically stable crystal lattices.

The crystallization of the magma is a selective process. Compounds with high melting points solidify first. According to their density in comparison with the rest of the doughlike melt, they either sink to the bottom of the magma hearth, keep floating where they form or rise to the surface. Among these early magmatic minerals (primarily iron- and magnesium-rich silicates) the ores of certain metals have already formed. Most of these ores are heavier than the nonmetallic silicates, and they tend to segregate at the bottom of the magma hearth. The world's chromium deposits were largely formed in this way, the ore



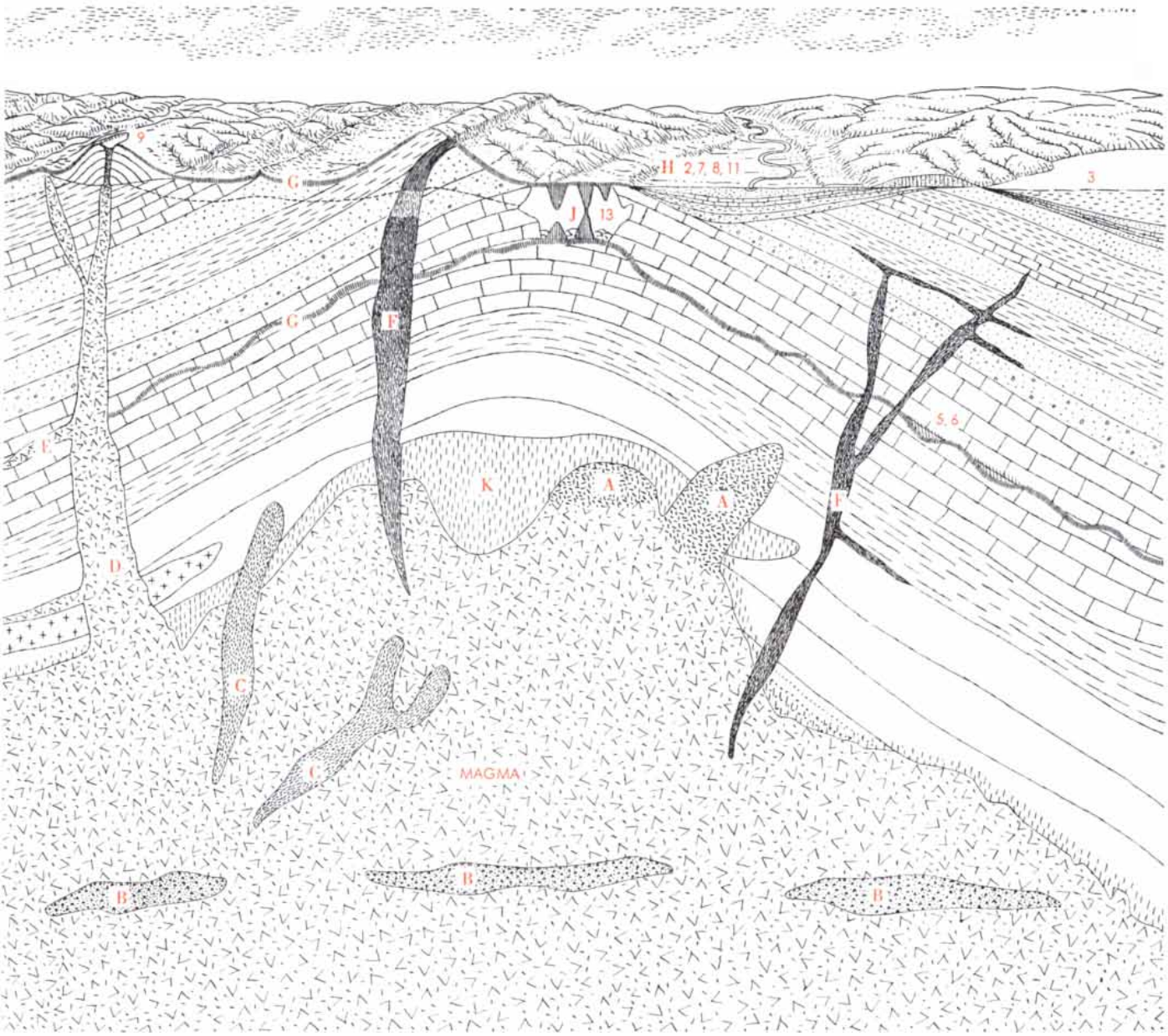
A PEGMATITE	1 ALUMINUM
B SEGREGATION	2 IRON
C INJECTION	3 MAGNESIUM
D DIKE	4 TITANIUM
E SILL	5 LEAD
F VEINS	6 ZINC
G WEATHERING	7 GOLD
H PLACERS	8 PLATINUM
J CAVES	9 SULFUR
K CONTACT METAMORPHISM	10 COPPER
L LOW-TEMPERATURE VEIN	11 TIN
M MEDIUM-TEMPERATURE VEIN	12 NICKEL
N HIGH-TEMPERATURE VEIN	13 LIMESTONE
O WATER TABLE	

TYPES OF ORE DEPOSIT, the metals they contain and several rock structures are represented schematically and are keyed to the table at left. Segregation deposits (B) form under high temperature and pressure, sinking slowly to the bottom of the magma. Injection deposits (C) form when sudden pressures cause the magmatic minerals to solidify rapidly, often forcing them into already solidified rock. The formation of pegmatites (A) begins at temperatures of 600 degrees centigrade or less. Contact metamorphism (K) is

being chromite, a heavy oxide of chromium and iron.

Though such simple segregation accounts for the origin of some deposits of early magmatic origin, the formation of others is more complicated [*see illustration below*]. If, for example, the droplets or crystals of a heavy mineral are not allowed to settle to the bottom of the magma, a process that takes thousands of years, but instead are forced by pressure into simultaneously hardening regions of rock, they form what is called an injection. Sometimes the rock has already solidified when such injections take place, but there are always fissures into which the mineral can be squeezed. The resulting deposits are therefore more dispersed than those formed by simple segregation. As a result more of the work of mining is concerned with the blasting and removal of the rock through which the mineral is scattered than with the recovery of the mineral itself [*see photograph on page 146 and bottom illustrations on next page*]. Despite these difficulties some of the world's richest ore-deposits belong to this type.

The nickel-copper deposits of Sudbury in the Canadian province of Ontario are the largest known concentration not only of nickel but also of platinum and platinum metals (*i.e.*, palladium, osmium, iridium, ruthenium and rhodium). Ingenious modern techniques have made possible the extraction of 14 different elements from the Sudbury ores. Another example is the famous magnetite deposit of Kiruna in Swedish Lapland,

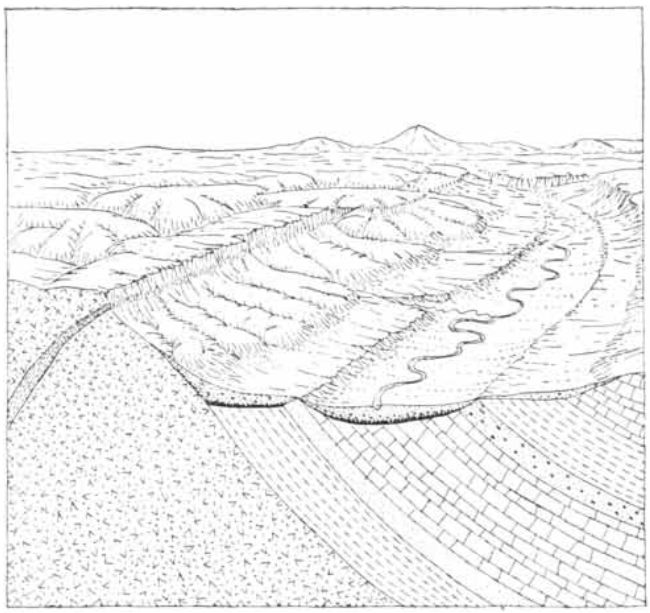


the interaction between magmatic material and the rock layers above it. Undifferentiated magma may also be forced into fissures in the crust to form dikes (D) and sills (E). Fluids and gases escaping toward the surface deposit various minerals and metals in veins (F). Depending on the temperature, three kinds of vein are formed (L, M, N). The two wavy hatched zones (G) indicate levels at which weathering effects form ore concentrations. Those at the surface are placer deposits (H). Lower down, weather solutions have descended from surface to interact with rock and mineral formations. Under varying conditions this interaction results in cementation zones (deposits of such metals as lead, zinc and copper). Two deposits of lead and zinc are at right (5, 6).

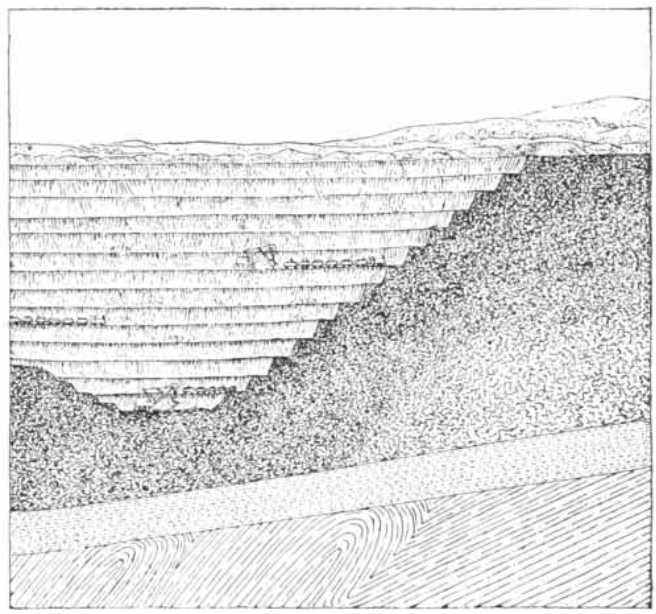
well above the Arctic Circle. Magnetite is an iron oxide with an iron content of up to 70 per cent. Smaller Swedish and Norwegian deposits, also of early magmatic origin, contain considerable amounts of titanium in addition to iron.

As the temperature of the magma falls and solidification continues, the more common silicate rocks are formed. Since this cycle of crystallization involves only a few elements, its products are not nearly so various and interesting as those that form in the solidification of the remaining part of the melt. The last of the crustal magma to crystallize is strongly enriched with gases and also contains many metals that have not formed compounds earlier, either because of their unsuitable atomic size or their abnormal energy states. When the magma reaches a temperature of about 600 degrees centigrade, there begins to form a group of rocks that are known to geologists as pegmatites. Pegmatites yield a large variety of colorful and well-crystallized minerals and a number of economically important ores. High-quality gem stones and most of the crystal specimens exhibited in museums come from pegmatites. The metals obtained from pegmatite ores include uranium, tungsten, molybdenum and tantalum.

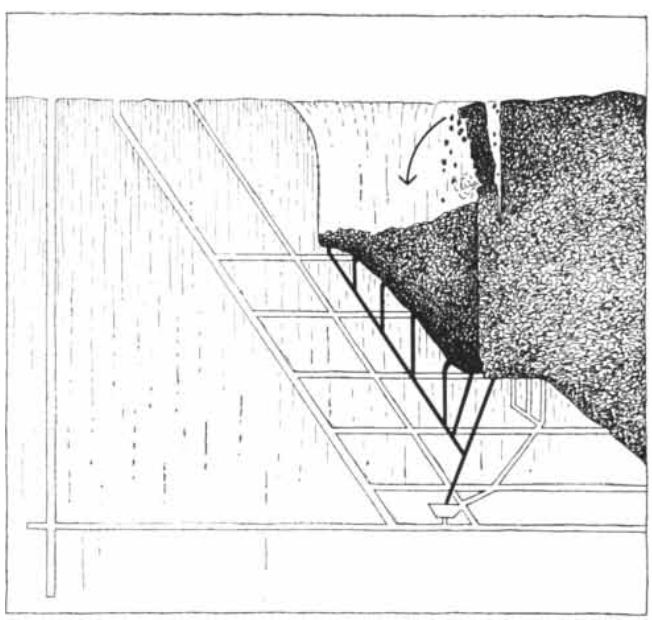
Though pegmatites represent the last



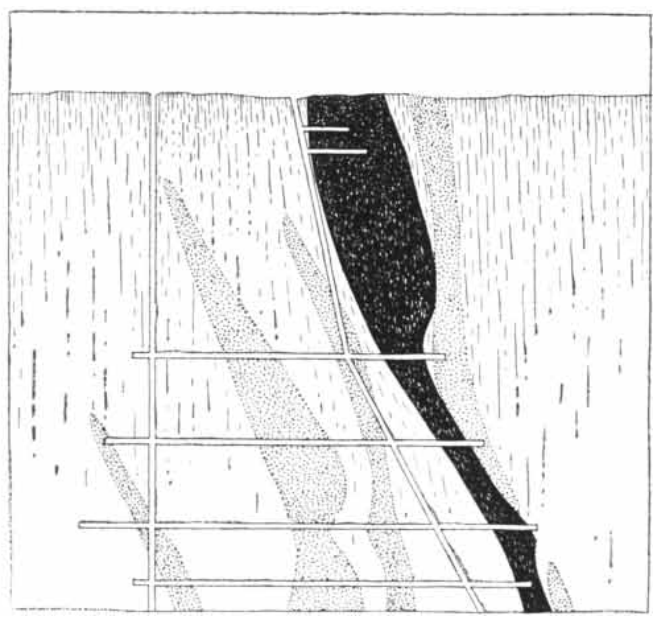
WEATHERING FORCES carry ore particles from an exposed vein (*at left*) down to a river, forming placer deposits (*stippled areas*). Heavier particles are deposited first on slope below vein. Lighter particles are deposited nearer river and on its opposite side.



OPEN-PIT MINING METHODS are used in huge sedimentary iron-deposits of the type found north of Lake Huron. Below the ore body (*dark area*) is a sloping layer of pokegama quartzite. The lowest layer consists of slate and conglomerate rock formations.



INDUCED CAVING METHOD of mining low-grade ore is depicted schematically. The ore (*dark area*) is dynamited into the pit (*arrow*) and transported down special shafts (*thick dark lines*) to an ore crusher. It is then carried to the surface for processing.



NICKEL-COPPER ORE-BODY representative of the injection deposits in Sudbury, Ontario, is vein-mined at levels where open-pit and induced-caving methods cannot be used. Stippled areas represent greenstone, a characteristic host rock of the district.

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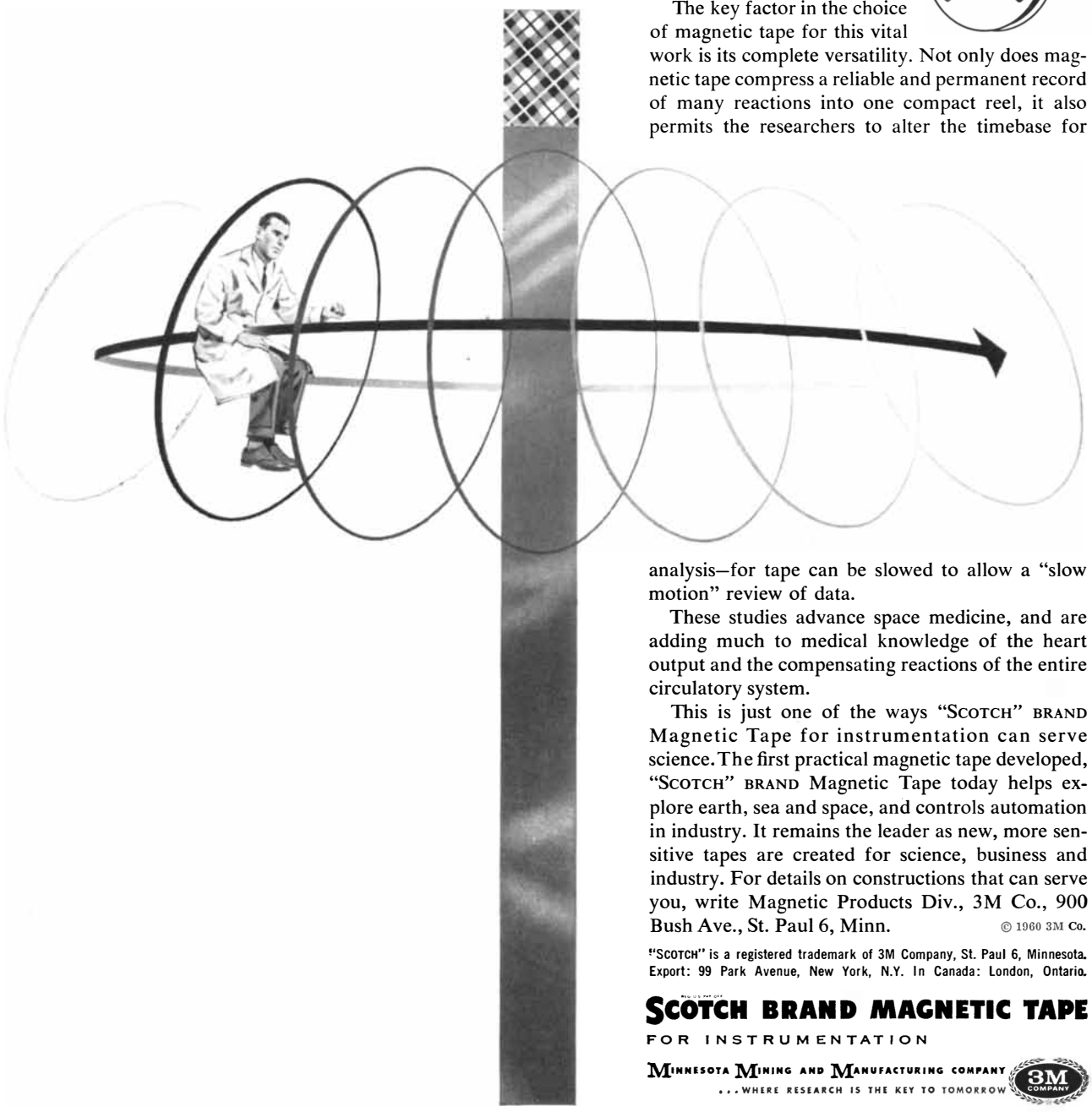
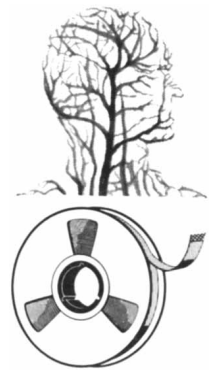


THE MODERN-DAY DERVISH takes his whirl mechanically — in a 34-ft. human centrifuge — and tape records all his reactions. In current medical experiments, the scientist is whirled at high speed until centrifugal force subjects his body to a crushing burden equal to 4 normal gravities.



To keep an accurate, permanent record of the subject's reactions to his terrible ride, the physiologists employ magnetic tape. Sensitive pickups are taped, clipped and even inserted in the subject's circulatory system. All these data, recorded automatically during the test on magnetic tape, are later reduced by analog computer for analysis.

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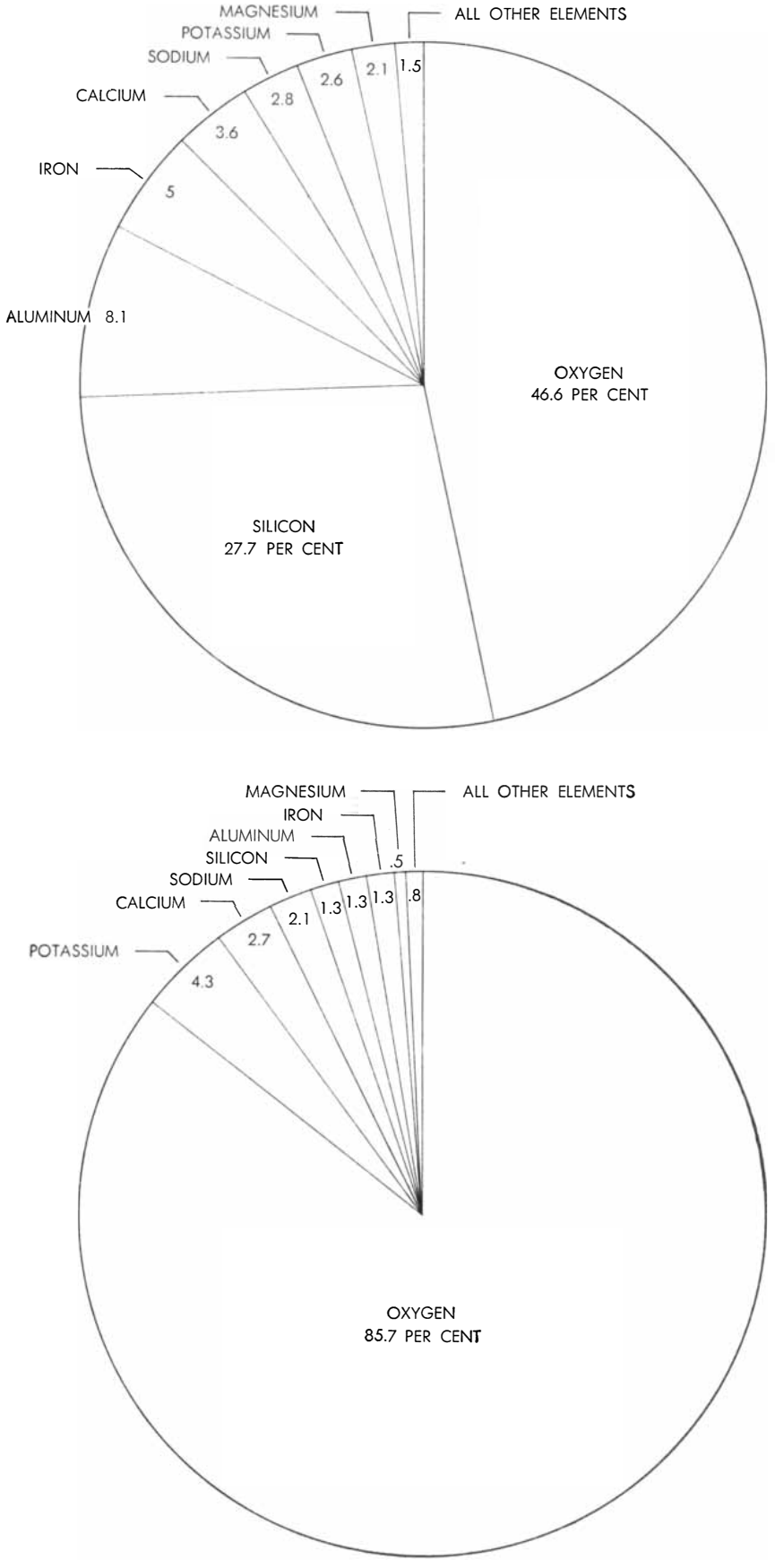

COMPOSITION OF THE CRUST in weight (*top*) and volume (*bottom*) shows predominance of lighter elements, of which iron alone has an atomic weight above 40. Oxygen and silicon constitute 75 per cent of the crust's weight and 87 per cent of its volume.

stage in magmatic crystallization, the activity of the magma hearth is not yet finished. Gases, vapors, fumes and fluids rise slowly toward the surface, carrying with them large quantities of metals, including most of the common industrial metals such as lead, zinc and copper. They remain in the magma as overheated solutions or gases, because they tend to form soluble or volatile compounds. When such gases and fluids reach cooler environments or come into contact with water descending from the surface (forming hydrothermal, or hot-water, solutions), they deposit in the fissures and cracks of the rocks surrounding the magma proper. At first these solutions are still very hot and under high pressure, but as they continue to move away from the magma, the temperature and pressure gradually decrease until finally surface conditions are reached. During each step of this slow process of pressure-reduction and temperature-decline various groups of ores are formed. Each ore deposit goes through its characteristic genesis; not only does the composition of the escaping fluids and gases vary from magma to magma, but the rocks they penetrate also differ, causing numerous complicated reactions between the rocks and the hot mineral solutions.

The majority of ore deposits presently worth mining are of this type, though they hardly form massive ore-bodies. They appear chiefly as veins, branching off in many directions, richer in ore content here and thinning out there. The mining of these deposits becomes an increasingly complex and extended operation, as it often does in injection deposits. Among the metals to be found in veins (in addition to lead, zinc and copper) are gold, silver, cobalt, arsenic, antimony, bismuth and mercury. The metals that are segregated in earlier magmatic processes also emerge at this stage, showing that some metals are not limited to one kind of differentiation process. Uranium, for example, appears in the pitchblende deposits at Great Bear Lake in the Northwest Territories of Canada. Pitchblende is hydrothermal in origin. Prospectors frequently find vein deposits of iron (which seems to be the most versatile metal in this respect), nickel, molybdenum, platinum and platinum metals.

The story told so far has led from the extremes of pressure and temperature in the magma to conditions typical of the surface of the earth's crust. However, not all ore deposits are of magmatic and hydrothermal origin. At the surface

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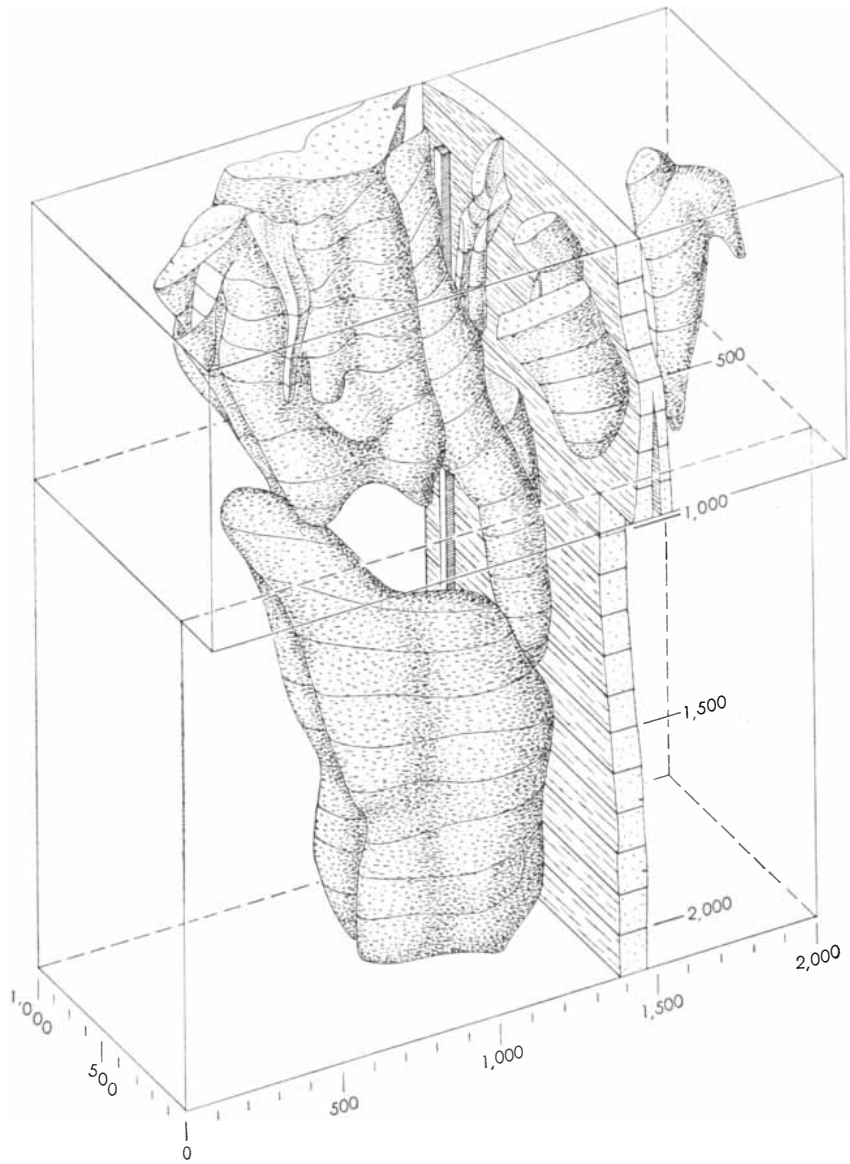
the forces of the hydrosphere and atmosphere come into play. The continuous action of rain, wind, ice, varying temperatures and other agents gradually breaks down exposed rocks and minerals that have been formed in the depths of the magma. Under intensive weathering the silicates of magmatic rock gradually dissolve, and the insoluble single grains of the crumbled material are transported over wide areas. If these grains resist decomposition, they are eventually redeposited, the time required for redeposition depending primarily on the specific gravity of the particular minerals.

Many magmatic ores are by nature heavy and resistant to decomposition. When a rock complex, for example a mountain, containing these ores begins to weather, the heavy minerals tend to accumulate as loose, rounded particles in rivers and streams, which act as transportation lines. In the course of time the river changes its course or dries up, and its bed is covered with other sediments, which protect the redeposited ores from further weathering. These so-called placer deposits of ores and even of pure metals offer easy mining conditions once they have been discovered. Gold and platinum, owing to their reluctance to enter into chemical combination and their high resistance to almost all chemical agents, appear in placer deposits in uncombined form. Metals such as tin, iron, titanium, zirconium, chromium, uranium and thorium (the last of growing importance as a fissionable material in nuclear reactors) show similar resistance in their compounds, mainly oxides.

Where the effects of weathering are more chemical than mechanical, some metallic compounds dissolve in the weathering solutions. Under highly favorable conditions they will recombine with other elements and precipitate out of the solution, forming extended sedimentary deposits. Again, such processes have produced significant deposits of iron and uranium, as well as deposits of manganese and of bauxite, the most important source of aluminum. The Mesabi Range in Minnesota, which is surface-mined by power shovel and has supplied the industrial civilization of the U. S. with most of its iron, was originally formed as a sediment. In later geologic periods pressure and strain turned these soft sedimentary formations into a flint-like ore with an iron content of between 50 and 60 per cent. The unique deposits of the uranium-vanadium mineral carnotite on the Colorado Plateau, the main source of uranium in the U. S., are considered by one group of investigators to be of sedimentary origin, though other workers believe that they were deposited by circulating ground waters in which the water-soluble uranium compounds had been dissolved.

There remains the role of the biosphere in the genesis of ores. Plants take up minerals from the soil in which they grow, and animals ingest the minerals in plants. Some of the minerals return to the soil, and others are stored by the organisms that originally ingested them. If biological conditions favor the existence of certain species of organic "concentrators" over a long enough period, important mineral deposits may result. Omnipresent iron crops up here too. In a complicated series of reactions with bacteria in the soil and later with surrounding plant life, iron is deposited as bog-iron, or iron-pan. Vanadium, best known as a component of vanadium steels, is in many of its deposits believed to be of organic origin. In Peru, for example, where one of the largest known deposits is found, the vanadium is associated with asphalt. Some deposits of coal and crude oil have a remarkably high content of vanadium. Where vanadium occurs in this way, it is classified with coal and oil as having an organic origin. Moreover, certain bacteria and marine organisms are known to concentrate this element.

Though the ore-segregation processes described here occurred long ago, and



MASSIVE SULFIDE-ORE BODIES in the Horne Mine of Noranda in Quebec are shown in three-dimensional projection. The deposits were formed by numerous reactions between minerals and surrounding rock. The thin vertical formation is a "dike" of undifferentiated magmatic material. To the left of the dike is a mine shaft. All dimensions are in feet.

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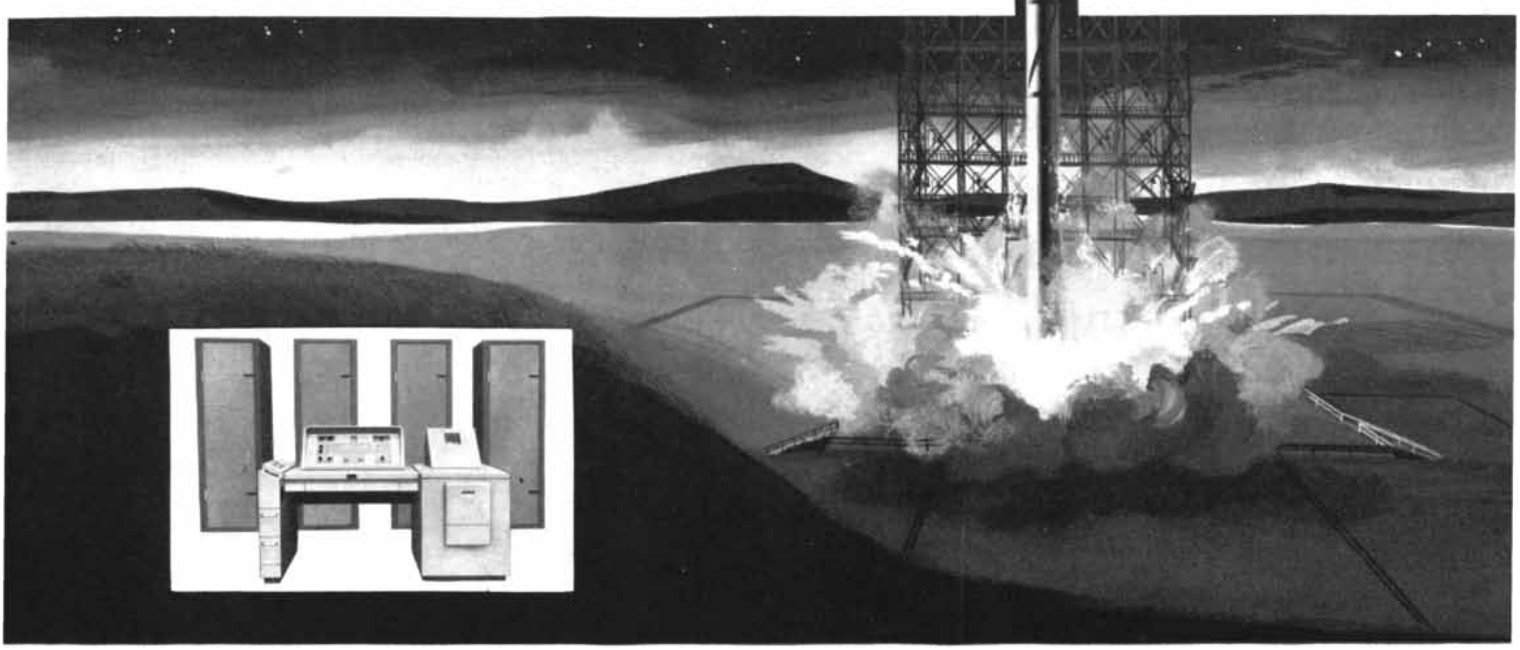
APCHE

(Pronounced "AP-SHE")



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

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

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though few of them can be re-enacted in the laboratory, the geochemist can advance them with confidence in explaining the origin of the ores. Experimental studies have established the equilibrium conditions for thousands of compounds observed in nature. The results match the observations of petrologists, those workers who study rocks and their mineral content and who try to evaluate the history of their formation. Crystallography has shown why certain minerals behave as they do, and what laws determine the formation of their crystal structures.

Only recently man himself has taken his place among the agents of nature that synthesize mineral compounds. One mineral hitherto synthesized only by nature has been crystallized in the laboratory; it is diamond. Using temperatures in the range of 2,500 degrees C. and pressures of 1.5 million pounds per square inch, workers of the General Electric Company have succeeded in making diamonds fundamentally identical with those found in nature [see "Synthetic Diamonds," by P. W. Bridgman; SCIENTIFIC AMERICAN, November, 1955]. They have also produced other minerals thought to originate in the same way as diamond, indicating that natural conditions had been successfully approximated. The same techniques have been employed to synthesize crystallized substances not found in nature, including borazon, which is harder than diamond [see "Ultrahigh Pressures," by H. Tracy Hall; SCIENTIFIC AMERICAN, November, 1959].

Many riddles remain unsolved, but geochemistry is a comparatively young discipline. It is one of those modern branches of science that draws heavily on the results of neighboring disciplines and grows with them. But the problems are clearly defined. Believing that these problems can be solved, the geochemist works toward a greater knowledge of the earth as a whole. The practical uses of this effort are apparent. Better understanding of the origin of the ores also teaches important lessons about the availability of ores. Man should no longer regard the earth's resources as inexhaustible, but rather as a store from which to take with care the irreplaceable gifts of nature. The understanding gained by geochemistry has still further significance: The biography of the earth, revealed in increasing detail, reflects processes at work elsewhere in the cosmos, especially in the evolution of the planetary systems of stars other than the sun.

SPACE PROBE: A program at Martin where teams of engineers work to get greater payloads farther into space. Data from these probes is making Martin the foremost Company in advancing the "state of the art." To advance yourself professionally, you should become a member of one of these teams. Write to N. M. Pagan (Dept. G-13), The Martin Company, Box 179, Denver 1, Colo.

MARTIN
DENVER

BORG-WARNER'S BETTER LIVING KITCHEN FOR 1960. Norge's new Never-Frost refrigerator ends the nuisance of defrosting forever—even in the freezer section. In Norge's built-in wall oven, you can broil and bake at the same time. The cook is always in command with the Custom Control Panel of the Norge counter-top range. Brightening this workaday world is color—coordinated, too, in the spacious Ingersoll-Humphryes sink. And a York air conditioner and KoolShade sun screens keep the kitchen comfortable, 'round the clock and 'round the calendar.

VING

BY BORG-WARNER

A report on the far-reaching ways in which a dynamic corporation helps enrich the lives of millions

The modern refrigerator has made a museum piece out of the old-fashioned icebox. Heating a home once involved manual labor, now requires only the touch of a thermostat. Gone are legs on bathtubs. Hand fans of yesteryear have given way to the fingertip-controlled air conditioner. And down are many clotheslines—replaced by automatic dryers.

Who wrought the revolution? The divisions and subsidiary companies of Borg-Warner Corporation helped importantly by developing new and better home equipment.

The Norge refrigerator was *first* with adjustable swing-out shelves—*first* with an automatic ice cube maker, in both gas and electric models. The *first* successful home air conditioner went down in history with the York name on it (1935)—leadership evident today in York's new Heat Pump that warms and cools by using only outside air and electricity. The three newest ideas in residential plumbing fixtures are *all* products of the Ingersoll-Humphryes Division. The *original* multiple-layer aluminum foil insulation is Alfol, and the *original* solar screening is KoolShade—both products of Reflectal Corporation, a B-W subsidiary.

Rest on laurels? Never. At the Roy C. Ingersoll Research Center in suburban Chicago, Borg-Warner is forever designing, testing, analyzing—creating equipment destined for homes of the future.

The 7 Hats of Borg-Warner . . . (top) national defense; oil, steel and chemicals; (middle row) agriculture; industrial machinery; aviation; (bottom) the automotive industry; home equipment.

BORG-WARNER

It's a better product when Borg-Warner makes it

Borg-Warner Corporation • 200 South Michigan Avenue • Chicago 4, Illinois

COLOR MAGNIFICENCE is yours in B-W's Ingersoll-Humphryes cast iron, steel and china residential plumbing fixtures. Available in six pastels, including three 1960 House & Garden Magazine selections, plus white.

A SINGLE OPERATION washes, rinses, fluff-dries in Norge's gas or electric Washer-Dryer Combination (also washes or dries separately). One setting washes synthetics safely; another gets denims perfectly clean.

A MIDSUMMER NIGHT'S REST is assured in a bedroom cooled by "library quiet" York air conditioning, install-it-yourself window model or central system. Dial choice of comfort level; York maintains it automatically.

LIFT FOR LIFE. York Comfort Center heats and humidifies in winter, cools and dehumidifies in summer—purifying air electronically. Two flames of gas-fired furnace heat more efficiently than one—yet do not use more fuel.

SUMMER COMFORT: KoolShade sunscreen by B-W's Reflectal Corporation blocks sun's hottest rays (note contrast where door is open!), keeps porch, house up to 15% cooler, glare-free—yet permits complete visibility.

BUILDING OR REMODELING? Reflectal's Alfol Aluminum Foil Insulation is clean to work with, easy to install. Reflects summer heat out, makes homes 15° cooler—reflects winter heat in, cuts fuel bills as much as 35%.

Also serving homeowners is the B-W Acceptance Corporation, with offices in principal cities, which finances appliance purchases to suit your budget.

WHAT BORG-WARNER MEANS TO YOU!

Many Borg-Warner products contribute essentially to your well-being. The preservation and preparation of food, for example. Others add immeasurably to comfort and security, like heating and cooling of your home. Still others, such as automatic washers and dryers, free the homemaker for more happy moments with her family. A state of well-being, an air of security, an atmosphere of happiness—these, then, are the "by-products" of products made for the home by Borg-Warner.

JIM SMITH IS BUILDING YOUR 1970 CAR

Pressed for a prediction, Jim Smith says you may be driving an "all-aluminum car" by the mid-70's. It's one of the things Alcoa's Development Division is working on, hand in glove with Detroit, from power plant to chassis and body. Take aluminum engines — Jim and the 49-man crew in the Development Division's automotive laboratories helped put them on the road. They laid the groundwork for a workable rocker arm . . . explored ways to let pistons and rings run directly on aluminum cylinder walls . . . confirmed previous conclusions that the aluminum engine can use lower octane fuel than cast-iron engines. Credit them, too, for a key assist in developing the aluminum radiators, bumpers, transmission housings and combination hub-wheel-brake drums in use on famous-name cars and trucks.

Like Jim Smith, 93 other Development Division engineers and designers share their aluminum knowledge with manufacturers of a wide variety of new consumer, military and industrial goods — diesel engines, compressors, missiles, army tanks, farm equipment, portable power tools, appliances and scores more. It's a service unmatched by any other light metals company and it's yours to call on — one more added value we put into every pound of Alcoa® Aluminum you buy. Aluminum Company of America, 2019-F Alcoa Building, Pittsburgh 19, Pa.

ALCOA ALUMINUM

helps you design it, make it, sell it

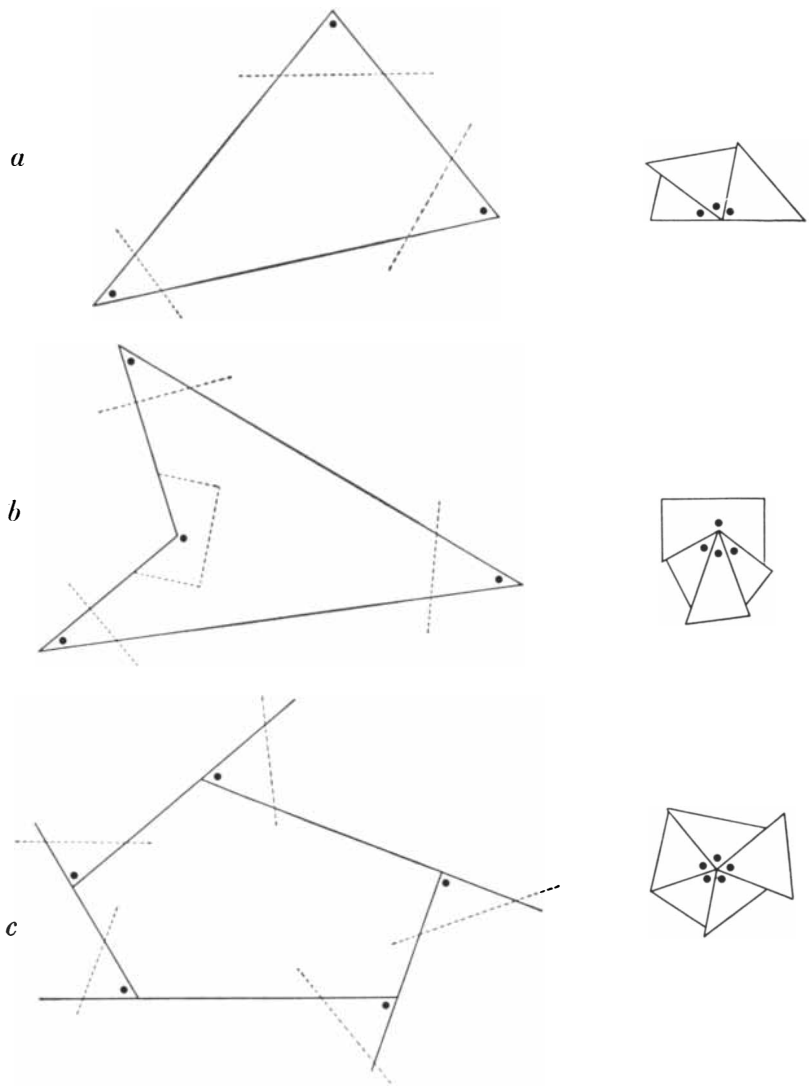
MATHEMATICAL GAMES

Recreations involving folding and cutting sheets of paper

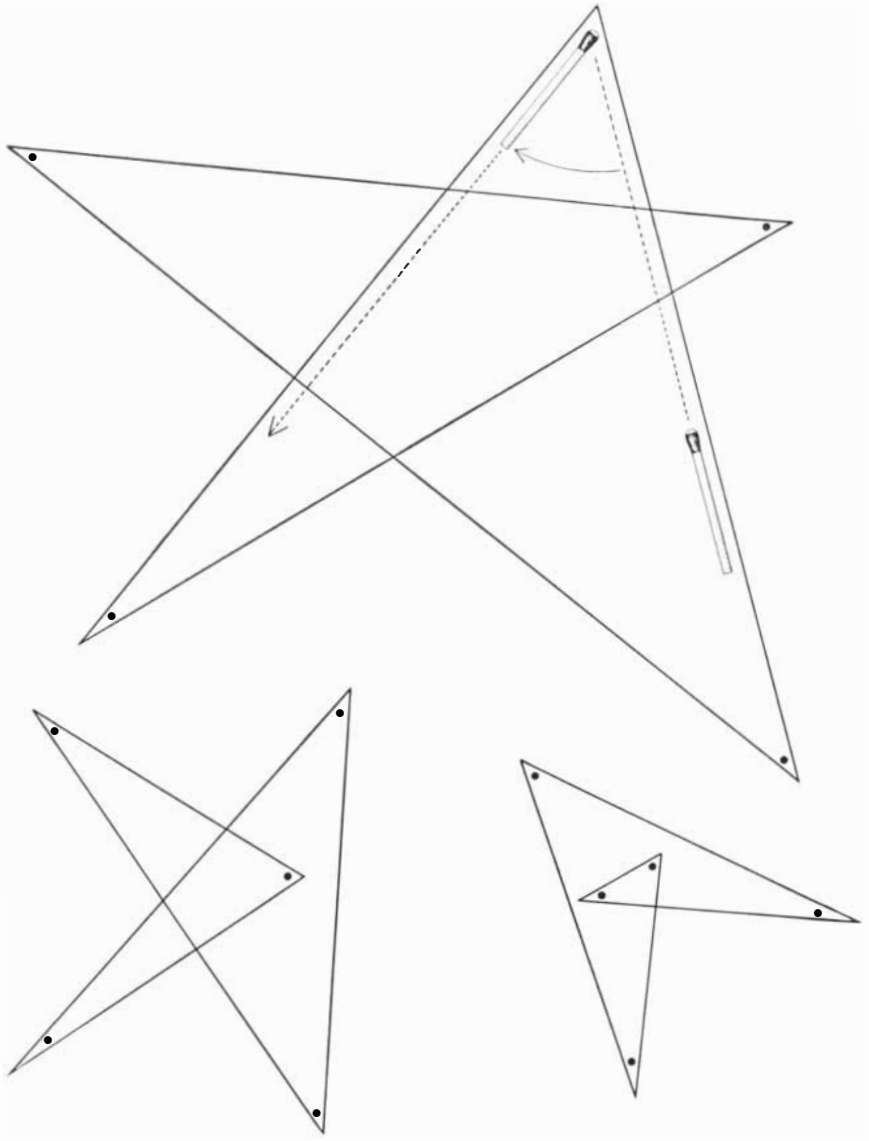
by Martin Gardner

In this department for last July I discussed a number of recreations that involve folding sheets of paper without cutting them. When a pair of scissors is brought into play, a wealth of interesting new possibilities open up, many of which serve to dramatize basic and important theorems of plane geometry in curious ways.

For example, consider the well-known theorem which states that the sum of the interior angles of any triangle is a straight angle (an angle of 180 degrees). Cut a triangle from a sheet of paper. Put a dot near the vertex of each angle, snip off the corners, and you will find that the three dotted angles always fit together neatly to form a straight angle [*see illustration "a" below*]. Try it with



How to discover theorems of plane geometry by cutting polygons



Sliding a match around pentagrams shows that the dotted angles add up to 180 degrees

the corners of a quadrilateral. The figure may be of any shape, including concave forms such as the one shown in illustration *b* on the preceding page. The four snipped angles always join to form a perigon: an angle of 360 degrees. If we extend the sides of any convex polygon as shown in illustration *c*, the dotted angles are called exterior angles. Regardless of how many sides the polygon may have, if its exterior angles are cut out and joined, they also will add up to 360 degrees.

If two or more sides of a polygon intersect, we have what is sometimes called a crossed polygon. The five-pointed star or pentagram, the fraternal symbol of the ancient Pythagoreans, is a familiar example. Rule the star as irregularly as you please (you may even include the degenerate forms shown in the illustration above, in which one or two points of the star fail to extend beyond the body), dot the five corners, cut out the star and trim off the corners. You may be surprised to find that, as in the case of the triangle, the points of any pentagram join to form a straight angle. This theorem can be confirmed by another quaint empirical technique that might be called the sliding-match method. Draw a large pentagram, then place a match alongside one of the lines as shown in the top illustration above. Slide the match up until its head touches the top vertex, then swing its tail to the left until the match is alongside the other line. The match has now altered its orientation on the plane by an angle equal to the angle at the top corner of the star. Slide the match down to the next corner and do the same thing. Continue sliding the match around the star, repeating this procedure at each vertex. When the

Structural imperfections, represented by this dislocation network in thin tantalum foil, determine the properties of a superconductor (electron transmission; 64,000x).

Superconductivity in Metals and Alloys

Superconductivity—the absence of electrical resistance at very low temperatures—is one of the most challenging of physical phenomena. Its appeal is almost universal; its application seems almost unlimited.

It has been suggested for use in frictionless bearings, motors, amplifiers, electromagnets, gyroscopes and electron-beam apparatus. IBM is concerned with still another possibility: the application of superconductivity to computer devices.

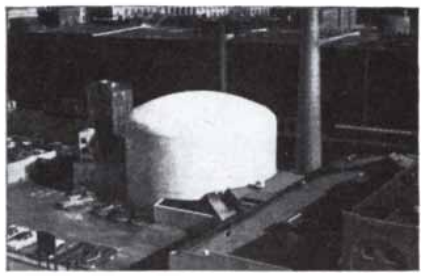
Scientists at IBM Research have demonstrated, with a thin-film superconducting device capable of switching in a few millimicroseconds, that computers of the future may be limited in their operating speeds only by the speed of light. Whether or not a metal is a superconductor depends on many things: its structure, its valence, and the presence and position of alien atoms, missing atoms or electrons. The operation of superconducting devices depends upon the fact that a magnetic field will drive a superconductor into the normal (resistive) state.

A superconductor placed in a magnetic field develops a surface current which shields out any external magnetic field to a characteristic penetration depth. Since this penetration depth is comparable to the film thickness used in making superconducting devices, the penetration depth is an important property.

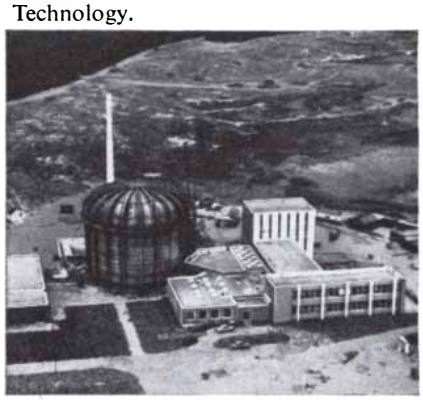
Superconducting alloys, with their inherent normal-state resistivity, offer promise for superior devices. Alloying can change the penetration depth, the electron density, and the ease by which a superconductor can be switched from one state to another.

Work is under way to outline the part played by impurities and structural defects in determining superconductivity. This work has already shown that microscopic homogeneity is a prerequisite of well-defined superconductive behavior. From such work may come devices that will make it possible to operate miniature computers at extremely high speeds.

Some of the Allis-Chalmers nuclear projects around the world

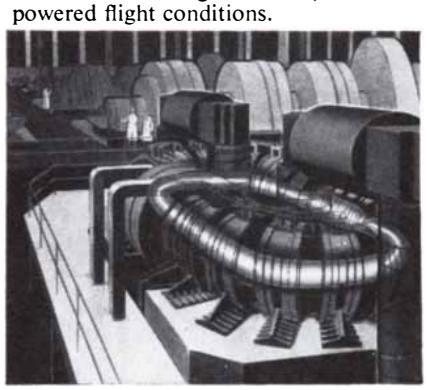


MASSACHUSETTS: 1,000-kw research reactor for Massachusetts Institute of Technology.



HOLLAND: 20,000-kw research and materials-testing reactor for Reactor Centrum Nederland.

OHIO: 10,000-kw reactor helps Air Force simulate high-altitude, nuclear-powered flight conditions.



NEW JERSEY: Princeton University scientists, researching thermonuclear fusion, will use a full-scale Stellarator facility engineered and equipped by Allis-Chalmers and Radio Corporation of America.

Allis-Chalmers speeds world-wide progress in nuclear power

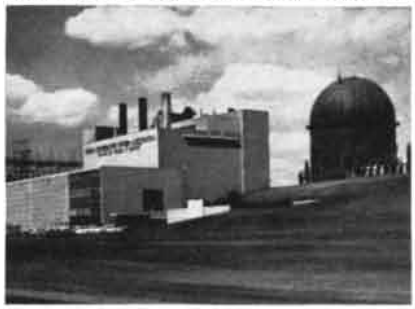
Helping provide power for a growing world has been part of the corporate way of life at Allis-Chalmers for more than a century. Power . . . from coal, oil, gas, falling water . . . and now, *atomic energy*. Pictured here is evidence that Allis-Chalmers is growing dynamically in this challenging field, offering unique capability to take nuclear projects all the way from "talk about" to "start up." Allis-Chalmers, Milwaukee 1, Wisconsin.

ALLIS-CHALMERS

POWER **FOR A GROWING WORLD**

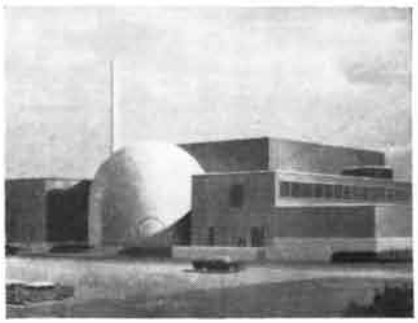
Some of the Allis-Chalmers nuclear projects around the world

ITALY: 5,000-kw reactor for Italian National Committee for Nuclear Research.



MINNESOTA: 22,000-kwe power reactor for Rural Cooperative Power Association of Elk River.

SWEDEN: New 30,000-kw research and materials-testing reactor for Atomic Energy Company of Stockholm.



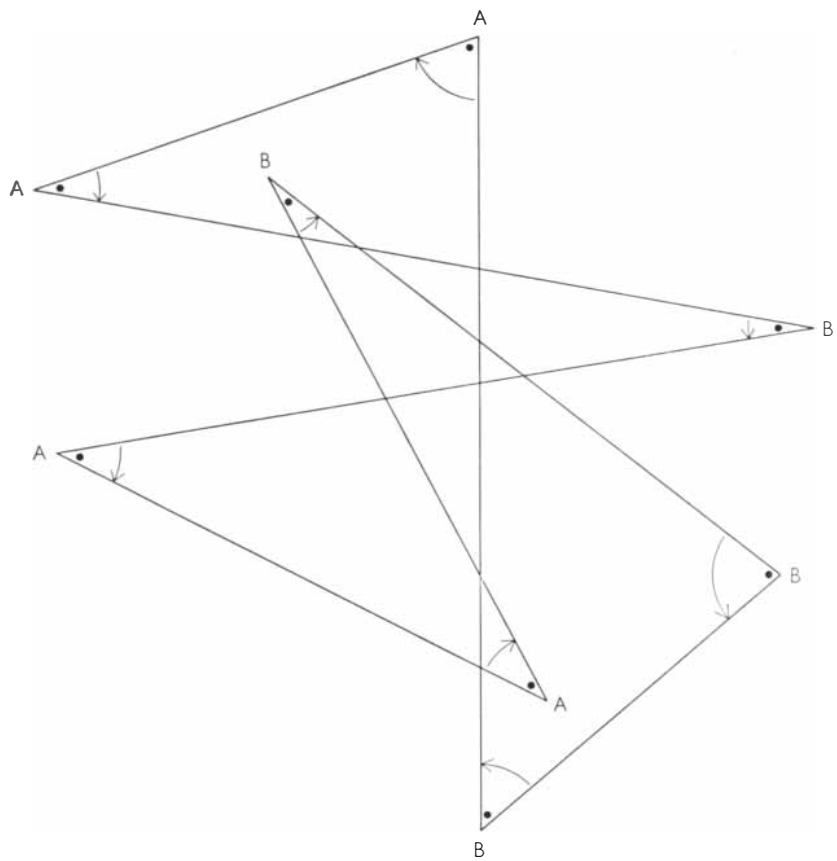
SOUTH DAKOTA: Architect's drawing of 66,000-kwe nuclear power plant with internal nuclear super-heat, now being designed for Northern States Power Company in cooperation with ten other midwest electric utilities.

match is back to its original position, it will be upside down, having made a clockwise rotation of exactly 180 degrees. This rotation is clearly the sum of the pentagram's five angles.

The sliding-match method can be used for confirming all of the theorems mentioned, as well as for finding new ones. It is a handy device for measuring the angles of any type of polygon, including the star forms and the helter-skelter crossed varieties. Since the match must return to its starting position either pointing the same way or in the opposite direction, it follows (providing the match has always rotated in the same direction) that the sum of the traversed angles must be a multiple of a straight angle. If the match rotates in both directions during its trip, as is often the case with crossed polygons, we cannot obtain a sum of the angles, although other theorems can be stated. For instance, a match slid around the perimeter of the crossed octagon in the illustration below will rotate clockwise at the angles marked A, and the same distance counterclockwise at the angles marked B. Thus we cannot arrive at the sum of the eight angles, but we can say that the sum of the four A angles equals the sum of the four B angles. This can be easily verified by the scissors method or by a formal geometrical proof.

The familiar Pythagorean theorem lends itself to many elegant scissors-and-paper demonstrations. Here is a remarkable one discovered in the 19th century by Henry Perigal, a London stockbroker and amateur astronomer. Construct squares on the two legs of any right triangle [*see illustration on page 166*]. Divide the larger square (or either square if they are the same size) into four identical parts by ruling two lines through the center, at right angles to each other and with one line parallel to the triangle's hypotenuse. Cut out the four parts and the smaller square. You will find that all five pieces can be shifted in position, without changing their orientation on the plane, to form one large square (shown by broken lines) on the hypotenuse.

Perigal discovered this dissection in about 1830, but did not publish it until 1873. He was so delighted with it that he had the diagram printed on his business card, and gave away hundreds of puzzles consisting of the five pieces. (Someone who has not seen the diagram will have considerable difficulty fitting the pieces together, first to make two squares, then one large square.) It is

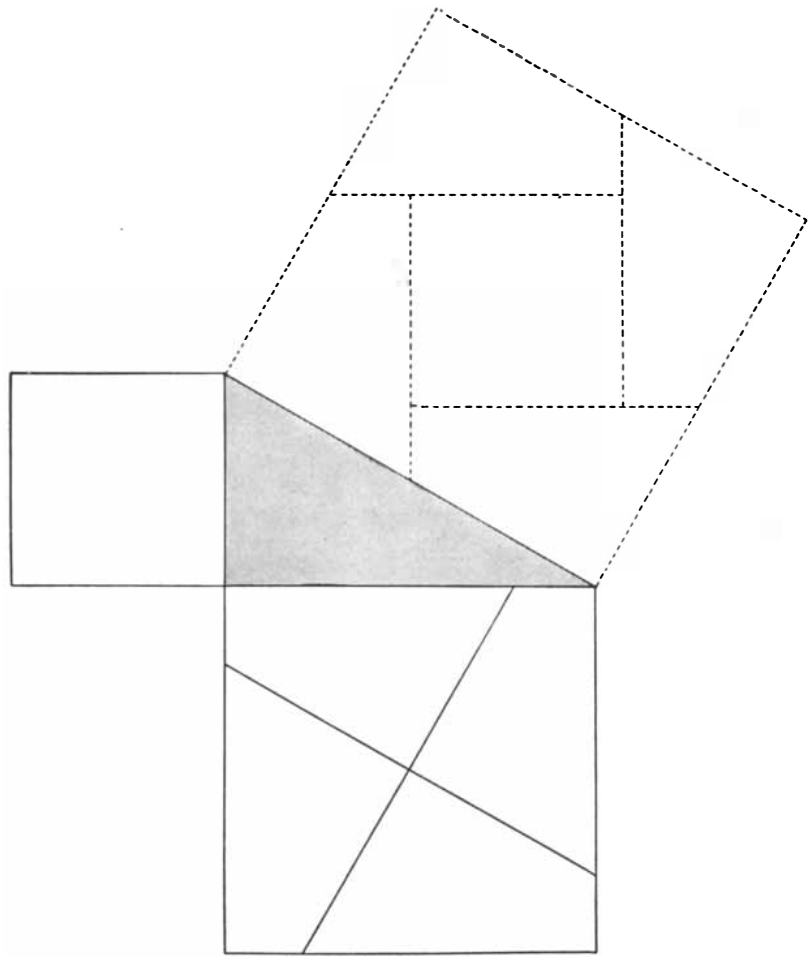


On this crossed octagon the sum of the angles marked A *equals the sum of those marked* B

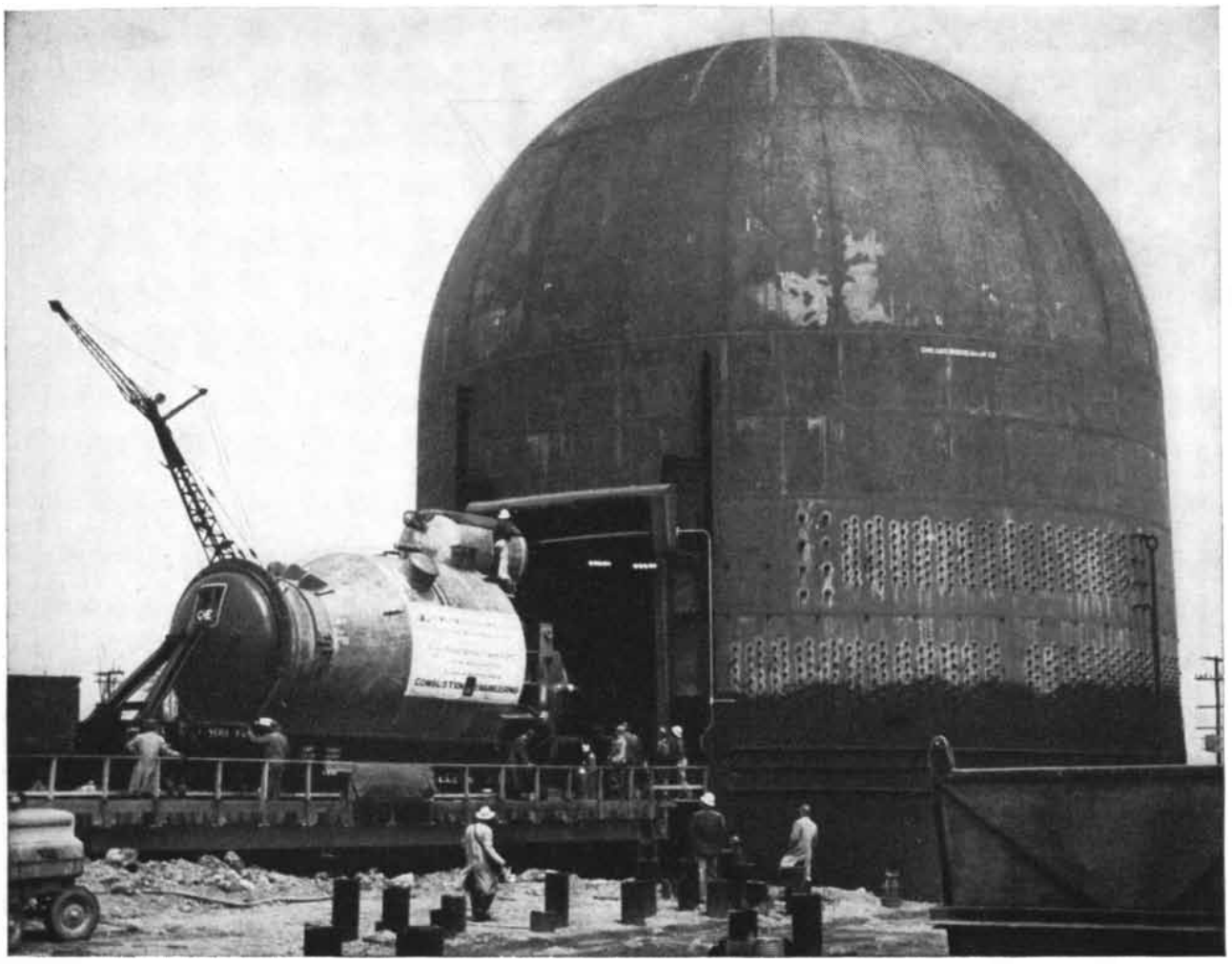
interesting to learn from Perigal's obituary, in the 1899 notices of the Royal Astronomical Society of London, that his "main astronomical aim in life" was to convince others, "especially young men not hardened in the opposite belief," that it was a grave misuse of words to say that the moon "rotates" as it revolves around the earth. He wrote pamphlets, built models and even composed poems to prove his point, "bearing with heroic cheerfulness the continual disappointment of finding none of them of any avail."

The dissection of polygons into pieces that form other polygons is one of the most fascinating branches of recreational mathematics. It has been proved that any polygon can be cut into a finite number of pieces that will form any other polygon of the same area, but of course such dissections have little interest unless the number of pieces is small enough to make the change startling. Who would imagine, for example, that the regular hexagram, or six-pointed Star of David, could be cut [*see top illustration on page 168*] into as few as five pieces that will form a square? (The regular pentagram cannot be dissected into a square with less than eight pieces.) H. Lindgren of the Australian patent office is perhaps the world's leading expert on dissections of this type. In the bottom illustration on page 168 we see his beautiful six-piece dissection of a regular dodecagon to a square.

A quite different class of paper-cutting recreation, more familiar to magicians than mathematicians, involves folding a sheet of paper several times, giving it a single straight cut, then opening up one or both of the folded pieces to reveal some sort of surprising result. For example, the unfolded piece may prove to be a regular geometric figure or design, or it may have a hole with such a shape. In 1955 the Ireland Magic Company of Chicago published a small book called *Paper Capers,* by Gerald M. Loe, which deals almost entirely with such stunts. The book explains how to fold a sheet so that a single cut will produce any desired letter of the alphabet, various types of stars and crosses, and such complex patterns as a circular chain of



Henry Perigal's scissors-and-paper demonstration of Euclid's famous 47th proposition



Atoms for Peace. This dome houses the 91-ton reactor vessel made of nickel-containing stainless steel for the new Enrico Fermi Atomic Power Plant on the shore of Lake Erie near Monroe, Michigan. Detail design and construction of the reactor vessel was done by Combustion Engineering, Inc. Plant will be built and operated by Power Reactor Development Company from designs supplied by Atomic Power Development Associates, Inc.

Atomic reactor "breeds" its own fuel

Stainless steel vessel must withstand high temperatures and corrosives

The world's largest full-scale nuclear reactor of the "fast-breeder" type is now being built. It may well answer the question:

> *When will atomic power be competitive with conventional methods of producing electric power?*

As the term "fast-breeder" indicates, the atom-splitting process is maintained by so-called *fast* or high-energy particles. It produces more nuclear fuel than it consumes. The fast-breeder actually turns out a kilogram and a fifth of new fuel for each kilogram it burns up!

The "breeding" takes place in a 36-foot high pressure vessel. Here, the high-energy particles (neutrons) travel at speeds of thousands of miles per second to keep the atom-splitting chain reaction going.

Accent on safety. A major objective was to make this reactor vessel safe. That called for a lot of highly specialized work.

It also called for a rugged metal: one capable of withstanding the tremendous heat given off in nuclear fission, and of bearing up under the temperatures and corrosives encountered. The final choice? Strong, corrosion-resisting Type 304 stainless steel. It's a stainless steel that contains Nickel – one of the big reasons for these superior properties.

How to "fast-breed" ideas. Problems involving reactor materials may never be a concern of yours. But you can run into *metal selection problems* involving corrosion, pressures, high temperatures and other destructive conditions almost any time. When you do, remember there is a good chance that a steel containing Nickel will provide the properties you want. Let us help you find out.

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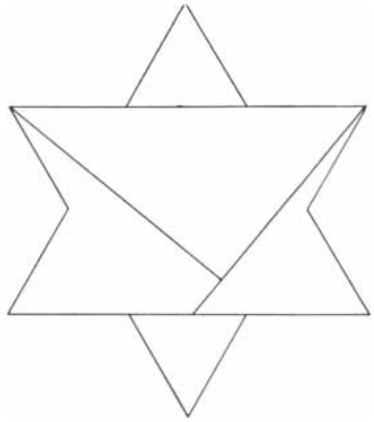
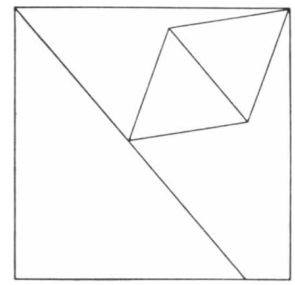




E. B. Escott of Chicago discovered this dissection of a regular hexagram to a square

stars, a star within a star, and so on. An unusual single-cut trick that is popular with American magicians is known as the bicolor cut. A square of tissue paper, colored red and black to look like an eight-by-eight checkerboard, is folded a certain way, then given a single straight snip. The cut separates the red squares from the black and simultaneously cuts out each individual square. With a sheet of onionskin paper (the thin paper makes it possible to see outlines through several thicknesses) it is not difficult to devise a method for this trick, as well as methods for single-cutting simple geometrical figures; but more complicated designs—the swastika for instance—present formidable problems.

It is obviously impossible to fold a sheet flat in such a way that a straight cut will produce curved figures, but if a sheet is rolled into a cone, plane slices through it will leave edges in the form of circles, ellipses, parabolas or hyperbolas, depending on the angle of the cut. These of course are the conic sections studied by the Greeks. Less well known is the fact that a sine curve can be quickly produced by wrapping a sheet of paper many times around a cylindrical candle, then cutting diagonally through both paper and candle. When unrolled, each half of the paper will have a cut edge in the form of a sine curve, or sinusoid, one of the fundamental wave forms of physics. The trick is also useful to the housewife who wants to put a rippling edge on a sheet of shelf paper.

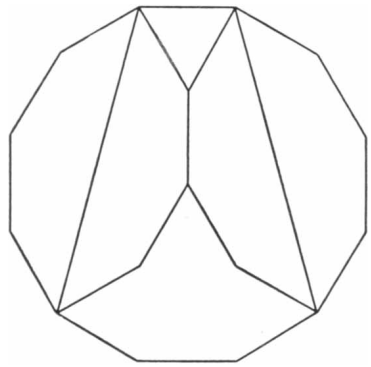
Here are two fascinating cut-and-fold problems, both involving cubes, that will be answered in this department next month. The first is easy; the second, not so easy.

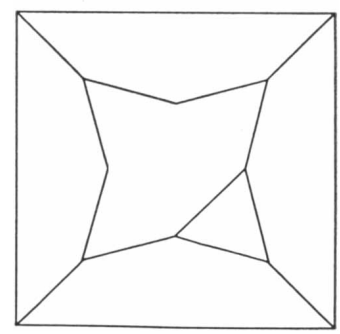
1. What is the shortest strip of paper one inch wide that can be folded to make all six sides of a one-inch cube?

2. A square of paper three inches wide is black on one side and white on the other. Rule the square into nine one-inch squares. By cutting only along the ruled lines, is it possible to cut a pattern that will fold along the ruled lines into a cube that is all black on the outside? The pattern must of course be a single piece, and no cuts or folds are permitted that are not along the lines that divide the sheet into squares.

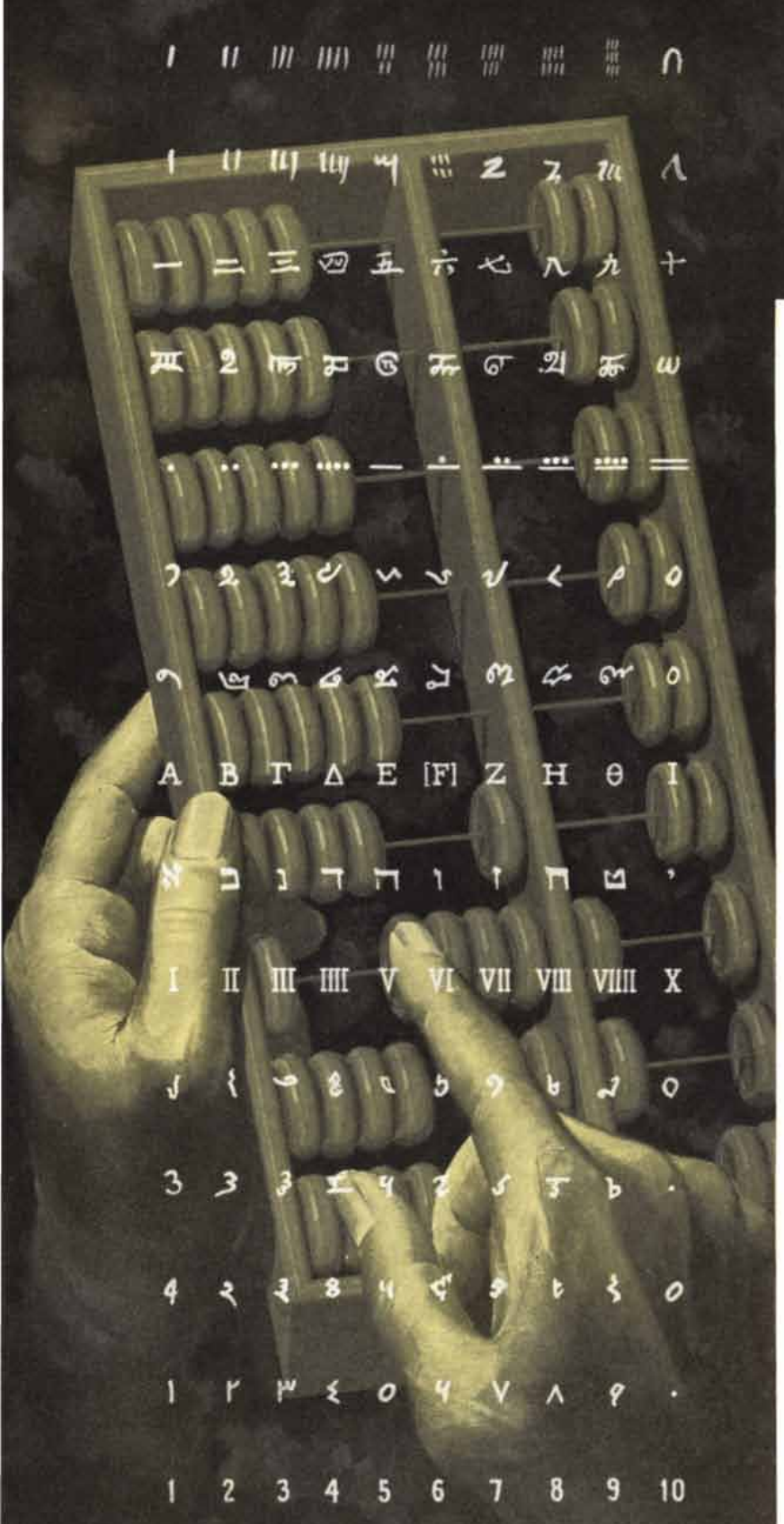
Last month's problems are solved as follows:

The smallest number of oranges that will form two tetrahedral pyramids of





H. Lindgren's dissection of a regular dodecagon to a square



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For nearly 2,000 years man's only computing machine was the Abacus. In varying forms, it was used by the ancient Egyptians, Greeks, Romans and Chinese.

LFE, long in the foreground of computer research and development, has improved upon the whole family of mathematical computers. For instance, now in production for the Air Force is an operational-digital computer that combines the convenience of real time computation with the inherent accuracy of digital data handling.

LFE is experienced in the design and manufacture of Computer Systems for both military and industrial applications.

Further details about LFE Computer Systems may be had by writing the Vice President of Marketing. Ask for Technical Data Digest No. 6041.

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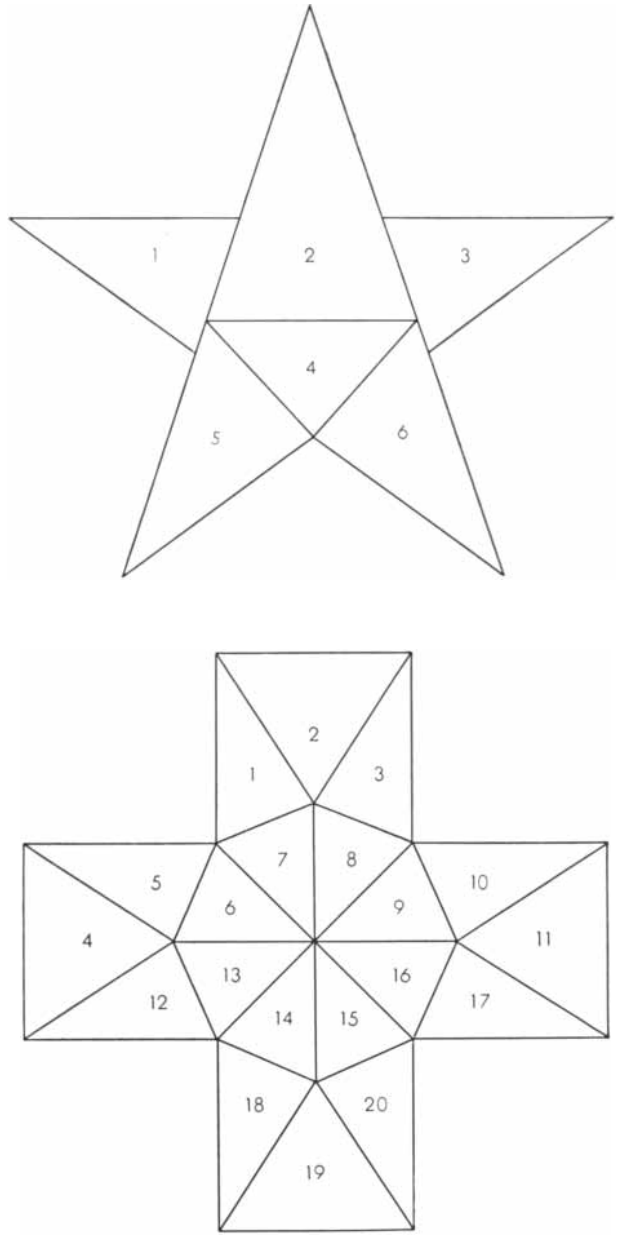
different sizes, and also one larger tetrahedral pyramid, is 680. This is a tetrahedral number that can be split into two smaller tetrahedral numbers: 120 and 560. The edges of the three pyramids are 8, 14 and 15.

A box 10 inches square and five inches deep can be close-packed with one-inch-diameter steel balls in a surprising variety of ways, each accommodating a different number of balls. The maximum number, 594, is obtained as follows: Turn the box on its side and form the first layer by making a row of five, then a row of four, then of five, and so on. It is possible to make 11 rows (six rows of five each, five rows of four each), accommodating 50 balls and leaving a space of more than .3 inch to spare. The second layer also will take 11 rows, alternating four and five balls to a row, but this time the layer begins and ends with four-ball rows, so that the number of balls in the layer is only 49. (The last row of four balls will project .28+ inch beyond the edge of the first layer, but because this is less than .3 inch there is space for it.) Twelve layers (with a total height of 9.979+ inches) can be placed in the box, alternating layers of 50 balls with layers of 49, to make a grand total of 594 balls.

The problems of dividing the pentagram and the Greek cross into a minimum number of acute triangles are answered in the illustration below.



The answers to last month's dissection problems

When crews of SAC's 1st Missile Division successfully launched the USAF ICBM Atlas from Vandenberg Air Force Base, September 9, 1959, the world became aware that the United States had brought into being a formidable retaliatory power for peace. Within four months after the first operational launch, the Air Force doubly underlined this missile's capability. On a single day, January 26, 1960, the 16th and 17th consecutive successful Atlases were fired intercontinental ranges to predetermined targets from both Atlantic and Pacific bases.

After only five years of intensive development, including concurrent research, testing and fabrication under this nation's top military priority, Atlas is extremely versatile as well as powerful. It was the Project Score satellite vehicle and is scheduled for use in Project Mercury, the Man in Space Program, and in other space exploration missions. Thus, used as a booster for space projects, Atlas provides the nation with a key capability in scientific as well as military applications.

Space Technology Laboratories provides the systems engineering and technical direction for the Atlas as well as other portions of the Air Force Ballistic Missile Program. Much of what was learned in building Atlas has helped cut the lead-time in the development of such other Air Force Ballistic Missiles as Thor, Titan and Minuteman.

Among the industrial organizations which have worked in concert in developing Atlas are such major contractors as: Convair, Division of General Dynamics Corp. for airframe, assembly and test; General Electric Co. and Burroughs Corp. for radio guidance; Arma, Division of American Bosch and Arma Corp. for inertial guidance; Rocketdyne Division of North American Aviation, Inc., for propulsion; General Electric Co. for re-entry vehicle; Acoustica Associates for propellant utilization.

America's first intercontinental ballistic missile...is helping to bear the burden of today's power for peace

ATLAS

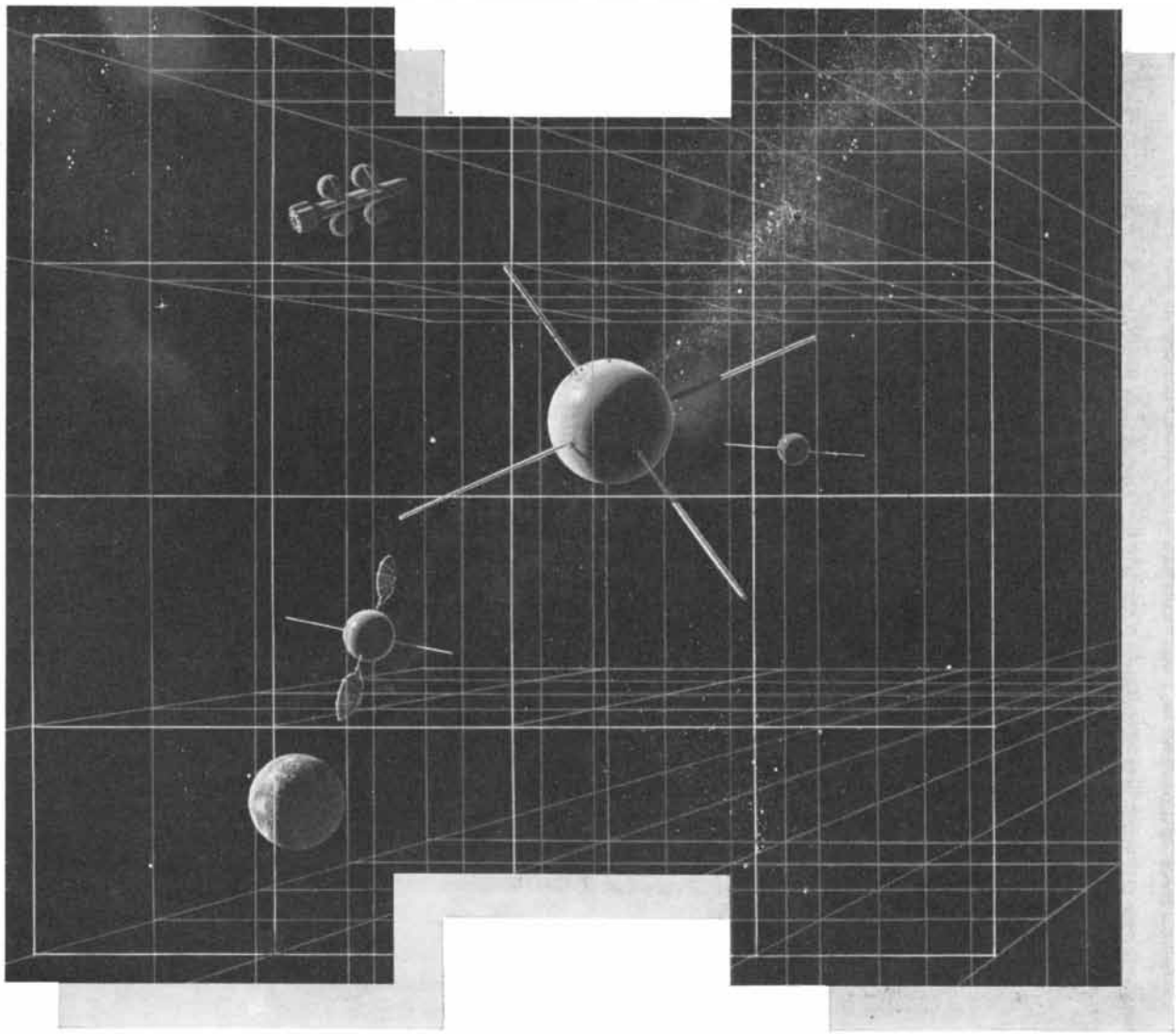
The continuing development of Atlas as well as other USAF missiles and related space probes, has created important positions on STL's technical staff for scientists and engineers with outstanding capabilities in: thermodynamics, aerodynamics, electronics, propulsion systems, structures, physics, computer technology, telemetry, and instrumentation. If you believe you can contribute in these or related fields and disciplines, you are invited to send your resume to:

SPACE TECHNOLOGY LABORATORIES, INC.

P. O. Box 95004, Los Angeles 45, California, Attention: Richard A. Holliday — Los Angeles • San Diego

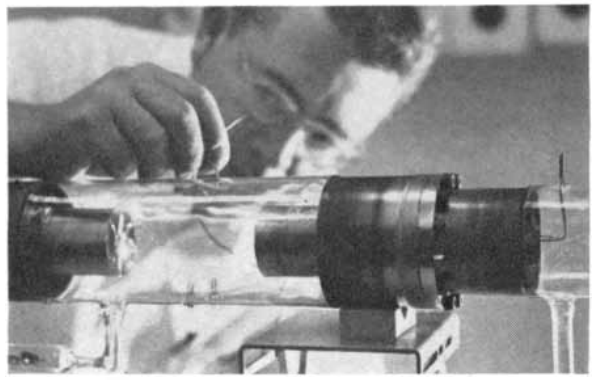
Santa Maria • Sacramento • Denver • Cheyenne • Cape Canaveral • Washington, D.C. • Manchester, England • Singapore • Hawaii

How to take a satellite



census

As a means for studying r-f containment concepts for use in thermonuclear machines, dense cesium plasmas are generated in this tube at the Hughes Research Laboratories in Malibu, California.



At present rates, man will soon have space cluttered with all sorts of orbiting objects. Keeping track of these thousands of new satellites will be a major factor in the success of future space explorations.

This extra-atmospheric clutter can be resolved, sorted, and classified at great range by a new systems concept of satellite intelligence developed by Hughes-Fullerton engineers. The prime sensor is a flexible, computer-programmed radar which can chop space into billions of small information cells on thousands of simultaneous beams.

This enormous multiple-beam capacity permits search, track, and examination of huge numbers of targets—in addition to providing the capability for transmitting control information to defense systems or satellite platforms.

This capability requires a new beam scanning technique, a major step beyond frequency or phase control of arrays. Such advances are typical of the Hughes engineers who pioneered electronic scanning. Here, thinking is not limited to today's problems, or even next year's but toward the next generation of information gathering systems—systems which will not be obsolete by the time they are operational.

Numerous other Hughes projects, in virtually every area of advanced electronics, provide similarly stimulating outlets for your abilities. Current areas of activity include: advanced electronic display systems, microminiaturized semiconductors, nuclear electronics, space vehicles, ASW systems, hydrofoil system, infrared devices, advanced control systems—and many others.

This variety of advanced projects makes Hughes the ideal environment for the engineer or scientist who wishes to increase his professional stature and personal growth.

Shown recording shock test data, the MEMO-SCOPE® Oscilloscope is one of the many commercial products developed by Hughes. Precise trace measurement is made possible by the Hughes-built MEMOTRON® Storage Tube.

Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:

Electroluminescence	RF Network Engineering
Infrared	Microwave & Storage Tubes
Solid State Physics	Communications Systems
Digital Computers	Inertial Guidance
Reliability & Quality Assurance	Field Engineering
Systems Design & Analysis	Circuit Design & Evaluation

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Hughes General Offices, Bldg. 6-F6, Culver City, Calif.

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RECOMP gives you far more capacity, versatility, and trouble-free service for your money. It's available now—for outright sale or at a moderate monthly rental that includes maintenance. *And there's no extra equipment to buy...no cost of installation.* For information on how RECOMP can solve *your* problems, write Autonetics Industrial Products, Dept. 106, 3584 Wilshire Boulevard, Los Angeles 5, California.

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THE AMATEUR SCIENTIST

Concerning experiments with rubber and how to re-create a classical electrostatic generator

Conducted by C. L. Stong

Of all the materials with which we come in daily contact, rubber is unique in having a peculiar charm. Given half an opportunity, we almost instinctively play with it; we stretch it, bounce it, knead it. Another of rubber's engaging qualities is that it comes in an extraordinary variety of forms, from soft foam rubber to hard rubber. This very versatility probably discourages the amateur who thinks of performing chemical experiments with rubber or of mixing his own rubber. The variety of rubbers suggests that to work with them requires a chemical manufacturing plant, or at least a well-equipped chemical laboratory.

Paul West of Park Ridge, Ill., has not found it so. With relatively simple equipment he compounds his own rubber in all sorts of interesting ways. He even makes special foam rubbers that can be molded into antivibration parts and can otherwise be applied in the home laboratory. West writes:

"Before dashing off to make a foam-rubber pillow, you may find it useful to review a few basic facts about the nature of rubber and to do some introductory experiments. The starting material is pure natural latex. It can be ordered, together with essential processing chemicals, through local dealers in chemical supplies or through druggists in most communities. Latex is a slightly viscous liquid drawn from the inner bark of such tropical trees as *Hevea brasiliensis*. It consists of a 35-per-cent dispersion of isoprene (the basic building block of rubber) in water, together with small quantities of fatty acids, proteins, resins, sugars and enzymes. For reasons of economy natural latex is usually concentrated for the market to an isoprene content of 62 per cent.

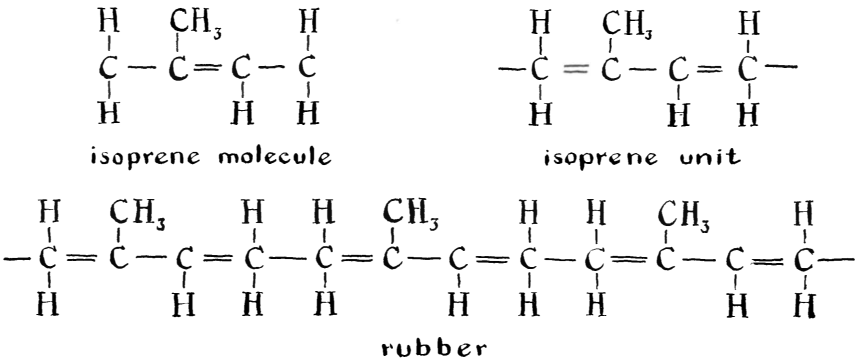
"The isoprene molecule (called a monomer) is a hydrocarbon consisting of 13 atoms; five of carbon and eight of hydrogen, arranged as shown in the accompanying structural formula [*upper left in illustration on next page*]. When isoprene is placed in a suitable environment, either physical or chemical, the electron configuration of its molecule is changed as illustrated [*upper right*]; in this state it tends to attach itself to a similarly modified molecule in its vicinity. The united pair annex still other molecules to form a growing chain or fiber that may ultimately contain as many as 5,000 monomers. The result is a giant molecule of rubber (called a polymer). In the absence of external mechanical force the rubber molecule assumes a randomly coiled form. When the coil is stretched, it straightens into a long strand that snaps back into the coiled pattern when the force is removed. It is this property that enables rubber to stretch, flex and absorb vibration.

"Latex is physically unstable. The monomers easily acquire the electron configuration that encourages the growth of rubber molecules. To observe this reaction pour an ounce or two of latex on a level sheet of clean glass and let the water evaporate. Within a matter of three to 12 hours, depending upon the temperature, the latex will coagulate into a solid sheet of rubber that you can peel from the glass. Examination of the sheet will quickly disclose, however, that it does not exhibit the properties we usually associate with rubber. You will find that although the sheet can be stretched, it never quite returns to its original shape. It is soft; you will doubtless find your fingerprints on the surface, and the material will stick to itself when pressed together. This was the only kind of rubber known until 1839, when Charles Goodyear discovered a chemical reaction, known as vulcanization, that made rubber tough.

"The molecular structure of the rubber sheet formed on the glass may be imagined as a thick layer of coiled chains or fibers piled at random. When the sheet is stretched, some of the individual chains are straightened, but most of them merely slide past each other. When the force is removed, the straightened chains return to their coiled state, but chains that have shifted position remain at their new sites. This accounts for the distortion of the stretched sheet. Goodyear accidentally hit upon a way to stitch adjacent polymers together so that they could not slide past one another in the pile. He did not know why his process worked, but according to modern theory he took advantage of the fact that each isoprene unit of the polymer contains a pair of carbon atoms that are joined by the electrical forces of two pairs of electrons that continuously exchange orbits; in other words, between each pair of carbon atoms there is a double chemical-bond. When an atom of sulfur wanders into the vicinity of the rubber molecule, the double bond in effect opens up, permitting a three-way exchange of electrons that includes those of the sulfur atom. A bond or bridge is thus established between the polymer and the sulfur atom. The same sulfur atom can react similarly with a second polymer and thus link the two. Similar bonds form throughout the rubber, their number depending upon the number of sulfur atoms present. Thereafter they restrict the freedom of the polymers to coil and uncoil; the closer the stitching, the more rigid the rubber. Toy balloons have relatively few crosslinks; they normally contain about .5 per cent of sulfur by weight. Conversely, bowling balls and hard-rubber objects such as combs are closely linked; they contain as much as 47 per cent sulfur.

"To produce vulcanized rubber, then, why not simply dissolve the desired amount of sulfur in latex, permit the water to evaporate and place the resulting coagulated mix in a heated oven to hasten formation of sulfur bonds? Essentially this is what Goodyear did, though he started with coagulated rubber. The procedure is impractical. First, sulfur does not dissolve in latex; second, unless an 'accelerator,' or catalyst, is added to speed the reaction, vulcanization requires a very large amount of heat.

"Sulfur can be introduced into latex



The monomer of natural rubber (top) *and polymer chain made up of monomer units*

as a colloidal dispersion in water, however. It is reduced to this form in a ball mill, along with a dispersing agent (such as Darvan) and a protective colloid (casein). As prepared commercially, these ingredients are poured into a rotating drum containing spheres of porcelain and are reduced to the required fineness by the tumbling balls. Having no mill, I purchase commercially prepared sulfur dispersions. Most come in a concentration of 50 per cent. When computing the weight of sulfur needed for an experimental batch, it is therefore necessary for me to allow for the water in the commercial preparation.

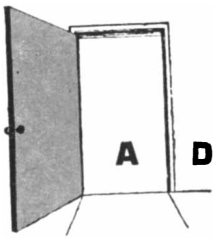
"The heat required for vulcanization is minimized by adding an accelerator to the mix. Although many chemicals can act as accelerators (some induce complete vulcanization in a few minutes at temperatures below 200 degrees Fahrenheit), not all are soluble in latex. They must be milled and dispersed in water just as sulfur is.

"Accelerators that are insoluble in water are in general more satisfactory than the water-soluble accelerators, because they are not lost by leaching, particularly when the heat for vulcanization is applied by immersing the rubber in hot water. A water-soluble accelerator ('Butyl Zimate,' or zinc dibutyldithiocarbamate) is used in the next experiment I shall describe, however, because of its convenience. A relatively small amount of the chemical, something less than 2 per cent by weight of the other ingredients, produces the desired acceleration. When accelerators are used in excessive amounts, they thicken the latex, and the resulting product appears to have been scorched. The catalytic action of Butyl Zimate is quite marked. As little as 1 per cent will induce complete vulcanization within five days at room temperature.

"For maximum catalytic action another ingredient is usually added to the mix: an activator. This agent provides the mix with a source of zinc ions. These appear to increase the rate at which the accelerator opens carbon bonds to the sulfur atoms, although the precise nature of the reaction is not fully understood. Zinc oxide is commonly used as the activating agent.

"To make a sheet of pure vulcanized rubber, then, you need four basic materials: latex, colloidal sulfur, an accelerator and an activator. Starting with 161 parts of 62-per-cent latex (which equals 100 parts of pure rubber hydrocarbon), add two parts of sulfur, one part of Butyl Zimate and one part of zinc oxide. These proportions are in terms of weight and are added as dispersions. If a 50-per-cent dispersion is used, the measured amount will be doubled; obviously half of the weight is represented by water. The solution is mixed thoroughly and poured onto a carefully leveled plate of clean glass. After the water has evaporated, the coagulated sheet of rubber is carefully stripped from the glass and immersed in a container of boiling water for 15 minutes. When you remove the sheet from the water, you will find that it exhibits all the familiar characteristics of soft, highly elastic rubber. When it is stretched and released, it immediately snaps back into its original form. If the sheet is stored for several years, or exposed to contaminating substances such as copper or magnesium, it will lose some of its elasticity and perhaps show minute surface cracks. To retard this 'aging' still another substance should be added to the mix: an antioxidant. As its name implies, this additive retards chemical reaction between the rubber and the oxygen in the air. A convenient and inexpensive antioxidant for amateur use is de-betanaphtyl-p-phenyleadiamine, dispensed under the trade name of Agerite White.

"This antioxidant is used in the next



A DOOR IS OPENED... TO NEW DEVELOPMENTS IN DIISOCYANATES

"Modern chemistry has made few discoveries of greater significance than polymerization. Few polymer formers have greater versatility, actual or potential, than diisocyanates."

This quotation is from a new free booklet prepared by our National Aniline Division. Entitled "Diisocyanates," it describes the origins and development of these polymer formers which are being used to achieve that revolutionary new plastics family, polyurethanes.

Polymeric building blocks

The booklet begins with a discussion of polymers in nature, from which chemists took their cue to devise their own building blocks. One of the most intriguing building blocks for forming large polymer molecules is the class of organic chemicals called diisocyanates. With them it is possible to duplicate the properties of almost all known types of plastics.

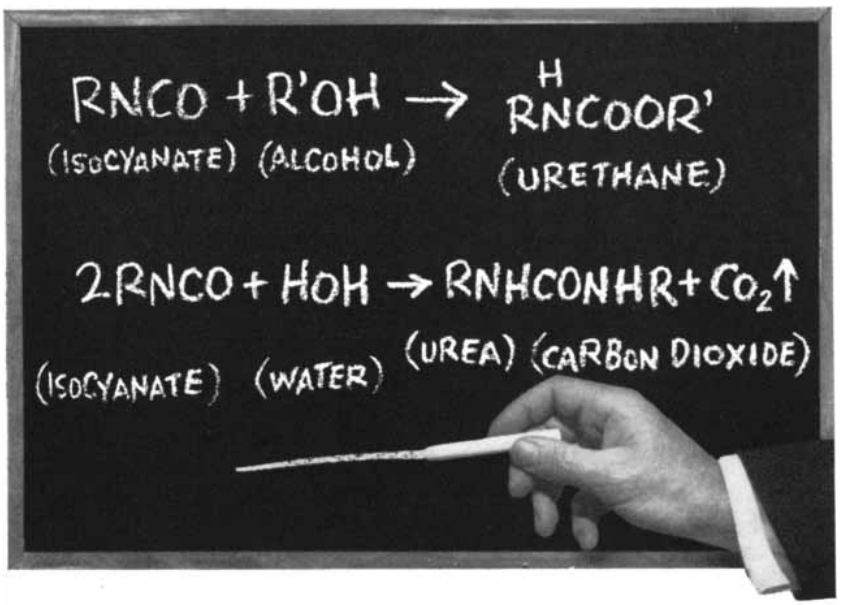
In order to help the reader appreciate the diverse materials that can be formed with diisocyanates, the booklet includes a brief history of their origins, followed by an outline of present day chemistry in the field.

Polyurethane foams

From there, the booklet takes us into a discussion of the most interesting and important polyurethanes (polymers based on diisocyanates)—the foams. It tells why and how these materials foam and describes the tremendous variations that are possible. Polyurethane foams range from one to 60 pounds per cubic foot in weight. They can be made rigid enough to support heavy loads or flexible enough to serve as mattresses and coat linings.

Flexible foams

Flexible foams may be produced which have little "bounce-back" and high shock absorbency. These are well adapted to such uses as automobile crash pads, where they minimize the danger of "snapback" injuries, inherent in pads with little absorbency, more bounce. Other flexible foam applications include pillows, furniture cushioning, vermin- and rot-proof carpet underlays, floor mops, clothes brushes, and warm yet lightweight linings for winter clothing.



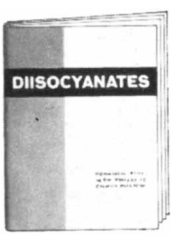
Key equations of urethane chemistry show the simultaneous reactions of isocyanates with alcohol and with water. The reaction produces a solid product and carbon dioxide, which "blows" the foam material. From "Diisocyanates," a free booklet just off the press.

Rigid foams

You'll read how polyurethanes can be cross-linked to form semi-rigid and rigid foams as well. The former of these can be sprayed onto walls as acoustical insulation or foamed in place in wall cavities where insulation is wanted. Rigid foams find application as harbor buoys, buoyancy chambers for boats, and as filling for aircraft wing tips. You may be surprised to learn that prefabricated sandwich wall panels for homes are now under test and that foamed-in-place polyurethane resins have been used for the setting of bones.

Other polyurethane products

The booklet describes the other forms of polyurethanes as well; for with more cross-links, polyurethanes become plastics that do not warp or swell and have high impact strength. Polyurethane rubbers for example: soles and heels that outlast conventionalshoe materials 10 to 1... hundred-thousand-mile tire treads that promise to be a commercial reality soon.



Anyone interested in the general subject of diisocyanate chemistry, or who is working with polyurethane materials, will find the booklet, "Diisocyanates," valuable. *For a free copy,* just write, on company letterhead, to Allied Chemical Corporation, Dept. 66-S, 61 Broadway, New York 6, New York, or phone HAnover 2-7300.

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experiment I shall describe—the compounding of foam rubber—along with still another ingredient, an agent that encourages the latex to gel or coagulate quickly. Such an agent is particularly desirable in the manufacture of foam rubber, because the reaction it promotes stiffens the foam before it can settle. The most popular gelling agent is sodium silicofluoride, an insoluble white powder that is added to the mix in the form of a dispersion. Gelling begins about six minutes after the agent is stirred into the other ingredients. The mechanism of gelation is not well understood, but sodium silicofluoride seems to combine with the water to form hydrofluoric acid, thus sending the latex into the highly unstable acid range. Moreover, hydrated silicic acid appears as a product of the reaction in the form of a gel that contributes to the stiffness of the cellular structure.

"In making foam rubber at home you should also add soap to the mix to encourage the formation of bubbles. An effective soap can be made by mixing together (by weight) 7.5 parts of potassium hydroxide, 37 parts of castor oil and 83 parts of water. The ingredients are then beaten (with an egg beater) until they react to form liquid soap. Three to seven parts (by weight) of soap are added to the latex mix. More will retard the gelling action and less will contribute little to the desired frothing.

"First combine all the ingredients listed under 'Phase 1' of the accompanying recipe [*right*]. An ordinary glass mixing-bowl will serve as a convenient vessel. When the batch is thoroughly mixed, it is allowed to set for 12 hours (to assure complete coagulation). The ingredients of Phase 2 are then added and beaten until the mix becomes frothy. If a household food-mixer is available for the job, set the motor for the highest speed. The resulting froth should occupy about eight times the volume of the unbeaten mix and resemble the color and consistency of a vanilla milkshake. The minute bubbles should be apparent only as a marked decrease in the density of the fluid. When it is judged that the beating is complete (by the eight-fold increase in volume), and before the mixer is turned off, add the gelling agent (Phase 3), beat for half a minute more and pour the contents into a mold.

"Almost any container with smooth sides will serve as a mold: a cake pan, a paper cup or a wax or plaster-of-Paris mold made in the shape of a desired part. The tendency of the rubber to adhere to the container can be minimized by applying a light coat of talcum powder to the mold. Gelling will be completed in about 30 minutes. In this unvulcanized state foam rubber, though firm, is tacky, and the inner walls of the bubbles will stick together if the foam is squeezed. If the rubber is to be vulcanized outside the mold, it must be removed gently.

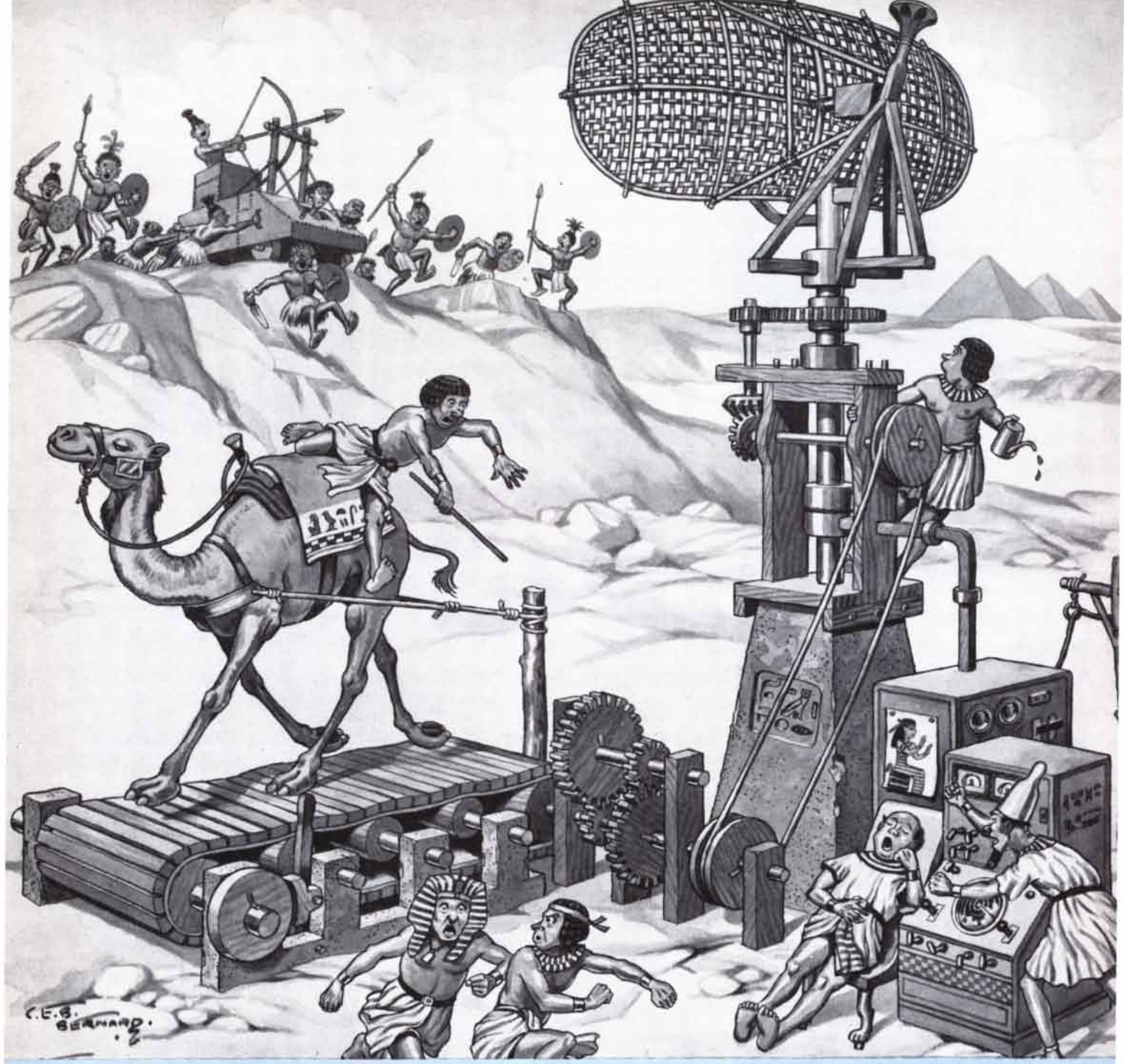
"You have a choice of three simple methods of applying heat to the rubber during vulcanization: hot air, hot water or steam. A hot-air oven is easy to construct from a breadbox fitted with a 300-watt lamp or a conventional electric heating element. The oven must also be provided with a thermometer calibrated to at least 300 degrees F., and a fan such as an electric hair dryer for circulating the air. A thermostat is convenient but not essential. If the oven is to be used for a series of experiments you may wish to substitute for the 300-watt lamp six 50-watt lamps wired with individual switches. The temperature can then be regulated by turning on the lamps as desired. If the box is reasonably well insulated, it should reach a temperature

PARTS	PHASE 1
161	62 PER CENT LATEX
4	50 PER CENT SULFUR DISPERSION
5	10 PER CENT AMMONIATED CASEIN SOLUTION
2	50 PER CENT DISPERSION ZINC SALT OF DIBUTYLDITHIOCARBAMATE

	PHASE 2
1	TRIMENE BASE
2	50 PER CENT DISPERSION ZINC OXIDE
15	20 PER CENT SOAP SOLUTION

	GELLING AGENT
6	50 PER CENT SODIUM SILICOFLUORIDE DISPERSION

A recipe for making foam rubber



NO. 2 OF A SERIES . . . BOMAC LOOKS AT RADAR THROUGH THE AGES

On April 7, 45 B.C., during the reign of Cleopatra, Memamadun Ptolemy (pronounced me-mama-done-toll-me), radar operator, fell asleep at just the time chosen by some unfriendly neighbors to make a border raid.

Memamadun (he was the only survivor) was brought before Cleopatra.

"Can you give me any reason why I shouldn't throw you to my pet crocodile Julius for letting such a terrible thing happen?" she asked.

Memamadun stifled a yawn.

"Even if I'd been awake, our radar wouldn't have prevented the attack," he said. "Our radar won't work."

"Why not?" the queen asked, stroking Julius' head.

"It can't," Ptolemy ptold her. "For one thing, Bomac tubes haven't been invented yet."*

"That's right, too!" Cleopatra said. "Case dismissed."

* *Bomac makes the finest microwave tubes and components this side of the Nile.*

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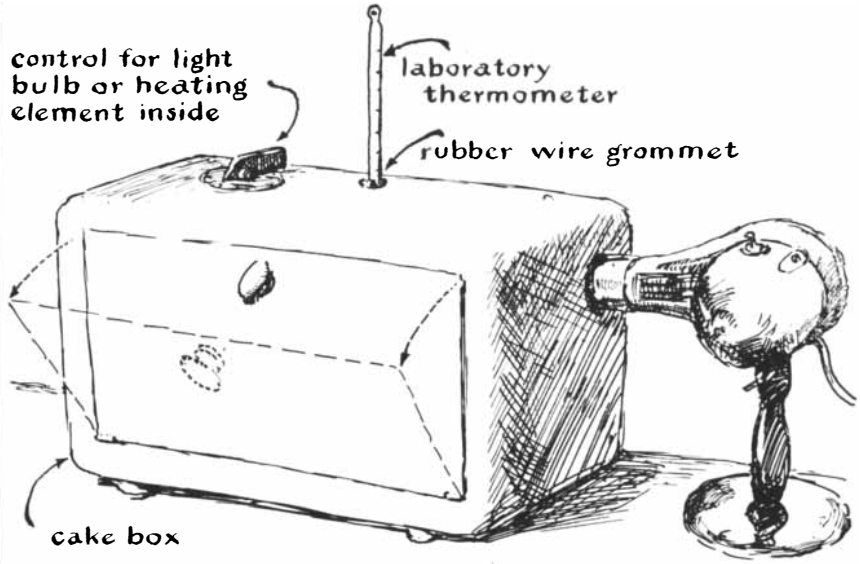


A homemade oven to vulcanize foam rubber with hot air

of at least 250 degrees F. This method of vulcanization suffers from the disadvantage that air is not an effective medium for transferring heat. A sketch of my oven appears in the accompanying illustration [*above*].

"It is of course possible to vulcanize rubber in hot water, as demonstrated by the experiment described earlier. The method is convenient, but it has two drawbacks. At sea level boiling water reaches a maximum temperature of only 212 degrees. Moreover, if unvulcanized foam is immersed, it can easily be collapsed by the weight of the water.

"I prefer steam vulcanization. This medium has the convenience of hot water, transfers heat more effectively than hot air, yet exerts no more mechanical force on the rubber than does air. A simple boiler for home vulcanization is shown in the accompanying illustration [*page 182*]. To vulcanize the foam bring about an inch of water to a boil, place the molded rubber on the wire grid and close the boiler with a lid. The time required for 'cure' will range from 10 minutes to an hour, depending upon the thickness of the rubber.

"Having made the basic experiments described above, you are prepared to delve into the variables of rubber technology. The broad field of rubber accelerators, for example, offers numerous experimental opportunities. The zinc salt of mercaptobenzothiazole is a particularly interesting accelerator. It is an insoluble yellow powder that reacts at low temperature, does not discolor latex and produces a foam of high quality that resists aging. Another is piperidine (pentamethylene dithiocarbonate), an extremely quick-acting accelerator that is also insoluble.

"The pore size of foam rubber varies with surface tension, viscosity, type of soap and method of beating. The higher the ratio of rubber to air, the denser the foam. A watery mixture can be thickened by adding casein in the form of a 10-per-cent solution, or by adding bentonite clay, sodium silicate, Karaya gum or starch. Thick solutions can be thinned by adding water.

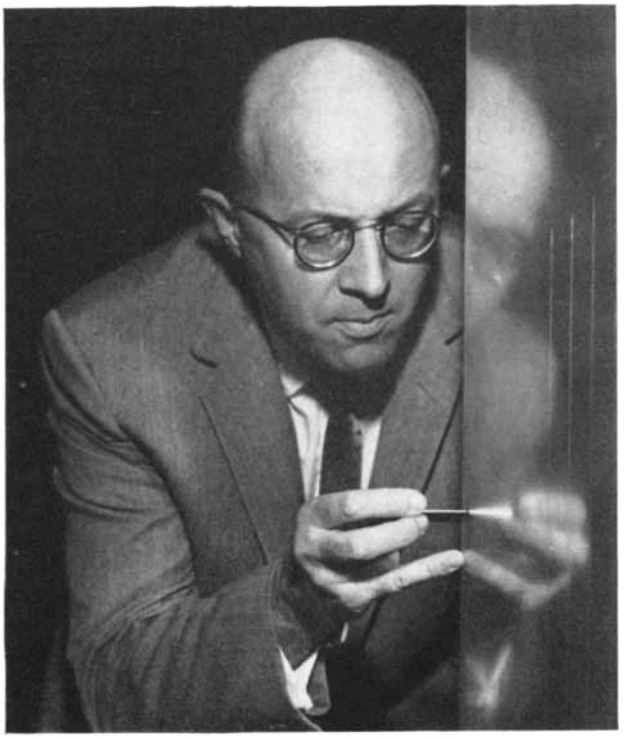
"Foaming can be encouraged by injecting air into the mix during the beating operation. To inject air, substitute a thermoplastic vessel for the glass mixing-bowl and force a heated glass tube through the bottom. (Cement the tube in place.) The outer end of the glass tube is attached to a bicycle pump or other source of compressed air. It is also interesting to investigate the effect of different gases (such as the inert gases, the halogens and acid anhydrides) on the resulting product. The technique of making spongy foams is equally interesting. The formation of large bubbles requires a low-viscosity latex. After beating, the mix is strengthened with unfrothed latex to which a thickener has been added. The hardness of the foam can also be controlled. The foam is made harder by loading the mix with clays; softer by the addition of emulsified oils. Typical loading agents are mineral oil and china clay.

"Latex and the chemicals essential for processing it can be ordered through your local chemical supply dealer or druggist from such firms as E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.; the Chicago Latex Products, Chicago, Ill.; and the R. T. Vanderbilt Co.,

How Boundary Layer Control Reduces Friction Drag on Aircraft in Flight, Can Increase Range 50% to 100%

by Dr. Werner Pfenninger

Dr. Pfenninger, internationally renowned for his work in laminar flow and low drag coefficients at the Federal Institute of Technology in Zurich, joined Northrop in 1949. Today he heads the scientific and engineering team working on Boundary Layer Control Research at Norair Division, Northrop Corporation.



The boundary layer is a very thin stratum of air that surrounds an aircraft in flight. Lying directly on the aircraft, it is formed by air that is slowed by the passage of the aircraft surface and flows more slowly than the free stream velocity of the air around it. Turbulence results. This increases air friction—waste friction drag (not to be confused with *induced* drag associated with lift).

Norair Low Drag Boundary Layer Control prevents this turbulence by smoothing the flow of air. BLC draws part of the turbulent air through slots in the aircraft skin with a suction compressor and exhausts it in the direction of thrust through the aft fuselage or the nacelle tailpipes. On wings and empennage this reduction can increase the aircraft's range or endurance 50 per cent. If BLC is applied to most of the airplane, this increase can go as high as 100 per cent.

BLC's reduction of friction drag increases endurance missions, flight efficiency, and amount of pay load. It reduces fuel consumption to the point where aircraft can remain on station for long periods of time. It reduces operating costs.

Any type of large, long-range aircraft can be quickly adapted to incorporate Norair's BLC aircraft skins. Cost of BLC application is approximately 10 per cent of the total airplane.

For military applications, BLC means advances in aircraft performance as an air-to-surface missile carrier on air defense missions, airborne early warning systems, anti-submarine warfare, tactical air support, intercontinental communications link. On logistic missions, BLC allows nonstop flights without refueling to decrease dependence on overseas bases. On commercial aircraft BLC's increased range, payload and cost advantage mean a remarkably increased ability to carry air freight. For flights of 2000 miles or more, direct ton-mile cost can be reduced by 10 to 50 per cent. On passenger flights, long-distance nonstop flights would be possible to any point in the world. For nuclear-powered aircraft of the future, BLC means smaller power plants with less heavy and costly radiation shielding that makes a lighter airplane possible.

Northrop Corporation—the only American aerospace company to conduct extensive research in the field—has pioneered Low Drag Boundary Layer Control for more than ten years. Today Norair has conducted more than 250 laminar flow flights with an F-94 jet fighter. Full laminar flow has been obtained in wind tunnel tests on varying shapes at varying speeds from low subsonic to high multi-sonic Mach numbers.

For the scientist and engineer at Norair, design, manufacture, and flight testing of BLC offers a gratifying opportunity to create advances in a new field. The specialist enjoys the advantages of working with the facilities of the entire Northrop Corporation in an atmosphere where management encourages, recognizes, and rewards individual achievement.

Current papers by Dr. Werner Pfenninger include:

Design Considerations of Large Subsonic Long-Range Transport Airplanes with Low Drag Boundary Layer Suction.

Design Considerations of Propulsion Systems for Low Drag Boundary Layer Control Airplanes Cruising at High Subsonic Speeds.

For copies of these papers and additional information about Northrop Corporation, write:

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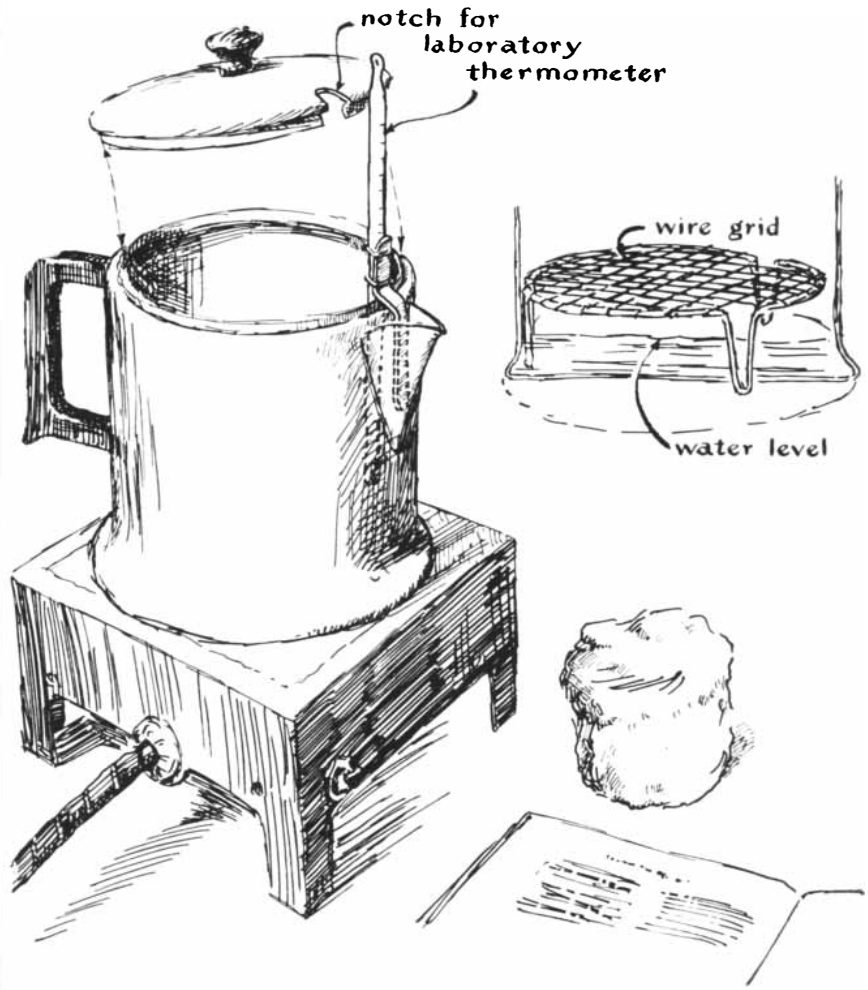
Inc., New York, N. Y. Your local dealer can also order latex from the Firestone Tire & Rubber Company, Akron, Ohio."

E. J. Gauss of the department of mathematics at the University of California has recently constructed several variations of Lord Kelvin's all but forgotten "water dropper," the primitive electrostatic machine on which the modern Van de Graaff generator is based. Both machines transform mechanical energy into electrical energy by employing mechanical force to separate electrical charges of unlike sign and to push like charges together. In other words, work is expended to overcome the mutual repulsion of like charges. The potential difference across the terminals of the machines is thereby increased.

In the Van de Graaff generator one set of charges is transported by a moving belt that runs between a second set of charges on the pulleys, the direction of the belt's travel being chosen so that mechanical work is expended in overcoming the electrical forces [see "The Amateur Scientist"; April, 1955]. Lord Kelvin accomplished the same result a century ago by lifting water into a reservoir (thus doing work) and permitting it to fall as drops through conductors arranged so that the drops acted as carriers of charge.

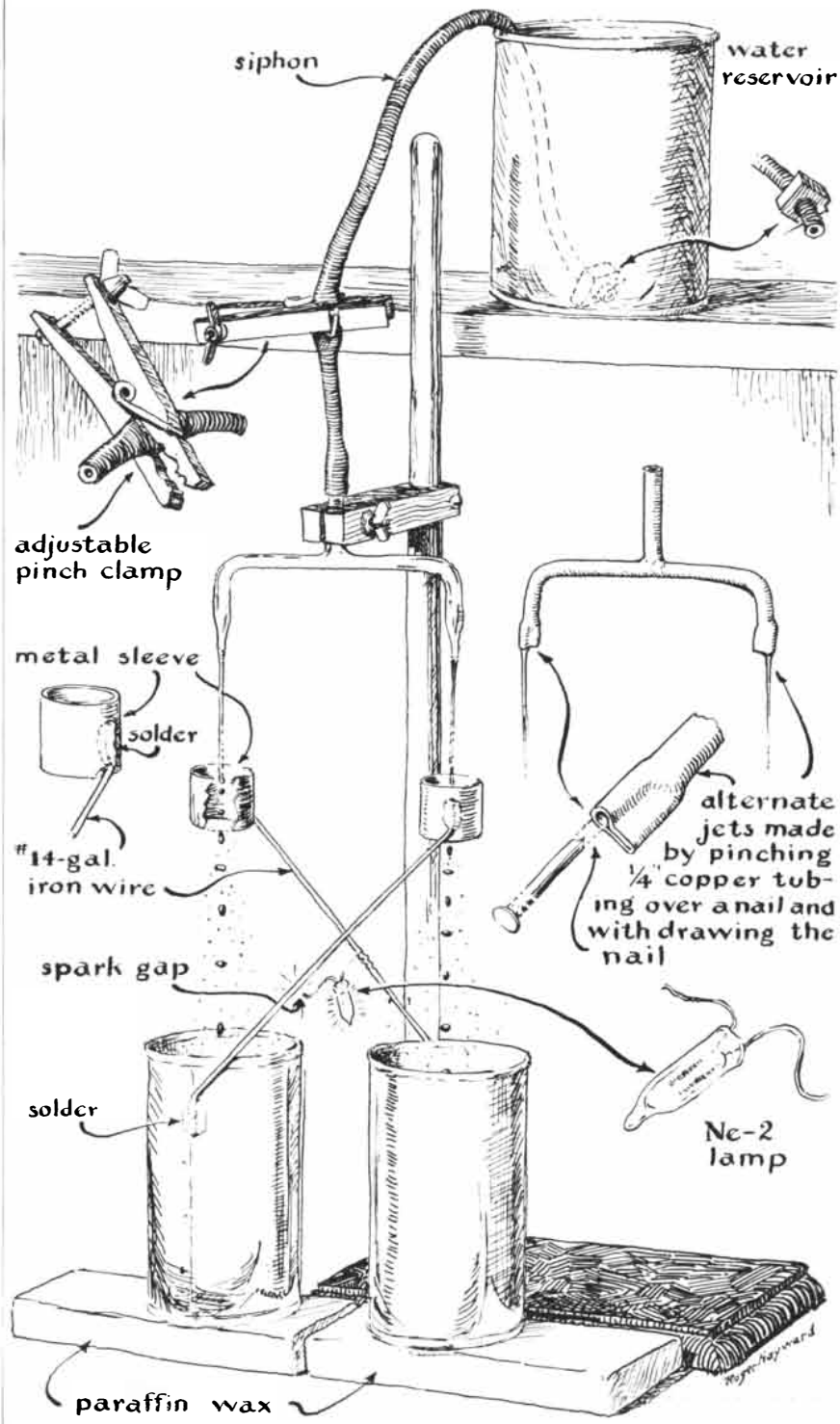
"It is a bit hard to believe," writes Gauss, "that such a simple device, using no moving parts other than a pair of dripping nozzles, can generate enough charge to cause a small neon bulb to flash. My reservoir is a separatory funnel and the water drips into a pair of collectors that formerly held frozen orange juice. (An ambitious friend has suggested that I substitute oil drums for the tin cans!) The collecting cans are insulated from the laboratory bench by two blocks of paraffin. A piece of stiff wire is soldered to each can and supports a ring about three inches above the top of the other can. The wires also serve as the electrical connections between the respective rings and cans. The rings may be either a one-inch piece of one-inch brass tubing or the equivalent made from pieces of tin can. A small neon bulb (NE-2) is soldered to one of the con-



A homemade boiler to vulcanize foam rubber with steam

ductors at the point where the two cross. A spark gap about a quarter of an inch wide is left between the other lead of the neon bulb and the second conductor.

"A reservoir made of a large tin can would work as well as a separatory funnel. I used the funnel merely because it chanced to be handy. You can substitute a tin can for the funnel by siphoning the water through a length of rubber tubing. Weight the end of the tubing with a nut to prevent it from slipping from the can, and rig a clothes pin with a bolt and wing-nut to serve as a pinch clamp as shown in the accompanying drawing [*below*]. The rate of flow is adjusted by turning the wing-nut. The nozzles must be positioned to direct the stream down the axis of the two metal rings and into the collecting cans below. To make the nozzles, heat a piece of quarter-inch glass tubing to the softening point in a gas flame and



An amateur's re-creation of Lord Kelvin's "water dropper" electrostatic machine

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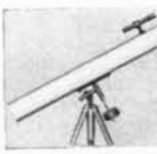

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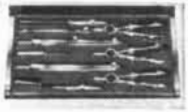

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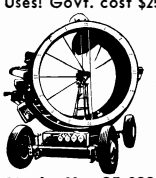

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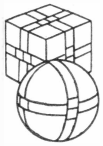

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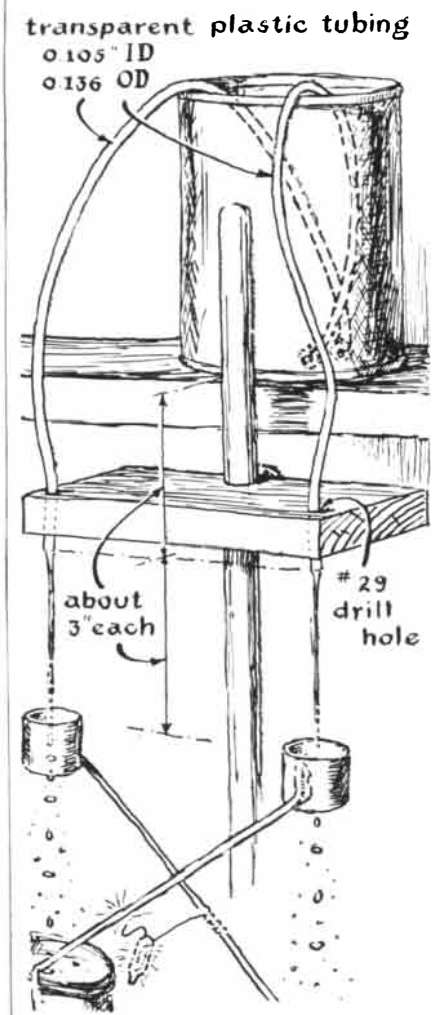
draw the ends apart quickly. Then nick the glass tips with a file and snap off the closed tips. The resulting orifices should be about a 16th of an inch in diameter. If you hesitate to tackle glass work, you can make adequate jets by crimping the end of a length of copper tubing over a shingle nail and then removing the nail. If you wish to avoid making the T-connection between the nozzles, use two supply tubes and equip each with a pinch clamp.

"The flow of water is adjusted so that the streams break into droplets inside the rings. Once the reservoir has been filled (ordinary tap water works well), this adjustment puts the machine into operation. The maximum voltage generated is limited by the spacing of the air gap between the free lead of the neon lamp and the conductor. Close spacing encourages small, frequent sparks to jump the gap, accompanied by weak lamp-flashes. With large gap-spacing the lamp flashes less frequently but more brightly. If the gap spacing is larger than a quarter of an inch, the electrical forces will alter the path of the falling drops. Instead of falling vertically they will veer toward the opposite collecting cans. This results in some pretty patterns of droplet flow, as well as a wet workbench! Moreover, fine spray will soon collect on the apparatus, and because the machine is sensitive to electrical leakage it will stop working.

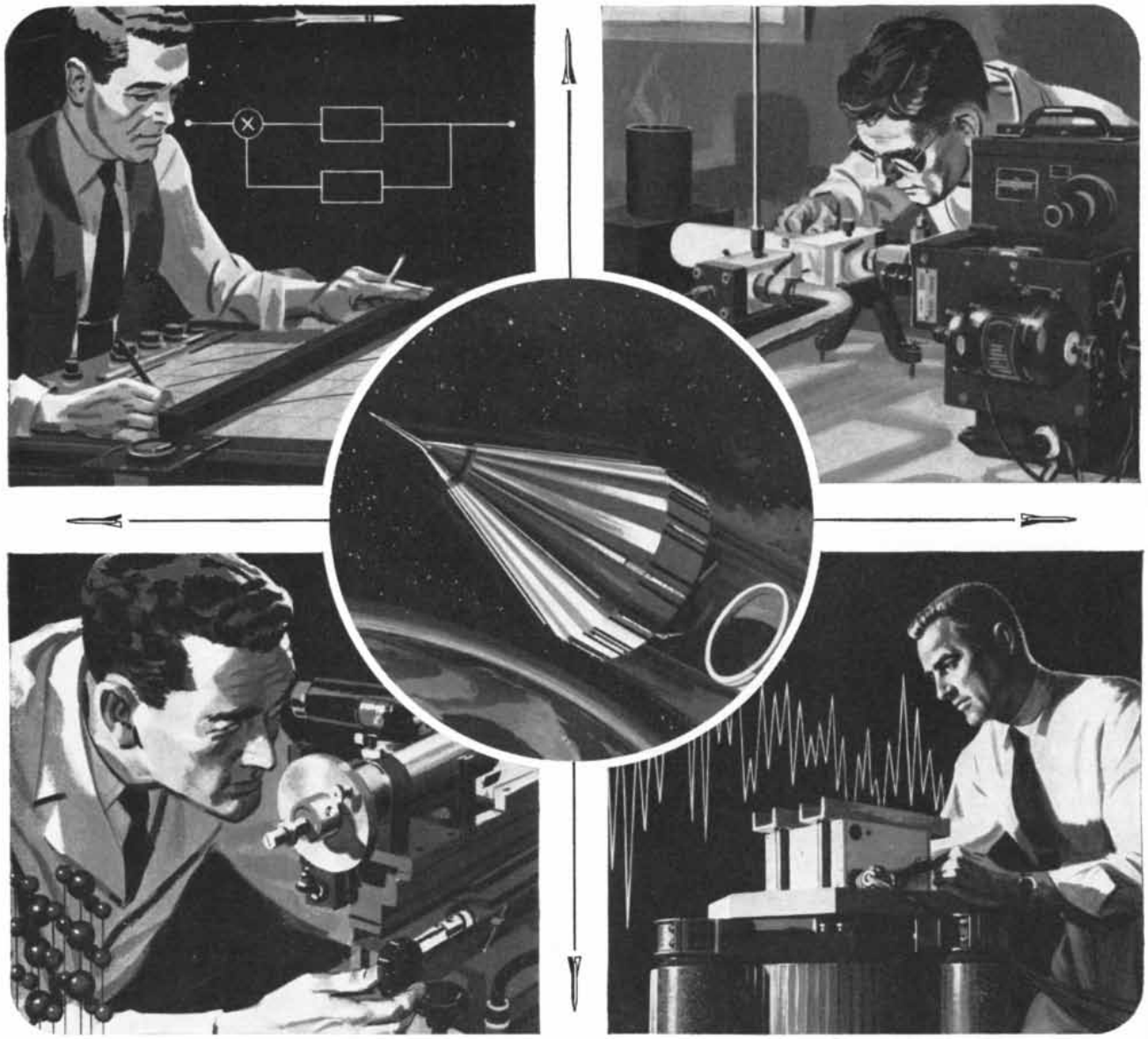


Another version of the water dropper

"The device starts and continues to work because it is electrically unstable. Assume that at the beginning the can at right is a bit more positively charged than the one at left. The left ring will be at the potential of the right can and vice versa. Negative charges (naturally present in water) will be attracted into the water stream of the positively charged left ring. As the stream breaks apart, negative charges are trapped on the droplets and carried (by gravity) away from the attracting ring and into the negatively charged can against the force of electrostatic repulsion. The charge in the left can therefore becomes increasingly negative (electric charge as well as water collects in the can). The identical mechanism is at work on the other side of the machine, where the accumulating charge is of opposite sign. Thus we have a runaway condition. The potential difference increases without limit save for the leakage of the system, the sparking potential of the gap and the diversion of the droplets. I leave for you to explain the existence of the initial charge-separation that triggers the whole performance."

In April this department included one inappropriate experiment for demonstrating the Coriolis force. It was stated that when you swing a small weight in a circular orbit at the end of a string and permit the string to wind up on your finger, the speed of the weight increases as the length of the string decreases. This suggests the conservation of angular momentum, when in fact it is the energy of the system and not the angular momentum that is conserved.

To demonstrate the conservation of angular momentum with the weight and string, hold the free end of the string in your right hand, hold the middle of the string loosely in your left, start the weight going in a circular orbit and then pull the string with your right hand (so as to shorten the radius of the orbiting weight). The Coriolis force, tending to speed up the weight, will be developed as a consequence of the inward radial motion imparted by the pull, just as a figure skater executing a spin with outstretched arms speeds up when he folds his arms against his body.



TASK FOR THE FUTURE

Since its inception nearly 23 years ago, the Jet Propulsion Laboratory has given the free world its first tactical guided missile system, its first earth satellite, and its first lunar probe.

In the future, under the direction of the National Aeronautics and Space Administration, pioneering on the space frontier will advance at an accelerated rate.

The preliminary instrument explorations that have already been made only seem to define how much there is yet to be learned. During the next few years, payloads will become larger, trajectories will become more precise, and distances covered will become greater. Inspections will be made of the moon and the planets and of the vast distances of interplanetary space; hard and soft landings will be made in preparation for the time when man at last sets foot on new worlds.

In this program, the task of JPL is to gather new information for a better understanding of the World and Universe.

"We do these things because of the unquenchable curiosity of Man. The scientist is continually asking himself questions and then setting out to find the answers. In the course of getting these answers, he has provided practical benefits to man that have sometimes surprised even the scientist.

"Who can tell what we will find when we get to the planets? Who, at this present time, can predict what potential benefits to man exist in this enterprise? No one can say with any accuracy what we will find as we fly farther away from the earth, first with instruments, then with man. It seems to me that we are obligated to do these things, as human beings."

DR. W. H. PICKERING, *Director, JPL*

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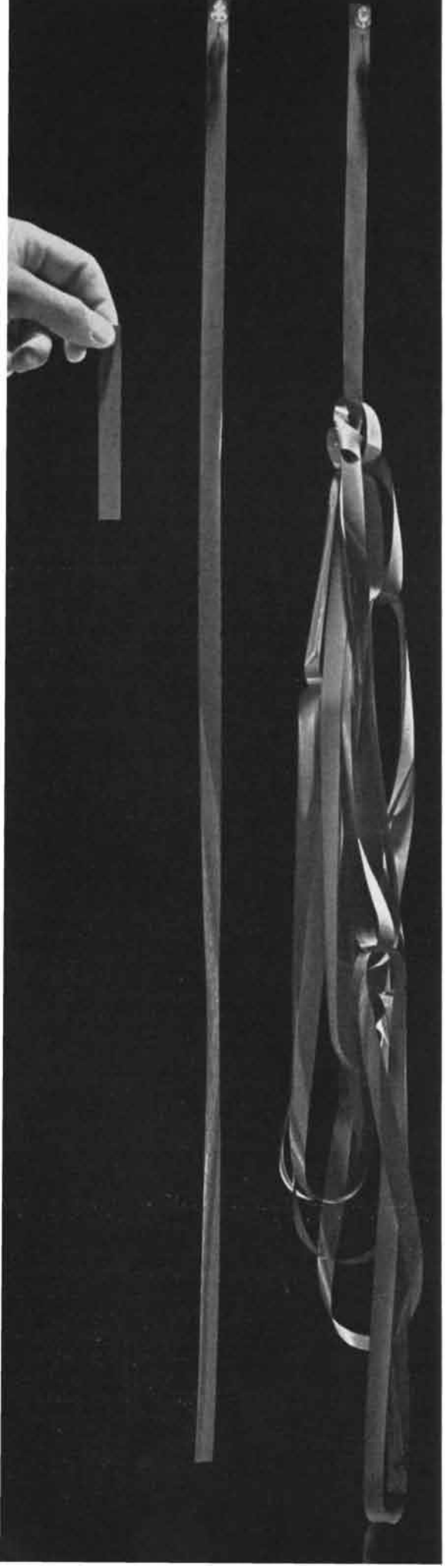


Higher Education for Computers

"Let's put the computer in at the start of a problem, rather than just having it buzz through the computations."

This is the approach being taken by computer specialists at the General Motors Research Laboratories as they explore ways of giving large-scale digital computers a greater role in the solution of problems. The object is to "teach" computers to apply the same rules men use in formulating, analyzing, and solving questions of modern science and engineering.

A recent outgrowth of this work is DYANA, GM Research's new automatic analysis and programming system. DYANA is one of the first computer systems to "understand" declarative statements. For a large class of dynamic problems, the engineer can simply describe his physical system to the computer. The computer figures out how to handle it.

For the solution, DYANA automatically directs the computer to prepare a mathematical model of the system, to write its own program for solving the model, then to execute the program and compute the desired answers.

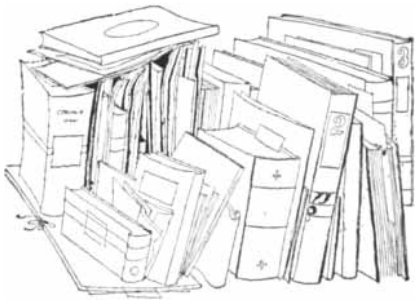
The higher education of computers currently involves studies in symbol manipulation, problem-oriented languages, character and pattern recognition, and engineering simulation.

Such advanced computer concepts are giving General Motors professional people more time for creative engineering and research—time to explore ideas and to develop "more and better things for more people."

General Motors Research Laboratories

Warren, Michigan

Comparison of program tapes for a vibrational problem expressed in DYANA language, in algebraic-oriented language, and in the basic machine language.



BOOKS

A symposium on the basic problems of measurement

by Herbert Dingle

MEASUREMENT: DEFINITIONS AND THEORIES, edited by C. West Churchman and Philburn Ratoosh. John Wiley & Sons, Inc. ($7.95).

This is a most valuable book. It contains the contributions to a symposium (held at the December, 1956, meeting of the American Association for the Advancement of Science) aimed at comparing the various aspects of measurement exhibited in widely different disciplines: physics, psychology, economics, accounting, philosophy, the social sciences. Measurement has forced its way into almost every field of study. The reason, so far as conscious motives are concerned, is that precise description usually requires it. As we shall see, however, the ultimate motive may be rather different. It is therefore essential that measurement should be understood, and the first step to this end is obviously to survey the processes of measurement used in various disciplines. This volume contains 13 articles, all by writers of distinction, so that we have before us as representative a picture as is possible of what measurement has come to mean in 20th-century thought.

The contributions to the volume are not uniformly easy to read. Though none of them is culpably obscure, some of the authors appear to have addressed themselves to their immediate colleagues rather than to the general scientific reader. Some knowledge had to be assumed, but it would not have been unreasonable to expect enlightenment on such a remark as "This theory of Markov chains could be put to good use in climatology," or "the degree of inconsistency is monotonically related to psychological distance." The poor nonspecialist can only shake his head over Markov chains and psychological distance. Still, the book as a whole will amply repay the effort of the reader who has an inclination to understand the working of the scientific mind in one of its most fruitful fields.

When we turn, however, from an assessment of the volume as a presentation of current views to an assessment of the views that it presents, there is a different story to tell. We are left with a profound sense of dissatisfaction, a feeling that the essence of the matter has been missed. The fundamental defect of the book is displayed in its first sentence: "Measurement presupposes something to be measured, and, unless we know what that something is, no measurement can have any significance." This fallacy pervades the book, expressed explicitly by many of the writers and implied by most, if not all, of the rest. The whole endeavor therefore steps off on the wrong foot, with the consequence that, although the actual procedures described are perfectly legitimate and of undoubted value, their significance is either lost or distorted.

To understand what measurement means we must turn to the physical sciences as the field affording the potentialities of measurement their widest scope; there alone are all the known processes of measurement exemplified. Consequently a true conception of measurement must cover physical measurements in their widest generality. Such a conception shows that measurement is a self-contained process, a process that implies nothing beyond that of which it gives a numerical estimation.

It is perfectly legitimate to ask an astronomer to measure the area in the sky of the constellation Orion as defined by the International Astronomical Union. But what is the "something" that he measures? We no longer think in terms of a "sky," and from another viewpoint the constellation ceases to exist. There is no "something," but beyond question there is a measurement.

Pursuing the matter, we see not only that all physical measurements are of this kind, but also that, far from starting with a something and then measuring it, we start with a measure and then try to find something to which we can attach it. We measure the weight, W, of a body, and its height, h, above the ground, and form the product Wh. This we regard as significant because it is equal to the kinetic energy with which the body, having been released, reaches the ground. We therefore invent something that Wh measures and call it the potential energy of the body. When the body falls, and h becomes O, it loses its potential energy. We are delighted, and think we have "discovered" potential energy. But we are now forced to say that when a body moves toward or away from the sun, it similarly loses or gains potential energy. Suppose, then, that our body falls to the earth when the sun is directly overhead. Has it gained or lost potential energy? We can take our choice, which means that potential energy is not "something to be measured," but a quantity devised after the measurement has shown its importance. In its devising we are free to exercise our choice among various possibilities; and, if we do not devise it at all, the measurement has exactly the same status as it had before.

Take another example. We make a measurement with a diffraction grating and call the result the "wavelength" of light. But we do not first perceive the waves and then measure their length; we make a measurement and then invent "wavelength" to attach to it. The invention is just as arbitrary as that of potential energy, and at present it is even less satisfactory. Another observer, moving away from us in the direction of the light, gets a different value. It is the same light. Which observer determines the "right" wavelength? Clearly, at least one of our measurements does not imply a "wavelength to be measured." But if the something is not wavelength, what is it? We do not know, though there can be no doubt that this measurement is important.

So we could continue. For this reason I some years ago proposed the rudiments of a theory in which measurement was defined as "any precisely specified operation that yields a number; that is, measurement is related to the operation performed and not to the hypothetical

"something" on which it is supposed to be performed. This theory appeared in *The British Journal for the Philosophy of Science* (Vol. 1, page 5), and as it seems not to have been noticed by any of the contributors to the present volume, I shall take the liberty of outlining its basic idea. But first of all I think it will be useful to take a step still further back and see how measurement came to be practiced at all. This point is not touched upon in the volume, yet it is of some relevance and is indeed essential if we are to understand fully what measurement signifies. The contributors to the volume take measurement for granted and then discuss—often admirably—what it is, but they do not ask why it must be taken for granted. They tacitly assume the strategy of the campaign, and concentrate on the tactics. Let us see why the strategy commits us to measurement.

The fundamental problem of philosophy is that of making sense of our experience. We are originally aware of a haphazard succession of experiences. After a while some regularities force themselves on our attention—night and day alternate, falling is followed by a pain, and so on. The first philosopher is the man who first conceives the possibility that other—perhaps all—experiences are related; that is, experiences form a rational system. Given a knowledge of some experiences, therefore, other experiences that seem quite independent can be predicted.

The earliest philosophers accepted the obvious relations and tried to supplement them—the alternation of night and day was associated with alternations of heat and cold, falling on grass hurt less than falling on stone—until in such a system as that of Aristotle, with its generalizations in terms of matter and form, a considerable area of experience became organized into a rational system. Two things characterized this approach: first, it was concerned entirely with involuntary experience; and second, progress in it was painfully slow.

By the 17th century the patience of philosophers was exhausted (I am of course describing not what consciously went on in their minds, but what we, knowing the outcome of their actions, can see to be the truest rationalization of them), and they said: "Look here; we aren't getting anywhere with ordinary experience; it is too difficult. Let us make some artificial experiences and find relations between them. Then perhaps ordinary experience will fit in later." So instead of studying the natural motions of birds and smoke and rivers, they made artificial motions—balls rolling down carefully prepared grooves. Thus was born scientific experiment: the deliberate production of artificial experiences more simply related to one another than those that come naturally.

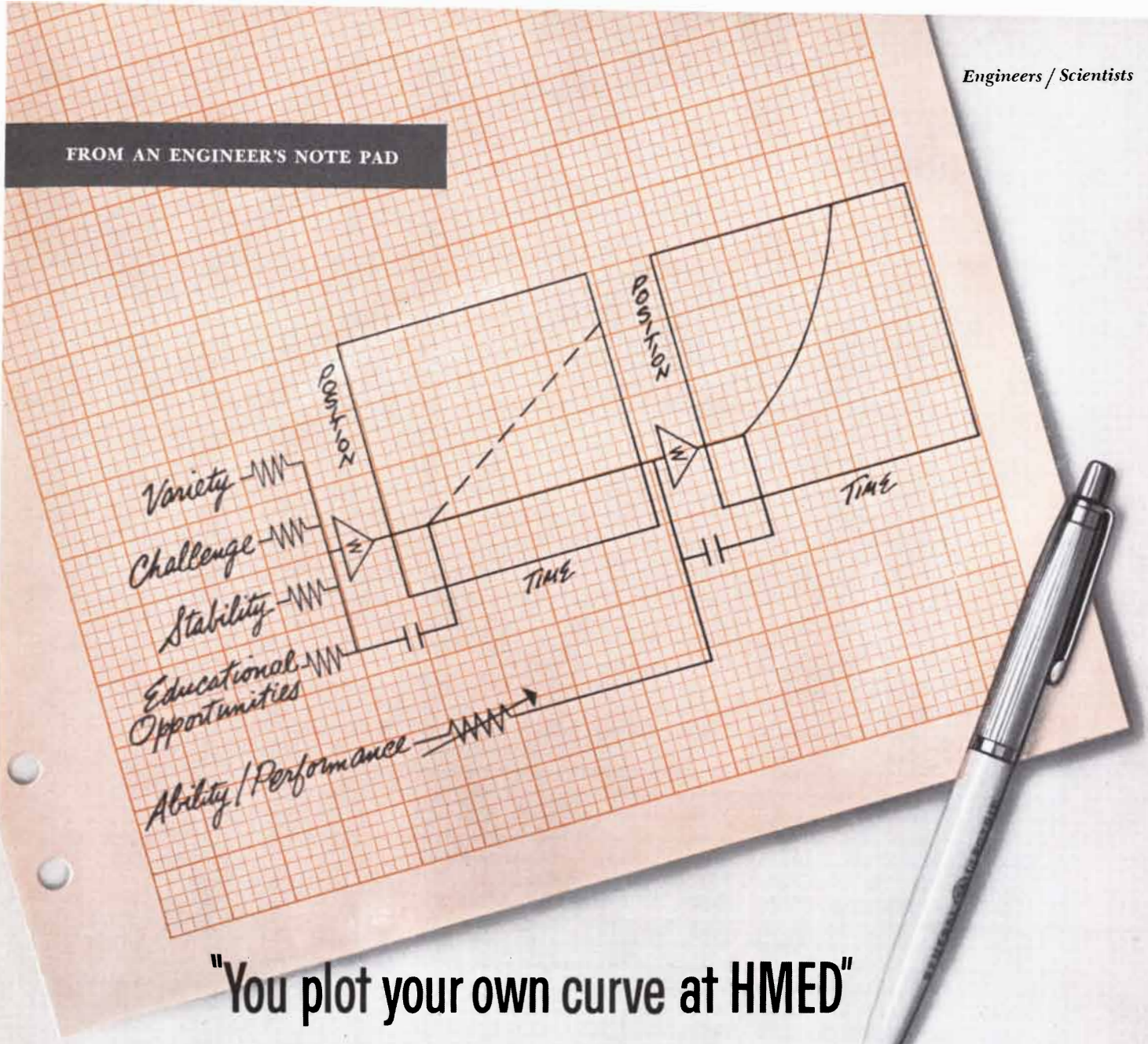
The aspect of the artificial experiences that was examined was the metrical aspect. The rolling ball did not pass from potentiality to actuality; it merely gave readings on a measuring scale and a form of clock, readings represented by numbers. What was the advantage of this? Simply that, since rational relations were required, it brought into operation the most highly developed form of reasoning known: pure mathematics. The artificial experiences were reduced to experiences of numbers, and then metrical science was born. Thus the original aim of relating all natural experience was transformed to that of relating the numbers yielded by contrived operations.

But this was not at all understood. It was thought that each measurement represented a property of something in the "external world." The object of philosophy was conceived to be the study of this external world. Our experience—which is ultimately all that is of any importance to anybody—was simply a trivial effect of the casual impinging of the "world" on our bodies; the "world" would be exactly the same if this had never occurred. This idea could persist because there happened to be a pretty close correspondence between the other "things" that were thought to be measured and the "things" that we actually experience, but in fact this correspondence is illusory. Take mass, for instance. This is the name given to something conceived to be responsible for the recordings of certain measuring instruments. But mass was imagined to be "the quantity of matter in a body," and this was plausible, because when the instrument recorded a big number, a large body was usually seen. Hence it was believed that Newton's law of gravitation described the path of a planet around the sun. In reality it describes the path of a mass-point in a gravitational field, and both mass-point and gravitational field belong to an invented world that only in part corresponds to the common-sense world of material objects. If the earth should explode to smithereens through internal stresses, the mass-point (the "center of gravity") would continue on its orbit undisturbed, but there would be no matter where it was situated.

Every symbol in every physical equation stands for the result of a measurement or a combination of such results, and fundamentally for nothing else. In a simple case like that of mass, the correspondence between symbol and some element of ordinary experience is fairly close; usually matters are more complex. Take, for example, Avogadro's number, N—the number of molecules in a cubic centimeter of gas in a certain state. N actually stands for a combination of measurements with thermometers, pressure gauges, balances and so on. (There are various combinations that give the same result; that is why the "number" is important.) But we describe N as "a number of molecules"—the name given to the result of the operation of counting. And we think of it as such. But in fact the operation of counting molecules is impossible. We can delude ourselves into believing that the operation of weighing is a discovery of the mass of a body, but no honest man can claim that when he is finding N he is counting anything. Yet such is our faith that each measurement is a measurement of "something" that we are ready to make such a claim in order to maintain that faith. Nor is that the worst. We even analyze the intricate concept that we call "the momentum of an electron" as though we had a particle of matter before us and were applying the process for measuring momentum to it; and then we imagine that we are learning something about the world of experience. God help us!

The whole world of physics is a set of relations between concepts that represents combinations of the results of measurements, *i.e.*, of artificially created experiences. Nothing that this world contains would ever have happened if we had not made it happen. To verify any of the relations you must adjust the conditions with the greatest care; let experience come naturally, and their supposed requirements are always violated. Go on dropping an object to the ground, and it will come to rest at a different place every time. Go out one day, and you feel warm; do the same the next day, and you feel cold. The laws of falling bodies and of heat are obeyed only in laboratories. Physics tells us a tremendous amount about the world, but it is not the natural world; it is a world of our own making.

How is it, then, that we have turned the results of physical research to such significant account in ordinary life? Simply because of a purely empirical relation between the natural and the artificial worlds. Over a large part of experience they maintain a close parallelism. When a balance gives a big number, we usually do see a big object (but we have seen that a large value of M does not always mean that). When the thermometer has a high reading, we usually feel



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hot (but in outer space we should probably die instantly of cold, although astronomers tell us that the temperature there can be over 1,000 degrees centigrade). Why the sight of a big object is usually attended by a large M, and the feeling of heat by a large θ, we understand no more than Thales could have if he had known the facts. With all our science we have learned nothing about the relations existing in the world of natural experience. We have discovered how to create a world between the elements of which rational relations do exist, and we exploit the empirical fact of its close parallelism with the natural world.

This is of the greatest importance in regard to the function of measurement in other sciences such as psychology and sociology. Here exactly the same considerations hold good, but whereas in physics the parallelism between the metrical concepts and ordinary experiences is the rule and its breakdown the exception, in the other sciences the reverse is more nearly true; at least any supposed measurement of a psychological attribute is much less uniformly related to actual experience than is normally the case in physics. To take but a single example, the primary importance of Intelligence Quotient is not that it measures "intelligence," whatever that may be, but that it stands in simple relations to other measurements (in particular, a relation approaching identity with further determinations of the same quantity with the same person). We may expect that in time a considerable system of relations between psychological measurements will be built up, but woe betide us if we imagine that its relation to the world of experience is other than purely empirical. A large I. Q. may go with a good performance in other specified operations, but its possessor may well be a gambling addict, and so one of the most "unintelligent" of persons.

It is in view of such facts as these that measurement must be defined in terms of its origin in the operations we perform, without reference to anything external. Having so defined it, we can begin its analysis. Each measurement includes a manual and a mental part; for example, in measuring length we lay an object along a specified scale (the manual part) and subtract the smaller from the larger of the end-readings (the mental part). We deliberately relax the precision of the specification in two respects. In the manual part we allow one element of the operation to be changed *ad lib.;* in the example of length we can make "the object" anything we like, and we call the result (merely as a name) the length of that object. In the mental part we allow ourselves to multiply the result of any fundamental measurement (that is, a measurement that does not include another measurement as a part of its prescription) by any number; we call this (again merely as a name) "changing the unit of measurement." The whole process is thus described without wandering outside into a hypothetical "something to be measured."

I have found nothing in the book under review to demand any change of this description, though there is much that receives an interesting interpretation in terms of it. For instance, "the central purpose" of the contribution by Patrick Suppes is to justify the classification as meaningless of such sentences as: "The mass of the sun is greater than 10^6"; accordingly a formidable rococo structure, involving three-valued logic, is erected. But the meaninglessness of this sentence follows at once from the liberty of multiplying the result of a fundamental measurement by any number.

Suppes mentions certain abnormal measurement-scales in which transformations other than the ordinary "change of unit" are applicable; these afford an interesting application of metrical theory. Space permits mention of only one—the ordinal number scale, applicable to such qualities as hardness, in which any monotonically increasing set of numbers can be substituted for the first choice. This corresponds to a change in the manual part of the operation other than the change allowed (*i.e.*, other than a change in the specimen to be measured). We substitute for, say, the standard specimen marked 3 a similar standard marked 7. The result is therefore a different measurement, and should not be called by the same name.

The case is parallel to that of changing the measurement of length from meters to yards. This is usually considered to be a change of unit equivalent to a change from meters to centimeters. But in fact the yard is a different material standard from the meter, and is known to be changing its length in relation to the meter; we therefore err in supposing the change to be merely the multiplication by a factor, like the change from meters to centimeters. The standards are changing at such a rate that the universe may be expanding with respect to one and contracting with respect to the other. That is an entirely different thing from "changing the unit of measurement."

Somewhat similar considerations are applicable to S. S. Stevens's classification of "scales of measurement": They all seem to fit naturally into the scheme I have described—even his logarithmic scale, about which he is unduly hesitant. It is hardly true to say that "it has thus far proved useless to the empirical business of science"; it is employed in the "magnitude" scale of stellar brightness.

A small but very revealing remark in Stevens's interesting paper deserves quotation: "Does utility behave as a prothetic or as a metathetic continuum? We do not really know, of course, but there seems good reason to expect that it is prothetic." It does not matter what "prothetic" and "metathetic" mean, and all we need to know of "utility" is that it is a measurement, expressed in "utiles" and supposed to assess "subjective value." "Utility," therefore, is something that we create; previous generations knew nothing of it, because it did not exist for them. So what Stevens is saying is that we do not know what we are doing: we have created something that has gotten out of hand. That is the inevitable result of confusing a measurement with natural experience. By all means hitch your wagon to a star, but do not imagine that it has any intrinsic affinity with the star or allow it to assume any of the star's mystery. You have made the wagon, and if you do not know what you have done, you should find out, or else, for safety's sake, destroy your creation.

Short Reviews

FALLOUT, A STUDY OF SUPERBOMBS, STRONTIUM 90 AND SURVIVAL, edited by John M. Fowler. Basic Books, Inc. ($5.50). This is a valuable and an important book that comes to grips with a peril as glaringly evident as the flash of an H-bomb. The "soaring sixties" have begun, everything is going up, and we have a good chance of going up too, unless we are prepared to act upon the facts here set forth. They are not new facts; they have been made known in journals and reports, in the testimony of competent specialists, in repeated warnings of sober men. But various attempts have been made to conceal, to obscure, to qualify, so that the average person does not know what or whom to believe. Official fallout pronouncements have given the impression that the quantity is negligible; and when this position was refuted conclusively, that what has been falling upon us is not much more dangerous than the gentle rain from heaven. Fowler's book corrects this impression in language plain enough, as Adlai Stevenson says in a foreword, for anyone to understand. There is much here for your

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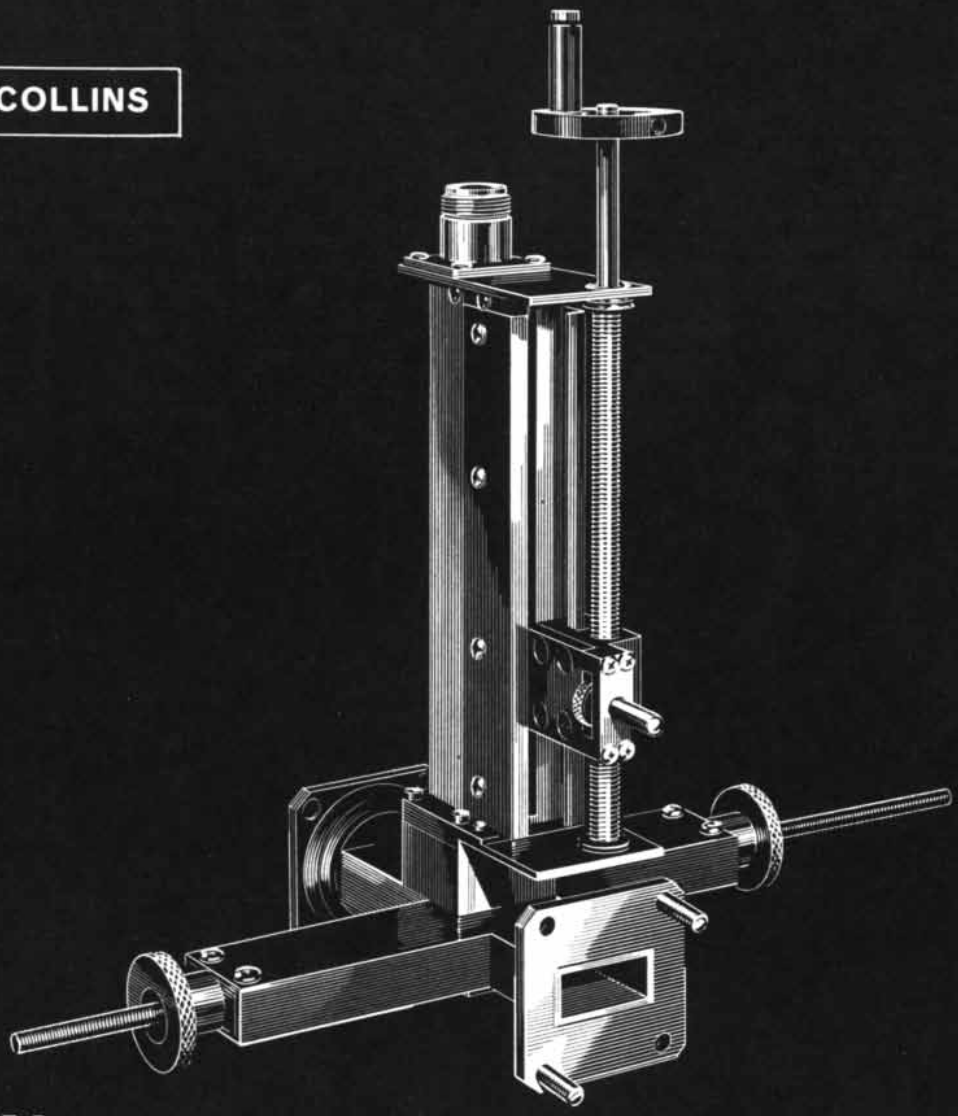

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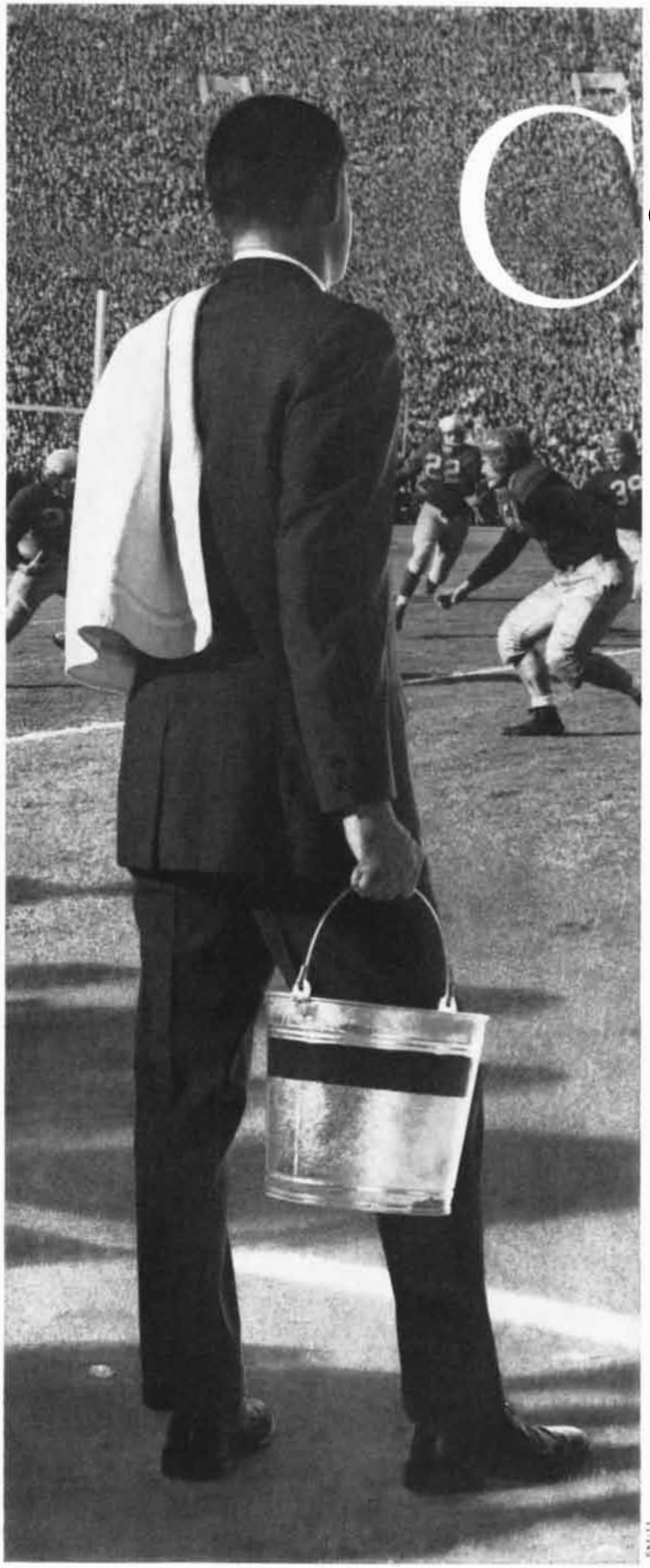
enlightenment, naught for your comfort. The different kinds of bomb and their products are examined, the global pattern of fallout, the vexed problem of hotspots (as to which the so-called averaging doctrine is as convincing as the argument that there is little danger of lead-poisoning to the average citizen from a gang war), the steadily rising level of fallout, the biological and genetic effects of radiation, the history of radiation accidents, protection and treatment, the detection of bomb tests. Ralph E. Lapp presents a dispassionate summary of the effects of a nuclear war, and there is a horrifying chapter on national survival that makes another chapter on civil defense sound completely fatuous. Appendices are included on radiation physics, fission and fusion, as well as a helpful glossary. This is the most level-headed, honest and comprehensive treatment of the subject that has appeared. But for a book that can do as much good as this book can, and which has only 250 pages and four pages of (essentially superfluous) plates, the price is much too high. Salvation ought to fit more purses.

TOWN AND SQUARE, by Paul Zucker. Columbia University Press ($15). How the builders of towns have treated the empty spaces—the agora, the green, the common, the square, the plaza—is almost as important artistically and architecturally as how they have designed the streets, parks, bridges and buildings. The square is in a sense the heart of the city: it has been the focal point and the stage of civic life, the scene of great political events, an oasis of light and air, a show place, a playground. Its role has changed over the centuries; after the culmination of its development in the 17th and 18th centuries, it has been encroached upon, squeezed by greed and neglected. But again in recent times the planners of cities have come to recognize its central importance. The history of the square from antiquity, through medieval times and the Renaissance up to the 19th century is told in this scholarly work by a leading student of the subject. A final chapter by Carl Feiss surveys the role of the square in early American life. Line cuts and 96 plates.

THE CONCEPTS AND THEORIES OF MODERN PHYSICS, by J. B. Stallo. Harvard University Press ($4.75). In November, 1881, there was published in New York City "a highly unusual sort of book, entirely without precedent in this country and with very few precedents in Europe." This book, the third U. S. edition (1888) of which has now been reissued with an introduction by Percy W. Bridgman, is an essay on the philosophy of science: an unorthodox, highly perceptive examination of the fundamental concepts of physics, so prophetic—and so presumptuous in its manhandling of certain sacred possessions—that a good many physicists thought it best simply to pretend that the book did not exist, hoping that in time it would go away and be forgotten. The author of this remarkable essay, Judge J. B. Stallo of Cincinnati, was a remarkable man; it is necessary, as Bridgman remarks, to know something of his background to understand both the independence and unconventionality of his scientific views. Johann Bernhard Stallo was born in southern Oldenburg in Germany in 1823. (His name is a Frisian one meaning "forester.") He was educated at home by his father and grandfather, who were schoolteachers, learned English and French as well as German, received instruction in Latin and Greek from two neighborhood priests and showed great precocity. Later he attended a gymnasium (*i.e.*, high school), but when the poverty of his parents made it impossible for him to enroll in a university, he decided to take his chances in a new country, and in the spring of 1839 he emigrated to Cincinnati. For a time he taught in a parish school, and at the age of 17 he published anonymously (in German) his *ABC, Spelling and Reading Book for the German Schools of America*. The book went through many editions, and in later years he referred to it ironically as his "most brilliant literary success." He continued his career as a teacher at a Catholic college, taught, and also studied, mathematics, physics and chemistry, and in 1844 became professor of these subjects at St. John's College in New York (now Fordham University). While at St. John's he wrote a book on the philosophy of nature, the Hegelian principles of which he was to repudiate in *The Concepts*. He now took up legal studies, returned to Cincinnati, passed his bar examination and began to practice. In the law he had a successful and distinguished career and earned a reputation both for his skill and his devotion to public affairs; for a time he served as a judge of common pleas. Stallo was a liberal Democrat and a great admirer of Thomas Jefferson, but as the slavery issue became acute, he changed his political affiliation and supported Lincoln. After the Civil War he rejoined the Democratic Party, and when Grover Cleveland was elected in 1884, Stallo was appointed ambassador to Rome. He remained abroad after this appointment terminated and lived in Florence until his death in 1900. Throughout his life he had a passionate interest in science and philosophy; yet he did not pass his time in an academic environment, and once he had turned to the law and politics, his friends and associates are unlikely to have stimulated his philosophical thinking. He read widely and reflected deeply on the hardest intellectual problems, but he tramped his own road; toward the end of his life he began a correspondence with the Austrian physicist and philosopher Ernst Mach (who had learned of *The Concepts* through a chance reference to it by Bertrand Russell), but Mach's illness prevented the exchange from coming to full growth, and soon after Mach recovered, Stallo died. *The Concepts* was intended, as Stallo wrote in his preface, "as a contribution, not to physics, nor, certainly, to metaphysics, but to the theory of cognition." As to this there may be debate, but there can be none as to the interest and value of his critique. Stallo's main object was to show that a single basic philosophical theory presided over the physical thought of the 19th century: namely, that all natural phenomena are ultimately reducible to Newtonian mechanics, "to the motion of elementary masses." Thus while many physicists nourished the conviction that metaphysics had been "purged" from their discipline, the conviction was an illusion. Their physics rested not only on metaphysics but, in Stallo's view, on bad metaphysics. Stallo was not a mathematician, and many of his opinions are as untenable as they are cocksure; his quasi-positivistic outlook led him to extremes, so that, for example, he repudiated the concept of atoms; but even here, as Bridgman points out, he was not illogical, but only mistaken in thinking that a physical theory is useless unless it stands in one to one correspondence with physical events. (Indeed, the fundamental inconsistency in atomic theory, which he nosed out, was not resolved until the invention of quantum theory.) He was far-sighted in recognizing the great importance for the future of physics of the law of conservation of energy, and his views on relativity, as the following passage shows, are thoroughly modern: "There is no absolute material quantity, no absolute material substance, no absolute physical unit, no absolute simple physical entity, no absolute physical constant, no absolute standard, either of quantity or quality, no absolute motion, no absolute rest, no absolute time, no absolute space." The reissue of the book



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is very welcome, and Bridgman's introduction is excellent.

THE SCIENCE OF MECHANICS IN THE MIDDLE AGES, by Marshall Clagett. University of Wisconsin Press ($8). In this source book, which students of the history of physics will value highly, Clagett offers a collection of documentary material on medieval mechanics: translations (and sometimes also the original text) of excerpts from influential Greek and Arabic treatises attributed to Archimedes, Euclid, Hero and al-Khāzinī; and of medieval writings on statics, kinematics and dynamics. The physical concepts of Galileo and Descartes did not, as everyone now knows, spring up suddenly as radical mutations in ideas. They were the culmination of a process of gradual change, in the course of which Aristotelian and Archimedean thought was modified "to the point where it was seriously undermined, thus requiring a new mechanical system," a requirement that the Galilean-Newtonian scheme of the 17th century fulfilled. Among the subverters of the old order were the 14th-century Merton College logicians and natural philosophers Thomas Bradwardine, William Heytesbury, Richard Swineshead and John Dumbleton, who worked on kinematics and developed a theorem of uniform acceleration (*i.e.*, distance traversed equals one half the product of the final velocity and the time of acceleration); the Parisian scholastic Nicole Oresme, who applied geometry to the concepts of velocity and acceleration, thus foreshadowing analytic geometry; and the Frenchman John Buridan, who put forward an impetus theory of motion. Clagett presents selections from the writings of these and other mechanicians and introduces each group of documents with his own informative commentary. This is a very respectable achievement of scholarship, and the book itself—700 well-printed, illustrated and stoutly bound pages—is reasonably priced.

WILLIAM HARVEY'S DE MOTU LOCALI ANIMALIUM, edited, translated and introduced by Gweneth Whitteridge. Cambridge University Press ($10.50). This volume, limited to an edition of 1,000 copies, presents in book form a hitherto-unpublished series of notes by William Harvey, the manuscript of which is in the British Museum. These notes, written while Harvey's famous *De Motu Cordis* was in press, are the rough draft of a book he intended to publish on the local movement of animals with special attention to the move-

ment of muscle; the notes are not based on any new experimental observations but show that his understanding "was sounder than that of most of his predecessors and even some of his successors." The editor gives the Latin text and an edited English translation that expands the notes by occasionally inserting words or phrases in order to show more immediately the meaning of the passage. This has been a difficult task, partly because of Harvey's dreadful handwriting.

THE UNITY OF THE UNIVERSE, by D. W. Sciama. Doubleday & Company, Inc. ($3.95). An attractively written, lucid account of the history of cosmology from the observations of Erastosthenes to the theories of Hermann Bondi and Thomas Gold. Cosmology is of course a subject that in our day dances with controversy. This is surely a good thing—a healthy, noisy excitement that interferes with dogmatic slumber. Sciama does not hesitate to cut his own steps. The first part of his book describes the evolution of the present observational picture of the universe, a relatively settled matter. He explains skillfully and simply, so that any ordinary reader can follow, how astronomers have arrived at the size of the solar system, the distance to the stars and the major discoveries that have been made about the Milky Way, the external galaxies and the expanding universe. In the second part he argues the view, which observation has yet to confirm or disprove, that the universe as a whole is unchanging in time, that all its parts are linked so that what happens in the most distant regions affects the phenomena of our immediate neighborhood, and that the continual creation of new matter compensates for the expansion of the universe. Thus he arrives at the conclusion that the universe is "indeed a single unit." The starting point in these considerations is the famous paradox of the 19th-century German astronomer Heinrich Olbers. On the basis of simple and seemingly irreproachable assumptions Olbers by correct reasoning reached a conclusion which is obviously false: that the amount of light near the earth should be just the same as at the surface of the average star; the temperature of space would then be some 6,000 degrees centigrade. The most effective way of meeting the paradox was to modify one of his assumptions, namely, that there are no systematic motions of the stars. By assuming instead that they are receding in a uniform way (and by taking the Doppler effect of a receding light source into account), one infers that their light is

sufficiently reduced to explain what is in fact observed; in other words, it is dark at night because the universe is expanding. An optical link therefore connects us to distant regions. That a mechanical link also joins us to these regions is the idea underlying Ernst Mach's celebrated principle, according to which the "fixed stars" are responsible for the inertial properties of matter. Thus inertial frames are those which are unaccelerated with respect to the "fixed stars," and centrifugal forces, which Newton conceived to be evidence of absolute motion (rotation), are in Mach's view relative motion with respect to the "fixed stars." The principle has been sharply attacked, even scoffed at as savoring of astrology. "I cannot persuade myself," wrote Alfred North Whitehead, "that a little star in its twinkling turned round Foucault's pendulum in the Paris Exhibition of 1851." But in recent years the opposition has thinned; Einstein, among others, was much impressed by Mach's arguments, and they played an important part in leading him to his explanation of the principle of equivalence: The inertial forces that arise in a noninertial frame of reference are gravitational forces exerted by accelerating stars. As Sciama shows, if one accepts Mach's principle, many puzzling things fall prettily into place. Centrifugal and Coriolis forces, the clock paradox of the special theory of relativity, which has driven good men to crave tranquilizers, the general theory of relativity, with its baffling concepts of curved space and the like—these are among the ideas Sciama succeeds in making plausible, natural, even palatable. To be sure, the big if of the validity of Mach's principle remains, but as long as one's disbelief is suspended, the persuasiveness of the exposition is irresistible. This is an engrossing book, an invigorating intellectual exercise that any mature reader can enjoy, and from which he will profit even if it should turn out tomorrow that Mach's principle is completely wrong.

PROCEEDINGS OF THE INTERNATIONAL CONGRESS OF MATHEMATICIANS, 1958, edited by J. A. Todd. Cambridge University Press ($12.50). The official record of the Congress held in Edinburgh in August, 1958, containing a remarkably diverse collection of English, French, German and Russian papers on logic and the foundations of mathematics, algebra and the theory of numbers, classical analysis and functional analysis, topology, algebraic and differential geometry, probability and statistics, applied mathematics, mathematical phys-

ics, numerical analysis, mathematical history and mathematical education.

THE WATERFOWL OF THE WORLD: VOLS. II AND III, by Jean Delacour. Country Life Limited (each volume six pounds six shillings). These final two volumes of an illustrated natural history of waterfowl cover the dabbling ducks, eiders, pochards, perching ducks, scoters, goldeneyes, mergansers and stiff-tailed ducks. The text gives descriptive characteristics, general habits and distribution data; there are distribution maps and 44 color plates by Peter Scott. An attractive set.

THE VIRUSES: VOL. I, GENERAL VIROLOGY; VOL. II, PLANT AND BACTERIAL VIRUSES, edited by F. M. Burnet and W. M. Stanley. Academic Press, Inc. (Vol. I, $16.50; Vol. II, $13). The first two volumes, a third being promised to complete the work, of what will be an encyclopedic treatise attempting to cover the significance of experimental work on viruses "for general problems within and on the borderlines of biochemistry, biology and biophysics." Among the topics discussed are the structural and chemical architecture of host cells, the physical properties of infective particles, the inactivation of viruses, the comparative chemistry of viruses, the biochemistry of insect and plant viruses, immunological methods, the reproduction of viruses, the bacteriophage as a model of host-virus relationships, the initiation of bacteriophage infection, the intracellular multiplication of bacterial viruses, bacteriophage genetics, the process of infection and virus synthesis as studied with tobacco-mosaic virus, lysogeny, the radiobiology of bacteriophages.

THE EARTH BENEATH THE SEA, by Francis P. Shepard. Johns Hopkins Press ($5). More than 70 per cent of the earth's surface is beneath the sea, but only in the past 30 or 40 years has the geology of this vast area attained the stature of a full-fledged branch of knowledge. The nature and origin of the sediments that partially cover these great submerged areas and the rocks that underlie the sediment have been studied, as have the depths of the waters, the effect of waves and currents on the sea floor, the cause and mechanism of tsunamis, the formation and destruction of beaches, the evolution and structure of the continental shelves, the profiles of the deep-sea floors, the natural history of coral reefs, the topography of the great slopes and deep canyons. Dredging, coring and photography have been

the most frequently used methods; bathyscaphs and aqualungs have made the marine geologist's life more adventurous. This book reviews what is known in submarine geology and presents the author's own experiences as an investigator. An agreeable and most instructive popularization. Illustrated.

LIVING INSECTS OF THE WORLD, by Alexander B. Klots and Elsie B. Klots. Doubleday & Company, Inc. ($9.95). In 175,000 words and 277 photographs (152 in color) this fine book surveys living insects from ants and bees to earwigs and thrips. Natural-history books of this kind, designed for the family circle, appear every year, and we have come to expect the accompanying gallery of photographs, in which the astonishing is the usual. The Klots volume, however, stands out for its clear, intelligent, fluent descriptions of the appearance of insects, their structure, physiology and habits, their relation to each other and to man. The authors have enthralling material to work with, and they make the best use of it by eschewing the spectacular and telling their story quietly.

LICHTENBERG: A DOCTRINE OF SCATTERED OCCASIONS, by J. P. Stern. Indiana University Press ($6.95). Georg Christoph Lichtenberg was an 18th-century German philosopher and wit who left behind a large number of fragmentary writings and aphorisms on physics, philosophy and literature. In this book an attempt is made to weave the fragments together into a more coherent whole and, by means of supplementary commentary, to show Lichtenberg's general view—which bears striking resemblances to the linguistic philosophy of Ludwig Wittgenstein and his followers—of the relation between experience and language. At least one of Lichtenberg's aphorisms, which Einstein was fond of quoting, deserves to be remembered: "When a book and a head collide and a hollow sound is heard, is it always the fault of the book?"

Notes

THE ORIGINS OF MODERN SCIENCE, 1300-1800, by Herbert Butterfield. The Macmillan Company ($1.25). A paperback edition of a first-class general historian's account of the growth of science.

THE CELLULAR SLIME MOLDS, by John Tyler Bonner. Princeton University Press ($4). An ably written monograph on these widely distributed but "enigmatic" organisms whose biology is of

special interest because of the light it may shed on embryology and the mechanics of development. A comprehensive bibliography is a feature of the book.

MATHEMATICAL METHODS AND THEORY IN GAMES, PROGRAMMING AND ECONOMICS, by Samuel Karlin. Addison-Wesley Publishing Company, Inc. ($25). A survey of the concepts of game theory and programming theory, together with the related concepts of mathematical economics, intended either as an advanced text or reference book.

THEORY OF DIFFERENTIAL EQUATIONS, by Andrew Russell Forsyth. Dover Publications, Inc. ($15). Out of print for more than a decade, Forsyth's classic treatise, the most comprehensive examination of differential equations, is now once more available.

THE THEORY OF SPACE TIME AND GRAVITATION, by V. Fock. Pergamon Press ($15). A translation, by N. Kemmer, of a leading Russian physicist's advanced treatise on the special and general theories of relativity. Fock has made original contributions to the subject, which are here reported, and the entire account is exceptionally clear, with a number of fresh and illuminating approaches.

CURARE AND CURARE-LIKE AGENTS, edited by D. Bovet, F. Bovet-Nitti and G. B. Marini-Bettòlo. D. Van Nostrand Company, Inc. ($15.75). Proceedings of an international symposium held in Rio de Janeiro in 1957, concerned with this centuries-old arrow poison: its preparation and use by South American Indians, its plant sources, the chemistry of naturally occurring curarizing alkaloids, the pharmacological and physiological aspects of curare and curare-like drugs, the various clinical applications of curarizing agents.

ART AS EXPERIENCE, by John Dewey. Capricorn Books ($1.35). A paper-back reprint of Dewey's distinguished work on the formal structures and characteristic effects of architecture, sculpture, painting, music and literature.

A CONCRETE APPROACH TO ABSTRACT ALGEBRA, by W. W. Sawyer. W. H. Freeman and Company ($1.25). A clear, well-designed introduction, for students, teachers and others interested in learning more about contemporary mathematics, to the subject of abstract algebra, in which the primary consideration is the structure of the system, rather

than applications. The author is a skillful teacher who has written two popular primers, *Mathematician's Delight* and *Prelude to Mathematics.*

AN INTRODUCTION TO STATISTICAL COMMUNICATION THEORY, by David Middleton. McGraw-Hill Book Company, Inc. ($25). A treatise on the application of probability concepts and statistical methods to the random phenomena that influence and control the design, operation and evaluation of communication systems.

AN INTRODUCTION TO LINGUISTIC SCIENCE, by Edgar H. Sturtevant. Yale University Press ($1.45). Reissue of a first-rate explanation of the essentials of the science of language. Paperbound.

THE LOGIC OF MODERN PHYSICS, by P. W. Bridgman. The Macmillan Company ($1.25). Percy Bridgman's well-known 1927 essay on the concepts of modern physics. A treat as well as a treatment. Paperback.

THE CONCISE ENCYCLOPEDIA OF WORLD RAILWAY LOCOMOTIVES, edited by P. Ransome-Wallis. Hawthorn Books, Inc. ($12.95). An illustrated reference work on railway locomotion: Diesel traction, electrics, steam locomotives, the testing of locomotives, steam turbines, gas turbines. Color and black-and-white plates and line drawings.

RELIGIONS OF THE EAST, by Max Weber. The Free Press ($15). English translations of Weber's noted sociological studies of Judaism and the religions of India and China.

SOLID STATE PHYSICS: VOL. VI, PART A, edited by K. Lark-Horovitz and Vivian A. Johnson. Academic Press, Inc. ($11.80). This volume in the series *Methods of Experimental Physics* contains papers on the preparation and purification of materials, crystal-structure determination, mechanical and thermal properties of solids and high-pressure solid-state studies.

COMMUNISM AND SOCIAL DEMOCRACY, 1914-1931, by G. D. H. Cole. St. Martin's Press, Inc. ($14.50). This volume, in two parts, is the last installment that the late G. D. H. Cole was able to complete of his erudite, highly readable *History of Socialist Thought,* a work of the first importance for an understanding of the social and political movements and ideas that have kept the cauldron bubbling for the last century and a half.

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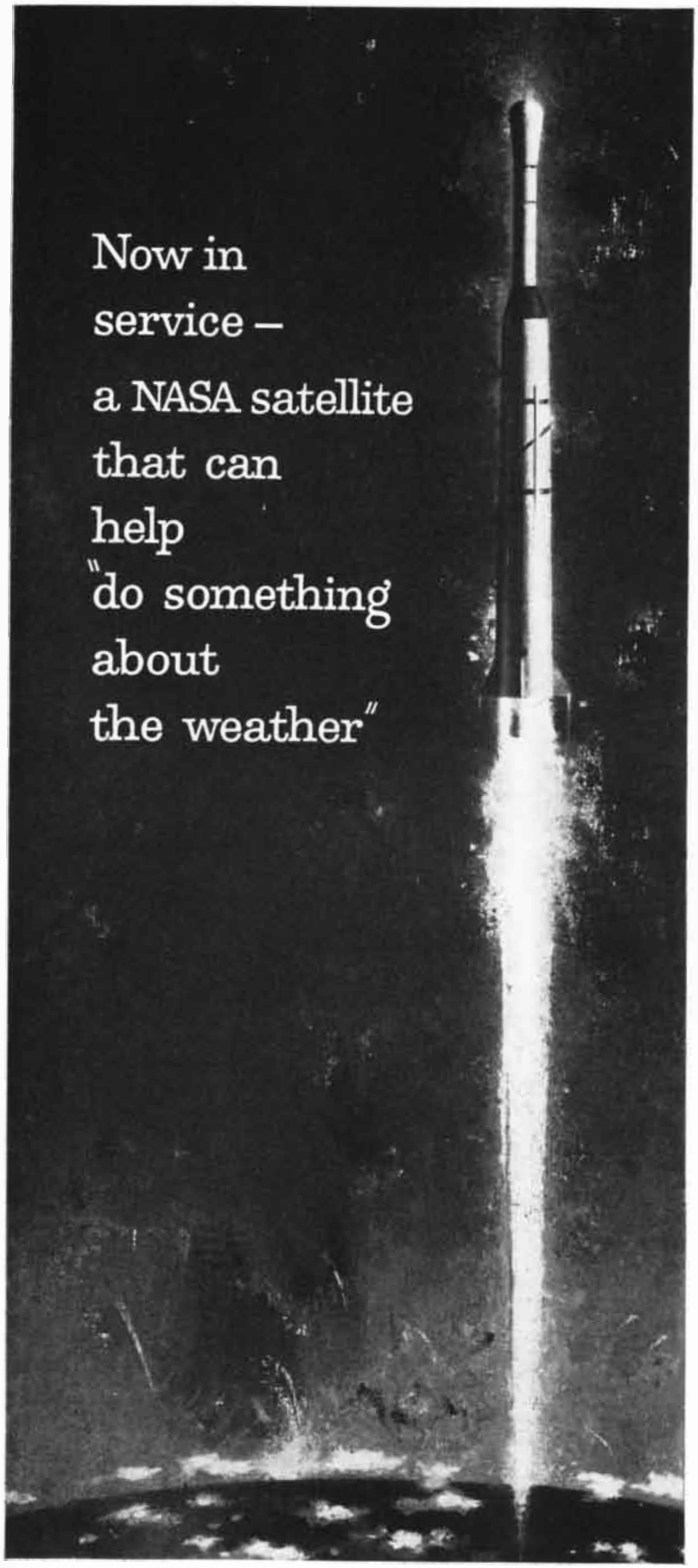

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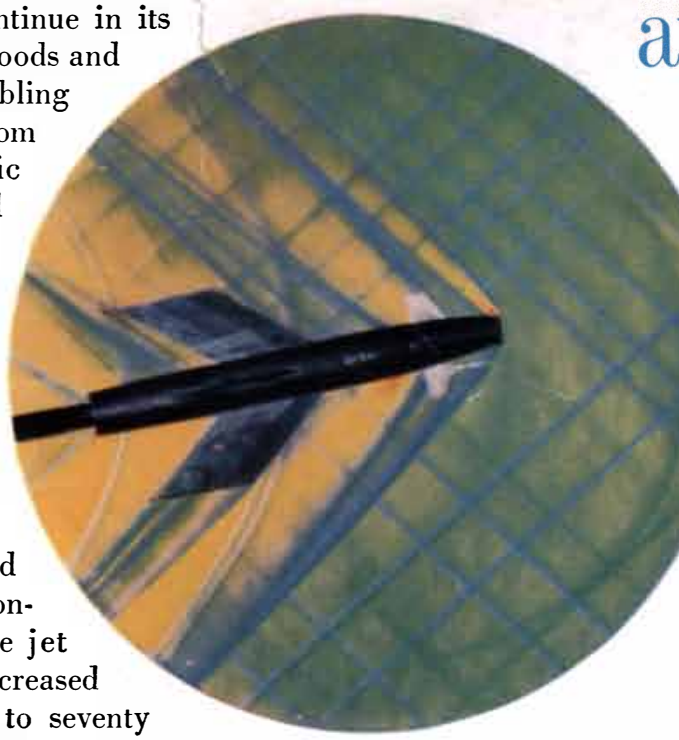

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